NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 132

RELATIONSHIPS BETWEEN PHYSIOGRAPHIC UNITS AND HIGHWAY DESIGN FACTORS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 132

RELATIONSHIPS BETWEEN PHYSIOGRAPHIC UNITS AND HIGHWAY DESIGN FACTORS

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION
OF STATE HIGHWAY OFFICIALS IN COOPERATION
WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- PAVEMENT DESIGN
- MINERAL AGGREGATES
- EXPLORATION-CLASSIFICATION (SOILS)
- FOUNDATIONS (SOILS)

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1972

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The study reported herein was undertaken under the aegis of the National Academy of Sciences—National Research Council. The National Cooperative Highway Research Program, under which this study was made, is conducted by the Highway Research Board with the express approval of the Governing Board of the NRC. Such approval indicated that the Board considered that the problems studied in this program are of national significance; that solution of the problems requires scientific or technical competence, and that the resources of NRC are particularly suitable to the conduct of these studies. The institutional responsibilities of the NRC are discharged in the following manner: each specific problem, before it is accepted for study in the Program, is approved as appropriate for the NRC by the Program advisory committee and the Chairman of the Division of Engineering of the National Research Council.

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FOREWORD

By Staff

Highway Research Board

This report identifies the severity and/or frequency of occurrence of aggregate availability, subgrade support, high volume change soils, and frost-susceptible soils within physiographic sections, and qualitatively assesses the potential for the influence of these factors on highway design and construction. The findings are founded on the premise that physiographic units can form an orderly filing system for accumulated engineering experience which, in the highway design field, constitutes engineering judgment. A large amount of information on the distribution of aggregates and soils in the contiguous U.S. has been compiled and presented on a series of maps. Highway engineering students and young engineers in the process of accumulating experience and acquiring engineering judgment will undoubtedly benefit from a study of the information contained in the report. It should also be particularly valuable to such organizations as consulting engineering firms and contractors that serve large geographical areas and thus may not have actual experience in many local areas.

The AASHO Road Test and other similar large-scale experimental investigations have provided substantial information on the relationships between traffic loadings and pavement performance for selected designs, materials, and climatic conditions. Lacking is an adequate understanding of the interaction between material properties, climate, and traffic to provide the ability to extend findings of empirical investigations such as the Road Test to different areas and sets of conditions. Approaches for resolving this technological gap in pavement design include (1) the establishment of satellite road tests to develop empirical relationships between the findings of the large road tests and regional or local areas, (2) the development of improved methods of material characterization under actual service conditions that will permit more rational approaches to pavement design, and (3) the application of the principles of meteorology, pedology, geology, and physiography to the identification of areas or regions with similar groupings of influencing factors that will permit an estimation of pavement performance. Approaches 1 and 2 described above for extending Road Test findings have been and continue to be explored within NCHRP, by the Federal Highway Administration, by individual state highway departments, and others. The project covered by this report used the third approach.

In the search for geographic units within which soil conditions, environment, and presumably highway design and construction problems exhibit some degree of homogeneity, jurisdictional and political units such as counties, states, or regions could be considered. However, because these units bear only coincidental relationship to the factors that influence pavement performance, they are generally unsuitable. It is important to recognize that, in general, a physiographic unit designates a particular combination of types of parent material, historical environment, and length of time in which environment processes have acted.

The Purdue University researchers selected a slightly modified version of an engineering-physiographic system developed by K. B. Woods and C. W. Lovell, Jr.* as the initial boundary system within which to group factors that influence pavement performance. Liberal use was made of other information on geology, pedology, and meteorology from published literature. Information dealing with aggregate sources and problems was obtained by means of responses to a questionnaire sent to state highway departments.

Owing to the limited availability of funds for this project, it was not possible to make a precise and detailed analysis of every pertinent characteristic existing within each physiographic Section with regard to its influence on highway design and construction. Major emphasis was placed on development of severity and/or frequency occurrence ratings for selected highway factors for each of the identified 97 physiographic Sections. It is readily acknowledged that many of the physiographic Sections exhibit a variability such that further subdivision would result in smaller and more homogeneous units.

The implications of this study are that (1) the severity rating and/or frequency of occurrence of such highway factors as aggregate availability, poor subgrade support, high volume change soils and frost-susceptible soils will exhibit some general uniformity within a physiographic Section, and (2) the severity and frequency of occurrence of these factors bear some general relationship to highway design and construction. The latter point indicates that, lacking more specific data or information, physiographic units might provide some insight into the selection of regional factors for use in pavement design.

* Woods, K. B., and Lovell, C. W., Jr., *Highway Engineering Handbook*. Section 9, "Distribution of Soils in North America." McGraw-Hill (1960).

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The research reported herein was performed under NCHRP Project 1-3(1) at the School of Civil Engineering, Purdue University, under the guidance of Professors K. B. Woods, E. J. Yoder, R. D. Miles, and C. W. Lovell, Jr., acting at various periods as principal investigator. The major effort of the work was carried out by Matthew W. Witczak, Graduate Assistant, now a staff engineer with The Asphalt Institute, College Park, Md. The study was an extension of research summarized in an earlier interim report on this same subject.

Acknowledgment also is made to Professors M. W. Melborn and C. F. Scholer for their instructive suggestions.

A portion of the analysis concerning high volume change soils and frost problems is based on the work conducted by H. P. Jensen and A. M. Osborne, formerly Graduate Assistants in Research at Purdue University.

Liberal use has been made of data appearing in published literature dealing with geology, geomorphology, and physiographic mapping. These sources are referenced in the report. Some of the information dealing with aggregate sources and problems was obtained by means of a questionnaire sent to the state highway agency of each of the 48 contiguous states.

Special acknowledgment is made to the works of Fenneman, Lobeck, and Woods and Lovell. The basic physiographic units studied are those proposed by Woods and Lovell (Ref. *390*).

RELATIONSHIPS BETWEEN PHYSIOGRAPHIC UNITS AND HIGHWAY DESIGN FACTORS

SUMMARY

This report concerns an investigation of the occurrence and distribution of selected highway design and construction factors in regional geomorphic units comprising the contiguous 48 states of the U.S. The regional classification system used as a basis of examination was that proposed by Woods and Lovell. This system was modified slightly to produce 97 Sections for investigation. The highway factors analyzed by Section were: availability of quality aggregate resources, soil origin and texture, high volume change soils, potentially poor subgrade support conditions (clayey and organic type), and frost-susceptible soils. A general evaluation of the use of physiographic Sections as information filing units for the highway factors was also conducted.

Several general national maps were developed to aid in the analysis of the factors considered. Potential aggregate maps of the U.S. were compiled and used with other sources of information, including a state highway aggregate questionnaire, to obtain a qualitative estimate of the potential aggregate availability rating for each Section. For factors of design relative to soil texture, a general soils map of the U.S. was developed. The frequency of occurrence for soil texture units was estimated for each Section. Based on the results, frequency of occurrence of organic deposits and the combined severity-frequency rating of plastic (clayey) soils was assessed for each Section. This served as a measure of the poor subgrade support potential. The frequency of occurrence of high volume change soils, in Sections showing a general climatic environment conducive to volume change, was developed via potential high volume change maps. These were obtained by a combined engineering case study, as well as from maps of potential high volume change areas derived from a pedologic and geologic analysis. A general frost-susceptibility map for the northern U.S. was compiled. Sections generally within the freezing zone were defined, and the frequency of occurrence by frost-susceptible soil type was qualitatively determined for each Section. A summary table of the salient composite highway factors investigated was compiled for each Section; it gives a brief and concise summary of the major findings (see Table 19).

To obtain a general evaluation of the utility of physiographic units for cataloging highway factors, the science of regional geomorphology was examined to ascertain the points of "uniqueness" used to delineate and separate Sections from their surrounding units. The presence of smaller units variant to the modal characteristics of the Sections also was investigated.

It was found that, because of the multiplicity of factors used to define and bound physiographic Sections, it is not possible to make a blanket conclusion regarding the validity of using these Sections as "filing systems" for highway factors. Although generalizations regarding the design factors can be and have been made within the physiographic units, the uniqueness of the units appears to

depend on the factor in question, the degree to which variant units are present in the Section, and the modal characteristics that define the Section.

The majority of Sections examined showed a significant presence of smaller, variant units within them. Based on this consideration, plus the over-all importance of the parent material-origin characteristics to the highway engineer, a suggested highway engineering-physiographic unit map (Figs. 18-23) of the U.S. is presented. This system is comprised of 242 tentative units.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

Although engineering design and construction decisions are unique solutions to particular problems, the efficacy of such solutions depends strongly on the store of highly relevant experiences that can be used as background or prospective input. General solutions do exist, and are as helpful in art-oriented decisions as are general solutions in rigorous scientific analysis. It is important to recognize that valid and instructive definitions of site and route conditions, and the engineering problems inherent to such conditions, can be deduced from descriptions generalized for areas that are vastly larger than the job area. Detailed investigations of the job area validate the predictions, quantify the characterization, and reveal the anomalies where and if present.

The requisite input for highway design and construction decisions is deduced by moving from a general understanding of a large piece of geography to the specifics of a site or route that is no more than a point or a thin line on any but a large-scale map. Where one starts in the defining process depends somewhat on the geographical scope of the operation—federal, regional, state, county, or municipal. Just as one might logically study an object first by unmagnified visual inspection and then by successively greater image magnification, the highway engineer might examine bedrock geology on first a national level, followed by successively larger-scale maps of region, state, county, topographic quadrangle, and, finally, special coverage of the site or route of specific and immediate practical concern. Descriptors attached to each level of the examination would differ in degree of specification but would not contradict (anomalies excepted).

In the search for geographic units in which ground conditions, environment, engineering problems, and, presumably, design and construction practice demonstrate significant homogeneity, one might first try the jurisdictional or political units (groupings of states, individual states, highway districts, individual counties, etc.). However, because such units bear only coincidental relationship to the factors that produce the surface materials (origin, parent material, and environment), they are largely unsuitable. The experienced highway engineer recognizes this to be the case and, for example, does not apply the same technology in areas of residual clay and clayey glacial till, even though these lie within the same highway district. Perhaps the most effective argument for formally developing the concept of generally unique regions lies in the strong framework it provides for organizing and relating experiences.

One of the most versatile and effective types of areal unit currently known for purposes of examining the concept of regions with common highway engineering factors of design, if not for implementing it in optimal form, is that developed by the regional physiographer. Subdivision of geography in this geological-geographical science is accomplished by reference to a number of major descriptive features of the surface and subsurface.

This report is based on the premise that physiographic (geomorphic) units can form an orderly filing system for the many engineering experiences that, when synthesized, constitute engineering judgment. This filing system can be particularly valuable for organizations with large geographical jurisdiction (regional, national) and for engineers with limited experience in the process of collecting and organizing experiences; i.e., in the process of acquiring engineering judgment.

PURPOSE

The major purpose of this research was to investigate the distribution and occurrence of several salient factors of highway location, design, and construction within a selected, preexisting regional physiographic classification system for the U.S. The classification system selected was a slightly modified version of the Woods-Lovell Engineering-Physiographic System, presented in 1960 (*82*). This version resulted in the establishment of 97 "unique" areas

(called physiographic sections) to be investigated in the U.S. (exclusive of Alaska and Hawaii).

The highway factors considered in this report are: the availability of aggregates, soil origin and textural considerations, high volume change soils, potentially poor subgrade support soils (clayey and organic types), and frost-susceptible soils.

An allied task of comparable importance was to evaluate the utility of physiographic units for organizing and correlating data and experiences. In so doing, the geologic science of regional geomorphology (physiography) was examined to determine the criteria used to define the "uniqueness" of a physiographic unit. As a result of such examination, pertinent conclusions could be reached as to the suitability of generalizing any highway factor within any defined physiographic unit.

SELECTED SCIENTIFIC AND ENGINEERING BACKGROUND INFORMATION

To provide a common base of understanding of frequently used geologic and engineering terminology, certain fundamental information about geomorphology, physiography, aggregates, and soil problems follows.

Fundamentals of Geomorphology

Physiography or Geomorphology?

Throughout the report the terms "physiographic" or "physiography" and "geomorphic" or "geomorphology" are used. Physiography is defined as (*2*):

> . . . synonymous with physical geography; a *description* of *existing* nature as displayed in the surface arrangement of the globe, its features, atmospheric and oceanic currents, climates, magnetism, life, as well as the changes or variations to which these are subjected.

Geomorphology, on the other hand, is defined as "the systematic examination of landforms and their *interpretation* as records of geologic history." The major dissimilarities between the two are:

1. Physiography consists primarily of describing the topographic expression and its geographic extent, whereas geomorphology emphasizes interpretation of the origin and development of landforms.
2. Physiography appears to be more inclusive, because it includes the "environment" of the topography (atmosphere, ocean, climate, etc).

Fenneman (*18*) states: "Geomorphology is definitely limited to the genetic [pertaining to the relationships of a common origin] study of landforms." Lobeck (*38*) points out that physiography includes climatology, geomorphology, and oceanography.

However, the examination and description of landforms or topographic expressions are basic to both sciences. Fenneman states: "The term Physiography as used in the United States is the approximate equivalent of Geomorphology." Further, if a geomorphologist studies the areal extent of landforms, he would be acting as a regional geomorphologist, and his activity would closely resemble that of the physiographer.

In the words of Thornbury (*65*):

> For many years, in the United States, the study of the origin of landforms has been called Geomorphology, whereas the discussion of the regional distribution and the geomorphic histories of landscapes has been termed Physiography. It seems to me that this inconsistency should be eliminated. . . .

Accordingly, in this report geomorphic unit is synonymous with physiographic unit.

The Physiographic (Geomorphic) Unit

Various physiographers have given definitions of a physiographic unit. Bowman (*65*) suggests it is "a tract in which the topographic expression is in the main uniform." Hinds (*65*) states it is "characterized by a distinguishing geological record, particularly in the later part of earth history, and by more or less uniform relief features or combinations of features throughout its area." Malott (*65*) somewhat more comprehensively explains:

> A physiographic unit is an area or division of the land in which topographic elements of attitude, relief and type of landforms are characteristic throughout, and, as such, is set apart or contrasted with other areas or units with different sets of characteristic topographic elements.

In simple terms, physiography is topographic expression, whereas the implication of a physiographic unit is that it contains a unique set of landforms (i.e., different from its physiographic neighbors). Landforms, or topographic expression, are not readily adapted to exact quantitative evaluation and generally are qualitatively categorized in terms of altitude, relief, form, and interrelationships of the landscape features (*65*).

Geomorphic Control Factors

A fundamental concept of geomorphic thought, advanced by Davis (*64*), is that topographic expression of any area depends on the three control factors of *structure, process,* and *stage*.

Structure has a slightly different context than the normal geologic use. Thornbury (*64*) defines structure as

> . . . all those ways in which the earth materials out of which landforms are carved differ from one another in their physical and chemical attributes. It includes such phenomena as rock attitudes, the presence or absence of joints, bedding planes, faults and folds, rock massiveness, physical hardness of the minerals, susceptibility of mineral constituents to chemical alternation, permeability (impermeability) of rocks, and various other ways in which rocks of the earth's crust differ from one another. The term structure also has stratigraphic implications. . . . Is the region one of essentially horizontal sedimentary rocks or is it one in which the rocks are steeply dipping or folded or faulted?

Process describes ways in which the land surface has been modified. Geomorphically, these processes may be thought of as those originating from agencies outside the earth's crust (degradational: tending to level down; or aggradational: tending to level up); or those that originate

within the earth's crust (diastrophism: forces that cause the deformation of the earth's crust; or vulcanism: the movement of molten rock or magma onto or toward the earth's surface).

Stage has no exact and universally accepted definition; however, in a broad sense it involves a change with time. Sparks (*58*) refers to this as the evolutionary phase of landform development.

Based on the foregoing, Thornbury (*65*) summarizes the importance of the geomorphic control factors by stating:

> This is equivalent to saying that a certain region possessed an initial geologic framework, as determined by the *kind* and *arrangement* of its rocks; this geologic structure has been subjected to gradational *processes* which have produced a certain assemblage of landforms; and the characteristics of these landforms are to a certain degree related to the *length of time* that the geomorphic processes have been at work.

Categories of Regional Physiographic (Geomorphic) Units

A physiographic unit is one of repetitive and/or unique landforms. Obviously, as the size of an area under consideration increases, detail gives way to generality. Consequently, one should expect a greater diversity of landforms or topography in the larger major units than in the smaller minor ones. Furthermore, because the definition of areal physiographic units is subjective, it is probable that, as Fenneman (*18*) has stated, "even in the single science of physiography, two men, or the same man at different times may wish to emphasize different elements of the picture, and accordingly, to divide the total area in a different manner."

Because land features may be examined at a variety of scales (different degrees of generalization), several levels or categories of physiographic units are needed. Fenneman (*18, 19*) used three categories *, in order of major to minor: (1) Division, (2) Province, and (3) Section.

Table 1 compares the physiographic Divisions of Fenneman with those of Lobeck (*38*). Lobeck divides North America into six Divisions, whereas Fenneman uses eight Divisions in the U.S. alone. The major difference is in the North American Cordillera Division of Lobeck. However, this discrepancy appears to be minor, because Lobeck divides this Division into three parts that match the Fenneman Divisions.

Differences are compounded at the Province and Section scale; these are discussed later. In addition, others—e.g., Freeman et al., as cited by Thornbury (*65*)—have inserted the intermediate grade of Subprovince.

A slightly different classification has evolved from the excellent work conducted in England by the Military Engineering Experimental Establishment (MEXE) (*43, 44*). The descriptors used (in order of major to minor) are: (1) Land Zone, (2) Land Division, (3) Land Province, and (4) Land Region.

* Fenneman states (*19*, p. 55), with respect to the Central Texas Section of the Great Plains Province, "the Section . . . embraces a number of clearly distinguished subdivisions which for lack of a technical term may here be called *districts*." The term has not however gained any consistent use.

Table 2 summarizes the various categorical terminologies. For this study, the terminology adopted is the system of: (1) Division, (2) Province, (3) Section, and (4) Subsection (adopted specially for this project).

Highway Design and Construction Factors

Aggregates

One of the more important facets of highway design and construction concerns the availability and selection of good quality mineral aggregates. In the U.S., a wide variety of natural granular deposits, crushed stone, and artificial aggregates presently are used for base/subbase, concrete, and bituminous pavement mixes. In some areas, however, good quality aggregate sources may be in short supply. The following discussion provides a basic background on the major sources and types of aggregates used in the highway industry, and on the potential problems associated with aggregate uses in different parts of the pavement structure.

Aggregate Types.—Aggregate types generally can be grouped by source into three categories (*142*): (1) natural sand and gravel, (2) crushed stone, and (3) artificial aggregates.

Sand and gravel deposits occur primarily through deposition by water. Hence, origins may be glacial (glacio-fluvial), alluvial, lacustrine, or marine. In 1958, approximately 680,080,000 short tons of sand and gravel were sold in the U.S. Of this total, 407,734,000 tons, or nearly 60 percent, were used by the paving industry (*131*).

A wide variety of rock is available for use as crushed stone (viz., sedimentaries, igneous, and metamorphics). Severinghause (*175*) states: "Satisfactory physical and chemical properties can be found in each type so that economic availability becomes the prime determinant for development."

The most widely used crushed stones are those of the carbonate group (limestones and dolomite). Gillson et al. (*107*) state that "no other solid rocks are as important as these in the industrial life of the world, nor are any so widely known." This statement is verified by Table 3 which gives the quantity by type and principal use for crushed stone in 1958 for the U.S. Although the data (in terms of quantity) are more than 10 years old, they provide a valuable guide to the relative quantities of each type used and to the principal types of crushed rock used for aggregates.

Artificial aggregates, as defined by Woods (*142*), consist of (1) blast-furnace slag, (2) cinders, and (3) other lightweight aggregates. Woods' definition of the last is confined primarily to "a manufactured aggregate," whereas Klinefelter (*128*) states:

> Lightweight aggregates may be natural or manufactured materials or by-products from other commercial operations. Natural materials include pumice and pumicite, tuffs, breccia, scoria, diatomite. . . . Manufactured materials include expanded perlite, vermiculite, slag, clay, shale and slate. By-products include cinders, air cooled slags and coke breeze.

Highway Aggregate Problems.—Although it is not the intent of this report to present a detailed treatise on the

historical backgrounds, pertinent variables, and general test procedures used to ascertain quality requirements for highway aggregates, a brief overview of general aggregate problems is given. It should be apparent to anyone familiar with aggregates and their subsequent problems that many factors other than those associated with a particular material type are intrinsic to the designation of an aggregate as being suitable or unsuitable for use in highway construction.

The highway design engineer must base his structural pavement design on the factors of traffic and environment, and their interrelationship with the foundation soil, for a particular type (rigid or flexible) of pavement; similarly, the materials engineer must examine the interrelated effects of traffic, environment, and pavement type on the materials (aggregate) used.

In bituminous pavement construction, there are a large number of combinations of aggregate-bituminous materials that may comprise any one of several bituminous layers. Rigid pavements generally are "simpler" because only one fundamental mix combination is used. Because of the fundamental differences in design concepts between a rigid and a flexible pavement, the importance and role of

TABLE 1

DIFFERENCES BETWEEN PHYSIOGRAPHERS IN PHYSIOGRAPHIC DIVISIONS

PHYSIOGRAPHIC DIVISIONS	
LOBECK [a]	FENNEMAN [b]
A. Appalachian Highlands	Appalachian Highlands
B. Atlantic Plain	Atlantic Plain
C. Canadian Shield	Laurentian Upland [c]
D. North American Cordillera [d]	Pacific Mountain System
—	Intermontane Plateau System
—	Rocky Mountain System
E. Interior Plains [e]	Interior Plains
—	Interior Highlands
F. Antillean Mountain System [f]	—

[a] Mapping of North America.
[b] Mapping of the U.S. only.
[c] One of three Provinces in Lobeck's Canadian Shield Division.
[d] Lobeck recognizes three subdivisions within the North American Cordillera, which are the same as the Fenneman Divisions.
[e] Lobeck's Interior Plains include Fenneman's Interior Highlands. Fenneman's Interior Highland Division contains the Ozark Plateau and Ouachita Provinces.
[f] Not in the U.S.

TABLE 2

SUMMARY OF REGIONAL PHYSIOGRAPHIC UNIT CATEGORIES

PHYSIOGRAPHIC UNIT CATEGORIES					
SCALE	FENNEMAN	LOBECK	FREEMAN ET AL.	MEXE	REPORT CATEGORIES
Small	—	—	—	Land Zone [b]	—
	Division	Division [a]	—	Land Division	Division
	Province	Province	Province	Land Province	Province
	Section	Section	Subprovince	Land Region	Section
Large	District	—	Section	—	Subsection [c]

[a] Sometimes separated into Subdivisions.
[b] A class level reflecting world extents of major climatic types.
[c] A category coined expressly for this study.

TABLE 3

CRUSHED AND BROKEN STONE SOLD OR USED BY PRODUCERS IN THE U.S., BY KIND AND PRINCIPAL USE, 1958 [a]

	STONE SOLD AND USED (1,000 SHORT TONS)					
TYPE OF STONE	CONCRETE AND ROAD STONE	R.R. BALLAST	RIPRAP	LIME AND CEMENT	OTHER	TOTAL
Limestone	226,693	4,306	4,763	88,484	66,222	390,468
Basalt [b]	39,187	1,421	2,177	—	1,160	43,945
Granite	26,269	1,876	1,023	—	2,124	31,292
Sandstone/quartzite	8,862	706	1,657	—	13,259	24,484
Oyster shell	11,216	—	—	6,258	1,442	18,916
Misc.	9,882	2,257	5,754	1,723	3,828	22,444

[a] Table abstracted and condensed from Lenhart (*131*).
[b] Includes gabbro, diorite, and other dark igneous rocks commercially classified as trap rock.

aggregate and aggregate-binder layers in each type differ. A rigid pavement derives its strength primarily through the binding medium in the form of slab action. Ideally, aggregates in a concrete pavement serve as an inert filler. Bituminous pavements are designed to distribute the load to the subgrade soils, and, as a result, the aggregate fraction plays an increasingly important role in strength considerations.

Traffic considerations may be of variable importance in relation to aggregate problems. Such problems as abrasion and skid resistance must be evaluated in light of anticipated traffic conditions. However, traffic does not affect the expansion of concrete pavements, which is caused by several cement-aggregate chemical reactions. The effect of the environment on aggregate performance is complex and variable. It is generally an active consideration in most problems.

It should be realized that generally it is not possible to state that an aggregate is either "good" or "bad" *per se*. However, for a given use (function) and environment (location), an over-all evaluation of the aggregate quality requirements can be made.

The most general descriptor of aggregate quality is durability. Lewis (*132*) states that durability "refers to the ability of the concrete to withstand the attack of natural agents of weathering and deterioration, without consideration of the structural adequacy of the materials to carry the loads to which it is subjected." Woods (*142*) notes that this term "refers to the resistance of a paving mixture to disintegration by weathering or the abrasive forces of traffic." Hveem (*116*) says: "Durability means, in a broad sense, the ability of the aggregate to remain unchanged over a fairly long period of time in spite of adverse natural processes or forces to which it is subjected."

To ensure aggregate durability, particularly in concrete pavement, aggregates must have soundness. Soundness implies a direct resistance to the forces of weathering (*142*). Neville (*152*) states that soundness is the

> . . . name given to the ability of an aggregate to resist excessive changes in volume as a result in changes in *physical* conditions. Lack of soundness is thus distinct from expansion caused by chemical reactions between the aggregate and the alkali in cement.

These physical changes are associated with freezing-thawing, heating and cooling, and wetting and drying (*152, 164*).

Another desirable durability characteristic, relevant only for aggregates used in portland cement concrete pavements, is the absence of certain chemical reactions with the cement matrix. In general, each type of harmful chemical reaction manifests itself by destructive expansion of the reactive products, eventually causing loss of pavement serviceability.

The most common type of reaction is the alkali-aggregate or alkali-silica reaction. In essence, the alkalies in cement attack the siliceous minerals of the aggregate, forming an alkali-silica gel around the aggregate which has a tendency to increase in volume. This gel "is confined, and internal pressures result leading to expansion, cracking and disruption of the cement paste" (*152*). The reactive forms of silica frequently occur in opaline or chalcedonic cherts, siliceous limestones, rhyolites and rhyolitic tuffs, dacites and dacite tuffs, andesites and andesitic tuffs and phyllites (*152*).

A more recently discovered and less frequently occurring chemical reaction is the carbonate reaction (alkali-carbonate or dedolomitization reaction). In this case, alkalies of the cement and a particular type of argillaceous, dolomitic limestone will react to form an expansive product that may lead to pavement destruction (*112, 158*). This reaction differs from the well-known alkali-silica type in that no visible gel or reaction products are formed (*158*). The characteristics of potentially reactive carbonate rocks, as postulated by Hadley, are dolomitic limestones in which the dolomite comprises 40 to 60 percent of the total carbonate fraction, there is an approximate 10 to 20 percent clay fraction, and a texture of small dolomite crystals is scattered through a matrix of extremely fine-grained calcite and clay (*112*).

Another cement-aggregate problem, occurring only in the central Great Plains area of the U.S., is the "sand-gravel reaction." It is similar to the alkali-silica reaction, except that limiting the alkali content of the cement within ordinary limits will not prevent excessive cracking, expansion, and general deterioration. Tests and field experience have demonstrated that the deterioration can be controlled if the sand and gravel aggregates are supplemented by 25 to 40 percent, by weight, of satisfactory coarse aggregates (*171*).

Another chemical problem is the sulphate reaction, which occurs by the formation of gypsum and calcium sulphoaluminate from a reaction of soluble sulphates with the cement pastes. The soluble sulphates may be present in the mineral aggregates [oxidation products of iron sulfides, gypsum, or aluminate-jarosite (*142*)], or may occur where certain acidic mine waters or soils containing alkali, magnesium, or calcium sulphates form an effective groundwater sulphate solution (*152*).

Aggregate degradation refers to the production of finer aggregates by weathering (both physical and chemical) and/or mechanical breakdown due to the action of mixers, mechanical equipment, and/or traffic (*94, 97*). This mechanical breakdown can occur by compressive failure from concentrated loads at points of contact between aggregates, as well as by the abrasive action of individual aggregates moving with respect to each other (*108*). Because of the intrinsic differences in rigid and flexible pavements, this factor is of greater relative importance in bituminous layers (*142*). The resistance to degradation is commonly measured by the Los Angeles Abrasion test. Moavenzadeh (*147*) found, however, that the aggregate of a bituminous mixture is more important in defining over-all degradation properties than the abrasion resistance of the aggregates themselves.

Goetz (*108*) noted that "stripping, or the separation of the bituminous film from the aggregate, through the action of water, is probably the greatest single problem in durability of bituminous mixes." This problem occurs primarily with aggregate high in silica (hydrophilic).

Rock types that are basic (rather than acidic) generally have a great affinity for bitumen and tend to hold the coating in the presence of water (hydrophobic).

Aggregates used in surface courses should possess a high skid or polishing resistance. Many factors affect the antiskid properties of any given surface; however, one of the more important factors is the polishing characteristics of the mineral aggregate used. Goodwin (*109*) has summarized the general features of aggregates that affect skid resistance. Although skidding is a problem on both portland cement and bituminous pavements, it is generally more magnified in the latter because

> . . . it usually requires less traffic to define the polishing characteristics of aggregates in bituminous mixtures since the degree of exposure is greater for the individual pieces of aggregate than with portland cement surfaces (*176*).

In addition, the skid resistance of portland cement surfaces depends primarily "on the fine aggregate portion of the mix . . . a coarse aggregate with high polishing characteristics can be permitted in a mix if the mortar surface has adequate skid resistance" (*89*).

In general, the polishing resistance of an aggregate is directly related to the hardness of the minerals comprising the aggregate. Pure limestones (i.e., pure calcium carbonate) characteristically exhibit the poorest skid resistance among the major aggregate sources. Limestones contain a wide variety of mineralogic compositions. Gray (*110*) observes that

> . . . blanket rejections of limestone for skid resistance purposes solely because they belong to this heterogeneous trade name group may result, in many cases, in the refusal to consider perfectly adequate materials.

Soils and Related Factors

Soil Origin and Texture.—Many definitions of the term "soil" exist in the sciences of geology and pedology, as well as in civil engineering. Each definition intrinsically fits the particular area of interest. An engineer may define soil as "everything from rubbish to sand, gravel, silt, clay, shale, partly cemented sandstone, soft or badly shattered rock; everything except solid rock" (*211*). The slaking test ordinarily is applied to distinguish solid rock, but there will obviously be a number of borderline cases.

An important aspect of soils is their mode of origin (i.e., transported or nontransported). Transporting agencies are ice, water, wind, and combinations of these. Nontransported soils have been developed residually by the combination of their physical and chemical environments. Detailed explanations of each mode of origin appear in many readily available reports (*214, 236, 237, 248, 279, 295*).

Soils may be divided into size fractions, and the relative amount of these fractions determines the over-all descriptor of texture. Particle size distribution or texture is the basis of certain classification schemes (viz., U.S. Department of Agriculture) and forms a basic portion of the Pedologic Soil Classification system. In general, the major limitation of such systems for engineering purposes lies in their failure to identify or measure the relative plasticity characteristics imparted by the clay size fraction. Stating this in another way, two samples of clay having an equivalent distribution of clay sizes may vary considerably in their engineering performance owing to differences in the types of clay minerals present.

Consequently, common engineering soil classifications combine textural and plasticity evaluations; e.g., Unified, AASHO, and FAA soil classification systems. Excellent reviews on the merits of the various classification systems are presented by Liu (*244*) and Wahls and Futrell (*293*).

Poor Subgrade Support Areas.—In general, the finer the soil texture and/or the greater the plasticity characteristics of the soil, the poorer the anticipated performance of this material as a subgrade for a highway or an airfield pavement. The effect of soil type on structural pavement analysis must be evaluated in detail against such design factors as type of pavement, traffic considerations, and environmental factors. However, it can be stated that, owing to the relative differences in stress-distributing characteristics between a rigid and a flexible pavement system, the effect of subgrade support is more important in a layered flexible pavement than in a rigid pavement (*213*).

As defined in this report, organic deposit refers to peat bogs, muck lands, and associated swamps and tidal marshes. Areas of organic terrain called muskeg also may be included, although this term usually is reserved for the widespread but relatively thin accumulations common north of the U.S. Various definitions for each of these categories of organic terrain are given in the literature (*296*). In essence, they are connected primarily with various stages of vegetative decomposition and/or high-water levels that either saturate most of the ground or completely cover it.

Organic materials are not used in embankments. Other problem materials are avoided for subgrade use as well. Because of their low topographic position, organic foundations for embankments are potentially numerous. A comprehensive technology exists for the handling of such so-called "soft ground" problems. These range from relocation to avoid them, through compressing them in place, to excavation and displacement, and, in rare instances, bridging with a "peat trestle."

High Volume Change Soils.—Throughout many areas of the U.S., an important highway design consideration is the swelling and shrinking of subgrades and foundation soils. The two most important prerequisites for potentially high volume changes are the presence of a relatively active clay structure and a combination of climatic conditions that allow alternate drying and saturation of the soil to occur to appreciable depths.

Swelling pressures vary greatly, but, in general, the relatively light "surcharge" of a highway pavement does not afford enough of a counter pressure to prevent volume change. As a result, highway pavements are subject to severe damage through cyclic heaving (swell) and loss of support (shrinkage).

Frost Action and Frost-Susceptible Soils.—Another important facet of highway design concerns the problems associated with frost action. This problem generally manifests itself in two effects: those induced during the

cold or freezing period (heave), and those associated with the warmer melting period (reduced strength).

Detrimental frost action requires three conditions: (1) freezing temperatures, (2) frost-susceptible soils, and (3) a source of water (*298*). Major heaving due to ice lense formation may be expected if a highly susceptible soil is frozen slowly, with water readily available.

In general design analysis, the air freezing index (FI) often is used to quantify the magnitude and duration of cold effects at the site. Frost-susceptible soils generally are defined as those soils having greater than 3 to 10 percent, by weight, finer in size than 0.02 mm (*243*). To appraise relative frost susceptibility among soils, the U.S. Army Corps of Engineers has adopted the Frost Rating Classification system. Ratings range from an F1, indicative of the least frost-susceptible soils (gravelly soils with between 3 and 20 percent finer than 0.02 mm in size), to an F4, indicative of the most susceptible soils (silts, lean clays, varved clays, etc.).

The problem of reduced strength is accentuated by deep freezing penetration. As thawing proceeds at shallow depths, drainage may be effectively prevented by the underlying still-frozen zone. Because the water present in this zone may be of greater volume than before freezing, owing to ice lense growth, the supporting capacity of the subgrade may be dramatically lowered.

INVESTIGATION PROCEDURES

The basic approach to achieve the previously defined objectives was to map either materials or the incidence of a potential highway engineering factor or problem for the U.S. or some part thereof. Whenever feasible, the severity of a problem also was rated. Significant input was derived from the sciences of physiography (geomorphology), geology, pedology, and climatology, as well as from engineering experience. This input was interpreted, summarized, and presented in a form deemed most suitable for the unique needs of the highway engineer.

However, although the concept of generalization is simple, its practical implementation in anything approaching optimal form is a most difficult matter. Of foremost concern is the choice of an appropriate level for the generalization. Broad generalizations have limited predictive capabilities; limited or local geographic generalizations require almost as much effort as specific job-location descriptions, and are difficult to justify economically as a separate step. This study accepted the regional physiographic *Section* as the base unit for generalization.

The source information varied widely in quantity (and probably in quality) from Section to Section. Because the researchers were almost wholly dependent on opinions of others, as extracted from maps, reports, and questionnaires, the validity of their inferences is variable. Another factor that worked to reduce the over-all reliability of the conclusions is the scope of the study. Because the study deals with more than 3 million square miles of geography, and with a multitude of highway factors, no one area or factor received the attention that a researcher would intrinsically desire. It remains for further studies to reexamine the conclusions, with concentration on certain areas and/or factors.

Regional Geomorphology

Information concerning the physiographic and geologic characteristics of the regional units was based heavily, although not entirely, on the work of Fenneman (*18, 19*), Lobeck (*38*), Thornbury (*65*), and Woods and Lovell (*82*). Much valuable information concerning the particular characteristics of many Sections was obtained from many other references, such as Jenkins (*31*) and Wright et al. (*84*).

The quantity of physiographic mapping available at a continental or national scale was known to the researchers, but the availability of larger scale work was uncertain. Accordingly, a reasonably comprehensive mapping search was conducted. As a result, the following information was located: 40 state physiographic diagrams for 30 states; one new Province diagram; and 6 Subsection diagrams.* In several instances, two or three different physiographic interpretations of a given state were located.

The detailed mapping can be placed in one of two broad groupings: (1) directly physiographic, and (2) indirectly physiographic. In the second category are the Agricultural Land Resource maps, which are delineated using not only physiographic concepts but also the relation of land use and management to the factors of soil, climate, and topography. In many instances the "physiographic" boundaries were those shown on a land resource or pedologic map.

In addition to the mapping search, a fairly detailed examination was undertaken of the physiographic boundaries of the basic report units.

Highway Design and Construction Factors

Aggregates

The over-all objectives of this phase of the project were to investigate the type and distribution of aggregates used in the U.S., and to obtain information concerning any quality problems or limitations inherent in these aggregates. From this, a qualitative estimate was made of the potential availability of quality aggregate resources in each of the report Sections.

Method of Analysis.—The analysis consisted of three phases: (1) identification and mapping of potential aggregate sources; (2) identification and correlation of quality problems with the sources, based on the literature; and (3) collection of current engineering experience through questionnaires directed to each state highway agency.

Mapping.—The major types of aggregates mapped were sand-gravel sources and crushed-stone sources. The latter were subdivided into carbonate rocks, granitic/metamorphic complexes, and other igneous (primarily basaltic-type) rocks. Several extant state or regional maps of real or potential sources were located in the literature.

* For purposes of brevity, these diagrams are not included, although many were used for the recommended physiographic-highway engineering units proposed herein.

(Refs. *90, 107, 166, 169,* and *172* were particularly valuable.) Where such information was not located, attempts were made to derive it from sources such as general state or regional geologic maps, origin-parent material diagrams, and aggregate production data.

The total output of individual counties (or parishes, in Louisiana) producing sand-gravel and/or crushed stone (irrespective of type) was obtained and plotted for 1964 (*189*). In addition, state productions of sand-gravel and crushed stone were obtained and mapped on the basis of output ratio of sand-gravel to crushed stone. This information was obtained from Severinghause (*175*), and the U.S. Department of the Interior (*189*). The factors of population and market demand obviously influence such data, but they did supply perspective and guidance in certain areas where such was otherwise lacking.

Aggregate Problems.—Many aggregate problems are identified and described in the literature, particularly by Miles et al. (*144*). This information was supplemented by that obtained through the materials questionnaire.

Materials Questionnaire.—The questionnaire responses provided a current resume of aggregate types, uses, quality, and availability. A sample response (from Missouri) is shown in Appendix A.

The questionnaire was written for coded answers that could be applied to the basic Sections with a minimum of effort. It was composed of seven basic questions and three enclosures. The questionnaire was mailed to each state with Column 1 (material type) of Enclosure 1 completed. This initial listing of probable aggregate type was based primarily on an examination of the "non-metallic" mineral industry summary for each state in Ref. *188*. Refs. *169* and *172* provided supplementary information.

Several general problems common to the physical and chemical properties of aggregates used in both concrete and bituminous pavements are listed in Question III. This problem listing is not all-inclusive, nor is each problem unique. For example, the chemical reactions for concrete aggregates also would be considered a durability problem. Another code permitted the respondent to rate the relative severity of any reported problem. Question IV deals with the general functional uses of each aggregate type.

Answers to Questions I through IV were recorded in specified forms on Enclosure I. Therefore, this enclosure provides a summation, with respect to basic report units, of aggregate uses, problems, and problem severities.

Question V asks the respondent to indicate on Enclosure 3 the approximate boundaries of areas lacking in suitable aggregates. Questions VI and VII attempt to identify areas where the availability of aggregates and/or cementing medium played a *major role* in the selection of pavement type (portland cement or bituminous).

General Limitations of Analysis.—There are several limitations of analysis, as follows.

Practical Limitations.—Input information on aggregates was interpreted for mapping, according to physiographic units. There are several inherent difficulties in such an interpretation.

For example, aggregates can be quarried in one physiographic unit and transported for use (and subsequent performance) in another unit. Although the researchers attempted to remove this factor from their interpretations, it was not always possible to do so with confidence. Population densities, and the consequent relative demand for aggregates, introduce an additional problem. The natural tendency is to overestimate the aggregate availability in high-density areas and to underestimate the potential where the density is low. Still another factor is the relative size and shape of the physiographic units. A small unit may be inherently impoverished in aggregate sources because of its geology, but the existence of quality sources in an adjacent unit effectively negates the potential shortage. The large unit, on the other hand, may contain enough geologic variability to admit both potential abundance and scarcity, depending on the local area.

Mapping Limitations.—The several different methods of mapping aggregate factors are noted previously. As pointed out, there were several broad geographic areas where the researchers' definition of potential aggregate areas was very qualitative.

In addition, because of the extreme variability in characteristics and performance of crushed sandstone, combined with the limited information concerning its actual production, the mapping of sandstone bedrock areas as potential sources was not undertaken on a national scale.

Another important and limiting factor concerns the distribution of sand-gravel sources. An attempt was made to map *major* potential river and stream deposits, in addition to areas associated with other modes of origin. However, because stream deposits can be extremely localized, they will show only on large-scale map. (Because this difficulty is encountered to some degree with all aggregate types, the general source mapping must be supplemented with at least as much information as is contained in the unit descriptions of this text.)

Quality Limitations.—The criteria of aggregate acceptance or rejection depend not only on the particular specifications of a given jurisdictional unit (e.g., state) but also on the particular use of the aggregate. Consequently, a particular aggregate source may be acceptable for a given use in one portion of the U.S. and rejected in another. Differences in service environments, relative scarcity of aggregates, or simple differences of opinion may account for this discrepancy. Because extensive information concerning aggregate problems was obtained from state units and then transformed for the basic report units, the factor of differing criteria between jurisdictional units should be kept in mind.

Soils and Related Factors

Soil Origin and Texture.—The major objective of this phase of the study was to map a general distribution of soil origin and texture for the U.S., and, accordingly, to define (to a small scale) the distributions in each report unit.

Method of Analysis.—For the examination of the factor of soil origin, primary emphasis was placed on

the work of Jenkins et al. (*236*). Numerous other state references, maps, and regional geomorphic descriptions provided supplemental information.

The general soil texture map of the U.S. (Figs. B-16 to B-21) was developed to a scale of 1:2,500,000, which corresponded to the scales of the national geologic map (*75*) and the U.S.D.A. pedologic map of the U.S. (*279*).

Many references were consulted in the preparation of the map. Principal among these were distribution reports and maps developed for national, regional, or state coverage.

The national group included Refs. *236, 250, 279, 295,* and *296*. Regional soil references were available for the western U.S. (*294*), the north-central region (*277*), the southeast region (*287*), and the northeastern U.S. (*263*). Many individual state soil maps also were extensively used for soil data. The references varied widely in content and in date of preparation; e.g., only old coverage was available for some geographic areas (*246, 247*), whereas later information was located for others (*227, 289*).

The mapping technique was to retain as much detailed soil information as practicable. This, in part, accounts for the wide variety of legended soil units in the map. In many areas, only a very qualitative assessment of the soil conditions could be made, owing to the limited information available.

Every attempt was made to distinguish and map the general texture of the parent material. In residual soil areas, this information was not always obtainable, and major emphasis was placed on the general texture in the subsoil (B horizon) and the weathered parent materials. Perhaps the most obvious limitation of this mapping technique is the possible obscuring of a highly clayey type of B horizon which may produce special highway problems.

Within each basic report unit, a qualitative assessment was made of the frequency of occurrence of each major soil type. This analysis was based primarily on the results of the general mapping.

Poor Subgrade Support Areas.—The major purpose of this phase was to rate for each Section the combined severity-frequency of occurrence of highly clayey soils, and the frequency of occurrence of organic deposits.

Method of Analysis.—The qualitative assessment of poor subgrade areas in each unit was based primarily on an examination of the national texture map (Figs. B-16 to B-21) and supplementary soil descriptions.

High Volume Change Soils.—The major purpose of this phase was to assess qualitatively the relative frequency of occurrence of high volume change soils in the Sections.

Method of Analysis.*—Three sources of input were available: (1) reports of occurrences of high volume change problems in the U.S.; (2) predictions of swelling soils in pedologic mapping; and (3) predictions from geologic mapping. Two distribution maps were drawn—one based on the pedologic input (Fig. B-24), and one for the geologic information (Fig. B-23).

Frequency of occurrence was qualitatively assessed for each method of analysis (pedologic and geologic), in each Section. A final rating of high volume change frequency in each unit was taken as the higher rating given by the two methods of analysis. (Several exceptions occurred in areas of surficial transported materials underlain by potential high volume change geologic formations. A detailed discussion of these areas appears in Appendix B.)

Characteristics of the Analysis.—The geologic- and the pedologic-based mappings reflect the potential of the mapped unit to produce swelling problems, but do not attempt to rate the degree of the potential. The general prediction also is significantly influenced by the scale of the mapping. Reported problems of swelling difficulties with engineering structures confirm that the potential has been realized by interaction with the climatic and loading environment.

Frost Action and Frost-Susceptible Soils.—The frequency of occurrence was determined for frost-susceptible soil groupings in the Sections generally lying within the freezing zone. No rating was attached to the severity of subsequent frost problems.

Method of Analysis.—The definition of that portion of the U.S. in which freezing is potentially a significant problem was based on the work of Sourwine (*90*). The boundaries suggested by Sourwine were compared with the Section borders, and the Sections were placed (1) wholly within the frost zone, or (2) outside the frost zone.

To ascertain the distribution of frost-susceptible soils within the previously defined freezing zone, a composite map (Figs. B-26, B-27, B-28) was developed, based on the work of Bloom (*90*) and Osborne (*166*). The map covered 29 northern states and a portion of Maryland. This map covered most but not all of the area within Sections previously defined as lying within the frost zone. The researchers rated the frequency of occurrence of frost-susceptible soils in each Section by combining the methods of Bloom (*90*) * with an examination of the general soil texture map of the U.S. (Figs. B-16 to B-21).

Characteristics of the Analysis.—Several minor difficulties were introduced by the differing generalizations effected by Bloom, Osborne, and the researchers. In many cases, continuity of frost-susceptible soil type was not maintained through political borders, and the researchers modified many of these areas to achieve it. Numerous other small difficulties had to be resolved (e.g., differences in base maps, boundaries, soil units generalized).

* The description provided is a combination of the work of the researchers and that of Jensen (*333*).

* Bloom (*90*), after work by Haas, and using the U.S. Army Corps of Engineers' system, considered sands and loamy sands as F2; silty clay loam, clay loam, silty clay, and clay as F3, and sandy loam, loam, silt loam, and silt as F4.

CHAPTER TWO

FINDINGS

Many difficulties are encountered in any attempt to summarize briefly and adequately the physiographic, geologic, and pertinent highway engineering factors peculiar to regional geomorphic units in the U.S. However, discussion is faciliated if the U.S. is divided into two major geographic groupings: an eastern portion and a western portion.

The western portion essentially corresponds to the U.S. portion of the North American Cordillera Division suggested by Lobeck. This unit is comprised of physiographic Provinces, identified in Table 4, with unit codes 1 through 9. The Provinces of the eastern group (unit codes 10 through 20) lie east of and include the Great Plains Province. Figure 1 shows the basic grouping and general locations of the various Divisions and Provinces of each major group; the legend is keyed to Table 5 which describes the physiographic units in question. Within these two groups, major differences can be characterized in terms of topography, population, climate, and historical geology.

TOPOGRAPHIC DIFFERENCES

The entire western unit generally may be considered as a highland unit. Elevations in this area are the highest in the U.S. (exclusive of Alaska), directly attributable to the two parallel trending mountainous systems found here. The orogenies that have occurred have naturally formed areas of high relief. Large changes of elevation are common not only in the mountainous areas but also much of the Intermontane Plateau system. Large changes occur between the basins and ranges proper, characteristic of the Basin and Range Province. In the Plateau Provinces relief is due primarily to destructional processes that have left some of the world's most majestic canyon areas.

In direct contrast to the west, with its high relief and elevations, most of the east is of low elevation and relief. The topographic differences are directly related to the presence of the Interior and Atlantic Plains Divisions, which are characterized primarily by relatively mild dipping sedimentary strata. In addition, many of the once "mountainous portions" of the area have been leveled by widespread erosion which has resulted in plateaus and uplands of mild relief.

Some areas of high relief are found in the east, particularly in the Appalachian Highlands Division. However, much of the "mountainous terrain" has been formed by erosion of flat-lying sedimentary strata (Appalachian Plateau Province) or folded sedimentary strata (Ridge and Valley). The "true" mountainous areas in the east are confined to the Blue Ridge (Older Appalachian Province), portions of the Adirondacks (Laurentian Upland Province), and along the western and northern portions of the New England Maritime Province.

GEOLOGIC DIFFERENCES

One of the more significant geological differences between the eastern and western areas is the liberal presence of vulcanism in the west. (Figs. B-3 and B-4, which show potential crushed stone areas in the U.S., illustrate this point.) Extrusive rocks of Tertiary and Quaternary age are widespread in the west, but are almost nonexistent from a regional viewpoint in the east. Granitic-type rocks, often associated with the mountain building common to the west, are widely present. Geologically, these rocks generally are confined to Jurassic and/or Precambrian Periods of time. In the east, these rocks generally are found in larger areas and occur in the "Crystalline Appalachians" (Older Appalachian and New England Maritime Provinces) and the Laurentian Upland Province.

In general, sedimentary strata are more predominant in the eastern U.S. than in the west. Figure 2 shows the distribution of Paleozoic strata in the U.S. These strata form a large portion of the eastern physiography; they are flat-lying to relatively mild dipping. In contrast, Paleozoic strata of the west are scattered and often occur as narrow bands in highly tilted structure around massive uplifts.

Tertiary and Mesozoic sedimentary strata are found throughout both areas. In the west, major areas of occurrence are the California and Oregon Coast Ranges of the Pacific Coast Ranges and much of the flat-lying sediments of the Colorado Plateau Province. In the east, the greatest concentrations are found in much of the Great Plains Province, the western portion of the Central Lowland Province, the Atlantic and Gulf Coastal Plains Province, and the Triassic Lowland Province. With the exception of the folded and faulted areas in the Pacific Coast Ranges and scattered areas surrounding the uplifts in the west, most of these strata are relatively undisturbed and horizontal to mildly dipping.

Although continental glaciation has occurred continously across the northern tier of the U.S., relatively little of the western portion was affected by glaciation, in contrast to the east. Figure 3 shows the general distribution of continental glaciation in the U.S. In the west, much of the glacial drift veneers rugged mountainous terrain and, as a result, affords only slight modification to the regional topography. In the east, the effect and distribution of glaciation is such that it becomes the modal characteristic for several Sections of the Central and Eastern Lowland Province.

TABLE 4

PHYSIOGRAPHIC UNIT CODE

PROVINCE AND SECTION CODE [a]

1. Western Mountains of the Pacific Coast Range Province
   a. Olympic Mountains
   b. Oregon Coast Range
   c. Klamath Mountains
   d. California Coast Range
   e. Los Angeles Ranges
2. Sierra-Cascade Province
   a. Northern Cascade Mountains
   b. Southern Cascade Mountains
   c. Sierra Nevada
   d. Lower California
3. Pacific Troughs Province
   a. Puget Sound
   b. Willamette Valley
   c. California Valley
4. Columbia Plateau Province
   a. Walla Walla
   b. Blue Mountains
   c. Snake River Plains
   d. Payette
   e. Harney
5. Basin and Range Province
   a. Great (Closed) Basin
   b. Sonoran Desert
   c. Salton Trough
   d. Open Basin (Mexican Highland)
   e. Sacramento Highland
   f. Great Bend Highland
6. Colorado Plateau Province
   a. High Plateaus of Utah
   b. Uinta Basin
   c. Canyon Lands
   d. Navajo
   e. Grand Canyon
   f. Datil
7. Northern Rocky Mountain Province
   a. Montana
   b. Bitterroot
   c. Salmon River Mountains
8. Middle Rocky Mountain Province
   a. Yellowstone
   b. Bighorn Mountains
   c. Wind River Mountains
   d. Wasatch
   e. Uinta Mountains
9. Southern Rocky Mountain Province
   a. Front Range
   b. Western
   c. San Juan Mountains
10. Great Plains Province
   a. Glaciated Missouri Plateau
   b. Unglaciated Missouri Plateau
   c. Bighorn Basin
   d. Wyoming Basin
   e. Black Hills
   f. High Plains
   g. Colorado Piedmont
   h. Raton Upland
   i. Pecos Valley

PROVINCE AND SECTION CODE [a]

   j. Plains Border
   k. Central Texas Mineral
   l. Edwards Plateau
   m. Osage Plains
11. Central and Eastern Lowlands Province
   a. St. Lawrence Lowlands
   b. Champlain Lowland
   c. Hudson River Valley
   d. Mohawk River Valley
   e. Eastern Lakes and Lacustrine
   f. Central Till Plains
   g. Driftless
   h. Western Lakes and Lacustrine
   i. Dissected Loessial and Till Plains
12. Laurentian Upland Province
   a. Superior Upland
   b. Adirondack
13. Ozark and Ouachita Province
   a. St. Francis Mountains
   b. Springfield-Salem Plateau
   c. 1. Boston Mountains
      2. Arkansas Valley
      3. Ouachita Mountains
14. Interior Low Plateaus Province
   a. Blue Grass
   b. Nashville Basin
   c. Shawnee Hills
   d. Highland Rim
15. Appalachian Plateau Province
   a. Catskill Mountains
   b. New York Glaciated
   c. Allegheny Mountains
   d. Kanawha
   e. Cumberland
16. Newer Appalachian (Ridge and Valley) Province
   a. Pennsylvania-Maryland-Virginia
   b. Tennessee
17. Older Appalachian Province
   a. Blue Ridge
   b. Piedmont
18. Triassic Lowland Province
19. New England Maritime Province
   a. Seaboard Lowland
   b. New England Upland
   c. Connecticut Lowland
   d. White Mountain
   e. Green Mountain
   f. Taconic
   g. Reading Prong
20. Atlantic and Gulf Coastal Plain Province
   a. Embayed
   b. Sea Island
   c. Florida
   d. East Gulf
   e. Mississippi Loessial Upland
   f. Mississippi Alluvial Plain
   g. West Gulf

[a] Numbers represent physiographic Provinces; letters represent physiographic Sections.

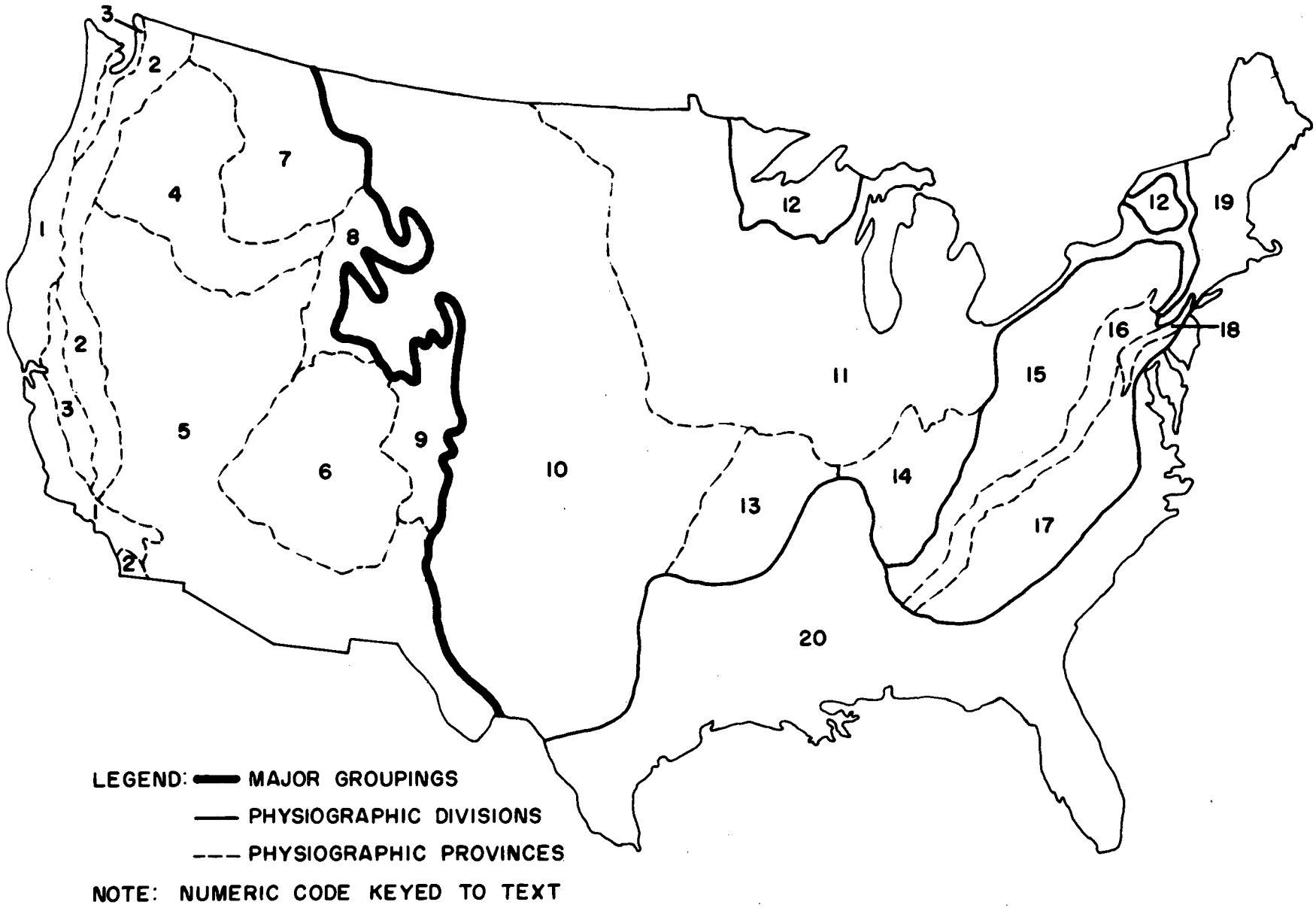


Figure 1. Location of major physiographic unit categories.

TABLE 5

CLASSIFICATION OF MAJOR PHYSIOGRAPHIC UNIT CATEGORIES IN THE U.S.

MAJOR U.S. GROUP	PHYSIOGRAPHIC UNIT			PROV. CODE
	DIVISION	SYSTEM	PROVINCE	
West	North America Cordillera	Pacific Mountain	Pacific Coast Ranges	1
			Sierra-Cascade	2
			Pacific Troughs	3
		Intermontane Plateau	Columbia Plateau	4
			Basin and Range	5
			Colorado Plateau	6
		Rocky Mountain	Northern Rocky Mountains	7
			Middle Rocky Mountains	8
			Southern Rocky Mountains	9
East	Interior Plains		Great Plains	10
			Central and Eastern Lowlands	11
			Ozark and Ouachita	13
			Interior Low Plateaus	14
	Atlantic Plain		Atlantic and Gulf Coastal Plain	20
	Appalachian Highland		Appalachian Plateau	15
			Triassic Lowland	18
			Ridge and Valley	16
			Older Appalachian	17
			New England Maritime	19
	Canadian Shield		Laurentian Upland	12

Figure 2. Distribution of Paleozoic formations occurring at or near the surface. Source: Tolman (185).

Figure 3. Distribution of Pleistocene ice sheet in the U.S. Source: Tolman (185).

The final geologic difference between eastern and western groupings is the rather widespread distribution of valley fill sediments in the west. In particular, the Basin and Range as well as the Pacific Troughs are characterized by this material. Smaller, scattered areas occur frequently in the mountainous units of the west. Valley fill materials (exclusive of Great Plains Outwash) are generally non-existent in the eastern Province grouping.

CLIMATIC DIFFERENCES

One of the most pronounced differences between the east and west groupings is in the climatic patterns of these two areas. It should be pointed out that topography exerts a powerful effect on the over-all climatic conditions in a given area. Because of the high elevations and relief in the west in relation to the east, much of the west experiences large changes in climate within relatively short distances. The climatic pattern associated with the lower relief and elevation of the east is characterized by gradual, uniform changes over large distances.

Annual Precipitation

Figure 4 shows the distribution pattern of annual precipitation in the U.S. As can be noted, much of the western area is characterized by 20 in. or less of precipitation. This fact is very pronounced for much of the Intermontane Plateau System separating the mountain systems. Exceptions occur primarily west of the Sierra-Cascade Province and along the Pacific sides of the higher mountainous locations. It is in the latter area that large variations in precipitation may occur in relatively short distances.

In contrast, most of the eastern grouping has precipitation in excess of 20 in., except along the western edge of the Great Plains Province. Generally, precipitation tends to increase gradually, from any point in the eastern area, toward the Mississippi and Alabama Gulf coast area. A notable exception to this climatic pattern occurs in the mountainous Blue Ridge area near northeastern Georgia; here the topographic effects on rainfall increase are quite noticeable.

Annual Temperature

If the earth were a flat featureless plain, the temperature would vary gradationally from the equator, decreasing as one proceeded to the poles. For most of the eastern U.S., this variation is quite marked (see Fig. 5 which shows distribution of annual temperature). The pattern of temperature for the west, although generally increasing to the south, is much more irregular.

Freezing Index

Because temperature is strongly related to the freezing index (FI), climatic patterns of this variable are similar to temperature patterns. Figure 6 shows the distribution of freezing index in the U.S. Again, because of the mountainous systems of the west, large changes in freezing index may be expected in short distances.

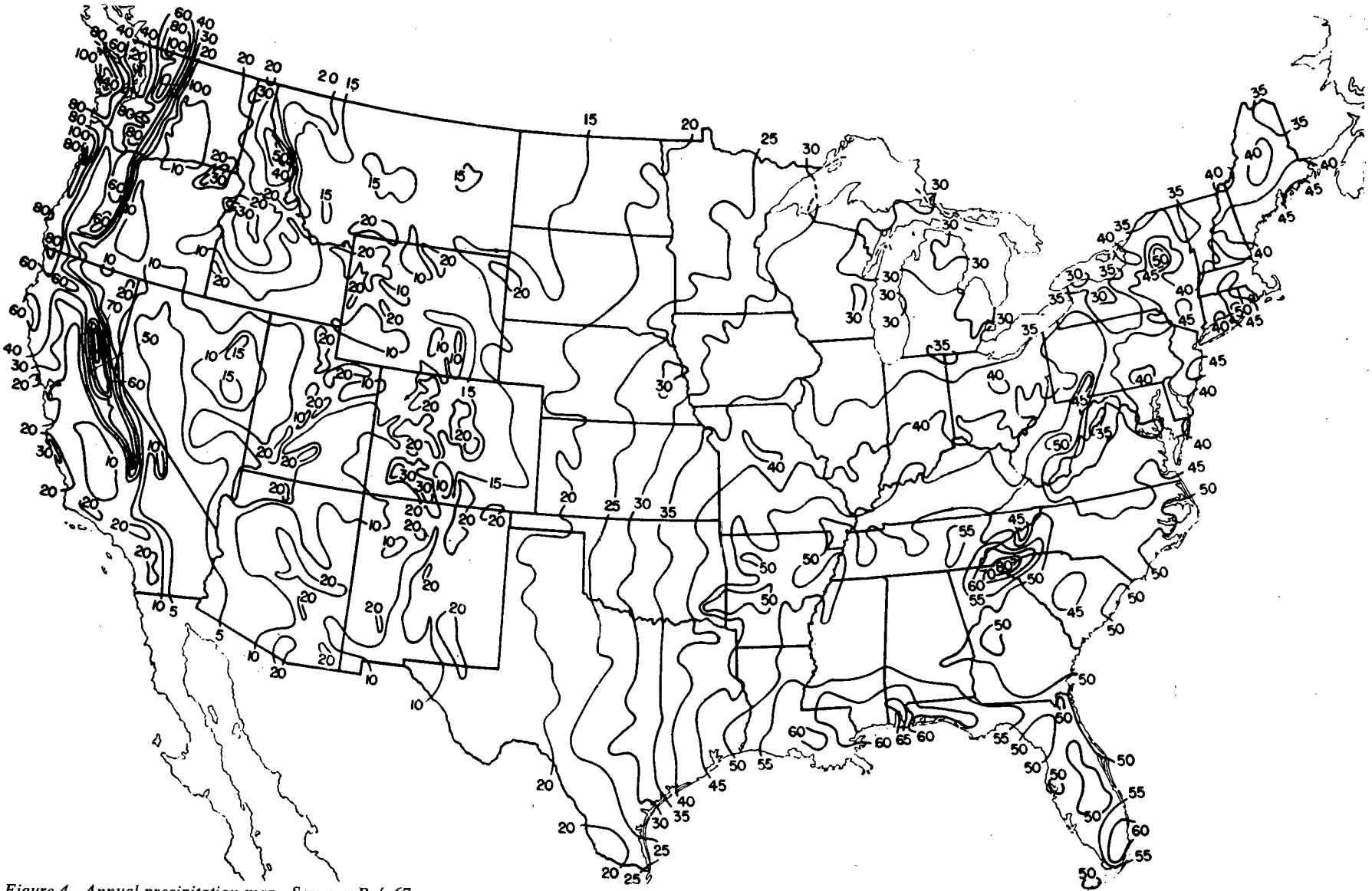


Figure 4. Annual precipitation map. Source: Ref. 67.

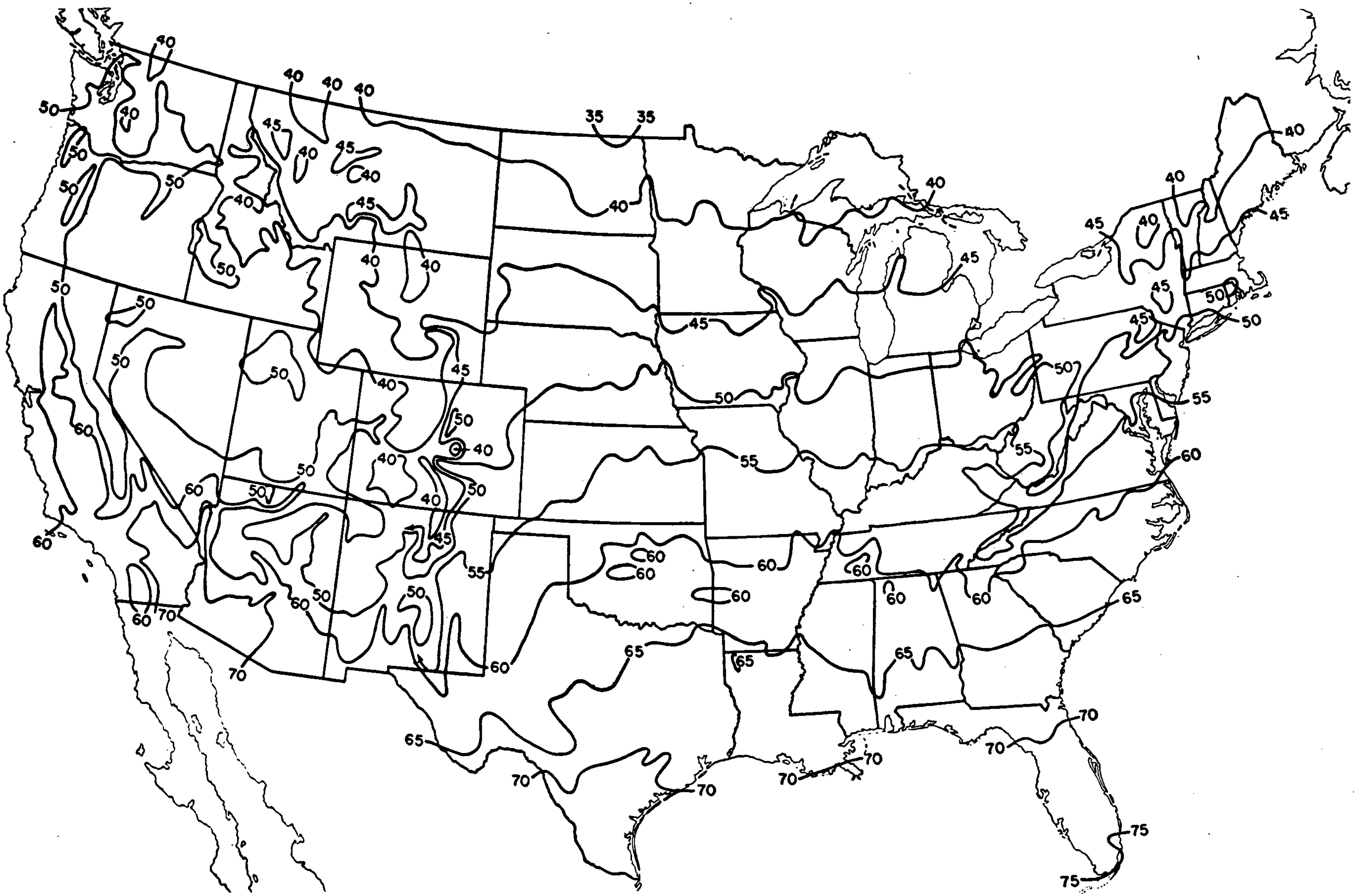


Figure 5. Annual temperature map. Source: Ref. 67.

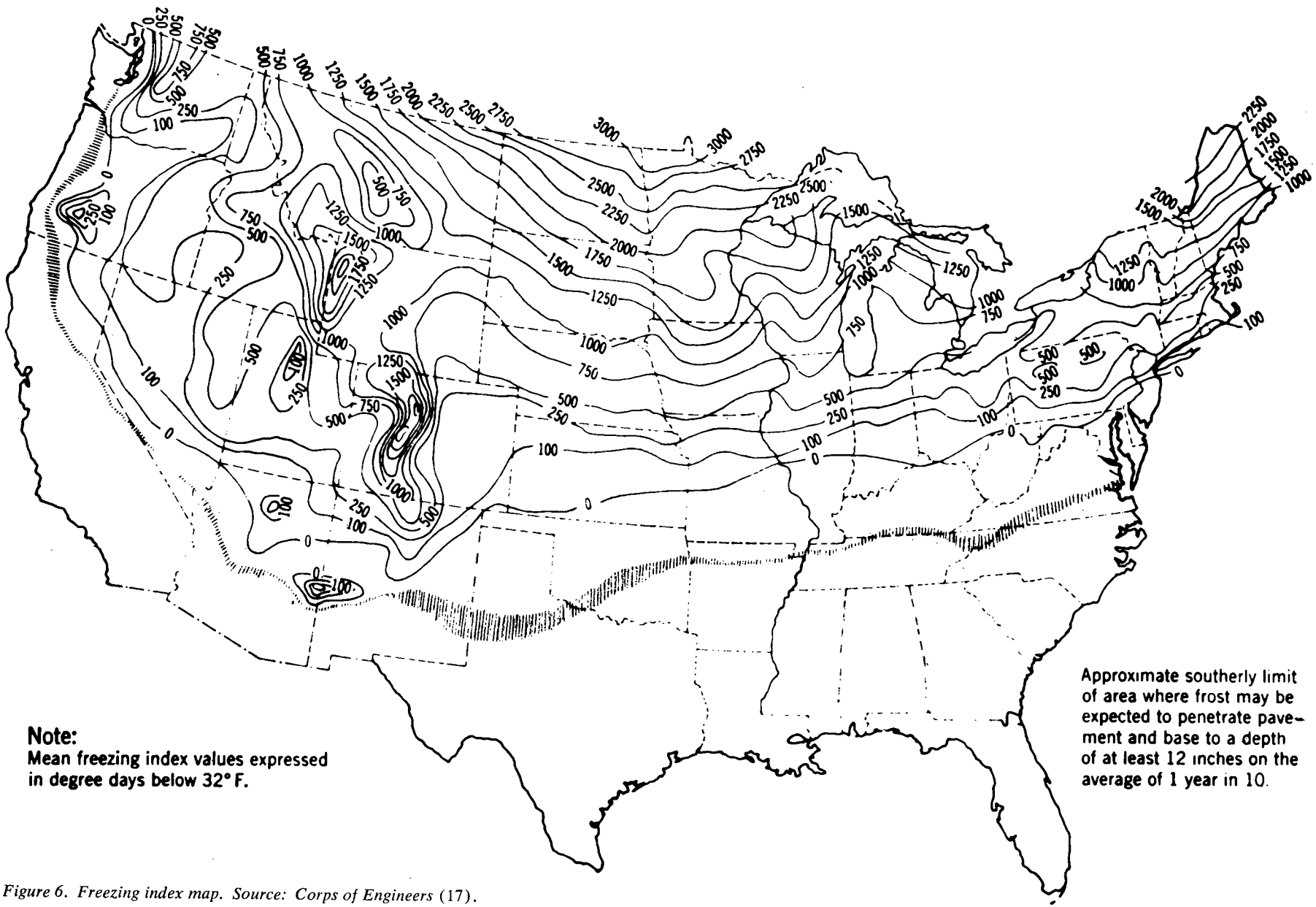


Figure 6. Freezing index map. Source: Corps of Engineers (17).

Potential Evapotranspiration

A climatic variable of importance to the high volume change soil problem in the U.S. is that of potential evapotranspiration. The distribution of this parameter is shown in Figure 7. As can be seen, the gradual change in the eastern grouping is contrasted to the sharp changes occurring in short distances in the west.

POPULATION DIFFERENCES

From the standpoint of highway engineering and pertinent to this study, a final, but important difference between the eastern and western Province groups is that of population densities. Figure 8 shows the distribution of the 1960 census for the U.S. The population density in the west, is generally less than that in the east. However, major exceptions to this pattern are found in both groups.

In the west, extremely high-density concentrations exist in much of the Pacific Troughs Province, as well as in and around the San Francisco and Los Angeles areas of California. Low-density areas in the east occur largely in the western portions of the Great Plains Province and in isolated northern areas of Minnesota, New York, and Maine.

In many cases the population density is strongly related to physiographic classifications. A dense population implies a higher level of highway engineering activity, which generally creates a greater demand for mineral aggregates, greater occurrence of highway soil problems, etc.

SUMMARY OF MAJOR DIFFERENCES

The west is characterized generally by abrupt changes in topography, geology, and climate within relatively short distances. In contrast, in the east these parameters are frequently marked by gradational changes over larger distances or areas. In addition, the gross differences in highway engineering activity, as related to differences in population concentration and distribution, become an important parameter in the over-all effort of using physiographic units to make generalizations about highway design factors in the U.S.

SUMMARY OF INDIVIDUAL SUBJECT AREAS CONSIDERED

Physiography and Regional Physiographic Units

An examination of the regional physiography (geomorphology) of the U.S. reveals the following:

1. Physiography is the science dealing with the description of landforms. Geomorphology is the science dealing with the interpretation or development (genesis) of landforms. However, when both sciences study the regional distribution of landforms, the activities of both resemble each other; i.e., there are few or no significant differences between a regional geomorphic or physiographic unit.

2. Landforms are described in nongenetic and qualitative terms of altitude, relief, and type of landform present. However, the development of landforms is due to the combined interaction of geomorphic processes acting over a period of time and under a particular historical climatic environment on a distinct type or set of parent material types existent with its own unique geologic structure.

3. A regional physiographic unit, at any level of examination, attempts to delineate an area having a unique or repetitive series of landforms (areas of similar topographic expressions). Variant areas (areas having geomorphic control factors that differ from the modal characteristics delineating the regional physiographic unit) may be an inherent part of any level of regional categorization. Generally, the larger the topographic unit examined, the greater the possibility of including more variant types in it; i.e., as larger and larger areas are examined, the degree of topographic generalization increases.

4. Because of the subjectivity involved in defining physiographic units, no strict or definite criteria are known to place consistently defined regional units to a particular (common) level of regional physiographic categorization (e.g., Province, Section). Consequently, it is possible for different physiographers to designate a given unit as a unique Province or even as Sections of differing Provinces. This point is illustrated by Figure 9, which shows four differing categorization systems for the physiographic units confined to the lowlands and valleys found primarily in New York. It can be noted that this report and the Woods-Lovell system consider the Mohawk Valley unit to be a Section of the Central and Eastern Lowland Province; Fenneman, the combined USGS-Fenneman System, and Thornbury (not shown in Fig. 9) consider it to be a Section of the Appalachian Plateau Province; Lobeck does not recognize this as a distinct unit category, but rather as a variant portion of the Eastern Lakes and Lacustrine Section of the Central and Eastern Lowland Province.

5. Physiographic unit borders are extremely variable in the degree to which they delineate adjacent units. In several cases, a given border segment may vary gradationally in its degree of noting contrasting units; e.g., in units separated by escarpments, the altitude difference between the units may decrease gradually until topographic significance is lost. An example is the western border portion of the Central and Eastern Lowland Province which is adjacent to the Great Plains Province from Kansas north to the Canadian-U.S. border. (This border segment corresponds to segment No. 18, Central and Eastern Lowland Province boundary description in Appendix C.)

6. Physiographic areas delineated at the Province or Section category, from a U.S. level of examination, may not necessarily serve as the "skeleton" framework for physiographic areas delineated at a level of greater detail (e.g., state level). Figure 10 shows this for the state of Kansas.

7. In general, regional physiographic units have a unique type or repetitive types of parent material and geologic conditions. However, uniform topographic expressions are not always indicative of uniform parent material or geologic characteristics. This implies that not all regional physiographic units have a unique parent material type. The most general ways in which this occurs in regional physiographic units in the U.S. are as follows:

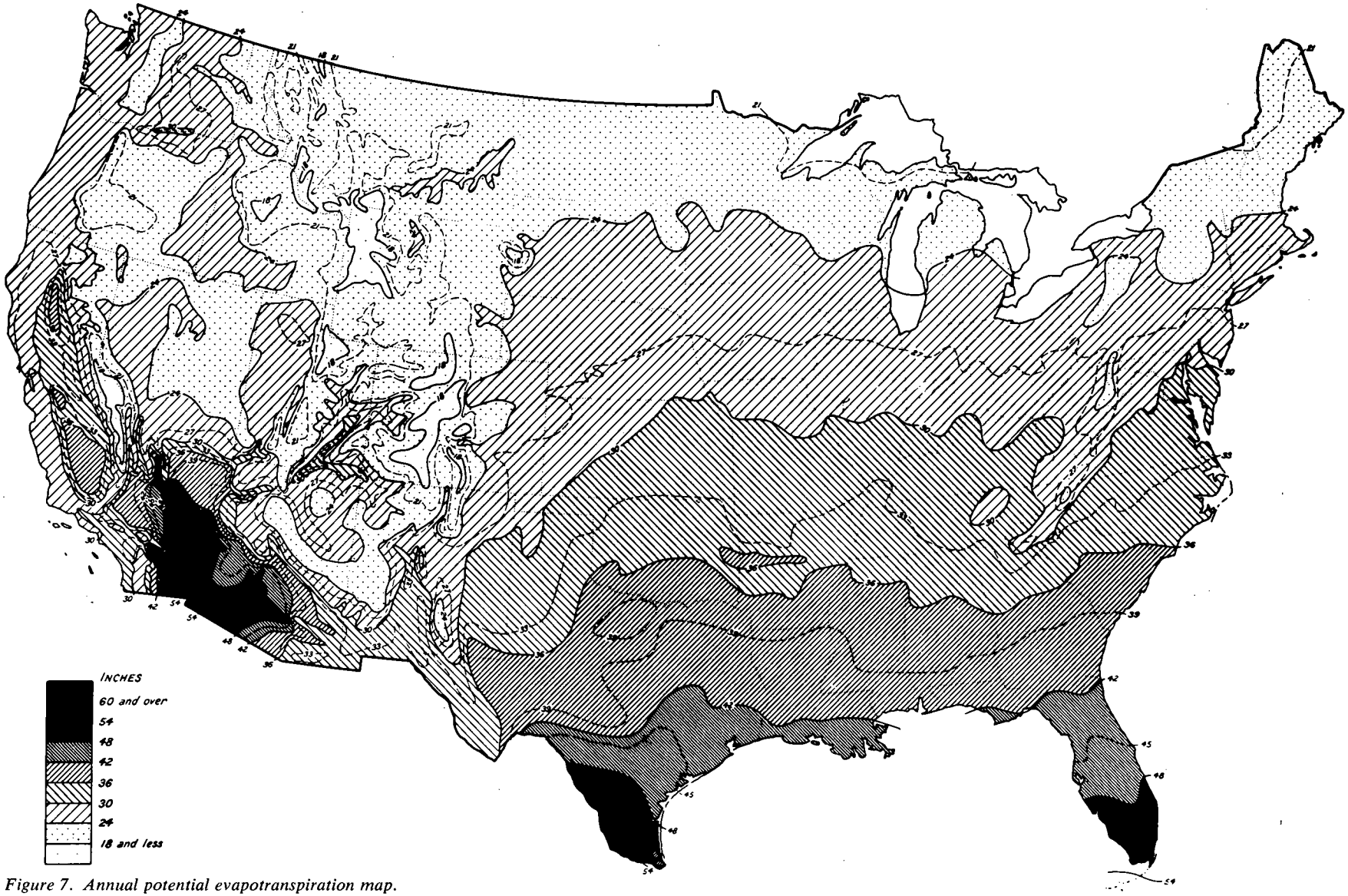


Figure 7. Annual potential evapotranspiration map.

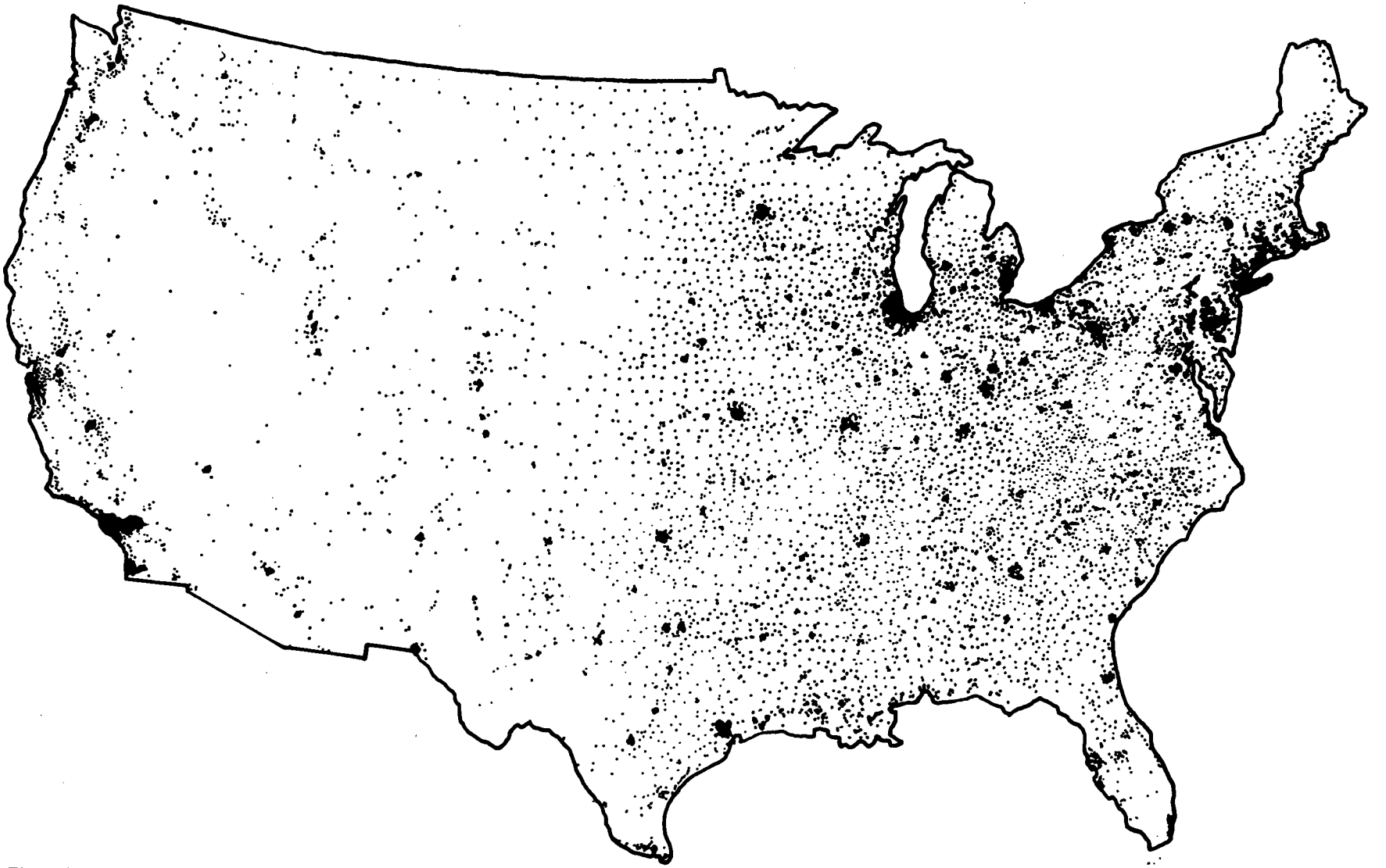


Figure 8. Population map, based on 1960 census. Source: Miller (45).

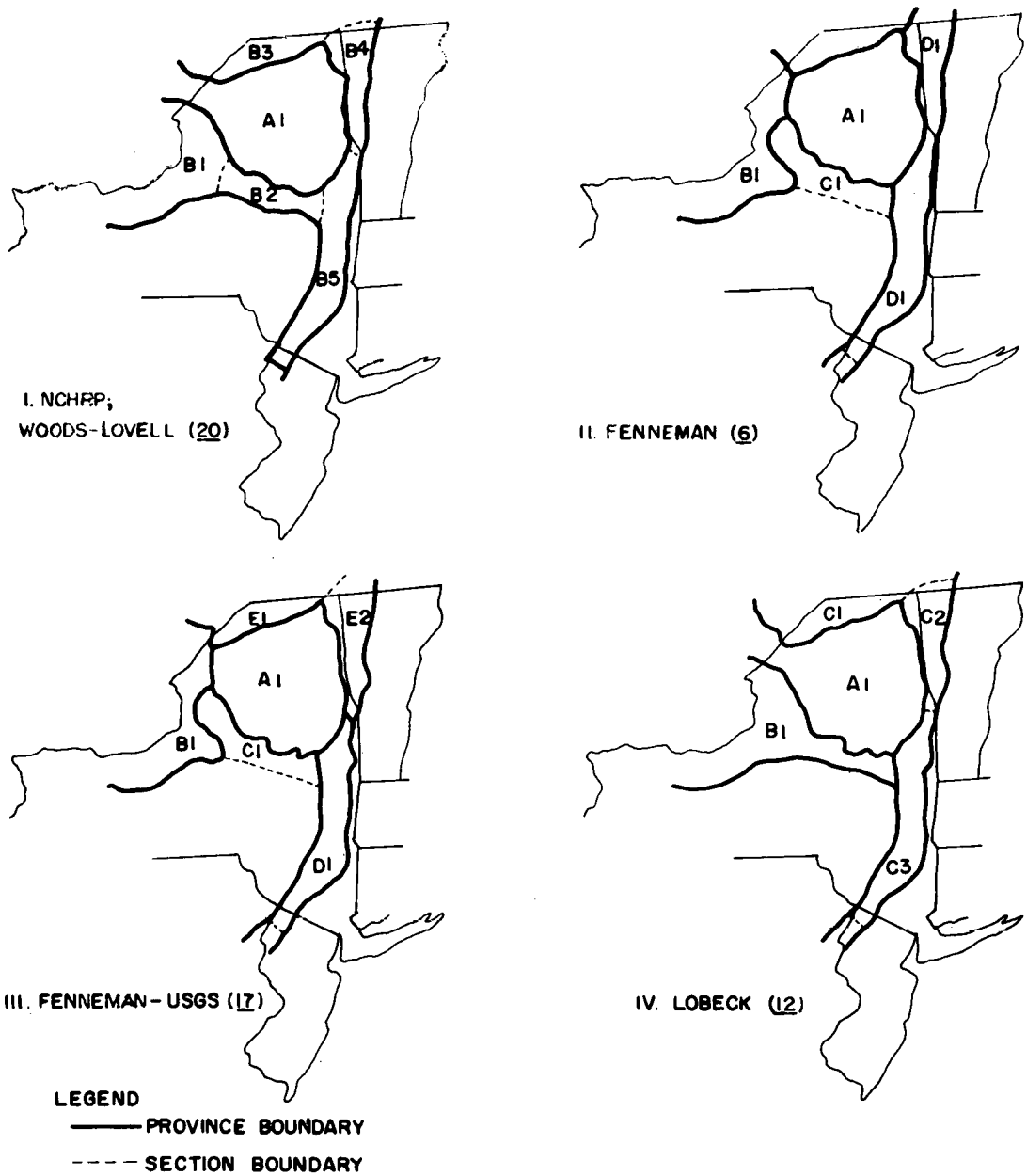


Figure 9. Comparison of eastern lowland and valley Sections between physiographers.

a. Highly faulted areas: The Basin and Range Province is a good example of this. Many of the mountain ranges vary greatly in geologic age and rock type. Likewise, in mineralogic composition the alluvium (valley fill) derived from these ranges is highly variable and complex. Another physiographic unit similar in its geologic and parent material complexity but unique in its topographic expression is the Montana Section (particularly the southwestern portion) of the Northern Rocky Mountain Province.

b. Regional facies changes: Lithology may differ due to facies changes in bedrock type but still maintain the over-all uniformity of topographic expression of the physiographic unit. An example occurs in the Osage Plains Section of the Great Plains Province. This Section has a modal topographic expression of north-south trending cuestas. However, in the northern portion of the Section, the topography is developed on shale lowlands and limestone scarps. As one proceeds south, the limestone is replaced by sandstone as the ridge makers.

c. Transported soil areas: In areas where a gradational change in origin occurs from a nontransported soil area (bedrock or residual soil) to transported soils (primarily of aeolian and glacial origin), physiographic units may be delineated on the gross features of the consolidated (bedrock) areas. These units may have transported soils that mantle the bedrock thickly enough to be significant in highway design and construction considerations, but their effect on the regional physiography is insignificant. An excellent example on a regional scale is the continuous loessial deposits in the midwest. There the loess occurs in portions of the High Plains and Plains Border Sections of the Great Plains Province and continues into the Central and Eastern Lowland Province, occurring in the Dissected Loessial and Till Plains, Driftless, and Central Till Plains Sections.

8. Distinctive and adjacent unique physiographic units may be of the same general parent material type or types. The major ways in which this can occur are as follows:

a. Differing levels of geomorphic stage: This obvious occurrence for differing regional physiographic unit delineation is generally manifested by similarity of elevation but differing factors of relief. An example is found in the Navajo and Canyon Lands Sections of the Colorado Plateau Province. In general, both Sections have similar parent material types of flat-lying, relatively soft sandstones and shales primarily of post-Paleozoic age. However, because of the perennial source of water (streams) from the Southern Rocky Mountain Province to the east, flowing within the Canyon Lands Section, the subsequent dissection in this unit differs enough from the Navajo Section to justify, from a physiographic viewpoint, separate regional units.

b. Partial regional peneplanation (erosion): A good example occurs at the contact of the Seaboard Lowland-New England Upland Sections. The Seaboard Lowland is a topographically lower unit developed by the beveling action of marine erosion on bedrock similar in type and geologic age to that found in the adjacent New England Upland Section. In some instances, "micro geologic-parent material units" may be continuous through the border segment separating the two units.

Another example may be found in the relationship of the Blue Ridge and Piedmont Plateau Sections of the Older Appalachian Province. There widespread erosion has beveled parent material in the Piedmont Plateau unit that generally is similar to that comprising the Blue Ridge Section. The topographic differences between the two units are distinguished by the mountainous area of the Blue Ridge Section and the plateau topography of the Piedmont Section.

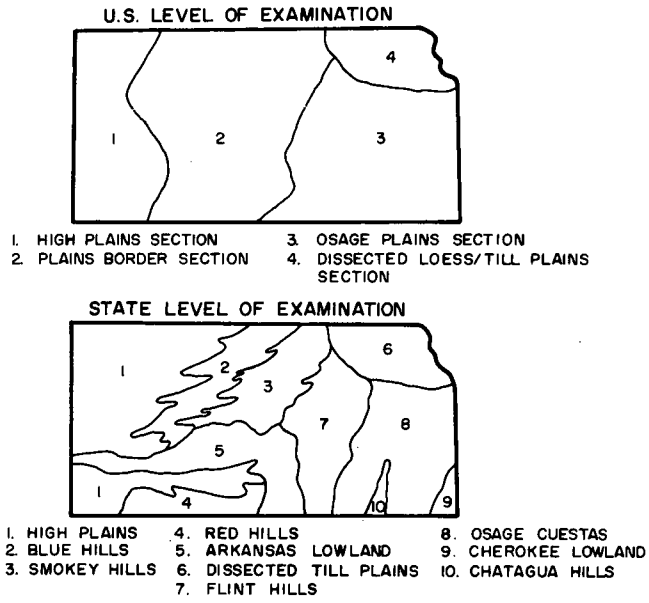


Figure 10. Difference in regional physiographic unit delineation at two different levels of examination, Kansas.

Aggregates

Design Factor Rating Summary

The examination of the potential aggregate availability for the physiographic Sections comprising the U.S. indicates that lack of suitable aggregate sources is an urgent problem facing a substantial part of the highway industry. Table 6 summarizes the estimated potential availability ratings of aggregates, by Section. Figure 11 shows the distribution of these ratings in the U.S.

Table 6 indicates that Section areas comprising more than 26 percent of the land mass have a poor potential for aggregate resources, and Sections totaling almost 6 percent have a very restricted potential aggregate supply. In addition, it should be mentioned that the "true" or "realistic" (in contrast to "potential") appraisal of aggregate resources may indicate a greater percentage of areas where aggregate availability would be a problem. This is because in many western areas of the U.S., where good potential aggregate sources exist (particularly crushed stone), the regions are sparsely populated and in many cases inaccessible owing to the extremely rugged, mountainous conditions. Here, the ruggedness and inaccessibility of these areas would tend to reduce effectively the potential rating to a more realistic lower supply of aggregates. In contrast, in the east many of the areas with potentially adequate supplies may be restricted in the exploitation and use of aggregates owing to urban

TABLE 6

SUMMARY OF ESTIMATED POTENTIAL AVAILABILITY RATINGS OF QUALITY AGGREGATES, BY SECTION

ABUNDANT TO ADEQUATE		ADEQUATE TO LIMITED		LIMITED TO PROBLEM		SEVERE PROBLEM	
SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)
1e	21,790	1a, c	27,130	1b, d	53,840	—	—
2b, c, d	74,530	2a	16,140	—	—	—	—
3a, b, c	42,310	—	—	—	—	—	—
4a, b	61,100	4d	20,560	4c, e	33,190	—	—
5a, b, d, e, f	352,170	—	—	5c	10,520	—	—
6f	9,290	6a, e	41,520	6b, c, d	73,110	—	—
7a	43,800	7b	34,480	7c	27,500	—	—
8b, c, e	16,950	8a, d	28,390	—	—	—	—
9a, b, c	60,450	—	—	—	—	—	—
10c, e, k, l	68,560	10h, m	124,690	10a, d, f, g, i, j	336,200	10b	123,390
11a, b, c, d	11,000	11e, f, i	262,850	11g, h	119,060	—	—
12a, b	72,540	—	—	—	—	—	—
13a	3,790	13b, c3	48,610	13c1, c2	14,090	—	—
14a, b, d	34,840	—	—	14c	16,540	—	—
—	—	15a, b, c, e	56,830	15d	45,930	—	—
16a, b	45,340	—	—	—	—	—	—
17a, b	90,670	—	—	—	—	—	—
18	6,040	—	—	—	—	—	—
19b, c, e, f, g	46,440	19a, d	23,080	—	—	—	—
—	—	20a, b, d, g	319,900	20c, e	57,540	20f	45,700
Total	1,061,610		1,004,180		787,520		169,090
Percent of U.S.[a]	35.1		33.2		26.1		5.6

[a] Exclusive of Alaska and Hawaii.

development associated with the high-population densities common to the area. This would have a similar reductive effect.

General Distribution of Aggregates

General East-West Differences.—In discussing the aggregate resources in the U.S., use of the east-west Province grouping is convenient in explaining general distributive characteristics, differences, and major types of aggregates used.

Generally, both the east and the west have an equivalent potential for crushed stone sources; however, they differ greatly by major type available. In the east, the greatest source of crushed stone exploited is invariably crushed carbonate, with less frequent occurrences of granitic/metamorphic complex and basaltic types being available. In contrast, the potential types in the west are associated more frequently with the last two categories of crushed stone, while the carbonates are of decreasing importance to the crushed stone industry.

In addition, large areas of sand-gravel deposits are found in the valley fill areas of the west, characteristic in many portions of this grouping, but generally are nonexistent in the east. The importance of glacial-associated sand-gravels is significant in most of the northern glaciated Sections of both the east and the west. Isolated regions of coastal plain gravels also are significant in the east but are generally absent as a regional source in the west. Sand-gravels obtained from and associated with the rivers and streams of the entire U.S. play a major and prominent role; these materials appear to be of equal importance as sources of highway aggregates, irrespective of any east-west border separation.

Crushed Stone Distribution.—Table 7 is a summary of the major types of crushed stone used as highway aggregate in Sections. The table is based on information in Table B-13. A general discussion of each grouping follows.

Carbonate Sources.—As Table B-3 indicates, the use of carbonate rocks (limestone and dolomite) for crushed stone far exceeds that of any other major crushed stone type in the U.S. Of the 48 contiguous states, 41 use this source as highway aggregate (Connecticut, Delaware, Louisiana, Mississippi, New Hampshire, North Dakota, and Oregon do not). By far the greatest concentration and use of these rocks occur in the vast Paleozoic formations in the east (Fig. 2). Figure 12 shows the distribution of the 20 leading state carbonate producers for the 1956-1958 period. The over-all importance of this geologic area is apparent from a comparison of Figures B-2, 2, and 12. California, shown in Figure 12 as one of the leading producers of carbonate stone, uses only a small portion (approximately 10 percent) of this for highway aggregate.

In terms of the physiographic units examined, this vast Paleozoic area forms much of the topography associated with the Ridge and Valley, Interior Low Plateau, Appalachian Plateau, and Ozark and Ouachita Provinces. However, in the last two Provinces, sizeable regional areas lack

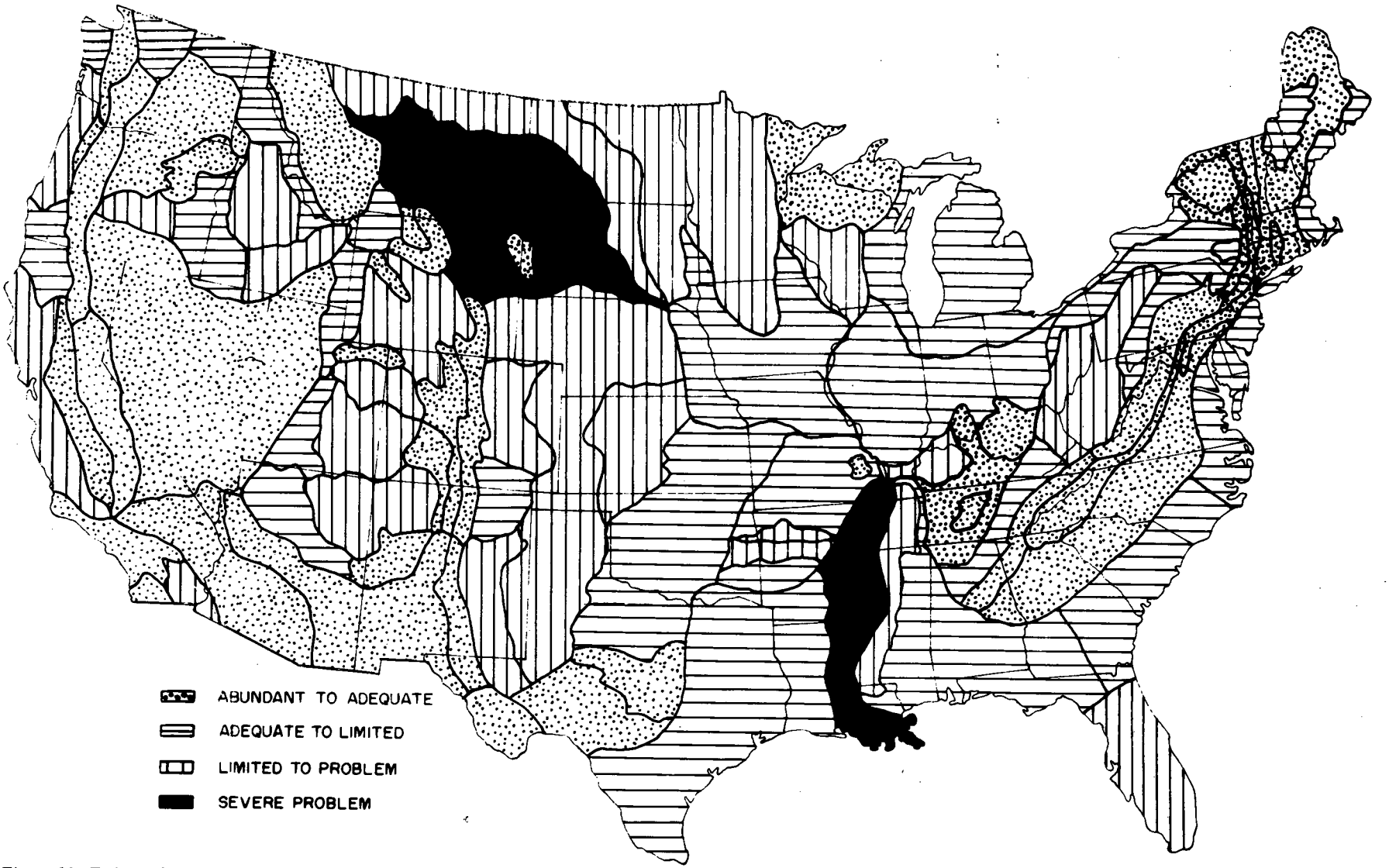


Figure 11. Estimated potential availability rating of quality aggregate resources, by physiographic unit.

TABLE 7

SUMMARY OF MAJOR CRUSHED STONE TYPES USED AS HIGHWAY AGGREGATE, BY SECTION [a]

	CRUSHED STONE TYPE, BY SECTION				
PROV. CODE	NONE	CARBONATE	SANDSTONE	GRANITIC/ META-MORPHIC	OTHER IGNEOUS
1	c*	d*, e*	a, b, d*	e*	a, b
2		b*, c*	a	a, c*, *d**	a, b*
3	c*	None	a	None	a, *b*
4		None	None	None	(*a-e*)
5	c*	a*, d*, e*, f*	d*	a*, b*, d*, e*	a*, b*, d*, f*
6	a, b	f	*c*, d	None	d, *e*, f
7		a, b	a	a, b	(a-*c*)
8	e	*b*, c, d	d	*a*, c, d	None
9		a, b	None	(a-c)	c
10	a	b-e, f*-h*, *i*, j*, *k**, *l**, m*	b-d, f*, j*, m*	d, e, f*, m*	c, g, h
11		(*a*, b, c, *d*, e, *f*, g*-i*)	c, e, g*	b, c, g*, h*, i*	None
12		None	None	(a*, b)	(a*, b)
13		(a-c3)	b-c3	a, c2	c2
14		(*a-c*, d)	d	None	None
15		b, *c*, d-e	a, b, d, e	None	None
16		(a, b)	(a, b)	b	a
17		(a, b)	None	(a, b)	(a, b)
18		(18)	None	(18)	(18)
19		a, b*, f, g	a	(a, b*, d-g)	a, b*, *c*, e, g
20	a, b*, e, f, g	*c*, *d*	None	None	None

[a] 1. Data summarized from Table B-10.
2. General quality of sources variable, but each major type noted to be used as highway aggregate in Section.
3. * = Sections for which data are incomplete.
4. ( ) = Provinces for which all Sections use crushed stone type.
5. *b* = Sections where the only major crushed stone used is that shown.

carbonate stone sources. Much of the bedrock underlying the Central and Eastern Lowland Province also is attributable to the presence of the Paleozoic area.

Carbonate rocks that are used as highway aggregate date from the Cenozoic and Mesozoic Eras. However, the occurrences of quality carbonates from these two Eras generally are not as widespread as those associated with Paleozoic age.

In the Mesozoic Era, the largest occurrence of carbonate rocks is associated with the Cretaceous Period. Carbonates of this age are found, to variable degrees, in the Atlantic and Gulf Coastal Plain and Great Plains Provinces. Other deposits are associated with many areas surrounding mountainous uplifts of the west. The only Cenozoic carbonate deposits, known to the researchers, that are used as highway aggregate are found in the Atlantic and Gulf Coastal Plain Province (Florida Section primarily).

Sandstone Sources.—Owing to the wide variability in properties of sandstone, coupled with poor geologic information regarding the location of these potential crushed stone areas, this aggregate source was not mapped at a U.S. level. However, the importance of this material as a crushed stone source in many areas cannot be overlooked, even with the regional analysis of aggregate availability.

Although crushed sandstone is used as highway aggregate in 31 of the 97 Sections examined, it is used as a concrete mix aggregate in only 11 of these Sections. Table 8 is a summary of the major highway functional uses of this aggregate, by Section. A major use of this aggregate is related to base/subbase aggregate, reflecting to some degree the generally lower aggregate quality that may be tolerated in nonsurficial pavement layers. In the west, these areas are generally associated with portions of the Pacific Coast Range Province. It appears that crushed sandstone sources are most widely used for concrete aggregate in the Appalachian Plateau Province. This, in part, may be necessitated by the relative lack of any other suitable crushed stone source in the area (crushed carbonates are restricted in their distribution and occurrence in this Province). A similar analysis may be applied to various other Sections such as the Wasatch (8d), Wyoming Basin (10d), Plains Border (10j), Arkansas Valley (13c2), and Ouachita Mountains (13c3).

Granitic/Metamorphic Sources.—The distribution of granitic/metamorphic rocks as a crushed aggregate source is primarily, but not always, restricted to either Precambrian or Jurassic ages. In the eastern U.S., these areas are located in the Older Appalachian, Laurentian Upland, and New England Maritime Provinces.

In the central U.S., but still confined to the eastern Province group, the distribution of these rocks is related

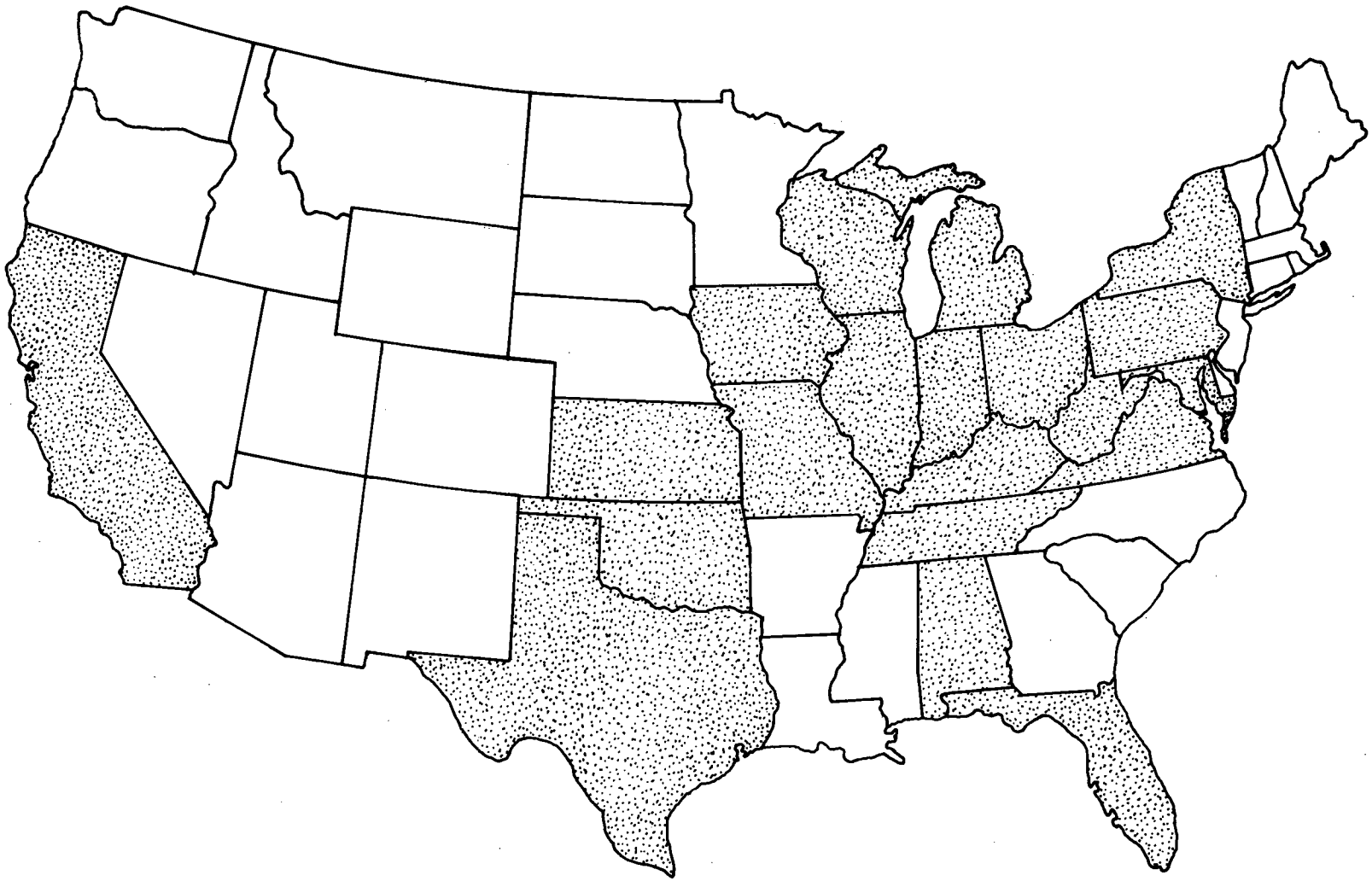


Figure 12. Distribution of 20 leading carbonate producing states, 1956-1958. Source: Freeman et al. (23).

TABLE 8

SUMMARY OF MAJOR HIGHWAY FUNCTIONAL USES OF CRUSHED SANDSTONE AGGREGATE, BY SECTION [a]

PROV. CODE	USE OF AGGREGATE, BY SECTION		
	BS (ONLY)	B/BS	C/B/BS
1	a, b, d	None	None
2	a	None	None
3	a	None	None
4	None	None	None
5	d	None	None
6	None	c	None
7	None	a	None
8	None	None	d
9	None	None	None
10	m	b, c, f	d, j
11	e, g	None	c
12	None	None	None
13	b	c1	c2, c3
14	None	None	None
15	None	None	a, b, d, e
16	None	b	a
17	None	None	None
18	None	None	None
19	a	None	None
20	None	None	None

[a] BS = base-subbase aggregate.
B = bituminous mix aggregate.
C = concrete mix aggregate.

principally to several isolated geologic structural uplifts or domes. Although most of these are small in areal extent, they frequently serve as important sources of aggregate. These areas are found primarily in the Llano Burnet area of Texas (Central Texas Mineral Section), the Wichita and Arbuckle areas of Oklahoma (variant areas of the Osage Plains Section), the St. Francis Mountain Section, the Sioux Uplift in the extreme southwest corner of Minnesota, and the Black Hills Section.

In the western Province group, this potential aggregate source occurs principally in portions of each Rocky Mountain Province, and in the Northern Cascade, Sierra Nevada, and Lower California Sections of the Sierra-Cascade Province. Scattered intrusions are found in many other isolated areas in the west.

Other Igneous Sources.—The distribution of other igneous rocks as a potential crushed stone source is concentrated primarily in the western U.S. This category is primarily basaltic in nature and occurs principally in the Cascade Mountains and the Columbia Plateau Province. In the east, a small but important occurrence is found as traprock in the Triassic sediments comprising the Connecticut Lowland Section and the Triassic Lowland Province. Smaller Triassic basins also are found as variant areas in the Piedmont Plateau Section of the Older Appalachian Province.

Sand-Gravel Distribution.—Because of the complexity involved in the distribution, frequency of occurrence, quality, and modes of natural sand-gravel deposits in the U.S., it is difficult to formulate a brief yet effective summary of the distributive characteristics of this aggregate category. Almost every Section contains this source, although quantity and mode of occurrence may differ significantly. McLaughlin et al. (*142*) provide an excellent general summary discussion.

Potential Aggregate Availability Ratings

Potential Ratings vs Areas Lacking Aggregate.—The procedure used in rating potential aggregate availability for each Section is discussed elsewhere. An important source of information that was extensively used as a tool for the evaluation rating was the composite map of areas lacking aggregate (Fig. B-12) obtained from the materials questionnaire response. In general, there are a few Sections to which a poor aggregate availability rating has been assigned, but in which few or no areas have been designated as lacking aggregate. In contrast, other Sections that show a good aggregate availability rating have areas lacking aggregate resources. Many of these discrepancies may be explained by the presence of variant materials areas in a Section and the attempt to designate the generalized potential availability based solely on a material type, quality distribution combination in a Section. Undoubtedly, some deviations are due to the lack of definite information used to assess the potential rating.

Table 9 summarizes all of the Sections that have a potential availability rating more severe than "adequate to limited," and gives pertinent remarks from the questionnaire response concerning the status of areas lacking aggregate. In general, it is believed that the following Sections show a distributive pattern of areas void of aggregate that is inconsistent (less areas than would be expected) with the assigned rating: 1b,d; 4e; 6b,c; 7c; 10f,i,j; and 13c1,c2. The basis for assigning these ratings to the Sections is explained in the geologic summary of areas lacking aggregates in the next section of the report.

Table 10 gives only those Sections (1) where areas lacking aggregates were noted by the questionnaire results, and (2) that have an availability rating less severe than "limited to problem." In general, with the exception of the Grand Canyon Section, the Sections do not exhibit any gross inconsistencies between the areas lacking aggregate and the assigned rating. The "adequate to limited" potential availability rating given to the Grand Canyon Section is in direct contrast to the rating of the Arizona Highway Department in the NCHRP materials questionnaire, which designated the entire Section as lacking aggregate. Although potential limestone sources do exist in the area, no limestone entry was made for the Section. As a result, the true potential quality of this area is unknown and it is possible that the areas noted as lacking aggregate may reflect the difficulty of exploiting this deeply dissected canyon portion rather than the quality limitations of the limestone source. Based on this limited information, aggregate availability in the area was designated as "adequate to limited" rather than as a "severe problem."

Geologic Summary of Sections with Poor Aggregate Availability Ratings.—Although each Section that has a

TABLE 9

SUMMARY COMPARISON: SECTIONS WITH AREAS LACKING AGGREGATE (FROM MATERIALS QUESTIONNAIRE) AND SECTIONS WITH AN AGGREGATE AVAILABILITY RATING MORE SEVERE THAN "ADEQUATE TO LIMITED"

SECTION CODE	RATING [a]	MATERIALS QUESTIONNAIRE RESPONSE CONCERNING AREAS LACKING AGGREGATE
Unglaciated Missouri Plateau (10b)	SP	Very large part of Section lacks aggregate.
Mississippi Alluvial Plain (20f)	SP	Very large part of Section lacks aggregate.
Oregon Coast Range (1b)	L-P	Scattered, small areas in Washington.
California Coast Range (1d)	L-P	Small regional coastal area in southern California.
Snake River Plains (4c)	L-P	Significant area in western part of Section.
Harney (4e)	L-P	No area noted.
Salton Trough (5c)	L-P	Significant area noted in California.
Uinta Basin (6b)	L-P	No area noted by Colorado; Utah not answering question.
Canyon Lands (6c)	L-P	No area noted by Colorado; Utah not answering question.
Navajo (6d)	L-P	Significant areas in Utah and Arizona noted.
Salmon River (7c)	L-P	Scattered areas along western flank of unit in Idaho.
Glaciated Missouri Plateau (10a)	L-P	Scattered areas that are generally contiguous with void areas in adjacent Unglaciated Missouri Plateau.
Wyoming Basin (10d)	L-P	Very large area in central part of Section.
High Plains (10f)	L-P	No areas delineated; Texas not answering question.
Colorado Piedmont (10g)	L-P	Very large portion noted.
Pecos Valley (10i)	L-P	No areas noted by New Mexico.
Plains Border (10j)	L-P	No areas noted by all states.
Driftless (11g)	L-P	Sizeable area noted in central Wisconsin.
West Lakes and Lacustrine (11h)	L-P	Regional areas noted in North and South Dakota; Minnesota not answering question.
Boston Mountains (13c1)	L-P	No area noted.
Arkansas Valley (13c2)	L-P	No area noted.
Shawnee Hills (14c)	L-P	Sizeable area in Indiana portion of Section.
Kanawha (15d)	L-P	Large regional area in West Virginia.
Florida (20c)	L-P	Significant area noted in southern Florida.
Mississippi Loessial Upland (20e)	L-P	Several regional areas noted in Mississippi.

[a] SP = severe problem.
L-P = limited to problem.

"limited to problem" or "severe problem" rating had its own peculiar combination of characteristics responsible for its rating, these units can be effectively grouped into three categories denoting general features responsible primarily for the poor potential aggregate rating. Table 11 is a general summary of the Sections having a poor availability rating, grouped by category.

It is significant that Sections that lack aggregate are those with a widespread distribution of sandstones and shales. This fact coupled with a relative lack of quality natural sand deposits generally yields areas of extremely poor potential. Table 11 indicates that most of these areas in the Type I grouping have geologic ages that correspond to Cenozoic, Mesozoic, late Paleozoic (Permian and Pennsylvanian), and early Paleozoic (Cambrian) Eras. It is in areas of the Paleozoic periods older than Pennsylvanian that the majority of the crushed carbonate zones are found in the U.S.

The existence of poor sandstone and shale bedrock comprising the modal bedrock in a Section is of course not always associated with an over-all poor aggregate availability rating for the Section in question. Examples of areas that, in general, are characterized by relatively soft sandstone and shale bedrock yet have abundant to adequate potential for aggregates are the Bighorn Basin (10c), the Triassic Lowland Province (18), and the Connecticut Lowland Section (19c). In these areas, the widespread distribution of quality sand gravels and/or crushed stone (obtained from variant bedrock types within the unit) may override the presence of poor quality crushed stone sources attributable to the sandstones and shales.

Soils and Related Factors

Soil Origin

Uniqueness of Origin to Basic Report Provinces/Sections. —In general, the surficial soil origin of the physiographic units viewed at a Province level is fairly homogeneous, although this homogeneity varies considerably by Province. Table 12 summarizes the estimated degree of origin homogeneity based on the major soil origins and their distribution in Sections of a particular Province (see Table B-14).

As Table 12 indicates, many Provinces exhibit an excellent "uniqueness" by major mode of origin. In addition,

TABLE 10

SUMMARY COMPARISON: SECTIONS WITH AREAS LACKING AGGREGATE (FROM MATERIALS QUESTIONNAIRE) AND SECTIONS WITH AN AGGREGATE AVAILABILITY RATING LESS SEVERE THAN "LIMITED TO PROBLEM"

SECTION CODE	RATING [a]	MATERIALS QUESTIONNAIRE RESPONSE CONCERNING AREAS LACKING AGGREGATE
Walla Walla Plateau (4a)	A-A	Very small areas in Idaho part of Section.
Great (Closed) Basin (5a)	A-A	Sizeable area noted in northwest California.
Sonoran Desert (5b)	A-A	Regional area noted in Arizona.
Piedmont Plateau (17b)	A-A	Very small area in Georgia.
Olympic Mountains (1a)	A-L	Several small areas noted in Washington.
Northern Cascade (2a)	A-L	Fairly large regional area noted in central part of unit.
Payette (4d)	A-L	Very small areas in Idaho portion.
Grand Canyon (6e)	A-L	Entire Section noted by Arizona.
Wasatch (8d)	A-L	Small portion in Wyoming continuous with area in Wyoming Basin.
Central Till Plains (11f)	A-L	Sizeable areas in western Illinois and southwest Indiana.
Dissected Loessial and Till Plains (11i)	A-L	Indefinite areas in Iowa and regional area of northwest Missouri.
Cumberland Plateau (15e)	A-L	Large area of Kentucky portion of Section.
Seaboard Lowland (19a)	A-L	Several isolated areas in Maine portion of Section.
White Mountain (19d)	A-L	Regional area in Maine portion noted.
Embayed (20a)	A-L	Virginia coastal areas noted.
Sea Island (20b)	A-L	Very small area in Florida; South Carolina not answering question.
East Gulf Coast (20d)	A-L	Areas occur in central and outer parts of Section.
West Gulf Coast (20g)	A-L	Small coastal area in Louisiana; Texas not replying.

[a] A-A = abundant to adequate.
A-L = adequate to limited.

several Provinces contain minor variant origins to justify their being rated slightly less than completely homogeneous. The Pacific Coast Range has, as a minor variant origin, valley fill deposits found primarily in the Los Angeles Section. This area is regionally extensive but is not the only origin of the Los Angeles Section. In the Sierra-Cascade Province only a minor portion of the Northern Cascade Section has been glaciated. The Triassic Lowland Province also has a glaciated portion in the northern part. The Interior Low Plateau, predominantly a Province of nontransported origin, has a loessial covering in a regionally significant portion of the Shawnee Hills Section. In the New England Maritime Province, sectioning of the Seaboard Lowland and New England Upland Sections generally isolates the marine clays common to the Lowland unit, although the marine origin is not exclusive in the Section.

Although the Central and Eastern Lowland Province is primarily of glacial origin, residual soils, loess deposits, glacial lacustrine, and marine deposits also occur. In general, the examination of origin at the Section level only slightly improves the relative homogeneity of origins. In the Appalachian Plateau Province, sectioning of the glaciated Catskill Mountains and New York Sections provides a perfect uniqueness of origin by Section. This uniqueness is also exhibited at the Section level in the Atlantic and Gulf Coastal Plain Province. Although the predominant origin is due to coastal sedimentation, sectioning of the Province isolates the two major variant origins: (1) the loess deposits (Mississippi Loessial Upland Section) and (2) the alluvial deposits that characterize the Mississippi Alluvial Plains Section. The only minor variant origin areas noted after sectioning are found in the glaciated Long Island and Cape Cod areas of the Embayed Section. The major reason for giving the Basin and Range Province a "fair to good" rating is the repetitive occurrence of valley fill deposits and the nontransported origin areas noted by the mountain ranges of the unit. The major variant origin unit is uniquely delineated by sectioning of the Salton Trough unit. Here the major origins are lacustrine and alluvial in nature. The Northern Rocky Mountain Province is characterized by a northern tier of continental glaciation and an eastern portion of valley fill and glacial debris. In general, sectioning improves the uniqueness of origin by physiographic units, particularly for the Montana Section, characterized by the basins and valley systems of the Section.

The Provinces that appear to have the greatest variability of origin are the Pacific Troughs, Columbia Plateau, and Great Plains Provinces. Although the predominant mode of origin of the Pacific Troughs is transported, areas of nontransported origin are found within the northern

TABLE 11

GENERAL SUMMARY OF THE PREDOMINANT GEOLOGIC CONDITIONS IN SECTIONS WITH AN AGGREGATE AVAILABILITY RATING MORE SEVERE TIIAN "ADEQUATE TO LIMITED"

SECTION CODE	REMARKS
Type I: Sections with widespread distribution of predominantly sedimentary sandstone and shale bedrock that significantly contributes to a poor aggregate availability rating	
Oregon Coast Range (1b)	Tertiary sandstones and shales
California Coast Range (1d)	Tertiary and Mesozoic sandstones, shales, and some slates
Uinta Basin (6b)	Tertiary sandstones and shales
Canyon Lands (6c)	Mesozoic sandstones and shales
Navajo (6d)	Mesozoic, Tertiary and late Paleozoic sandstones and shales
Unglaciated Missouri Plateau (10b)	Tertiary and Cretaceous sandstones and shales
Wyoming Basin (10d)	Tertiary sandstones and shales
Colorado Piedmont (10g)	Tertiary and Cretaceous sandstones and shales
Pecos Valley (10i)	Triassic sandstones and shales; Permian sandstones, shales, limestone, and gypsum
Plains Border (10j)	Cretaceous and Permian sandstones and shales; Cretaceous limestone
Driftless (11g)	Cambrian sandstone and shales; Ordovician carbonates in southwest may be used as crushed stone
Boston Mountains (13c1)	Pennsylvanian sandstones and shales
Arkansas Valley (13c2)	Pennsylvanian sandstones and shales
Shawnee Hills (14c)	Pennsylvanian sandstones and shales; Mississippian limestones quarried
Kanawha (15d)	Pennsylvanian sandstones and shales; Permian limestones and shales
Type II: Sections with widespread distribution of bedrock with poor crushed stone capability other than that noted in Type I that significantly contributes to a poor aggregate availability rating	
Snake River Plains (4c)	Cenozoic acidic lava plain; regional sand-gravel sources generally available only near mountain borders
Harney (4e)	Cenozoic acidic lava plain with widespread pumice deposits and lacking regionally distributed sand-gravels
Salmon River (7c)	Jurassic granitic rocks are not suitable for use as highway aggregate
Type III: Sections generally with a nonexistent to poor bedrock crushed stone potential overlain by transported deposits either deficient in quantity or quality of natural granular deposits	
Salton Trough (5c)	Widespread presence of fine-grained alluvial and lacustrine deposits characterize much of Section
Glaciated Missouri Plateau (10a)	Glaciated region with sand-gravel deposits of general poor quality underlain by bedrock similar to that found in Unglaciated Section (see 10b in Type I grouping)
High Plains (10f)	Crushed stone potential nonexistent in Section; major source of aggregates obtained from major rivers and tributaries of Section. Higher density of rivers occurs in northern portion of unit; however, much of the aggregate lacks coarse fraction and may be reactive with cement
Western Lakes and Lacustrine (11h)	Western portion of unit has Cretaceous sandstones and shales similar in characteristics to those found in Type I grouping. Major areas void of aggregate associated with glacial lacustrine areas (Lake Agassiz and Dakota)
Florida (20c)	Sandy unconsolidated coastal deposits veneer almost entire Section. Regional crushed carbonate zones present in portions of the unit, but much of entire Section lacks coarse aggregate
Mississippi Loessial Upland (20e)	Widespread loessial deposits overlie nonexistent crushed stone potential areas
Mississippi Alluvial Plain (20f)	Widespread distribution of fine-grained alluvium throughout most of unit

TABLE 12

SUMMARY OF GENERAL DEGREE OF HOMOGENEITY OF MAJOR SOIL ORIGINS FOUND IN SECTIONS, BY PROVINCE

HOMOGENEITY RATING AND PROVINCE	MAJOR MODE OF ORIGIN [a]									
	NONTRANSPORTED		TRANSPORTED							
	B	R	L	G	Wow	Wvf	Wl	Wm	Wal	Wcs
Excellent:										
Colorado Plateau	×	×								
Ozark and Ouachita		×								
Ridge and Valley	×	×								
Older Appalachian	×	×								
Middle Rocky Mountains	×	×								
Southern Rocky Mountains	×									
Laurentian Upland				×						
Good to excellent:										
Pacific Coast Range	×	×				×				
Sierra-Cascade	×			×						
Interior Low Plateau		×								
Triassic Lowland		×								
New England Maritime	×			×				×		
Fair to good:										
Central and Eastern Lowlands		×	×	×			×	×		
Appalachian Plateau		×		×						
Atlantic and Gulf Coastal Plain			×						×	×
Basin and Range	×	×				×	×			
Northern Rocky Mountains	×					×				
Poor to fair:										
Pacific Troughs		×		×		×			×	
Columbia Plateau	×	×	×				×			
Great Plains	×	×	×	×	×					

[a] Nontransported soils:
B—Bedrock
R—Residual soil

Transported soils:
L—Loessial
G—Glacial
W—Water
ow—outwash
vf—valley fill
l—lacustrine
m—marine
al—alluvial
cs—coastal sediments

trough. In addition, valley fill areas, alluvial deposits, and glaciated regions exist in the Province. In general, sectioning of the Province increases the uniqueness of origin by physiographic unit, although areas of nontransported origin are common in both Sections of the northern trough. In the Columbia Plateau Province, nontransported origin predominates; however, loessial deposits and lacustrine areas are widespread. Sectioning generally improves the uniqueness of origin by isolating the major loessial deposits to the Walla Walla Plateau and Snake River Plains Sections and the major lacustrine areas to the Payette Section. However, these origins are not exclusive to these Sections. The materials of the Great Plains Province probably are as variable as the materials in all the U.S. Provinces. Nontransported areas, water-deposited outwash, and glacial and loessial deposits occur. Sectioning of the Province improves the uniqueness of origin by delineating the glaciated area (Glaciated Missouri Plateau Section) and generally restricting the outwash to the High Plains Section. However, loessial origin areas are not unique to any particular section. The Plains Border Section, with its alluvial soils, outwash areas, loessial deposits, and nontransported origin areas, affords the poorest indicator of uniqueness of origin of any of the 97 basic report Sections.

Relation of Transported Surficial Origin Areas to Regional Physiographic Units.—It is apparent that although several Provinces are unique in mode of origin, examination of physiographic units at the Section level improves this uniqueness in a given physiographic unit. However, it should be realized that, based on the natural laws inherent to material transport and the principles used to delineate physiographic units, a total uniqueness of origin for transported soils can never occur in all physiographic units.

This is due primarily to the variable thicknesses associated with deposition (and subsequent erosion) characteristic to aeolian, glacial, and water transport. As a result, where "thin" transported soils partially overlie physiographic units formed on the gross features characteristic of bedrock, little or no relation to regional physiographic units may exist. Examples of this are found extensively with the loessial deposits in the Great Plains Province and portions of the Central and Eastern Lowland Province. In many cases where a "thin" mantle of transported material completely covers a physiographic unit delineated by the underlying bedrock, a "pseudo uniqueness" of origin for that particular regional unit may occur; i.e., if the transported material were stripped from the area, a new physiographic unit of identical outline would be

noted. Many examples of this occurrence can be found associated with the glacial cover of the New England Maritime Province and of the lowlands and valleys in the New York portion of the Central and Eastern Lowland Province and with the loess deposits in the Snake River Plains Section.

The major zone where distinctive regional physiography has developed on relatively "thick" transported material is in portions of the Central and Eastern Province. In particular, the Eastern and Western Lakes and Lacustrine Sections, and the Central Till Plains and Dissected Loessial and Till Plains Sections possess modal topography distinctive to glaciation. If the transported material were not present in these areas, delineation of physiographic units would in no way correspond to the present system and, in fact, would be more continuous with the surrounding nontransported physiographic units.

Poor Subgrade Support Areas—Organic Deposits

Design Factor Rating Summary.—In general, the presence of organic-type deposits is an important highway design factor in only a relatively small portion of the U.S. Table 13 summarizes the frequency of occurrence rating of this factor of design, by Section. Figure 13 shows the distribution of the ratings. The soil texture maps of the U.S. (Figs. B-16 through B-21) show the actual regional distribution of these areas. As the table indicates, physiographic Sections comprising an area of almost 87 percent of the U.S. have, at most, a "nonexistent to limited" frequency rating of this factor.

Distribution.—In a general east-west Province grouping, the greatest frequency of occurrence of organic soils is in the east, in the Eastern Lakes and Lacustrine Plains Section of the Central and Eastern Lowland Province and in the Florida Section of the Atlantic and Gulf Coastal Plain Province. It is in the two geomorphic conditions (glaciation and coastal plain development) that characterize these Provinces that the greatest majority of organic-type terrain becomes a factor in highway engineering. Table 14 summarizes the Sections having organic-type deposits, by major geomorphic mode.

1. Glaciated Areas: In the west, the physiographic units that have organic deposits associated with glaciation exist only in limited parts of the Puget Sound Section and in the Jackson Hole areas of the Middle Rocky Mountain Province. In the east, every Province that has glaciated areas has an occurrence of organic-type deposits. Although the Triassic Lowland Province is generally characterized as being of nontransported origin (Tertiary sandstones and shales), its northern portion is glaciated. It is in this small area that the organic deposits may be found.

TABLE 13

SUMMARY OF ESTIMATED FREQUENCY OF OCCURRENCE RATING OF ORGANIC POOR SUBGRADE SUPPORT AREAS, BY SECTION

NONEXISTENT		NONEXISTENT TO LIMITED		LIMITED TO MEDIUM		MEDIUM TO WIDESPREAD		VERY WIDESPREAD	
SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)
1c, e	41,830	1a, b, d	60,930	—	—	—	—	—	—
2a, b, c, d	90,670	—	—	—	—	—	—	—	—
3b	4,700	3a, c	37,610	—	—	—	—	—	—
4a, b, c, d	99,000	4e	15,850	—	—	—	—	—	—
5a, b, c, d, e	362,690	—	—	—	—	—	—	—	—
6a, b, c, d, e, f	123,920	—	—	—		—	—	—	—
7a, b, c	103,780	—	—	—	—	—	—	—	—
8a, b, c, e	28,200	8d	17,140	—	—	—	—	—	—
9a, b, c	60,450	—	—	—	—	—	—	—	—
10a-m	652,840	—	—	—	—	—	—	—	—
11i	89,580	11b, c, d, f, g	114,730	11a, h	100,590	11e	88,010	—	—
—	—	—	—	12a, b	72,540	—	—	—	—
13a, b, c1, c2, c3	66,480	—	—	—	—	—	—	—	—
14a, b, c, d	51,380	—	—	—	—	—	—	—	—
15a, c, d, e	80,260	15b	22,500	—	—	—	—	—	—
16a, b	45,340	—	—	—	—	—	—	—	—
17a, b	90,670	—	—	—	—	—	—	—	—
—	—	18	6,040	—	—	—	—	—	—
19e, f, g	8,760	19b, c, d	48,940	19a	11,820	—	—	—	—
20e	22,860	20d, f, g	278,420	20a, b	87,180	20c	34,680	—	—
Total	2,025,420		602,160		272,130		122,690		0
Percent of U.S.[a]	67.0		19.9		9.0		4.1		0

[a] Exclusive of Alaska and Hawaii.

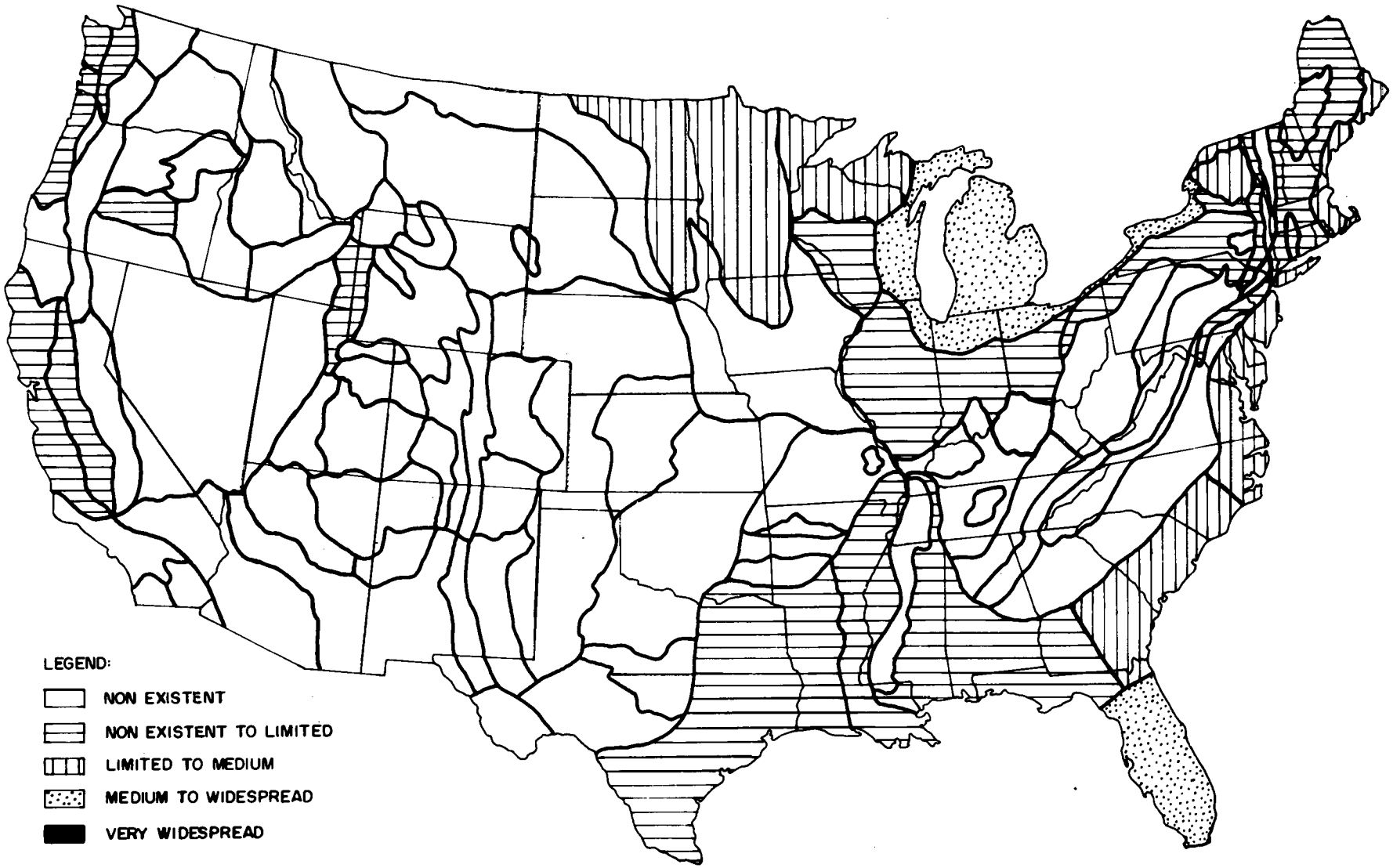


Figure 13. Estimated frequency of occurrence rating of potential poor subgrade support areas (organic deposits) by physiographic unit.

TABLE 14

SUMMARY OF SECTIONS WITH ORGANIC-TYPE DEPOSITS, BY MAJOR GEOMORPHIC MODE

SECTION CODE	RATING [a]	REMARKS
(*a*) Glaciated areas		
Puget Sound (3a)	N-L	
Wasatch (8d)	N-L	Found with glacial outwash in Jackson Hole area
Champlain Lowland (11b)	N-L	
Hudson River Valley (11c)	N-L	
Mohawk River Valley (11d)	N-L	
Central Till Plains (11f)	N-L	
St. Lawrence Lowlands (11a)	L-M	
Western Lakes and Lacustrine (11h)	L-M	
Eastern Lakes and Lacustrine (11e)	M-W	
Superior Upland (12a)	L-M	
Adirondack (12b)	L-M	
New York Glaciated (15b)	N-L	
Triassic Lowland (18)	N-L	Associated with northern glaciated area
New England Upland (19b)	N-L	
Connecticut Lowland (19c)	N-L	
White Mountain (19d)	N-L	
Seaboard Lowland (19a)	L-M	
(*b*) Coastal and embayed areas		
Oregon Coast Ranges (1b)	N-L	Found in small coastal plain areas of Oregon
California Coast Ranges (1d)	N-L	Associated with Section 3c in San Francisco Bay area
California Valley (3c)	N-L	Associated with Section 1d in San Francisco Bay area
East Gulf Coast (20d)	N-L	Occurs primarily in outer coastal plain
West Gulf Coast (20g)	N-L	Occurs primarily in outer coastal plain
Embayed (20a)	L-M	
Sea Island (20b)	L-M	
Florida (20c)	M-W	Has largest swamp area in U.S.
(*c*) Deltaic areas		
Mississippi Alluvial Plain (20f)	N-L	Associated with Mississippi delta area

[a] M-W—medium to widespread; L-M—limited to medium; N-L—nonexistent to limited.

With the exception of the mountainous Catskill, Green, Taconic, and Reading Prong Sections, every glaciated physiographic Section north and east of the New York Glaciated Section was noted to contain organic-type terrain. The pattern of frequency of occurrence and distribution of organic terrain in the glaciated Sections to the west of this area is of noteworthy significance. It is in the central portion of the Central and Eastern Lowland Province that the presence and frequency of organic terrain may be associated with the various glacial ice stages of the lowland area.

Figure 14 shows the distribution of the major ice sheets in this area. A comparison of either Figure 13 and/or Figures B-19 and B-21 to Figure 14 shows that the greatest frequency of organic deposits is associated with the most youthful glacial substages, Cary and Younger Wisconsin age. This type of terrain forms the modal topography of the Eastern and Western Lakes and Lacustrine Sections, as well as the Superior Upland Section. Delineation of these physiographic units separates areas of greatly differing frequency of occurrence ratings for organic deposits.

Similarly, as older glacial terrains are encountered, the frequency of organic terrain decreases. The oldest glacial drift in the area is Kansan. This glacial terrain, with variable loessial cover, forms the characteristic topography of the Dissected Loessial and Till Plain Section. As Figure 13 shows, organic deposits are nonexistent in this area.

The major geomorphic reason for this feature is that youthful glacial terrains are often associated with a poorly integrated drainage system. The presence of this type of drainage system is conducive to the formation of organic-type deposits in young glacial topography.

2. Coastal and Embayed Areas: In the west, the Sections associated with organic-type terrain are found in a

small coastal plain region of Oregon in the Oregon Coast Range Section and Sections in California associated with the significant organic deposits in the San Francisco Bay area.

In the east, the Atlantic and Gulf Coastal Plain Province is the only physiographic unit where this geomorphic mode occurs. Figures B-18, B-20, and 13 show that in the East and West Gulf Coast Sections only a limited quantity of organic deposits is encountered. The location of these areas is notably confined to the outer coastal plain areas of the units.

The Atlantic Plain portion of the Province, particularly

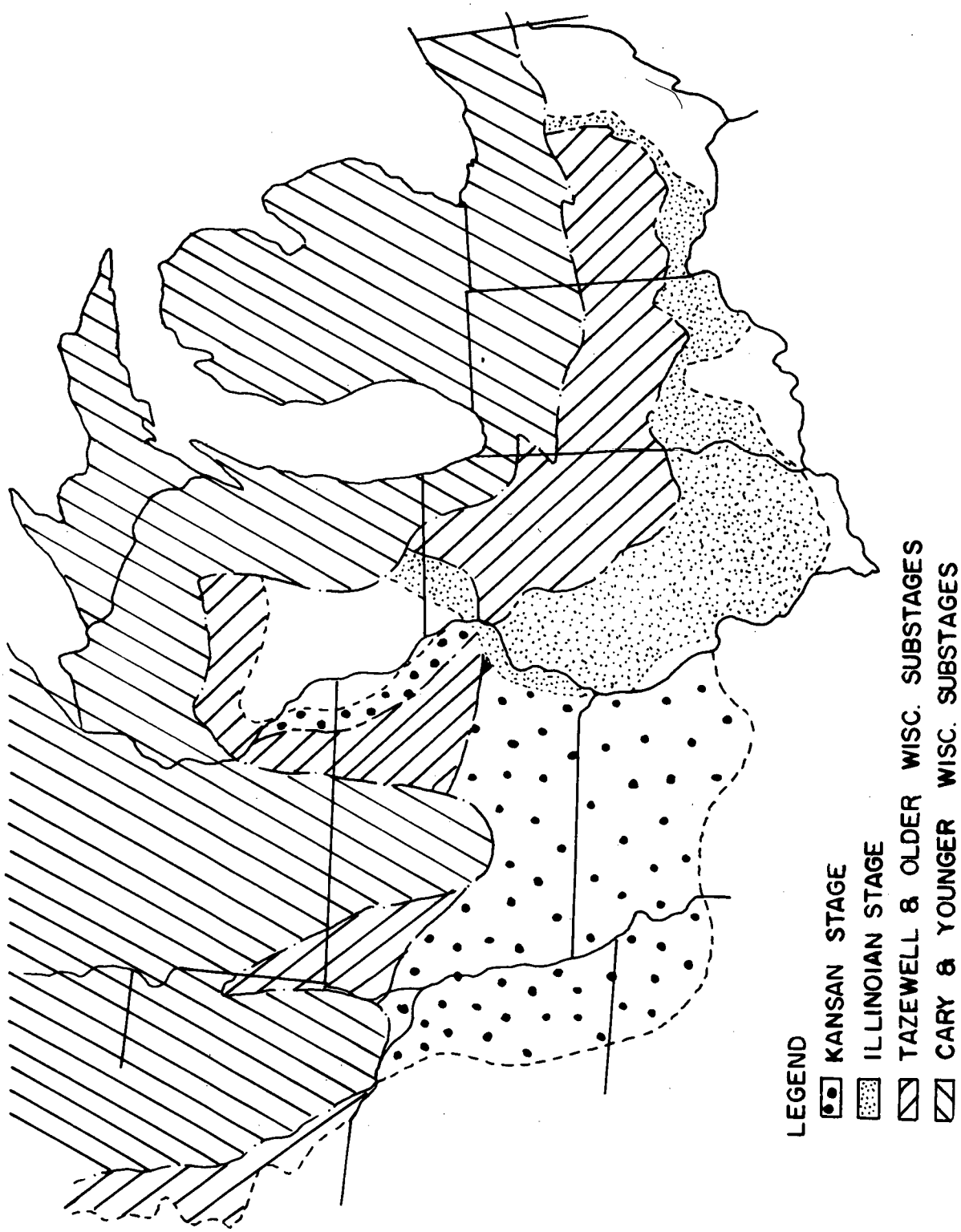


Figure 14. Distribution of major ice sheets in the central portion of the Central and Eastern Lowland Province.

the Embayed and Sea Island Sections, generally have a greater frequency of organic deposits than the Gulf Sections. The Florida Section is the most unique organic area in the U.S. This Section includes the largest continuous swampland (Everglades) in the country.

It is significant that the presence of organic type terrain occurs primarily in the outer portions of the entire Province. Because this Province is relatively young and the structure of the sediments is mildly dipping to the outer coastal areas, the youngest deposits are associated with the outer coastal plains. Hence, there is a general relationship between youthfulness of glacial and coastal plain type terrain and the presence and frequency of organic terrains.

3. Deltaic Areas: As Figure B-18 shows, the Mississippi River delta area, in the Mississippi Alluvial Plain Section, is a fairly extensive area of organic-type terrain.

Poor Subgrade Support Areas—Inorganic Deposits *

Design Factor Rating Summary.—Table 15 summarizes the estimated frequency of occurrence-severity rating of clayey-soil-type areas in the basic report Sections. Figure 15 shows the distribution of these ratings. It is noteworthy that the summary illustrates the relative lack of clayey-type areas in the western Province grouping. Approximately 75 percent of the western Province group has Sections with a severity rating of less than or equal to "nonexistent to limited"; only slightly more than 3 percent of the area has Sections showing a rating of "medium to widespread" or greater. In contrast, in the eastern group, almost 40 percent of the area has Sections with a rating of "medium to widespread" or greater.

There are several probable reasons for this pattern, each perhaps interrelated to the others, as follows:

1. The climatic environment (humid type) prevalent in the east is more conducive to chemical weathering processes (in contrast to physical weathering) that generally are associated with clay development.

2. The over-all topographic features (elevation, relief) of the eastern U.S., in combination with the climatic regime of the area, are more favorable for chemical weathering.

3. The groupings of origin-parent material types in the east are conducive to clay deposition and/or development. In the glaciated northern portion of the area, the most highly plastic soils generally are associated with water deposition from glacial lacustrine or marine origin. Like-

* Throughout this portion of the report, the word "clay" is meant to imply plastic properties of a soil rather than pure textural connotations.

TABLE 15

SUMMARY OF ESTIMATED FREQUENCY OF OCCURRENCE-SEVERITY RATING OF INORGANIC (CLAYEY) POOR SUBGRADE SUPPORT AREAS, BY SECTION

NONEXISTENT		NONEXISTENT TO LIMITED		LIMITED TO MEDIUM		MEDIUM TO WIDESPREAD		VERY WIDESPREAD	
SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)
1c	20,040	1a, b, e	44,180	1d	38,540	—	—	—	—
2a, d	22,940	2b, c	67,730	—	—	—	—	—	—
—	—	3a	14,510	3b	4,700	3c	23,100	—	—
4a, b, c, e	94,290	4d	20,560	—	—	—	—	—	—
—	—	5b, d, e, f	176,630	5a	175,540	5c	10,520	—	—
—	—	6a, b, c, d, e	114,630	6f	9,290	—	—	—	—
7b, c	61,980	7a	43,800	—	—	—	—	—	—
8a, b, c, e	28,200	8d	17,140	—	—		—	—	—
9a, b, c	60,450	—	—	—	—	—	—	—	—
—	—	10c, d, e, f, i, j, k	268,310	10a, g, h, l	150,160	10b, m	234,370	—	—
—	—	11g, h	119,060	11d, e	90,370	11a, b, c, f, i	183,480	—	—
12b	8,990	12a	63,550	—	—	—	—	—	—
—	—	13a, c2	12,300	13b, c1, c3	54,190	—	—	—	—
—	—	—	—	14c	16,540	14d	23,580	14a, b	11,260
—	—	15a, e	23,640	15b, c	33,190	15d	45,930	—	—
—	—	—	—	16a, b	45,340	—	—	—	—
17a	19,770	—	—	—	—	17b	70,900	—	—
—	—	—	—	—	—	18	6,040	—	—
19c, d, e, g	20,160	19b, f	37,540	—	—	19a	11,820	—	—
—	—	20a, b, e	110,040	20c, d	126,920	20g	140,480	20f	45,700
Total	336,820		1,133,620		744,780		750,220		56,960
Percent of U.S.[a]	11.2		37.6		24.5		24.8		1.9

[a] Exclusive of Alaska and Hawaii.

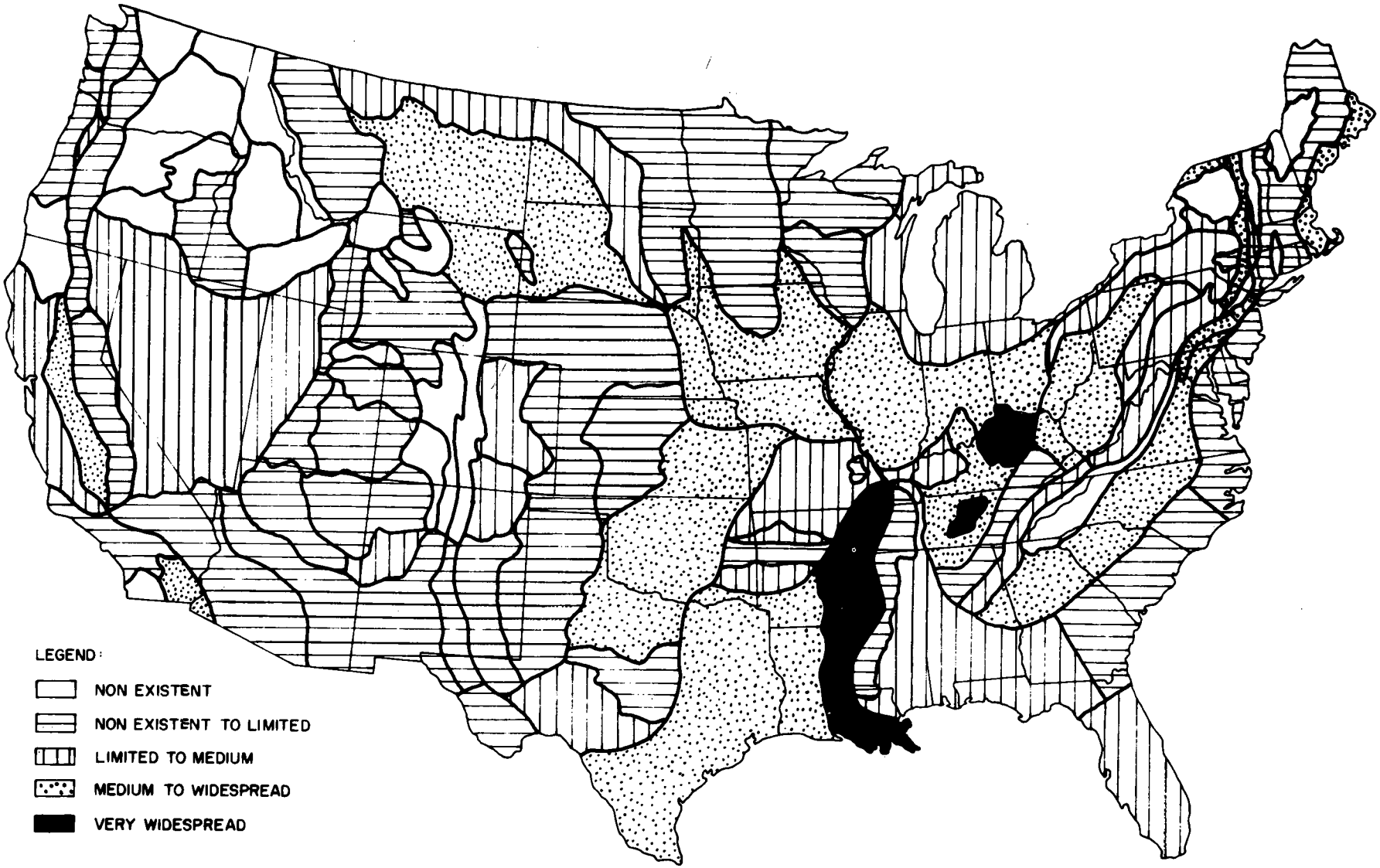


Figure 15. Estimated frequency-severity occurrence rating of potential poor subgrade support areas (inorganic/clayey deposits), by physiographic unit.

wise, the clays of the coastal plain are primarily associated with either the coastal limestones and chalks or widespread fine-grained alluvial deposition. Within these two zones lies the consolidated bedrock region. This area is composed primarily of sedimentary types, in which clayey-type residuum is often developed within the climatic and topographic environments peculiar to this region.

Distribution.—This section discusses the general distribution of clayey-type poor subgrade support areas, by major origin groupings in the east and west Province zones. (See Table B-11 for the general listings of major origin by Province.)

Western Province Group.—In the mountainous Provinces of the west, most potentially poor subgrade support areas are associated with residual soil development. In general, these areas are not widespread in relation to the total area of the units, nor are they generally considered to be of a heavy clay category. The most frequent occurrence of clayey soils is in the California Coast Range Section where the major parent materials are sandstones and shales. Smaller areas of lean clays also exist in the Oregon Coast Range Section and the Wasatch Section (Middle Rocky Mountain Province). Residual lean clays developed from granite may also be found in portions on the western flank areas of the Sierra Nevada Section. Clays of a more plastic nature are found near the western flank of the Southern Cascade Section, associated with residual development from basaltic-type rocks. These last two clay areas do not form a significant portion of the modal soil conditions (or lack thereof) that exist in that Section. The only other regionally defined area of clay soils in the mountainous Provinces of the west is associated with the Montana Section of the Northern Rocky Mountain Province. In this Section, the clays, frequently of a "varved" nature, generally are confined to the basins that characterize this Section as a unique topographic area.

In the Columbia Plateau and Colorado Plateau Provinces, clayey or poor subgrade soil conditions are generally not widespread. The lacustrine areas, characteristic of the Payette Section of the Columbia Plateau, may be associated with the most potentially plastic soils of the Province. Plastic clay soils found in the Colorado Plateau Province generally are associated solely with the shales and clay shales of the Province. The occurrence of these soils is common to each Section of the Province, but the greatest frequency of occurrence is in the eastern Sections. In general, the predominating texture of the residual soils in both the Columbia and the Colorado Plateau Provinces is a thin, sandy-type residuum.

In general, the most potentially severe subgrade support conditions occurring in the western Provinces are associated with deposition by water. Plastic soils associated with alluvium and valley fill frequently are encountered in the central portions of the California Valley Section. The Willamette Valley Section, in addition to having clayey soils from residual basalts and sandstones and shales, has much alluvial plain deposits of a plastic nature. Within the Basin and Range proper, the major areas of potential clay areas are associated with the old lacustrine deposits and fine-textured valley fill occurring in the central portions of the basins. A fairly significant poor subgrade area is found in the Salton Trough Section from the widespread lacustrine and alluvial deposits of the area.

Eastern Province Group.—Of the three Provinces almost completely veneered by glaciation (Central and Eastern Lowland Province, Laurentian Upland Province, and New England Maritime Province), clayey-type occurrences have the greatest over-all frequency in the Central and Eastern Lowland Province. The most highly plastic soils noted in the Provinces appear to be associated uniquely with water deposition.

In the entire New England Maritime Province, the only occurrence of poor subgrade clay areas is associated with the marine deposits found primarily in the Seaboard Lowland Section. Of the two Sections comprising the Laurentian Upland Province, the Adirondack Section lacks any regional clayey deposits, and the Superior Upland Section has only minor areas of clayey soils, associated with lacustrine origin.

The Central and Eastern Lowland Province and the corresponding Section level breakdown afford a framework for discussion of clayey deposits in the unit. Clay soils in the Province are associated with glacial lacustrine, marine, and some glacial drift deposits. However, the most highly plastic deposits are those associated with the glacial lacustrine and marine areas. The lacustrine areas are generally confined to the Eastern and Western Lakes Sections and are peculiar, like the occurrence of organic deposits, to the Cary and Younger Wisconsin drift areas. The marine deposits are associated exclusively with the eastern Sections of the Province, occurring in the St. Lawrence Lowland, Champlain Lowland, and Hudson River Valley Sections.

In contrast, the older glacial drift sections (Central Till Plain and Dissected Loessial and Till Plain Sections) lack the highly plastic lacustrine areas, but generally afford a wider distribution of leaner clays attributable directly to the drift texture.

The most plastic till soils appear to be associated with the older (Illinoian and Kansas) drift. These drift sheets generally are found, respectively, in the Central Till Plain and Dissected Loessial and Till Plain Sections. Drift of a leaner variety comprises the rest of the Central Till Plain Section (Tazewell and Older Wisconsin) and also is found in the western and southern portions of the Western Lakes and Lacustrine Section (Cary and Younger Wisconsin).

The wide variety of clay soils and origins common to the Central and Eastern Lowland Province also occurs in the Atlantic and Gulf Coastal Plain Province. In general, poor subgrade support regions from clayey soils are more pronounced in the Gulf portions than in the Atlantic coastal areas. The only potential regional area of clays in the Embayed Section occurs in the Cretaceous Raritan Lowland Area. Heavy plastic clays are found throughout the Florida Section, generally in conjunction with limestones and marls common to the area. In the East Gulf Coast Section, highly plastic soils normally are associated with the Cretaceous chalks and limestones common to the

inner (belted) coastal plain. Similar geologic and geomorphic occurrences of clayey soils are found in the West Gulf Coast Section. In addition, large areas of marine clays form much of the outer coastal plain of the West Gulf Coast Section. These two types of poor subgrade areas, plus the clayey soils associated with much of the alluvium in the area, constitute a sizeable portion of this Section. The Mississippi Alluvial Plain Section is one of the largest and most homogeneous poor subgrade support areas in the U.S. In general, most of the alluvium is very fine grained and affords highly plastic soil conditions.

Much of the concentration of poor subgrade support conditions in the eastern Provinces is associated with the residual development of clayey soils. One of the more extensive zones of clayey-type soils occurs in the Piedmont Section of the Older Appalachian Plateau Province. The widespread lean to plastic clay soils are derived from a wide variety of granites, gneisses, schists, and basic igneous rocks.

Residual soils, frequently of a highly plastic nature, are associated with limestone in many Sections of the east. Extensive areas are found throughout much of the Springfield-Salem Plateau Section of the Ozark and Ouachita Province, the Interior Low Plateaus Province, and the Ridge and Valley Province. However, in many of these areas, the limestone is frequently cherty, and residuum may frequently contain various percentages of these chert, or gravel, particles. Sandstones and shales often may residually weather into poor subgrade support areas. One of the more pronounced examples of this condition occurs in the Kanawha Section of the Appalachian Plateau Province. In the Province, lean clays also are associated with the glacial drift of the New York Glaciated Section. In general, the plasticity of this drift texture appears to be greater in the western (Ohio) portion of the unit.

Highly plastic soils also may be associated with the sandstones and shales characteristic of the Triassic Lowland Province, the Boston Mountain and Arkansas Valley Sections, and portions of the Ouachita Mountain Sections. In the Great Plains Province, the over-all residual character of the sandstone and shale sections appears to be of sandy silt variety; however, soils associated directly with the shales and clay shales generally are plastic. A major exception occurs in the Osage Plains Section; there much of the residual nature of the soil may be associated with highly plastic soil conditions. In the glaciated portion of the Province, the over-all drift character is of a clayey variety, increasing in plasticity characteristics to the west.

*High Volume Change**

Design Factor Rating Summary.—Table 16 summarizes the final adjusted frequency of occurrence rating for high volume change soils, by Section. Figure 16 shows the distribution of the ratings. Based on the analysis, high volume change soils exist, to some degree, in Sections that, combined, amount to more than 57 percent of the U.S. In addition, Sections comprising 22 percent of the U.S. have been noted as having a frequency of occurrence rating more severe than "limited to medium." This distribution, and its subsequent effect on proper highway design and performance, is a problem in much of the country.

Distribution.—Of the 20 physiographic Provinces that comprise the U.S., high volume change soils have been noted to exist in half. The greatest frequency of occurrence is in the Great Plains and Atlantic and Gulf Coastal Plain Provinces. These Provinces constitute the western and southern areas of the eastern Province grouping. The following discussion follows the generalized east-west Province groupings, to afford maximum insight into the distribution of this problem.

Western Province Group.—Although seven of the nine western Provinces were noted to have high volume change soils, the frequency of occurrence in a large portion of these units is not widespread.

In the Southern Rocky Mountain Province, Jensen (*333*) notes the existence of small scattered areas in the San Luis Valley portion of the Western Section. These areas were mapped on a pedologic basis and correspond to the Lahontan series which is associated primarily with identical geomorphic units in the Closed Basin Section but that occur locally in the Sonoran Desert and Open Basin Sections.

The high volume change areas noted in the Pacific Coast Range Province are associated primarily with the clayey soils developed residually from the sandstones and shales in the area. The most frequent occurrence of these soils is in the California Coast Range Section where these rocks are the modal bedrock to the unit. These same soils, however, are continuous along much of the California coastline to Mexico. Consequently, they are noted to exist in the Los Angeles and Lower California Sections proper; however, they are not considered as the modal bedrock of either of these predominantly granitic units.

In the Pacific Troughs Province, the California Valley Section, with its associated clayey valley deposits, was noted on the basis of both a geologic and a pedologic analysis to exhibit volume change areas. The areas mapped in the Colorado Plateau Province generally are associated with the presence of Cretaceous sandstones and shales and clay shales found throughout the Province. The "medium to widespread" rating for the Grand Canyon Section may not represent the correct potential rating. The area mapped in question is the Valera series, associated with residual limestones. Based on the basic map reference used by Jensen in the pedologic mapping phase, the Valera series occurs primarily in the Edwards Plateau unit of Texas as well as in the Grand Canyon Section of Arizona. However, based on the researchers' work concerning soil textural distribution in the U.S., the residual soil from the limestone in the Grand Canyon Section is silty in nature, in contrast to the clayey residuum noted in the Edwards Plateau limestone.

Eastern Province Group.—In the east, 4 of 11 Provinces were noted to have areas showing high volume change characteristics. Of these four Provinces, two are con-

* The material in this portion of the report is based primarily on the work of Jensen (*333*).

TABLE 16

SUMMARY OF ESTIMATED FREQUENCY OF OCCURRENCE RATING OF HIGH VOLUME CHANGE SOILS (FINAL ADJUSTED RATING), BY SECTION

NONEXISTENT		NONEXISTENT TO LIMITED		LIMITED TO MEDIUM		MEDIUM TO WIDESPREAD		VERY WIDESPREAD	
SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)	SECT. CODE	AREA (SQ MI)
1a, b, c	42,430	—	—	1e	21,790	1d	38,540	—	—
2a, b, c	83,870	2d	6,800	—	—	—	—	—	—
3a, b	19,210	—	—	3c	23,100	—	—	—	—
4a, b, c, d, e	114,850	—	—	—	—	—	—	—	—
5c, e, f	50,410	5b, d	136,740	5a	175,540	—	—	—	—
—	—	—	—	6a, b, c, f	65,300	6d, e	58,620	—	—
7a, b, c	105,780	—	—	—	—	—	—	—	—
8a, b, c, d, e	45,340	—	—	—	—	—	—	—	—
9a, c	37,960	9b	22,490	—	—	—	—	—	—
10e, i	35,250	10a, f	206,300	10c, d, j, k, l	137,100	10h	13,710	10b, g, m	260,480
11a, b, c, d, e, f, g, i	294,280	11h	98,630	—	—	—	—	—	—
12a, b	72,540	—	—	—	—	—	—	—	—
13a, b, c1, c3	57,980	13c2	8,510	—	—	—	—	—	—
14a, b, c, d	51,380	—	—	—	—	—	—	—	—
15a, b, c, d, e	102,760	—	—	—	—	—	—	—	—
16a, b	45,340	—	—	—	—	—	—	—	—
17a	19,770	17b	70,900	—	—	—	—	—	—
18	6,040	—	—	—	—	—	—	—	—
19a, b, c, d, e, f, g	69,520	—	—	—	—	—	—	—	—
20a	33,850	20e	22,860	20b, c	88,010	—	—	20d, f, g	278,420
Total	1,278,040		573,130		510,840		110,870		538,900
Percent of U.S.[a]	42.8		18.9		16.8		3.7		17.8

[a] Exclusive of Alaska and Hawaii.

sidered to be insignificant in defining the scope of the high volume change problem.

1. In the Central and Eastern Lowland Province, the only area noted by Jensen occurred in association with the water-deposited clays in old glacial Lake Agassiz (Red River Lowland). This occurs in the Western Lakes and Lacustrine Section and is the only reason for noting this area as having a "nonexistent to limited" frequency.

2. In the Piedmont Section of the Older Appalachian Province the Iredell soil series was found to exhibit high volume change tendencies. These units were mapped only up to South Carolina by Jensen. The occurrence of this material is generally minor in comparison to the granites, gneiss, and schists of the Piedmont Plateau Section; however, it is an important clay soil as it is of the montmorillonite variety.

The two Provinces with the greatest occurrence of high volume change soils in the entire U.S. are the Great Plains and Atlantic and Gulf Coastal Plain. In the latter, the greatest concentration of these soils is in the Gulf portion (including the Florida Section). The major soils of potential high volume change in the Florida Section are associated with the plastic clays from the Ocalla and similar limestone formations of the unit. In both the East and West Gulf Coast Sections, clayey soils are associated with Cretaceous deposits forming the lowland belts (Selma chalk, Austin chalk, and Taylor marl). In addition, lowlands in the East Gulf, formed by the Eocene (Tertiary) Jackson formation, and clayey marine deposits along much of the coastline of the West Gulf possess similar high volume tendencies. The Mississippi Alluvial Plain Section, with its fine-textured alluvium, also has a widespread distribution pattern of these potential volume change soils. The "nonexistent to limited" rating of the Mississippi Loessial Upland Section is due solely to the presence of a similar type of alluvium and not the loessial deposits, which form the modal parent material of the unit.

The Sections with the severest rating of frequency in the Great Plains Province are the Osage Plains, Colorado Piedmont, and Unglaciated Missouri Plateau. The parent material of the last two Sections is characterized strongly by the presence of Tertiary and Cretaceous sandstones, shales, and clay shales, not too dissimilar to the high volume change areas associated with much of the Colorado Plateau Province. The most frequent potential soil showing high volume change characteristics in the Osage Plains is the Permian sandstones and shales of the unit. The reason for the "nonexistent to limited" rating associated with the High Plains Section is similar to that given for the Mississippi Loessial Upland Section. The potential high volume change areas in the High Plains Section are associated with geologic formations common to the Plains Border Section. This unit occurs as an interfingering across the indefinite border area that separates the two Sections. Hence, the rating of the Section is attributable to a variant

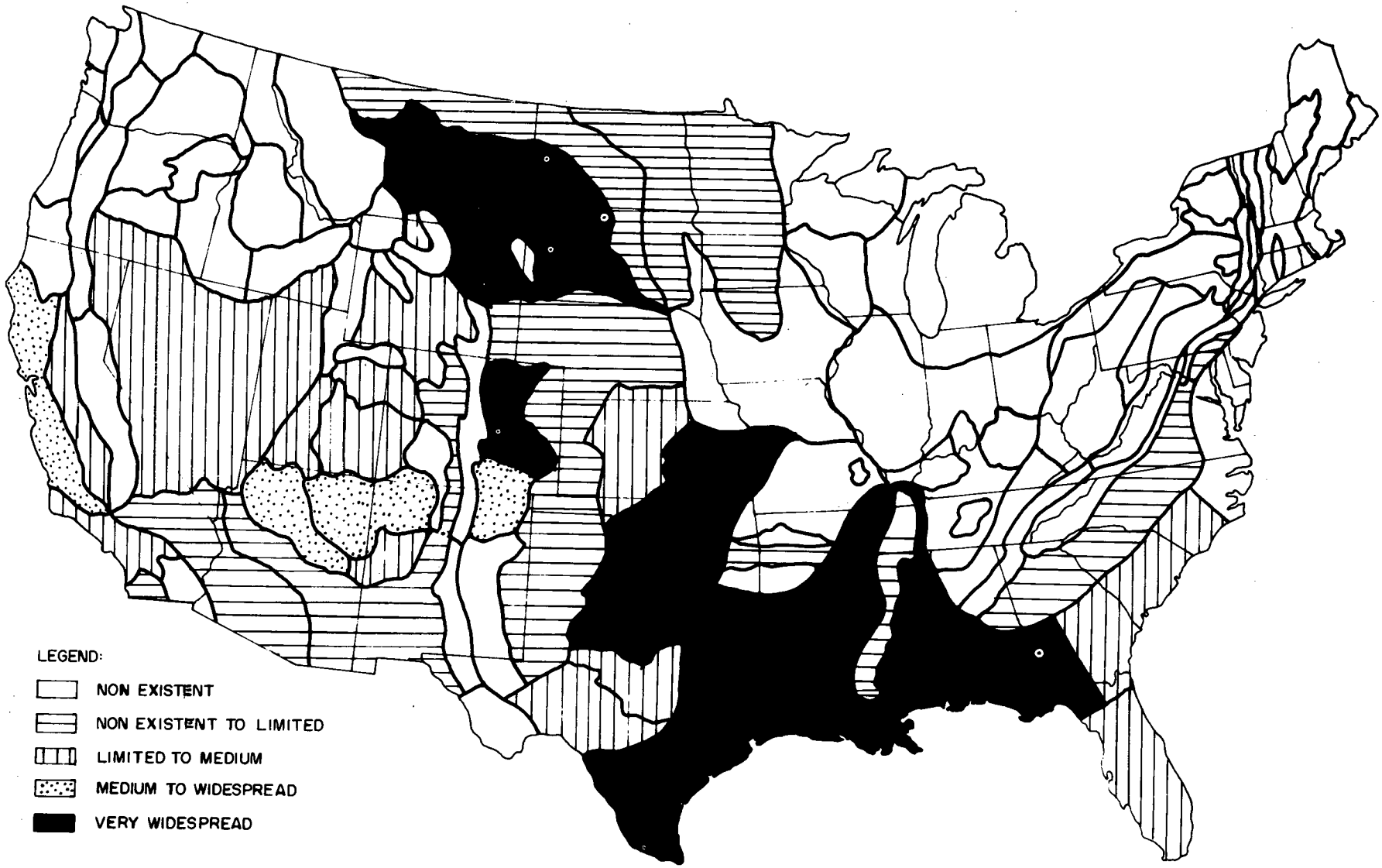


Figure 16. Estimated final adjusted frequency of occurrence rating of high volume change soils, by physiographic unit.

material rather than the modal Tertiary outwash of the area.

General Geologic-Origin/Parent Material Inferences.—As Table B-17 indicates, the geologic formations that exhibit high volume change conditions in the U.S. are associated primarily with geologic youthfulness. Areas related to the Cenozoic and Mesozoic Eras occur most frequently; areas of the Permian (late Paleozoic) period also exhibit soils of a high volume change nature. However, one should not infer that older geologic formations do not have the potential for high volume change. The important point is that in the west, most of the older geologic formations are associated with the mountainous topography of the area, generally not conducive to the development of residual clayey soils. In the east (as stated in the discussion of poor subgrade support—clayey—areas) many regional clay soil areas residually developed from older Paleozoic and even Precambrian formations exist. However, as discussed in the next section, the humid climatic environment of these soil areas generally is not conducive to the development of high volume change occurrences on a regional level of examination.

Table B-19 indicates that a wide variety of origin-parent materials are of potential high volume soils. An obvious and notable origin not present is that of an aeolian (loessial) nature. The mechanics of aeolian transport generally restrict the occurrence of cohesive or plastic clays within aeolian deposits. Loessial soils *generally* are nonpotential high volume change soils, even in climatic environments very favorable to the shrink-swell condition.

Importance of Climate on Regional Distribution of High Volume Change.—The phenomenon of high volume change encountered in portions of the country is due to the complex interrelationship between a potentially high volume change soil and a variation in the soil-water equilibrium. It is important to recall that Jensen's analysis of the high volume problem, conducted from an engineering case study viewpoint, in essence reflects the complex combination of both the soil and water-balance factors. Because all clayey-type soils have a potential for swell, and large areas of clayey soils are found east of the generalized limit of specific high volume change locations shown in Figure B-22, climatic conditions play a dominant role in the high volume change phenomenon.

An attempt to collectively determine a single climatic parameter and its distribution in the U.S., which takes into account all the inherent factors of the soil-water balance picture, has not been undertaken. However, some attempt has been made for the eastern U.S. (*375*). Jensen has noted that the procedure of combining major variables that measure the major incoming phase (average annual precipitation) and the major outgoing phase (average annual potential evapotranspiration) of the water balance provides a fairly good, but general, indicator of the average water balance for the year.

Figure 17 shows the areas where average annual precipitation is less than the average annual potential evapotranspiration. There is a good probability that the soil in these areas may be dried out sometimes during the year, hence triggering a high volume change occurrence.

A comparison of Figures B-22 and 17 shows there is a good agreement between most of the case study locations and the area shown in Figure 17. The major area not shown in Figure 17, where the case study indicates a high volume change occurrence has taken place, is the eastern Gulf Coast regions. However, Jensen has noted that a marked summer deficit in the water balance in much of this area has been reported in the literature (*375*).

Frost and Frost-Susceptible Soils

Distribution.—The frequency of occurrence rating for each category of frost-susceptible soil in a Section is given in Table B-23. Table 17 summarizes the results by type of frost-susceptible soil relative to the frequency rating and Section of occurrence. Table 18 summarizes the largest frequency rating and subsequent frost-susceptible soil type for each Section.

In general, the western Province group is characterized extensively by either nonfrost-susceptible areas (bedrock) or by F4 soils. The eastern Province group has a somewhat equitable distribution of both F3 and F4 soils. (See Tables 17 and 18.) An explanation of F1 to F4 soils is given in Chapter One.

These general statements are consistent with the previous discussion of poor subgrade support soils (clayey). Clayey soils are lacking in the western Provinces but appear adequately distributed throughout much of the eastern Provinces. It should also be pointed out that several physiographic units with clayey-type soils are not considered to be within the defined freezing area (e.g., Piedmont Plateau Section, Tennessee Section, Interior Low Plateau Province, and Osage Plains Section). Hence, the relative lack of F3 soils in the east contrasted to the presence of clayey soils is due to the subsequent exclusion of many potential F3 soil areas from the freezing zone.

Western Province Group.—In the mountainous portions of the west, the relative lack of substantial soil cover is responsible for the widespread pattern of nonfrost-susceptible areas noted for much of the Sierra-Cascade and Rocky Mountain Provinces. A similar occurrence is noted in the Blue Mountain Section of the Columbia Plateau Province. This unit contrasts rather strongly with neighboring sections. In the adjacent units, the widespread distribution of silty loessial deposits and sandy to silty residual soil produces major occurrences of F4 soils. A similar occurrence of frost-susceptible soils also is found in much of the Colorado Plateau Province from the residual sandy to silty soils developed from the standstones and shales. The major difference between this Province and the Columbia Plateau Province is the greater frequency of occurrence of F3 materials attributable directly to the presence of shales and clay shales. The most notable and obvious feature of the distribution and occurrence of frost-susceptible soils in the Great (Closed) Basin Section is the large variability by type. This variation in rating reflects the presence of bedrock (ranges) as well as the gradational texture of the basin fill.

Eastern Province Group.—The predominant frost-susceptible soil type over much of the Great Plains Province

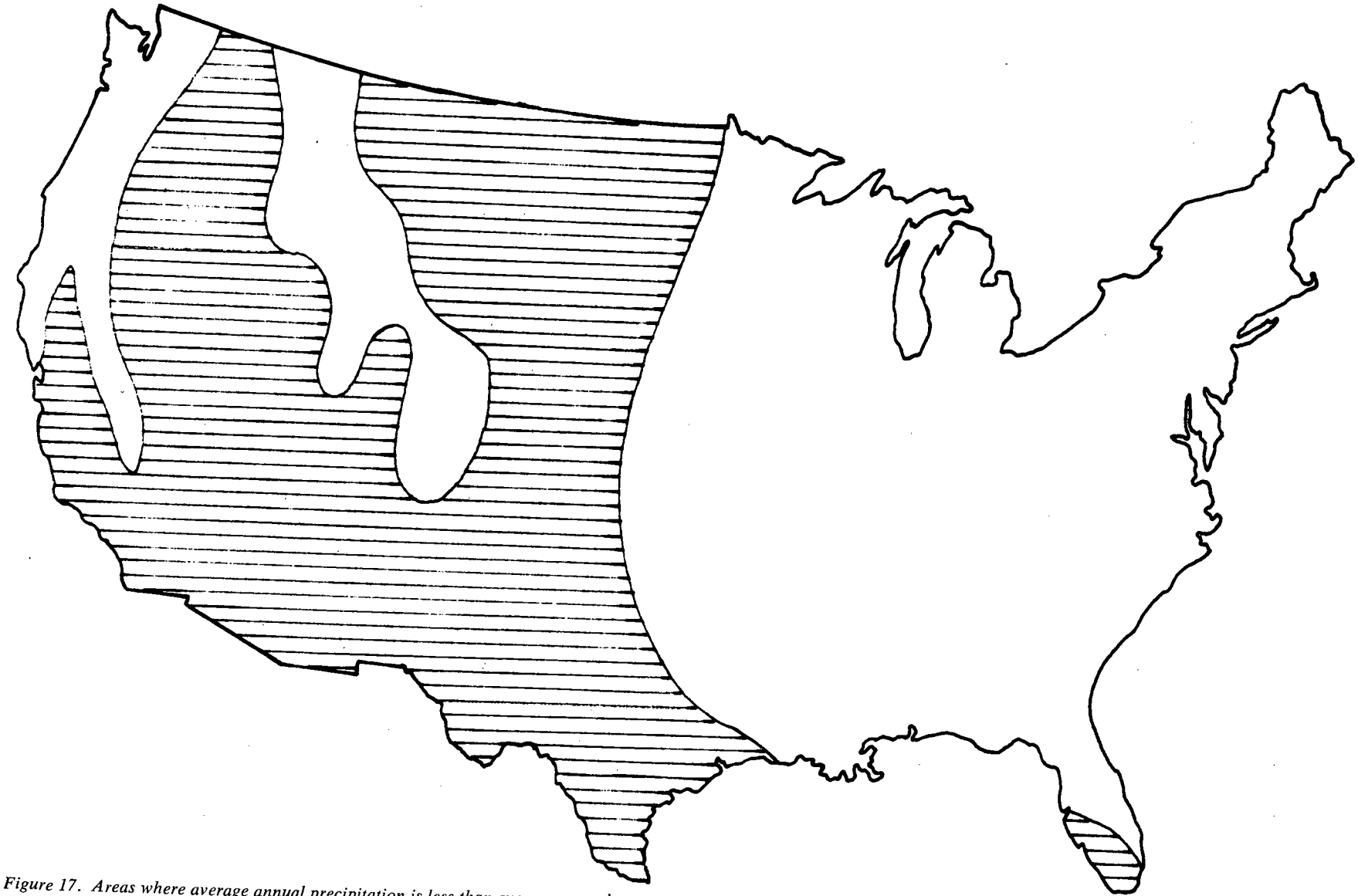


Figure 17. Areas where average annual precipitation is less than average annual evapotranspiration (inferred boundaries).

TABLE 17

SUMMARY OF SECTION FREQUENCY OF OCCURRENCE RATING, BY FROST-SUSCEPTIBLE SOIL TYPE [a]

PROV. CODE	FREQUENCY OF OCCURRENCE RATING, BY SECTION				
	NE	N-L	L-M	M-W	VW
	(*a*) F4 soils				
2	a, b	—	c	—	—
4	—	—	b	a, e	c, d
5	—	—	a	—	—
6	—	—	a, b, f	c, d, e	—
7	b, c	—	a	—	—
8	a, d	b, c, e	—	—	—
9	a, c	—	b	—	—
10	e	j	c, d	b, f, g, h	a
11	b	—	a, c, e-h	d, i	—
12	b	—	a	—	—
13	a, b	—	—	—	—
15	—	—	—	b-d	a
16	—	—	a	—	—
18	—	—	—	18	—
19	g	a, d, e	b, c, f	—	—
	(*b*) F3 soils				
2	a, c	b	—	—	—
4	c, e	a, b, d	—	—	—
5	—	—	a	—	—
6	e	c, d	a, b, f	—	—
7	a, c	b	—	—	—
8	a-c, e	—	—	d	—
9	a-c	—	—	—	—
10	c, f-h	a	b, e	d	j
11	d	—	a, c, e-h	b, i	—
12	—	—	a	—	b
13	—	—	—	—	a, b
15	a, c	—	—	b, d	—
16	—	—	a	—	—
18	—	18	—	—	—
19	c, e, f	—	a, d, g	b	—
	(*c*) F2 soils				
2	a-c	—	—	—	—
4	b, c, e	d	a	—	—
5	—	a	—	—	—
6	a, b, d-f	c	—	—	—
7	a, c	b	—	—	—
8	a-e	—	—	—	—
9	a-c	—	—	—	—
10	b-e, h, j	a	f, g	—	—
11	a-d, f, i	h	e, g	—	—
12	b	a	—	—	—
13	a, b	—	—	—	—
15	a-d	—	—	—	—
16	a	—	—	—	—
18	18	—	—	—	—
19	c, e-g	a, b, d	—	—	—
	(*d*) F1 soils				
2	a-c	—	—	—	—
4	a-d	—	e	—	—
5	—	a	—	—	—
6	a, d-f	b, c	—	—	—
7	a-c	—	—	—	—
8	a-e	—	—	—	—
9	c	a, b	—	—	—
10	a, b, d-g, j	h	c	—	—
11	b, e-i	a, c, d	—	—	—
12	a, b	—	—	—	—
13	a, b	—	—	—	—
15	a, c, d	b	—	—	—
16	a	—	—	—	—
18	—	18	—	—	—
19	b, e-g	a, d	c	—	—
	(*e*) NFS soils (includes bedrock) [b]				
2	—	—	—	—	a, b, c
4	e	a, c, d	—	—	b
5	—	—	—	a	—
6	—	a, d-f	b, c	—	—
7	—	—	—	a, b	c
8	—	—	d	—	a-c, e
9	—	—	—	b	a, c
10	a, f, j	b, d, g, h	c	e	—
11	c, d, f, g, i	a, b, e, h	—	—	—
12	b	a	—	—	—
13	a, b	—	—	—	—
15	a	b, d	c	—	—
16	—	—	a	—	—
18	—	18	—	—	—
19	a	b, c	f	d, e, g	—

[a] VW—very widespread; M-W—medium to widespread; L-M—limited to medium; N-L—nonexistent to limited; NE—nonexistent.
[b] NFS = nonfrost susceptible.

is F4, owing to the general widespread distribution of sandy silt residual soils from the sandstones and shales, Tertiary outwash deposits in much of the High Plains, and widespread loessial deposits over much of the central portion. Much of the F3 soils in the area are attributable to the shales and clay shales found in most of the Sections. The largest distribution of F2 regional frost soils in the U.S. is in the Nebraska Sand Hill portion of the High Plains Section.

In the Sections characterized primarily by residual soil development, much of the F3 soils found in the Triassic Lowland, Ozark and Ouachita, and Ridge and Valley Provinces are a result of the plastic residual soils developed from limestones in these areas. Soils associated with an F4 rating in these units appear to be from sandstones and shales. They are found in portions of the Ridge and Valley, Triassic Lowland, and Appalachian Plateau Provinces. In the New York Glaciated Section of the last Province, soils in the eastern portion have an F4 rating; in the western portion the predominant rating is F3. This rating is in general agreement with the soil texture descriptions previously provided for this unit.

TABLE 18

SUMMARY OF HIGHEST FREQUENCY OF OCCURRENCE RATING OF FROST-SUSCEPTIBLE SOIL CATEGORY, BY SECTION

SECT. CODE	FREQ.[a]	SOIL TYPE [b]
2a	VW	NFS
2b	VW	NFS
2c	VW	NFS
4a	M-W	F4
4b	VW	NFS
4c	VW	F4
4d	VW	F4
4e	M-W	F4
5a	M-W	NFS
6a	L-M	F3, F4
6b	L-M	F3, F4, NFS
6c	M-W	F4
6d	M-W	F4
6e	M-W	F4
6f	L-M	F3, F4
7a	M-W	NFS
7b	M-W	NFS
7c	VW	NFS
8a	VW	NFS
8b	VW	NFS
8c	VW	NFS
8d	M-W	F3
8e	VW	NFS
9a	VW	NFS
9b	M-W	NFS
9c	VW	NFS
10a	VW	F4
10b	M-W	F4
10c	L-M	F1, F4, NFS
10d	M-W	F3
10e	M-W	NFS
10f	M-W	F4
10g	M-W	F4
10h	M-W	F4
10j	VW	F3
11a	L-M	F3, F4
11b	M-W	F3
11c	L-M	F3, F4
11d	M-W	F4
11e	L-M	F2, F3, F4
11f	L-M	F3, F4
11g	L-M	F2, F3, F4
11h	L-M	F3, F4
11i	M-W	F3, F4
12a	L-M	F3, F4
12b	VW	F3
13a	VW	F3
13b	VW	F3
15a	VW	F4
15b	M-W	F3, F4
15c	M-W	F4
15d	M-W	F3, F4
16a	L-M	F3, F4, NFS
18	M-W	F4
19a	L-M	F3
19b	M-W	F3
19c	L-M	F1, F4
19d	M-W	NFS
19e	M-W	NFS
19f	L-M	F4, NFS
19g	M-W	NFS

[a] VW—very widespread; M-W—medium to widespread; L-W—limited to medium.
[b] NFS = nonfrost-susceptible soil.
F1 to F4 = U.S. Army Corps of Engineers frost-susceptible soil category.

In glaciated sections found within the freezing zone the distribution of frost-susceptible soil types is generally complex. In the New England Maritime Province the mountainous sections generally possess a nonfrost susceptibility rating as the major soil type and F4 types as the minor variety. F3 soils generally are restricted to the northern parts of the Seaboard Lowland and the New England Upland Sections. A fairly significant portion of the Connecticut Lowland Section has been categorized as F2 soils. The two glaciated Sections of the Laurentian Upland Province vary markedly in frost-susceptible soil type. In the Adirondack Section the uniform and widespread occurrence of F3 soils is in strong contrast to the nonfrost-susceptible F2, F3, and F4 areas common to the Superior Upland Section.

In the Central and Eastern Lowland Province, the most common frost-susceptible soil types are F3 and F4. The distribution of the F4 soils is strongly related to the presence of loessial deposits in the Driftless, Central Till Plains, and Dissected Loessial and Till Plains Sections. In addition, F4-type drift is found in the western portion of the Western Lakes Section and in much of the valleys and lowlands of the eastern lowland portion of the Province. The distribution of F3 soils is strongly related to the plastic drift found in the eastern portion of the Western Lakes, Dissected Loessial and Till Plains, and Central Till Plains Sections. Distribution of these soil ratings also is associated with the marine deposits of the St. Lawrence Lowland and Champlain Lowland Sections. The most extensive deposits of F2-type soils are found in the Central Sand Plain area of the Driftless Section and in the northern drift areas of the Eastern Lakes and Lacustrine Section.

COMPOSITE FACTOR OF DESIGN SUMMARY RATING, BY SECTION

Table 19 summarizes the ratings for each factor of design considered in this report, by Section. These data form the basis for subsequent discussion relative to the recommended design units in the U.S.

TABLE 19

COMPOSITE FACTOR OF DESIGN SUMMARY RATING, BY SECTION

RATING [a]

SECT. CODE	AGGR. AVAIL.	POOR SUBGRADE SUPPORT		HIGH VOLUME CHANGE SOILS	FROST-SUSCEPTIBLE SOILS [b]					
		INORG.	OGR.		RSFF	NFS	F1	F2	F3	F4
1a	A-L	N-L	N-L	NE	X					
1b	L-P	N-L	N-L	NE	X					
1c	A-L	NE	NE	NE	X					
1d	L-P	L-M	N-L	M-W	X					
1e	A-A	N-L	NE	L-M	X					
2a	A-L	NE	NE	NE		VW	NE	NE	NE	NE
2b	A-A	N-L	NE	NE		VW	NE	NE	N-L	NE
2c	A-A	N-L	NE	NE		VW	NE	NE	NE	L-M
2d	A-A	NE	NE	N-L	X					
3a	A-A	N-L	N-L	NE	X					
3b	A-A	L-M	NE	NE	X					
3c	A-A	M-W	N-L	L-M	X					
4a	A-A	NE	NE	NE		N-L	NE	L-M	N-L	M-W
4b	A-A	NE	NE	NE		VW	NE	NE	N-L	L-M
4c	L-P	NE	NE	NE		N-L	NE	NE	NE	VW
4d	A-L	N-L	NE	NE		N-L	NE	N-L	N-L	VW
4e	L-P	NE	N-L	NE		NE	L-M	NE	NE	M-W
5a	A-A	L-M	NE	L-M		M-W	N-L	N-L	L-M	L-M
5b	A-A	N-L	NE	N-L	X					
5c	L-P	M-W	NE	NE	X					
5d	A-A	N-L	NE	N-L	X					
5e	A-A	N-L	NE	NE	X					
5f	A-A	N-L	NE	NE	X					
6a	A-L	N-L	NE	L-M		N-L	NE	NE	L-M	L-M
6b	L-P	N-L	NE	L-M		L-M	N-L	NE	L-M	L-M
6c	L-P	N-L	NE	L-M		L-M	N-L	N-L	N-L	M-W
6d	L-P	N-L	NE	M-W		N-L	NE	NE	N-L	M-W
6e	A-L	N-L	NE	M-W		N-L	NE	NE	NE	M-W
6f	A-A	L-M	NE	L-M		N-L	NE	NE	L-M	L-M
7a	A-A	N-L	NE	NE		M-W	NE	NE	NE	L-M
7b	A-L	NE	NE	NE		M-W	NE	N-L	N-L	NE
7c	L-P	NE	NE	NE		VW	NE	NE	NE	NE
8a	A-L	NE	NE	NE		VW	NE	NE	NE	NE
8b	A-A	NE	NE	NE		VW	NE	NE	NE	N-L
8c	A-A	NE	NE	NE		VW	NE	NE	NE	N-L
8d	A-L	N-L	N-L	NE		L-M	NE	NE	M-W	NE
8e	A-A	NE	NE	NE		VW	NE	NE	NE	N-L
9a	A-A	NE	NE	NE		VW	N-L	NE	NE	NE
9b	A-A	NE	NE	N-L		M-W	N-L	NE	NE	L-M
9c	A-A	NE	NE	NE		VW	NE	NE	NE	NE
10a	L-P	L-M	NE	N-L		NE	NE	N-L	N-L	VW
10b	SP	M-W	NE	VW		N-L	NE	NE	L-M	M-W
10c	A-A	N-L	NE	L-M		L-M	L-M	NE	NE	L-M
10d	L-P	N-L	NE	L-M		N-L	NE	NE	M-W	L-M
10e	A-A	N-L	NE	NE		M-W	NE	NE	L-M	NE
10f	L-P	N-L	NE	N-L		NE	NE	L-M	NE	M-W
10g	L-P	L-M	NE	VW		N-L	NE	L-M	NE	M-W
10h	A-L	L-M	NE	M-W		N-L	N-L	NE	NE	M-W
10i	L-P	N-L	NE	NE	X					
10j	L-P	N-L	NE	L-M		NE	NE	NE	VW	N-L

TABLE 19 (*Continued*)

RATING [a]										
SECT. CODE	AGGR. AVAIL.	POOR SUBGRADE SUPPORT		HIGH VOLUME CHANGE SOILS	FROST-SUSCEPTIBLE SOILS [b]					
		INORG.	OGR.		RSFF	NFS	F1	F2	F3	F4
10k	A-A	N-L	NE	L-M	X					
10l	A-A	L-M	NE	L-M	X					
10m	A-L	M-W	NE	VW	X					
11a	A-A	M-W	L-M	NE		N-L	N-L	NE	L-M	L-M
11b	A-A	M-W	N-L	NE		N-L	NE	NE	M-W	NE
11c	A-A	M-W	N-L	NE		NE	N-L	NE	L-M	L-M
11d	A-A	L-M	N-L	NE		NE	N-L	NE	NE	M-W
11e	A-L	L-M	M-W	NE		N-L	NE	L-M	L-M	L-M
11f	A-L	M-W	N-L	NE		NE	NE	NE	L-M	L-M
11g	L-P	N-L	N-L	NE		NE	NE	L-M	L-M	L-M
11h	L-P	N-L	L-M	N-L		N-L	NE	N-L	L-M	L-M
11i	A-L	M-W	NE	NE		NE	NE	NE	M-W	M-W
12a	A-A	N-L	L-M	NE		N-L	NE	N-L	L-M	L-M
12b	A-A	NE	L-M	NE		NE	NE	NE	VW	NE
13a	A-A	N-L	NE	NE		NE	NE	NE	VW	NE
13b	A-L	L-M	NE	NE		NE	NE	NE	VW	NE
13c1	L-P	L-M	NE	NE	X					
13c2	L-P	N-L	NE	N-L	X					
13c3	A-L	L-M	NE	NE	X					
14a	A-A	VW	NE	NE	X					
14b	A-A	VW	NE	NE	X					
14c	L-P	L-M	NE	NE	X					
14d	A-A	M-W	NE	NE	X					
15a	A-L	N-L	NE	NE		NE	NE	NE	NE	VW
15b	A-L	L-M	N-L	NE		N-L	N-L	NE	M-W	M-W
15c	A-L	L-M	NE	NE		L-M	NE	NE	NE	M-W
15d	L-P	M-W	NE	NE		N-L	NE	NE	M-W	M-W
15e	A-L	N-L	NE	NE	X					
16a	A-A	L-M	NE	NE		L-M	NE	NE	L-M	L-M
16b	A-A	L-M	NE	NE	X					
17a	A-A	NE	NE	NE	X					
17b	A-A	M-W	NE	N-L	X					
18	A-A	M-W	N-L	NE		N-L	N-L	NE	N-L	M-W
19a	A-L	M-W	L-M	NE		NE	N-L	N-L	L-M	N-L
19b	A-A	N-L	N-L	NE		N-L	NE	N-L	M-W	L-M
19c	A-A	NE	N-L	NE		N-L	L-M	NE	NE	L-M
19d	A-L	NE	N-L	NE		M-W	N-L	N-L	L-M	N-L
19e	A-A	NE	NE	NE		M-W	NE	NE	NE	N-L
19f	A-A	N-L	NE	NE		L-M	NE	NE	NE	L-M
19g	A-A	NE	NE	NE		M-W	NE	NE	L-M	NE
20a	A-L	N-L	L-M	NE	X					
20b	A-L	N-L	L-M	L-M	X					
20c	L-P	L-M	M-W	L-M	X					
20d	A-L	L-M	N-L	VW	X					
20e	L-P	N-L	NE	N-L	X					
20f	SP	VW	N-L	VW	X					
20g	A-L	M-W	N-L	VW	X					

[a] A-A—abundant to adequate; A-L—adequate to limited; L-P—limited to problem; SP—severe problem.
VW—very widespread; M-W—medium to widespread; L-M—limited to medium; N-L—nonexistent to limited; NE—nonexistent.
[b] RSFF = relatively safe from freezing.
NFS = nonfrost-susceptible soil.
F1 to F4 = U.S. Army Corps of Engineers frost-susceptible soil category.

CHAPTER THREE

INTERPRETATIONS AND CONCLUSIONS

The major purpose of this research was to evaluate selected highway design factors on the basis of regional physiography. The results concerning the design factors are described in the form of a severity and/or a frequency of occurrence rating for each of the 97 physiographic Sections.

Major emphasis was placed on the ratings established, their distribution, and their occurrence, and on any general physiographic and geologic implications developed. However, in the idealized process of assigning a rating to each Section two important assumptions were made:

1. The physiographic unit is the optimum unit for cataloging highway engineering problems, performance, and factors of design.
2. The initial physiographic unit classification system used is the optimum classification system for highway engineering purposes.

Because of the level of generalization of this investigation, a precise and detailed summary of every pertinent highway characteristic existing in each Section examined is beyond the scope of the report. The major reason for this is the variable input information regarding geologic, geomorphic, and highway engineering facts for the U.S. as a whole. In addition, it is acknowledged that many of the Sections can be divided into smaller and more homogeneous physiographic units. Examples of how physiographic information and physiographic units can be used for highway engineering purposes follow.

IDEALIZED CONCEPTS OF REGIONALIZATION

Regionalization Scheme

In considering the benefits of an idealized system for regionalizing a particular factor within a given areal unit, one should be cognizant of three considerations: (1) selection of the primary variables affecting the factor in question that will be considered in the regionalization, (2) selection of the type of areal unit to effect the regionalization of the parameter, and (3) examination of the distributive characteristics of the factor within the areal unit selected.

As an example of the first consideration, assume that the factor to be regionalized is the distribution of high volume change occurrences. Three primary variables affecting this factor are soil type, climate, and construction control. It should be obvious that of these three variables only the first two can be mapped and regionalized on any state or national level. The level of construction control (e.g., controlling initial compaction water content) can only be considered as being peculiar to local conditions and to the level of engineering control administered for each project. When one or more of the variables affecting the factor to be regionalized is not subject to regionalization, the factor may be termed *conditional* in nature. Another example of a *conditional* factor would be the distribution of aggregates having poor skid-resistant characteristics. The aggregate may have a poor skid quality and hence be subject to some level of regionalization. However, traffic level is a primary variable to be considered and is not a factor that is conducive to any regionalization effort.

The alternative type of factor, other than conditional, is termed a *true* factor. This implies that all the primary variables considered to affect the factor can be considered in the regionalization. Hence, the factor of the occurrence of organic soil deposits is a *true* factor because one is concerned only with the distribution of a particular soil type.

The second consideration, and perhaps the most salient, involves the selection of what type of areal unit will be used or examined to effect the regionalization. Should an areal unit based on political borders (county, or state), surficial soil borders, geologic borders, or physiographic borders be selected? If one is given a choice of areal units, which unit affords the greatest degree of optimization for making the generalization? It should be noted that a generalization or a statement of the average condition of any factor can be made in any type of areal unit.

The third consideration is really an examination of how well the factor being regionalized is confined within the areal unit selected. In this consideration, two important questions should be asked: (1) Is the factor selected for regionalization *uniquely* confined to the areal unit? and (2) At what level or degree does the factor exist within the areal unit?

As an example, consider the distribution of organic soils. Their mapped occurrence has been found to be confined solely to a physiographic unit and is therefore considered *unique* to the unit. A political unit (county) that would be within (either partially or totally) the physiographic unit would thus have a *nonunique* relationship to this factor because the boundary of the factor bears no relationship to the political border.

The final portion of this consideration involves the distributive rating of the factor to the areal unit. If the factor is widely distributed throughout the unit it is termed *homogeneous.* If its occurrence is confined to a particular portion of the areal unit, it is termed *nonhomogeneous.* It should be noted that complete *homogeneity* of a factor does not necessarily imply a *unique* relationship. Similarly, a *nonhomogeneous* factor may not necessarily imply a *nonunique* relationship.

From this idealized scheme, several types of regionalization combinations may be obtained. The ideal combination is a generalization that it is *unique, true,* and *homogeneous.*

This would imply a precise measure of a particular factor that is uniform throughout an areal unit that is the most effective for making the generalization. The worst type of generalization that may be effected is the *nonunique, conditional,* and *nonhomogeneous* rating.

Basic Concepts of Regionalization Within Physiographic Units

Because physiographic units are delineated as areas of uniform topographic expression, the validity of regionalization within physiographic units can be related to topographic expression (i.e., by nongenetic descriptors of altitude, relief, and type of landform present).

However, it is most important to understand that the more fundamental question is: "What is the relationship between the geomorphic control factors to the highway design factors considered?" It must be recognized that it is a unique combination of a particular type or repetitive types of parent material, its arrangement, the modifying processes that act on it, the length of time in which the processes have acted, and the historical climatic environment that results in the landform or landforms peculiar to and characteristic of the physiographic unit.

Each factor considered in this report has as a primary variable, either by itself or in combination with other variables, material type. That is, for each factor considered, engineering experience can be related, to a variable degree, to the material type. The basic concept in applying physiographic units to engineering experiences is to formulate an experience with a material condition at a micro level (e.g., engineering site or project) and then define the regional extent or macro area of this experience via the application of homogeneous topography, or regional physiographic units.

In the majority of Sections considered, the application of this concept is a valid approach to the analysis. However, important exceptions do occur within Sections, as it is possible for similar material types to exist in adjacent Sections, or to have differing material types in a unique topographic unit.

The first exception does not imply any major limitations to the concept of regionalization. For these units, the major implication is that the chances of having identical generalizations for the adjacent Sections are high. The second exception, however, does pose limitations to the concept of regionalization. In a uniform topographic unit composed of differing parent material and geologic conditions, the basic concept is not applicable because the generalizations effected on a micro level are *not* valid for the macro or regional topographic unit.

VALUE OF PHYSIOGRAPHIC UNITS TO FACTORS OF DESIGN

Aggregates

Crushed Stone

The results of this study suggest that the greatest value of physiographic units concerning aggregates and their distribution lies in the ability to make effective generalizations concerning the potential of crushed stone areas for many Sections in the U.S.

In physiographic Sections where effective generalizations cannot be made about crushed stone areas the topography generally is formed from transported material but has bedrock underlying the surface such that generalizations about the potential of the bedrock as crushed stone sources can still be made. For the remaining Sections, it is generally possible to formulate generalizations concerning crushed stone sources. Sections whose modal characteristics are based on gross bedrock features, regardless of the presence (either total or partial) or absence of any surficial transported deposits, will generally result in having effective generalizations made. In addition, in Sections with very thick deposits of transported soils, generalizations concerning the distribution of crushed stone areas can be made because the potential of such Sections is nonexistent.

An excellent example of Sections that are not optimal or good areal units for making generalizations of their crushed stone sources is found in the central lowland portion of the Central and Eastern Lowland Province (Sections 11e,f,g,h,i). In this area lie a large number of the major carbonate-producing states. As the modal characteristics of the Sections comprising this area are based on differences in glacial terrains, or lack thereof, there is no relationship of the major potential crushed carbonate areas to the physiographic units. That is, these Sections do *not* afford the optimum unit in these areas for cataloging crushed stone potential.

However, if one were to follow the underlying bedrock strata from the glaciated Lowland Province to the Interior Low Plateau Province (nontransported origin), the value of using physiographic units becomes apparent. In this Province, regional carbonate zones are found in the Nashville Basin Section and portions of the remaining Sections. Other areas, characterized by nontransported origins, where potential carbonate zones occur are the Springfield-Salem Plateau Section of the Ozark and Ouachita Province and the limestone valleys of the entire Ridge and Valley Province.

Other examples further illustrate the value of using physiographic units to categorize crushed stone aggregate information. In the eastern U.S. exist several small, variant, but well-defined physiographic units. In these units the potential for crushed carbonate stone is considered good. The physiography of all these areas is similar in that old Paleozoic strata predominate as the variant valley units. These areas are the Sequatchie-Wills Creek Valleys of the Cumberland Plateau Section, the Frederick, Conestoga (Lancaster), and Chester Valleys of the Triassic Lowland Province, and the Limestone Valley of Vermont of the Taconic Section. (The distribution of the units is shown in the recommended physiographic-highway engineering units introduced in the next part of this report. They correspond to unit numbers 192, 207, 208, and 214.) It should also be noted that a more detailed division of subunits in the Interior Low Plateau Province greatly increases the usefulness of physiographic units as an engineering filing system.

Other types of potential crushed stone area examples

can be found in many Sections. Granitic/metamorphic crushed stone areas are uniquely associated with the Black Hills Section or St. Francis Mountain Section; the crushed basalts of the Columbia Plateau and the traprock of the Triassic Lowland Province and Connecticut Lowland Section are examples of other potential igneous crushed stone areas that can be effectively and truly regionalized to the physiographic unit.

Sections also may be categorized as having a poor or nonexistent potential for crushed stone; e.g., Sections such as the Kanawha, Cumberland Plateau, California, and Oregon Coast Range, and many Sections of the Colorado Plateau and Great Plains Provinces. In general, the bedrock characteristics in these units are unfavorable for good performance as highway aggregates. Other Sections, such as the California Valley and the High Plains, and most of the Sections of the Atlantic and Gulf Coastal Plains Province, have a nonexistent potential, owing to the widespread presence of relatively deep layers of transported sediments.

Sand-Gravel

In cataloging sand-gravel sources in physiographic units, it is convenient to divide this aggregate source into deposits that occur regionally and those that are associated primarily with alluvial origin and therefore have a more lineal type of distribution.

The use of physiographic units to note pertinent factors concerning sand-gravel deposits is considered variable, but generally good. Table 20 summarizes Sections where the characteristics of sand-gravel sources are unique. The origins of these regional sand-gravel occurrences are generally associated with widely distributed patterns of stratified drift, valley (includes glacial sluiceways) and basin deposits generally filled with glacial outwash, and potential areas associated with valley fill deposits near mountainous areas.

Smaller regional sand-gravel areas also exist in Sections which, when divided in Subsections, increase the ability of the physiographic unit to provide effective generalizations about the aggregate potential. These areas are found in the Jackson Hole unit of the Middle Rocky Mountain Province, the North Park, Middle Park, and San Luis Valley areas of the Southern Rocky Mountain Province, and the Southern Pine Hills Area of the East Gulf Coast Section.* Only the last area has a distinct topographic expression as a direct result of the gravel cap (Citronelle formation) providing an area of slightly differing relief relative to adjacent units. The other units are delineated primarily because they are intermontane basins veneered by outwash sands and gravels.

Small regional areas of sand and gravel do exist with remnental gravel caps that afford little or no alteration of the regional physiography of the Section where they are found. Examples of these sporadic deposits are associated with many outwash areas adjacent to mountains, areas in both the Glaciated and Unglaciated Missouri Plateau Sections (Flaxville, Cypress Hills) and the Osage Plains Section of the Great Plains Province, as well as preglacial and interglacial gravels (Buchanan and Aftonian gravels) found in the Dissected Loessial and Till Plains Section.

The use of physiographic units for noting factors relative to sand-gravel deposits is poorest with alluvial sand-gravel deposits. This is unfortunate because of their importance in the complex totality of aggregate resources. In many areas of the U.S. these are the only potential sources of aggregate available.

The poor correlation of alluvial deposits to physiographic units is related to the direct contrast between conditions necessary to delineate adjacent physiographic units and those necessary for fluvial development. In general, the differences in base levels (i.e., elevation difference) necessary for drainage development and subsequent river and stream development frequently delineate differing physio-

* The distribution of these units is shown and described in the next part of this report. They correspond to unit numbers 75 (Jackson Hole), 59 (North and Middle Parks), 65, 67 (San Luis Valley), and 242 (Southern Pine Hills).

TABLE 20

SUMMARY OF SECTIONS WHERE UNIQUENESS OF REGIONAL SAND-GRAVEL DISTRIBUTION AND OCCURRENCE IS GENERALLY GOOD

SECTION CODE	REMARKS
Eastern Lakes and Lacustrine (11e) New England Upland (19b) Puget Sound (3a)	Widespread distribution of stratified drift deposits
Connecticut Lowland (19c)	Associated with stratified drift and valley terraces
Walla Walla (4a)	Associated with sluiceway and valley terrace deposits
Central Till Plains (11f)	Associated with glacial sluiceway terraces
Montana (7a)	Associated with glacial outwash in basin and valley areas
Bitterroot (7b)	Similar to Section 7a but generally found in northern portion
California Valley (3c) Great (Closed) Basin (5a) Sonoran Desert (5b) Open Basin (5d) Sacramento Highland (5e) Great Bend Highland (5f)	Associated with valley fill areas adjacent to mountains

graphic units. Thus, the streams that radiate from the Front Range flow through the Colorado Piedmont, High Plains, and Plains Border Sections, and into the Mississippi River to the Gulf of Mexico. Although generalizations may be made in any of these Sections concerning the alluvial sand-gravel sources, the generalizations are not associated with only that particular Section.

Soils and Related Factors

All of the soil and related factors of design investigated in the project have had associated with them, either uniquely or in conjunction with other major variables (e.g., climate), characteristic properties peculiar to the surficial soil type. Thus, the delineation of potentially poor subgrade support areas by physiographic units led to the categorization on the basis of either organic-type deposits or clayey areas. The high volume change study also noted clayey-type soils existing in a very general climatic environment suitable for high volume change development. The analysis of frost-susceptible soils was related to the textural characteristics of soil units generally located within the frost zone. Consequently, the general usefulness of physiographic Sections to categorize potentially unique and homogeneous factors of design depends on the soil texture and the design factor relative to the modal characteristics of the Section.

In general, the ability to generalize about soil factors of design is good in most units developed solely from non-transported origins. In these areas, the soil type is developed on the principles of pedology. Hence, units with similar parent material types, topographic patterns, climatic histories, age, and vegetation ideally will form similar soil types. With the exception of the vegetation variable, each of the other pertinent factors to soil genesis also is common to the geomorphic control factors that characterize a physiographic unit. The ability to effectively generalize in a large regional area is directly related, in sedimentary areas, to the geologic structure of the strata. In areas underlain by horizontal to slightly dipping strata, the residual soil types are relatively homogeneous or possess a predictable texture range over large areas. Physiographic units with these characteristics frequently are found in the Appalachian Plateau, Interior Low Plateau, Ozark and Ouachita, much of the Great Plains, and Colorado Plateau Provinces. Conversely, where geologic structure is greatly dipping, the regional (areal) patterns of similar soil type units cover relatively small areas. Examples are the massive mountainous uplifts that frequently are flanked by highly tilted strata. The soil regions of the Black Hills Section and many areas in the Rocky Mountain Provinces exhibit this pattern.

In Sections characterized by rugged mountainous areas, topography, more than any other factor, affects soil development. Many of the Sections in the mountainous areas of the west, and much of the Blue Ridge Section of the east are, in general, nonsoil areas.

The ability to effectively generalize about soil-related factors of design is highly variable in Sections having transported soils. Where transported soils, in part, overlie a physiographic unit based on geomorphic factors related to underlying bedrock *or* different transported origin, the over-all ability of the unit to denote soil factors of design is considered poor. If transported soils completely overlie a physiographic unit, regardless of the basis for geomorphic unit identification, the ability may be considered as good.

Perhaps the most notable example of this is found with the distribution of regional aeolian (loessial) deposits in the U.S. and their relationship to physiographic units. In general, the major occurrences of loess are in the Columbia Plateau Province, the midwest U.S. (in parts of the Great Plains and Central and Eastern Lowland Provinces), and the Mississippi Loessial Upland Section.

The status of the Mississippi Loessial Upland Section to be identified as a unique soil unit is considered good because, in the main, the basis for sectioning is due to the presence of a topographic unit developed from the loess itself. (This statement is more correct for the western portion of the Section where the thickest loess deposits occur. In the east the thickness of loess decreases and topography is somewhat influenced by the underlying coastal sediments.) The ability of the loessial areas of the Columbia Plateau Province also is considered good. However, these loessial areas in the Snake River Plain and Walla Walla Sections are considered good only because they are pseudo-origin units. That is, if the loess covering were removed from these areas, the two Sections would still be considered unique physiographic Sections, because the modal characteristics are based on the underlying bedrock rather than the loess. In contrast, the loess deposits in the midwest bear little, if any, correlation to the regional physiography in the area because the modal characteristics are based on parent material other than the loess, and the loess deposits nowhere completely veneer a Section.

This example lends itself to a discussion of a basic point of conflict between the physiographer and the highway engineer. The important question here, for the highway engineer, is whether the depth of transported soil is sufficient to justify a regional unit attributable to the transported soil. In areas where this is a factor to be considered, the use of transported origin boundaries (even though gradational in nature) appears to be a much better areal unit for making *soil*-related design factor generalizations than areal units established on the basic principles of regional physiography.

COMPOSITE UTILITY OF UNITS

Because of the variety of factors that determine physiographic Sections, it is not possible to make a blanket conclusion that the use of Sections as "filing systems" for highway design factors is either satisfactory or unsatisfactory. The use of a Section as a filing system depends on the factor being regionalized, relative to the modal characteristics that define the unit.

The best use of regional physiography to generalize both aggregate (crushed stone) sources and soil-related factors generally occurs in a Section whose modal characteristics are based on consolidated (bedrock) material having no regional areas of transported material in the unit, or units whose modal topography is formed from very thick trans-

ported soils, with the depth to underlying bedrock being such that the bedrock is of no practical engineering concern.

In the former case, crushed stone (aggregate) and soil factor generalizations may be developed from the same parent material-topographic pattern. In the latter case, the ability of the Section to generalize about crushed stone sources is considered as good because it does not exist in the unit. Soil factor generalizations may be formed directly from an evaluation of the transported soils in the unit.

In Sections where modal characteristics are based on bedrock material but the Section has a partial covering of thin, transported soil, the ability of the unit for crushed stone generalizations may be good but the ability to effectively generalize soil factors is considered poor.

Conversely, where the Section consists mainly of transported materials but underlying bedrock is at such a depth that generalizations may be made, the uniqueness between crushed stone and soil factors to the physiographic units is reversed. Here the ability of regionalizing soil factors may be good, while the crushed stone generalizations effected are very poor.

CONCEPT OF A UNIQUE PHYSIOGRAPHIC-HIGHWAY ENGINEERING CATEGORY

From a purely physiographic viewpoint, the concept of a categorization system (i.e., Division—Province—Section) is a necessary and integral part of the science. This system places topographic differences at a more detailed level of examination. However, not all Sections of a Province are geomorphically related. For example, there is more similarity in physiography (geomorphology) between the Uinta Section of the Middle Rocky Mountain Province, the Colorado Front Range Section of the Southern Rocky Mountain Province, and the variant Belt Mountain areas of the Northern Rocky Mountain Province than there is between the Uinta and Wasatch Sections of the same Province.

When one is using physiographic areas as a means of filing particular characteristics (occurrence, distribution, severity, etc.) of design and construction factors, physiographic attributes are translated into engineering factors in a given Section. Consequently, the use of a Section level to rate engineering experiences does not and should not imply to the highway engineer a similarity of these engineering experiences for all Sections of a particular Province.

For engineering purposes, a physiographic Province is best used as an areal unit that is a starting or reference point for analyzing smaller "engineering" units (Sections). A Section should be viewed as an areal unit that is a starting point for analyzing even smaller units.

Because of these factors, the use of a categorical classification system for engineering purposes is not necessary and may, in fact, be misleading. Therefore, the use of the term "highway engineering unit" is recommended in lieu of any Province, Section, or Subsection categories used in regional physiography. This term may be defined as the smallest detailed area in which highway engineering generalizations have been effected.

RECOMMENDED PHYSIOGRAPHIC-HIGHWAY ENGINEERING UNITS OF THE U.S.

The Woods-Lovell physiographic system, patterned after a true regional physiographic classification framework (and modified for this report), affords some significant engineering differences that improve on a pure physiographic categorization. However, it should be noted that it is a part of a continental divisioning system; therefore, its units (Sections) may in some cases exhibit excessive variability when viewed at the state level. Therefore, many of the generalizations effected at the Section level may be too broad for maximum use for each state highway department.

Recommended System

With the previously noted factor in mind, the U.S. has been further divided into a more homogeneous physiographic-highway engineering unit classification system. These areas have been delineated with several factors in mind:

1. As many individual state physiographic units as possible have been incorporated into the system.
2. Because of the over-all importance of origin and parent material considerations in highway engineering, major emphasis in unit delineation has been placed on these factors as well as isolating variant parent material areas in the Sections of the typical physiographic system.
3. A classification system of higher order units is not necessary and, in fact, may be misleading.

Consequently, the system is simply composed of 242 physiographic-highway engineering units. Figures 18 through 23 show the distribution of the recommended units.

For the proposed system, only a general description of the factors pertinent to the highway engineer (geology, geomorphology, and parent material-origin characteristics) is given. The numeric code is keyed to the figures that show the occurrence of these areas.

General Description of Recommended Units

1. Olympic Mountains—A rugged, highly dissected mountainous area with several peaks higher than 7,000 ft. The area is heavily glaciated. The major rock types are Cretaceous volcanic and metamorphic sediments. Locally, basalts, volcanic tuffs, breccias, and interbedded marine beds of Eocene age as well as Oligocene marine sediments are found.
2. Willapa Hills—This area occurs as the Oregon portion of the Oregon Coast Ranges. The major reason for distinction is the Tertiary volcanic cover overlying the Tertiary sandstones and shales of the Oregon Ranges.
3. Oregon Coast Range—Parallel trending series of north-south ridges and valleys formed by mild folding of relatively weak Tertiary sandstones and shales.
4. Oregon Coastal Plain—Relatively small sandy coastal area of Oregon.
5. Klamath Mountains—Extremely rugged, dissected, uplifted plateau composed predominantly of Paleozoic schist, flanked on the east by deformed Paleozoic sedimen-

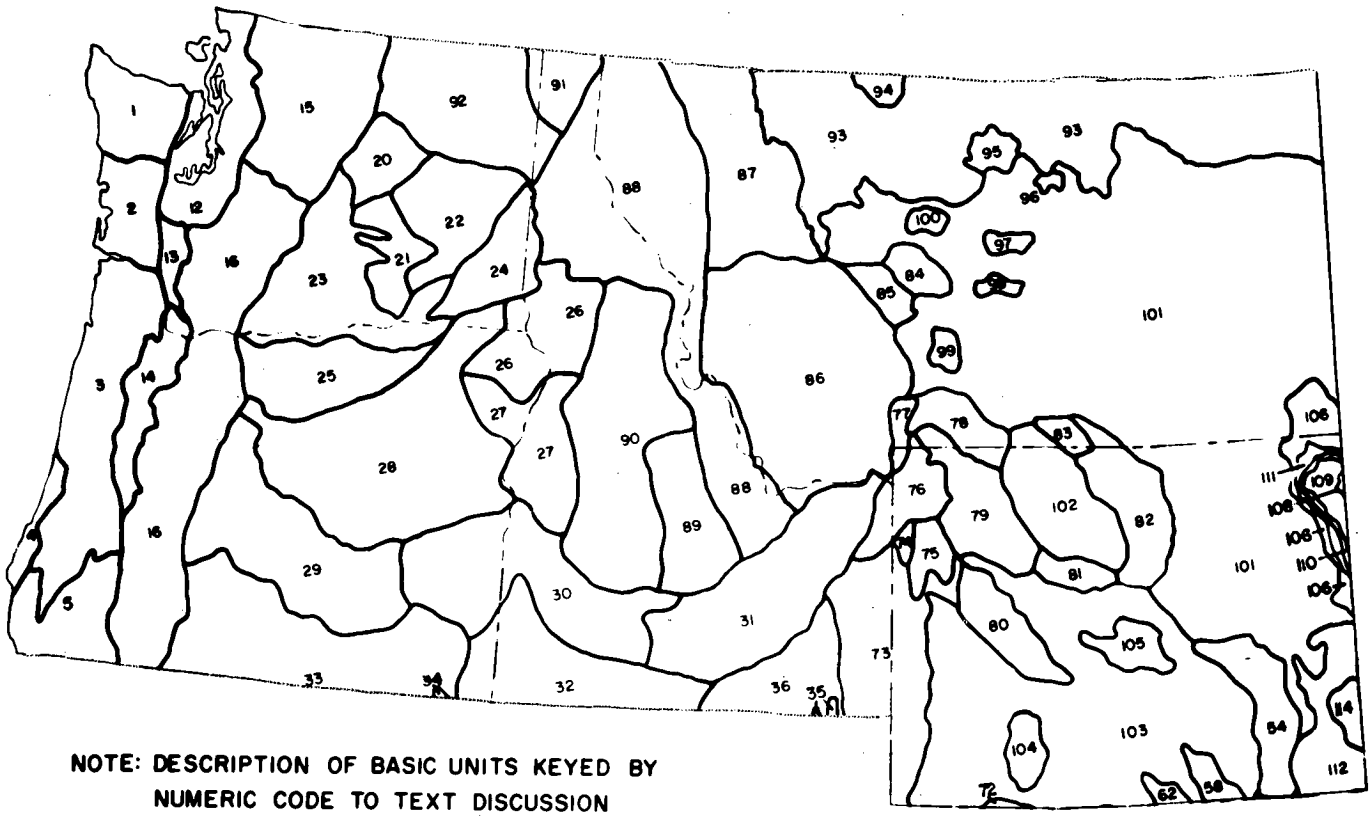


Figure 18. Recommended physiographic-highway engineering units. Map Sheet I: Northwest U.S.

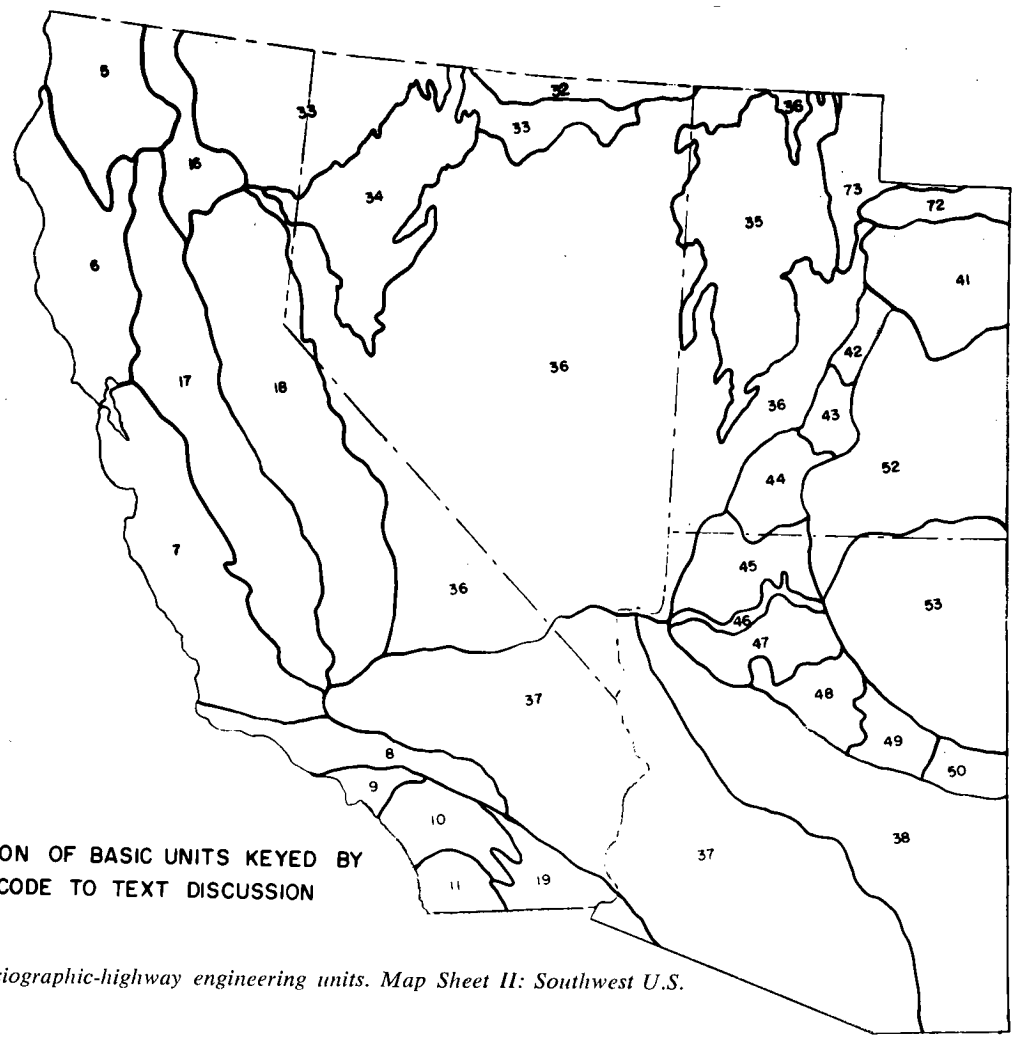
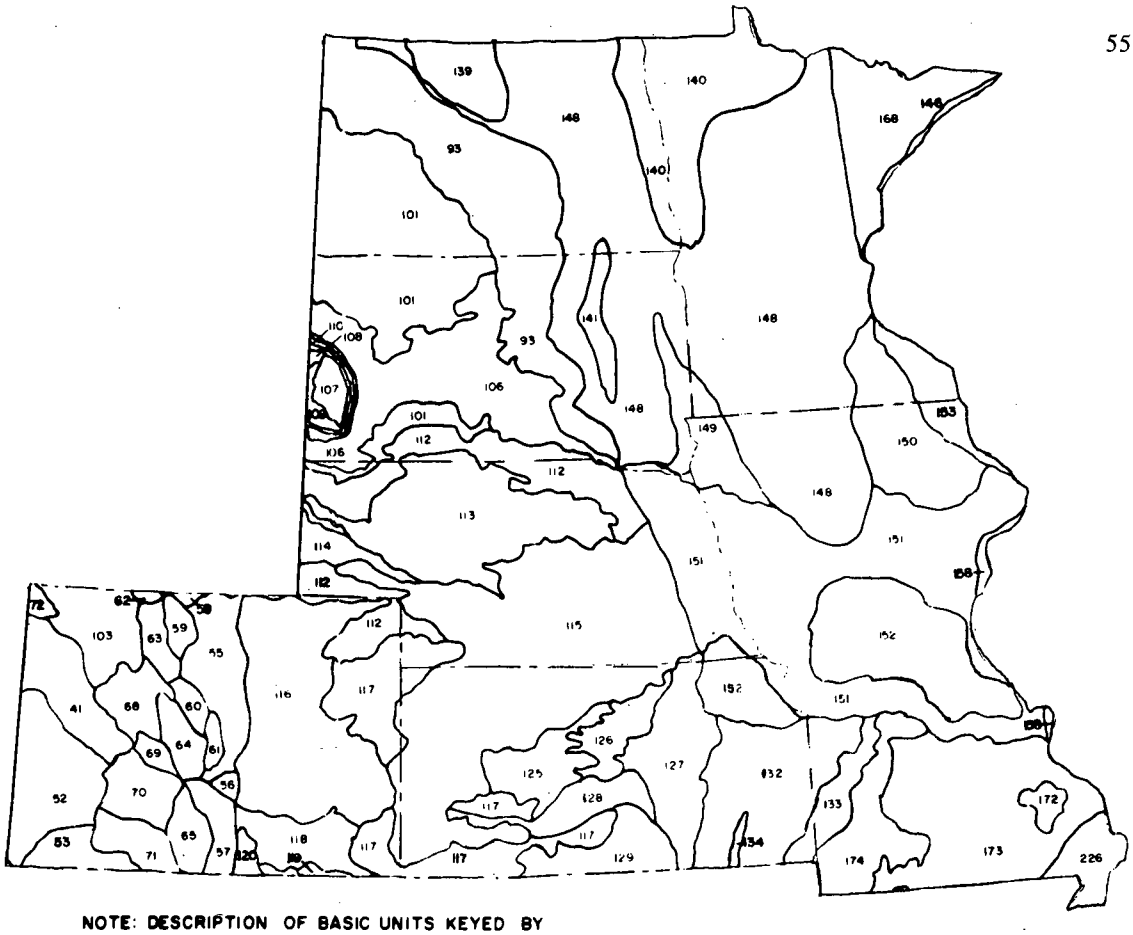
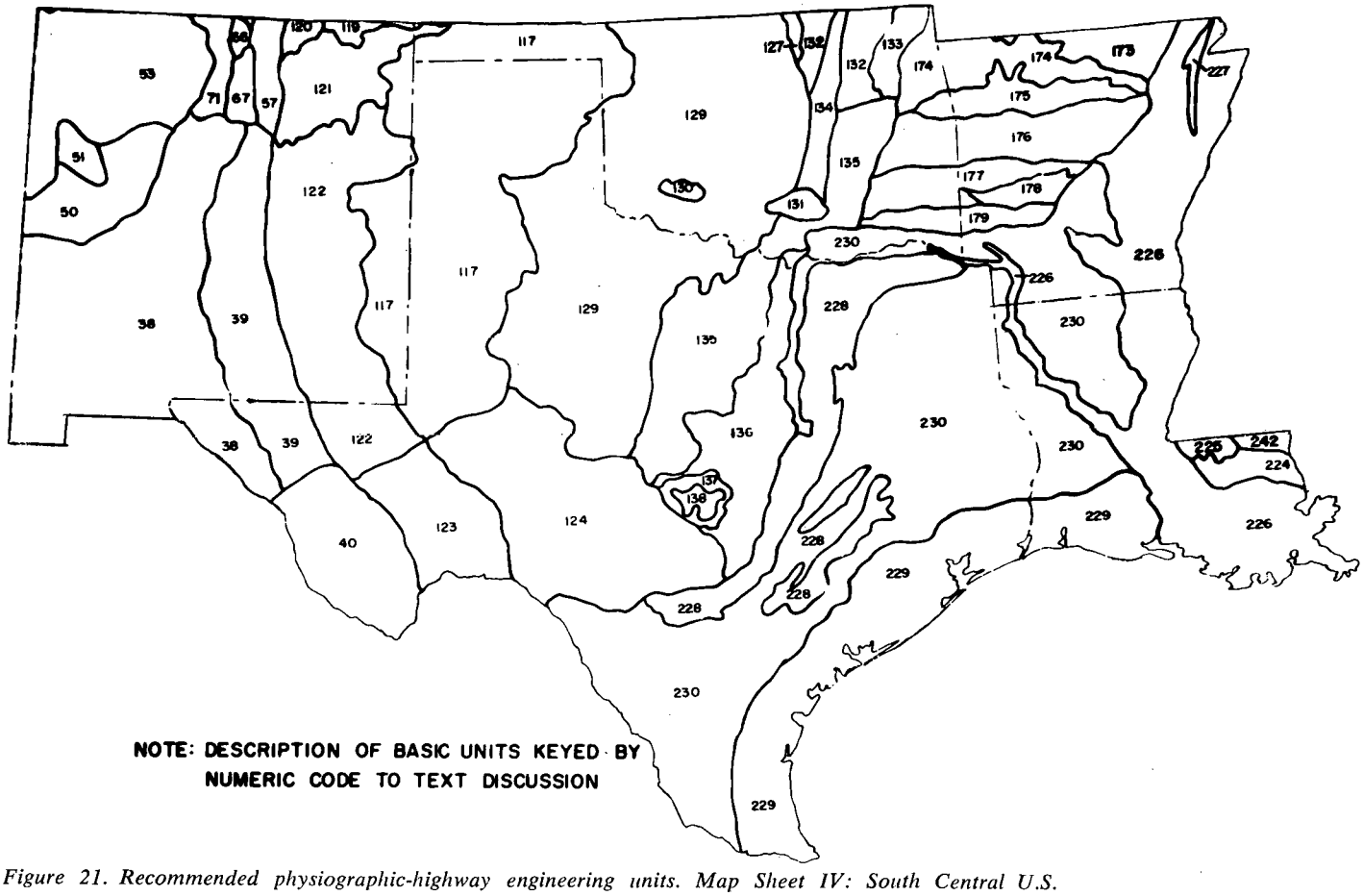


Figure 19. Recommended physiographic-highway engineering units. Map Sheet II: Southwest U.S.



NOTE: DESCRIPTION OF BASIC UNITS KEYED BY NUMERIC CODE TO TEXT DISCUSSION

Figure 20. Recommended physiographic-highway engineering units. Map Sheet III: North Central U.S.



NOTE: DESCRIPTION OF BASIC UNITS KEYED BY NUMERIC CODE TO TEXT DISCUSSION

Figure 21. Recommended physiographic-highway engineering units. Map Sheet IV: South Central U.S.

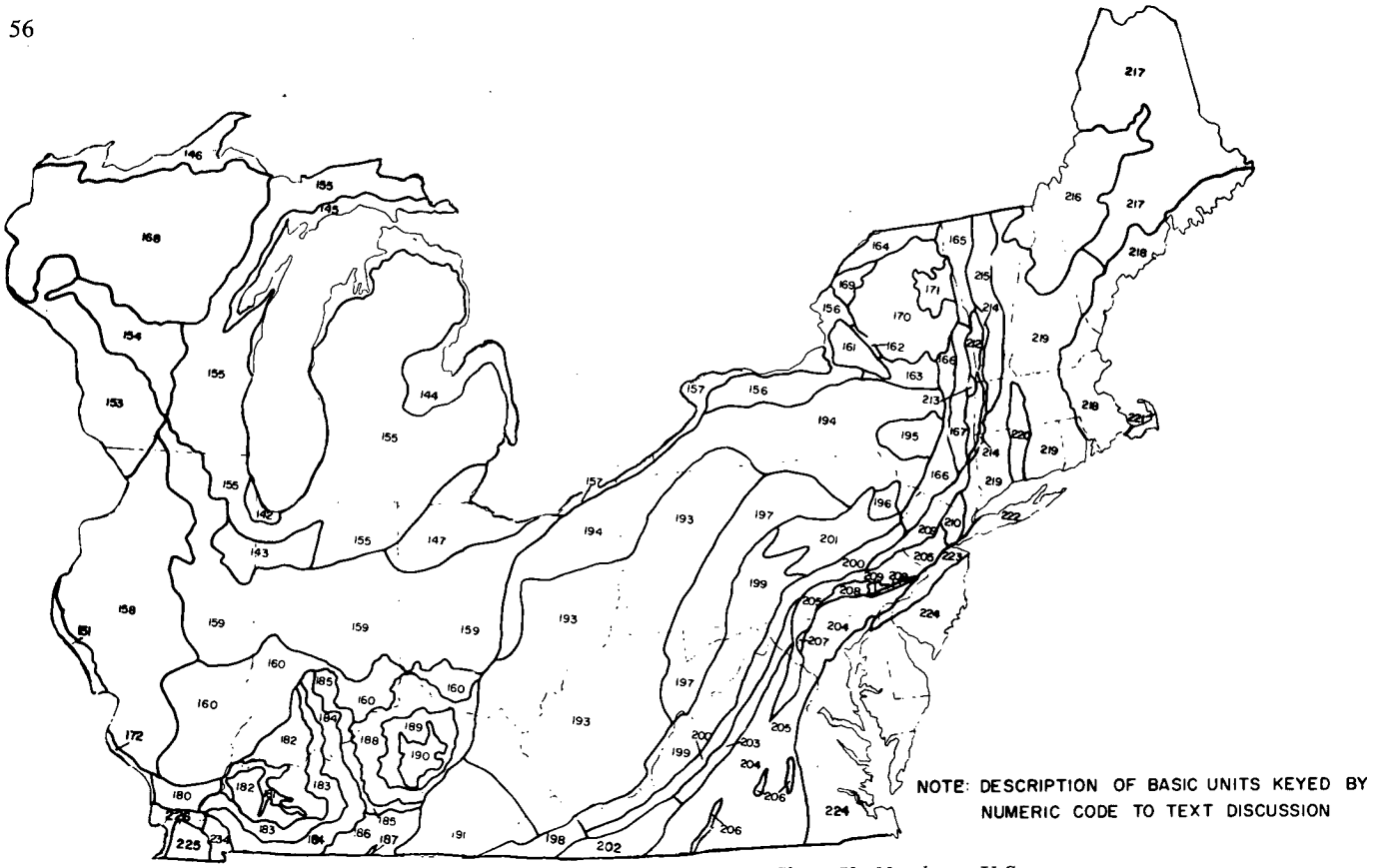


Figure 22. Recommended physiographic-highway engineering units. Map Sheet V: Northeast U.S.

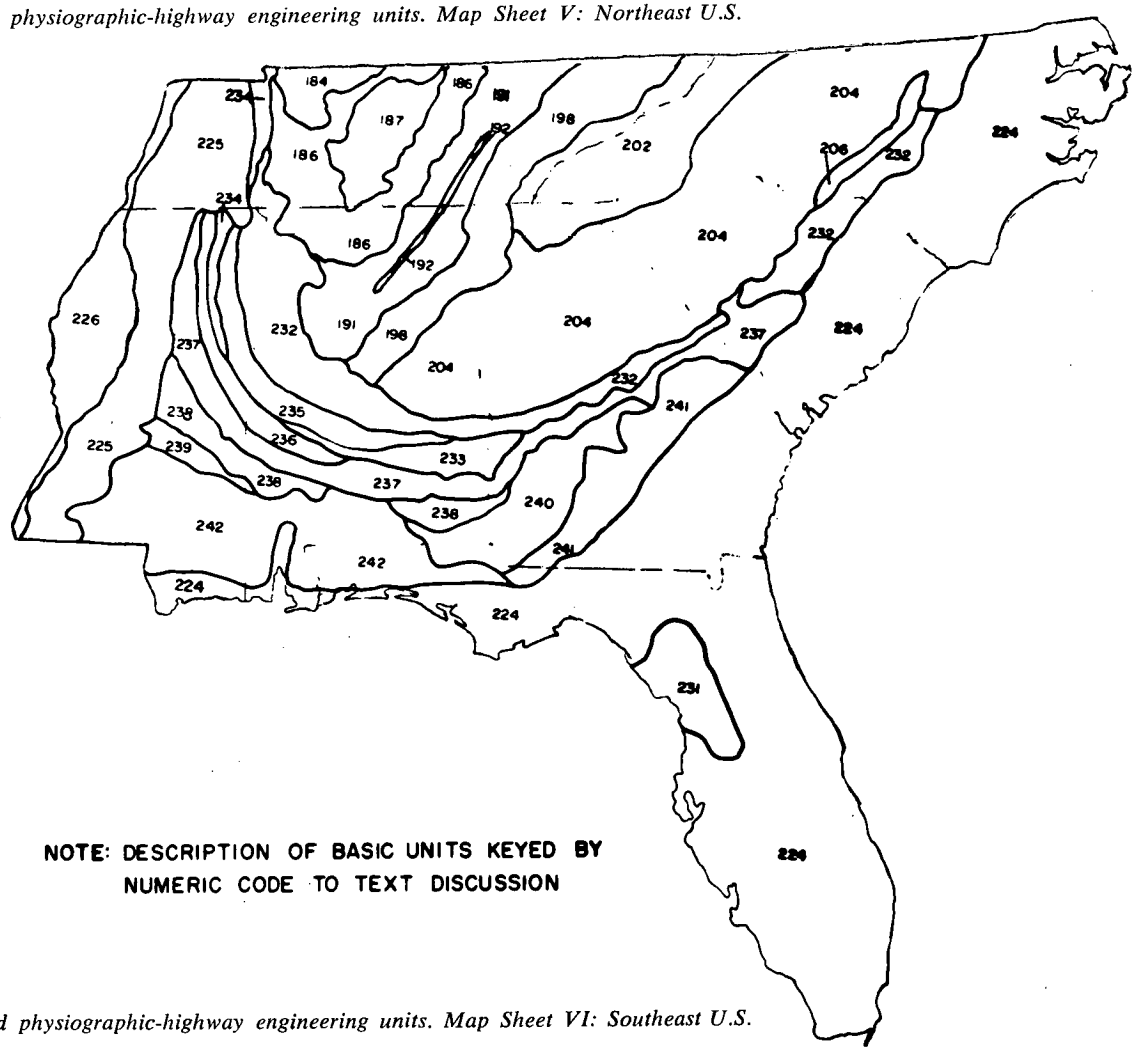


Figure 23. Recommended physiographic-highway engineering units. Map Sheet VI: Southeast U.S.

taries and volcanics and on the west by metamorphic rocks of Jurassic age.

6. Northern California Coast Range—Maturely dissected continuous highland area composed predominantly of Tertiary and Cretaceous sandstones, shales, and slates.

7. Southern California Coast Range—Similar to the Northern California Coast Range except faulting is more pronounced in the area, resulting in a more noticeable ridge and valley appearance. The predominant rock type is Tertiary sandstones and shales; but Jurassic granites, similar to those found in the Sierra Nevada, underlie a central portion of the area.

8. Traverse Ranges—Distinctive east-west trending ranges composed primarily of granitic batholithic cores.

9. Los Angeles Basin—Lowland basin area of accumulated marine and continental Tertiary sediments. The eastern portion is generally coarse alluvium from the San Gabriel and San Bernardino Mountains.

10. Faulted Peninsular Range—Highly faulted Jurassic granitic area with aggrading valleys being common.

11. Peninsular Ranges—Westward tilted fault block of Jurassic granite rising to elevations of 10,000 ft. A terraced lowland borders the Pacific Ocean and gradually merges into the broadly dissected granitic upland.

12. Puget Sound Basin—The glaciated area of the Woods-Lovell Puget Trough Section. Predominantly a mixture of morainic hill and outwash or terrace topography.

13. Basaltic Hills Area—The residual area that separates the glaciated Puget Sound Basin to the north from the predominantly alluviated Willamette Valley unit to south. Topography is generally a disconnected series of basaltic hills.

14. Willamette Valley—Fairly flat alluvial plain of the Willamette River and its tributaries overlying Tertiary and Quaternary sediments derived from sedimentary and volcanic rocks. Minor hilly areas, similar to those of the Basaltic Hills Area to the north, are located in the area.

15. Northern Cascade Mountains—Rugged, mountainous area composed of Paleozoic sedimentaries and metamorphics intruded by several granitic batholiths. Alpine glaciation is heavy in the area but relief is due primarily to constructional vulcanism rather than destructional processes.

16. Southern Cascade Mountains—Mountainous area similar in topography to the Northern Cascade Mountains but formed primarily from Tertiary basalts and andesites.

17. California Valley—An immense, flat valley filled with both Recent and Quaternary sediments in the form of alluvial fans, aprons, mudflows, and floodplains.

18. Sierra Nevada Mountains—Immense westward-tilting fault block with elevations ranging from 7,500 to 13,200 ft. The major bedrock type is a Jurassic granitic batholith. Paleozoic and Mesozoic metamorphic slates, phyllites, graywacke, and basalt flows are subordinate in the area. Alpine glaciation is intense.

19. Salton Trough—Large basin area formed in part by alluvial deposits of the Colorado River lying over valley outwash.

20. Waterville Plateau—Relatively flat-lying basalt flows cut by a number of coulee systems and in part glaciated.

21. Central Plains—Major downwarped area of basalts and related fluviatile lacustrine and aeolian sediments.

22. Channeled Scablands—Areas cut by vast meltwater deposits exposing bare tracts of Columbia River basalt. The uplands are covered by loess deposits.

23. Yakima Folds—Area of high, broad anticlinal ridges and synclinal valleys. Ridges are predominantly basaltic; valleys are predominantly granular to semi-granular sediments and volcanic ash.

24. Palouse Hills—Maturely dissected hills formed on deep loess.

25. North Central Oregon Plateau—Moderately dissected basaltic plateau area.

26. Tristate Uplands—Upwarped lava plateau in which dissection has produced 2,000- to 4,000-ft canyons.

27. Wallowa/Seven Devils—Complexly folded and faulted area overlain by basaltic flows of variable thickness.

28. Blue Mountains—Area characterized by mountain ranges and dissected plateaus. Bedrock type in the area is variable as granitic cores, similar to the Rockies, rise as "islands" above the basaltic lavas. Folded Paleozoic and early Mesozoic sedimentary strata also are located in the area.

29. Harney/High Desert—Flat area of recent lava flows, ash deposits, and cinder cones.

30. Malheur/Boise Basin—Moderately dissected areas of interbedded lava and lacustrine-fluviatile sediments.

31. Snake River Plain—Structurally depressed area covered with young (Snake River) lava flows which in turn are overlain by loessial deposits.

32. Owyhee Uplands—Structurally upwarped area of lavas more dissected and of older age than those to the north. Large areas are underlain by rhyolites and quartz latites.

33. Northwest Basaltic Basin Range Area—Somewhat large area comprised in part by plateau topography in the extreme west and basin-range fault controlled topography elsewhere. The major rock type in the area is basaltic lavas, similar to those to the north.

34. Lake Lahontan—One of two large basin areas in the Basin and Range Province characterized by the existence of old Pleistocene lakes. Mountain ranges divide this area into irregular straits where the lake deposits occur.

35. Lake Bonneville—Largest of the two areas noted in unit 34. Characteristics essentially identical to those of Lake Lahontan.

36. Great (Closed) Basins—Numerous mountain ranges of complex geologic age and type, and valleys existing in about equal proportions.

37. Sonoran Desert—Characteristics similar to those of Great Basin unit except that the general altitude is much lower and valleys and basins occur proportionally greater than the ranges.

38. Mexican Highland—Characteristics similar to those of the Great Basin unit except that geologic structure and rock type are more complex and most of the basins have external outlets (open basins).

39. Sacramento Highland—Faulted area producing cuesta or plateau-type topography on Permian limestones

and sandstones (predominantly). The area does not exhibit the typical basin-range topography common to other units of the Basin and Range Province; however, basins do occur in the area.

40. Great Bend Highland—Mountainous area comprised of Tertiary igneous (intrusive and extensive) and Cretaceous sedimentary (primarily limestone) mixed with numerous plains and aggradational basins.

41. Uinta Basin—Dissected plateaus existing in a structural basin filled with Tertiary shales and sandstones, with lesser amounts of limestone.

42. Northern Plateau and Valley Area—Exceptionally high north-trending plateau separated by scarps and fault-controlled valleys. The horizontal rock strata are primarily Tertiary massive sandstones and some shale, with minor Cretaceous and Jurassic areas present.

43. Central Lava Area—Similar to the Northern Plateau and Valley Area, except capped by Tertiary lavas and is not as dissected.

44. Colored Cliffs—Similar in characteristics to unit 42 except a series of east-west trending cliffs present a "stair step" topography toward the lower Grand Canyon Section (Faulted Plateau unit).

45. Faulted Plateaus—North of the Colorado River; parallel-type faults divide the area into a series of plateaus developed from young sedimentary rocks that overlook the Grand Canyon area to the south.

46. Grand Canyon—The majestic canyon area of the Grand Canyon Section.

47. San Francisco Plateau (Western Portion)—Homogeneous plateau area of slight relief on Permian limestones. Dissection and sapping have exposed sandstones and shales in some areas.

48. San Francisco Mountains—Mountainous areas of high relief formed by Tertiary and some Quaternary lava flows.

49. San Francisco Plateau (Eastern Portion)—Similar in characteristics to its western counterpart (unit 47).

50. Datil Volcanic Field—Area characterized by intense volcanic activity in the form of flows, volcanic necks and cones, primarily on the eastern side of the unit. The remaining area is plateau-like, derived from horizontal young sedimentary sandstones and shales.

51. Zuni Uplift—Mountainous uplifted area exposing Precambrian crystalline rocks in its core and typical gradational dip patterns of sedimentary rocks of Carboniferous to Cretaceous age which form cuestas and hogback topography.

52. Canyon Lands—Deeply incised canyon area cut in sandstones and shales of Cretaceous, Triassic, and Carboniferous age. A few Tertiary intrusives occur as isolated laccolithic domes in the region.

53. Navajo—Somewhat poorly defined area of scarped plateaus developed from rock type and ages somewhat similar to the Canyon Lands; however, the extreme dissection characteristic of that unit is lacking.

54. Laramie Range—Mountain range consisting of a central Precambrian igneous (predominantly granitic)-metamorphic complex core with steeply dipping, flanking Paleozoic-Mesozoic sedimentary strata (predominantly sandstone and shale) that often form homoclinal ridges.

55. Colorado Front Range—Similar to Laramie Range.

56. Wet Mountain Range—Similar to Laramie Range.

57. Sangre de Cristo Range—Similar to Laramie Range.

58. Medicine Bow Range—Similar to Laramie Range.

59. North and Middle Parks—Fairly level intermontane basin area covered by granular Tertiary material and glacial outwash. The Parks are separated by a chain of volcanoes known as Rabbit Ears Range. Middle Park has, in general, more relief than North Park.

60. Gore Range—Similar to Laramie Range.

61. South Park—Structural intermontane basin comprised predominantly of granitic rocks.

62. Sierra Madre Range—Similar to Laramie Range.

63. Park Range—Similar to Laramie Range.

64. Sawatch Range—Similar to Laramie Range.

65. Northern San Luis Valley—Relatively level basin area filled with deep deposits of glacial and alluvial outwash.

66. San Luis Hills—Northeast-southwest range of Tertiary basaltic mesas, lower in elevation and less dissected than the San Juan Mountains to the west.

67. Southern San Luis Valley—Topographic area somewhat similar to its northern counterpart. Sediments are primarily Tertiary in age.

68. Western Sedimentary Section—Characterized by uplift without folding, resulting in a submature dissected plateau of fairly horizontal Paleozoic-Mesozoic strata. The northern portions are lava-covered. In many respects, this unit is more like units found in the Colorado Plateau than the Rocky Mountains.

69. Elk Range—Similar to Laramie Range.

70. San Juan Plateau—Basaltic lava-covered area lacking the mature dissection characteristic of the San Juan Mountain unit.

71. San Juan Mountains—Maturely dissected plateau area of high relief carved from basaltic lavas and tuffs of Tertiary age.

72. Uinta Mountains—Similar to Laramie Range.

73. Wyomide/Wasatch Mountains—Mountainous areas characterized primarily by complex Paleozoic-Mesozoic sedimentary rocks strongly influenced by thrust faulting.

74. Teton Range—Similar to Laramie Range.

75. Jackson Hole—Downfaulted intermontane basin with Cretaceous-Tertiary sediments covered in the north by glacial till and outwash.

76. Yellowstone Lava Plateau—Plateau surface composed of late Tertiary rhyolitic flows.

77. Gallatin Range—Mountainous area composed predominantly of volcanic breccia.

78. Beartooth Mountains—Similar to Laramie Range.

79. Absaroka Mountains—Heavily dissected plateau composed of late Cretaceous and early Tertiary breccias and basalts.

80. Wind River Mountains—Similar to Laramie Range.

81. Owl Creek Range—Similar to Laramie Range.

82. Bighorn Mountains—Similar to Laramie Range.

83. Pryor Mountains—Small but noticeable uplift that is primarily a dissected plateau of strong limestone.

84. Little Belt Mountains—Similar to Laramie Range.

85. Big Belt Mountains—Similar to Laramie Range.

86. Southwest Montana—Structurally this area differs from its northern counterpart in that basin-range faults are more conspicuous, leaving a random display of ranges and intervening Tertiary basins. The bedrock type in the ranges varies greatly by age and type.

87. Northwest Montana—Like the Southwest Montana unit, the major characteristic is the presence of Tertiary basins. The western portion of this area is characterized by Precambrian igneous-metamorphic complex; the eastern portion contains Paleozoic strata. A large portion contains linear-type ranges due to eastward thrust faulting.

88. Bitterroot—Complex and diverse mountainous area generally comprised of Precambrian metamorphic rock complexes. The mountains in the area vary from sprawling to linear.

89. Salmon River Meta/Volcanic Area—Topography not different from the Idaho Batholith unit but carved primarily from Tertiary volcanics.

90. Salmon River (Idaho Batholith) Area—Fairly homogeneous area of sprawling mountains developed on Jurassic granite.

91. Selkirk Mountains—Rugged mountainous area developed primarily on Jurassic granite.

92. Okanogan Highlands—In general, not as rugged as the Selkirk unit. It has been covered by variable thicknesses of glacial drift overlying Jurassic granites (primarily).

93. Glaciated Missouri Plateau—Glaciated plateau area with smooth rolling hills and terraced valleys. Underlying bedrock is predominantly Tertiary and Cretaceous sandstones and shales which form the surficial rock of the unglaciated Missouri Plateau unit.

94. Sweetgrass Hills—Mountainous area formed by Precambrian intrusives now being exhumed.

95. Bear Paw Mountains—Mountains formed by extinct volcanic group.

96. Little Rocky Mountains—Similar to Laramie Range.

97. Judith Mountains—Mountain group of eroded laccoliths.

98. Big Snowy Mountains—Similar to Laramie Range.

99. Crazy Mountains—Mountains of volcanic origin.

100. Highwood Mountains—Maturely dissected mountains.

101. Missouri Plateau/Badland Complex—Vast plateau-like area with large badland topographic features. The majority of the area is underlain by Tertiary and Cretaceous clay shales, shales, and sandstones. Infrequently, lignite and limestones are found.

102. Bighorn Basin—Basin area filled by fluvial aggradation from surrounding mountain areas during the Great Plains Tertiary alluviation. Bedrock is predominantly sandstones and shales, with desert lands, badlands, and alkali flats being common.

103. Wyoming Basins—Comprised of several individual basin areas with characteristics identical to the Bighorn Basin unit.

104. Rock Springs/Leucite Hills—Much eroded domal area with steep hogbacks and cuestas of Cretaceous sandstone. The Leucite Hills area is a volcanic region north of the Rock Springs area.

105. Sweetwater (Granite) Mountains—Scattered granitic core islands surrounded by Tertiary sediments of the basins.

106. Pierre Hills—Rolling topography formed on Cretaceous shale.

107. Black Hills Central Crystalline Area—Precambrian granitic core of the exposed domal uplift which is the rugged and mountainous area associated with the Black Hills.

108. Black Hills Volcanic Mountains—Series of scattered Tertiary igneous laccoliths found in the northern portion of the Section.

109. Black Hills Limestone Plateau—Plateau area of Permian limestone that encircles (unsymmetrically) the older core of the dome.

110. Black Hills Red Valley—Lowland area derived from soft shaley Triassic rocks that encircle the Limestone Plateau unit.

111. Black Hills Hogback Ridges—Narrow cuesta scarp or hogback ridge developed on Cretaceous sandstone. This area gradually merges in all directions into the Missouri Plateau Badland Complex and Pierre Hills units.

112. Arikaree Outwash Area—Greatly eroded older Tertiary (Arikaree) outwash (unconsolidated).

113. Nebraska Sand Hills—Dunal type topography developed from sand deposits.

114. Goshen Hole Lowland—Denuded badland area developed on clays (Brule formation) of Tertiary age.

115. Loess Hills Region—Gently rolling surface developed on loess. The thickness of loess gradually changes from 100 ft in Nebraska to a thin veneer in Kansas where it eventually disappears.

116. Colorado Piedmont—Denuded basin area with gently undulating topography developed on Cretaceous clay shales. More highly tilted and dissected rocks occur along the Rocky Mountain foothills. Sandstones, limited limestones and chalks, and basalt flows occur occasionally.

117. Ogallala Outwash Area—In essence, this is the original Tertiary outwash mantle that veneered most of the Great Plains Province. Topography is essentially flat on the younger (relative to the older Arikaree outwash) unconsolidated sands, silts, and gravels.

118. Chautauqua Plateau—Stripped plain cut by canyons and surrounded by volcanic landforms. Rock types in the plateau are primarily Cretaceous sandstones and shales.

119. Raton Mesa—Somewhat indefinite area delineating lava-capped mesas underlying softer horizontal to slightly dipping sedimentary rocks. Dissection, which gradually increases westward, has removed portions of the volcanic cover leaving many gaps between the mesas.

120. Park Plateau—Heavily dissected highland developed on late Cretaceous to early Tertiary sandstones and shales.

121. Las Vegas Plateau—Similar in characteristics to the Chautauqua Plateau.

122. Pecos Valley—Eroded lowland area developed on

Permian and Triassic shales, sandstones, gypsum, and some limestone. Deeply filled with alluvium, in part.

123. Stockton Plateau—Predominantly flat plateau developed in Cretaceous limestone.

124. Edwards Plateau—Similar to the Stockton Plateau, which is separated from it by the Pecos Canyon.

125. Blue Hills—A flat, plateau-like upland surface with occasional buttes and mesas developed from Cretaceous limestone with interbedded shale.

126. Smoky Hills—North-south trending rolling hill area consisting of Cretaceous shales capped by resistant sandstones in places.

127. Flint Hills—Rolling hill area with escarpments developed on cherty limestones of Permian age.

128. Arkansas Lowland—Flat alluvial plain of the Arkansas River.

129. Permian Rolling Plains—Gently rolling topography developed on Permian shales with minor sandstone areas. Gypsum occurs along the western portion.

130. Wichita Mountains—Low mountainous area developed on Precambrian igneous rocks and flanking sandstone and limestone of early Paleozoic age.

131. Arbuckle Uplift—Plateau-like uplift of slight relief exposing a Precambrian core of granitic rocks flanked by early Paleozoic limestones and Pennsylvanian shales.

132. Limestone Scarped Plains—Parallel trending cuesta-type topography developed on Pennsylvanian limestone (scarps) and shales (lowlands).

133. Cherokee Lowland—Gently undulating lowland developed on Pennsylvanian shale.

134. Sandstone Hills—Rolling hills developed primarily from Pennsylvanian sandstones.

135. Sandstone Scarped Plains—The topographic counterpart of the Limestone Scarped Plains to the north. Sandstone of Pennsylvanian age replaces the limestone of the northern unit as the scarp maker.

136. Grand Prairie—Somewhat topographically diverse area varying from slightly rolling in the north to highly dissected in the central and southern portions. This unit is distinguished by Cretaceous limestones and shales that form most of the parent material of the area.

137. Llano Dissected Limestone Plateau—This area has, as its counterpart, the Black Hill Limestone Plateau unit. The topography is primarily a maturely dissected plateau-like area on Cambrian and Ordovician limestones.

138. Llano Uplift—Central basin (topographic) area carved from the old Precambrian granites, gneisses, and schists. This area is the counterpart of the Black Hills Central Crystalline Area.

139. Lake Souris—Lacustrine plain associated with high-water phases during Pleistocene glaciation. Lacustrine sediments are primarily very fine textured. Associated with the lacustrine deposits are irregular granular beach deposits marking former levels of the old lake.

140. Lake Agassiz—Similar in characteristics to Lake Souris unit.

141. Lake Dakota—Similar in characteristics to Lake Souris unit.

142. Lake Chicago—Similar in characteristics to Lake Souris unit.

143. Kankakee Sand Basin—Basin area filled by water-deposited sands associated with glacial drainage and ponding of several glacial drainage outlets in northern Indiana and Illinois.

144. Lake Saginaw—Similar in characteristics to Lake Souris unit.

145. Lake Green Bay—Similar in characteristics to Lake Souris unit.

146. Lake Duluth—Similar in characteristics to Lake Souris unit.

147. Lake Maumee—Similar in characteristics to Lake Souris unit.

148. Western Lakes Drift Area—Prominent to gently rolling morainic topography with poorly integrated drainage system developed on Cary and younger type of glacial drift.

149. Dissected Loess Covered Iowan Drift Area—One of two prongs of highly dissected Iowan drift that serve as the northerly extension of the Dissected Loessial and Till Plain Section. However, unlike the eastern extending prong, this area is covered by loessial deposits.

150. Dissected Iowan Drift Area—Similar in characteristics to the Dissected Loess Covered Iowan Drift unit except lacking the loess deposits common to that unit.

151. Dissected Loess Covered Kansan Drift Area—This highly dissected unit is similar in topography to the Dissected Loess Covered Iowan Drift unit except that the glacial till is Kansan in age. The depth of loess overlying the drift varies in thickness.

152. Dissected Kansas Drift Area—These dissected units occur where the loess gradually thins and disappears as the surficial covering over the Kansas Drift.

153. Loess Covered Southwest Cuestas—The loess-covered portion of the Driftless Section. Underlying the loess in cuesta fashion (facing the northeast) are Cambrian sandstones and shales, and Ordovician and Silurian carbonates as one proceeds to the southwest. Geologic structure is influenced by the Wisconsin dome.

154. Central Sand Plain—Relatively flat plain broken by occasional island-like buttes of standstone formed in part by glacial Lake Wisconsin and in part by the residual weathering of soft Cambrian sandstones and shales.

155. Eastern Lakes Drift Area—Similar to the Western Lakes Drift unit, except for bedrock in the form of slightly exposed cuesta areas.

156. Erie-Ontario Rolling Plains—Rolling plain area developed on glacial till. Much of the area is dominated by large drumlin topography.

157. Erie-Ontario Lacustrine Plain—Relatively flat-lying area; similar to the Lake Souris unit in that it was developed by a former level of the present Lake Erie and Ontario.

158. Loess Plains of Western Illinois—Loess plains of relatively small relief that veneer Illinoian drift and small areas of Tazewell and older Wisconsin drift.

159. Tipton Till Plain—Typical till plain area exhibiting flat to gently undulating terrain developed on Tazewell and older Wisconsin Drift.

160. Illinoian Drift Area—Drift plain developed on Illinoian drift. Relief is slightly more excessive than that

found in the Tipton Till Plain. The depth of the Illinoian drift gradually thins to the south so that the physiography may, in part, reflect the character of the underlying bedrock to a greater degree in these areas.

161. Tug Hill Cuesta—Glaciated cuesta area of moderate relief developed primarily by Ordovician sandstones and shales.

162. Black River Valley—Fairly small valley area underlain by Ordovician limestones and shales. The valley is surfaced by widespread lacustrine and deltaic deposits deposited during Pleistocene glaciation.

163. Mohawk Lowland—Glaciated plain of high relief due to the slightly dipping sedimentary strata that are continuous with the Appalachian Plateau. The major bedrock underlying the till is Ordovician shale and limestones, with subordinate Silurian sandstones locally overlying them.

164. St. Lawrence Lowland—Smooth glacial plain covered largely by marine clay deposits. Underlying bedrock is primarily early Paleozoic limestone and sandstone which do not affect relief in the drift.

165. Champlain Lowland—Rolling glaciated lowland, partially covered by marine clays. Bedrock similar in age and type to the St. Lawrence Lowland unit frequently protrudes through the glacial and marine deposits.

166. Glaciated Ridge and Valley—Topography and geomorphic history similar to the unglaciated portions of the Ridge and Valley Province to the south except that the area is covered by glacial deposits. The ridges are primarily Devonian sandstones; the valleys are primarily Ordovician shales and limestones.

167. Slate Hills Area—Glaciated area exhibiting rounded knoll or "mammillary" topography produced on glacial drift or slate of Ordovician age. The northern portion is covered by marine clays similar to those found in the St. Lawrence and Champlain Lowland units.

168. Superior Upland—Dissected, glaciated peneplain on Precambrian igneous and metamorphic rocks of complex structure. Glacial drift is similar in age to those found in the East and West Lakes units (Cary and Younger Wisconsin drift) and in many areas controls the physiographic details.

169. Northwest Lowland—Glaciated lowland area of the Adirondack Section which is due to the poor resistance of the underlying metasedimentary rocks of Precambrian age.

170. Central Highland Plateau—Uplifted and dissected glaciated peneplain formed on Precambrian granites and syenite gneisses.

171. High Peaks Region—Glaciated mountainous portion of the Adirondack Section formed by very resistant anorthosites of the Adirondack batholith.

172. St. Francis Mountains—Mountain area developed on the structural crest of the Ozark dome. Cambrian sandstones and carbonates, deposited before the uplift, are now in various stages of erosion, thereby exhuming the Precambrian granitic-type core rocks.

173. Salem Plateau—Dissected plateau formed primarily on Ordovician sedimentary rocks. Cherty carbonates predominate.

174. Springfield Plateau—Plateau area formed primarily on Mississippian sedimentary rocks. Similar to the Salem Plateau; carbonate rocks of cherty character are prevalent.

175. Boston Mountains—Maturely dissected plateau of Pennsylvanian sandstones and shales left as denudation remnants of the Ozark Domal Uplift.

176. Arkansas Valley—East/west trending structural trough formed by the synclinorium of Pennsylvanian sandstones and shales.

177. Fourche Kiamichi Belt—Rugged mountainous area formed on carboniferous sandstones and shales.

178. Novaculite Uplift—Ridge and basin topography. Arkansas novaculite forms the ridges; the basins are formed on Pennsylvanian shales.

179. Athens Piedmont Area—The geologic type and age of the bedrock are similar to that of the Fourche Kiamichi Belt unit. However, this unit is distinguished by the plateau-like nature of the bedrock.

180. Southern Illinois Loessial Area—Hilly loess area veneering Mississippian limestones, shales, and sandstones at the extreme southern tip of Illinois.

181. Island Hills—Characterized by widespread valley alluviation in which remnants of Pennsylvanian sandstones and shales protrude as hills above the flat alluvial terrain.

182. Indiana/Kentucky Coal Fields—Maturely dissected upland formed on Pennsylvanian sandstones, shales, and clays.

183. Mammoth Cave Plateau—Heavily dissected plateau. Topography somewhat similar to the Kentucky/Indiana Coal Fields unit; however, the bedrock is primarily complex Mississippian formations of shale, sandstone, and limestone.

184. Western Pennyroyal Limestone Plain—Plain formed primarily on Mississippian limestones. Karst topography is prevalent in much of the unit.

185. Knob Hill—Generally conical or hilly-type terrain. Bedrock is primarily Mississippian-Devonian in age. Massive shale with standstone or limestone caps comprise the higher hill portion; shale predominates in the lower hill area.

186. Kentucky/Tennessee Eastern Pennyroyal—Varies somewhat topographically, ranging from karst topography on limestone to undulating on shales. The bedrock age is Mississippian.

187. Nashville Basin—Fairly homogeneous topographic basin area of rolling plains and low relief developed on Ordovician limestones and some shale.

188. Outer Blue Grass—Gently rolling topography developed on alternating, thinly bedded shales and limestones of upper Ordovician age.

189. Eden Shale—Thoroughly dissected plateau developed on Ordovician shales.

190. Inner Blue Grass—Undulating topography formed primarily on Lower Ordovician limestones.

191. Cumberland Plateau—Submaturely dissected plateau, similar to but lacking the advance degree of dissection of the Kanawha unit. Characterized primarily by strong Pennsylvanian sandstones and, to a more limited extent, shales.

192. Sequatchie/Wills Creek Valley—Valleys formed

by the erosion of upper strata along the axis of the Sequatchie anticline exposing Ordovician limestones.

193. Kanawha—Maturely dissected plateau formed on predominantly horizontal to slightly dipping sandstones and shales of Pennsylvanian age and soft shales and limestones of Permian age. Toward the outer portions of the Section, Mississippian rocks occur.

194. New York Glaciated Plateau—Maturely dissected plateau of predominantly horizontal to slightly dipping shales, sandstones, and some limestones of Devonian (primarily) and Mississippian and Pennsylvanian (minor) age. However, the area has been significantly modified by late Wisconsin glaciation.

195. Catskill Mountains—Mountainous upland area of Devonian sandstones, conglomerates, and shales. The area has been glaciated, but physiographic significance is not as great as in the New York Glaciated Plateau unit.

196. Pocono Mountains—Dissected area of flat-lying resistant Mississippian sandstone.

197. Allegheny Mountains—Heavily dissected area that has lost the plateau-type characteristics common to the remainder of the Province. Mild folding is evident in portions. Primary ridge makers of the unit are sandstones of Pennsylvanian and Mississippian age, with Mississippian shales and minor limestone areas being brought to the surface on the slopes of some of the ridges.

198. Tennessee—Series of linear trending ridges and valleys developed primarily from faulting, folding, and subsequent erosion of the sedimentary rocks. Valleys are predominant over ridges. Lowlands are primarily developed on Cambrian and Ordovician carbonates and shales, with subordinate areas of Mississippian cherty limestone. Ridges are primarily sandstones of Devonian, Silurian, Mississippian, and Pennsylvanian age.

199. Parallel Folded Ridge and Valley Area—Series of linear parallel ridges and valleys developed primarily from folding and erosion of sedimentary rocks of an anticlinorium. Most of the valley areas are derived from Cambrian and Ordovician shales. Ridges are primarily Pennsylvanian, Mississippian, and Devonian sandstones.

200. Great Valley—Fairly large continuous lowland area developed on Cambrian and Ordovician limestone. This area is generally developed as the synclinorium portion of the combined anticlinorium-synclinorium combination comprising units 199 and 200.

201. Zig-Zag Mountains—Similar in bedrock type and age to the Parallel Folded Ridge and Valley Area. The major distinction is the northeast plunging characteristics of the folds, resulting in a series of zigzag ridges in lieu of the parallel ridges of the former unit.

202. Southern Blue Ridge—Belt of mountains that are remnants of a former highland antedating the lower peneplains on either side. Rock type and structure are complex, with Cambrian metasediments (quartzites, sandstone, graywacke, and slates) forming a western strip and the remaining bedrock consisting of Precambrian gneissic and granitic type. Very small areas of Ordovician limestone, called "coves" or "windows," are found.

203. Northern Blue Ridge—The northern counterpart of the Southern Blue Ridge area. Differences between this area and the latter are: rock type is primarily Precambrian gneissic and granitic; the area is not a belt of mountains, but rather a single subdued ridge; elevations, in general, are lower.

204. Piedmont Plateau—Broadly undulating to rolling topography created by peneplanation on complex metamorphic and plutonic rocks and structure. Precambrian and Cambrian granites, gneisses, and schist predominate in the bedrock.

205. Triassic Lowland—Fairly large basin lowland developed by weak Triassic sandstones and shales. Lowland topography is occasionally modified by igneous "trap ridges."

206. Triassic Lowland Inlier—Small scattered areas having characteristics identical to the Triassic Lowland unit.

207. Frederick Valley—Small lowland area merging in topographic features with the Triassic Lowland unit, but developed on Ordovician limestone.

208. Chester-Conestoga (Lancaster) Valleys—Similar in characteristics to the Frederick Valley unit.

209. Piedmont Crystalline Inlier—A small area separated from the Piedmont Plateau unit by the Chester-Conestoga Valleys. Its characteristics are identical to those of the Piedmont Plateau unit.

210. Glaciated Triassic Lowland—Bedrock characteristics similar to those of the Triassic Lowland unit, but topographic features modified by Wisconsin glacial drift.

211. Reading Prong—Southwestward extending crystalline prong of the New England Upland composed predominantly of low mountains developed on Precambrian crystalline rocks. The majority of the unit has been glaciated.

212. Taconic Mountains—Disordered glaciated mountain area developed primarily on metasedimentary schists, slates, and phyllites.

213. Rensselaer Plateau—Glaciated plateau surface with relief generally expressed by broad swells and long slopes. Rock type is primarily Cambrian quartzites.

214. Limestone Valley of Vermont—This lowland area is not as continuous as the diagram shows. The valley is underlain primarily by Cambrian limestones, dolomites, and marble.

215. Green Mountains—Structurally complex mountainous area of primarily Precambrian metamorphic rocks (schists, gneisses, and quartzites) that have been intruded by granite and basic igneous rocks. The area is glaciated.

216. White Mountains—Somewhat irregular and indefinitely delineated area containing several mountain groups. Continental as well as alpine glaciation covers bedrock of extreme complexity. Rock types are chiefly early Paleozoic and Precambrian igneous and metamorphic.

217. Northern New England Slate/Shale Area—A maturely dissected peneplained surface that slopes gradually to the southeast. Stoney granular Wisconsin drift overlies bedrock, generally, at very thin depths. The underlying bedrock is developed primarily upon sandstones, shales, and slates, interrupted by scattered granitic intrusions.

218. Seaboard Lowland—Seaboard sloping margin of

smoother topography (relative to the Northern and Southern Upland units), underlain by bedrock identical to that found in the adjacent upland units, and characterized, in part, by marine deposits thought to be a result of late Pleistocene submergence.

219. Southern New England Upland—Over-all topographic features are similar to the Northern Slate/Shale unit. However, this area is underlain primarily by an uplifted and tilted peneplain of granite and schist. Glacial drift characteristics are also similar to the Northern unit.

220. Connecticut Lowland—Extensively glaciated lowland area underlain by weak Triassic sandstones and shales containing numerous igneous (trap) ridges.

221. Cape Cod—Glaciated area exhibiting hummocky topography underlain by granular unconsolidated coastal plain deposits.

222. Long Island—Similar in general characteristics to the Cape Cod unit.

223. Raritan Lowland—Lowland area developed on weakly resistant Cretaceous clays (for the most part) of coastal plain origin.

224. Atlantic and East Gulf Terraced Coastal Plain—This rather extensive strip of land mass is primarily the terraced (outer) portion of the Coastal Plain. A series of terraces, primarily of granular (sandy) character, are evident throughout the area. Extreme outer portions of the unit frequently possess swampy areas due to relatively high-ground-water zone. In the northern portion, embayments almost reach the fall line border.

225. Mississippi Loessial Upland—Upland area mantled with loessial deposits gradually thinning and disappearing as one proceeds eastward.

226. Mississippi Alluvial Plain—Alluvial and deltaic plain area of the Mississippi and Red Rivers. Alluvial terraces are found inland and coastwise deltaic terraces are found along its seaward margin. The sediments generally are fine-textured.

227. Crowley's Ridge—Upland area existing within the confines of the Mississippi Alluvial Plain developed by loess deposits generally overlying granular coastal sediments.

228. Blackland Prairie—Lowland area of gently undulating character developed on upper Cretaceous limestones and marls of the Coastal Plain.

229. West Gulf Terraced Coastal Plain—This outer coastal plain area consists, in general, of marine clays of Quaternary age.

230. West Gulf Coastal Plain—A series of alternating inland facing cuesta and lowlands developed primarily on Tertiary coastal plain sediments.

231. Florida Lime Sink Region—This unit, although indefinite in delineation, represents the area where the Ocalla uplift significantly modifies the terrain in the Florida Section. Karst features are extensively developed and are generally overlain by recently emergent sandy terrace deposits of the coastal plain.

232. Sand and Fall Line Hills—The innermost zone or strip of belted areas quite pronounced in the East Gulf Coast Section and portion of the Sea Island Section of the Woods-Lovell classification. The unit is primarily a belt of maturely dissected hills produced on the oldest Cretaceous formations of the coastal plain. These deposits are primarily granular in nature.

233. Ripley Cuesta—This cuesta or escarpment-type area is an upland belt formed on the late Cretaceous sandy Ripley formation.

234. Pontotac Ridge—Essentially the same as the Ripley Cuesta unit, being separated geographically only by the thinning out of the Ripley formation in west-central Alabama.

235. Black Belt—A lowland developed on the weak Cretaceous Selma chalk.

236. Flatwoods—A lowland developed on Eocene clays (Midway). This formation is not as "clayey" as those to the north in the Black Belt unit; therefore, relief is slightly greater.

237. Red Hills—This upland or escarpment area is formed on the Eocene Wilcox formation (sandy). Dissection is variable, ranging from mature to undissected.

238. Buhrstone Cuesta—An upland cuesta-type belt developed on the very resistant Buhrstone formation of Tertiary age.

239. Jackson Prairie—This lowland belt is developed on clays of the Eocene Jackson formation.

240. Dougherty Plains—A relatively flat plain forming an upland developed on Tertiary limestones. Karst features are evident. The unit is similar to the Florida Lime-Sink unit.

241. Tifton Uplands—This upland area is submaturely dissected; topography is generally rolling-hill type. The parent materials of the coastal deposits are primarily Miocene in age.

242. Southern Pine Hills—This hilly area is the outermost of the cuesta (belted) coastal areas. Coastal sediments are primarily late Tertiary in age; the caprock of the area is generally the gravelly Pliocene Citronelle formations.

REFERENCES

Because of the wide range of subject areas considered in this report, the bibliography is divided into four groups, based on the major subjects discussed. In each group, references are arranged in alphabetical sequence. The numeric listing of the references is, however, continuous. Multiple listings are made of those references that are pertinent to more than one major subject area. The references cited for high volume change soils are from an unpublished report by H. P. Jensen.

REGIONAL PHYSIOGRAPHY (GEOMORPHOLOGY)

1. Agricultural and Industrial Development Board of Kentucky, *Land Areas of Kentucky and Their Potential for Use.* Frankfort (1953).
2. American Geological Institute, *Glossary of Geology and Related Sciences—With Supplement.* 2d ed. (Nov. 1960).
3. ATWOOD, W. W., *The Physiographic Provinces of North America.* Ginn and Co. (1940).
4. AVERITT, P., "Coal Reserves of the United States." Progress Rep., *U.S. Geol. Survey Bull. 1136* (1960).
5. BAKER, R. F., and CHIERUZZI, R., "Regional Concept of Landslide Occurrence." *HRB Bull. 216* (1959) pp. 1-16.
6. BECKMAN, H. C., and HINCHEZ, N. S., "The Large Springs of Missouri." *Missouri Geol. Survey and Water Resources,* Vol. 29, 2d series (1944).
7. BELCHER, D. J., GREGG, L. E., and WOODS, K. B., "The Formation, Distribution and Engineering Characteristics of Soils." *Joint Hwy. Res. Project Bull. No. 87,* Purdue Univ. (1943).
8. BLACK, R. F., "The Physical Geography of Wisconsin." Reprint from *Blue Book,* Dept. of Geology, Univ. of Wisc. (n.d.).
9. BRANCH, J. R., "The Geology of Flora Quadrangle." *North Dakota Geol. Survey Bull. No. 22* (1947).
10. BRYAN, K., "The Formation of Pediments." *Rep. 16th Internat. Geol. Cong.,* Part II (1935).
11. "Bulletin No. 17, Maryland Department of Geology, Mines, Water Resources." (1956).
12. "Bulletin No. 37, Minnesota Geologic Survey." *Minnesota Rocks and Waters,* Univ. of Minn. (by Sins, P. K.) (1963).
13. Bureau of Mines, Manufacturing and Agriculture, "Minerals of Arkansas." (1925).
14. CARTER, R. L., and GIDDENS, J., "Soils of Georgia—Their Formation, Classification and Management." *College Experiment Station Bull. No. 52* (Jan. 1953).
15. CHERRY, R. N., "Chemical Quality of Water of Georgia Streams—A Reconnaissance Study." *Geol. Survey Bull. No. 69, Georgia State Div. of Conservation* (1961).
16. Cornell University, "Soils and Soil Associations of New York." *Bull. No. 930* (rev. May 1961).
17. Corps of Engineers, "Engineering and Design, Pavement Design for Frost Conditions." *EM-1110-345-306* (1958).
18. FENNEMAN, N. M., *Physiography of Eastern United States.* McGraw-Hill (1938).
19. FENNEMAN, N. M., *Physiography of Western United States.* McGraw-Hill (1931).
20. FLINT, R. F., "Physical Divisions of South Dakota." *Professional Paper No. 262,* U.S. Geol. Survey (1962).
21. FLINT, R. F., "The Surficial Geology of the New Haven and Woodmont Quadrangles." *State Geol. and Natural Hist. Survey of Conn., Quadrangle Rep. No. 18* (1965).
22. Florida Agricultural Experiment Station, "Major Land Resources of Florida—General Soil Map of Florida." (May 1962).
23. FREEMAN, O. W., FORRESTER, J. D., and LUPHER, R. L., "Physiographic Divisions of the Columbia Intermontane Province." *Annals, Assn. of American Geographers* (1945).
24. Geological Society of America, "Glacial Map of North America." N.Y. (1945) (Scale 1:4,555,000).
25. Geological Survey of West Virginia, "Physiographic Divisions of West Virginia." (Map) (n.d.).
26. GIRRALNIK, D. B. (Ed.), *Webster's New World Dictionary and Student Handbook.* The Southwestern Co. (1966).
27. HAMMOND, E. H., "Classes of Land-Surface Form in the Forty-Eight States, U.S.A." Univ. of Wisc. (1963) (Scale 1:5,000,000).
28. HARDESTY, J. S., *Land Resource Areas of Maine.* U.S. Dept. of Agriculture (July 1957).
29. JOHN, R. H. (Ed.), "Geology of Southern California." *Bull. 170,* Div. of Mines, Dept. of Natural Resources, San Francisco (Sept. 1954).
30. JENKINS, D. S., BELCHER, D. J., GREGG, L. E., and WOODS, K. B., "The Origin, Distribution and Airphoto Identification of United States Soils." *Tech. Development Rep. No. 52,* Civil Aeronautics Admin. (1946).
31. JENKINS, O. P., "Geomorphic Map of California." *Bull. 188,* State of Calif., Dept. of Natural Resources (1938) Plate 2.
32. KARRAKER, P. E., "Soils of Kentucky." *Univ. of Ky. Agricultural Experiment Station Circ. 67* (June 1955).
33. Kentucky Geological Survey, "Physiographic Divisions of Kentucky." (Map) (n.d.).
34. LATIMER, W. J., "Soil Survey of Vermont—Reconnaissance." *No. 43, Series 1930,* U.S. Dept. of Agriculture.

35. LEIGHTON, M. M., EKBLAW, G. E., and HORBERG, I., *Illinois State Geological Survey Report of Investigations No. 129.* (n.d.).
36. LEIGHTON, M. M., and WILLMAN, H. B., "Loess Formations of the Mississippi Valley." *J. of Geol.,* Vol. 58 (1960).
37. LOBECK, A. K., "Geologic Map of the United States." Geographical Press, Columbia Univ. (1941; rev. 1948).
38. LOBECK, A. K., "Physiographic Diagram of North America." Geographical Press, C. S. Hammond & Co., N.J. (1950) (includes Physiographic Province diagram and accompanying text discussion).
39. MALLOTT, C. A., "Handbook of Indiana Geology—Part II." *Indiana Dept. Cons. Publ. No. 21* (1922).
40. MARBUT, C. F., *Atlas of American Agriculture, Part III, Soils of the United States.* U.S. Dept. of Agriculture (1935).
41. MCALPIN, G. W., and HOFMANN, W. P., "Soil Explorations." Sect. 10, *Highway Engineering Handbook* (ed. by K. B. Woods), McGraw-Hill (1960).
42. MILES, R. D., SCHOLER, C. F., SHURIG, D. G., WOODS, K. B., and YODER, E. J., "Regional Factors Influencing Highway Pavement Design and Performance." Interim Report, NCHRP Project 1-3(1) (Sept. 1965) unpublished.
43. Military Engineering Experimental Establishment, "Field Trials of a Terrain Classification System Organization and Methods." *MEXE No. 873,* England (Aug. 1965).
44. Military Engineering Experimental Establishment, "Report of the Working Group on Land Classification and Data Storage." *MEXE No. 940,* England (Feb. 1966).
45. MILLER, D. W., "Water Atlas of the United States." Water Info. Center, Port Washington, N.Y. (1962).
46. NEAL, J. T. (Ed.), "Geology, Mineralogy, and Hydrology of U.S. Playas." *Environmental Res. Paper No. 96,* Air Force Cambridge Res. Laboratories (Apr. 1965).
47. New York State Museum and Science Service, *Geology of New York—A Short Account.* Albany (1966).
48. North Carolina Agricultural Experiment Station, "The Soils of North Carolina—Their Formation, Identification and Use." *Tech. Bull. No. 115* (Dec. 1955).
49. Pennsylvania Topographic and Geologic Survey, "Physiographic Provinces of Pennsylvania." (Map) (n.d.).
50. PURI, H. S., and VERNOR, R. C., "Summary of the Geology of Florida and a Guidebook to the Classic Exposures." *Florida Geol. Survey Spec. Publ. No. 5* (1959).
51. RAISZ, E., *Landforms of the United States.* To accompany Atwood's *Physiographic Provinces of North America* (1957).
52. REED, R. D., *Geology of California.* American Assn. of Petroleum Geologists, Tulsa (1951).
53. Ross, F., "Geomorphic Map of Idaho and Adjacent Areas." *Idaho Bureau of Mines and Geology Bull. No. 15* (May 1958).
54. SCHOEWE, W. H., "The Geography of Kansas, Part 2—Physical Geography." *Kansas Academy of Science Trans.,* Vol. 52, No. 3 (1949).
55. SCHWARTZ, G. M., and PROKOPOVICH, N., "Map of Mineral Resources of Minnesota." Univ. of Minn., Minn. Geo. Survey (1956).
56. South Carolina Agricultural Experiment Station, "Soils of South Carolina." *Agronomy and Soils Res. Series 23,* Clemson (Feb. 1960).
57. "South Dakota State Geologist Report of Investigation—No. 93." *Geology of Selected Highway Strips in South Dakota* (by Cox, E. J.) (1962).
58. SPARKS, B., *Geomorphology.* Longmans, Green & Co., London (1960).
59. STEVANT, D. P., "Glacial Geology of Vermont." *Vermont Geol. Survey Bull. No. 19* (1961).
60. STORIE, R. E., and HARRADINE, F., "Soils of California." *Soil Science,* Vol. 85, No. 4 (Apr. 1958).
61. STOSE, G. W. (Ed.), "Preliminary Geologic Map of Washington." State of Wash., Div. of Geology, Pullman (1936).
62. SWANSON, C. L. W., SHEARIN, A. E., and BOURBEAU, G. A., "Characteristics of Some Brown Podzolic Profiles in the Central Lowland of Connecticut and Massachusetts." *Proc. Soil Science Society of Amer.,* Vol. 16, No. 2 (Apr. 1952).
63. Texas Agricultural Experiment Station, "Land Resources of Texas." *No. L-400* (Map) (n.d.).
64. THORNBURY, W. D., *Principles of Geomorphology.* Wiley (1954).
65. THORNBURY, W. D., *Regional Geomorphology of the United States.* Wiley (1965).
66. TOLMAN, C. F., *Ground Water.* McGraw-Hill (1937).
67. U.S. Department of Agriculture, "Climate and Men." *Yearbook of Agriculture* (1940).
68. U.S. Department of Agriculture, Soil Conservation Service, "Descriptions of Soil Resource Areas in Connecticut." (Sept. 1967).
69. U.S. Department of Agriculture, Soil Conservation Service, "Land Resource Areas of Colorado." In cooperation with Colorado Agricultural Experiment Station, *General Series No. 727* (Apr. 1960).
70. U.S. Department of Agriculture, Soil Conservation Service, "Soils of Illinois." In cooperation with Illinois Agriculture Experiment Station, *Bull. No. 725* (July 1967).
71. U.S. Department of Agriculture, Soil Conservation Service, "Soil Association Map, State of Arkansas." In cooperation with Univ. of Ark. Experimental Station (Apr. 1959).
72. U.S. Department of Agriculture, Soil Conservation Service, "Major Land-Resource Areas—Arizona." (Sept. 1964).
73. U.S. Department of the Interior, "Physical Divisions of the United States." Prepared by N. M. Fenneman in cooperation with Physiographic Comm. of the Geol. Survey (1946) (Map).

74. U.S. Geological Survey and American Association of Petroleum Geologists, "Tectonic Map of the U.S." (1962) (Scale 1:2,500,000).
75. U.S. Geological Survey, "Geologic Map of the United States." (1932) (Scale 1:2,500,000).
76. U.S. Geological Survey, "Relief Map of the United States." Dept. of the Interior (n.d.) (Scale 1:7,000,000).
77. Virginia Polytechnic Institute, "Soils of Virginia." *VPI Bull. 203,* Eng. Extension Series (rev. Mar. 1968).
78. Washington State Division of Mines and Geology, "Mineral and Water Resources of Washington." *Bull. No. 37* (1960).
79. WIDMER, K., "The Geology and Geography of New Jersey." *New Jersey Hist. Series,* Vol. 19 (1964).
80. WILSON, E. D., "A Resume of the Geology of Arizona." *Ariz. Bureau of Mines Bull. No. 171* (1962).
81. WINSOR, J. H., and BAILEY, H. H., "A Key to Kentucky Soils." Univ. of Ky. Agricultural Experiment Station (Map) (1956).
82. WOODS, K. B., and LOVELL, C. W., JR., "Distribution of Soils in North America." Sect. 9, *Highway Engineering Handbook,* McGraw-Hill (1960).
83. WOODS, K. B., and LOVELL, C. W., JR., "Physiographic Regions of North America Modified for Engineering Purposes." (1958) (Scale 1:2,000,000).
84. WRIGHT, H. E., FREY, D. G., ET AL., *The Quaternary of the United States.* Princeton Univ. Press (1965).

AGGREGATES

85. Alabama: NCHRP State Highway Materials Questionnaire Response (1967).
86. Arizona: NCHRP State Highway Materials Questionnaire Response (1967).
87. Arkansas: NCHRP State Highway Materials Questionnaire Response (1967).
88. AUGENBAUGH, N. B., JOHNSON, R. B., and YODER, E. J., "Degradation of Base Course Aggregates During Compaction," NCHRP Report, School of Civil Engineering, Purdue University (May 1963).
89. BALMER, G. G., and COLLEY, B. E., "Laboratory Studies of the Skid Resistance of Concrete." *Report D-109,* Portland Cement Assn. (n.d.).
90. BLOOM, M. J., "An Analysis of the Highway Frost Problem in the North Central United States." M.S. Thesis, Purdue Univ. (Aug. 1965).
91. BUGG, S. L., and FIRMAGE, D. A., "Properties of Plain and Reinforced Limerock Concrete." *Proc. HRB,* Vol. 30 (1950) pp. 217-231.
92. California: NCHRP State Highway Materials Questionnaire Response (1967).
93. CALVIN, S., "The Buchanan Gravels: An Interglacial Deposit in Buchanan County, Iowa." *American Geologist,* Vol. 17 (1896).
94. COLLETT, F. R., WARNICK, C. C., and HOFFMAN, D. S., "Prevention of Degradation of Basalt Aggregates Used in Highway Base Construction." *HRB Bull. 344* (1962) pp. 1-7.
95. Colorado: NCHRP State Highway Materials Questionnaire Response (1967).
96. Connecticut: NCHRP State Highway Materials Questionnaire Response (1967).
97. DAY, H. L., "A Progress Report on Studies of Degrading Basalt Aggregate Bases." *HRB Bull. 344* (1962) pp. 8-16.
98. Delaware: NCHRP State Highway Materials Questionnaire Response (1967).
99. FENNEMAN, N. M., *Physiography of Eastern United States."* McGraw-Hill (1938).
100. FENNEMAN, N. M., *Physiography of Western United States.* McGraw-Hill (1931).
101. Florida: NCHRP State Highway Materials Questionnaire Response (1967).
102. FRENCH, R. R., and CARR, D. C., "Geologic Factors Affecting the Exploration for Mineral Aggregates in the Indianapolis Area." *Proc. 18th Ann. Highway Geology Symposium,* Purdue Univ. (Apr. 1967).
103. FRENCH, R. R., "Crushed Stone Resources of the Devonian and Silurian Carbonate Rocks of Indiana." *Dept. of Natural Resources Geol. Survey Bull. No. 37* (1967).
104. FRENCH, R. R., "Indiana's Crushed Stone Industry: 1947-1965." *Indiana Business Review,* Vol. 42 (1967).
105. Georgia: NCHRP State Highway Materials Questionnaire Response (1967).
106. GIBSON, W. E., "A Study of Map Cracking in Sand-Gravel Pavements." *Proc. HRB,* Vol. 18, Part I (1938) pp. 227-237.
107. GILLSON, J. L., ET AL., "The Carbonate Rocks." Chap. 8, *Industrial Minerals and Rocks,* Amer. Inst. of Mining, Metallurgical and Petroleum Engineers, N.Y. (1960).
108. GOETZ, W. H., and WOOD, L. E., "Bituminous Materials and Mixtures." Sect. 18, *Highway Engineering Handbook,* McGraw-Hill (1960).
109. GOODWIN, W. A., "Aggregate Characteristics Influencing Skid Resistance." National Limestone Inst., *Limestone* (Fall 1968).
110. GRAY, J. E., and RENNINGER, F. A., "The Skid-Resistant Properties of Carbonate Aggregates." *Hwy. Res. Rec. No. 120* (1966) pp. 18-34.
111. GREGG, L. E., and HAVENS, J. H., "Application of Geology to Highway Engineering in Kentucky." Presented at Fourth Ann. Symposium on Geology as Applied to Highway Eng., Morris Harvey College, Charleston, W. Va. (1953).
112. HADLEY, D. W., "Alkali Reactivity of Carbonate Rocks." *Res. Dept. Bull. 139,* Portland Cement Assn. (1961).
113. HANSEN, W. C., "Attack on Portland Cement Concrete by Alkali Soils and Waters—A Critical Review." *Hwy. Res. Record No. 113* (1966) pp. 1-32.
114. HAVENS, J. H., and WILLIAMS, E. G., "A Study of the Properties and Performance of Kentucky (Natural Sandstone) Rock Asphalt." Ky. Dept. of Highways, Highway Res. Lab., Univ. of Ky. (1956).

115. Highway Research Board, "Report of Committee on Warping of Concrete Pavements." *Proc. HRB,* Vol. 25 (1945) pp. 199-250.
116. HVEEM, F. N., and SMITH, T. W., "A Durability Test for Aggregates." *Hwy. Res. Record No. 62* (1964) pp. 119-136.
117. Idaho: NCHRP State Highway Materials Questionnaire Response (1967).
118. Illinois: NCHRP State Highway Materials Questionnaire Response (1967).
119. Indiana Department of Conservation, "Generalized Geologic Map of Indiana." *Survey Rep. of Progress No. 7* (1956).
120. Indiana: NCHRP State Highway Materials Questionnaire Response (1967).
121. Iowa: NCHRP State Highway Materials Questionnaire Response (1967).
122. Iowa State Highway Commission, "Iowa—An Engineering Report on Soils, Geology, Terrain and Climate." (1959).
123. JENKINS, D. S., BELCHER, D. J., GREGG, L. E., and WOODS, K. B., "The Origin, Distribution and Airphoto Identification of United States Soils." *Tech. Development Rep. No. 52,* Civil Aeronautics Admin. (1946).
124. JONES, T. R., JR., and HIRSCH, T. J., "Creep and Shrinkage in Lightweight Concrete." *Proc. HRB,* Vol. 38 (1959) pp. 74-89.
125. Kansas: NCHRP State Highway Materials Questionnaire Response (1967).
126. Kentucky: NCHRP State Highway Materials Questionnaire Response (1967).
127. Kentucky Rock Asphalt Institute, "Kentucky Rock Asphalt—Specifications and Designs." (Apr. 1937).
128. KLINEFELTER, T. A., "Lightweight Aggregates." Chap. 22, *Industrial Minerals and Rocks,* Amer. Inst. of Mining, Metallurgical and Petroleum Engineers, N.Y. (1960).
129. LANDGREN, R., and SWEET, H. S., "Investigation of Durability of Wyoming Aggregates." *Proc. HRB,* Vol. 31 (1952) pp. 202-217.
130. LEIGHTON, M. M., "The Road Building Sands and Gravels of Washington." *Bull. No. 22,* Wash. Geol. Survey, Olympia (1919).
131. LENHART, W. B., "Sand and Gravel." Chap. 41, *Industrial Minerals and Rocks,* Amer. Inst. of Mining, Metallurgical and Petroleum Engineers, N.Y. (1960).
132. LEWIS, D. W., "Research on Concrete Aggregates." *Eng. Reprint No. 61,* Purdue Univ. Eng. Experiment Station (1950).
133. Louisiana Geological Society, "Generalized Map of Louisiana Showing Regions of Gravel Exposures." *La. Geol. Bull. No. 19* (n.d.).
134. Louisiana: NCHRP State Highway Materials Questionnaire Response (1967).
135. LOSSING, F. A., "Sulphate Attack on Concrete Pavements in Mississippi." *Hwy. Res. Record No. 113* (1966) pp. 88-107.
136. Maine: NCHRP State Highway Materials Questionnaire Response (1967).
137. MARBUT, C. F., *Atlas of American Agriculture, Part III, Soils of the United States.* U.S. Dept. of Agriculture (1935).
138. Maryland: NCHRP State Highway Materials Questionnaire Response (1967).
139. Massachusetts: NCHRP State Highway Materials Questionnaire Response (1967).
140. MAYTIN, I. L., and GILKESON, R., "Soils of Walla Walla County." *Engineering Soils Manual, Bull. 257,* Washington State Univ., Pullman (1962).
141. MAYTIN, I. L., and STAN, W. A., "Soils of Yakima County." *Eng. Soils Manual, Bull. 249,* Washington State Univ., Pullman (1960).
142. MCLAUGHLIN, J. F., WOODS, K. B., MIELENZ, R. C., and ROCKWOOD, N. C., "Distribution, Production, and Engineering Characteristics of Aggregates." Sect. 16, *Highway Engineering Handbook,* McGraw-Hill (1960).
143. Michigan: NCHRP State Highway Materials Questionnaire Response (1967).
144. MILES, R. D., SCHOLER, C. F., SHURIG, D. G., WOODS, K. B., and YODER, E. J., "Regional Factors Influencing Highway Pavement Design and Performance." Interim Report, NCHRP Project 1-3(1) (Sept. 1965) unpublished.
145. Mississippi: NCHRP State Highway Materials Questionnaire Response (1967).
146. Missouri: NCHRP State Highway Materials Questionnaire Response (1967).
147. MOAVENZADEH, F., and GOETZ, W. H., "Aggregate Degradation in Bituminous Mixtures." *Hwy. Res. Record No. 22* (1963) pp. 106-137.
148. Montana: NCHRP State Highway Materials Questionnaire Response (1967).
149. MOULTROP, K., "Rhode Island Aggregate Survey." Div. of Eng. Res. and Development, Univ. of R.I. (June 1964).
150. Nebraska: NCHRP State Highway Materials Questionnaire Response (1967).
151. Nevada: NCHRP State Highway Materials Questionnaire Response (1967).
152. NEVILLE, A. M., *Properties of Concrete.* Wiley (1963).
153. New Hampshire: NCHRP State Highway Materials Questionnaire Response (1967).
154. New Jersey: NCHRP State Highway Materials Questionnaire Response (1967).
155. New Mexico: NCHRP State Highway Materials Questionnaire Response (1967).
156. New York: NCHRP State Highway Materials Questionnaire Response (1967).
157. New York State Museum and Science Service, *Geology of New York—A Short Account.* Albany (1966).
158. NEWLON, H. H., and SHERWOOD, W. C., "An Occurrence of Alkali-Reactive Carbonate Rock in Virginia." *HRB Bull. 355* (1962) pp. 27-44.
159. North Carolina: NCHRP State Highway Materials Questionnaire Response (1967).

160. North Dakota: NCHRP State Highway Materials Questionnaire Response (1967).
161. Ohio: NCHRP State Highway Materials Questionnaire Response (1967).
162. Oklahoma: NCHRP State Highway Materials Questionnaire Response (1967).
163. Ontario Department of Highways, "Research on Skid Resistance." *Rep. No. 114,* Ontario, Canada (1966).
164. ORCHARD, D. F., *Concrete Technology—Volume 2.* Wiley (1962).
165. Oregon: NCHRP State Highway Materials Questionnaire Response (1967).
166. OSBORNE, A., "Frost Barrier for Highway and Airfield Regional Studies." Part II, Dow Chemical Co. (1967).
167. Pennsylvania: NCHRP State Highway Materials Questionnaire Response (1967).
168. BERGENDOFF, R. N., "Research Studies in Connection With Design Features of the Florida Turnpike." *Proc. HRB,* Vol. 37 (1958) pp. 194-200.
169. Pit and Quarry Publications, *Pit and Quarry Directory of the Non-Metallic Minerals Industries.* Chicago (1965).
170. Portland Cement Association, *Aggregates for Concrete.* (1962).
171. RHOADES, R., and MIELENZ, R. C., "Petrographic and Mineralogic Characteristics of Aggregates." *ASTM Spec. Tech. Publ. No. 83* (1948).
172. Rigid Pavement Laboratory, Corps of Engineers, "Report of Aggregate Availability in the Continental United States." Ohio River Div., Corps of Engineers, Mariemont, Ohio (Dec. 1952).
173. SCHUSTER, R. L., and MCLAUGHLIN, J. F., "A Study of Chert and Shale Gravel in Concrete." *HRB Bull. 305* (1961) pp. 51-73.
174. SCHWARTZ, G. M., and PROKOPOVICH, N., "Map of Mineral Resources of Minnesota." Univ. of Minn., Minn. Geol. Survey (1956).
175. SEVERINGHAUSE, N., "Crushed Stone." Chap. 13, *Industrial Minerals and Rocks,* Amer. Inst. of Mining, Metallurgical and Petroleum Engineers, N.Y. (1960).
176. SHUPE, J. W., and GOETZ, W. H., "A Laboratory Investigation of Pavement Slipperiness." *Purdue Univ. Eng. Reprint No. CE 174* (June 1960).
177. SHUPE, J. W., "Pavement Slipperiness." Sect. 20, *Highway Engineering Handbook,* McGraw-Hill (1960).
178. STEPHENS, J. E., and GOETZ, W. H., "Designing Fine Bituminous Mixtures for High Skid Resistance." *Purdue Univ. Eng. Reprint CE 181* (Jan. 1961).
179. STOSE, G. W. (Ed.), "Preliminary Geologic Map of Washington." Wash. State Univ., Div. of Geology, Pullman (1936).
180. South Dakota: NCHRP State Highway Materials Questionnaire Response (1967).
181. SWINEFORD, A., "Cemented Sandstone of the Dakota and Kiowa Formations in Kansas." *State Geol. Survey of Kansas, Bull. 70,* Part 4, Lawrence (1947).
182. Tennessee: NCHRP State Highway Materials Questionnaire Response (1967).
183. Texas: NCHRP State Highway Materials Questionnaire Response (1967).
184. THORNBURY, W. D., *Regional Geomorphology of the United States.* Wiley (1965).
185. TOLMAN, C. F., *Ground Water.* McGraw-Hill (1937).
186. TREMPER, B., "Freeze-Thaw Resistance of Concrete as Affected by Alkalies in Cement." *Proc. ASTM* (1951).
187. U.S. Department of Commerce, Bureau of Public Roads, "Results of Physical Tests of Road Building Aggregate." (1953).
188. U.S. Department of the Interior, "Metals and Minerals (Except Fuels)." Vol. 1, *1964 Minerals Yearbook* (1965).
189. U.S. Department of the Interior, "Area Reports: Domestic." Vol. 3, *1964 Minerals Yearbook* (1965).
190. U.S. Geological Survey, "Geologic Map of the United States." (1932) (Scale 1:2,500,000).
191. Utah: NCHRP State Highway Materials Questionnaire Response (1967).
192. Vermont: NCHRP State Highway Materials Questionnaire Response (1967).
193. Virginia: NCHRP State Highway Materials Questionnaire Response (1967).
194. Washington: NCHRP State Highway Materials Questionnaire Response (1967).
195. Washington State Division of Mines and Geology, "Sand and Gravel." *Bull. No. 37,* Part I, Plate 33 (Sand and Gravel Pits of Washington); Plate 34 (Map Showing Principal Areas of Sand and Gravel) (n.d.).
196. West Virginia: NCHRP State Highway Materials Questionnaire Response (1967).
197. Wisconsin: NCHRP State Highway Materials Questionnaire Response (1967).
198. WITCZAK, M. W., "Physiographic Areas of the United States." Vol. I, Purdue Univ. (1968) unpublished.
199. WOODS, K. B., JOHNSTONE, J. C., and YODER, E. J., "Some Engineering Problems Associated with the Preglacial Marietta River Valley." Presented at Fourth Annual Symposium on Geology as Applied to Highway Eng., Charleston, W. Va. (1953).
200. WOODS, K. B., and LOVELL, C. W., JR., "Distribution of Soils in North America." Sect. 9, *Highway Engineering Handbook,* McGraw-Hill (1960).
201. WOODS, K. B., "Materials and Engineering Problems of North America." Unpublished course notes, Grad. School of Civil Eng., Purdue Univ.
202. WOODS, K. B., SWEET, H. S., and SHELBOURNE, T. E., "Pavement Blow-ups Correlated with Source of Coarse Aggregate." *Proc. HRB,* Vol. 25 (1945) pp. 147-168.
203. WOOLF, D. O., "Field Experience with Alkali-Aggregate Reaction in Concrete: Eastern United States." *HRB Res. Report 18-C* (1958) pp. 8-11.

204. WRIGHT, H. E., FREY, D. G., ET AL., *The Quaternary of the United States.* Princeton Univ. Press (1965).
205. Wyoming: NCHRP State Highway Materials Questionnaire Response (1967).

SOILS—ORIGIN AND TEXTURE

206. Agricultural and Industrial Development Board of Kentucky, *Land Areas of Kentucky and Their Potential for Use.* Frankfort (1953).
207. Alabama Department of Agriculture and Industries, "Soil Map—State of Alabama." Montgomery (1953).
208. ARNEMAN, H. F., "Soils of the Red River Valley." *Minn. Farm and Home Science* (1961).
209. BEAUMONT, A. B., "Soil Associations of Massachusetts." U.S. Dept. of Agriculture Extension Service, Mass. State College (1939).
210. BEAUMONT, A. B., "The Soils of Massachusetts." *Univ. of Mass. Special Circ. No. 64* (Jan. 1950).
211. BELCHER, D. J., GREGG, L. E., and WOODS, K. B., "The Formation, Distribution and Engineering Characteristics of Soils." *Joint Hwy. Res. Project Bull. No. 87,* Purdue Univ. (1943).
212. BOURBEAU, G. A., and SWANSON, C. L. W., "The Morphology, Mineralogy and Genesis of Two Southern New England Soils." *Conn. Agricultural Experiment Station Bull. 584* (June 1954).
213. BUICK, T. R., "Analysis and Synthesis of Highway Pavement Design." *Joint Hwy. Res. Project Bull. No. 13,* Purdue Univ. (July 1968).
214. BUNTING, B. T., *The Geography of Soil.* Aldine Publ. Co., Chicago (1965).
215. CARTER, R. L., and GIDDENS, J., "Soils of Georgia —Their Formation, Classification and Management." *College Experiment Station Bull. No. 52,* Athens (Jan. 1953).
216. CLINE, M. G., "Soils and Soil Associations of New York." *Cornell Extension Bull. 930* (May 1961).
217. COLLINGS, G. H., and MONTGOMERY, P. H., "Land Resource Areas—State of South Carolina." *S.C. Experiment Station Circ. 112* (June 1957).
218. Colorado Agricultural Experiment Station, "Land Resource Areas of Colorado." *General Series 727* (Apr. 1960).
219. Corps of Engineers, "Forecasting Trafficability of Soils—Airphoto Approach." *Tech. Memo. No. 3-331,* Rep. 6, Vol. II (June 1963).
220. DAVISDON, D. T., ET AL., "Geologic and Engineering Properties of Pleistocene Materials in Iowa." *Bull. No. 20,* Iowa Hwy. Res. Board (Dec. 1960).
221. DONAHUE, R. L., TEMPLIN, E. H., THORNTON, M. K., and MILLER, E. A., "The Soils of Texas." *Texas Agricultural Experiment Station Bull. 431* (1948).
222. DREGNE, H. E., "Soils of Idaho." *Mimeo-Leaflet No. 107,* Univ. of Idaho Dept. of Agronomy (June 1947).
223. EPPERSON, G. R., and PORTER, H. C., "A Key to the Soils of the Southern Piedmont of Virginia." *VPI Agronomy Circ. No. 3* (June 1962).
224. FEHRENBACKER, J. B., "Loess Distribution and Composition in Portions of the Lower Wabash and Ohio River Basins." Doctoral dissertation, Purdue Univ. (June 1964).
225. Federal Housing Administration, "Engineering Soil Classification for Residential Developments." *FHA No. 373* (1961).
226. Federal Housing Administration, "Evaluation of Soils and Use of Soil Surveys for Engineering Purposes in Urban Development." *FHA No. 723* (Oct. 1963).
227. Florida Agricultural Experiment Station, "Major Land Resources of Florida—General Soil Map of Florida." (May 1962).
228. Florida State Geological Survey, "Generalized Soil Map of Florida." (1925).
229. FOSS, J. E., and RUST, R. H., "Soil Development in Relation to Loessial Deposition in Southeastern Minnesota." *Proc. Soil Science Society of Amer.,* Vol. 26, No. 3 (June 1962).
230. HAMPTON, D., YODER, E. J., and BURR, I. W., "Variability of Engineering Properties of Brookston and Crosby Soils." *Purdue Univ. Civil Eng. Reprint 199* (July 1963).
231. HILL, D. E., and GONICK, W. N., "The Paxton Soils." *Conn. Experiment Station Bull. 662* (Dec. 1963).
232. HOLE, D. F., and BEATTY, M. T., "Soils of Wisconsin—A Generalized Map." Univ. of Wisc. (1957).
233. Illinois Agriculture Experiment Station, "Soils of Illinois." *Bull. No. 725* (July 1967).
234. Iowa State Highway Commission, "Iowa—An Engineering Report on Soils, Geology, Terrain and Climate." (1959).
235. Iowa State University Cooperative Extension Service, "Principal Soil Association Areas of Iowa." (June 1950).
236. JENKINS, D. S., BELCHER, D. J., GREGG, L. E., and WOODS, K. B., "The Origin, Distribution and Airphoto Identification of United States Soils." *Tech. Development Rep. No. 52,* Civil Aeronautics Admin. (1946).
237. JENNY, H., *Factors of Soil Formation.* McGraw-Hill (1941).
238. Joint Highway Research Project, Purdue University, "Engineering Soil Parent Material Areas of Indiana." Rev. ed. of 1943 Map of *Bulletin No. 87* (1950).
239. KARRAKER, P. E., "Soils of Kentucky." *Univ. of Ky. Agricultural Experiment Station Circ. 67* (June 1955).
240. LATIMER, W. J., "Soil Survey of Vermont—Reconnaissance." *No. 43, Series 1930,* U.S. Dept. of Agriculture (1930).
241. LEE, W. D., and GOLDSTON, E. F., "North Carolina Soil Association Map." (1955).
242. LIGON, W. S., and KARRAKER, P. E., "A Key to Kentucky Soils." *Univ. of Ky. Agricultural Experiment Station Circ. 64* (Nov. 1949).
243. LINELL, K. A., "Frost Action and Permafrost."

Sect. 13, *Highway Engineering Handbook,* McGraw-Hill (1960).

244. LIU, T. K., "A Review of Engineering Soil Classification Systems." *Hwy. Res. Record No. 156* (1967) pp. 1-22.
245. Louisiana Agricultural Extension Service, "Soil Divisions of Louisiana." *Agricul. Ext. Publ. 1217* (Sept. 1961).
246. MANGUM, A. W., ET AL., "Reconnaissance Survey of Southwestern Washington." U.S. Dept. of Agriculture (May 1913).
247. MANGUM, A. W., ET AL., "Reconnaissance Survey of the Western Part of the Puget Sound Basin, Washington." U.S. Dept. of Agriculture (June 1912).
248. MARBUT, C. F., *Atlas of American Agriculture, Part III, Soils of the United States.* U.S. Dept. of Agriculture (1935).
249. MCMILLER, P. R., "Soils of Minnesota." *Univ. of Minn. Agricultural Extension Service Bull. No. 278* (Dec. 1954).
250. MILES, R. D., SCHOLER, C. F., SHURIG, D. G., WOODS, K. B., and YODER, E. J., "Regional Factors Influencing Highway Pavement Design and Performance." Interim Report, NCHRP Project 1-3 (1) (Sept. 1965) unpublished.
251. Military Engineering Experimental Establishment, "Field Trials of a Terrain Classification System Organization and Methods." *MEXE No. 873,* England (Aug. 1965).
252. Military Engineering Experimental Establishment, "Report of the Working Group on Land Classification and Data Storage." *MEXE No. 940,* England (Feb. 1966).
253. Mississippi State Department of Agriculture, "Soil Map of Mississippi." Jackson (1942).
254. MORSE, R. K., and THORNBURN, T. H., "Reliability of Soil Map Units." *Univ. of Ill. Civil Eng. Studies, Soil Mechanics Series No. 5* (1961).
255. NEAL, J. T. (Ed.), "Geology, Mineralogy, and Hydrology of U.S. Playas." *Environmental Res. Paper No. 96,* Air Force Cambridge Res. Laboratories (Apr. 1965).
256. New Jersey Agricultural Experiment Station, "Land Type Areas of New Jersey." (Map).
257. New York State College of Agriculture, "Soil Association Map of New York State." Dept. of Agronomy, Cornell Univ. (1961).
258. North Carolina Agricultural Experiment Station, "The Soils of North Carolina—Their Formation, Identification and Use." *Tech. Bull. No. 115* (Dec. 1955).
259. North Dakota Agricultural College, "General Soil Areas of North Dakota." (1941).
260. Ohio Department of Natural Resources, "Our Ohio Soils." Div. of Lands and Soil (Apr. 1958).
261. POMERENING, J. A., "Soil Association Map of Maryland." Dept. of Agronomy (1962).
262. Portland Cement Association, *PCA Soil Primer.* Chicago (1962).
263. PRINCE, A. B., and RANEY, W. A. (Review Eds.), "Some Morphological, Physical, and Chemical Properties of Selected Northeastern United States Soils." *Univ. of New Hampshire Agricultural Experiment Station Misc. Publ. 1* (June 1961).
264. QUAKENBUSH, G. A., "Our New Jersey Land." *N.J. Agricultural Experiment Station Bull. 775* (Jan. 1955).
265. RUST, R. H., FARNHAM, R. S., and ROBERTSON, A. S., "The Nebish Rockwood Soils of Northern Minnesota." *Minn. Farm and Home Science,* Vol. 16 (Oct. 1958).
266. SMITH, J. B., and GILBERT, B. E., "Rhode Island Soil Types: Texture and Chemical Composition, and a Utility Index." *R.I. State College Agricultural Experiment Station Bull. 296* (Mar. 1945).
267. South Carolina Agricultural Experiment Station, "Soils of South Carolina," *Agronomy and Soils Res. Series 23,* Clemson (Feb. 1960).
268. South Dakota Agricultural Experiment Station, "Soils of South Dakota." *Soil Survey Series No. 3* (Mar. 1959).
269. State of Ohio, Department of Natural Resources, "Know Ohio's Soil Regions." (1962).
270. STEVENS, J. C., MANER, A. W., and SHELBURNE, T. E., "Pavement Performance Correlated With Soil Areas." Va. Council of Highway Investigation and Res. (Dec. 1949).
271. STORIE, R. E., and HARRADINE, F., "Soils of California." *Soil Science,* Vol. 85, No. 4 (Apr. 1958).
272. STORIE, R. E., and WEIR, W. W., "Generalized Soil Map of California." *Calif. Agricultural Experiment Station Manual 6,* Berkeley (Apr. 1951).
273. SWANSON, C. L. W., and RITCHIE, A., JR., "Significance of Sand and Gravel in the Classification, Mapping and Management of Some Coarse-Textured Soils." *Conn. Agricultural Experiment Station Bull. 580* (Jan. 1954).
274. TEDROW, J. C. F., "Soils of New Jersey." N.J. Agricultural Experiment Station (1962).
275. University of Illinois Agricultural Experiment Station, "Principal Soil Association Areas of Illinois." (Apr. 1962).
276. University of Missouri Agricultural Experiment Station, "Reconnaissance Survey Soil Map of Missouri." (1931).
277. University of Wisconsin Agricultural Experiment Station, "Soils of the North Central Region of the United States." *Bull. No. 544* (June 1960).
278. U.S. Department of Agriculture, "Soil Association Map of New England." (1959).
279. U.S. Department of Agriculture, "Soils and Men." *Yearbook of Agriculture* (1938).
280. U.S. Department of Agriculture, Soil Conservation Service, "A Look at the Caribou Soils." (1962).
281. U.S. Department of Agriculture, Soil Conservation Service, "Description of Soil Resource Areas in Connecticut." (Sept. 1959).
282. U.S. Department of Agriculture, Soil Conservation Service, "General Soil Map—Vermont." (1962).

283. U.S. Department of Agriculture, Soil Conservation Service, "Land Resource Areas of Maine." (July 1957) (Map).
284. U.S. Department of Agriculture, Soil Conservation Service, "Major Land Resource Areas, Arizona." (Sept. 1964) (Map).
285. U.S. Department of Agriculture, Soil Conservation Service, "Soil Association Map, State of Arkansas." (Apr. 1959).
286. U.S. Geological Survey, "Soil Association Areas of Georgia." (1944) (Map).
287. Virginia Agricultural Experiment Station, "Certain Properties of Selected Southeastern United States Soils and Mineralogical Procedures for their Study." *Southern Regional Bull. 61* (Jan. 1959).
288. Virginia Agricultural Experiment Station, "Genesis and Morphology of Virginia Soils." *VPI Bull. 540* (Apr. 1962).
289. Virginia Polytechnic Institute and the U.S. Department of Agriculture, "A Key to the Soils of the Coastal Plains of Virginia." *VPI Agronomy Circ. No. 4* (Feb. 1963).
290. Virginia Polytechnic Institute and the U.S. Department of Agriculture, "A Key to the Soils of the Appalachian Division of Virginia." *VPI Agronomy Circ. No. 2* (July 1960).
291. Virginia Polytechnic Institute, "Soils of Virginia." *VPI Bull. 203* (Mar. 1958).
292. Wahls, H. E., Buchanan, W. T., Futrell, G. E., and Lucas, S. P., "Distribution and Engineering Properties of North Carolina Soils." Eng. Res. Dept., N.C. State (June 1964).
293. Wahls, H. E., and Futrell, G. E., "A Comparison of Soil Classification Systems by Analysis of Variance." *Proc. Nat. Conf. on Statistical Quality Control Methodology in Highway and Airfield Construction,* Univ. of Va. (1966).
294. Washington State University, *Soils of the Western United States.* (Sept. 1964).
295. Woods, K. B., and Lovell, C. W., Jr., "Distribution of Soils in North America." Sect. 9, *Highway Engineering Handbook,* McGraw-Hill (1960).
296. Woods, K. B., Miles, R. D., and Lovell, C. W., Jr., "Origin, Formation and Distribution of Soils in North America." Chap. 1, *Foundation Engineering* (ed. by G. A. Leonards), McGraw-Hill (1962).
297. Wright, H. E., Frey, D. G., et al., *The Quaternary of the United States.* Princeton Univ. Press (1965).
298. Yoder, E. J., *Principles of Pavement Design.* Wiley (1959).

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299. Alabama Geological Survey, "Geology of Alabama." *Spec. Rep. No. 14* (1926).
300. Anonymous, "Homebuilders Protest New Slab Design Criteria." *Eng. News-Record* (Jan. 6, 1966) pp. 32-33.
301. Bates, T. F., "The Application of Electron Microscopy in Soil Clay Mineralogy." In *Soil Clay Mineralogy—A Symposium,* by Rich, C. I., and Kunze, G. W., Univ. of N.C. (1964).
302. Benson, J. R., "Discussion of Holtz, W. G., 'Expansive Clays—Properties and Problems.' " *Quarterly, Colo. School of Mines,* Vol. 54, No. 4 (Oct. 1959).
303. Bolt, G. H., "Physico-Chemical Analysis of the Compressibility of Pure Clays." *Geotechnique,* 6:86 (1956).
304. Bradley, W. F., "X-Ray Diffraction Analysis of Soil Clays and Structure of Clay Minerals." In *Soil Clay Mineralogy—A Symposium,* by Rich, C. I., and Kunze, G. W., Univ. of N.C. (1964).
305. Brindley, G. W., "Identification of Clay Minerals by X-Ray Diffraction Analysis." In *Clays and Clay Technology, Bull. 169,* Dept. of Natural Resources, State of Calif. (1955).
306. Brown, J. L., "Laboratory Techniques in the Electron Microscopy of Clay Minerals." In *Soil Clay Mineralogy—A Symposium,* by Rich, C. I., and Kunze, G. W., Univ. of N.C. (1964).
307. Budge, W. D., Sampson, E., Jr., and Schuster, R. L., "A Method of Determining Swell Potential of an Expansive Clay." *Hwy. Res. Record No. 119* (1966) pp. 22-23.
308. Carson, A. B., *Foundation Construction.* McGraw-Hill (1965).
309. Carter, W. T., "The Soils of Texas." *Texas Agriculture Experiment Station Bull. 431* (1931).
310. Chen, F. H., "The Use of Piers to Prevent the Uplifting of Lightly Loaded Structures Founded on Expansive Clays." Presented at Internat. Res. and Eng. Conf. on Expansive Clay Soils, Texas A&M (1965).
311. Collins, L. E., "Some Observations on the Movement of Buildings on Expansive Soils in Vereeninging and Odendaalsrus." Presented at Symposium on Expansive Clays, South African Inst. of Civil Eng. (1957-58).
312. Department of Highways, State of Colorado, and the University of Colorado, "A Review of Literature on Swelling Soils." (1964).
313. Croney, D., Lewis, W. A., and Coleman, D., "Calculation of the Moisture Distribution Beneath Structures." *Civil Eng. and Pub. Works Rev.,* Vol. 45, No. 524, London (1950).
314. Croney, D., Coleman, D., and Black, W. P. M., "Movement and Distribution of Water in Soil in Relation to Highway Design and Performance." *HRB Spec. Rep. 40* (1958).
315. Dawson, R. F., "Movement of Small Houses Erected on an Expansive Clay Soil." *Proc. 3rd Internat. Conf. on Soil Mechanics and Foundation Eng.,* Vol. 1, Switzerland (1953).
316. Dawson, R. F., "Modern Practices Used in the Design of Foundations for Structures on Expansive Soils." *Quarterly, Colo. School of Mines,* Vol. 54, No. 4 (Oct. 1959).
317. Dodd, C. G., "Dye Absorption—A Method of Identifying Clays." In *Clays and Clay Technology, Bull.*

169, Dept. of Natural Resources, State of Calif. (1955).

318. DUNNEWALD, T. J., "Wyoming Soils and Soil Materials." *Univ. of Wyoming Agricultural Experiment Station Bull. 349* (Apr. 1957).
319. FELT, E. J., "Influence of Soil Volume Change and Vegetation on Highway Engineering." 26th High-Way Conf., *Univ. of Colo., Eng. Experiment Station Circ. 26* (1953).
320. FRYE, J. C., and LEONARD, A. B., "Pleistocene Geology of Kansas." State Geol. Survey of Kansas, *Bull. 99* (1962).
321. GIDDENS, J., PERKINS, H. F., and CARTER, R. L., "Soils of Georgia." *Soil Science,* Vol. 89 (1957).
322. GIESECKE, S. E., "Columns and Walls Lifted by Swelling Clay Under Floor." *Eng. News-Record,* Vol. 88 (1922).
323. GRIFFIN, J. G., "Studies on Soil Movement Due to a Change in Moisture Content as it Affects Foundation Construction of Farm Houses." *Miss. State Univ. Agriculture Experiment Station Info. Sheet 687* (Dec. 1960).
324. GRIFFIN, J. G., "Soil Movement and Moisture Change as They Affect Footings and Foundations for Dwellings in Heavy Clay Soils." *Miss. State Univ. Agriculture Experiment Station Info. Sheet 767* (June 1962).
325. GRIM, R. E., *Clay Mineralogy.* McGraw-Hill (1953).
326. GRIM, R. E., "Petrographic Study of Clay Minerals." In *Clays and Clay Technology, Bull. 169,* Dept. of Natural Resources, State of Calif. (1955).
327. HARDY, R. M., "Identification and Performance of Swelling Soil Types." *Canadian Geotech. J.,* Vol. 2 No. 2 (May 1966).
328. HEPWORTH, R. C., "Heaving in the Subgrade of Highways Constructed on the Mancos Shale." *Trans. AIME,* Vol. 231 (1965).
329. HOLTZ, W. G., and GIBBS, H. J., "Engineering Properties of Expansive Clays." *Trans. ASCE,* Vol. 121 (1956) pp. 641-663.
330. HOLTZ, W. G., "Expansive Clays—Properties and Problems." *Quarterly, Colo. School of Mines,* Vol. 54, No. 4 (Oct. 1959).
331. JACKSON, M. L., and MACKENZIE, R. C., "Chemical Analysis in the Quantitative Mineralogical Examination of Clays." In *Soil Clay Mineralogy—A Symposium,* by Rich, C. I., and Kunze, G. W., Univ. of N.C. (1964).
332. JENNINGS, J. E. B., and KNIGHT, K., "The Prediction of Total Heave from the Double Oedometer Test." Presented at Symposium on Expansive Clays, South African Inst. of Civil Eng. (1957-58).
333. JENSEN, H. P., "High Volume Change Soils—Distribution and Engineering Experience, U.S." Purdue Univ. (May 1967) unpublished.
334. JOHNSTONE, J. G., RAMARATHNAN, S., and RICHARDS, D. B., "The Soils of Eastern Colorado, Their Origin, Distribution and Engineering Characteristics." *Quarterly, Colo. School of Mines,* Vol. 57, No. 3 (July 1962).
335. KASSIFF, G., and WISEMAN, G., "Control of Moisture and Volume Changes in Clay Subgrades by Subdrainage." *Hwy. Res. Record No. 111* (1966) pp. 1-11.
336. KELLER, W. D., "Processes of Origin and Alteration of Clay Minerals." In *Soil Clay Mineralogy—A Symposium,* by Rich, C. I., and Kunze, G. W., Univ. of N.C. (1964).
337. KELLEY, W. P., "Interpretation of Chemical Analysis of Clays." In *Clays and Clay Technology, Bull. 169,* Dept. of Natural Resources, State of Calif. (1955).
338. KERR, P. F., "Formation and Occurrence of Clay Minerals." In *Clays and Clay Technology, Bull. 169,* Dept. of Natural Resources, State of Calif. (1955).
339. KUNZE, G. W., OAKES, H., and BLOODWORTH, M. E., "Grumusols of the Coast Prairie of Texas." *Proc. Soil Science Society of Amer.,* Vol. 27, No. 4 (July-Aug. 1963) pp. 412-421.
340. LADD, C. C., "The Identification and Behavior of Expansive Clays." *Proc. 5th Internat. Conf. on Soil Mechanics and Foundation Eng.,* Paris (1961).
341. LADD, C. C., and LAMBE, T. W., "Mechanisms of Swelling by Compacted Clay." *HRB Bull. 245* (1960) pp. 10-26.
342. LADD, E. F., "North Dakota Soils." *North Dakota Agriculture Experiment Station Bull. 24* (1896).
343. LAMBE, T. W., and WHITMAN, R. V., "The Role of Effective Stress in the Behavior of Expansive Soils." *Quarterly, Colo. School of Mines,* Vol. 54, No. 4 (1959).
344. LAMBE, T. W., "The Character and Identification of Expansive Soils." *FHA Bull. 701* (Dec. 1960).
345. LECLERC, R. V., "How to Handle Swelling Soils." *Proc. 1954 Northwest Conf. on Road Building,* Univ. of Wash. (1954).
346. LOGAN, J., "Clay Foundation Problem, Friant-Kern Canal, California." *Bull. Geol. Society of America,* Vol. 61, Part 2, No. 12 (Dec. 1950).
347. LYON, R. J. P., "Infrared Analysis of Soil Minerals." In *Soil Clay Mineralogy—A Symposium,* by Rich, C. I., and Kunze, G. W., Univ. of N.C. (1964).
348. MACKENZIE, R. C., "The Thermal Investigation of Soil Clays." In *Soil Clay Mineralogy—A Symposium,* by Rich, C. I., and Kunze, G. W., Univ. of N.C. (1964).
349. MARBUT, C. F., BENNETT, H. H., LAPHAM, J. E., and LAPHAM, M. H., "Soils of the United States." U.S. Bureau of Soils, *Bull. 96* (1913).
350. MCDOWELL, C., "The Relation of Laboratory Testing to Design for Pavements and Structures on Expansive Soils." *Quarterly, Colo. School of Mines,* Vol. 54, No. 4 (1959).
351. MCLEAN, E. O., and BAKER, F. E., "Cationic Activities as Indexes for Characterizing Five Arkansas Soils Occurring in the Southern Region." *Proc. Soil Science Society of Amer.,* Vol. 18 (1954).

352. MEANS, R. E., "Soil Investigation for Building Foundation." *Publ. 94,* Eng. Experiment Station, Okla. A&M, Stillwater (1955).
353. MEANS, R. E., "Buildings on Expansive Clay." *Quarterly, Colo. School of Mines,* Vol. 54, No. 4 (1959).
354. MEANS, R. E., and PARCHER, J. V., *Physical Properties of Soils.* Merrill Books, Columbus, O. (1963).
355. MIELENZ, R. C., and KING, M. E., "Physical-Chemical Properties and Engineering Performance of Clays." In *Clays and Clay Technology, Bull. 169,* Dept. of Natural Resources, State of Calif. (1955).
356. MORGAN, E. L., "Volume Changes in Soils." *The Structural Engineer* (Oct. 1958) pp. 345-351.
357. NAHIN, P. G., "Infrared Analysis of Clays and Related Minerals." In *Clays and Clay Technology, Bull. 169,* Dept. of Natural Resources, State of Calif. (1955).
358. "Swelling Measurement and Prediction of Heave for a Lacustrine Clay." *Canadian Geotech. J.,* Vol. 2, No. 1 (Feb. 1966).
359. "Dark-Clay Soils of Warm Regions Variously Called Pendzina, Black Cotton Soils, Regur or Tirs." *Proc. Soil Science Society of Amer.,* Vol. 15 (1960).
360. OSTHAUS, B. B., "Interpretation of Chemical Analysis of Montmorillonites." In *Clays and Clay Technology, Bull. 169,* Dept. of Natural Resources, State of Calif. (1955).
361. PETERSON, R., and PETERS, N., "Heave of Spillway Structures on Clay Shales." *Canadian Geotech. J.,* Vol. 1, No. 1 (Sept. 1963).
362. PHILBRICK, S. S., "Foundation Problems of Sedimentary Rocks." In *Applied Sedimentation,* by Trask, P. D., Wiley (1950).
363. REDUS, J. F., "Experience with Expansive Clays in the Jackson (Miss.) Area." *HRB Bull. 313* (1961) pp. 40-46.
364. RING, G. W., III, "Shrink-Swell Potential of Soils." *Public Roads,* Vol. 33, No. 6 (1965) pp. 97-105.
365. SCOTT, R. F., *Principles of Soil Mechanics.* Addison-Wesley (1963).
366. SEED, H. B., MITCHEL, J. K., and CHAN, C. K., "Studies of Swell and Swell Pressure Characteristics of Compacted Clays." *HRB Bull. 313* (1961) pp. 12-39.
367. SEED, H. B., WOODWARD, R. J., JR., and LUNDGREN, R., "Prediction of Swelling Potential for Compacted Clays." *Trans. ASCE,* Vol. 128, Part 1 (1963).
368. SIMPSON, W. E., "Foundation Experience with Clay in Texas." *Civil Engineering,* Vol. 4, No. 1 (Nov. 1934).
369. SMITH, C. K., "Soil Properties of Fort Union Clay Shales." *Proc. 3rd Internat. Conf. on Soil Mechanics and Foundation Eng.,* Vol. 1, Switzerland (1953).
370. South Dakota Geological Survey, "Geology of Selected Highway Strips in South Dakota." *South Dakota Geol. Survey Rep. of Investigation No. 93* (1963).
371. Southern Cooperative Series, "Certain Properties of Selected Southeastern United States Soils and Mineralogical Procedure for their Study." *Bull. 61,* U.S. Dept. of Agriculture (1959).
372. SOWERS, G. F., DALRYMPLE, G. B., and KENNEDY, C. M., "High Volume Change Clays of the Southeastern Coastal Plain." Law Engineering Testing Co., Atlanta, Ga. (1961) unpublished.
373. STORIE, R. E., and WEIR, W. W., "Key to the Soil Series of California." Univ. of Calif., College of Agriculture (Apr. 1941).
374. THORNBURY, W. D., *Regional Geomorphology of the United States.* Wiley (1965).
375. THORNTHWAITE, C. W., MATHER, J. R., and CARTER, D. B., "3 Water Balance Maps of Eastern North America." Resources for the Future, Inc. (Nov. 1958).
376. University of Texas, "The Geology of Texas." *Univ. of Texas Bull. 3232* (1932).
377. UNDERWOOD, L. B., "Classification and Identification of Shales." *ASCE Water Resources Eng. Conf. Preprint 354,* Denver (May 1966).
378. U.S. Department of Agriculture, "County Soil Survey Series." (n.d.).
379. U.S. Department of Agriculture, "Soils of the United States." Part III, *Atlas of American Agriculture* (1935).
380. U.S. Department of Agriculture, "Soils and Men." *Yearbook of Agriculture* (1938).
381. U.S. Army Corps of Engineers, Missouri River Division, "Report of Investigation of Expansive Characteristics of Shale and Weak Rocks." *Civil Works Investigation No. 465* (May 1954).
382. U.S. Department of the Interior, Bureau of Reclamation, "Stabilization of Expansive Clay Soils with Hydrated Lime and with Portland Cement, Friant-Kern Canal—Lower-Cost Canal Lining Program—Central Valley Project." *Earth Lab. Rep. EM-500,* Denver (June 1957).
383. U.S. Department of the Interior, Bureau of Reclamation, "Design of Small Dams." (1960).
384. U.S. Geological Survey, "Geological Map of North America." North Amer. Map Committee (1965).
385. VANDERFORD, C. F., "The Soils of Tennessee." *Tenn. Agriculture Experiment Station Bull. 10* (1897).
386. VANDERFORD, H. B., "Soils of Mississippi." Miss. State Univ. Agriculture Experiment Station (Feb. 1962).
387. VENTSKEVITCH, G. Z., "Agrometeorology." Translation from Russian USDA and National Science Foundation, Wash., D.C. (1963).
388. VISHER, S. S., *Climatic Atlas of the United States.* Harvard Univ. Press (1954).
389. Washington State University, *Soils of the Western United States.* (Sept. 1964).
390. WOODS, K. B., and LOVELL, C. W., JR., "Distribution of Soils in North America." Sect. 9, *Highway Engineering Handbook,* McGraw-Hill (1960).

391. WOOLTORTON, F. L. D., *The Scientific Basis of Road Design.* Arnold Press, London (1954).

392. YONG, R. N., and WARKENTIN, B. P., *Introduction to Soil Behavior.* Macmillan (1966).

393. RANGMATHAN, B. V., and SATYANARAYANA, B., "A Rational Method of Predicting Swelling Potential for Compacted Expansive Clays." *Proc. 6th Internat. Conf. on Soil Mechanics and Foundation Eng.,* Vol. 1, Canada (1965).

APPENDIX A

SAMPLE NCHRP MATERIALS QUESTIONNAIRE

Sample NCHRP Materials Questionnaire

Re: NCHRP Project 1-3(1) Part II
Subject: Materials Questionnaire

I. Enclosure 1 shows an abbreviated listing of probable aggregate materials: compiled from a literature search, indicating materials being produced in your state. Enclosure 2 is a list identifying the abbreviated materials. Check the material listing of Enclosure 1 for completeness. If a material type is not shown on the list but is used as a highway aggregate source, enter the abbreviated form under Others.

II. Enclosure 3 is a map of your state showing coded areas (location code). Indicate the occurrence of each material type shown in Column 1, Enclosure 1 within these areas by placing the location code/codes in Column 2. Place only one location type code in each row within a given material type.

III. Below is a list of general aggregate problems and a severity description. Place the problem code and associated severity code for that particular problem in Column 3 for each entry in Column 2. If multiple entries are necessary, place all entries in the row corresponding to the referenced location code entry of Column 2. A format example of an entry for Column 3 would be (CSu-Il).

Problem Code	Problem
Concrete Pavement Aggregate	
CAb	Abrasion Loss
CD	Durability
	Chemical Reaction
CSu	Sulphate
CAl	Alkali
CCb	Carbonate
CDe	Deleterious Substances*

*includes presence of organic silt and clay, coal lignite, soft particles, clay lumps or chert particles.

Problem Code	Problem
Bituminous Pavement Aggregate	
BAb	Abrasion Loss
BD	Durability
BAd	Adhesion (Stripping)
BSk	Skid (polishing)

Severity Code	Severity
Ll	Limited Local
Wg	Widespread General

IV. Indicate the general functional use or uses of each respective entry of Column 2 by placing the appropriate function code (shown below) in Column 4. Note that more than one function code may be placed in each row.

Function Code	Function
B	Bituminous Pavement** Aggregate
C	Concrete Pavement*** Aggregate
BS	Base/Subbase Aggregate
NS	Not Suitable for above uses

**Material above base course

***Material above subbase course

V. Indicate on Enclosure 3 approximate general boundaries of areas you feel lack suitable aggregate sources for normal highway use. If no such areas exist, check below.

None_____

VI. Does the availabilty (non-availability) of suitable aggregate sources within a geographic area act as a major factor in the selection of a specific pavement type (Concrete or Bituminous)?

Yes

If yes, state the location code of the area/areas affected.

Location Code 13b
20f
11i
_____

VII. Does the availability (non-availability) of a given cementing material (Portland cement or Bituminous material) within a geographic area act as a major factor in the selection of a specific pavement type (Concrete or Bituminous)?

Yes_____ No X

If yes, state the location code of the area/areas affected.

Location Code _____
_____
_____
_____

MISSOURI

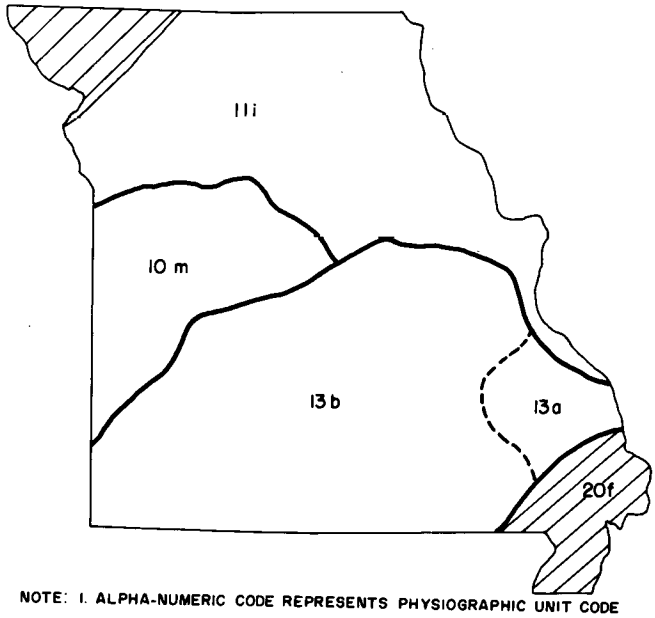
Enclosure 1 Re: NCHRP Project 1-3(1) Part II

Col (1) Material Type	Col (2) Location Code	Col (3) Problem-Severity Code	Col (4) Function Code
Ls	10m	CD-Wg;CDe-Wg;BSK-Wg	B;C;BS
	11i	CAb-Ll;CD-Wg;CDe-Wg;BAb-Ll;BSK-Wg	B;C;BS
	13a		B;C;BS
	13b	CAb-Ll;CDe-Wg;BAb-Ll;BSK-Wg	B;C;BS
Ss	10m	CAb-Wg;CDe-Wg;BAb-Wg;BD-Wg	NS
	11i	CAb-Wg;CDe-Wg;BAb-Wg;BD-Wg	NS
	13a	CAb-Wg;CDe-Wg;BAb-Wg;BD-Wg	NS
	13b	CAb-Wg;CDe-Wg;BAb-Wg;BD-Wg	NS
Do	10m	CD-Wg;BSK-Wg	B;BS
	11i	CD-Wg;BSK-Wg	B;BS
	13a	CD-Wg;BSK-Wg	C;B;BS
	13b	CD-Wg;BSK-Wg	B;BS
Gr	11i	CD-Ll;BAd-Ll	C;B;BS
	10m	CD-Wg;BAd-Ll	B;BS
	13a	CD-Wg;BAd-Ll	B;BS
	13b	CD-Wg;BAd-Ll	B;BS
	20f	CD-Wg;BAb-Ll	B;BS
S	10m		C;BS
	11i		C;BS
	13a		C;BS
	13b		C;BS
	20f		C;BS
Gn	13a		B
Ma			
Sg			

Enclosure 2 Re: NCHRP Project 1-3(1) Part II

Material Abbreviations

Material	Abbreviation
Andesite	An
Amphilbolite	Am
Basalt	Ba
Clam/Oyster Shell	Cs
Coquina	Co
Diabase	Db
Diorite	Dr
Dolomite	Do
Gabbro	Ga
Gneiss	Gs
Granite	Gn
Gravel	Gr
Limestone	Ls
Marble	Ma
Peridotite	Pe
Quartzite	Qz
Rhyolite	Rh
Sand	S
Sand/Gravel	Sg
Sandstone	Ss
Schist	Sc
Slag	Sl
Syenite	Sy



NOTE: 1. ALPHA-NUMERIC CODE REPRESENTS PHYSIOGRAPHIC UNIT CODE

2. CROSS HATCHED AREAS INDICATE GENERAL BOUNDARIES THAT LACK SUITABLE AGGREGATE SOURCES FOR NORMAL HIGHWAY USE

Figure A-1. Completed sample NCHRP materials questionnaire diagram enclosure for Missouri.

APPENDIX B

PHYSIOGRAPHIC AND HIGHWAY DESIGN FACTORS

Information compiled from the literature review and responses from state highway departments to the materials questionnaire on physiographic and highway design factors (see Appendix A) is summarized here.

PHYSIOGRAPHY (GEOMORPHOLOGY)

Summary of Basic Report Units

Description and Location

The basic physiographic units were bounded and named in essentially the form suggested by Woods and Lovell (*82*). Table B-1 lists each basic report Province and Section, and provides a code for identification. Table B-2 keys the Sections to the states of the U.S. Individual Province and Section diagrams appear in Appendix C.

Areas

Approximate areas of each Section and Province were determined by planimetering a national map with a scale of 1:5,000,000. The area of the U.S. (exclusive of Hawaii and Alaska) was taken as 3,022,396 sq mi (*26*). Table B-3 summarizes area data keyed to the unit code of Table B-1.

Geomorphic Characteristics

Table B-4 summarizes the general geomorphic characteristics of each Section. This table is not meant to replace or be a substitute for the monumental works of Fenneman and others. Liberal use has been made of information found in these works. However, primary emphasis has been accorded to certain physiographic factors deemed most relevant to highway engineers; these are: origins of surficial materials, topography, parent material type, and geologic age.

Comparison of Units Among Physiographers

Although this report basically follows the physiographic system of Woods and Lovell (*82*), there are several minor differences. These changes are primarily in: the Basin and Range Province (5), the Sierra-Cascade Province (2), the Northern Rocky Mountain Province (7), and the Older Appalachian Province (17). They are generally in accord with two distinguished physiographers (Fenneman or Lobeck). Table B-5 is a summary of differences between the basic report units and the various "standard" physiographic categorizations.

The most likely reason for the variations is the qualitative and subjective nature of the classification criteria. Thus, it is not surprising, for example, that Lobeck and Fenneman place the Osage Plains Section in the Central Lowlands Province, while Woods and Lovell consider that the nonglaciated plains do not belong in a predominantly glaciated Province.

Other differences may stem from chronology or from variations in special knowledge of particular areas. The physiographic subdividing of Fenneman was completed with the publication of his two companion volumes covering the U.S. (*19, 18*) in 1931 and 1938, respectively. Lobeck's divisioning was published in 1948. The work of Woods and Lovell (1958) had a definite engineering perspective. Difference in detail of subdividing is pronounced in the Rocky Mountains, where Fenneman stops at the Province level and Lobeck formally divides into Sections.

Physiographic Boundaries

Definition

Fenneman (*18*) states that each defined physiographic unit "should be as homogeneous as possible; that is, it should admit of the largest number of general statements before details and exceptions become necessary." In fact, any physiographic unit, except the ultimate landform, consists of two parts: (1) a *modal* topographic expression developed from a *unique* set (or sets) of geomorphic control factors, and (2) inherent variations from this modal expression. Consequently, a physiographic boundary ideally delimits different modal topographic expressions, but of practical necessity admits certain variants in any bounded unit.

Description of Basic Unit Boundaries

Extensive information was obtained concerning the description of the boundaries of the basic units. This information has been summarized and coded to the physiographic diagrams and appears in Appendix C. Not all of the borders are described; in particular, most of the Rocky Mountain areas, portions of the Basin and Range Province, and the Columbia Plateau Province have not been summarized.

Types

Physiographic boundaries are either relatively definite or indefinite, depending on the contrast of adjacent topographic expressions. As Thornbury (*65*) points out: "An escarpment comes as near as any topographic feature to representing a sharp change from one topographic area to another." He emphasizes the indefinite nature of most boundaries:

> Classifications of any sort are to a considerable degree artificial. They represent man's attempt to pigeonhole natural phenomena into distinct compartments with sharply drawn boundaries between them. In nature,

TABLE B-1

PHYSIOGRAPHIC UNIT CODE

PROVINCE AND SECTION CODE [a]

1. Western Mountains of the Pacific Coast Range Province
   a. Olympic Mountains
   b. Oregon Coast Range
   c. Klamath Mountains
   d. California Coast Range
   e. Los Angeles Ranges
2. Sierra-Cascade Province
   a. Northern Cascade Mountains
   b. Southern Cascade Mountains
   c. Sierra Nevada
   d. Lower California
3. Pacific Troughs Province
   a. Puget Sound
   b. Willamette Valley
   c. California Valley
4. Columbia Plateau Province
   a. Walla Walla
   b. Blue Mountains
   c. Snake River Plains
   d. Payette
   e. Harney
5. Basin and Range Province
   a. Great (Closed) Basin
   b. Sonoran Desert
   c. Salton Trough
   d. Open Basin (Mexican Highland)
   e. Sacramento Highland
   f. Great Bend Highland
6. Colorado Plateau Province
   a. High Plateaus of Utah
   b. Uinta Basin
   c. Canyon Lands
   d. Navajo
   e. Grand Canyon
   f. Datil
7. Northern Rocky Mountain Province
   a. Montana
   b. Bitterroot
   c. Salmon River Mountains
8. Middle Rocky Mountain Province
   a. Yellowstone
   b. Bighorn Mountains
   c. Wind River Mountains
   d. Wasatch
   e. Uinta Mountains
9. Southern Rocky Mountain Province
   a. Front Range
   b. Western
   c. San Juan Mountains
10. Great Plains Province
   a. Glaciated Missouri Plateau
   b. Unglaciated Missouri Plateau
   c. Bighorn Basin
   d. Wyoming Basin
   e. Black Hills
   f. High Plains
   g. Colorado Piedmont
   h. Raton Upland
   i. Pecos Valley
   j. Plains Border
   k. Central Texas Mineral
   l. Edwards Plateau
   m. Osage Plains
11. Central and Eastern Lowlands Province
   a. St. Lawrence Lowlands
   b. Champlain Lowland
   c. Hudson River Valley
   d. Mohawk River Valley
   e. Eastern Lakes and Lacustrine
   f. Central Till Plains
   g. Driftless
   h. Western Lakes and Lacustrine
   i. Dissected Loessial and Till Plains
12. Laurentian Upland Province
   a. Superior Upland
   b. Adirondack
13. Ozark and Ouachita Province
   a. St. Francis Mountains
   b. Springfield-Salem Plateau
   c. 1. Boston Mountains
      2. Arkansas Valley
      3. Ouachita Mountains
14. Interior Low Plateaus Province
   a. Blue Grass
   b. Nashville Basin
   c. Shawnee Hills
   d. Highland Rim
15. Appalachian Plateau Province
   a. Catskill Mountains
   b. New York Glaciated
   c. Allegheny Mountains
   d. Kanawha
   e. Cumberland
16. Newer Appalachian (Ridge and Valley) Province
   a. Pennsylvania-Maryland-Virginia
   b. Tennessee
17. Older Appalachian Province
   a. Blue Ridge
   b. Piedmont
18. Triassic Lowland Province
19. New England Maritime Province
   a. Seaboard Lowland
   b. New England Upland
   c. Connecticut Lowland
   d. White Mountain
   e. Green Mountain
   f. Taconic
   g. Reading Prong
20. Atlantic and Gulf Coastal Plain Province
   a. Embayed
   b. Sea Island
   c. Florida
   d. East Gulf
   e. Mississippi Loessial Upland
   f. Mississippi Alluvial Plain
   g. West Gulf

[a] Numbers represent physiographic Provinces; letters represent physiographic Sections.

TABLE B-2

OCCURRENCE OF PHYSIOGRAPHIC SECTIONS WITHIN STATES

STATE	SECTION CODE [a]	STATE	SECTION CODE [a]
Alabama	14d; 15e; 16b; 17b; 20d	Nebraska	10b, f, j; 11i
Arizona	5a, b, c, d; 6d, e, f	Nevada	2c; 4c, d; 5a, b
Arkansas	13b, c1, c2, c3; 20f, g	New Hampshire	19a, b, d
California	1c, d, e; 2b, c, d; 3c; 5a, b, c	New Jersey	11c; 18; 19g; 20a
Colorado	6b, c, d; 8e; 9a, b, c; 10d, g, h, f	New Mexico	5d, e; 6d, f; 9a, b, c; 10f, h, i
Connecticut	19b, c, f	New York	11a, b, c, d, e; 12b; 15a, b, d; 18; 19b, f, g
Delaware	17b; 20a	North Carolina	17a, b; 20a, b
Florida	20b, c, d	North Dakota	19a, b; 11h
Georgia	15e; 16b; 17a, b; 20b, d	Ohio	11e, f; 14a; 15b, d
Idaho	4a, b, c, d; 5a; 7a, b, c; 8a, d	Oklahoma	10f, j, m; 13b, c1, c2, c3; 20g
Illinois	11e, f, g, i; 14c; 20d	Oregon	1b, c; 2b; 3b; 4a, b, d, e; 5a
Indiana	11e, f; 14a, c, d	Pennsylvania	11c, e; 15b, c, d; 16a; 17a, b; 18; 19g; 20a
Iowa	11g, h, i	Rhode Island	19a, b
Kansas	10f, j, m; 11i	South Carolina	17a, b; 20b
Kentucky	14a, b, c, d; 15d, e; 20d, e, f	South Dakota	10a, b, e, f; 11h, i
Louisiana	20d, e, f, g	Tennessee	14b, d; 15e; 16b; 17a; 20d, e, f
Maine	19a, b, d	Texas	5d, e, f; 10f, i, j, k, l, m; 20g
Maryland	15c; 16a; 17a, b; 18; 20a	Utah	5a; 6a, b, c, d, e; 8d, e
Massachusetts	19a, b, c, e, f; 20a	Vermont	11b; 19b, d, e, f
Michigan	11e; 12a	Virginia	15d, e; 16a, b; 17a, b; 18; 20a
Minnesota	11g, h, i; 12a	Washington	1a, b; 2a, b; 3a; 4a, b; 7b
Missisippi	20d, e, f	West Virginia	15c, d; 16a; 17a
Missouri	10m; 11i; 13a, b; 20f	Wisconsin	11e, f, g; 12a
Montana	7a, b; 8a, b; 10a, b, c	Wyoming	7a; 8a, b, c, d; 9a, b; 10b, c, d, e, f

[a] See Table B-1 for description of physiographic unit code.

clear-cut (geomorphic) boundaries are the exception rather than the rule.

The difficulties of defining a boundary between two modal expressions are categorized in Figure B-1 as: (1) Interfingering, (2) Gradational (Transitional), (3) Overlapping (Inclusive), and (4) Exclusive.

When viewed at a large scale, Type 1 shows an irregular boundary, either definite or indefinite, between the modal areas. However, when it is reduced to a smaller mapping scale, the detail is lost and the mapped boundary must be classed as indefinite. An example has been noted by Fenneman (*18*) to exist between the Western Lakes and Lacustrine Section and the Superior Upland Section. Thornbury (*65*) states: "The arbitrary straight-line boundary at the west [of the Superior Upland] reflects the difficulty of determining where it should be drawn here."

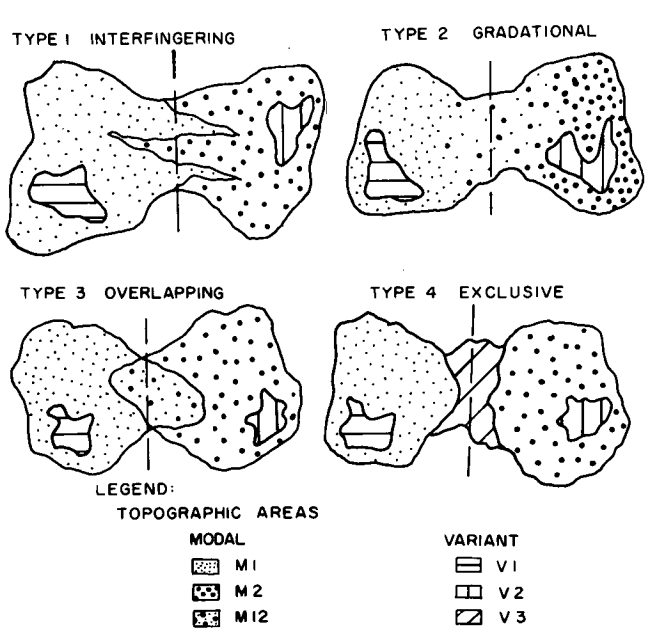


Figure B-1. Types of indefinite boundaries.

Type 2 borders are characterized by a gradual merging of modal expressions. An example is the boundary between the Mississippi Loessial Upland Section and the East Gulf Section. The distinguishing characteristic of the first Section is the surficial cover of aeolian materials. However, because the thickness of loess decreases gradually from west to east in the Section, the location of the eastern boundary is arbitrary. The Type 2 indefinite boundary can be anticipated where soil origin is used as a discriminating factor; e.g., glacial-origin areas bordering residual-origin areas.

Type 3 borders occur when a major descriptive characteristic of one modal area extends into an adjacent modal area. An excellent example is the Driftless Section-Superior Upland Section contact. The Driftless Section is characterized by Cambrian sedimentaries and the absence of glacial till. The Superior Upland Section was covered by the ice sheets and is underlain principally by Precambrian crystalline rocks. However, in the area between the Sections, glacial till overlies Cambrian rocks. Hence, within a modal area shown as M12 on Figure B-1, the glacial origin is common to the Superior Upland Section while

TABLE B-3

AREA SUMMARY OF BASIC REPORT UNITS

AREA, BY PROVINCE		AREA, BY SECTION		
PROV. CODE	% U.S LAND	SECT. CODE	% OF PROV.	TOTAL (SQ MI)
1	3.4	a	6.9	7,090
		b	14.9	15,300
		c	19.5	20,040
		d	37.5	38,540
		e	21.2	21,790
				102,760
2	3.0	a	17.8	16,140
		b	39.4	35,720
		c	35.3	32,010
		d	7.5	6,800
				90,670
3	1.4	a	34.3	14,510
		b	11.1	4,700
		c	54.6	23,100
				42,310
4	3.8	a	36.6	42,040
		b	16.6	19,060
		c	15.1	17,340
		d	17.9	20,560
		e	13.8	15,850
				114,850
5	12.0	a	48.4	175,540
		b	15.1	54,770
		c	2.9	10,520
		d	22.6	81,970
		e	6.4	23,210
		f	4.6	16,680
				362,690
6	4.1	a	13.2	16,360
		b	10.2	12,640
		c	21.8	27,010
		d	27.0	33,460
		e	20.3	25,160
		f	7.5	9,290
				123,920
7	3.5	a	41.4	43,800
		b	32.6	34,480
		c	26.0	27,500
				105,780
8	1.5	a	24.8	11,250
		b	20.7	9,380
		c	7.9	3,580
		d	37.8	17,140
		e	8.8	3,990
				45,340
9	2.0	a	41.7	25,210
		b	37.2	22,490
		c	21.1	12,750
				60,450
10	21.6	a	11.2	73,120
		b	18.9	123,390
		c	0.6	3,920
		d	5.4	35,250
		e	1.0	6,530
		f	20.4	133,180
		g	4.0	26,110
		h	2.1	13,710
		i	4.4	28,720
		j	6.1	39,820
		k	3.2	20,890
		l	5.7	37,220
		m	17.0	110,980
				652,840
11	13.0	a	0.5	1,960
		b	0.7	2,750
		c	1.0	3,930
		d	0.6	2,360
		e	22.4	88,010
		f	21.7	85,260
		g	5.2	20,430
		h	25.1	98,630
		i	22.8	89,580
				392,910
12	2.4	a	87.6	63,550
		b	12.4	8,990
				72,540
13	2.2	a	5.7	3,790
		b	55.4	36,840
		c1	8.4	5,580
		c2	12.8	8,510
		c3	17.7	11,770
				66,490
14	1.7	a	16.3	8,380
		b	5.6	2,880
		c	32.2	16,540
		d	45.9	23,580
				51,380
15	3.4	a	3.2	3,290
		b	21.9	22,500
		c	10.4	10,690
		d	44.7	45,930
		e	19.8	20,350
				102,760
16	1.5	a	57.4	26,020
		b	42.6	19,320
				45,340
17	3.0	a	21.8	19,770
		b	78.2	70,900
				90,670
18	0.2	None	—	6,040
19	2.3	a	17.0	11,820
		b	51.5	35,800
		c	2.7	1,880
		d	16.2	11,260
		e	7.6	5,280
		f	2.5	1,740
		g	2.5	1,740
				69,520
20	14.0	a	8.0	33,850
		b	12.6	53,330
		c	8.2	34,680
		d	21.8	92,240
		e	5.4	22,860
		f	10.8	45,700
		g	33.2	140,480
				423,140
Total	100.0			3,022,400

the bedrock is that of the Driftless Section. Another example occurs at the Columbia Plateau Province-Basin and Range Province border, where the blocky topographic expression of the Basin and Range coexists with the geologic parent material of the Columbia Plateau.

A Type 4 boundary exists when two modal expressions are separated by a small area of variant expression; i.e., one that is not clearly identified with either modal area. Prime examples occur extensively in the Atlantic and Gulf Coastal Plain Province. In particular, the Embayed Section-Sea Island Section and the Florida Section-Sea Island Section-East Gulf Section borders are of this type.

Other Considerations

The guidelines for classifying and bounding physiographic units are qualitative and thus subject to much individual interpretation. Where the topographic expressions lack contrast, recourse to such factors as rock type and age, or even soil type or color, may be required to establish the boundary. One example occurs where the Triassic Lowland Province adjoins the Atlantic Coastal Plain. Thornbury (*65*) states:

> . . . [T]here is no marked topographic break; the Fall Line is missing here. However, the two areas are readily recognizable because of the contrast that the red soils of the Triassic Lowland make with the soils of the Coastal Plain.

It is well to focus on the control factors that characterize the modal topographic expressions, rather than on the arbitrary line enclosing them. Or, as Fenneman (*18*) states:

> Some of the boundary lines are almost as sharp in nature as on the map. Some of them represent broad generalizations which are highly important in a rational discussion, even though the lines themselves are hard to locate in the field. . . . No one can be so conscious of the limitations of such a map as the men who labor to produce it. No geological reader will be misled by its seemingly definite commitments.

TABLE B-4

GEOMORPHIC SUMMARY OF PHYSIOGRAPHIC SECTIONS

SECT. CODE	CHARACTERISTICS [a, b] PHYSIOGRAPHIC UNIT	ELEV.	RELIEF	GEOLOGIC MATERIAL	STRUCTURE	AGE
1a	Mn	4, 8	H	GnM	Cx	8
				IgE*	Vc	6
				S/Ss, Sh*	Ho	5, 6
1b	Rg, Val	2-4	S-H	S/Ss, Sh	Ho-Sd, Fo	(3-7) und
				IgE*	Vc	(3-7) und
1c	Mn	3-6, 9	H	C	Cx, Fau, Fo	9, (11-17) und
1d	Rg, Val	2-4, 7	S-H	S/Ss, Sh	Fo, Fau	(3-10) und
				IgE*	Vc	(3-7) und
				GnM*	Cx	9
1e	Rg, Val	1, 4, 11	S-H	GnM	Cx, Fau, Fo	9, 18
				Wvf		(3-7) und
2a	Mn	6-9	H	GnM	Cx	9
2b	Mn	6-9	S	IgE	Vc-Sd	(3-7) und
				GnM*	Cx	9
2c	Mn	8-13	H	GnM	Cx, Fau	9
2d	Mn	10	H	GnM	Cx, Fau	9
3a	Val	1-2	M	G		2
				IgE	Vc	(3-7) und
				S/Ss, Sh	Ho-Sd	(3-7) und
3b	Val	1	L	Wa		1
				Wvf		(3-7) und
				IgE*	Vc	(3-7) und
3c	Val	1	L	Wvf		(1-2) und
				Wa*		1
4a	Pl, Rg*, Val*	2, 6	M-H	(u)IgE	Vc-Ho, Fo	4
				A		2
4b	Mn, Pl*	5-8, 9	S	GnM	Cx	9
				S/Ss, Sh, Ls	Ho-Sd	9, 10, (11-13) und
				IgE	Vc	(3-7) und
				A*		2
4c	Pn	4-6	S	(u)IgE	Vc-Ho	2
				A		2
4d	Pn, Mn*	6	M	Wl	Ho	4
				IgE	Vc-Ho	(1-7) und
4e	Pl	4	M	IgE	Vc-Ho	(1-7) und

TABLE B-4 (*Continued*)

SECT. CODE	CHARACTERISTICS [a, b] PHYSIOGRAPHIC UNIT	ELEV.	RELIEF	GEOLOGIC MATERIAL	STRUCTURE	AGE
5a	Rg, Bs	5, 10	S	Wvf		1, 2
				C	Cx, Fau, Fo	Cx
5b	Bs, Rg	2, 4	M	Wvf		1, 2
				C	Cx, Fau	Cx
5c	Bs	0	L	Wvf-a	Fau	1, 2
				IgE*	Vc	(3-7) und
5d	Bs, Rg	5, 10	M	Wvf		1, 2
				C	Cx, Fau, Fo	Cx
5e	Pl, Bs	5-6, 8-10	S	S/Ls, Ss	Ho, Fo, Fau	11
				Wvf		1, 2
				IgE*	Vc	(3-7) und
5f	Mn, Pn, Bs	4-5, 9	H	IgE	Vc	(3-7) und
				S/Ls	Ho-Sd, Fau	8
				Wvf		1, 2
				GnM	Cx	(3-7) und
6a	Pl, Val*	9-11	H	S/Ss, Sh	Ho, Fau	(3-7) und
				IgE	Vc	(3-7) und
				S/Ss, Sh*	Ho, Fau	8, 9
6b	Pl	8-10	H	S/Sh, Ss, Ls	Ho-Std	(3-7) und
				IgE*	Vc-Ho	(3-7) und
6c	Pl	4-10	H	S/Ss, Sh	Ho-Std, Fo	8-10
				IgE*	Vc	(3-7) und
6d	Pl	5-8	M	S/Ss, Sh	Ho-Sd	8
				S/Ss, Sh*	Ho-Sd	(3-7) und, 9, 10
				IgE*	Vc	(3-7) und
6e	Pl, Mn	8-11	M-S	S/Ls, Ss, Sh	Sd, Fau	11
				IgE	Vc	(1-7) und
6f	Pl, Mn	6-9	S	IgE	Vc, Ho	(1-7) und
				S/Ss, Sh, Ls	Ho-Sd	8, 9
				GnM*	Cx	18
				S/Ls, Ss, Sh*	Sd-Std	11
7a	Bs, Mn, Rg	10	H	GnM	Cx, Fau, Fo	18
				S/und	Cx, Fau	(11-17) und
				Wl-vf	Fau	(3-7) und
				C	Fau, Fo, Cx	Cx
				G*		2
7b	Mn, Rg	9	H	GnM	Cx	9
7c	Mn	9	H	GnM	Cx	9
				IgE*	Vc	(3-7) und
				S/und*	Cx	(11-17) und
				G*		2
8a	Mn, Pl	9	H	IgE	Vc	(3-7) und
				GnM*	Cx	18
8b	Mn, Rg	10	H	GnM	Cx	18
				S/Ss, Sh, Ls*	Std	(8-10) und
8c	Mn, Rg	12	H	GnM	Cx	18
				S/Ss, Sh, Ls*	Std	(8-10) und
8d	Mn, Bs*	12	S	S/Ss, Sh, Ls	Fau, Fo	(8-10) und
				GnM*	Cx	18
				IgE*	Vc	4
				G*		2
				Wvf*	Ho	(3-8) und
8e	Mn	12	H	GnM	Cx	18
				S/Ss, Sh, Ls*	Std	(8-10) und
9a	Mn	14	H	GnM	Cx	18
				S/Ss, Sh, Ls*	Std	(8-10) und
9b	Bs, Val, Mn*, Pl*	12	H	S/und	Ho	(3-7) und
				Wvf	Ho	(3-7) und
				G		2
				GnM*	Cx	18
				IgE*	Vc	(3-7) und
9c	Mn, Pl	12	H	IgE	Vc	(3-7) und
				GnM*	Cx	18
				S/und*	Std	(8-10) und

TABLE B-4 (*Continued*)

SECT. CODE	CHARACTERISTICS [a, b] PHYSIOGRAPHIC UNIT	ELEV.	RELIEF	GEOLOGIC MATERIAL	STRUCTURE	AGE
10a	Pl	2-3	L	G		2
				(u)S/Sh, Ss	Ho	(3-7) und, 8
10b	Pl, Mn*, Val*	2-4	L-M	S/Sh, Ss, Ls	Ho	(3-7) und, 8
				GnM*	Cx	18
				IgE*	Vc	(3-7) und
10c	Bs	5-6	S	S/Ss, Sh	Ho-Std	(3-7) und
10d	Bs, Mn*	7-9	M-H	S/Ss, Sh	Ho-Std, Fo	(3-7) und
				S/Ss, Sh	Ho-Std	8
				IgE*	Vc	(3-7) und
				GnM*	Cx	18
10e	Mn, Pl*	5-7	S-H	GnM	Cx	18
				S/Ls*	Sd-Std	11
				S/Sh*	Sd-Std	10
				S/Ss*	Ho-Std	8
				IgE*	Vc	(3-7) und
10f	Pn	3-4	L	Wvf	Ho-Sd	(3-7) und
				A*		2
10g	Pl	4-7	M	S/Ss, Sh, Ls	Ho-Std	(3-7) und, 8
				IgE*	Vc	(3-7) und
10h	Pl, Mn	6-9, 13	S	S/Ss, Sh, Ls	Ho-Std	(3-7) und, 8
				IgE*	Vc-Ho	(3-7) und
				GnM*	Cx	
10i	Val	2-5	M-S	S/Sh, Ss, Ls	Ho-Sd	10-11
10j	Pn	1-2	M	S/Ss, Sh	Ho-Sd	11
				S/Ss, Ls, Sh	Ho-Sd	8
				Wvf		(3-7) und
				Wa		1
				A		2
10k	Pl, Mn*	2	M-S	S/Ls	Ho	8
				S/Ss, Sh	Ho	12
				S/Ls, Ss, Sh*	Sd-Std, Fau	16, 17
				GnM*	Cx	18
10l	Pl	2	M-S	S/Ls	Ho-Sd	8
10m	Pn, Mn*	1-2	M	S/Ls, Sh, Ss	Ho-Sd	11
				S/Ls, Ss, Sh	Ho-Sd	12
				GnM*	Cx	18
				IgE*	Vc	18
				S/Ls, Ss, Sh*	Sd-Std	16, 17
				Wa*		1
11a	Pn	1	L	G		2
				(u)S/Ls, Ss, Sh	Ho-Std	16, 17
11b	Pn	1	L	G		2
				(u)S/Ls, Ss, Sh	Ho-Std	16, 17
11c	Pn, Val	1-2	M	G		2
				(u)S/Ls, Sh	Fo	16
				(u)S/Ss	Fo	14
				(u)GnM	Fo	17
11d	Pn, Val	1-2	S	G		2
				(u)S/Sh, Ls, Ss	Ho-Std	16
				(u)S/Ss*	Ho-Std	15
11e	Pn	1	M	G		2
				(u)S/und	Ho-Sd	(12-17)
				(u)GnM*	Cx	18
11f	Pn	1	L	G		2
				A*		2
				(u)S/und	Ho-Sd	(12-16)
11g	Pn	2	M	S/Ss, Sh	Ho-Sd	17
				(u)S/und*	Ho-Sd	15, 16, 18
				A*		2
11h	Pn	2	L	G		2
				(u)S/Ss, Sh	Ho-Sd	8
				(u)S/und*	Ho-Sd	(12-18)

TABLE B-4 (*Continued*)

SECT. CODE	CHARACTERISTICS [a, b] PHYSIOGRAPHIC UNIT	ELEV.	RELIEF	GEOLOGIC MATERIAL	STRUCTURE	AGE
11i	Pn	1	M	G		2
				A		2
				(u)S/und	Ho-Sd	(8, 12-14)
				(u)S/und*	Ho-Sd	(11, 15-18) *
12a	Pn	2	M	G		2
				(u)GnM	Cx	18
				(u)S/Ss, Sh*	Ho-Sd	17
12b	Pl, Mn	1-4	H	G		2
				(u)GnM	Cx, Fau	18
13a	Mn, Val*	2	S	GnM	Cx	18
				S/Ls, Ss*	Ho-Sd	17
13b	Pl	2	L	S/Ls	Ho-Sd	16
				S/Ls	Ho-Sd	13
13c1	Pl	2-3	S	S/Ss, Sh, Ls	Ho-Sd	12
				S/Sh*	Ho-Sd	14
13c2	Val	1	M	S/Ss, Sh	Fo, Fau	12
				Wa*		1
13c3	Mn, Rg	2-3	S-H	S/Ss, Sh	Fo, Fau	12
14a	Pl	1-2	M	S/Ls, Sh	Sd	16
				S/Ls, Sh*	Sd	15
14b	Pl	1-2	M	S/Ls	Sd	16
14c	Pl	1	M	S/Ss, Sh	Sd	12
				S/Ss, Sh, Ls	Sd	13
				Wa*		1
				A*		2
14d	Pl	1-2	M	S/Ls, Sh	Sd	13
				S/Sh, Ss, Ls	Sd	14
15a	Pl	4	H	(u)S/Ss, Sh	Ho	14
				G		2
15b	Pl	2	M-S	G		2
				(u)S/Sh, Ss, Ls	Ho-Sd	14
				(u)S/Ss*	Ho-Sd	13
				(u)S/Ss, Sh, Ls*	Ho-Sd	12
15c	Pl, Rg*	2-4	S	S/Ss, Sh	Ho-Std, Fo	12
				S/Ss	Ho-Std, Fo	12, 13
				S/Sh, Ls*	Ho-Std, Fo	13
				S/Sh, Ss*	Ho-Std, Fo	14
15d	Pl	3-4	M-S	S/Sh, Ss, Ls	Ho	12
				S/Sh, Ls	Ho	11
				S/Ss, Sh, Ls	Ho	13
15e	Pl, Mn, Val*	3	M-S	S/Ss, Sh	Ho	12
				S/Ss, Sh*	Fau	12
				S/Ls*	Fo	16
				S/Ls, Ss, Sh	Ho-Sd	13
16a	Rg, Val	1-3	S	S/Ls, Sh, Ss	Fo, Fau	12-17
16b	Val, Rg	1-3	S	S/Ls, Sh, Ss	Fau, Fo	12-17
17a	Mn, Rg	2-6	M-S	GnM	Cx, Fau	17, 18
				S/Ls*	Ho	16
17b	Pn, Val*	1-2	L	GnM	Cx	18, (11-17) und
				S/Ss, Sh*	Ho	10
18	Val	1	L	S/Ss, Sh	Ho, Fau	10
				IgE	Vc	10
				S/Ls*	Fo	16
				GnM*	Cx	18
				G*		2

TABLE B-4 (*Continued*)

SECT. CODE	CHARACTERISTICS [a, b] PHYSIOGRAPHIC UNIT	ELEV.	RELIEF	GEOLOGIC MATERIAL	STRUCTURE	AGE
19a	Pn	1	L	G		2
				Wcs		2
				(u)GnM	Cx	18
				(u)S/und	Cx, Ho-Sd	(11-17) und
19b	Pl	1-2, 4	M	G		2
				(u)GnM	Cx	18
				(u)S/und	Cx, Ho-Sd	(11-17) und
19c	Val	1	M	G		2
				(u)S/Ss, Sh	Ho, Fau	10
				(u)IgE	Vc	10
19d	Mn	4, 6	H	GnM	Cx	18
				G*		2
19e	Mn	2-3, 5	H	GnM	Cx, Fo	18
				G*		2
19f	Rg, Pl*, Val*	2, 4	S	GnM	Cx	18
				GnM*	Cx-Ho	17
				S/Ls*	Ho-Sd	17
				G*		2
19g	Rg	2	M	GnM	Cx	18
				G*		2
20a	Pn	1	L	Wcs	Ho-Sd	2, (3-7) und
				Wcs	Ho-Sd	8
20b	Pn	1	L	Wcs	Ho-Sd	(3-7) und, 8
				Wcs*	Ho-Sd	2
20c	Pn	1	L	Wcs	Ho	2
				Wcs/Ls	Ho-Sd	6
20d	Pn	1	L	Wcs	Ho-Sd	1-8
20e	Pn	1	L	A		2
20f	Pn	1	L	Wa		1
20g	Pn	1	L	Wcs	Ho-Sd, Fau	1-8

[a] Physiographic characteristics:

Unit	Elevation	Relief
Mn—Mountain	1—0 to 1,000 ft.	L—Low (0-100 ft)
Rg—Ridge, Range	2—1,000 to 2,000 ft.	M—Moderate (100-500 ft)
Pl—Plateau	3—etc.	S—Strong (500-1,000 ft)
Pn—Plain		H—High (≧ 1,000 ft)
Val—Valley		
Bs—Basin		

Geologic characteristics:

Material	Age		
G—Glacial drift	1—Recent	Quaternary (1-2)	Cenozoic (1-7)
A—Windblown	2—Pleistocene		
W—Water			
Wl—Lacustrine	3—Pliocene	Tertiary (3-7)	
Wa—Alluvial	4—Miocene		
Wvf—Valley fill-outwash	5—Oligocene		
Wcs—Coastal sediments	6—Eocene		
GnM—Granitic/Metamorphic Complex	7—Paleocene		
IgE—Ingeous Extrusive			
S—Sedimentary Rocks	8—Cretaceous		Mesozoic (8-10)
S/Ls—Limestone/Dolomite	9—Jurassic		
S/Sh—Shale	10—Triassic		
S/Ss—Sandstone			
C—Combination of Sedimentary, Igneous, and Metamorphic	11—Permian		Paleozoic (11-17)
	12—Pennsylvanian		
	13—Mississippian		
Structure	14—Devonian		
Ho—Horizontal	15—Silurian		
Sd—Slightly dipping	16—Ordovician		
Std—Steeply dipping	17—Cambrian		
Fo—Folded			
Fau—Faulted	18—Precambrian		Precambrian (18)
Vc—Volcanic			
Cx—Complex	Cx—Complex mixture		

[b] Explanatory notes:
* = minor or variant characteristic compared to the major or modal characteristics of the Section.
und = undifferentiated. This may be applied to material or age; e.g., (11-17) und = age is undifferentiated Paleozoic; (11-17) = *all* systems of Paleozoic Era are present in Section.
(u) = material (generally consolidated) that underlies a transported material.

TABLE B-5

DIFFERENCES IN PHYSIOGRAPHIC CATEGORIZATIONS BETWEEN PHYSIOGRAPHERS AND BASIC REPORT UNITS [a]

BASIC REPORT UNIT	WOODS-LOVELL	FENNEMAN	LOBECK
1. Western Mountains of the Pacific Coastal Range	Western Mtns. or Pacific Coast Ranges	Pacific Border Prov.	Pacific Coast Ranges
a. Olympic Mountains	nd	nd	nd
b. Oregon Coast Range	nd	nd	nd
c. Klamath Mountains	nd	nd	nd
d. California Coast Range	nd	nd	nd
e. Los Angeles Ranges	nd	nd	nd
2. Sierra-Cascade	Eastern Mtns. or Sierra-Cascade-Coast Mtns.	Cascade-Sierra Mtns.	Sierra-Cascade-Coast Mtn. Prov.
a. Northern Cascade Mountains	Cascade and Sierra Nevada Mtns.	Nor., Mid., Sou. Cascade Mtns.	Cascade Sect.
b. Southern Cascade Mountains			
c. Sierra Nevada		nd	nd
d. Lower California	nd	Lower Calif. Prov.	nd
3. Pacific Troughs	nd	Part of Pacific Border Prov.	nd
a. Puget Sound	nd	Puget Trough Sect.	Puget Sound Sect.
b. Willamette Valley	nd		
c. California Valley	nd	Calif. Trough Sect.	nd
4. Columbia Plateau	nd	nd	nd
a. Walla Walla	nd	nd	nd
b. Blue Mountains	nd	nd	nd
c. Snake River Plains	nd	nd	nd
d. Payette	nd	nd	nd
e. Harney	nd	nd	nd
5. Basin and Range	Basin and Range and Mex. Highlands Prov.	nd	Basin and Range and Mex. Highlands Prov.
a. Great (Closed) Basin	nd	nd	nd
b. Sonoran Desert	nd	nd	nd
c. Salton Trough	nd	nd	nd
d. Open Basin (Mexican Highland)	Sects. of Mex. Highlands Prov.	Part of Mex. Highlands Sect.	nd
e. Sacramento Highland		nd	nd
f. Great Bend Highland		Part of Mex. Highlands Sect.	Sect. of Mex. Highlands Prov.
6. Colorado Plateau	nd	nd	nd
a. High Plateaus of Utah	nd	nd	nd
b. Uinta Basin	nd	nd	nd
c. Canyon Lands	nd	nd	nd
d. Navajo	nd	nd	nd
e. Grand Canyon	nd	nd	nd
f. Datil	nd	nd	nd
7. Northern Rocky Mountains	nd		nd
a. Montana	nd	No subdivision	Including parts of Purcell Range and Selkirk Mtns.
b. Bitterroot	Includes small portions of Purcell, Selkirk, and Colum. Range Sect.		
c. Salmon River	nd		nd
8. Middle Rocky Mountains	nd	nd	Including Wyoming Basin
a. Yellowstone	nd		nd
b. Bighorn Mountains	nd		nd
c. Wind River Mountains	nd	No subdivision	Part of Wyoming Basin Sect.
d. Wasatch	nd		nd
e. Uinta Mountains	nd		nd
9. Southern Rocky Mountains	nd	nd	nd
a. Front Range	nd		nd
b. Western	nd	No subdivision	nd
c. San Juan Mountains	nd		nd

TABLE B-5 (*Continued*)

BASIC REPORT UNIT	WOODS-LOVELL	FENNEMAN	LOBECK
10. Great Plains	nd	Parts of 3 Provs.	Parts of 2 Provs.
a. Glaciated Missouri Plateau	nd	nd	nd
b. Unglaciated Missouri Plateau	nd	nd	nd
c. Bighorn Basin	nd	Part of Middle Rocky Mtns.	Sect. of Middle Rocky Mtns.
d. Wyoming Basin	nd	Wyoming Basin Prov.	Sect. of Middle Rocky Mtns.
e. Black Hills	nd	nd	nd
f. High Plains	nd	nd	nd
g. Colorado Piedmont	nd	nd	nd
h. Raton Upland	nd	nd	nd
i. Pecos Valley	nd	nd	nd
j. Plains Border	nd	nd	nd
k. Central Texas Mineral	nd	nd	nd
l. Edwards Plateau	nd	nd	nd
m. Osage Plains	nd	Sect. of Cent. Low. Prov.	Sect. of Cent. Low. Prov.
11. Central and Eastern Lowlands	Cent. and East. Lowlands and Plains	Parts of 4 Provs.	Parts of 2 Provs.
a. St. Lawrence Lowlands	nd	Nor. Sect., St. Lawrence Valley	Sect. of Newer Appalachian Prov.
b. Champlain Lowlands	nd	Champlain Sect., St. Lawrence Valley	Sect. of Newer Appalachian Prov.
c. Hudson River Valley	nd	Sect. of Valley and Ridge Prov.	Sect. of Newer Appalachian Prov.
d. Mohawk River Valley	nd	Sect. of Appalachian Plat. Prov.	Part of East. Lake Sect.
e. Eastern Lakes and Lacustrine	nd	East. Lake Sect.	Includes Mohawk R. Valley
f. Central Till Plains	nd	nd	nd
g. Driftless	nd	nd	nd
h. Western Lakes and Lacustrine	nd	West. Lake Sect.	West. Lake Sect.
i. Dissected Loess and Till Plains	nd	Dissect. Till Plains Sect.	Dissect. Till Plains Sect.
12. Laurentian Upland	nd	Parts of 2 Provs.	nd
a. Superior Upland	nd	nd	nd
b. Adirondack	nd	Adirondack Prov.	nd
13. Ozark and Ouachita	nd	Ozark Plateaus and Ouachita Provs.	Ozark and Ouchita Provs.
a. St. Francis Mountains	nd	Part of Springfield-Salem Plat.	nd
b. Springfield-Salem	nd	Includes St. Francis Mtns.	nd
c1. Boston Mountains		nd	nd
c2. Arkansas Valley	Grouped	nd	nd
c3. Ouchita Mountains		nd	nd
14. Interior Low Plateaus	nd	nd	nd
a. Blue Grass	nd	Lexington Plain	nd
b. Nashville Basin	nd	nd	nd
c. Shawnee Hills	nd	Suggested; not delimited	Part of Highland Rim Sect.
d. Highland Rim	nd	nd	Includes Shawnee Hills
15. Appalachian Plateau	nd	nd	nd
a. Catskill Mountains	nd	nd	nd
b. New York Glaciated	nd	Sou. New York Sect.	New York State Sect.
c. Allegheny Mountains	nd	nd	nd
d. Kanawha	nd	nd	nd
e. Cumberland	nd	Subdivided into Mtn. and Plateau Sects.	nd
16. Newer Appalachian (Ridge and Valley)	Ridge and Valley Prov.	Valley and Ridge Prov.	Newer or Folded Appalachian Prov.
a. Pennsylvania-Maryland-Virginia	nd	Middle Sect.	nd
b. Tennessee	nd	nd	nd
17. Older Appalachian	No counterpart	No counterpart	nd
a. Blue Ridge	Blue Ridge Prov.	Blue Ridge Prov.	nd
b. Piedmont	Piedmont Prov.	Piedmont Upland of Piedmont Prov.	nd

TABLE B-5 (*Continued*)

BASIC REPORT UNIT	WOODS-LOVELL	FENNEMAN	LOBECK
18. Triassic Lowland	nd	Piedmont Lowlands of Piedmont Prov.	nd
19. New England Maritime	nd	N.E. Prov.	nd
a. Seaboard Lowland	nd	nd	nd
b. New England Upland	nd	nd	nd
c. Connecticut Lowland	nd	Part of N.E. Upland Sect.	nd
d. White Mountains		nd	nd
e. Green Mountains	Grouped	nd	nd
f. Taconic		nd	nd
g. Reading Prong			Part of N.E. Upland Sect.
20. Atlantic and Gulf Coastal Plain	nd	Coastal Plain Prov.	nd
a. Embayed	nd	nd	nd
b. Sea Island	nd	nd	nd
c. Florida	nd	nd	nd
d. East Gulf	nd	Includes Miss. Loess. Upland	Includes Miss. Loess. Upland
e. Mississippi Loessial Upland	nd	Part of East Gulf Coast Plain	Part of East Gulf Sect.
g. Mississippi Alluvial Plain	nd	nd	nd
h. West Gulf	nd	nd	nd

[a] nd = essentially no difference in name or boundary from basic report unit.

HIGHWAY DESIGN FACTORS

Aggregates

Questionnaire Response

The over-all response to the materials questionnaire was considered good. Of the 48 contiguous states, 39 answered the entire questionnaire, 4 states partially completed it, and 5 states did not answer any of the questions. As an aid to the development and presentation of the results, the response to the questionnaire is summarized in Table B-6.

Mapping

Potential Aggregate Areas and Pit and Quarry Locations.—Figures B-2 to B-5 summarize the attempt to delineate regions in the U.S. where potential regional crushed stone and sand-gravel deposits occur. The crushed stone sources are further divided into carbonate rocks, granitic/metamorphic-complex-type rocks, and other igneous rocks. The mapping of the carbonate zones east of the Rocky Mountain-Great Plains border affords a relatively accurate pattern of the distribution of these sources. Not all of the carbonate rock sources have been mapped, owing to the great difficulty in determining their distribution. Areas where regional carbonate sources may occur but are not mapped are:

1. The northern portion of the New England Upland Section (19b) (e.g., in Maine).
2. The Pecos Valley Section (10i).
3. Ranges of the Basin and Range Province (5), composed of carbonate rocks (in part or total).
4. Along the western flank of the Sierra Nevada Section (2c) and other minor areas in California.

The relative accuracy of the granitic/metamorphic complex areas is slightly less than that of the carbonate rocks. For the most part, the former areas were distinguished on the basis of geologic distribution rather than by any qualitative estimate of the problems associated with their use as aggregates.

The relative accuracy of definition of the other igneous rock areas is the poorest of the three crushed stone areas. Distribution of these rocks was obtained by a method similar to that used for the granitic/metamorphic map.

The relative accuracy of the sand-gravel map is variable, owing to the wide range of references interpreted for assembly of the zones. Further division of types of granular deposits is shown on this map.

TABLE B-6

RESPONSE TO MATERIALS QUESTIONNAIRE, BY STATE [a]

STATE	RESPONSE [b]
California	Reply—answered question Nos. 5-7
Kentucky	Reply—answered question No. 4 (partially), Nos. 5-7
Minnesota	No reply
Nevada	Reply—no parts answered
New Mexico	Reply—answered question No. 5
Rhode Island	No reply
South Carolina	No reply
Texas	Reply—answered question No. 7
Utah	Reply—no parts answered

[a] All states *not* listed replied and answered all parts of the materials questionnaire.
[b] For partial replies, question numbers are referenced to the materials questionnaire in Appendix A.

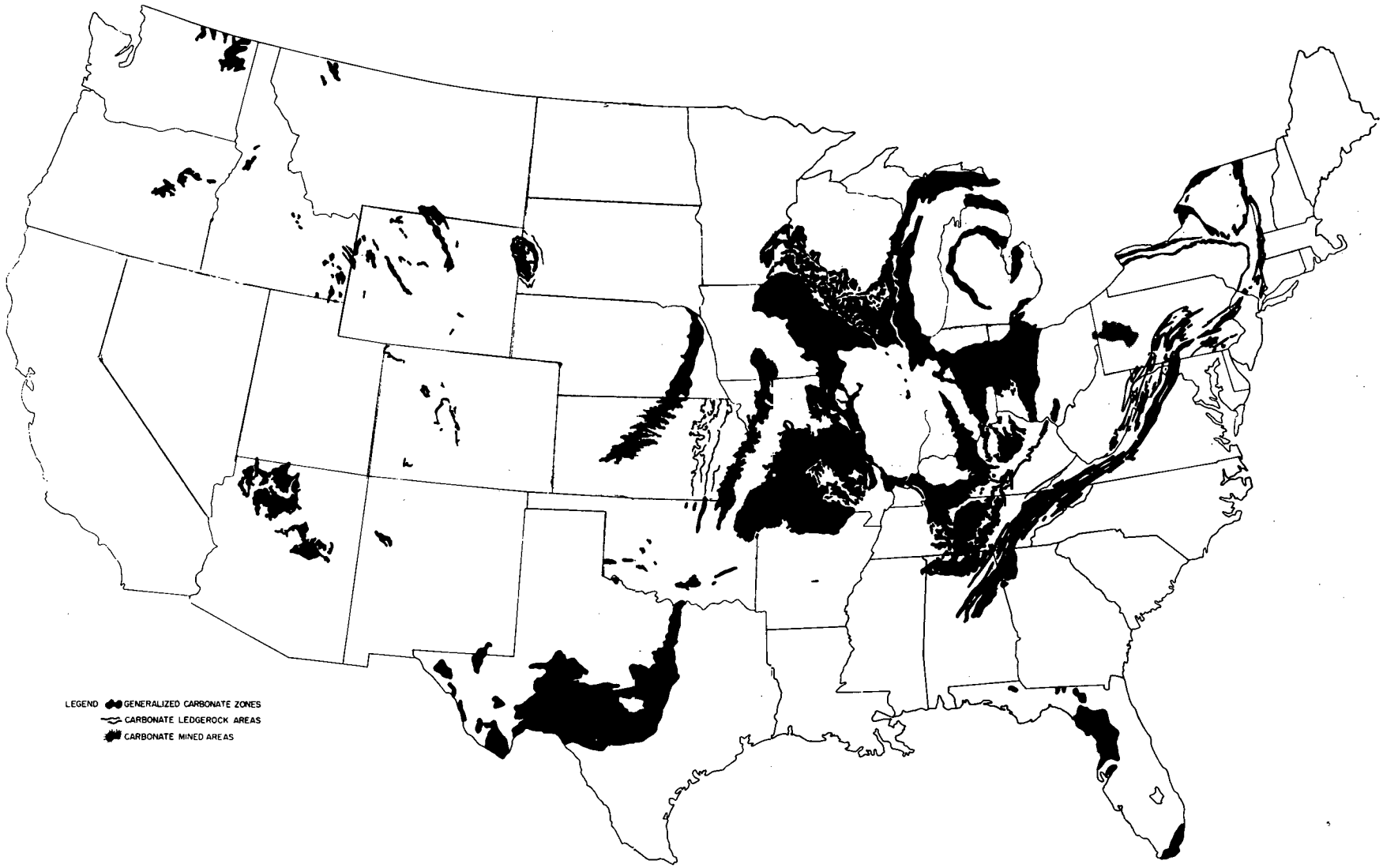


Figure B-2. Distribution of general potential crushed carbonate stone areas.

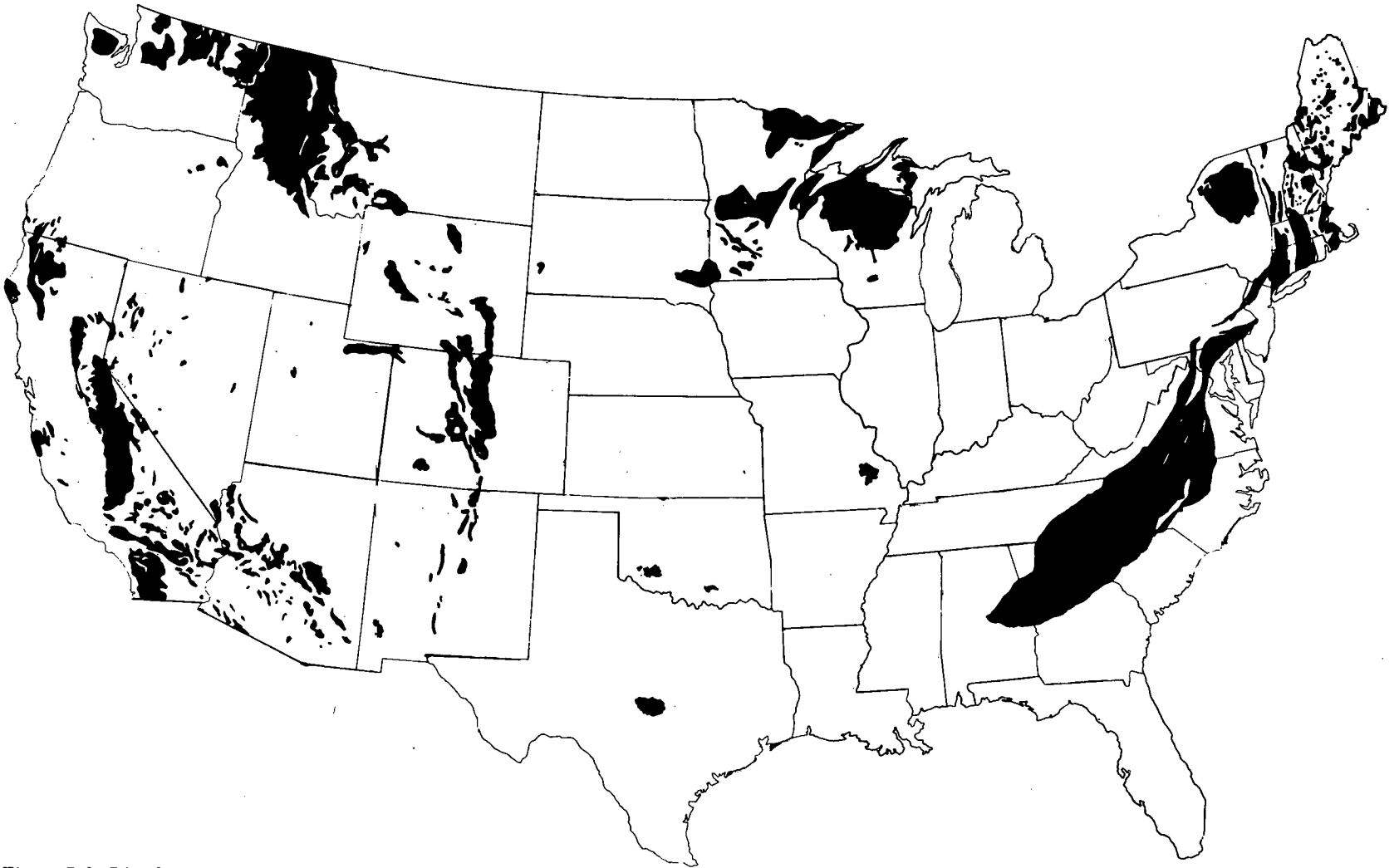


Figure B-3. Distribution of general potential crushed granitic metamorphic complex stone areas.

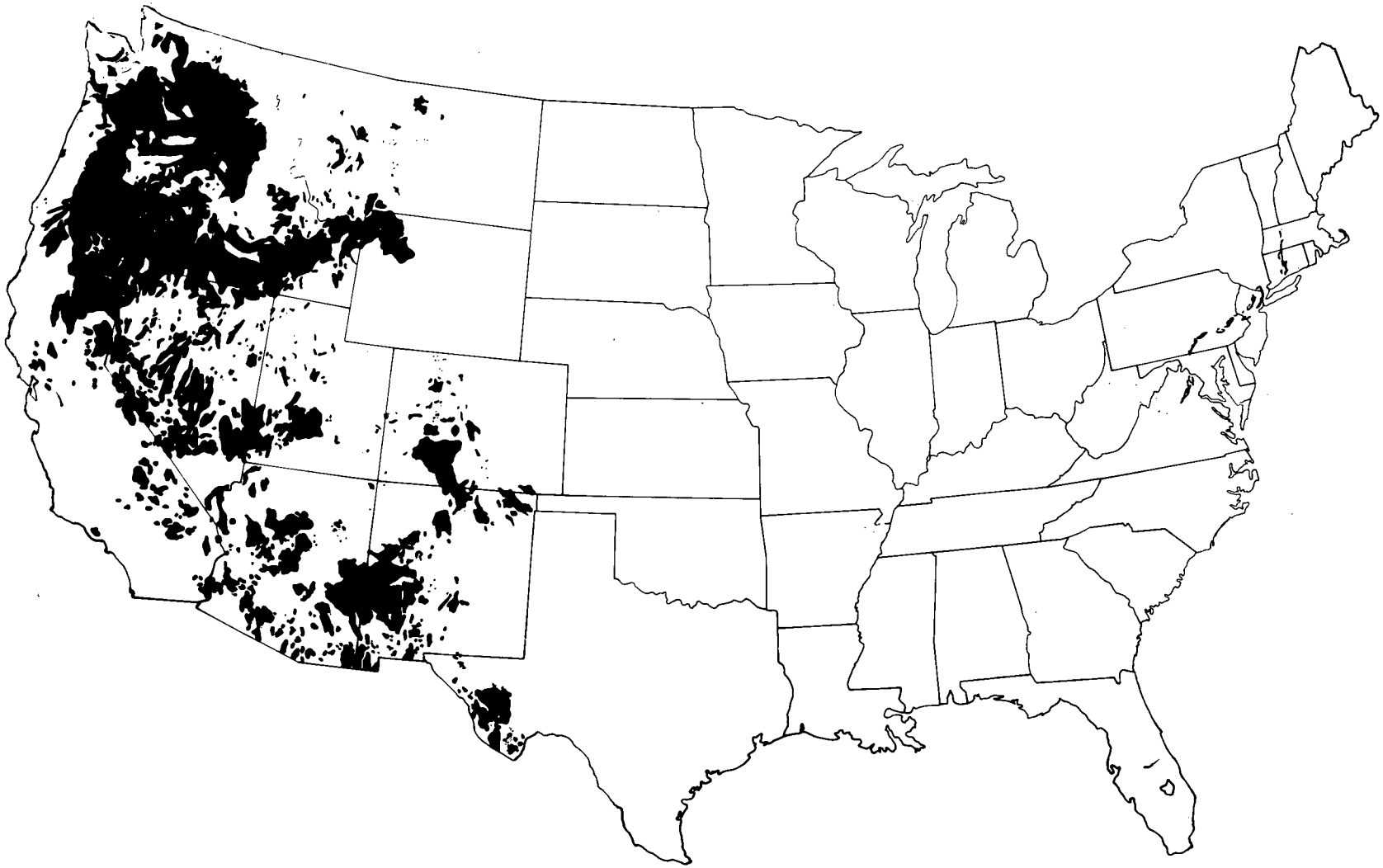


Figure B-4. Distribution of general potential crushed igneous (exclusive of granite) stone areas.

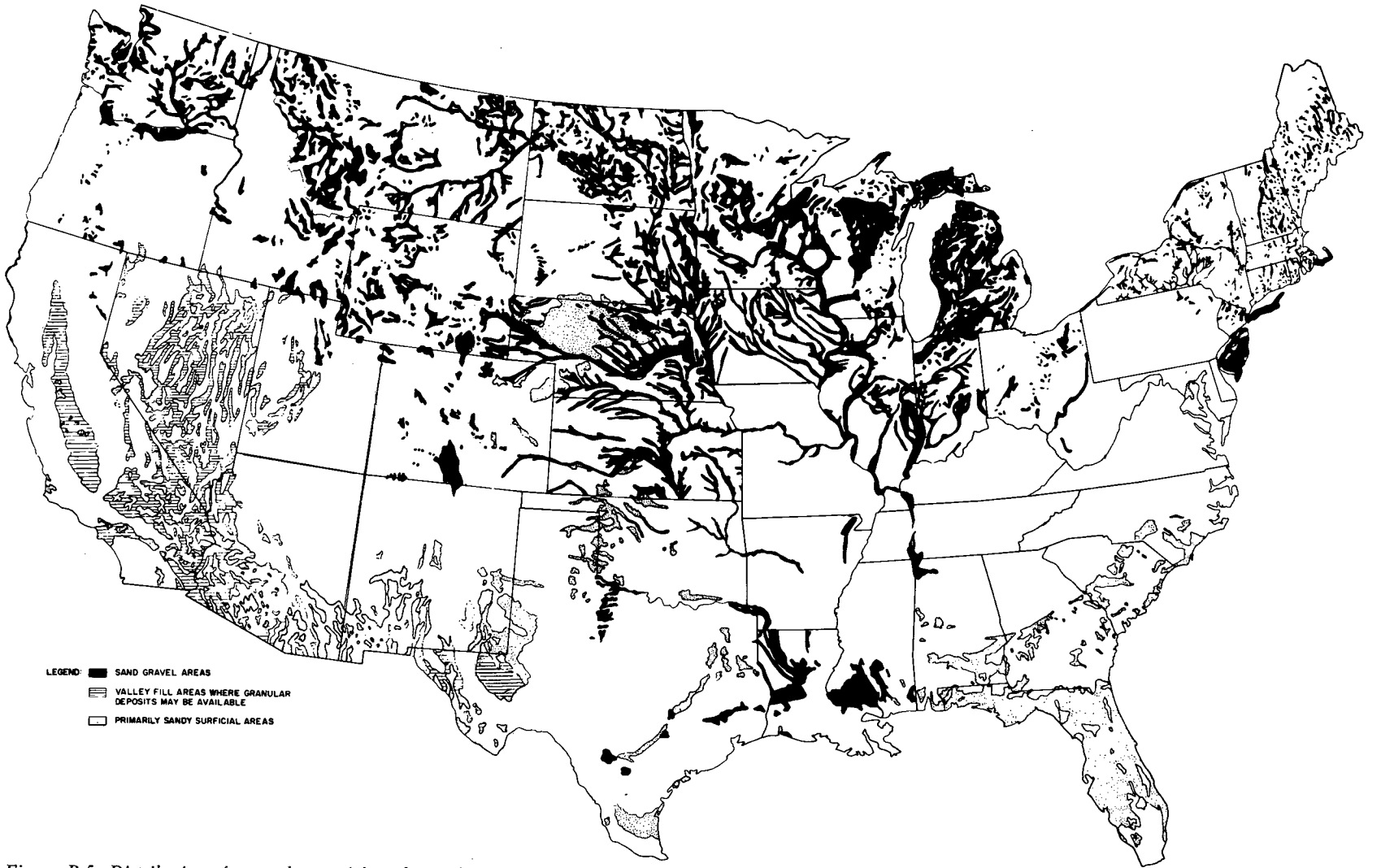


Figure B-5. Distribution of general potential sand-gravel areas.

Figures B-6, B-7, and B-8 show the distribution of pits and quarries in the U.S. Figure B-6 shows available data concerning the distribution of sand and sand-gravel pits. Figure B-7 shows crushed stone quarries, irrespective of major geologic rock types (i.e., metamorphic, igneous, and carbonates). Figure B-8 shows the distribution of miscellaneous-type sources. Included in this group, but not separately identified, are slag, lightweight aggregate, caliche, clam/oyster shells, and coquina.

Table B-7 summarizes by state the references from which information concerning potential aggregate areas and pit and quarry distribution was obtained.

Distribution of Counties Not Producing Aggregate Sources.—Individual counties not producing sand-gravel and crushed stone during 1964 were located from Ref. *189*. Figures B-9 and B-10 show the distribution of those units not producing sand-gravel or crushed stone, respectively. Figure B-11 shows counties not producing either (i.e., non-aggregate-producing counties). The large size of western counties limited the usefulness of this mapping in gen-

TABLE B-7

REFERENCE SUMMARY OF STATE PIT/QUARRY-AGGREGATE AREAS

STATE	REFERENCES [a] PITS/QUARRIES	CRUSHED STONE	SAND-GRAVEL
Alabama	(*169, 172*)	(*107, 137, 190*)	(*123*)
Arizona	(*169, 172*)	(*190*)	(*123*)
Arkansas	(*169, 172*)	(*190*)	(*123, 190*)
California	(*107, 169, 172*)	(*107, 190*)	(*123, 204*)
Colorado	(*166, 169, 172*)	(*166, 190*)	(*123, 166*)
Connecticut	(*166, 169, 172*)	(*166, 190*)	(*184*)
Delaware	(*169, 172*)	(*190*)	—
Florida	(*169, 172*)	(*107*)	(*123*)
Georgia	(*169, 172*)	(*123, 190*)	(*123*)
Idaho	(*166, 169, 172*)	(*166, 190*)	(*166, 204*)
Illinois	(*107, 169, 172*)	(*90, 107, 190*)	(*90*)
Indiana	(*90, 104, 169, 172*)	(*90, 104, 190*)	(*90*)
Iowa	(*90, 122, 169, 172*)	(*90, 107, 190*)	(*90, 122*)
Kansas	(*107, 169, 172*)	(*90, 190*)	(*90, 123*)
Kentucky	(*169, 172*)	(*107, 190*)	(*123*)
Louisiana	(*169, 172*)	—	(*123, 133*)
Maine	(*166, 169, 172*)	(*166, 190*)	(*184*)
Maryland	(*169, 172*)	(*190*)	—
Massachusetts	(*166, 169, 172*)	(*166, 190*)	(*184*)
Michigan	(*169, 172*)	(*107, 190*)	(*90*)
Minnesota	(*169, 172, 174*)	(*90, 174, 190*)	(*90, 174*)
Mississippi	(*169, 172*)	—	(*123, 204*)
Missouri	(*169, 172*)	(*90, 107, 190*)	(*190*)
Montana	(*166, 169, 172*)	(*166, 190*)	(*166*)
Nebraska	(*169, 172*)	(*90, 190*)	(*90, 123*)
Nevada	(*169, 172*)	(*190*)	(*123*)
New Hampshire	(*166, 169, 172*)	(*166, 190*)	(*166, 184*)
New Jersey	(*166, 169, 172*)	(*166, 190*)	(*166*)
New Mexico	(*155, 169, 172*)	(*190*)	(*123*)
New York	(*107, 157, 166, 169, 172*)	(*107, 166*)	(*137*)
North Carolina	(*169, 172*)	(*190*)	(*123*)
North Dakota	(*90, 169, 172*)	—	(*90*)
Ohio	(*107, 169, 172*)	(*90, 107, 190*)	(*90*)
Oklahoma	(*107, 169, 172*)	(*107, 190*)	(*123, 190*)
Oregon	(*166, 169, 172*)	(*166, 190*)	(*166*)
Pennsylvania	(*166, 169, 172*)	(*107, 166, 190*)	(*166*)
Rhode Island	(*166, 169, 172*)	(*190*)	(*149, 184*)
South Carolina	(*166, 169*)	(*190*)	(*123*)
South Dakota	(*90, 166, 169*)	(*90, 190*)	(*90*)
Tennessee	(*107, 166, 169*)	(*107, 190*)	(*123*)
Texas	(*107, 166, 169*)	(*107, 123, 190*)	(*123*)
Utah	(*166, 169, 172*)	(*190*)	(*123, 166*)
Vermont	(*166, 169, 172*)	(*166, 190*)	(*184*)
Virginia	(*107, 169, 172*)	(*107, 137, 190*)	(*190*)
Washington	(*95, 166, 169, 172*)	(*190*)	(*95, 166*)
West Virginia	(*107, 166, 169*)	(*107, 190*)	(*166*)
Wisconsin	(*90, 169, 172*)	(*90, 190*)	(*90*)
Wyoming	(*166, 169, 172*)	(*166, 190*)	(*166*)

[a] Numbers refer to bibliography reference number.

Figure B-6. Distribution of sand and sand-gravel pits.

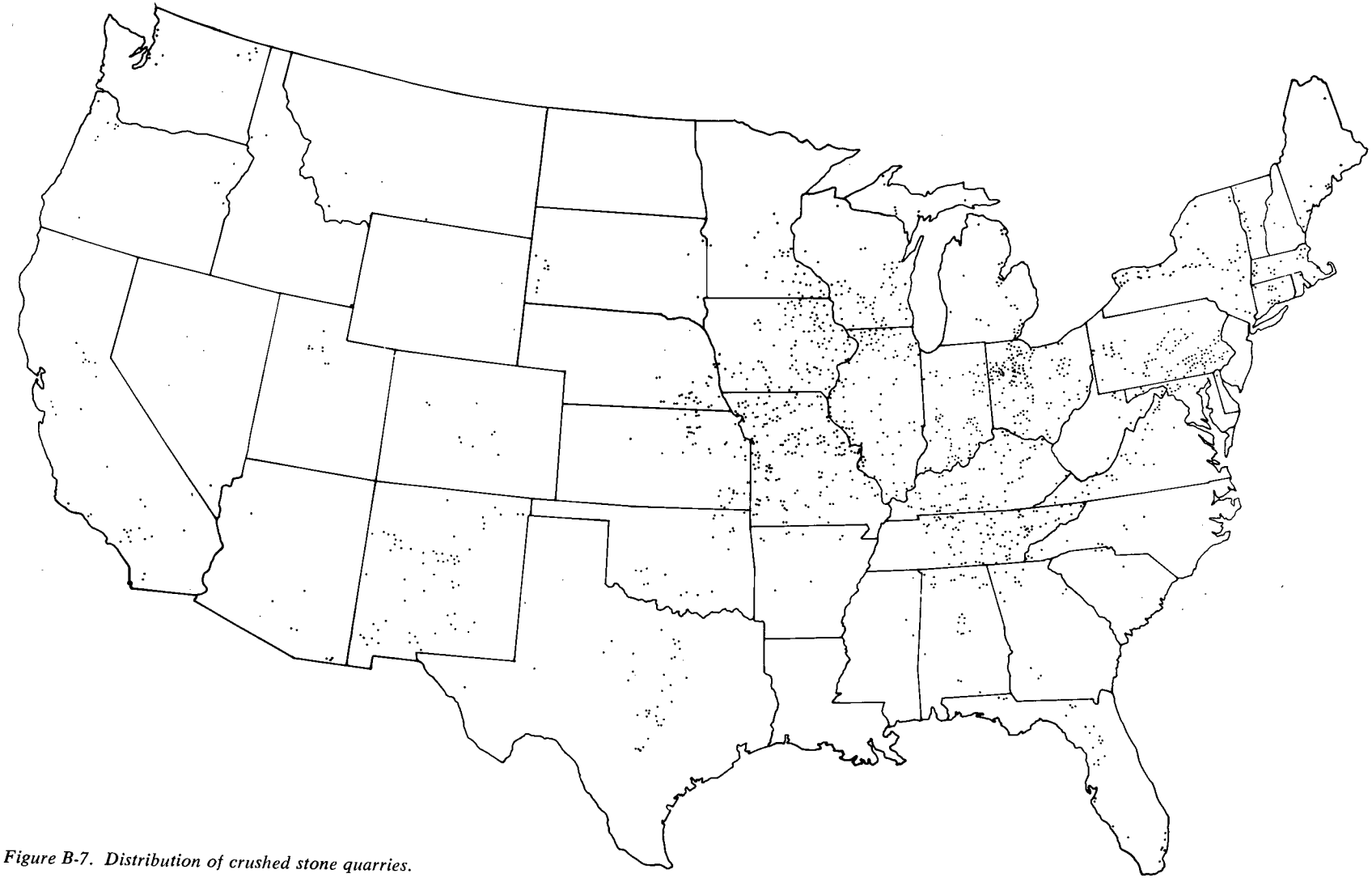


Figure B-7. Distribution of crushed stone quarries.

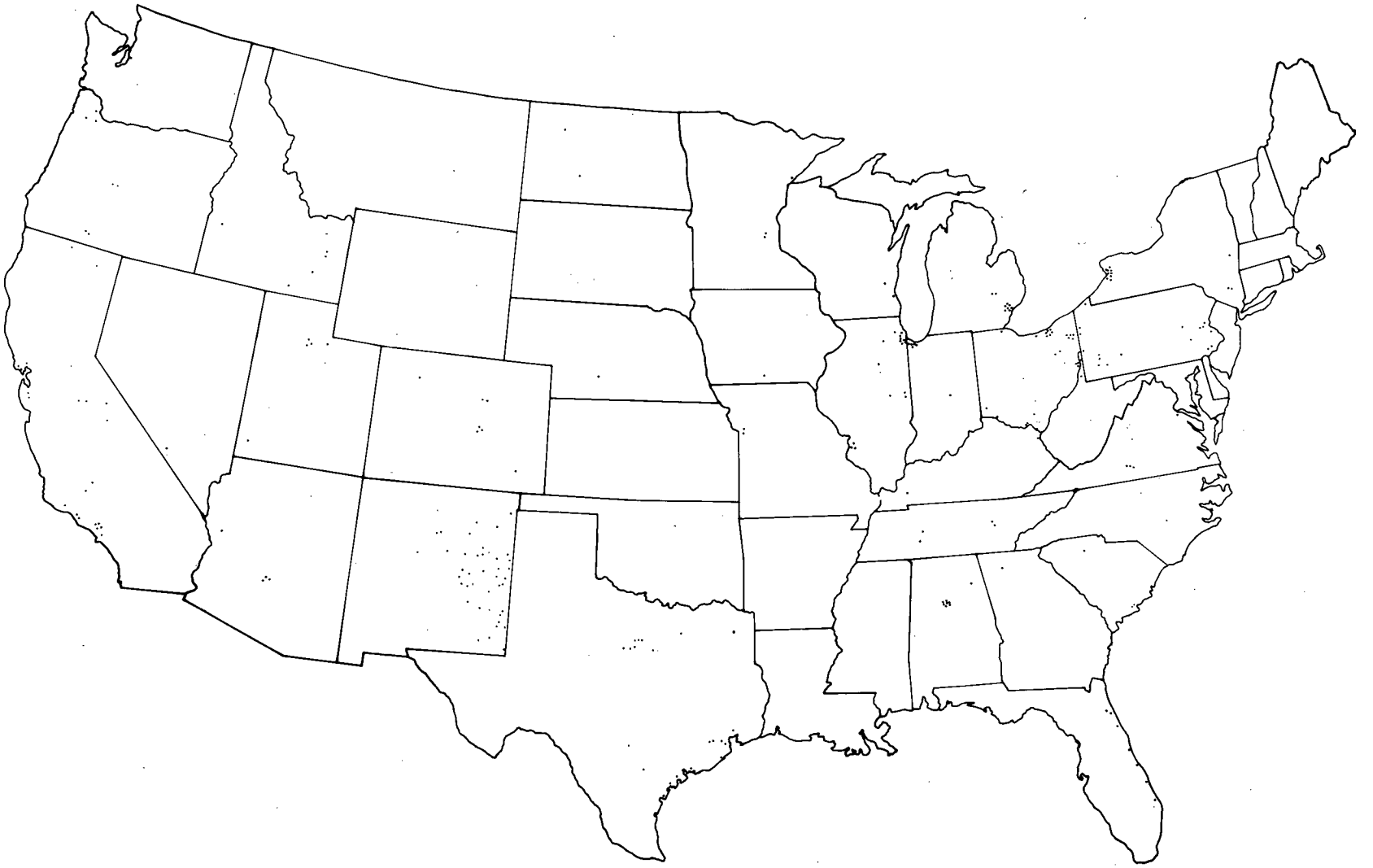


Figure B-8. Distribution of miscellaneous aggregate type locations (includes slag, caliche, coquina, shells, and lightweight aggregate).

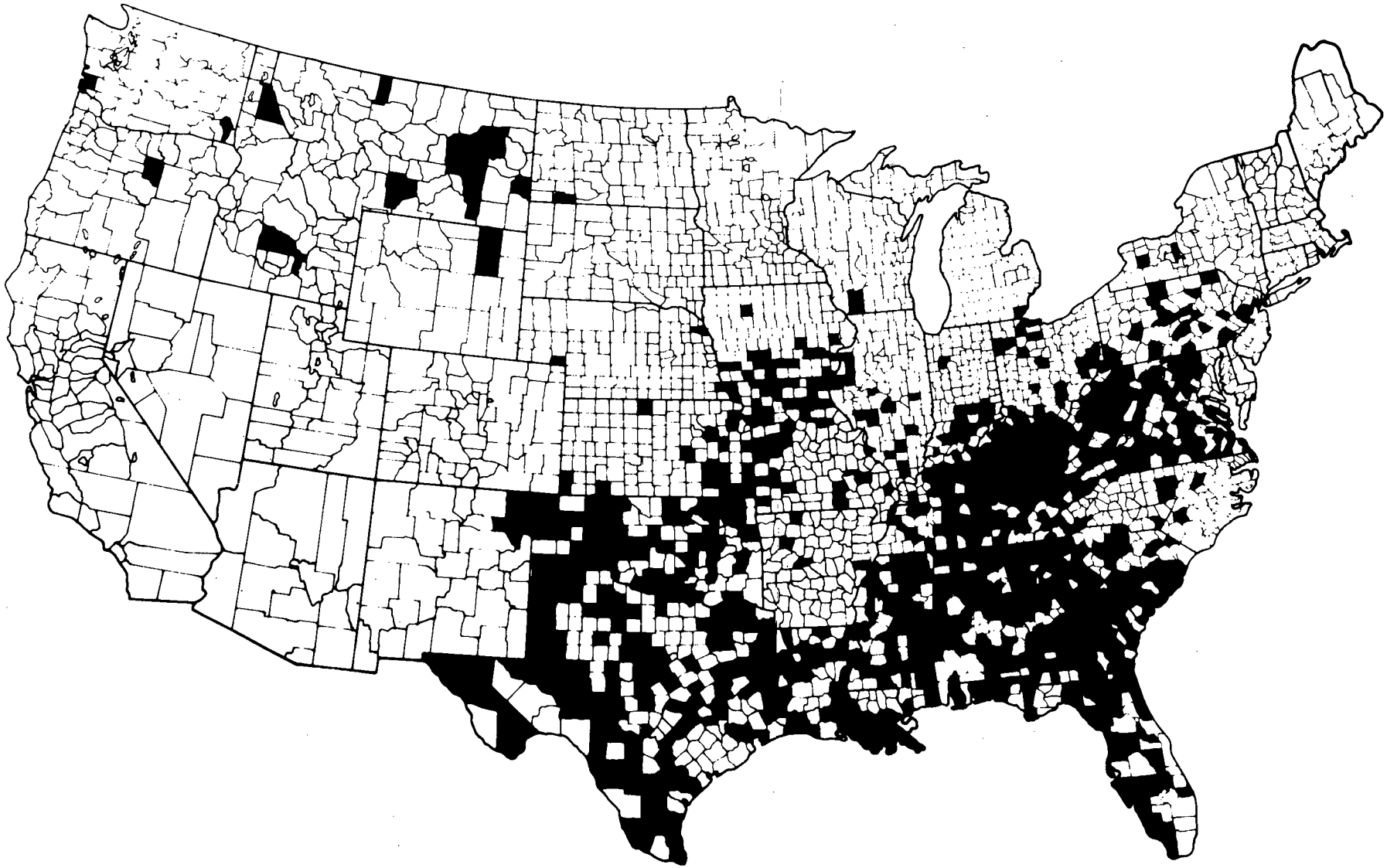


Figure B-9. Distribution of counties not producing sand-gravel in 1964. Source: Ref. 189.

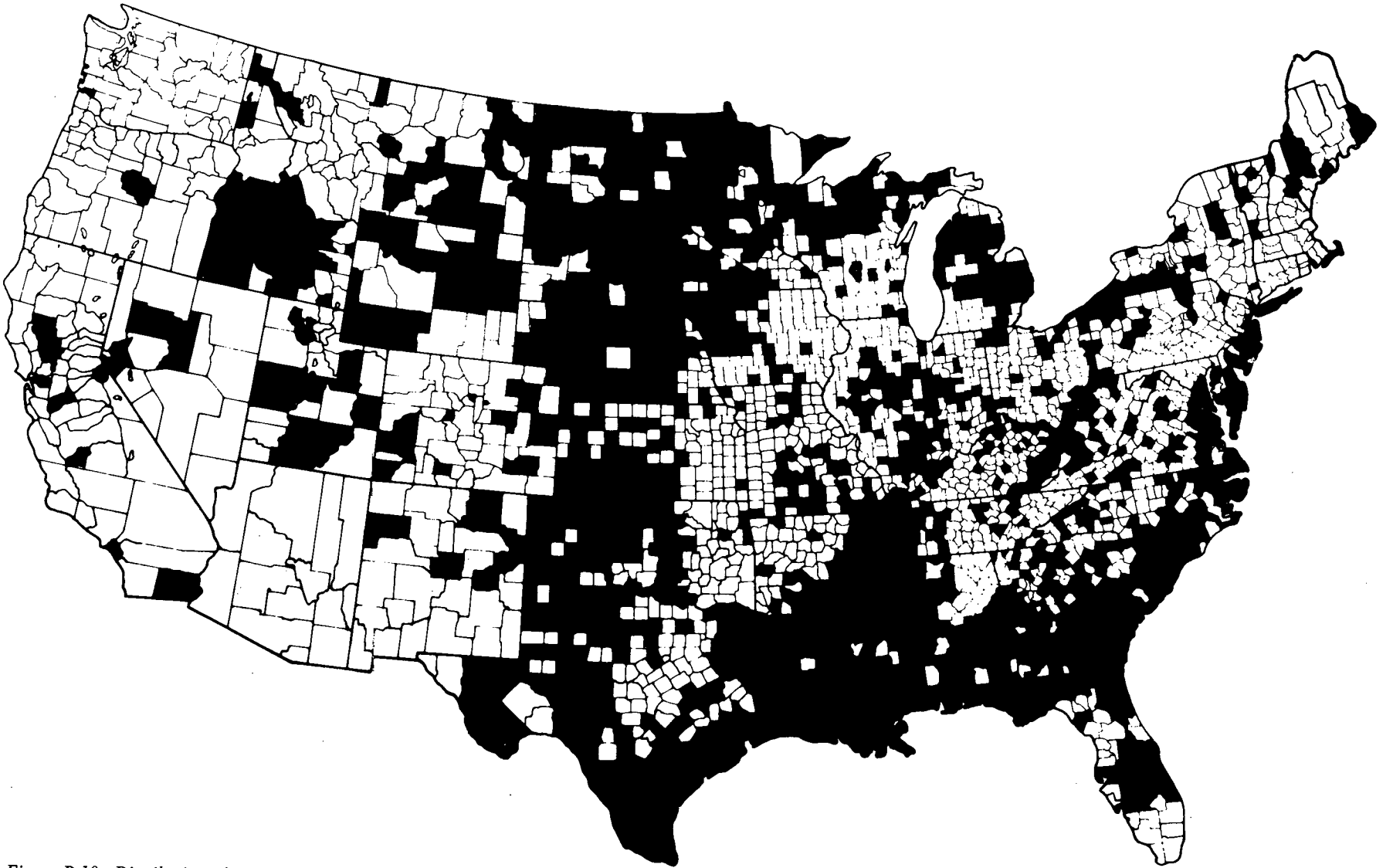


Figure B-10. Distribution of counties not producing crushed stone in 1964. Source: Ref. 189.

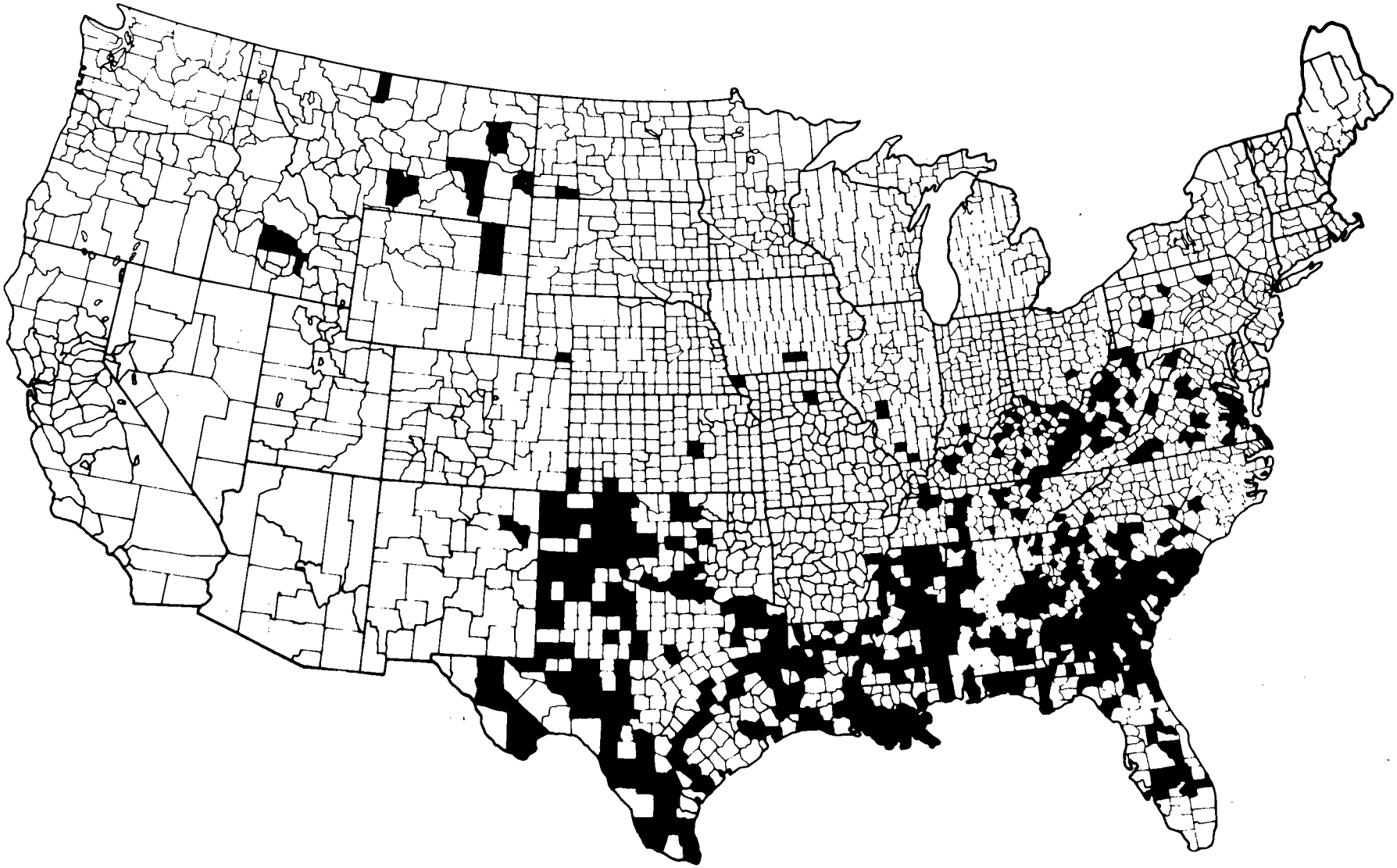


Figure B-11. Distribution of counties not producing sand-gravel or crushed stone in 1964. Source: Ref. 189.

eralizing as to potential aggregate areas. Consequently, use of these maps was limited to the eastern U.S.

Areas Lacking Quality Aggregates (Materials Questionnaire).—Additional guidance in identifying areas lacking quality aggregate resources was obtained from the materials questionnaire. Figure B-12 shows the aggregate-poor areas reported by the representative state highway officials who completed this portion of the questionnaire. This map was relied on heavily to provide the estimated potential availability ratings of each basic report unit.

State Aggregate Production Data.—Quantitative state production data for sand-gravel and crushed stone sources were obtained from Refs. *175* and *189*. The sand-gravel data were for 1964; data for crushed stone were the reported output for 1958. Differences between states were determined in part by variations in demand caused by size of population and area. In an attempt to "normalize" these production outputs, they were divided by the product of area times population, yielding a "production density" (tons/sq mi/capita). These were arranged in numerical order and divided into three groups or zones.

In addition, a production output ratio of sand-gravel to crushed stone was determined for each state. This ratio was grouped in five zones based on a visual examination of the numerical ranking. Pertinent data for production tonnage, population, and area for each state are given in Appendix D. Figures B-13 to B-15 show the zones previously described.

Aggregate Types

Aggregate Type Code.—A wide variety of aggregate sources is used in the highway industry; 34 types are recognized in this report. Table B-8 lists these aggregates, keyed to a numerical code. The aggregates are grouped as sands and gravels, crushed stone, and miscellaneous. The last group consists primarily of artificial aggregates as well as the researchers' interpretation of several "localized" aggregate sources (e.g., coquina, clam/oyster shell). The crushed stone group is further divided by type of rock. The relation between the coded aggregate number and the general category of aggregate should be apparent (sedimentary crushed stone types have the 10 series; igneous crushed stones, the 20 series; etc.).

State Use.—Table B-9 is a resume of the major aggregate type sources used by each state. This summary is based primarily on the responses to the materials questionnaire. Where states did not provide such information, input was obtained from Miles (*144*) and Refs. *169, 172,* and *188,* and is accordingly more tentative. Pertinent remarks extracted from the questionnaire responses, as well as several by the researchers, are given in the table.

Section Use.—Table B-10 is a summary of the aggregate types used, by Section. Results were compiled primarily from the materials questionnaire. In addition, where the literature review indicated an aggregate source *not* appearing in the questionnaire response, the reference is cited.

TABLE B-8

AGGREGATE TYPE CODE

AGGREGATE TYPE	KEY
I. *Sands and gravels*	
Sand	1
Gravel	2
Sand-gravel	3
II. *Crushed stone*	
A. Sedimentary	
Limestone	10
Dolomite	11
Chert	12
Sandstone	13
Novaculite	14
Argillite	15
B. Igneous	
1. Extrusive	
Basalt	21
Diabase	22
Rhyolite	23
Andesite	24
Greenstone	25
2. Intrusive	
Diorite	26
Gabbro	27
Granite	28
Syenite	29
C. Metamorphic	
1. Nonfoliated	
Marble	30
Quartzite	31
Serpentine	32
2. Foliated	
Gneiss	33
Schist	34
Amphibolite	35
III. *Miscellaneous*	
Limerock	40
Coquina	41
Clam/oyster shell	42
Scoria	43
Volcanic cinders	44
Pumice	45
Expanded clay	46
Slag	47
Silicified chalk	48
Caliche	49

Availability of Quality Aggregates, by Section

The primary objective of this phase of the project was to determine a potential availability rating of quality aggregate resources for each Section. This rating was based on an analysis of the various inputs of data previously described. An arbitrary rating scale was devised, consisting of: (1) abundant to adequate, (2) adequate to limited, (3) limited to problem, and (4) severe problem.

Ratings were assigned to the Sections by: (1) determining the major type or types of aggregates used, (2) examining their relative distribution in the unit, and (3) assessing the major quality problems of the aggregate sources. Thus, it was possible for an area having an abundant distribution of a potential aggregate type to

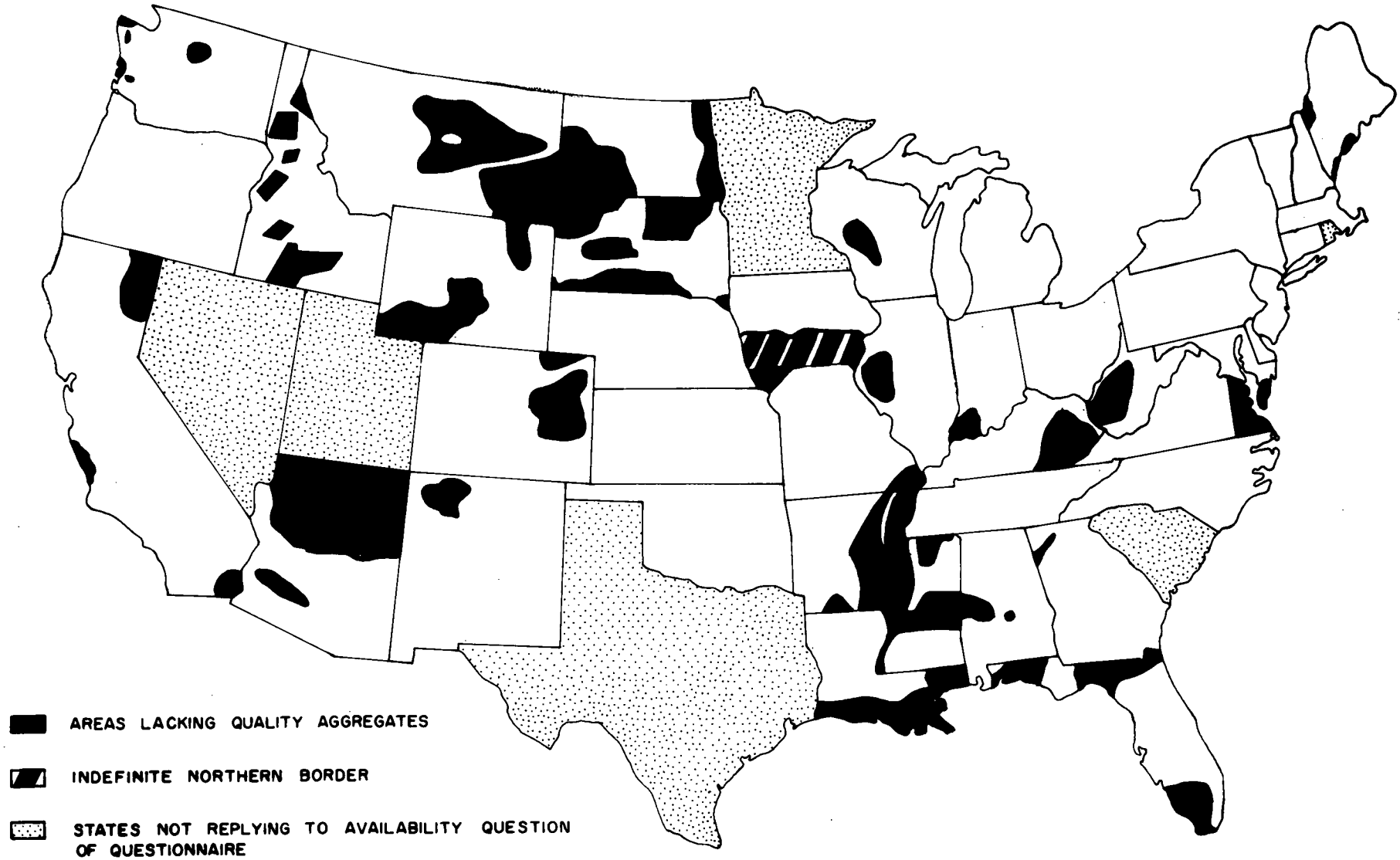


Figure B-12. Questionnaire summary of areas lacking quality aggregates.

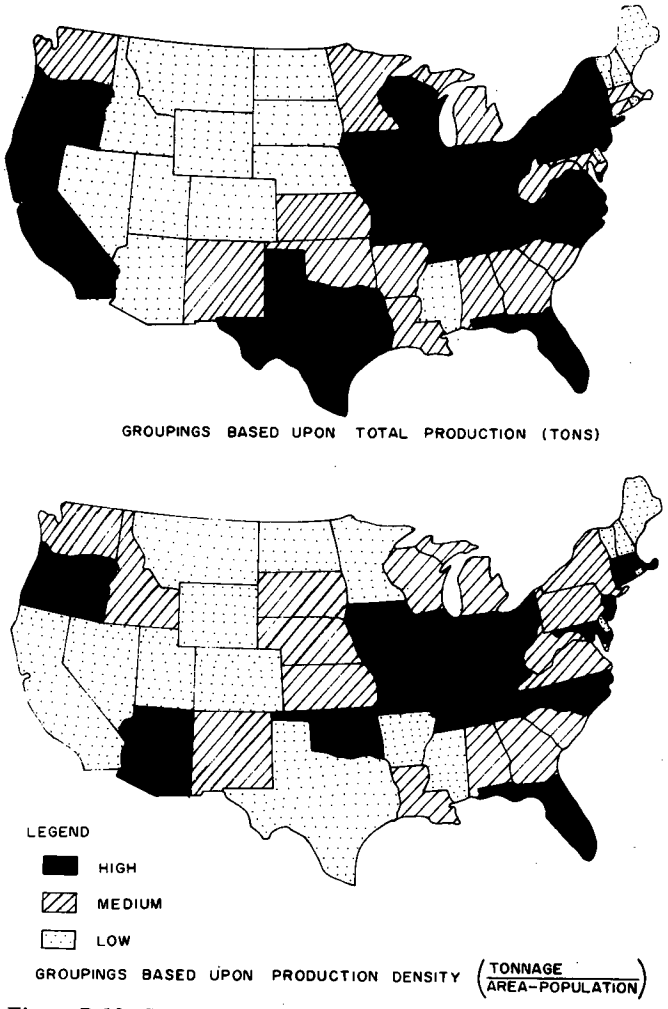


Figure B-13. Summary of state crushed stone production groupings. Data based on 1958 production.

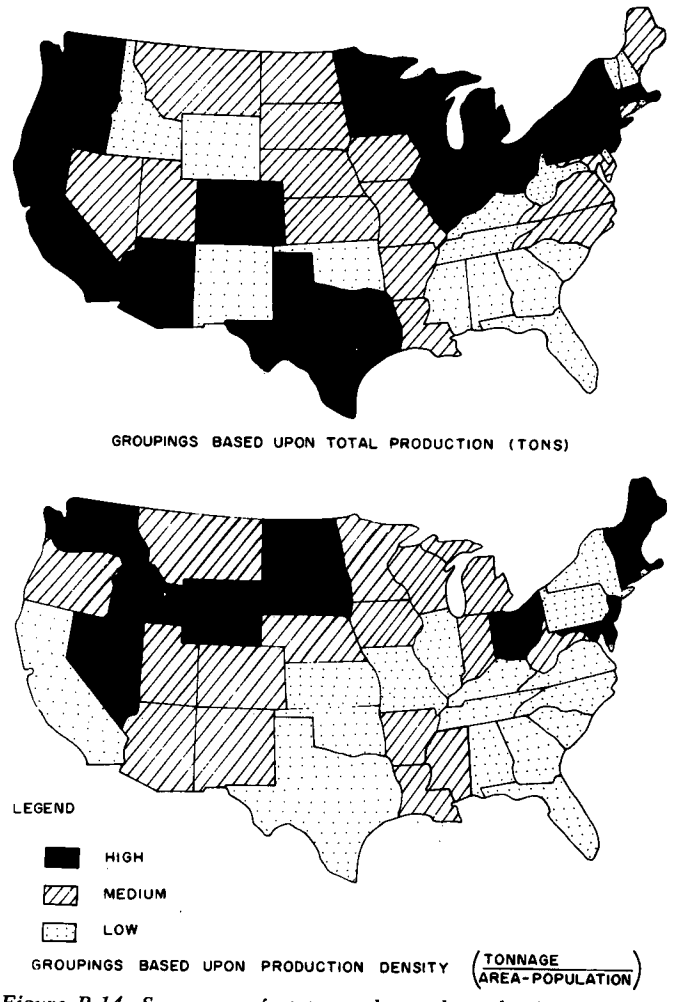


Figure B-14. Summary of state sand-gravel production groupings. Data based on 1964 production.

receive a "compromised" rating of "adequate to limited" because of the presence of a major (widespread) problem with that particular aggregate type. An example is the Springfield-Salem Plateau, where an abundance of cherty carbonate rocks yields widespread durability problems when used as concrete pavement aggregate. On the other hand, a more limited supply of a good quality aggregate type, which was well-distributed in the basic unit, could produce an "abundant to adequate" rating. The Triassic Lowland unit, with its areally limited but well-distributed good quality trap ridges, is an excellent example.

Estimated Potential Availability Rating, by Section.— The following gives the availability ratings for the aggregate resources in the 97 Sections, and briefly describes the aggregate types, uses, and problems. The discussion sequence follows the physiographic unit code given in Table B-1.

Section: 1a Olympic Mountains
Avail. Rating: Adequate to Limited
Remarks: Crushed stone sources are limited. The major portion of the bedrock comprising the area is slates, phyllites, and argillites, none of which is currently used as an aggregate source in Washington. Crushed sandstone is used as subbase/base aggregate. Basalt is used as both bituminous and concrete aggregate; however, widespread abrasion and durability problems are frequently encountered. Sand-gravel sources are generally located along the periphery of the Section. Several scattered but regionally defined areas lacking quality aggregates occur.

Section: 1b Oregon Coast Range
Avail. Rating: Limited to Problem
Remarks: The widespread soft sandstones and shales afford little, if any, suitable aggregate. Crushed sandstones of suitable quality for base/subbase aggregate may be locally obtained. Crushed basalts, of quality similar to those of the Olympic Mountain Section, are used for all aggregate functions. Sand-gravel sources do not appear to be widely distributed, and frequently give abrasion and durability problems when used locally as concrete pavement aggregate.

Section: 1c Klamath Mountains
Avail. Rating: Adequate to Limited
Remarks: This rating is based solely on an examination of existent geologic conditions, and should be considered

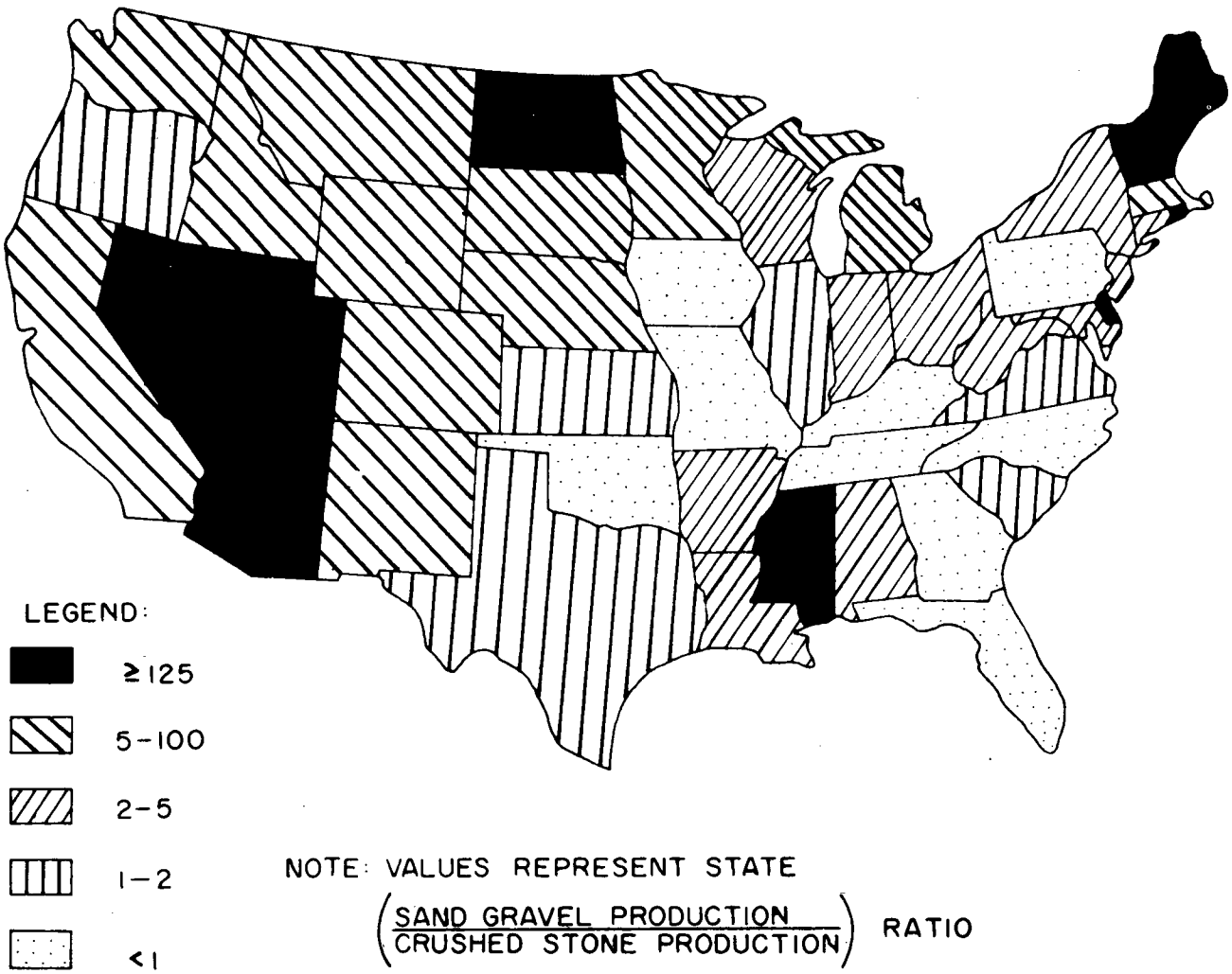


Figure B-15. State sand-gravel/crushed stone production ratio groupings.

TABLE B-9

SUMMARY OF GENERAL AGGREGATE TYPES USED, BY STATE

STATE	AGGREGATE TYPE CODE [a]	REMARKS
Alabama	2, 3, 10, 11, 13, 28, 30, 33, 42, 47	
Arizona	3, 10, 13, 21, 22, 23, 28, 31	
Arkansas	3, 10, 11, 13, 14, 29, 31	
*California [b]	3, 10, 13, 21, 28, 47	
Colorado	3, 10, 13, 21, 28, 30, 45, 47	a. Scoria present in small and scattered areas; not used for any function. b. Marble used as bit. filler only.
Connecticut	3, 21	a. Granite and dolomite used only for minor road projects; primarily used for chemical and building material industry.
Delaware	1, 2, 3, 33	
Florida	3, 10, 41, 42	a. Sand-gravel generally not suitable for bit. base course.

TABLE B-9 (*Continued*)

STATE	AGGREGATE TYPE CODE [a]	REMARKS
Georgia	3, 10, 12, 28, 30, 31, 33	a. Considerable difference in limestone of Coastal Region and remainder of state (Ridge and Valley Province).
Idaho	1, 2, 3, 10, 11, 21, 31, 47	a. Granite in Rocky Mountain Section generally not suitable as aggregate source.
Illinois	3, 10, 11, 47	
Indiana	3, 10, 11, 47	
Iowa	3, 10, 11	
Kansas	3, 10, 11, 12, 13, 48	
Kentucky	3, 10, 47	
Louisiana	3, 42, 46	a. Limestone and standstone sources depleted.
Maine	3, 10, 13, 28, 31	a. Majority of aggregates used are glacial sand-gravel.
Maryland	1, 2, 10, 27, 28, 30, 32, 33, 35, 37	
Massachusetts	3, 10, 21, 22, 23, 26, 33	a. Granite not suitable.
Michigan	1, 2, 3, 10, 11, 13, 21, 23, 47	a. Open-hearth slag not used as pavement mix aggregate. b. Sandstone used for "special" bit. mix aggregate only. c. Limestone and dolomite used for low traffic bit. mix. d. Gravel used for bit. mix aggregate is crushed.
*Minnesota	3, 11, 21, 28, 31	
Mississippi	3, 42	a. Note *absence* of crushed stone group (i.e., 10 through 35).
Missouri	1, 2, 10, 11, 13, 28	
Montana	3, 10, 13, 15, 21, 28, 31, 43, 47	a. Uses sand-gravel sources for all of concrete pavement aggregate and most of bit. surface mix.
Nebraska	1, 2, 3, 10	
*Nevada	3, 10, 13, 21, 28, 30, 31	
New Hampshire	3, 28, 31	
New Jersey	1, 3, 10, 11, 15, 21, 22, 28, 31, 33, 47	
New Mexico	3, 10, 21, 23, 24, 26, 31, 49	a. Aggregate uses not stated in questionnaire.
New York	3, 10, 11, 13, 22, 27, 28, 30, 31, 47	a. Gabbro and granite in Adirondacks obtained from iron mine tailings.
North Carolina	2, 3, 10, 26, 28, 30, 33	a. Limestone and marble limited to 50 percent of total aggregate in bit. surface mix.
North Dakota	3, 43	
Ohio	1, 2, 10, 13, 47	
Oklahoma	3, 10, 11, 13, 28	
Oregon	1, 2, 3, 21	
Pennsylvania	3, 10, 13, 22, 28, 47	
*Rhode Island	3, 10, 28	
*South Carolina	3, 10, 28	
South Dakota	3, 10, 13, 28, 31	
Tennessee	3, 10, 11, 13, 47	
*Texas	3, 10, 13, 21, 28, 30, 42, 47, 49	
*Utah	3, 10, 13, 28, 30	a. Aggregate sources are primarily sand-gravel deposits.
Vermont	3, 10, 11, 25, 28, 31, 32, 35	a. Marble not suitable for any use.
Virginia	3, 10, 11, 13, 21, 22, 28, 30, 33, 42	
Washington	3, 10, 13, 21, 28, 31	a. Andesite and rhyolite not suitable for use.
West Virginia	1, 3, 10, 13, 47	a. Sandstone used as base/subbase only.
Wisconsin	1, 3, 11, 13, 21, 28, 31	
Wyoming	3, 10, 11, 13, 21, 28, 43	

[a] See Table B-8 for key to aggregate type.

[b] For the states *not* marked with an aseterisk, information has been obtained from the materials questionnaire; information for those marked by an asterisk has been obtained through a literature search as *possible* aggregate types only.

TABLE B-10

SUMMARY OF GENERAL AGGREGATE TYPES USED, BY SECTION

	RESULTS OF MATERIALS QUESTIONNAIRE			RESULTS OF LITERATURE REVIEW	
SECT. CODE	AGGREGATE TYPE CODE [a]	APPROX. % OF UNIT RESULTS REPORTED FOR	REFERENCES [b]	OTHER AGGREGATE TYPES [a]	REFERENCES [b]
1a	3, 13, 21	100	(*194*)	—	—
1b	1, 3, 13, 21	100	(*165, 194*)	—	—
1c	—	0	—	3	(*142*)
1d	—	0	—	3, 10, 11, 13	(*116*)
1e	—	0	—	3, 10, 11, 28	(*116*)
2a	3, 13, 21, 28	100	(*194*)	—	—
2b	3, 10, 21	80	(*165, 194*)	—	—
2c	—	0	—	3, 10, 28	(*107, 116, 142*)
2d	—	0	—	3, 28	(*107, 116, 142*)
3a	3, 13, 21	100	(*194*)	—	—
3b	3, 21	100	(*165*)	—	—
3c	—	0	—	3	(*142, 144, 169, 172, 200*)
4a	1, 2, 3, 21	100	(*117, 165, 194*)	—	—
4b	1, 2, 3, 21	100	(*117, 165*)	—	—
4c	1, 2, 3, 21, 47	(100—)	(*117*)	—	—
4d	1, 2, 3, 21	(100—)	(*117, 165*)	—	—
4e	2, 21	100	(*165*)	—	—
5a	1, 2, 3, 10, 11, 21, 31	20	(*117, 151, 165, 191*)	—	—
5b	3, 21, 23, 28	60	(*86, 151*)	—	—
5c	3	25	(*86*)	—	—
5d	3, 10, 13, 21-24, 28, 31, 44	95	(*86, 155*)	—	—
5e	3, 10, 31, 49	75	(*155*)	—	—
5f	—	0	—	3, 10, 21	(*190*)
6a	3	100	(*191*)	—	—
6b	3	100	(*95, 191*)	—	—
6c	3, 13	100	(*95, 191*)	—	—
6d	3, 13, 21	100	(*86, 95, 155, 191*)	—	—
6e	3, 21	100	(*86*)	—	—
6f	3, 10, 21, 44	100	(*86, 155*)	—	—
7a	3, 10, 13, 15, 21, 28, 31, 34, 47	100	(*117, 148*)	—	—
7b	1, 2, 3, 10, 15, 21, 28, 31, 34	100	(*117, 148, 194*)	—	—
7c	2, 3, 21	100	(*117*)	—	—
8a	3, 28	100	(*117, 148, 205*)	—	—
8b	3, 10	100	(*148, 205*)	—	—
8c	3, 10, 34	100	(*205*)	—	—
8d	3, 10, 11, 13, 34, 47	100	(*117, 191, 205*)	—	—
8e	3	20	(*95*)	—	—
9a	3, 10, 28	100	(*95, 155, 205*)	—	—
9b	3, 10, 28, 30	100	(*95, 155*)	—	—
9c	3, 21, 31	100	(*95, 155*)	—	—
10a	3	100	(*148, 160, 180*)	—	—
10b	1, 3, 10, 13, 43	100	(*148, 150, 160, 180, 205*)	—	—
10c	3, 10, 11, 13, 21	100	(*148, 205*)	—	—
10d	3, 10, 13, 28	100	(*95, 205*)	—	—
10e	10, 28	100	(*180, 205*)	—	—
10f	1, 2, 3, 10, 11, 13, 28, 49	70	(*95, 125, 150, 155, 162, 205*)	—	—
10g	3, 10, 21, 47	100	(*95*)	—	—
10h	3, 10, 21, 26	100	(*95, 155*)	—	—
10i	3, 10, 49	85	(*155*)	—	—
10j	1, 3, 11, 13, 48	95	(*125, 150, 162*)	—	—
10k	—	0	—	3, 10	(*144, 200*)
10l	—	0	—	3, 10	(*144, 200*)
10m	1, 2, 3, 10, 11, 12, 13, 28	75	(*125, 146, 162*)	—	—

TABLE B-10 (*Continued*)

	RESULTS OF MATERIALS QUESTIONNAIRE			RESULTS OF LITERATURE REVIEW	
SECT. CODE	AGGREGATE TYPE CODE [a]	APPROX. % OF UNIT RESULTS REPORTED FOR	REFERENCES [b]	OTHER AGGREGATE TYPES [a]	REFERENCES [b]
11a	3, 10, 11	100	(*156*)	—	—
11b	3, 10, 11, 31	100	(*156, 192*)	—	—
11c	1, 3, 10, 11, 13, 31, 33	100	(*154, 156, 167*)	—	—
11d	3, 10, 11	100	(*156*)	—	—
11e	1, 2, 3, 10, 11, 13, 47	100	(*118, 120, 143, 156, 161, 167, 197*)	—	—
11f	1, 2, 3, 10, 11, 47	100	(*118, 120, 161, 197*)	—	—
11g	1, 3, 10, 11, 13, 28, 31	95	(*118, 121, 197*)	—	—
11h	3, 10, 11, 31	60	(*121, 160, 180, 197*)	28	(*174*)
11i	1, 2, 3, 10, 11, 28, 31, 47	90	(*118, 121, 125, 146, 150, 180*)	—	—
12a	1, 2, 3, 21, 23, 30	40	(*143, 197*)	31	(*90*)
12b	3, 27, 28	100	(*156*)	—	—
13a	1, 2, 10, 11, 28	100	(*146*)	—	—
13b	1, 2, 3, 10, 11, 13	100	(*87, 146, 162*)	—	—
13c1	3, 10, 13	100	(*87, 162*)	—	—
13c2	3, 10, 13, 29, 31	100	(*87, 162*)	—	—
13c3	3, 10, 13, 14	100	(*87, 162*)	—	—
14a	1, 2, 3, 10, 11	100	(*120, 126, 161*)	—	—
14b	3, 10, 47	100	(*182*)	—	—
14c	3, 10	100	(*118, 120, 126*)	—	—
14d	3, 10, 11, 13	100	(*85, 120, 126, 182*)	—	—
15a	3, 13	100	(*156*)	—	—
15b	1, 2, 3, 10, 13, 47	100	(*156, 161, 167*)	—	—
15c	10	100	(*138, 167, 196*)	—	—
15d	1, 2, 3, 10, 13, 47	(95+)	(*126, 156, 161, 167, 196*)	—	—
15e	1, 2, 3, 10, 11, 12, 13, 47	(100—)	(*85, 105, 126, 182*)	—	—
16a	1, 2, 3, 10, 11, 13, 22, 47	100	(*138, 167, 193, 196*)	—	—
16b	1, 2, 3, 10, 11, 12, 13, 30, 47	100	(*85, 105, 182, 193*)	—	—
17a	2, 3, 10, 21, 22, 28, 30, 33	(100—)	(*105, 159, 167,193, 196*)	—	—
17b	1, 2, 3, 11, 21, 22, 26-28, 30-35	85	(*85, 98, 105, 138, 159, 167, 193*)	—	—
18	1, 3, 10, 21, 22, 28	100	(*138, 154, 156, 167, 193*)	—	—
19a	3, 10, 13, 23, 26, 28, 31, 33	(100—)	(*136, 139, 153*)	—	—
19b	3, 10, 11, 21, 22, 25, 26, 28, 31-33, 35	(90+)	(*96, 136, 139, 153, 156, 192*)	—	—
19c	3, 21, 22	100	(*96, 139*)	—	—
19d	3, 28	100	(*136, 153, 192*)	—	—
19e	3, 25, 28, 32, 35	100	(*139, 192*)	—	—
19f	3, 10, 11, 31	100	(*96, 139, 156, 192*)	—	—
19g	1, 3, 10, 11, 15, 22, 28, 30, 31, 33, 47	100	(*154, 156, 167*)	—	—
20a	1, 2, 3, 28, 42, 47	100	(*98, 138, 139, 154, 156, 159, 193*)	—	—
20b	1, 2, 3, 42	70	(*101, 105, 159*)	—	—
20c	1, 10, 41, 42, 47	100	(*101*)	—	—
20d	1, 2, 3, 10, 11, 40, 42	100	(*85, 101, 105, 118, 126, 134, 145, 182*)	—	—
20e	3	100	(*126, 134, 145, 182*)	—	—
20f	1, 2, 3, 42, 46	100	(*87, 118, 126, 134, 145, 146, 182*)	—	—
20g	3, 42	25	(*87, 134, 162*)	—	—

[a] See Table B-8 for key to aggregate type.
[b] Numbers refer to bibliography reference number.

as highly speculative. In this rugged mountainous area, adequate crushed stone sources appear to be available. Sand-gravels may be obtained from rivers, such as the Klamath (*200*).

Section: 1d California Coast Range
Avail. Rating: Limited to Problem
Remarks: This Section is similar to the Oregon Coast Ranges. Sandstones are prominent; however, they gen-

erally are of low abrasion resistance (*116*). Crushed limestone sources are found south of the San Francisco area in the Southern California Coast Range (*107*). Sand-gravel sources from the Salinas River have been noted to be reactive with cement (*171*).

Section: 1e Los Angeles Ranges
Avail. Rating: Limited to Problem
Remarks: The availability and general quality of crushed granitic and carbonate sources appears to be good (*107, 116*). The crushed stone sources are primarily developed in the Traverse Ranges; sand-gravel deposits appear to be abundantly available in the southern part of the Section. Alkali-aggregate reactions have occurred with sand-gravel sources from the Santa Clara River (*171*).

Section: 2a Northern Cascade
Avail. Rating: Adequate to Limited
Remarks: The potential for crushed stone sources appears to be good. Crushed granites of good quality, basalts exhibiting localized abrasion and durability problems, and sandstones of quality suitable for base/subbase aggregate are available. Sand-gravels of good quality are generally located along the borders of the Section. A region near the Glacier Peak lacks quality aggregate sources.

Section: 2b Southern Cascade
Avail. Rating: Abundant to Adequate
Remarks: Crushed basalt of fairly good quality and sand-gravel are the major sources of aggregate for all functions. Crushed limestone suitable for base/subbase aggregate may be locally available. In general, the potential supply of aggregates appears adequate.

Section: 2c Sierra Nevada
Avail. Rating: Abundant to Adequate
Remarks: Crushed granite and natural granular deposits are abundantly available. Localized carbonate areas exist on the western side of the Section. Cement-aggregate reactions may occur with sand-gravel sources.

Section: 2d Lower California
Avail. Rating: Abundant to Adequate
Remarks: This Section is similar to the Sierra Nevada in major types of potential aggregates. Crushed granites of good quality are adequately available.

Section: 3a Puget Sound
Avail. Rating: Abundant to Adequate
Remarks: This Section possesses an abundant distribution of glacial granular deposits in the form of terraces and outwash plains. Localized deposits of sand-gravel may cause alkali-aggregate reaction. Quality crushed stone sources (primarily basalt) are available. Localized problems of stripping, abrasion, and durability occur with this aggregate. Andesite and rhyolite are generally not suitable for use.

Section: 3b Willamette Valley
Avail. Rating: Abundant to Adequate
Remarks: This Section is similar to the Puget Sound Section in that the major aggregate sources are sand-gravel and crushed basalt. However, the granular material is obtained primarily from either alluvial fans adjacent to the mountainous areas and/or the river and stream system in the Section. Quality aggregates are generally available; however, problems with volcanic rock may be somewhat similar to the Puget Sound Section.

Section: 3c California Valley Section
Avail. Rating: Abundant to Adequate
Remarks: Sand-gravel may be obtained from fans and aprons near mountain ranges surrounding the Section and from alluvial deposits associated with its rivers and streams. Bedrock sources are little exploited, owing to the relatively deep alluvial cover in the Valley. Quality crushed stone sources must be obtained from nearby mountainous area.

Section: 4a Walla Walla
Avail. Rating: Abundant to Adequate
Remarks: Sand-gravel sources are generally well-distributed in the Washington portion of the Section, both from glacial outwash and along major rivers such as the Snake and Columbia. Loess and caliche may be present in the outwash deposits. Quality crushed basalts are generally available.

Section: 4b Blue Mountains
Avail. Rating: Abundant to Adequate
Remarks: The major sources of aggregate are sand-gravels and crushed basalt; the general quality of both sources appears to be good. Sedimentary rocks and granite are available, although, at present, they are not used as aggregate sources by Oregon.

Section: 4c Snake River Plains
Avail. Rating: Limited to Problem
Remarks: Much of the area is veneered by loessial deposits that overlie young basaltic and acidic flows. In general, crushed basalts, where available, appear to possess poor abrasion, durability, and adhesion characteristics (*117*). Sand-gravel sources are generally lacking except near the mountainous borders and along some terrace portions of the Snake River. Idaho indicates that suitable concrete gravels are generally lacking. Limited sand-gravels frequently create a wide spectrum of aggregate problems, including the alkali-aggregate reaction.

Section: 4d Payette
Avail. Rating: Adequate to Limited
Remarks: The sources of granular deposits are located primarily along the major river terraces. The quality of these sources appears highly variable. Widespread abrasion, durability, alkali-aggregate reaction, and adhesion problems are noted in the Idaho portion. Crushed basalt sources, where available, appear to be of variable quality. Basalts may frequently be interbedded with fluvial sediments.

Section: 4e Harney
Avail. Rating: Limited to Problem

Remarks: The Section does not have an over-all abundance of either natural granular deposits or suitable crushed stone sources. Rivers and streams are scarce, and a vast portion of the area is surfaced by the disintegrated pumice deposits of the Great Sandy Desert. Limited problems with alkali-aggregate reaction are encountered with gravels of the area; crushed basalt, where available, produces widespread adhesion problems.

Section: 5a Great Basin
Avail. Rating: Abundant to Adequate
Remarks: Natural sand-gravel sources from alluvial fans and aprons near the mountain ranges are abundant. Granular lacustrine deposits are used as aggregates in old Lakes Lahontan and Bonneville. Many mountain ranges may afford suitable crushed stone resources. Occurrence of alkali-aggregate reactions have been noted in some portions of the Section.

Section: 5b Sonoran Desert
Avail. Rating: Abundant to Adequate
Remarks: Natural sand-gravel deposits are found near the mountain ranges (similar to Section 5a). Quality crushed stones (primarily igneous) are located in and developed from ranges in the Section. Alkali-aggregate reactions are associated with the widespread igneous activity. Localized areas lacking quality aggregates occur.

Section: 5c Salton Trough
Avail. Rating: Limited to Problem
Remarks: Although sand and fine gravel are locally available, aggregate sources are generally lacking in the Southern California portion (Imperial Valley). Alkali-aggregate reactions may be a problem with sources in and east of the Section.

Section: 5d Open Basin
Avail. Rating: Abundant to Adequate
Remarks: Natural sand-gravel sources are generally available from the nearby mountain ranges (similar to Sections 5a and 5b). Many different types of quality crushed stone sources can be developed from the mountain ranges.

Section: 5e Sacramento Highlands
Avail. Rating: Abundant to Adequate
Remarks: Sand-gravel and crushed limestone sources appear to be well distributed and extensively used. [From the general pit and quarry locations provided by New Mexico (*155*).] Information concerning the aggregate quality was lacking.

Section: 5f Great Bend Highlands
Avail. Rating: Abundant to Adequate
Remarks: Sand-gravel, crushed igneous, and limestone sources appear, from geologic maps, to be well distributed. Definite information on aggregate type and quality was lacking.

Notes: In general, the ratings given to the individual Sections of the Basin and Range Province are based on potential availability of aggregate resources and are not greatly modified by quality limitations due to insufficient data.

Section: 6a High Plateaus
Avail. Rating: Adequate to Limited
Remarks: The quality of sand-gravel sources is extremely variable. Alluvial gravels derived from Mesozoic sandstone and shales are of poor quality.

Section: 6b Uinta Basin
Avail. Rating: Limited to Problem
Remarks: Generally, the best quality usually is found in the northern portion near the Uinta Mountains. Tertiary sandstones and shales, which comprise most of the Section, are of very poor quality for road aggregates.

Section: 6c Canyon Lands
Avail. Rating: Limited to Problem
Remarks: The area is primarily soft sandstone deposits from the Mesozoic and the late Paleozic Eras, that afford very poor quality (abrasion) aggregates. Riverbed gravels are available in limited quantity and quality.

Section: 6d Navajo
Avail. Rating: Limited to Problem
Remarks: Much of the Section is underlain by soft sandstones and shales, which are poor aggregate sources. Localized igneous areas exist, and crushed basalt of good quality may be obtained.

Section: 6e Grand Canyon
Avail. Rating: Adequate to Limited
Remarks: The rating given to this Section is based on the geologic potential and may be too high because of practical problems of accessibility. Potential crushed limestone sources may be developed in the Kaibab and other limestone formations. Ingeous activity is widespread in the central portion of the Section and good quality crushed basalt may be obtained.

Section: 6f Datil
Avail Rating: Abundant to Adequate
Remarks: This rating, like that of the Grand Canyon Section, is questionable, as information concerning quality of aggregate sources is not complete. This Section appears to have a good potential in crushed limestone and basalt. The use of volcanic cinders generally results in durability problems.

Section: 7a Montana
Avail. Rating: Abundant to Adequate
Remarks: The Section has a wide variety of suitable crushed stone sources as well as regional sand-gravel deposits. The Belt Mountains in the east have potential materials of construction that are similar in type and quality to the anticlinal ranges found throughout the Rocky Mountain System. The Tertiary Basins afford variable quality glacial sand-gravel deposits which generally veneer the basin fill. Sedimentary, metamorphic, and igneous rocks are crushed as aggregates in Montana; however, sand-gravels are the primary aggregate source

in the Section (*148*). The main problem, associated with serveral aggregate types, is poor adhesion.

Section: 7b Bitterroot
Avail. Rating: Adequate to Limited
Remarks: In general, the Washington portion of the Section contains good quality glacial valley gravels, as well as suitable granites, quartzites, and limestones (*194*). The remainder of the Section has a wide array of crushed stone sources that may be of poor quality. The major problems are adhesion and abrasion.

Section: 7c Salmon River Mountains
Avail. Rating: Limited to Problem
Remarks: The major rock of this Section is the massive Idaho batholith (Jurassic age). Idaho (*117*) notes that this prevalent rock is generally unsuitable for use as a highway aggregate. Crushed basalt is used, but it frequently has poor abrasion and adhesion properties. Sand-gravel sources, where available, frequently contain substances deleterious to concrete. Idaho (*117*) notes that quality concrete aggregates generally are not available.

Section: 8a Yellowstone
Avail. Rating: Adequate to Limited
Remarks: The use and quality of volcanic areas as crushed stone sources was not noted in the questionnaire responses. However, quality sand-gravels and crushed limestone (steeply dipping flanking strata around the Precambrian core) are major sources of aggregates.

Section: 8b Bighorn Mountain
Avail. Rating: Abundant to Adequate
Remarks: Use and quality information concerning the bedrock type (Precambrian crystalline rock) was not obtained through the questionnaire. However, quality sand-gravels as well as crushed limestone (possible source in steeply dipping strata surrounding Precambrian core) are used as the major source of aggregates. No areas lacking aggregate sources within the Section were noted from the questionnaire.

Section: 8c Wind River Mountains
Avail. Rating: Abundant to Adequate
Remarks: (Remarks identical to Section 8b)

Section: 8d Wasatch
Avail. Rating: Adequate to Limited
Remarks: The rating is based primarily on the quality information concerning aggregate problems in the Idaho portion of the Section. The *potential* sources of crushed stone are extremely variable by type and geologic age. Idaho indicates that the sand-gravels and crushed carbonate (limestone and dolomite) sources may have extremely poor abrasion and durability characteristics. Alkali-aggregate reactions may occur with sand-gravels and limestones as well. The Jackson Hole area of Wyoming has adequate glacial outwash sands and gravels.

Section: 8e Uinta Mountain
Avail. Rating: Abundant to Adequate
Remarks: (Remarks identical to Section 8b)

Section: 9a Front Range
Avail. Rating: Abundant to Adequate
Remarks: In general, the potential availability of good quality crushed stone obtained from the Precambrian crystalline ranges is high. The primary sources of crushed aggregates are granites and flanking limestones.

Section: 9b Western
Avail. Rating: Abundant to Adequate
Remarks: Owing to the presence of numerous ranges identical to those of the Front Range Section, the Western Section has a similar crushed stone potential. Regional sand-gravel sources derived predominantly from glacial outwash are found in the North and Middle Parks and the San Luis Valley portions.

Section: 9c San Juan Mountains
Avail. Rating: Abundant to Adequate
Remarks: Sand-gravels and crushed basalts of good quality are available.

Section: 10a Missouri Plateau (Glaciated)
Avail. Rating: Limited to Problem
Remarks: Suitable crushed stone sources are nonexistent in most of the Section and, as a result, sand-gravel sources are exclusively used as highway aggregate (*148, 160, 180*). These aggregates are located primarily along portions of the Missouri River, from limited stratified glacial deposits, and from isolated gravel-capped benches in Montana [viz., Flaxville gravels (*142*)]. In general, the over-all quality of the sand-gravel sources is poor. The widespread presence of deleterious material in the gravels, due to the underlying soft sandstone and shale bedrock, renders them unsuitable for use in concrete, particularly in North and South Dakota.

Section: 10b Missouri Plateau (Unglaciated)
Avail. Rating: Severe Problem
Remarks: Sand-gravels, crushed limestones, some sandstones, and scoria are used as highway aggregates. The major sources of sand-gravels are the terraces associated with the Yellowstone River in Montana (*142, 148*) and the Cheyenne and White Rivers in South Dakota (*180*). A potential source of sand-gravel appears along the eastern portion of the Black Hills-Unglaciated Plateau border in South Dakota. Availability of crushed stone sources is extremely limited in the Section, owing to the widespread presence of soft sandstones and shales. The quality of sand-gravel sources in the Section appears to be poor, with the most noted problems being abrasion and deleterious constituents. Almost the entire Section has been categorized by the respective state highway departments as lacking quality aggregate supplies.

Section: 10c Bighorn Basin
Avail. Rating: Abundant to Adequate
Remarks: Sand-gravels, crushed carbonates, sandstones, and basalts are used. Of these, the sand-gravels are the most important source, and appear to be widely distributed. The quality of these aggregates appears to be good, as no problems were reported. Crushed

stone sources are available only near the surrounding mountain ranges. The regional bedrock of the unit (Tertiary sediments) is generally unsuitable for crushing.

Section: 10d Wyoming Basin
Avail. Rating: Limited to Problem
Remarks: A large area in the central portion of the unit has been reported to lack quality aggregate (*205*). The major source of aggregate is sand-gravel, but limited supplies of crushed limestones, sandstones, and granites are available. These aggregates are available primarily between the mountain extensions of the bordering Middle Rocky Mountain Province. In particular, basin areas such as the Wind River, the northern part of the Green River Basin, and the Waskakie Basin appear to possess a good regional supply of aggregates (*166, 200*). Problems in the unit are associated with durability (*205*), alkali-aggregate reaction (*144*), and adhesion (*95*). These problems generally are of a localized nature, and are predominantly associated with the sand-gravels.

Section: 10e Black Hills
Avail. Rating: Abundant to Adequate
Remarks: In general, good quality crushed limestones, granites, felsites, and felsite porphyries are abundantly available (*90, 180, 205*).

Section: 10f High Plains
Avail. Rating: Limited to Problem
Remarks: There is an almost complete absence of bedrock suitable for crushing, owing to the modal parent material of Tertiary outwash. The major aggregates are sand-gravels from major rivers (and their tributaries) originating in the Rockies and flowing directly east to the Missouri and Mississippi Rivers. These occur in the northern portion of the Section and include the Niobrara, Platte, Republican, Arkansas, and Canadian Rivers. In general, these sand-gravels are deficient in the coarse sizes and frequently cause the unique "sand-gravel" reaction in concrete. Localized, but noteworthy, adhesion problems also are associated with the sand-gravels in the north (*200*). In the south, sand-gravels are not abundant and caliche is frequently used as aggregate.

Section: 10g Colorado Piedmont
Avail. Rating: Limited to Problem
Remarks: This unit bears many marked similarities in general aggregate characteristics to the Unglaciated Missouri Plateau (10b). Aggregate types are sand-gravels, restricted to areas adjacent to the Rocky Mountains and along the South Platte and Arkansas Rivers (*95, 144*), and limited sources of limestones, basalts, and slag. A large area has been cited by Colorado (*95*) as lacking quality aggregates. This area is underlain primarily by relatively soft sandstone, shale, and clay shales. Problems of adhesion are the most common problem associated with the sand-gravels.

Section: 10h Raton Upland
Avail. Rating: Adequate to Limited
Remarks: Sand-gravels, crushed limestone, basalts, and diorites are commonly used as highway aggregate; igneous rocks appear to be the most abundant source. Localized adhesion problems, identical to those of the Colorado Piedmont, are encountered with sand-gravels. No areas were identified by Colorado and New Mexico as lacking in aggregate sources.

Section: 10i Pecos Valley
Avail. Rating: Limited to Problem
Remarks: The major sources of aggregates are sand-gravel, caliche, and very limited crushed limestone. Caliche pits are widely distributed. Limestone quarries are not extensive in the Permian and early Mesozoic deposits, which are characteristically gypsum, sandstone, and shale bedrock.

Section: 10j Plains Border
Avail. Rating: Limited to Problem
Remarks: Sand-gravels, crushed dolomites, sandstones, and silicified chalk are used as highway aggregates (*125, 150*). The sources of sand-gravel are primarily limited to the major rivers and tributaries. The Republican and Arkansas Rivers provide aggregates similar in quality to the High Plains Section to the west. Potential crushed stone areas are generally confined to the Blue Hills Subsection of Kansas. Widespread carbonate reactions have been noted by Kansas (*125*). The quality of crushed sandstone appears reasonably good, although widespread adhesion and limited durability problems are associated with its use. The unit rating tends toward the "limited" rather than the "problem" category.

Section: 10k Central Texas Mineral
Avail. Rating: Abundant to Adequate
Remarks: This rating is based on fairly limited information. The major sources of potential aggregates are sand-gravels, limestones, and granites. Crushed limestones of Upper Cretaceous (Edwards and Commanche) are similar to those of the Edwards Plateau. Carbonates of Cambrian to Ordovician age are located around the flanks of the Llano uplift granitic core. The quality of aggregates is unknown to the researchers; the rating is based primarily on the abundant distribution of potential sources.

Section: 10l Edwards Plateau
Avail. Rating: Abundant to Adequate
Remarks: Cretaceous limestone of quality acceptable for most engineering purposes is widespread throughout the area and forms an important part of the crushed stone industry of Texas (*107, 200*). In addition, numerous river valleys provide gravels of both carbonaceous and siliceous character (*144*).

Section: 10m Osage Plains
Avail. Rating: Adequate to Limited
Remarks: The major types of aggregates used for highway construction are sand-gravels and crushed carbonate rocks. In addition, minor uses of sandstones, granites, and chat occur (*170, 125, 144, 146, 162*). There is an extremely wide range of aggregate availability. Gravels occur in substantial quantities in Texas and

Oklahoma (*142, 144*). Four major carbonate zones of variable quality are present. The cherty limestones of the Flint Hills offer little suitable aggregate for concrete, but can be used as base/subbase aggregates (*144*). The Pennsylvanian limestones found in the Scarped Plains (northeast portion of Section) also possess undesirable durability characteristics for concrete aggregate (*125, 146*). Limestones of Ordovician age, found adjacent to the Wichita and Arbuckle uplifts, have provided one-third to one-half of Oklahoma's annual limestone production (*107*). The carbonates found in the southwestern portion are similar in characteristics to carbonates found in the Central Texas Mineral and Edwards Plateau Sections of Texas (*107*). Crushed granites of good quality are located in the uplift cores of the Wichita and Arbuckle areas of Oklahoma. Locally, sandstones of quality suitable for base/subbase use can be obtained. The remaining bedrock of the area is composed of sandstone and shale, and generally affords little if any suitable aggregate.

Section: 11a St. Lawrence Lowlands
Avail. Rating: Abundant to Adequate
Remarks: Major aggregate sources are good quality glacial sand-gravels and crushed carbonates (Ordovician). The carbonates are adequately distributed throughout the Section.

Section: 11b Champlain Lowland
Avail. Rating: Abundant to Adequate
Remarks: The major sources of aggregates used are glacial sand-gravels and crushed carbonates (Cambrian-Ordovician). Crushed quartzite is used in the Section but the source is outside its boundaries. Crushed marble is not suitable as normal highway aggregate owing to its poor abrasion characteristics. The quality of the remaining aggregates appears to be good.

Section: 11c Hudson River Valley
Avail. Rating: Abundant to Adequate
Remarks: Major sources of aggregate are glacial sand-gravels and crushed carbonates. The Ordovician limestones are located primarily near the contacts with the adjacent uplands. New Jersey reports that the sand-gravel sources contain much deleterious matter. The crushed carbonates may exhibit poor skid resistance. Crushed sandstone is used for all aggregate functions. Crushed quartzites and gneisses are used in the Section, but their origin is the older crystalline areas to the east (New England Maritime Province).

Section: 11d Mohawk River Valley
Avail. Rating: Abundant to Adequate
Remarks: Good quality sand-gravels and crushed carbonates are located in the Section. The carbonates are found primarily near the border contacts with the Adirondacks to the north and the Appalachian Plateau to the south. Low skid resistance is locally a problem with these carbonates.

Section: 11e Eastern Lakes and Lacustrine Plains
Avail. Rating: Adequate to Limited
Remarks: The availability, type, and distribution of aggregates used in the Section are highly variable. Much stratified granular material is present in the Cary and younger Wisconsin drift in Michigan. The quality of these deposits, however, is generally compromised by the presence of chert particles, as well as high abrasion loss. Crushed carbonate sources are generally found along the outer periphery of the Michigan Basin in eastern Wisconsin, in the upper peninsula of Michigan, and in southeastern Michigan. A major problem with many of these carbonate rocks is their poor skid resistance. Slag also is used extensively.

Section: 11f Central Till Plains
Avail. Rating: Adequate to Limited
Remarks: This Section appears to have the most variable aggregate availability rating in the Province. Major aggregate sources are crushed carbonates (predominantly dolomites) and glacial sand-gravel. The major sand-gravel deposits occur in the numerous glacial sluiceways. Stratified glacial landforms are not present in any great quantity. The availability of crushed carbonates in the Section ranges from abundant in the Indiana-Ohio area due to the Cincinnati Arch (predominantly Silurian dolomites) to almost nonexistent in the Illinoian Coal Basin (western portion of the Section). Regional areas lacking aggregate in the Section are located in this Structural Basin area.

Section: 11g Driftless
Avail. Rating: Limited to Problem
Remarks: The major sources are limited sand-gravels, crushed carbonates (predominantly dolomites), sandstones, granites, and quartzites. The supply is variable, with a large area in the central portion of Wisconsin (Central Sand Plain) generally lacking in coarse aggregates. The availability of aggregates generally increases to the southwest. Ordovician dolomites afford crushed stone of variable quality. They generally have poor abrasion resistance and durability. The crushed sandstone (Cambrian) also is weak and is used primarily for subbases. Good quality crushed quartzites are located in the Baraboo area. Sand-gravel sources are confined to limited glacial outwash in and along the Mississippi River and its tributaries in Minnesota.

Section: 11h Western Lakes and Lacustrine Plains
Avail. Rating: Limited to Problem
Remarks: The major type of aggregate is sand-gravel of glacial origin. Crushed stone sources are limited to: the good quality, but rather small Sioux Uplift area in South Dakota; scattered granitic areas in Minnesota; and localized Devonian and Mississippian limestones in Iowa. Large areas are completely void of aggregates; viz., large old glacial lakebeds (Dakota and Agassiz). Sand-gravels, where available, frequently are contaminated by standstone and shale particles from the dominant regional bedrock.

Section: 11i Dissected Loessial and Till Plains
Avail. Rating: Adequate to Limited
Remarks: As in the Central Till Plain Section, the avail-

ability of aggregates is variable. Alluvial, glacial, and interglacial gravels are used as aggregates. Crushed stone sources are primarily limestones, with the Sioux Uplift area providing good quality crushed quartzites and granites in South Dakota and Minnesota. Quality aggregates also are found in the northeast, where Silurian and Devonian carbonates are extensively quarried for road aggregate. Crushed stone sources are limited to nonexistent in the western portion; quality natural granular deposits are limited in the south. Large regional areas in southwest Iowa and northwest Missouri are void of quality aggregate supplies. Localized alkali-carbonate reactions have occurred in the Iowa portion of the Section. Alkali-silica reactions of a more frequent nature occur with the sand-gravels found in Nebraska and Kansas.

Section: 12a Superior Upland
Avail. Rating: Abundant to Adequate
Remarks: The availability of good quality crushed stone sources and glacial sand deposits generally is adequate. Major crushed stone sources are primarily Precambrian igneous-metamorphic complexes. Regional sand-gravel sources may be lacking in the northeast portion of Minnesota where bedrock is generally near the surface.

Section: 12b Adirondack Mountains
Avail. Rating: Abundant to Adequate
Remarks: This Section is similar in aggregate characteristics to the Superior Upland. Quality potential crushed stone sources (Precambrian igneous-metamorphic complex) are presently used as a source of aggregate. Sand-gravel deposits of glacial origin exist and are used as aggregates in the Section.

Section: 13a St. Francis
Avail. Rating: Abundant to Adequate
Remarks: Limestone and granite generally are the best sources of crushed stone. The Cambrian limestone generally lacks chert impurities and contrasts strongly with the carbonates in the surrounding Springfield-Salem Plateau. Dolomite is generally of poor quality, frequently cherty, and similar in performance characteristics to Section 13b. Gravel deposits produce widespread durability problems when used in concrete. Sandstone is generally unsuitable for use.

Section: 13b Springfield-Salem Plateau
Avail. Rating: Adequate to Limited
Remarks: Although carbonate rocks predominate in the entire Section, their use in concrete mixes is limited by chert impurities. Carbonate rocks provide poor skid resistance when used in bituminous pavements. As in Section 13a, river gravels are suspect for concrete pavement. Sandstone is generally low in abrasion resistance and consequently cannot be considered as a major source. Aggregate availability may be a major factor in the selection of pavement type.

Section: 13c1 Boston Mountains
Avail. Rating: Limited to Problem
Remarks: Potential sources may be extremely limited owing to the widespread distribution of sandstone and shale. Limestone, where available, is frequently cherty and performs similarly to Section 13b. Sandstone generally has poor abrasion resistance. Aggregate availability may be a significant factor in determining pavement type.

Section: 13c2 Arkansas Valley
Avail. Rating: Limited to Problem
Remarks: The type and quality of aggregate sources are similar to Section 13c1. Sandstone is generally of low abrasion resistance, but may be of slightly better quality than that of the Boston Mountain Section. Alluvial sand-gravel deposits, where available, are generally good sources. Availability of aggregates is less of a problem than in the Boston Mountain Section.

Section: 13c3 Ouachita Mountains
Avail. Rating: Adequate to Limited
Remarks: As a large portion of this Section is underlain by sandstone and shales, similar to Sections 13c1 and 13c2, quality sources are not abundant. However, the Novaculite Uplift Subsection is generally a good potential crushed stone source. Sandstone may be of questionable quality. Alluvial sand-gravel sources are generally of good quality.

Section: 14a Blue Grass
Avail. Rating: Abundant to Adequate
Remarks: Good quality crushed carbonate sources (lower Ordovician) are available in the Inner Blue Grass Subsection and in scattered inliers of the Outer Blue Grass Subsection. Most of the upper Ordovician limestone in the Outer Blue Grass Subsection is argillaceous and unsuitable for use in construction. Skid resistance may be a problem with the carbonates. Sand-gravels (Ohio River) generally are of good quality.

Section: 14b Nashville Basin
Avail. Rating: Abundant to Adequate
Remarks: Good quality crushed limestone (lower Ordovician) is available throughout the Section. Low skid resistance may be a problem with the carbonate sources. The gravels may be cherty and generally of poor durability in concrete. Poor adhesion with bituminous materials may be a problem with the gravels of the Section.

Section: 14c Shawnee Hills
Avail. Rating: Limited to Problem
Remarks: A major source of quality crushed carbonates is the Mississippian age rocks. The remaining rocks are of Pennsylvanian age and generally are of little value for highway aggregates. Sand-gravel deposits are badly contaminated with chert and shale of low specific gravity and demonstrate poor durability in concrete.

Section: 14d Highland Rim
Avail. Rating: Abundant to Adequate
Remarks: The availability of good quality sources is commonly adequate but highly variable. Quality crushed carbonate sources are generally widespread in the Western Pennyroyal Limestone Plain Subsection. Chert particles may be abundant in the sand-gravels.

Section: 15a Catskill Mountains
Avail. Rating: Adequate to Limited
Remarks: The major sources are sand-gravels and crushed sandstones. Over-all, good quality aggregates can be obtained; however, there is much relatively soft sandstone and associated glacial sand-gravels.

Section: 15b New York Glaciated
Avail. Rating: Adequate to Limited
Remarks: Suitable crushed carbonate aggregate is located adjacent to the outfacing escarpment in New York. Some hard, quality sandstones are crushed in southeast New York and northern Pennsylvania. Slag is available near the Youngstown, Ohio, area and near other steel centers outside the Section in the Central Lowlands Province. Glacial outwash sands and gravels are well-distributed along the river valleys. Sandstone, of variable hardness, may form the largest percentage of gravel particles.

Section: 15c Allegheny Mountains
Avail. Rating: Adequate to Limited
Remarks: This Section is difficult to categorize for potential aggregate availability. The only highway aggregate type used is crushed limestone, and its occurrence is restricted. Hard limestones, conglomerates, and local quartzites do exist and *may* provide quality supplies. The same may be said of river sands and gravels (*144*).

Section: 15d Kanawha
Avail. Rating: Limited to Problem
Remarks: In general, there is a shortage of quality aggregate resources. Limited crushed stone sources are primarily limestones and sandstones. The *over-all* quality of these sources is considered poor due to durability problems, although localized sources of suitable quality may exist. Major streams provide an important source of sand-gravel aggregates in much of the Section. The coarseness and amount of gravel decrease to the south and west.

Section: 15e Cumberland Plateau
Avail. Rating: Adequate to Limited
Remarks: The availability of aggregates is highly variable. Crushed aggregate sources (primarily limestones) are generally abundant to adequately available in the southern portions of the Section, owing to the presence of variant Ordovician limestone valleys and limestone found along the outfacing escarpments. In and around the Kentucky and northern Tennessee portions, the availability of quality aggregate supplies is considered to be of a "limited to problem" nature.

Section: 16a Pennsylvania-Maryland-Virginia
Avail. Rating: Abundant to Adequate
Remarks: Valleys in Cambrian and Ordovician carbonate rocks generally provide a good source of crushed stone; however, widespread skid problems may occur. Cherty layers or pockets may exist in the carbonate formations, but their presence is less widespread than in the Tennessee Section (16b).

Section: 16b Tennessee
Avail. Rating: Abundant to Adequate
Remarks: Aggregate sources and skid problems are similar to Section 16a. The regional distribution of chert may be more widespread in this Section, owing to the Mississippian Fort Payne formation (*99, 137, 184*).

Section: 17a Blue Ridge
Avail. Rating: Abundant to Adequate
Remarks: Construction materials have characteristics similar to the Piedmont Section (17b).

Section: 17b Piedmont
Avail. Rating: Abundant to Adequate
Remarks: Complex and numerous types of potential crushed stone sources exist. Granitic and gneissic sources are generally of good quality. Triassic basins in the Section possess traprock (basalts, diabase, etc.) of good to excellent quality. Sand-gravels are primarily river deposits and may create several localized problems.

Section: 18 Triassic Lowland (no Sections)
Avail. Rating: Abundant to Adequate
Remarks: Crushed stone of good quality is generally obtained from traprock sources in the Triassic Sediments. Crushed limestone is available from the Ordovician limestone valleys which occur as inliers. Crushed granite can be obtained from local Piedmont areas in and surrounding the Province. Glacial sand-gravel deposits are available in the northern portion. These deposits may contain deleterious materials for concrete. Triassic sandstone is generally soft, and its use as an aggregate source is *not* cited.

Section: 19a Seaboard Lowland
Avail. Rating: Adequate to Limited
Remarks: The distribution of the Precumscot formation (fine-grained marine deposits) overlying much of the area may increase localized areas where aggregate sources are lacking. Crushed stone sources are generally similar in types and problems to Section 19b.

Section: 19b New England Upland
Avail. Rating: Abundant to Adequate
Remarks: Good quality glacial fluvial sand-gravels are generally abundantly distributed. Crushed stone sources of granite and limestone may be of poor quality due to poor abrasion resistance and durability.

Section: 19c Connecticut Lowland
Avail. Rating: Abundant to Adequate
Remarks: Glacial and terrace sand-gravels are generally abundant and of good quality. *Occasionally,* soft sandstone particles may be encountered in the gravels. The traprock found in the Triassic sediments is generally an excellent crushed stone source.

Section: 19d White Mountains
Avail. Rating: Adequate to Limited
Remarks: The region is sparsely inhabited, and no known or existent pits or quarries were cited for the Section. Granite may have poor abrasive characteristics. A re-

gion in Maine was stated in the questionnaire to lack quality aggregate resources.

Section: 19e Green Mountains
Avail. Rating: Abundant to Adequate
Remarks: This rating is based on limited information. The crushed stone potential in the old Precambrian crystalline rocks of the Section is considered good. Questionnaire results indicated no widespread problems with aggregates in the area.

Section: 19f Taconic Mountains
Avail. Rating: Abundant to Adequate
Remarks: The major bedrock type of the Taconic *Ranges* is schist. However, its use was *not* reported in the materials questionnaire. Sand-gravels, crushed carbonates, and quartzite sources occur and are of good quality. Vermont marble is not a suitable highway aggregate.

Section: 19g Reading Prong
Avail. Rating: Abundant to Adequate
Remarks: New Jersey reports that marble found in the Section is unsuitable. A wide variety of good quality crushed stone types are available in and surrounding the Section.

Section: 20a Northern Embayed
Avail. Rating: Adequate to Limited
Remarks: The availability of aggregate sources is extremely variable. Long Island and Cape Cod generally have abundant quantities of glacial sand-gravel. In the remainder of the Section, sand-gravels are generally found in the higher terraces. The coastal portion of Virginia has very restricted supplies of aggregates. The major aggregate source is sand-gravel, with minor use of slag and clam/oyster shells for highway aggregate.

Section: 20b Sea Island
Avail. Rating: Adequate to Limited
Remarks: Sand-gravel from river and stream terraces, as well as along the Fall-Line Hills, generally affords the major aggregate supply.

Section: 20c Florida
Avail. Rating: Limited to Problem
Remarks: Crushed limestone sources are available in the Lime-Sink Area (northwest portion of the peninsula) and in the extreme southern tip. Coquina is used, particularly along the east coast of Florida. The remainder of the area is veneered with sand, resulting in large areas in the southern and central portions being void of coarse aggregate. Florida (*101*) states that concrete aggregate is lacking everywhere except along the southern tip. Florida considers the availability of aggregates to be a major factor in the selection of pavement type.

Section: 20d East Gulf Coast
Avail. Rating: Adequate to Limited
Remarks: The availability of aggregates appears to be extremely variable. The occurrence of quality aggregates decreases as one proceeds toward the coast, except in the Southern Pine Hills of Mississippi. Local limestones, limerock, and clam/oyster shells are used, but sand-gravel sources are the most important. These deposits are nowhere widespread, except in the southern portions of Mississippi and Louisiana. Skid resistance, adhesion, and the presence of deleterious materials in the sand-gravels are the most salient problems. The limestones of the Coastal Plain appear to be significantly different in quality from limestones found in the adjacent Provinces.

Section: 20e Mississippi Loessial Upland
Avail. Rating: Limited to Problem
Remarks: In general, aggregate supplies are lacking. The only sources of aggregates are sand-gravel deposits from terraces along some major rivers and from the "Lafayette gravels" in the southern portion of the Section. Skidding problems, associated with sand-gravel sources, may be a major problem. Mississippi reports that aggregate availability is a major factor in determining pavement type (*145*).

Section: 20f Mississippi Alluvial Plain
Avail. Rating: Severe Problem
Remarks: The only sources of aggregates are local terrace and point bar sand-gravels. An exception to the areal deficiency is the good quality sand-gravel deposits of Crowley's Ridge in Arkansas. Aggregates play an important role in determining pavement type in Mississippi and Missouri (*145, 146*). Much of the needed aggregate must be imported from bedrock regions in Arkansas, Missouri, and Tennessee, or from coastal plain sediments in these states (*144*).

Section: 20g West Gulf Coast
Avail. Rating: Adequate to Limited
Remarks: The characteristics of aggregates are similar to those of the East Gulf Coast. No information concerning aggregate problems was available.

Soils and Related Factors

Soil Origin

The basic Provinces are divided by soil origin into three major categories and six minor or subcategories. The major categories are (1) nontransported, (2) transported, and (3) mixtures.

The nontransported class is further divided into areas in which: bedrock predominates (nonsoil), thin residual soils predominate, and significant residual soils are developed. Transported-soil Provinces are divided into those in which water is the dominant mode of transport, and areas characterized by glacial surficial deposits. Wind-deposited soils are not the predominant soil origin of any Province, although they do characterize several Sections. Table B-11 lists the Sections by soil origin.

Soil Texture

A wide variety of information was used to map the general distribution of soils in the U.S. By far the greatest amount

TABLE B-11

SUMMARY OF SURFICIAL SOIL ORIGIN, BY SECTION [a]

SECT. CODE	MAJOR ORIGIN	MINOR ORIGIN
I. Provinces characterized by nontransported soils		
A. Bedrock predominating		
1a	NT-B	NT-R, T-W(vf)
1b	NT-B	NT-R, T-W(vf)(cs)
1c	NT-B	NT-R, T-W(vf)
1d	NT-R	NT-B, T-W(vf)
1e	NT-B, T-W(vf)	NT-R
2a	NT-B, T-G	
2b	NT-B	NT-R
2c	NT-B	NT-R
2d	NT-B	T-W(vf)
7a	NT-B, T-W(vf)	
7b	NT-B, T-G	T-W(vf)
7c	NT-B	T-W(vf)
8a	NT-B, R	
8b	NT-B	
8c	NT-B	T-W(vf)
8d	NT-B	NT-R, T-W(vf)
8e	NT-B	
9a	NT-B	NT-R
9b	NT-B	NT-R, T-W(vf)
9c	NT-B	NT-R
B. Thin residual soil development		
4a	T-L	NT-B
4b	NT-B, R	
4c	T-L	NT-B
4d	T-W(l), NT-R	
4e	NT-R	
6a	NT-B	T-W(vf)
6b	NT-R, B	
6c	NT-R, B	
6d	NT-R	
6e	NT-R	
6f	NT-R	
C. Significant soil development		
13a	NT-R	
13b	NT-R	
13c1	NT-R	
13c2	NT-R	T-W(Al)
13c3	NT-R	NT-B
14a	NT-R	
14b	NT-R	NT-B
14c	NT-R	
14d	NT-R	T-W(Al)
15a	T-G	
15b	T-G	
15c	NT-R	NT-B
15d	NT-R	
15e	NT-R	NT-B
16a	NT-R, B	
16b	NT-R	NT-B
17a	NT-B	
17b	NT-R	
18	NT-R	T-G
II. Provinces characterized by transported soils		
A. Water-deposited soils		
3a	T-G, NT-R	
3b	T-W(Al), NT-R	
3c	T-W(vf)	NT-R
5a	T-W(vf), NT-B	T-L
5b	T-W(vf), NT-B	
5c	T-W(l)(vf)	NT-B
5d	T-W(vf), NT-B	
5e	T-W(vf), NT-B, R	
5f	T-W(vf), NT-B, R	
20a	T-W(cs)	T-G
20b	T-W(cs)	
20c	T-W(cs)	NT-R
20d	T-W(cs)	
20e	T-L	
20f	T-W(Al)	
20g	T-W(cs)	
B. Glacial-deposited soils		
11a	T-W(m), G	NT-B
11b	T-W(m), G	
11c	T-G, W(m)	
11d	T-G	
11e	T-G, W(l)	
11f	T-G	T-L
11g	NT-R, T-L	
11h	T-G, W(l)	
11i	T-G, L	
12a	T-G	NT-B
12b	T-G	
19a	T-G, W(m)	
19b	T-G	NT-B
19c	T-G	
19d	T-G, NT-B	
19e	T-G, NT-B	
19f	T-G	NT-B
19g	T-G, NT-B	
III. Provinces characterized by mixed origin		
10a	T-G	
10b	NT-R	
10c	NT-R	
10d	NT-R	T-W(ow)
10e	NT-R, B	
10f	T-W(ow)	T-L, NT-R
10g	NT-R	T-W(ow)
10h	NT-R, B	
10i	NT-R	T-W(vf)
10j	NT-R, T-L, T-W(Al)(ow)	
10k	NT-R, B	
10l	NT-R, B	
10m	NT-R	

[a] NT—Nontransported soils
B—Bedrock
R—Residual soil

T—Transported soils
G—Glacial
L—Wind
W—Water

(ow)—outwash
(vf)—valley fill
(l)—lacustrine
(Al)—Alluvium
(m)—marine
(cs)—coastal sediments

of detailed information was in terms of soil texture. However, data varied from classification by engineering systems to such generalities as "fine textured" or "moderately coarse." Table B-12, developed from Cline (*216*) and the U.S. Army Corps of Engineers (*219*), was helpful in the requisite correlations and interpretations of descriptions.

The soil texture map of the U.S. is shown in Figures B-16 to B-21. Every effort has been made to keep the level of map unit descriptions as detailed as the information from which it was obtained. This factor resulted in a wide range of map unit combinations. In general, three broad categories of units are mapped: (1) single-textured units, (2) multiple-textured units, and (3) gradationally textured units. When soil types occur in combination, and one is known to dominate, it is underlined in the designation. The legend for the soil types is shown on Figure B-16.

Section Distribution.—The major soil types in each Section are given in Table B-13. In some cases, several map units have been combined for brevity. The order of the descriptions follows the Province sequence given in Table B-11.

Poor Subgrade Support Areas

Inorganic Soils.—Soils are used in two general ways along a highway route. They are either (1) stressed in place as foundations for structures (including embankments) and in cut slopes, or (2) excavated and compacted to form embankments, backfills for structures, and subgrades. The poorer soils are wasted (e.g., organics are not used as construction materials and are often excavated and/or displaced in embankment foundation situations). Local "problem" soils are avoided in subgrade locations, often because they are difficult to handle and/or compact. A number of soil textures can be troublesome in subgrades (i.e., nonplastic silts, micaceous silts, poorly graded sands), but problems of subgrade support are most common with clays. For this reason, the rating of Sections with respect to problems of subgrade support was accomplished by a combined consideration of the clayeyness of surficial soils and the frequency of occurrence of such soils.

The rating is compromised as topography becomes rough and more subgrade soils originate from deposits not mapped in the surficial coverage (Figures B-16 to B-21). All textural types coarser than (and including) the very fine sandy loam in Table B-12 were considered to afford satisfactory subgrade support. Finer textures were grouped into four severity categories based on the most probable Unified Soil Classification, also given in Table B-12. The resulting severity groups are given in Table B-14.

Severity ratings of each Section were then qualitatively formulated by combining textural type and distribution information with the general severity rating of Table B-14. The severity ratings and descriptive remarks in Table B-15 follow the Province sequence used in Table B-11.

Organic Soils.—No attempt was made to rate the severity of support problems associated with organic deposits in the Sections. Qualitatively assessed frequency of occurrence ratings are given under the description of soil textures. The reader is referred to this discussion.

High Volume Change Soils

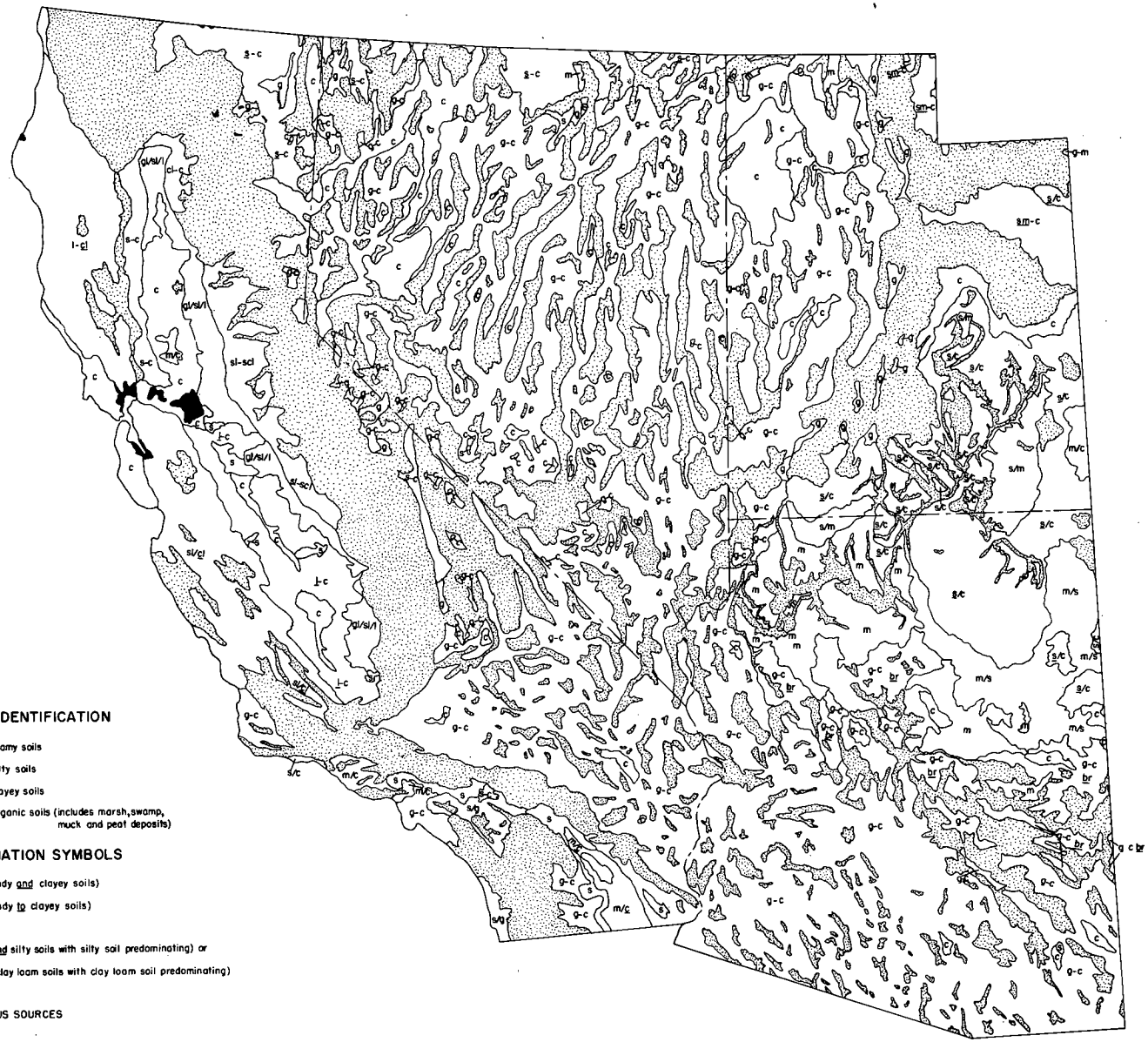
Engineering Literature.—A literature search of high volume change occurrences was undertaken; Figure B-22 shows the locations in which the swelling potential was realized. The numbers in the figure correspond to those in Table B-16, which is a summary of the references containing the information.

TABLE B-12

GENERAL SOIL CLASSIFICATION CORRELATION [a]

GENERAL TEXTURE	TEXTURE TYPE	U.S.C.S.[b] CATEGORY	
		MOST PROBABLE	OTHER
Coarse	Gravel	GP; GW	GM; GC
	Sand	SM; SP-SM	SM-SC
	Loamy sand	SM	SC
Moderately coarse	Sandy loam	SM	ML; SC
	Fine sandy loam	SM; ML	SC; SM
Medium	Very fine sandy loam	SM; ML	
	Loam	CL	ML; ML-CL
	Silt loam	CL	ML; ML-CL
Moderately fine	Sandy clay loam	CL	SC
	Silt	ML	CL
	Silty clay loam	CL	CH
	Clay loam	CL	CH
Fine	Sandy clay	SC; CL	
	Silty clay	CH	CL
	Clay	CH	CL; MH

[a] Developed from Cline (*216*) and the U.S. Army Corps of Engineers (*219*).
[b] Unified soil classification system.



LEGEND: BASIC SOIL TEXTURE IDENTIFICATION

or (br): bedrock
r : stoney soils
g : gravelly soils
s : sandy soils
l : loamy soils
m : silty soils
c : clayey soils
: organic soils (includes marsh, swamp, muck and peat deposits)

SOIL TEXTURE COMBINATION SYMBOLS

/ : infers "and" (eg., s/c : sandy and clayey soils)
- : infers "to" (eg., s-c : sandy to clayey soils)
_ : infers major soil texture
(eg., c/m : clayey and silty soils with silty soil predominating) or
(eg., l-cl : loam to clay loam soils with clay loam soil predominating)

NOTE: MAP DEVELOPED FROM NUMEROUS SOURCES

Figure B-16. General soil texture map. Map Sheet I: Southwest U.S.

NOTE: SEE MAP SHEET I FOR LEGEND

Figure B-17. General soil texture map. Map Saeet II: Northwest U.S.

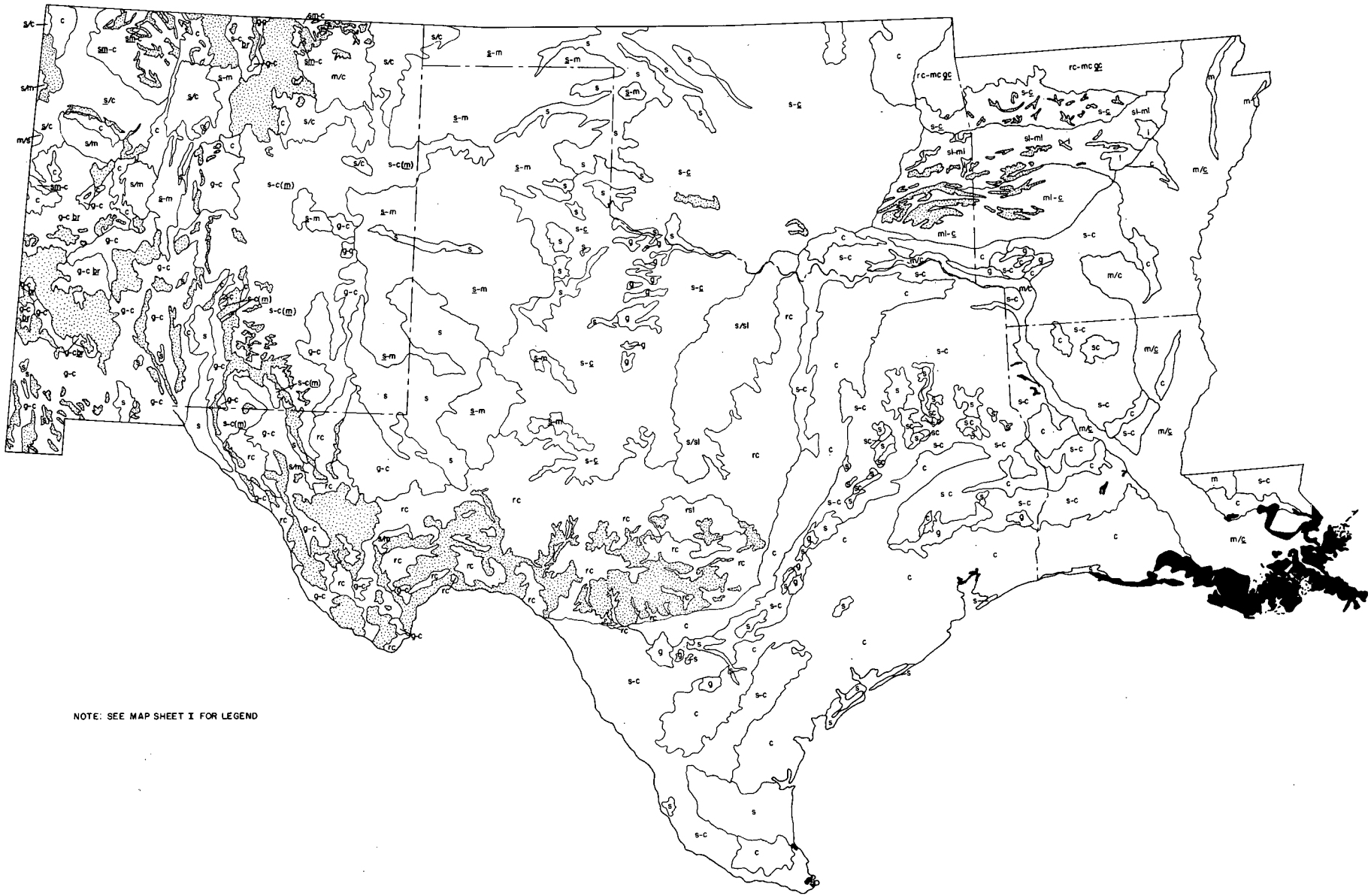
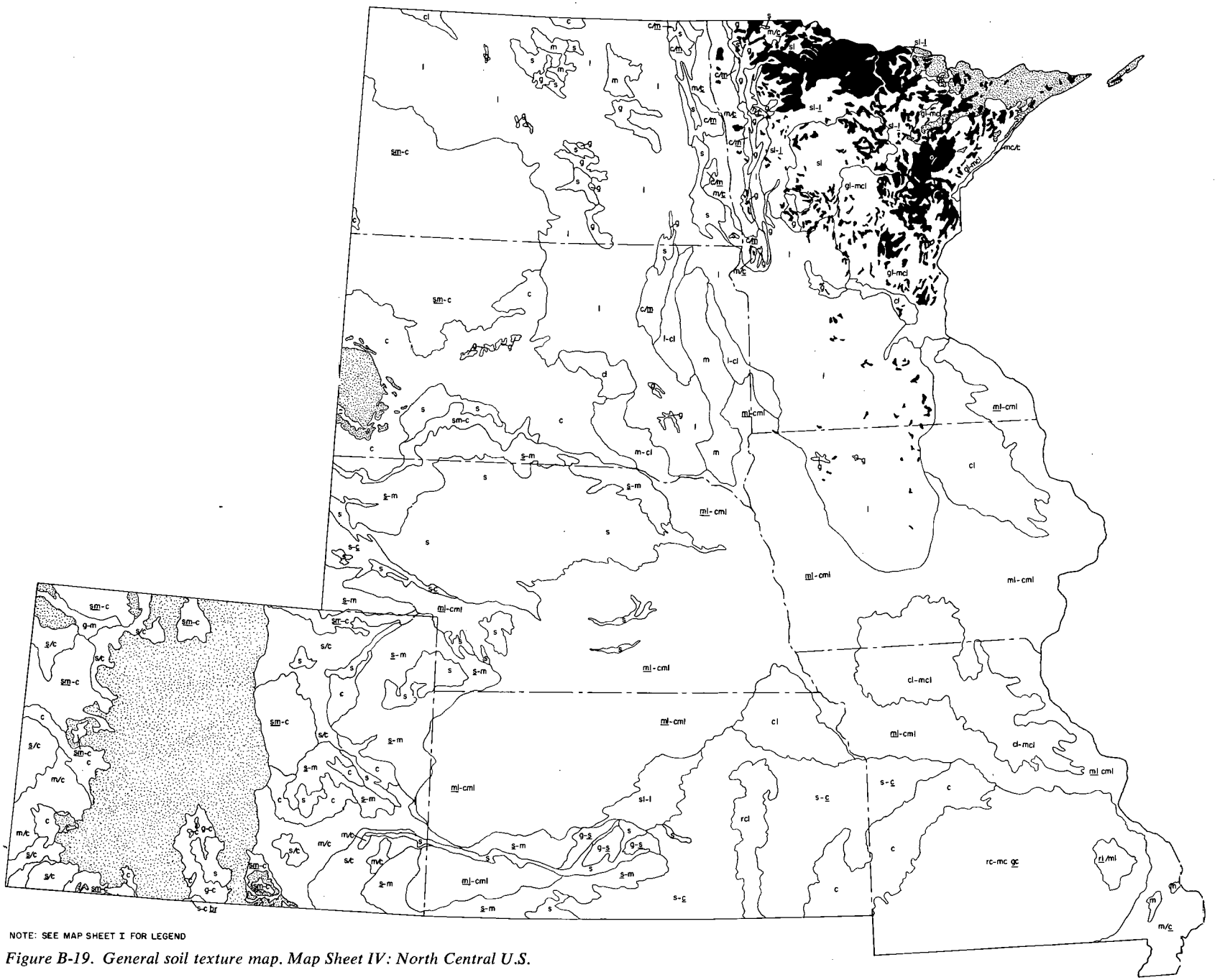


Figure B-18. General soil texture map. Map Sheet III: South Central U.S.



NOTE: SEE MAP SHEET I FOR LEGEND

Figure B-19. General soil texture map. Map Sheet IV: North Central U.S.

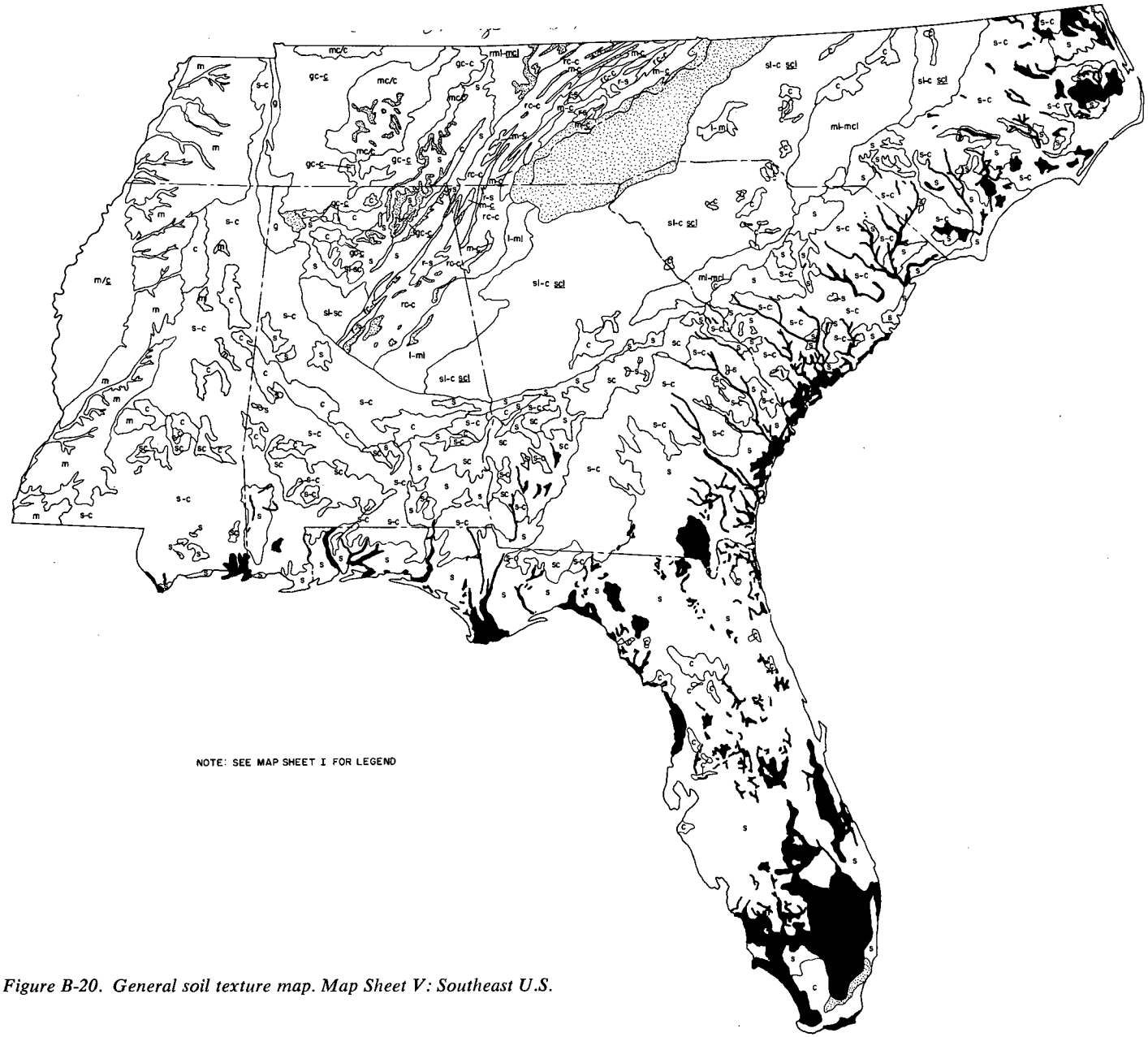


Figure B-20. General soil texture map. Map Sheet V: Southeast U.S.

Figure B-21. General soil texture map. Map Sheet VI: Northeast U.S.

TABLE B-13

DISTRIBUTION OF SOILS, BY BASIC REPORT UNIT

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

Province 1

Section 1a
1. Nonsoil area (VW).
2. Loamy to clay loam soils (L-M): thin residual soils developed from sandstones and shales.
3. Gravelly soils (N-L): surround north and east flanks of the mountainous part.
4. Organic soils (N-L).

Section 1b
1. Nonsoil area (VW): sandstone and shale bedrock.
2. Loamy to clay loam soils (N-L): residually developed from sandstones and shales.
3. Sandy soils (N-L): appear in small coastal plain areas.
4. Organic soils (N-L): associated with coastal plain areas.

Section 1c
1. Nonsoil area (VW).
2. Loamy to clay loam (N-L): residual sandstones and shales in small areas near coast.

Section 1d
1. Nonsoil area (L-M).
2. Loamy to clay loam (clay loam predominating) (L-M): residual sandstones and shales found primarily in northern coastal range area.
3. Sandy loam to clay loam (clay loam predominating) (L-M): residual sandstones and shales found primarily in southern coastal range area.
4. Clayey soils (N-L): generally associated with shale hills near San Francisco.
5. Organic soils (N-L): muck deposits near San Francisco Bay.

Section 1e
1. Nonsoil area (M-W): generally associated with Transverse Ranges.
2. Gravelly to clayey soils (L-M): primarily found in Los Angeles Basin; appears that coarse-textured soils predominate.

Province 2

Section 2a
1. Nonsoil area (VW): generally granitic-type mountains.
2. Gravelly soils (N-L): associated with valley outwash and glacial drift.

Section 2b
1. Nonsoil area (VW): generally igneous rocks.
2. Clay loam to clay (L-M): residual soils on western flank developed from basic igneous rocks. In many cases this unit gradually merges into the troughs as foothills.
3. Sandy to clayey soils (sandy predominating) (L-M): residual soils primarily from basic and acidic igneous rocks on the eastern flanks of the mountain range.

Section 2c
1. Nonsoil area (VW): generally granitic rocks.
2. Sandy loam to sandy clay loam (L-M): residual soils from granitic rocks occurring along the western part.

Section 2d
1. Nonsoil area (VW): generally granitic rocks.
2. Gravelly to clayey soils (gravelly soils predominating) (N-L): associated with valley fill material.

Province 7

Section 7a
1. Nonsoil area (M-W): rugged mountainous areas.
2. Gravelly to clayey soils (L-M): associated with basin areas characteristic of the Section; texture is frequently coarse, but clayey soils are in many basins.

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

Section 7b
1. Nonsoil area (M-W).
2. Gravelly soils (L-M): occur as coarse-textured glacial drift in the Washington portion and valley fill in the remaining areas.

Section 7c
1. Nonsoil area (VW): primarily associated with granitic batholith.

Province 8

Section 8a
1. Nonsoil area (VW): rugged igneous/metamorphic rocks.
2. Gravelly to clayey soils (bedrock predominating) (L-M): generally associated with thin residual soils from volcanic rocks.

Section 8b
1. Nonsoil area (VW).

Section 8c
1. Nonsoil area (VW).

Section 8d
1. Nonsoil area (M-W).
2. Gravelly to clayey soils (gravelly predominating) (N-L): associated with coarse-textured glacial outwash in Jackson Hole.
3. Sandy silt to clay (sandy silts predominating) (N-L): thin residual soils developed from sandstones and shales.
4. Organic (N-L): associated with glacial outwash in Jackson Hole.

Section 8e
1. Nonsoil area (VW).

Province 9

Section 9a
1. Nonsoil area (VW).

Section 9b
1. Nonsoil area (VW).
2. Gravelly and sandy soils (N-L): generally associated with the glacial and alluvial outwash found in the San Luis Valley.

Section 9c
1. Nonsoil area (VW).
2. Sandy to clayey (bedrock predominating) (N-L): associated with thin (generally) residual soils developed from basalts in the San Luis Hills portion.

Province 4

Section 4a
1. Silty soils (VW): aeolian (loessial deposits).
2. Sandy and gravelly soils (L-M): generally coarse-textured deposits from alluvial deposition.
3. Nonsoil areas (L-M): generally basaltic rock.

Section 4b
1. Nonsoil area (VW).
2. Stoney to clayey (stoney predominating) (L-M): generally residual soils developed from basic igneous rocks.

Section 4c
1. Silty soils (VW): aeolian deposits overlying acidic flows.
2. Nonsoil area (N-L): bare acidic lava areas.

Section 4d
1. Sandy to clayey soils (sandy predominating) (L-M): generally thin residual soils from extrusive flows.
2. Gravelly to clayey (L-M): associated with lacustrine areas that characterize the unit; textures vary considerably.
3. Silty (N-L): small aeolian area that is variant to the Section.

TABLE B-13 (*Continued*)

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

Section 4e
1. Sandy to clayey soils (sandy predominating) (M-W): thin residual soils developed from flows present in the Section.
2. Sandy (L-M): associated with pumice deposits in Great Sandy Desert area.
3. Organic (N-L): appear in isolated areas in the western part.

Province 6

Section 6a
1. Nonsoil areas (VW).
2. Sandy and clayey soils (sandy predominating) (N-L): thin residual soils from sandstone and shale.
3. Gravelly soils (N-L): associated with valley deposits.

Section 6b
1. Sandy silt to clay (sandy silt predominating) (M-W): thin residual soils developed primarily from Tertiary sandstones and shales.
2. Nonsoil area (L-M): sandstones and shales.
3. Gravelly soils (N-L): associated with outwash from Uinta Mountains; occur in northernmost part of the Section.

Section 6c
1. Sandy, silty, and clayey soils (sandy predominating) (M-W): generally thin residual soils from sandstones and shales.
2. Clayey soils (N-L): associated with clay shales.
3. Nonsoil area (N-L): associated with canyon lands.

Section 6d
1. Sand, silts, and clays (sandy predominating) (M-W): associated with residual development from sandstones and shales.
2. Nonsoil area (N-L).
3. Clayey soils (N-L): associated with clay shales.

Section 6e
1. Silty soils (M-W): thin residual soils from limestone.
2. Silty and sandy soils (L-M): thin residual soils from sandstones and shales.
3. Gravelly to clayey soils (bedrock predominating) (L-M): thin residual soils from flows.
4. Nonsoil area (N-L).

Section 6f
1. Clayey soils (L-M): associated with clay shales.
2. Sands, silts, and clays (sandy predominating) (L-M): thin residual soils associated with sandstones and shales.
3. Gravelly to clayey (bedrock predominating) (L-M): thin residual soils from flows.
4. Nonsoil areas (N-L).

Province 13

Section 13a
1. Stoney loams (VW): residual soils developed from granitic-type rocks.
2. Silty loams (L-M): residual soils from sedimentary rocks in isolated valley areas.

Section 13b
1. Stoney clays to silty clays (gravelly clay predominating) (VW): associated with residual development from cherty limestones (primarily).

Section 13c1
1. Sandy to clayey soils (clayey predominating) (M-W): residual soils primarily from sandstones and shales; stoney soils may occur locally.
2. Nonsoil areas (N-L): associated with rugged sandstone outcrops.

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

Section 13c2
1. Sandy loam to silty loam (M-W): residual soils from folded sandstones and shales.
2. Loamy soils (N-L): associated primarily with alluvial deposits from Arkansas River.
3. Nonsoil areas: rugged sandstone (primarily).

Section 13c3
1. Silty loam to clayey soils (clayey predominating) (M-W): residual soils from sandstones, shales, and minor areas of slates and quartzites.
2. Nonsoil area (L-M): associated with rugged sandstones, and novaculite; appears to be more widespread in northern and eastern (Oklahoma) parts.

Province 14

Section 14a
1. Silty clay loam to clayey soils (clayey predominating) (M-W): residual soils developed in the Outer Blue Grass and Eden Shale Belt units; parent materials are argillaceous limestones (Outer Blue Grass) and shale with minor siltstone (Eden Shale Belt).
2. Silty clays and clays (L-M): residual soils developed in Inner Blue Grass from pure limestones.

Section 14b
1. Silty clays and clays (VW): residual soils from limestones.
2. Nonsoil area (N-L): associated with bare limestones outcrops known as glades.

Section 14c
1. Sandy loams to sandy clay loams (L-M): residual soils from sandstones, shales, and minor amounts of limestone.
2. Sandy clay loam to silty clay loam (L-M): residual soils similar to soil unit 1, above.
3. Silts and clays (N-L): associated with alluvial areas.
4. Silty loam to clayey silt loam (silty loam predominating) (N-L): aeolian deposits generally found in western part of area and irregularly along portions of the Ohio.

Section 14d
1. Gravelly clay to clayey (clayey predominating) (M-W): residual soils generally associated with cherty limestones.
2. Silty clay and clayey soils (L-M): residual soils from relatively pure limestones.

Province 15

Section 15a
1. Nonsoil area (M-W): bare, hard sandstone bedrock.
2. Stoney soils (M-W): associated with sandstone-derived drift.
3. Sandy loams to silty loams (silty loams predominating) (L-M): glacial drift generally in valley portions.

Section 15b
1. Sandy loam to silt loam (silt loam predominating) (M-W): glacial drift found primarily in New York and Pennsylvania generally derived from hard sandstones with some shale.
2. Clay loam and loamy soils (L-M): glacial drift found primarily in western part (Ohio and northwest Pennsylvania); drift is generally more plastic (i.e., less silty) than drift noted in soil unit 1, above.
3. Gravelly and sandy soils (N-L): generally associated with valley (glacial) outwash; found primarily in New York State.
4. Organic soils (N-L): small scattered areas.

TABLE B-13 (*Continued*)

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

Section 15c
1. Stoney silt loam to silty clay loam (silty clay loam predominating) (M-W): associated with residual soil developed primarily from sandstones and shales; appears similar to soil in adjacent Kanawha unit.
2. Nonsoil areas (L-M): associated with rugged sandstone areas in the southern part.

Section 15d
1. Stoney silt loam to silty clay loam (silty clay loam predominating) (M-W): residual soils primarily from Mississippian rocks and the Pottsville and Allegheny formations of Pennsylvanian age.
2. Sandy clay loam to clayey (clayey predominating) (M-W): residual soils from parent material having more soft shale and limestone outcrops than soil unit 1, above; geologically, this area conforms to the Conemaugh and Monongahela formations of Pennsylvanian age and the Dunkard formation of Permian age. Residuum developed from these rocks is generally more plastic than soil unit 1.
3. Nonsoil area (N-L): isolated areas in southern part.

Section 15e
1. Sandy soils (M-W): generally associated with residual soils from sandstone.
2. Sandy loam to sandy clay (N-L): residual soils similar to soil unit 1, above.
3. Nonsoil areas (N-L): rugged sandstone areas.
4. Gravelly clay to clay (clay predominating) (N-L): residual soil from cherty limestones in the Sequatchie and Wills Creek Valleys.
5. Clayey (N-L): residual soils from pure limestone, and associated with the variant limestone valleys of soil unit 4, above.

Province 16

Section 16a
1. Stoney to sandy soils (M-W): generally associated with thin residual cover from sandstones occupying ridges of the area.
2. Nonsoil areas (L-M): sandstone ridges.
3. Silty to clayey (clayey predominating) (L-M): residual soils from limestones and shales in the valley portion; texture varies greatly but fine-textured soil residuum is generally common in many portions of the valley areas.

Section 16b
1. Stoney clays to clays (M-W): residual soils from carbonate rocks that are frequently cherty; chert residue may yield a stoney or gravelly to clayey matrix.
2. Silty to clayey (clayey predominating) (L-M): residual soils from chert-free carbonates.
3. Nonsoil area (N-L): sandstone ridges.
4. Stoney to sandy soils (N-L): thin residual development from sandstone ridges.

Province 17

Section 17a
1. Nonsoil area (V-W): although the entire Section is noted to be of a nonsoil area type, thin to moderately thick residual soils are present. Generally, soil type depends on the parent rock and has a counterpart soil in the Piedmont Plateau Section to the southeast.

Section 17b
1. Sandy loam to clay (sandy clay loam predominating) (VW): residual soils developed primarily from granitic and gneissic rocks.
2. Silty loam to silty clay loam (L-M): associated with residual soils of the Slate Belt areas of the Carolinas.

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

3. Loamy to silty loam (L-M): residual soils generally developed from schists.
4. Clayey soils (N-L): residual soils primarily associated with basic igneous rocks.
   Special remarks: This Section is characterized by a relatively deep development of residual soil. Generally, almost all soils have very heavy (clayey) B horizons. In addition, much mica is present in the soil and frequently yields A-7-5 or MH Engineering soil classification.

Province 18
1. Sandy to clayey (clayey predominating) (VW): residual soils from Triassic sandstones and shales.
2. Clayey (N-L): residual soils from limestones in valleys.
3. Stoney to clayey (N-L): residual soils associated with trap ridges; portions may be nonsoil area.
4. Sandy loam to clay (sandy clay loam predominating) (N-L): residual soils from granitic and gneissic rocks.
5. Sandy and gravelly (N-L): glacial drift in northern part.
6. Organic soils (N-L): associated with glaciated parts.

Province 3

Section 3a
1. Gravelly and sandy soils (M-W): associated with glacial deposits.
2. Clay loam to clay (L-M): residual soils developed from basalts in the Trough.
3. Organic (N-L): found in glaciated part.

Section 3b
1. Gravelly to clayey (VW): associated with alluvium of floodplains or nonmarine terraces occupying much of the section; soil texture is extremely variable.
2. Loamy to clayey loam (N-L): residual soils from sandstones and shales along west flank of the valley.
3. Clayey loam to clay (N-L): residual soils from basic igneous rocks on east side of the valley.

Section 3c
1. Loamy to clayey (loam predominating) (L-M): associated with flatter trough areas.
2. Clayey (L-M): generally associated with mixed alluvium and valley terraces in the Trough.
3. Gravelly loams, sandy loams, and loams (L-M): generally associated with alluvial fans along the Sierra Nevada.
4. Sandy (N-L): wind-modified areas predominate in the southern part of the valley.
5. Organic (N-L): occurs in Sacramento-San Joaquin delta.

Province 5

Section 5a
1. Gravelly to clayey (M-W): valley fill areas that characterize the basin portion; soil texture is generally highly variable but varies gradationally in size as one proceeds toward the center of the basins.
2. Nonsoil area (M-W): mountain ranges.
3. Clayey (L-M): associated with old lacustrine beds (playas) common to the central basin area.
4. Silty soils (N-L): aeolian deposits occurring in the northeast part.
5. Sandy to clayey (sandy predominating) (N-L): residual soils, generally thin, developed from extrusive rocks in the northwest part.

Section 5b
1. Gravelly to clayey (M-W): associated with valley fill; general characteristics similar to those found in Section 5a.
2. Nonsoil area (L-M): ranges.

TABLE B-13 (*Continued*)

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

3. Clayey (N-L): associated with playas similar to Section 5a; frequency of occurence is not as great as in Section 5a.

Section 5c
1. Silts and clays (clayey predominating) (M-W): associated with fine-textured lacustrine and alluvial soils.
2. Sandy soils (N-L): wind-modified dune areas.
3. Gravelly to clayey (N-L): valley fill.
4. Nonsoil area (N-L): mountain range to the east.

Section 5d
1. Gravelly to clayey (M-W): valley fill.
2. Nonsoil area (L-M): ranges and mountains.
3. Gravelly to clayey (bedrock predominating) (N-L): thin residual soils from extrusive rocks; found in northern part.
4. Clayey (N-L): found in central basin areas.

Section 5e
1. Nonsoil areas (L-M).
2. Sandy to clayey (silty predominating) (L-M): residual soils derived primarily from sandstones and shales.
3. Gravelly to clayey (L-M): associated with water-deposited soils (predominantly valley fill).
4. Stoney clays (N-L): residual soil from limestone.

Section 5f
1. Nonsoil area (M-W).
2. Stoney clays (L-M): residual soils from limestones comparable to those found in the Edwards Plateau.
3. Gravelly to clayey (L-M): valley fill.

Province 20

Section 20a
1. Sandy (M-W): associated with coastal terraces.
2. Mixed sands and clays (M-W): coastal deposits.
3. Organic (L-M): associated with tidal marshes that occupy areas of the outer coastal plain but which may follow estuaries up to the inner zone.
4. Clayey (N-L): associated with Cretaceous deposits in Raritan Lowland; often associated with greensand belt.
5. Sandy and gravelly soils (N-L): glacial deposits on Cape Cod and Long Island.

Section 20b
1. Mixed sandy and clayey (M-W): coastal deposits.
2. Sandy (L-M): coastal deposits.
3. Organic (L-M): similar to Section 20a.
4. Sand clay (N-L): coastal deposits.

Section 20c
1. Sandy (VW): coastal deposits.
2. Organic (M-W): area contains many large swamps.
3. Clayey (L-M): generally associated with residual soils from water-deposited marls and chalky limestones; major concentration occurs around the Ocalla uplift and in southern Florida.
4. Nonsoil area (N-L): minor area of limerock south of Everglades.

Section 20d
1. Mixed sands and clays (M-W): coastal deposits.
2. Sandy clay (L-M): coastal deposits.
3. Sands (L-M): coastal deposits.
4. Clayey soils (L-M): primarily associated with residual development on Cretaceous and younger limestones and chalks in the Belted Coastal Plain area.
5. Organic (N-L): small outer coastal areas have isolated deposits.

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

Section 20e
1. Silty (VW): loessial deposits.
2. Silts and clays (clays predominating) (N-L): associated with floodplains of rivers dissecting the area.

Section 20f
1. Silts and clays (clays predominating) (VW): alluvium from Mississippi and Red Rivers.
2. Silty (N-L): loessial area variant to alluvial plain called Crowley's Ridge.
3. Organic (N-L): associated with deltaic deposits of the Mississippi River.

Section 20g
1. Clayey (M-W): generally associated with three distinct areas and types; residually developed from limestones and chalks (Cretaceous); marine clays found along the coast; and isolated alluvial clays similar to those that characterize the Mississippi Alluvial Plain Section.
2. Mixed sands and clays (L-M): coastal deposits.
3. Sands and gravels (N-L): coastal deposits.
4. Organic (N-L): minor areas along coast.

Province 11

Section 11a
1. Clays and silts (clays predominating) (M-W): associated with marine deposits; frequently interspersed with silty-type till.
2. Organic deposits (L-M).
3. Nonsoil areas (N-L).
4. Sandy soils (N-L).

Section 11b
1. Clayey soils (VW): associated with marine deposits.
2. Organic (N-L).

Section 11c
1. Clayey soils (M-W): marine clays restricted to northern part.
2. Loamy (M-W): glacial drift derived from slates, limestones, and sandstones in southern parts.
3. Organic (N-L): occurs in southern part.

Section 11d
1. Loamy to silty clay loams (M-W): glacial till predominantly from dark shale; low in lime.
2. Stoney soils (L-M): occurs in Tug Hill Cuesta.
3. Gravelly soils (N-L): occurs near Tug Hill Cuesta.
4. Organic (N-L).

Section 11e
1. Organic (M-W).
2. Soils associated with glacial lacustrine areas (reworked till in part) (L-M):
   a. Silty clays, clays, silty clay loam, clay loam.
3. Soils associated with glacial drift (primarily late Wisconsin age) (M-W):
   a. Gravelly loam, sandy loams, and loams (M-W): occur extensively in Michigan and Wisconsin.
   b. Loam to silty clay loam (L-M): occurs in New York and portions of Illinois and Wisconsin.
   c. Sandy loam to loam (N-L): occurs in Indiana.
   d. Loam to silty loam (N-L): occurs in parts of Wisconsin, Michigan, and Indiana.
   e. Clay loam (N-L): occurs primarily in tri-state area of Michigan, Ohio, and Indiana.

Section 11f
1. Organic (N-L).
2. Silty loam to clayey silt loam (L-M): loessial deposits in western Illinois and southwestern Indiana.
3. Gravelly soils (N-L): alluvial (sluiceway) terraces.

TABLE B-13 (*Continued*)

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

4. Soils associated with glacial drift (M-W).
   a. Illinoian till (L-M):
      i. Loam to clay (clay loam predominating).
      ii. Clay loam: occurs primarily in Illinois.
   b. Wisconsin (early) till (L-M):
      i. Silty clay loam (L-M): occurs in Illinois, Indiana, and Ohio.
      ii. Loam (L-M): generally occurs in a belt south of soil unit bi.
      iii. Loam to silty clay loam (L-M): Illinois.
      iv. Loam to silty loam (N-L): Illinois.

Section 11g
1. Sandy soils (M-W): associated with old glacial lacustrine area and residual soils from Cambrian sandstones and shales; forms greatest part of Central Sand Plain of Wisconsin.
2. Silty loam to clayey silt loam (silty loam predominating) (M-W): aeolian deposits that mantle Cambrian sandstones and shales and younger Paleozoic carbonates.
3. Organic (N-L): occur principally in northeast part.

Section 11h
1. Soils associated with glacial till (VW).
   a. Loamy (M-W): occurs in all states in the Section.
   b. Gravelly loam, sandy loam, and sandy clay loam (L-M): occurs primarily in northern Minnesota.
2. Soils associated with glacial lacustrine areas (L-M):
   a. Clays and silts: fine-textured lacustrine deposits.
   b. Sandy and gravelly soils: water-sorted (beach) deposits.
3. Organic (L-M): occur primarily in northeast.
   Special Remarks: The clayey textured soils appear to be more prominent in the Lake Agassiz area, with silty soils flanking the finer clays on all sides. Sandy beach deposits predominate on the western side (North Dakota); gravelly material is found in Minnesota. Lake Souris appears to have an equitable distribution of both silt and clay size deposits; Lake Dakota appears more silty in texture; both of these lacustrine areas have associated granular beach deposits.

Section 11i
1. Silty loam to clayey silt loam (silty loam predominating) (M-W): aeolian deposits overlying glacial drift.
2. Clay loam to silty clay loam (clay loam predominating) (M-W): glacial drift; primarily Kansan, in part Iowan.

Province 12

Section 12a
1. Soils associated with glacial drift (M-W): mainly gravelly loams, sandy loams, sandy clayey loams, and silty clay loams.
2. Nonsoil areas (L-M).
3. Organic (L-M).
4. Silty clays and clays (N-L): lacustrine deposits.

Section 12b
1. Nonsoil area (VW).
2. Relatively thin cover of stony glacial drift (L-M).
3. Organic (L-M).

Province 19

Section 19a
1. Clayey soils (M-W): marine clays generally present in northern part.
2. Stoney sandy and gravelly soils (M-W): glacial drift, generally thin and similar to that found in the adjacent upland unit to the north.
3. Organic (L-M): includes muck and peat bogs associated with glaciation, as well as marshy deposits in estuarine deltas near mouths of rivers and streams.
4. Nonsoil area (N-L).

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

Section 19b
1. Stoney sandy and gravelly soils (M-W): generally thin glacial drift of Wisconsin age derived from two major rock groups: (1) granites, gneisses, and schists, and (2) shales and limestones; sedimentary-rock-derived till found primarily in northern part.
2. Nonsoil areas (L-M).
3. Clayey gravelly soils (N-L): glacial till generally derived from limestones and shales in northeast Maine.
4. Organic (N-L).
5. Clayey soils (N-L): small scattered areas of marine clays which are modal to the adjacent Seaboard Lowland unit; existence of this soil unit may be due to the relatively indefinite border that separates the New England Upland from the Seaboard Lowland.

Section 19c
1. Sandy and gravelly soils (VW): coarse glacial drift occurring within till, outwash plains, and terraces.
2. Organic (N-L): small area noted in southern part.
3. Nonsoil area (N-L): associated with trap ridges.

Section 19d
1. Nonsoil area (VW).
2. Stoney gravelly and clayey gravelly soils (N-L): isolated patches of glacial drift similar to that found in New England Upland Section.
3. Organic (N-L).

Section 19e
1. Nonsoil area (M-W).
2. Stoney gravelly soils (M-W): generally thin cover of coarse glacial drift.

Section 19f
1. Loamy (VW): glacial till derived from schists, slates, shales, and limestones; minor areas may be stoney.
2. Nonsoil areas (N-L).

Section 19g
1. Nonsoil area (M-W): occurs in glaciated part.
2. Stoney loam (M-W): thin residual soils developed from primarily gneissic rocks; occurs in nonglaciated part.

Province 10

Section 10a
1. Loamy soils (M-W): forms bulk of glacial till of North Dakota and South Dakota portions of Section.
2. Clay loam (M-W): glacial till found primarily in Montana and smaller isolated areas of the Dakotas.
3. Nonsoil areas (N-L): several Rocky Mountain outliers.
4. Gravelly soils (N-L): found near Montana border with Rocky Mountains and in north central Montana.

Section 10b
1. Sandy silt to clayey (sandy silt predominating) (M-W): residual soils derived from sandstones and shales.
2. Clayey (M-W): associated with clay shales of the unit; Pierre Hills area is a primary example.
3. Gravelly soils (N-L): smal isolated areas associated with outwash.
4. Nonsoil areas (N-L).

Section 10c
1. Sandy silts to clayey (sandy silt predominating) (M-W).
2. Clayey (N-L): associated with scattered areas of clay shales.
3. Gravelly to clayey (N-L): coarse textures generally predominate; associated with outwash from surounding mountain areas; occur in areas that lie between Rocky Mountain appendages that protrude into the Section.

TABLE B-13 (*Continued*)

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

4. Nonsoil area (N-L): scattered exhumed granitic areas protruding through Tertiary sediments.

Section 10e
1. Nonsoil area (L-M): associated with granitic core and volcanic rock areas.
2. Clayey soils (L-M): residual soils developed from Triassic shales and Permian limestones.
3. Sandy and silty soils (N-L): associated with residual soils developed from the Cretaceous Dakota Sandstone; this soil area encircles the area and gradually merges (topographically) into the surrounding Missouri Plateaus.

Section 10f
1. Sandy to silty (sandy predominating) (M-W): original plains outwash mantle; gravelly textures and clays occasionally found.
2. Sandy (L-M): corresponds to Nebraska Sand Hills plus several other scattered areas; in part wind-reworked.
3. Silty loam to clayey silt loam (silt loam predominating) (L-M): aeolian deposits occur in northeast and extend into the Central Lowland Province.
4. Sandy to clayey (clayey predominating) (N-L): residual soils developed primarily from Brule clay in Goshen Hole Lowland area of Nebraska and Wyoming.

Section 10g
1. Sandy to clayey (M-W): residual soils from Tertiary and Cretaceous sandstones and shales.
2. Clayey (L-M): associated with clay shales.
3. Sandy to silty (sandy predominating) (L-M): variant Great Plains outwash mantle.

Section 10h
1. Sandy to clayey (VW): see comments of Section 10g.
2. Nonsoil areas (N-L).

Section 10i
1. Sandy to clayey (silt predominating) (VW): residual soils developed from sandstones and shales (minor limestones) of Triassic, Jurassic, and Permian age; may be thinly developed and lack any widespread clayey residue.
2. Gravelly to clayey (L-M): valley fill in southern part.

UNIT CODE, SOIL, AND FREQUENCY OF OCCURRENCE [a]

3. Sandy to silty (sandy predominating) (N-L): isolated areas of Great Plains outwash units.

Section 10j
1. Silty loam to clay silt loam (silty loam predominating) (L-M): aeolian areas overlying bedrock and Plains outwash.
2. Sandy to clayey (clayey predominating) (L-M): residual soils from sandstones, shales, and limestones of Cretaceous and Permian age.
3. Sandy loam to loam (N-L): residual soil in Smokey Hills area.
4. Sandy to silty (sandy predominating) (N-L): Tertiary Plains outwash variant to unit.
5. Sandy and gravelly soils (N-L): generally associated with alluvial soils in Arkansas Lowland; portion may be wind-reworked.

Section 10k
1. Sandy to clayey (clayey predominating) (L-M): residual soils from Permian sandstones and shales.
2. Stoney sandy loams (L-M): residual soils from granitic-type rocks of Llano Uplift.
3. Stoney clays (L-M): residual from Cretaceous limestones.
4. Sands and sandy loams (N-L): residual soils from Pennsylvanian sandstones and shales.
5. Nonsoil areas (N-L).

Section 10l
1. Stoney clays (M-W): residual soils from Cretaceous limestones.
2. Nonsoil area (M-W): bare limestone outcrops.

Section 10m
1. Sandy to clayey (clayey predominating) (VW): residual soils from Permian sandstones and shales and Pennsylvanian limestones, sandstones, and shales.
2. Stoney clay loams (N-L): residual from cherty limestones in Flint Hills.
3. Clayey (N-L): associated with Pennsylvanian shales in Cherokee Lowland.
4. Nonsoil area (N-L): Wichita and Arbuckle Mountains.
5. Sands and gravels (N-L): scattered soils of water-transported origin.

[a] (VW) very widespread; (M-W) medium to widespread; (L-M) limited to medium; (N-L) nonexistent to limited; and (NE) nonexistent.

Geologic Investigation.—The association of high volume change soils with particular geologic formations was determined from literature searches. Table B-17 summarizes the results by geologic age and formation, as reported and mapped by Jensen (*333*). Figure B-23 shows the distribution of these formations. The base map used by Jensen was Ref. *384*. These are areas of swelling potential.

Based on information obtained from this phase of the project, the occurrence and frequency of high volume change formations in the Sections were examined. Table B-18, the result of this effort, rates the potential for volume change problems.

Pedologic Investigation.—A comparable study was undertaken with pedologic information. Table B-19 summarizes the data, based on parent-material origins. Figure B-24 shows the distribution of these areas. The base map used by Jensen was Ref. *379*.

A frequency of occurrence rating also was established for each Section with high volume change soil series

TABLE B-14

GENERAL SEVERITY CATEGORY OF POOR SUBGRADE SUPPORT POTENTIAL, BY TEXTURAL CLASSIFICATION

CATEGORY	TEXTURAL CLASS.	U.S.C.S. CATEGORY [a] MOST PROBABLE	OTHER
1 (least severe)	Sandy clay	SC; CL	—
	Sandy clay loam	CL	SC
2	Silt	ML	CL
	Silt loam	CL	ML; ML-CL
	Loam	CL	ML; ML-CL
3	Clay loam	CL	CH
	Silty clay loam	CL	CH
4 (most severe)	Silty clay	CH	CL
	Clay	CH	CL

[a] Unified soil classification system.

TABLE B-15

SEVERITY RATING, BY BASIC REPORT UNIT

SECTION CODE	SEVERITY RATING [a]	REMARKS
1a	N-L	Lean clays developed from residual sandstones and shales may be present in minor parts of the area.
1b	N-L	Comments similar to Section 1a.
1c	NE	
1d	L-M	Lean clays may be found over much of the area from residual sandstones and shales.
1e	N-L	Minor areas of lean to highly plastic clays may be found in the Los Angeles Basin.
2a	NE	
2b	N-L	Lean and plastic clays may be associated with residual soils from basic igneous rocks on the western flank of the Range.
2c	N-L	Minor area of residual soils from granitic rocks may afford lean clay development.
2d	NE	
7a	N-L	Clay soils generally confined to basin areas.
7b	NE	
7c	NE	
8a	NE	
8b	NE	
8c	NE	
8d	N-L	Lean to plastic clays may be found in minor areas from residual sandstones and shales.
8e	NE	
9a	NE	
9b	NE	
9c	NE	
4a	NE	
4b	NE	
4c	NE	
4d	N-L	Highly plastic clays may be associated with lacustrine areas.
4e	NE	
6a	N-L	Clays may be associated with shales in southern part; remainder of soils may be thin and coarse-textured.
6b	N-L	Highly plastic clays may be associated with shales.
6c	N-L	Clays may be associated with clay shales; sandy texture predominates.
6d	N-L	Similar to Section 6c.
6e	N-L	Plastic clays may be associated locally with residual soils from volcanic material.
6f	L-M	Highly plastic clays are associated with shales and clay shales.
13a	N-L	Silt loam developed from sedimentary rocks may be of a lean clay variety.
13b	L-M	Highly plastic soils may be found throughout the area; however, chert residue in stoney or gravelly form may increase the subgrade support.
13c1	L-M	Highly plastic residual soils may be associated with sandstones and shales.
13c2	N-L	Lean clays are associated with the residual soils and alluvial deposits of the area; clay shales also are found in the area.
13c3	L-M	Highly plastic soils may develop from residual soils.
14a	VW	Development of highly plastic residual soils is very widespread.
14b	VW	Same as Section 14a.
14c	L-M	Residual soils appear to be less plastic (i.e., more silty and sandy) than in other Sections of Province; lean clays may be associated with residual soils while the more plastic soils are associated with the limited alluvial deposits in the area.
14d	M-W	Highly plastic soils frequently may be encountered with residual soils.
15a	N-L	Silty loam glacial drift in the valleys may frequently be of a lean clay variety.
15b	L-M	Lean clays from glacial drift are present throughout most of the Section; plasticity of the drift may be greater in the western part; highly plastic soils generally are nonexistent.
15c	L-M	Silty clay loam residual soils may generally be a lean to heavy clay material.
15d	M-W	Comments similar to Section 15c; in addition, residual soils developed from Conemaugh, Monongahela, and Dunkard formations may be highly plastic.
15e	N-L	Only clayey type soils are associated with the variant limestone valleys in the Section; residual soils developed in these limestones may be highly plastic.
16a	L-M	Lean to heavy plastic clays are generally associated with the limestone and shale residual soils of the valley.
16b	L-M	Clayey soils are associated with residual soils of the area; quantity of cherty residue in clay matrix may increase potential subgrade support.
17a	NE	
17b	M-W	Lean clays are present throughout entire Section; highly plastic soils are associated with residual soils developed from basic igneous rocks.
18	M-W	Lean to highly plastic clay soils are associated with each residual soil type in the area.
3a	N-L	Lean to highly plastic clays may be associated with residual basalts.
3b	L-M	Highly plastic clays may frequently underlie portions of the floodplains; similar type clays may be associated with residual soils found in the adjacent border uplands.
3c	M-W	Clays of variable plasticity characteristics frequently are associated with both alluvium and valley trough soils in the central part of the valley.
5a	L-M	Plastic clay soils generally are associated with lacustrine areas in the central parts of the basins.
5b	N-L	Comments similar to Section 5a, except frequency of occurrence is less.

TABLE B-15 (*Continued*)

SECTION CODE	SEVERITY RATING [a]	REMARKS
5c	M-W	Highly plastic soils are widely distributed in association with lacustrine and alluvial deposits.
5d	N-L	Comments similar to Section 5b.
5e	N-L	Clayey soils of unknown plasticity characteristics may be associated with valley fill and residual soils from limestones.
5f	N-L	Comments similar to Section 5e.
20a	N-L	Highly plastic clays are primarily associated with Cretaceous rocks in the Raritan Lowland.
20b	N-L	Clays may be associated with mixed coastal sediments; sand clay of unit *not* considered as a poor subgrade material in this unit.
20c	L-M	Highly plastic clay soils may be residually developed from carbonate rocks.
20d	L-M	Clays developed from limestones and chalks are frequently highly plastic.
20e	N-L	Highly plastic clays are generally associated with minor alluvial areas.
20f	VW	Highly plastic soils are widespread from alluvial origin.
20g	M-W	Highly plastic clays are widespread from a variety of origins.
11a	M-W	Highly plastic clays are widely distributed throughout the area from marine deposits.
11b	M-W	Comments similar to Section 11a.
11c	M-W	Lean and plastic clays from marine and glacial deposits may be distributed throughout the area; marine clays may be highly plastic.
11d	L-M	Major portion of drift may be of a lean clay variety.
11e	L-M	Most highly plastic clays are associated with the lacustrine areas; clayey till appears to be limited to the outer (southern and western) limits of drift; this till is generally of the lean clay variety and not widely distributed; till is predominantly coarse-textured.
11f	M-W	Has a more extensive areal distribution of clayey type soils than the Eastern Lakes and Lacustrine Sections; generally the most plastic soils are associated with the oldest drift (Illinoian); these soils, however, are not as plastic as those associated with glacial lacustrine origin; over-all, a lean clay type of soil may be prevalent throughout most of the Section.
11g	N-L	Lean clays may occasionally be associated with aeolian deposits; major texture of unit is primarily sandy to silty.
11h	N-L	Most plastic soils appear in glacial lacustrine deposits (primarily Lake Agassiz); major till texture of unit is gravelly loam to loam, with loamy till predominating, somewhat similar in coarseness to that of the Eastern Lakes and Lacustrine Section; lean clays may be associated with the loamy drift.
11i	M-W	Lean clay soil is distributed throughout most of the area; less plastic (silty) soils are associated with the loess deposits; highly plastic soils are associated with the Kansan drift.
12a	N-L	Highly plastic clays are associated only with minor areas of lake deposits; drift texture is granular.
12b	NE	
19a	M-W	Highly plastic clays are associated with marine clays widely distributed in area.
19b	N-L	Minor areas of marine clays similar to those in Section 19a may protrude into unit.
19c	NE	
19d	NE	
19e	NE	
19f	N-L	Although loam texture predominating in unit has a potential for a lean clay classification, it is generally the finest texture present; much of the area has a stoney fraction, and subgrade support should not be a problem.
19g	NE	
10a	L-M	Entire till portion may be considered as clayey type; lean clays will be more prominent in the Dakotas, while plasticity of the till increases in the Montana portion; most probable clay throughout unit is a lean clay type.
10b	M-W	Widely distributed and highly plastic clays are often associated with the clay shales and shales of the area.
10c	N-L	Highly plastic clays may frequently be associated with shales; however, predominant texture is semigranular.
10d	N-L	Comments similar to Section 10c.
10e	N-L	Highly plastic clays are associated with shales of the area; clays from residual limestones are frequently less plastic.
10f	N-L	Only potential clayey area is that found in Goshen Hole Lowland from shaley bedrock; predominant texture of unit is sandy to silty.
10g	L-M	Highly plastic soils are associated with clay shales and shales.
10h	L-M	Comments similar to Section 10g.
10i	N-L	Generally lacks any regional clay-type soils; occasionally, highly plastic soils may be associated with shales.
10j	N-L	Most plastic soils associated with residual sandstones and shales in southeast and eastern parts.
10k	N-L	Highly plastic soils are generally confined to the residual soils developed from Permian rocks in the western part.
10l	L-M	Plastic clays may be associated with residual limestones found throughout the area.
10m	M-W	Highly plastic soils may be frequently associated with the residual soils throughout much of the area.

[a] VW—very widespread; M-W—medium to widespread; L-M—limited to medium; N-L—nonexistent to limited; NE—nonexistent.

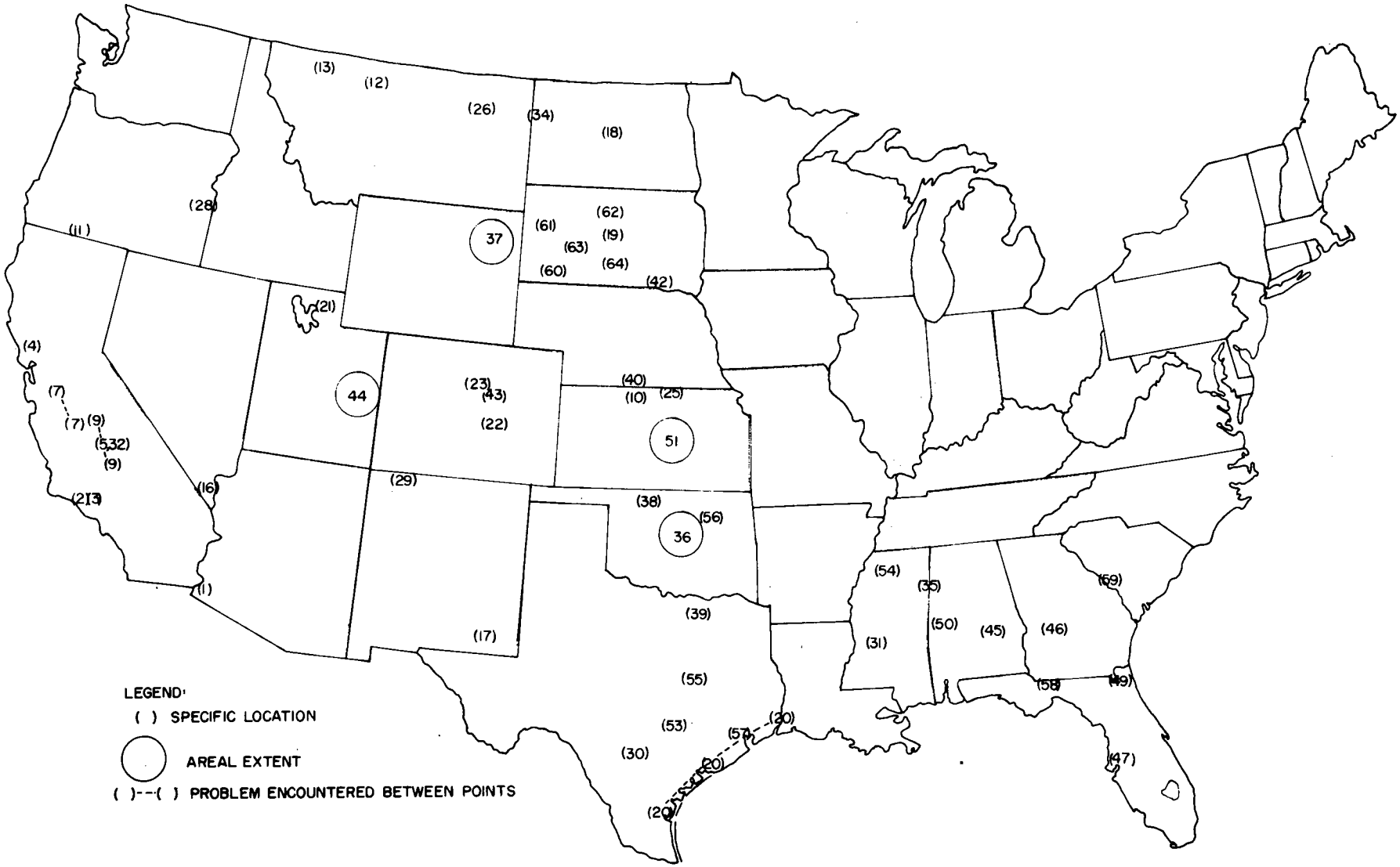


Figure B-22. Location of high volume change soils problems as encountered in engineering literature. For locations of map numbers, see Table B-16. From Jensen (333).

(Table B-20). Again, the rating is largely one of potential volume change problems.

Adjusted Frequency of Occurrence Rating, by Section.—The final frequency of occurrence rating for each Section with high volume change potential generally is based on the higher geologic or pedologic rating. Several exceptions occur, however, where transported surficial deposits mantle high volume change geologic formations. An example occurs in the Mississippi Loessial Upland Section. Based on the pedologic mapping, a "nonexistent to limited" rating was obtained.

However, a frequency rating of "very widespread" was obtained from the geologic phase, owing to the existence of high volume change formations underlying the loessial mantle. As the basic characteristics of the Section are based on loessial parent material, and these are not conducive to high volume change, a final rating of "nonexistent to limited" was selected.

Table B-21 gives the adjusted frequency of occurrence rating for each Section containing potential high volume change areas.

Frost Action and Frost-Susceptible Soils

Physiographic Sections Within the Freezing Zone.—The selection of Sections experiencing significant frost was based on an analysis by Sourwine (*90*). Figure B-25 shows the relationship between Sections considered to be within the freezing zone and the limit proposed by Sourwine. Table B-22 summarizes the separation of Sections into groupings where (1) ground freezing is assumed to be a potential hazard, and (2) ground freezing probably is insignificant.

Composite Frost-Susceptible Soils Map—Northern States.—Figures B-26, B-27, and B-28 show the composite frost-susceptible soils map for the northern U.S., using the Corps of Engineers' susceptibility classification. This map is modified slightly from the work of Bloom (*90*) and Osborne (*166*).

Distribution of Frost-Susceptible Soils, by Section.—For each Section considered to be within the freezing zone, a qualitative assessment of the frequency was made of the frost-susceptible soils. The ratings are based on an examination of the frost maps (Figs. B-26, B-27, and B-28). For portions of Sections not mapped by Bloom (*90*) or Osborne (*166*), but occurring within the freezing zone, the generalized frost-susceptible soil conditions were evaluated by the researchers with the procedure described in Chapter One.

Table B-23 gives the frequency of occurrence rating of frost-susceptible soils in each Section considered to be in the frost zone.

TABLE B-16

REFERENCE SUMMARY OF HIGH VOLUME CHANGE SOIL LOCATIONS OBTAINED FROM ENGINEERING LITERATURE

MAP NO.[a]	PROJECT-LOCATION	REFERENCE[b]
1	Gila Canals; Ariz.	(*383*)
2	Casitas Canal; Calif.	(*383*)
3	Ojai Valley Pump; Calif.	(*383*)
4	Putah Canal; Calif.	(*383*)
5	Lind-Strath Reservoir; Calif.	(*383*)
6	Lindmore Reservoir; Calif.	(*383*)
7	Delta-Mendota Canal; Calif.	(*383*)
8	Contra Costa Canal; Calif.	(*383*)
9	Friant-Kern Canal; Calif.	(*383*)
10	Kirwin Dam; Kan.	(*383*)
11	Emigrant Dam; Ore.	(*383*)
12	Tiber Dam Spillway; Mont.	(*383*)
13	Shelburne Dam; Mont.	(*383*)
14	BLM-Collins Dam; Mont.	(*383*)
15	Little Porcupine Plant; Mont.	(*383*)
16	Boulder City; Nev.	(*383*)
17	McMillan Reservoir; N.M.	(*383*)
18	McClusky Canal; N.D.	(*383*)
19	Oahe Pump; S.D.	(*383*)
20	Gulf Coast Canal; Tex.	(*383*)
21	Gateway Canal; Utah	(*383*)
22	Colorado Springs; Colo.	(*383*)
23	Denver-Boulder Turnpike; Colo.	(*383*)
24	Fire Mountain Canal; Colo.	(*383*)
25	Courtland Canal; Neb.	(*383*)
26	Fort Peck Dam; Mont.	(*383*)
27	Ortega Reservoir; Calif.	(*383*)
28	Malheur River Siphon; Ore.	(*383*)
29	Navajo Dam; N.M.	(*383*)
30	San Antonio; Tex.	(*368*)
31	Jackson; Miss.	(*363*)
32	Porterville; Calif.	(*346*)
33	Bexar County; Tex.	(*378*)
34	Fort Union Dam; N.D.	(*369*)
35	West Point; Miss.	(*323, 324*)
36	Permian Red Beds; Okla.	(*352, 353*)
37	Heavy Bentonite Areas; Wyo.	(*382, 383*)
38	Great Salt Plains Dam; Okla.	(*381*)
39	Sherman; Tex.	(*381*)
40	Harlan County Dam; Neb.	(*381*)
41	Kanopolis Dam; Kan.	(*381*)
42	Fort Randall Dam; S.D.	(*381*)
43	Denver; Colo.	(*310*)
44	East central Utah	(*328*)
45	Montgomery; Ala.	(*372*)
46	Central Ga.	(*372*)
47	Central Fla.	(*372*)
48	Northeast Miss.	(*372*)
49	North central Fla.	(*372*)
50	Tombigbee River; Ala.	(*372*)
51	Kansas	(*300*)
52	Texas	(*322*)
53	Austin; Tex.	(*315, 316*)
54	Panola County; Miss.	(*378*)
55	Waco, I-35; Tex.	(*350*)
56	Tulsa; Okla.	(*352, 353*)
57	Houston-Urban Freeway; Tex.	(*329*)
58	I-10 N.W. of Limon; Colo.	(*307*)
59	Tallahassee; Fla.	(*372*)
60–64	Western South Dakota	(*370*)

[a] Map number keyed to Figure B-22.
[b] Number refers to bibliography reference number.

TABLE B-17

GEOLOGIC AGE SUMMARY OF HIGH VOLUME CHANGE FORMATIONS [a]

GEOLOGIC AGE	DESCRIPTION
Quaternary	1. Mississippi alluvium
	2. Alluvial and lakelaid deposits
	3. Houston fm
Quaternary-Tertiary	4. Quaternary and Tertiary marine and fresh-water deposits (alluvial fans, lakebeds)
Tertiary (Undifferentiated)	5. Jackson, Chickasawhay, Barnwell, and Ocalla fm
	6. Tampa and Hawthorn fm
	7. Jackson fm
	8. Ft. Union shale
Tertiary-Cretaceous	9. Lower Cretaceous fm (Porters Creek and Nahoela)
	10. Laramie and Denver fm
Cretaceous (Upper)	11. Selma and Euthaw fm
	12. Eagleford and Woodbine fm
	13. Taylor and Austin fm
	14. Upper Cretaceous fm (Eagleford, Pierre, and Bearpaw)
	15. Pierre and Bearpaw shale fm
	16. Mesaverde, Mancos, and Lewis shale fm
	17. Mesaverde, Mancos, Lewis, and Cody shale fm
Cretaceous (Undifferentiated)	18. Cretaceous fm (Cody, Mowry, Frontier, Benton, Niobrara fm)
	19. Cretaceous fm (Cody and Benton)
	20. Cretaceous fm (Mowry and Frontier)
	21. Cretaceous marine shale
Permian	22. Permian Red Beds

[a] Information summarized from Jensen (*333*).

TABLE B-18

SUMMARY OF GEOLOGIC FORMATIONS SHOWING HIGH VOLUME CHANGE, BY FREQUENCY OF OCCURRENCE WITHIN SECTIONS [a]

SECTION CODE	HIGH VOLUME CHANGE FORMATIONS	ESTIMATED OCCURRENCE WITHIN SECTION (ALL FORMATIONS CONSIDERED) [e]
1d California Coast Range	1. Quaternary and Tertiary marine and freshwater deposits (alluvial fans, lakebeds)	M-W
	2. Cretaceous marine shales	
1e Los Angeles Ranges	1. Quaternary and Tertiary marine and freshwater deposits (alluvial fans, lakebeds)	L-M
2d Lower California	1. Quaternary and Tertiary marine and freshwater deposits (alluvial fans, lakebeds)	N-L
3c California Valley	1. Quaternary and Tertiary marine and freshwater deposits (alluvial fans, lakebeds)	L-M
5a Great Basin	1. Quaternary and Tertiary marine and freshwater deposits (alluvial fans, lakebeds)	L-M
5b Sonoran Desert	1. Quaternary and Tertiary marine and freshwater deposits (alluvial fans, lakebeds)	N-L
6a High Plateaus of Utah	1. Mesaverde, Mancos, and Lewis shale fm	L-M
	2. Quaternary and Tertiary marine and freshwater deposits (alluvial fans, lakebeds)	
6b Uinta Basin	1. Mesaverde, Mancos, and Lewis shale fm	L-M

TABLE B-18 (*Continued*)

6c	Canyon Lands	1. Cretaceous fm (Cody, Mowry, Frontier, Benton, and Niobrara)	L-M
6d	Navajo	1. Mesaverde, Mancos, and Lewis shale fm 2. Cretaceous fm (Cody, Mowry, Frontier, Benton, and Niobrara)	M-W
6e	Grand Canyon	1. Quaternary and Tertiary marine and freshwater deposits (alluvial fans, lakebeds)	L-M
6f	Datil	1. Mesaverde, Mancos, and Lewis shale fm 2. Cretaceous fm (Cody, Mowry, Frontier, Benton, and Niobrara)	L-M
10a	Glaciated Missouri Plateau [b]	1. Pierre and Bearpaw shale fm 2. Cretaceous fm (Cody and Benton)	L-M
10b	Unglaciated Missouri Plateau	1. Pierre and Bearpaw shale fm 2. Cretaceous fm (Cody and Benton) 3. Ft. Union shale 4. Mesaverde, Mancos, Lewis, and Cody shale fm	VW
10c	Bighorn Basin	1. Cretaceous fm (Cody and Benton) 2. Mesaverde, Mancos, Lewis, and Cody shale fm	L-M
10d	Wyoming Basin	1. Ft. Union shale 2. Mesaverde, Mancos, Lewis, and Cody shale fm 3. Cretaceous fm (Cody and Benton)	L-M
10g	Colorado Piedmont	1. Mesaverde, Mancos, and Lewis shale fm 2. Upper Cretaceous fm (Eagleford, Pierre, Bearpaw) 3. Laramie and Denver fm 4. Cretaceous fm (Cody, Mowry, Frontier, Benton, and Niobrara)	VW
10h	Raton Upland	1. Cretaceous fm (Cody, Mowry, Frontier, Benton, and Niobrara)	M-W
10j	Plains Border	1. Cretaceous fm (Cody, Mowry, Frontier, Benton, and Niobrara)	L-M
10k	Central Texas Mineral	1. Permian Red Beds	L-M
10m	Osage Plains	1. Permian Red Beds	M-W
11i	Dissected Loessial and Till Plains [c]	1. Permian Red Beds 2. Cretaceous fm (Cody, Mowry, Frontier, Benton, and Niobrara)	N-L
20b	Sea Island	1. Lower Cretaceous fm (Porters Creek and Nahoela) 2. Jackson, Chickasawhay, Barnwell, and Ocalla fm	L-M
20c	Florida	1. Tampa and Hawthorn fm 2. Jackson, Chickasawhay, Barnwell, and Ocalla fm	L-M
20d	East Gulf Coast	1. Tampa and Hawthorn fm 2. Jackson, Chickasawhay, Barnwell, and Ocalla fm 3. Selma and Euthaw fm 4. Lower Cretaceous fm (Porters Creek and Nahoela)	VW
20e	Mississippi Loessial Upland [d]	1. Tampa and Hawthorn fm 2. Jackson, Chickasawhay, Barnwell, and Ocalla fm	VW
20f	Mississippi Alluvial Plain	1. Mississippi alluvium	VW
20g	West Gulf Coast	1. Taylor and Austin fm 2. Eagleford and Woodbine fm 3. Jackson fm 4. Houston fm	VW

[a] Information summarized from Jensen (*333*).
[b] Formations overlain by glacial drift within Section.
[c] Formations overlain by glacial drift and loessial deposits within Section.
[d] Formations overlain by loessial deposits within Section.
[e] VW—very widespread; M-W—medium to widespread; L-M—limited to medium; N-L—nonexistent to limited; NE—nonexistent.

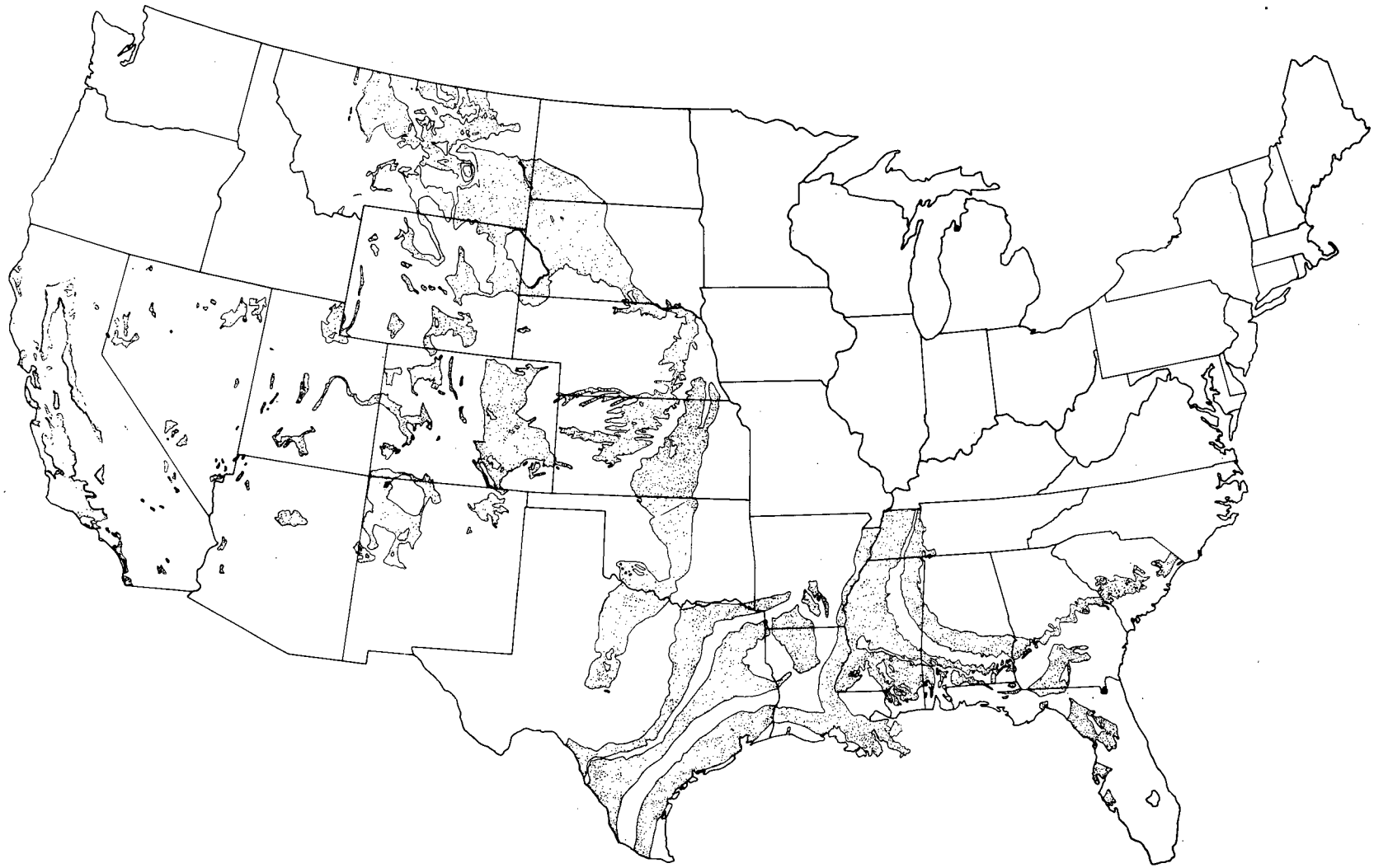


Figure B-23. Distribution of general high volume change soil areas (geologic analysis). Source: Jensen.

TABLE B-19

ORIGIN-PARENT MATERIAL SUMMARY OF HIGH VOLUME CHANGE PEDOLOGIC SOIL SERIES [a]

			TYPICAL SOIL PROPERTIES			
					APPROX. % PASSING	
ORIGIN	SOIL SERIES	PARENT MATERIAL	LL	PI	0.005 MM	0.002 MM
Residual	Altamont	Metamorphosed sandstone/shale	45	21	65	
	Crawford	Limestone and calcareous shale	70	40		50
	Crete	Shale and limestone	60	35	50	
	Houston	Limestone, marls, and chalk	75	45		50
	Iredell	Dark basic igneous rocks	50	35	55	
	Kirkland	Calcareous shale	55	30	50	
	Parsons	Shale	60	30		50
	Pierre	Shale	75	45	90	
	Valera	Limestone and interbedded chalky marl	60	35	45	
	Vernon	Shale and clays	55	30	90	
Glacial	Phillips	Calcareous glacial drift	60	35	50	
Water						
Coastal plain	Crowley	Coastal plain sediments, marls, and limestone	50	35	55	
	Kathy	Coastal plain sediments of clay, sandy clay	65	40	50	
	Lake Charles	Coastal plain clays and marls	75	40		50
	Oktibbeha	Heavy clays	65	35	60	
	Susquehanna	Sandy clays and clays	80	60	70	
	Victoria	Calcareous clays	70	40		50
Alluvial fans	San Joaquin	Alluvial fans (wide range of rock)	65	30	50	
	Placentia	Alluvial fans (granitic-type rocks)	70	40	80	
River alluvium	Miller	Fine-grained alluvium	75	45	90	
	Sharkey	Fine-grained alluvium	85	60		70
	Waverly	Fine-grained alluvium	70	35		50
Lakelaid	Fargo	Fine-textured sediments	60	30		50
	Lahontan	Fine-textured sediments	70	40		60

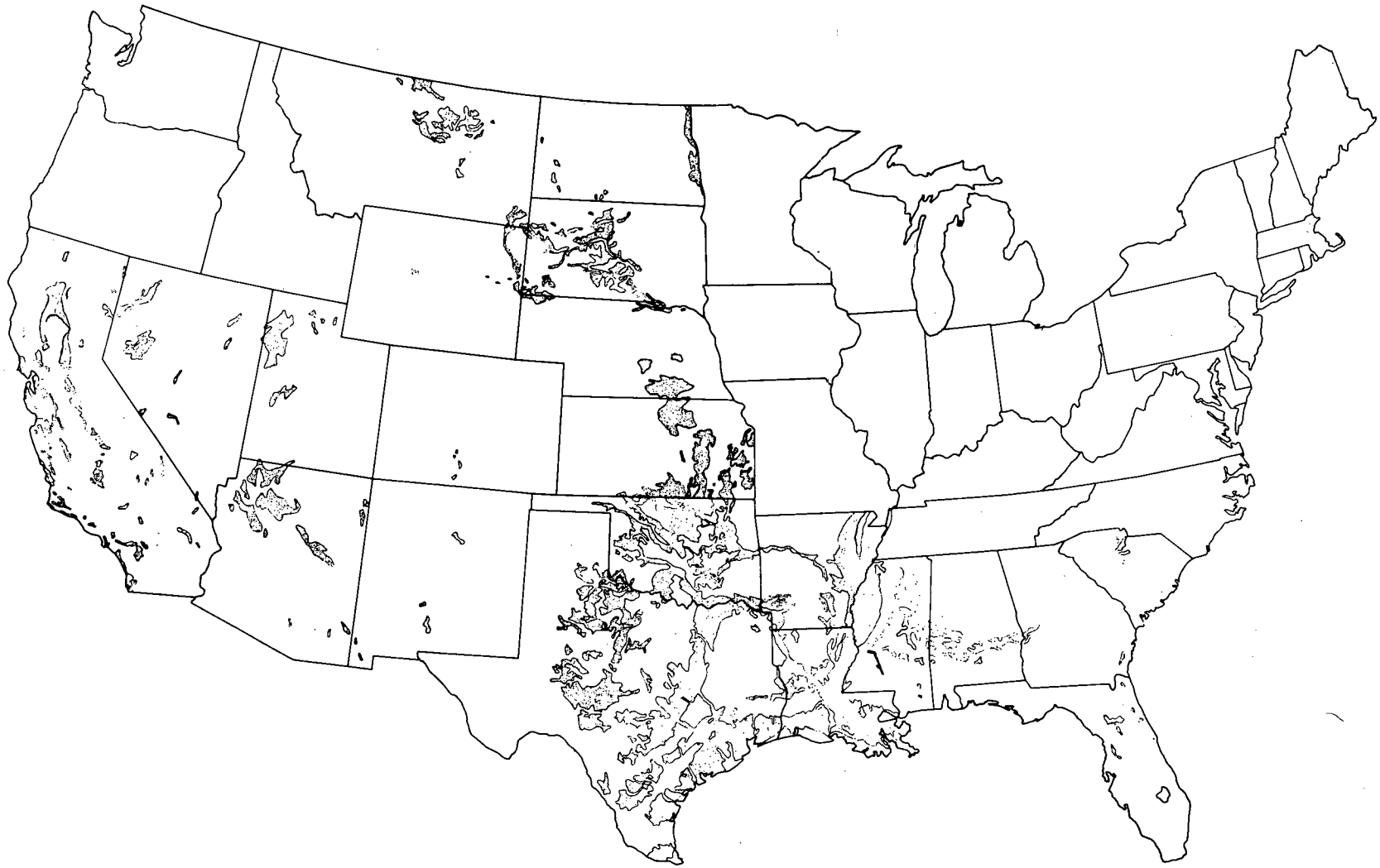


Figure B-24. Distribution of general high volume change soil areas (pedologic analysis). Source: Jensen.

TABLE B-20

SUMMARY OF PEDOLOGIC SOIL SERIES SHOWING HIGH VOLUME CHANGE BY FREQUENCY OF OCCURRENCE WITHIN SECTIONS [a]

SECTION CODE		HIGH VOLUME CHANGE SOIL SERIES	ESTIMATED OCCURRENCE WITHIN SECTION (ALL SOIL SERIES CONSIDERED)[b]
1d	California Coast Range	1. Placentia	L-M
		2. Altamont	
1e	Los Angeles Ranges	1. Placentia	N-L
		2. Altamont	
2d	Lower California	1. Placentia	N-L
		2. San Joaquin	
3c	California Valley	1. Placentia	L-M
		2. San Joaquin	
		3. Altamont	
5a	Great Basin	1. Lahontan	L-M
5b	Sonoran Desert	1. Lahontan	N-L
5d	Open Basin	1. Lahontan	N-L
6d	Navajo	1. Altamont	N-L
6e	Grand Canyon	1. Valera	M-W
9b	Western	1. Lahontan	N-L
10a	Glaciated Missouri Plateau	1. Phillips	N-L
10b	Unglaciated Missouri Plateau	1. Pierre	L-M
10d	Wyoming Basin	1. Phillips	N-L
10f	High Plains	1. Crete	N-L
10j	Plains Border	1. Crete	L-M
		2. Miller	
		3. Vernon	
		4. Kirkland	
10k	Central Texas Mineral	1. Valera	L-M
		2. Crawford	
10l	Edwards Plateau	1. Valera	L-M
10m	Osage Plains	1. Vernon	VW
		2. Miller	
		3. Kirkland	
		4. Crawford	
		5. Parsons	
11h	Western Lakes and Lacustrine Plains	1. Fargo	N-L
13c2	Arkansas Valley	1. Miller	N-L
17b	Piedmont	1. Iredell	N-L
20d	East Gulf Coast	1. Susquehanna	L-M
		2. Houston	
		3. Oktibbeha	
		4. Crowley	
20e	Mississippi Loessial Upland	1. Waverly	N-L
20f	Mississippi Alluvial Plain	1. Sharkey	VW
		2. Waverly	
		3. Crowley	
		4. Miller	
20g	West Gulf Coast	1. Susquehanna	M-W
		2. Waverly	
		3. Miller	
		4. Houston	
		5. Crowley	
		6. Lake Charles	
		7. Kathy	
		8. Victoria	
		9. Valera	

[a] Information summarized from Jensen (*333*).

[b] VW—very widespread; M-W—medium to widespread; L-M—limited to medium; N-L—nonexistent to limited; NE—nonexistent.

TABLE B-21

FINAL ADJUSTED HIGH VOLUME CHANGE FREQUENCY OF OCCURRENCE RATINGS, BY SECTION

SECT. CODE	RATING [b]		
	PEDOLOGIC	GEOLOGIC	FINAL
1d	L-M	M-W	M-W
1e	N-L	L-M	L-M
2d	N-L	N-L	N-L
3c	L-M	L-M	L-M
5a	L-M	L-M	L-M
5b	N-L	N-L	N-L
5d	N-L	NE	N-L
6a	NE	L-M	L-M
6b	NE	L-M	L-M
6c	NE	L-M	L-M
6d	N-L	M-W	M-W
6e	M-W	L-M	M-W
6f	NE	L-M	L-M
9b	N-L	NE	N-L
10a [a]	N-L	L-M	N-L
10b	L-M	VW	VW
10c	NE	L-M	L-M
10d	N-L	L-M	L-M
10f	N-L	NE	N-L
10g	NE	VW	VW
10h	NE	M-W	M-W
10j	L-M	L-M	L-M
10k	L-M	L-M	L-M
10l	L-M	NE	L-M
10m	VW	M-W	VW
11h	N-L	NE	N-L
11i [a]	NE	N-L	NE
13c2	N-L	NE	N-L
17b	N-L	NE	N-L
20b	NE	L-M	L-M
20c	NE	L-M	L-M
20d	L-M	VW	VW
20e [a]	N-L	VW	N-L
20f	VW	VW	VW
20g	M-W	VW	VW

[a] Adjusted rating.
[b] VW—very widespread; M-W—medium to widespread; L-M—limited to medium; N-L—nonexistent to limited; NE—nonexistent.

TABLE B-22

STATUS OF PHYSIOGRAPHIC SECTIONS AND THEIR GENERAL RELATIONSHIP TO GROUND FREEZING

1. SECTIONS ANALYZED FOR DISTRIBUTION AND OCCURRENCE OF FROST-SUSCEPTIBLE SOIL TYPE (CONSIDERED, IN THE MAIN, TO BE WITHIN ZONE OF GROUND FREEZE DANGER)

(*a*) Sections with entire area within dangerous freezing zone

4c	6a	7a	8a	9a	10a	11a	12a	13a	15a	19a
4d	6b	7b	8b	9b	10b	11b	12b		15b	19b
4e	6c	7c	8c	9c	10c	11c			15c	19c
	6d		8d		10d	11d				19d
	6f		8e		10e	11e				19e
					10g	11f				19f
					10h	11g				19g
					10j	11h				
						11i				

(*b*) Sections with portion of area outside dangerous freezing zone

2a	4a	5a	6e	10f	13b	15d	16a	18
2b	4b							
2c								

2. SECTIONS NOT ANALYZED FOR DISTRIBUTION AND OCCURRENCE OF FROST-SUSCEPTIBLE SOIL TYPE (CONSIDERED, IN THE MAIN, TO BE OUTSIDE ZONE OF GROUND FREEZE DANGER)

(*a*) Sections with entire area outside dangerous freezing zone

1a	2d	3a	5b	10k	13c1	14b	15e	16b	20b
1b		3b	5c	10l	13c2				20c
1d		3c	5f		13c3				20d
1e									20e
									20f
									20g

(*b*) Sections with portion of area within dangerous freezing zone

1c	5d	10i	14a	17a	20a
	5e	10m	14c	17b	
			14d		

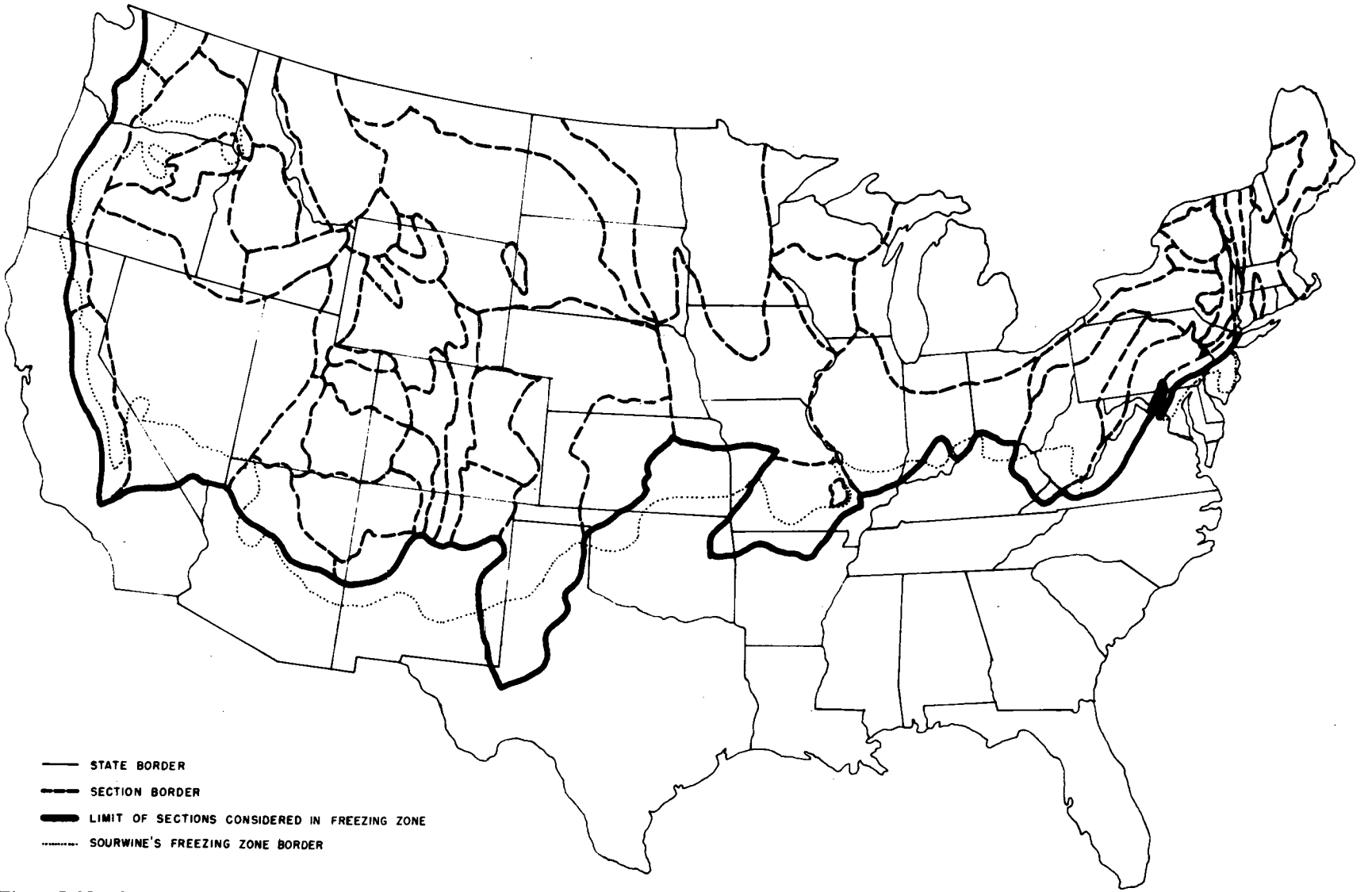


Figure B-25. Physiographic Sections considered within the freezing zone and their relationship to Sourwine's freezing border.

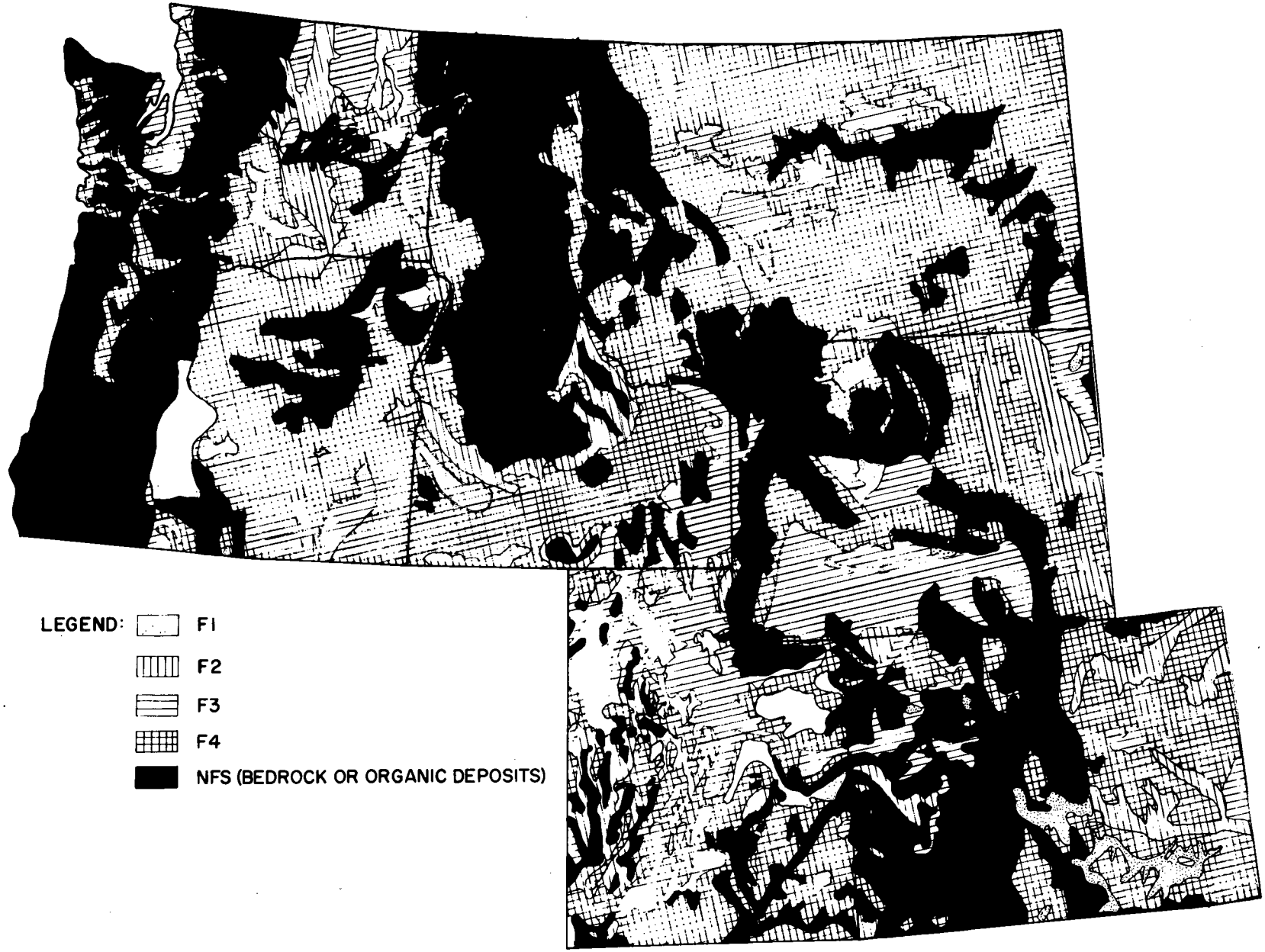


Figure B-26. General frost-susceptible soils map, northern states. Map Sheet I: Northwest U.S. Source: Bloom (90) *and Osborne* (166).

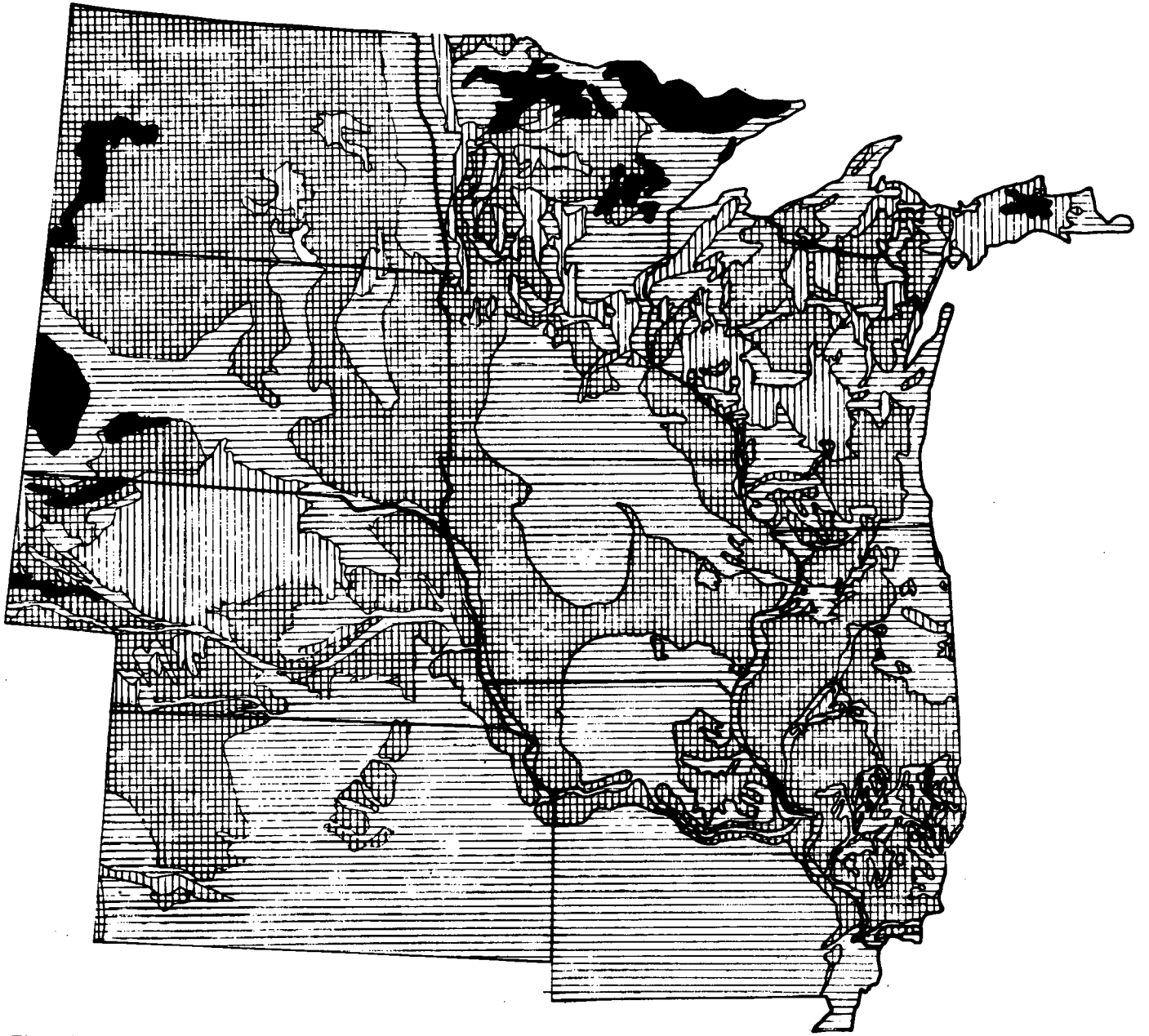


Figure B-27. General frost-susceptible soils map, northern states. Map Sheet II: North Central U.S.

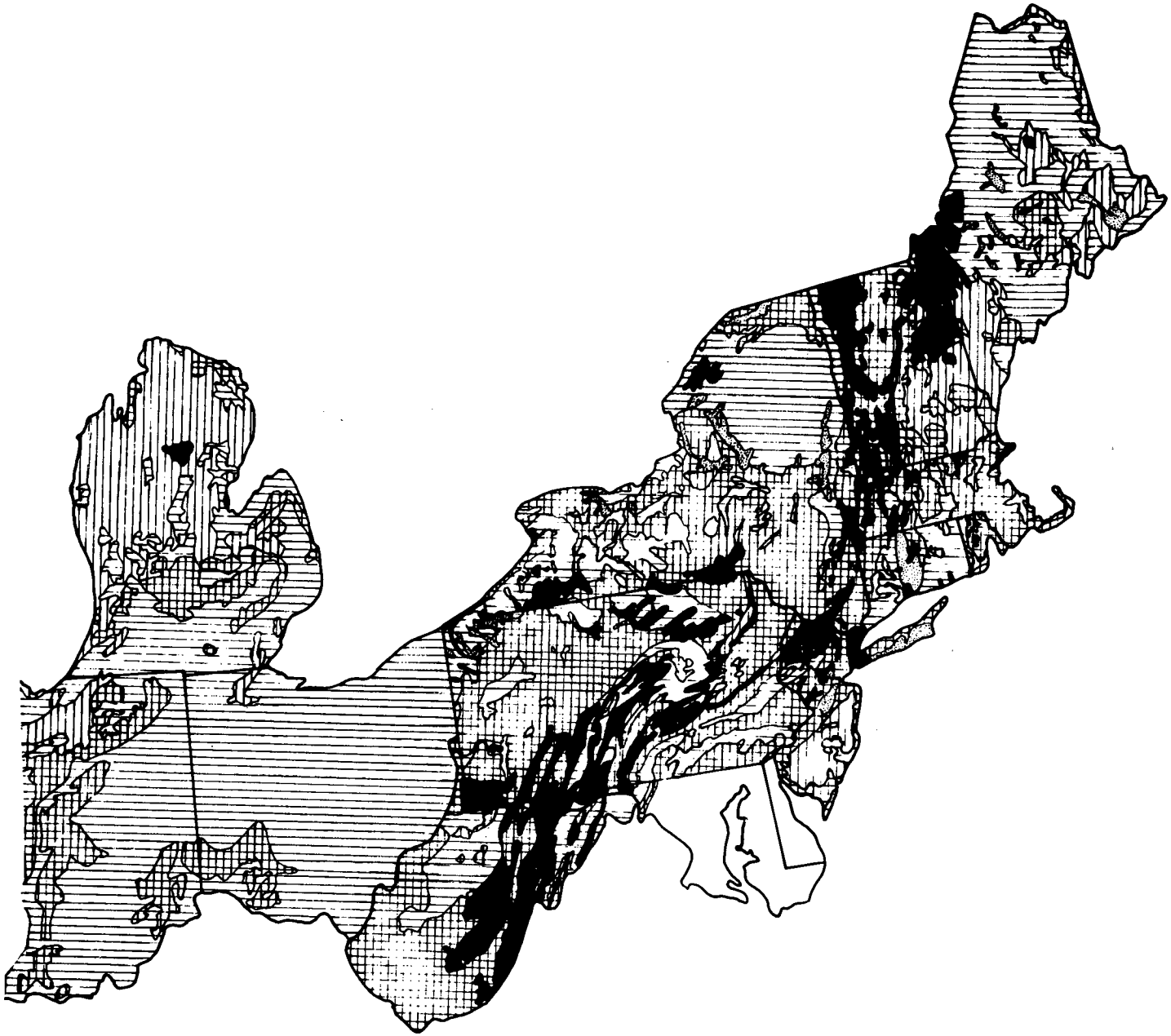


Figure B-28. General frost-susceptible soils map, northern states. Map Sheet III: Northeast U.S.

TABLE B-23

FREQUENCY OF OCCURRENCE RATINGS OF FROST-SUSCEPTIBLE SOILS IN SECTIONS CONSIDERED IN THE FREEZING ZONE

SECT. CODE	RATINGS, BY FROST-SUSCEPTIBLE SOIL CATEGORY [a, b]				
	NFS	F1	F2	F3	F4
2a	VW	NE	NE	NE	NE
2b	VW	NE	NE	N-L	NE
2c	VW	NE	NE	NE	L-M
4a	N-L	NE	L-M	N-L	M-W
4b	VW	NE	NE	N-L	L-M
4c	N-L	NE	NE	NE	VW
4d	N-L	NE	N-L	N-L	VW
4e	NE	L-M	NE	NE	M-W
5a	M-W	N-L	N-L	L-M	L-M
6a	N-L	NE	NE	L-M	L-M
6b	L-M	N-L	NE	L-M	L-M
6c	L-M	N-L	N-L	N-L	M-W
6d	N-L	NE	NE	N-L	M-W
6e	N-L	NE	NE	NE	M-W
6f	N-L	NE	NE	L-M	L-M
7a	M-W	NE	NE	NE	L-M
7b	M-W	NE	N-L	N-L	NE
7c	VW	NE	NE	NE	NE
8a	VW	NE	NE	NE	NE
8b	VW	NE	NE	NE	N-L
8c	VW	NE	NE	NE	N-L
8d	L-M	NE	NE	M-W	NE
8e	VW	NE	NE	NE	N-L
9a	VW	N-L	NE	NE	NE
9b	M-W	N-L	NE	NE	L-M
9c	VW	NE	NE	NE	NE
10a	NE	NE	N-L	N-L	VW
10b	N-L	NE	NE	L-M	M-W
10c	L-M	L-M	NE	NE	L-M
10d	N-L	NE	NE	M-W	L-M
10e	M-W	NE	NE	L-M	NE
10f	NE	NE	L-M	NE	M-W
10g	N-L	NE	L-M	NE	M-W
10h	N-L	N-L	NE	NE	M-W
10j	NE	NE	NE	VW	N-L
11a	N-L	N-L	NE	L-M	L-M
11b	N-L	NE	NE	M-W	NE
11c	NE	N-L	NE	L-M	L-M
11d	NE	N-L	NE	NE	M-W
11e	N-L	NE	L-M	L-M	L-M
11f	NE	NE	NE	L-M	L-M
11g	NE	NE	L-M	L-M	L-M
11h	N-L	NE	N-L	L-M	L-M
11i	NE	NE	NE	M-W	M-W
12a	N-L	NE	N-L	L-M	L-M
12b	NE	NE	NE	VW	NE
13a	NE	NE	NE	VW	NE
13b	NE	NE	NE	VW	NE
15a	NE	NE	NE	NE	VW
15b	N-L	N-L	NE	M-W	M-W
15c	L-M	NE	NE	NE	M-W
15d	N-L	NE	NE	M-W	M-W
16a	L-M	NE	NE	L-M	L-M
18	N-L	N-L	NE	N-L	M-W
19a	NE	N-L	N-L	L-M	N-L
19b	N-L	NE	N-L	M-W	L-M
19c	N-L	L-M	NE	NE	L-M
19d	M-W	N-L	N-L	L-M	N-L
19e	M-W	NE	NE	NE	N-L
19f	L-M	NE	NE	NE	L-M
19g	M-W	NE	NE	L-M	NE

[a] U.S. Army Corps of Engineers frost classification. NFS = nonfrost susceptible.
[b] VW—very widespread; M-W—medium to widespread; L-M—limited to medium; N-L—nonexistent to limited; NE—nonexistent.

APPENDIX C

DESCRIPTION OF BASIC UNIT BOUNDARIES

This appendix summarizes available information concerning the description of the basic unit boundaries. Figures C-1 to C-18 are individual Province/Section diagrams for the units discussed in the report. Each unit is identified by the unit code in Table 4. The coded border segments shown on the diagrams are keyed to the descriptions, for a particular Province/Section, that follow. Liberal use has been made of information from Thornbury (*65*), Fenneman (*18, 19*), and Lobeck (*38*).

BORDER DESCRIPTIONS

Province 1

Figure C-1 shows the border portions used to describe the various Sections of the Province. They are:

1. See Pacific Troughs Province.
2. The Pacific Ocean (for highway engineering purposes) is taken as the entire western border of the Province.
3. The Chehalis River is taken as the border. Although this is not precisely accurate it adequately delimits the topographically and geologically different physiographic Sections.
4. This border is taken as the southern limit of Tertiary rocks common to the Oregon Coast Ranges. The Klamath Mountains are older, stronger, and, in general, higher.
5. This border portion is common to the Cascade Section and is denoted primarily by differences in lithology between the two Sections. The Tertiary sedimentaries contrast with the volcanics common to the Cascades.
6. This border is determined by the western limit of Cenozoic volcanics of the Cascades which contrast with the older and differing rocks of the Klamath Mountains.
7. The northern boundary of the California Coast Range Section is taken as the South Fork Mountains which have the characteristic topography of the Coast Ranges but, because their geology has more in common with the Klamath Mountains, they are placed in that Section. All rocks older than Jurassic are included in the Klamath Section.
8. This border distinguishes differences in the trends of the ranges common to the Transverse Range Subsection.
   a. This portion is the San Rafael Mountains of the California Coast Ranges.
   b. The San Gabriel and San Bernardino Mountains comprise the major portion of this border.
9. This arbitrary border is taken as the southern limit of the Santa Ana and San Jacinto Mountains. These ranges are parallel northwest-southeast trending block mountains.

Province 2

Figure C-2 shows the border segments used to distinguish the Sierra-Cascade Province. They are:

1. See Pacific Troughs Province.
2. See Western Mountains of the Pacific Coast Range Province.
3. See Columbia Plateau Province.
4. The east side of this Section presents a steep face due to a series of fault scarps that overlook the Salton Trough Section.
5. This border segment is terminated by the Garlock fault.
6. This border segment is terminated by the San Andreas fault.
7. This border notes a definite geologic contrast where the bedrock of the Sierra Nevada disappears under the Cenozoic volcanic cover of the Southern Cascade Range.
8. This border is topographically conspicuous as a series of fault scarps of the Sierra Nevada overlook the Basin-Range Area.
9. This border segment can be only generally defined by topographic differences. The bedrock type (Cenozoic volcanics) is contiguous between the Cascade Range portion and the adjacent Basin and Range area (in California known as the Modoc Plateau). This border is similar to the southwest border of the Columbia Plateau Province.
10. This border distinguishes the volcanic materials of the Southern Cascade Section from the older metamorphosed and intruded granitic areas of the Northern Cascade Section.

Province 3

Figure C-3 shows the border portions used to describe the Pacific Troughs Province. With few exceptions, the delineation of borders is fairly definite topographically, owing to contrast with the surrounding mountainous uplands. The border portions are:

1. This border presents a fairly distinct topographic contrast with the Olympic Mountains.
2. The topographic contrast is broken by the Chehalis River Valley which traverses the Coast Range to the Pacific Ocean.
3. This border is similar to No. 1, except that the Oregon Coast Ranges do not provide as definite a contrast.
4. This border presents a fairly definite topographic contrast with the Cascade Range.
5. This border is a notable topographic contrast. It occurs with the Sierra Nevada and Cascade Mountains.
6. This border is similar in many respects to No. 1. This segment separates the California Coast Ranges from the Valley Section.
7. This border is the Lower Columbia River Valley, located in the Puget Sound Section.

Province 4

Figure C-4 shows only a few major border features of Province 4. For the most part, the borders, as denoted by Fenneman, are ill-defined. The two border portions are:

1. This border is, in general, topographically definite, as it contrasts with surrounding mountainous uplands.
2. The southern border is generally indefinite, as it is a transitional zone, with much of its length being the drainage divide between the Snake River and undrained basins of the Basin and Range Province.

Province 5

Figure C-5 shows the general location of the Sections comprising the Basin and Range Province. No border segments are shown on the diagram.

Province 6

Figure C-6 shows the border portions used to describe the Colorado Plateau Province. They are:

1. This border is generally controlled by massive scarps

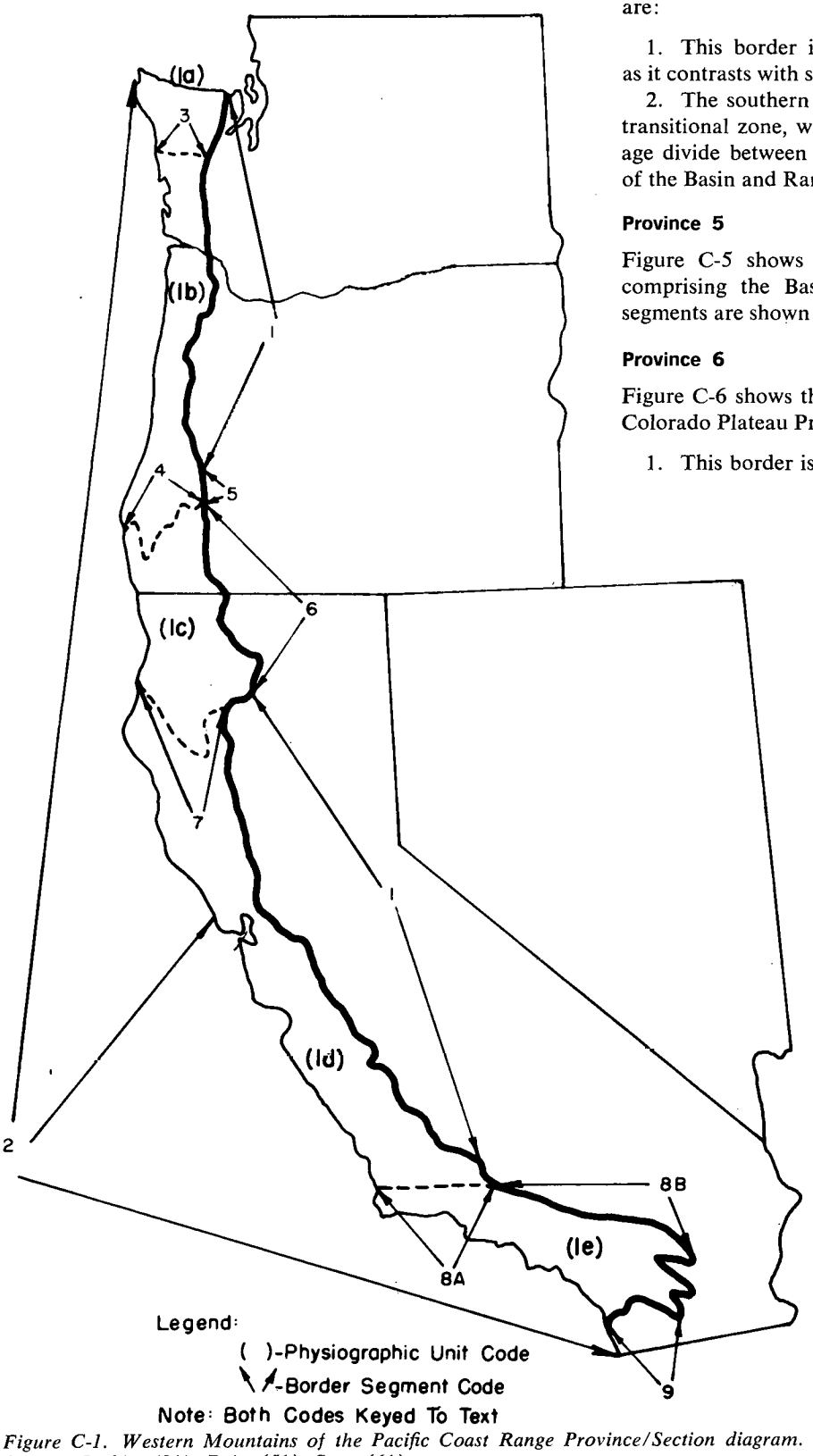


Figure C-1. Western Mountains of the Pacific Coast Range Province/Section diagram. Source: Jenkins (31), *Raisz* (51), *Stose* (61).

overlooking the topographically lower Basin and Range Province.

a. Called Mogollon Rim.
b. Called Grand Wash Cliffs (Fault).
c. Called Hurricane Fault.
d. Called Sevier Fault.

2. This border is a fairly definite topographic contrast caused by the higher Wasatch Range overlooking the area. This range ends in the vicinity of Mt. Nebo.

3. This border is similar to No. 2 and is overlooked by the Uinta Mountains.

4. This border is fairly indefinite topographically and geologically. Topographically the area gradually merges into the Wyoming Basin Section.

5. This border is, in general, topographically definite with the Southern Rocky Mountain Province.

a. The steeply dipping Dakota formation forms hogback ridges as the border between the Uinta Basin and the Rockies.
   1. This segment is overlooked by the White River Plateau.

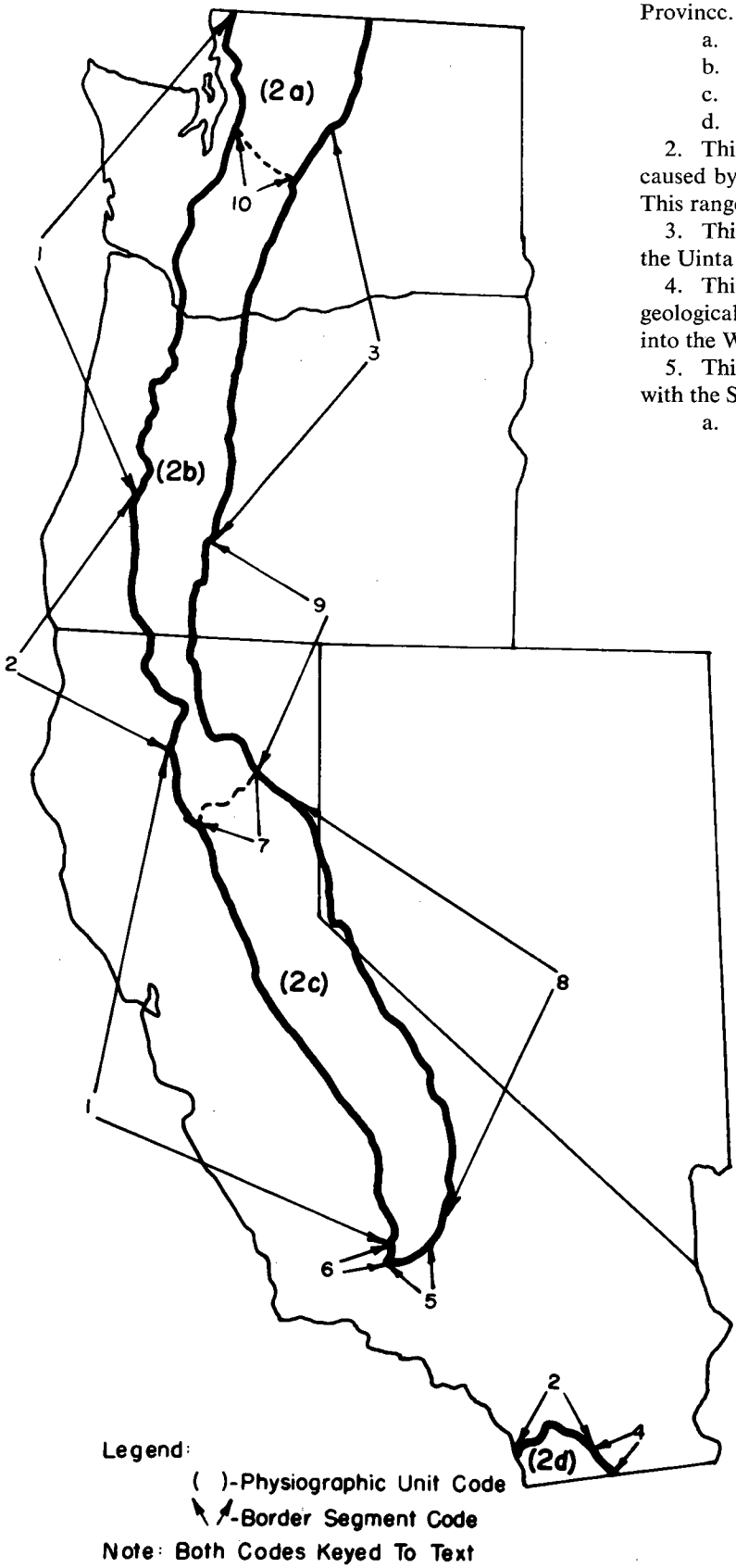
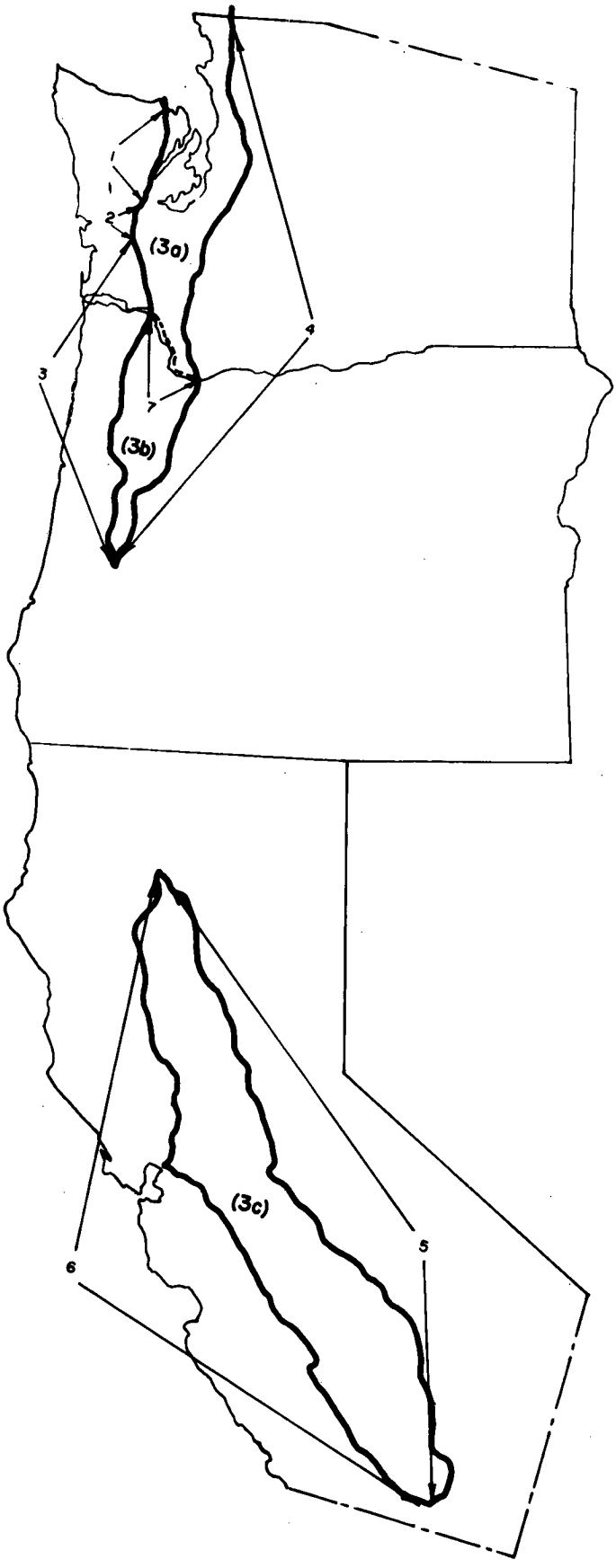


Figure C-2. Sierra-Cascade Province/Section diagram. Source: Jenkins (31), *Raisz* (51), *Stose* (61).



6. The boundary with the Rio Grande Depression of the Mexican Highland Section is marked by the westernmost fault of the Rio Grande Depression (very generalized, especially on the southern portion of the border).

7. An escarpment (Vermillion Cliffs) formed by the Jurassic Windgate sandstone overlooks the Grand Canyon Section and represents the boundary in this area.

8. This border is a great escarpment overlooking the Canyon Lands Section.

9. This border is arbitrarily limited by a 1,000- to 2000-ft transverse valley in the vicinity of the Old Denver and Rio Grande Railroad.

10. This border is the south-facing escarpment (Book and Roan Cliffs) developed by the dipping strata that comprise the Tavaputs Plateau within the Uinta Basin.

11. This border is the southern edge of the Grande Mesa.

12. This border, although geographically precise, is fairly indefinite geomorphically. The major distinguishing modal characteristics of the adjacent Sections are based on differences in dissection. The border is generally taken as the San Juan and Colorado Rivers.

13. No information obtained.

14. This border separates Carboniferous age formations from younger strata in the adjacent Sections (Triassic in the Navajo Section and Jurassic in the Canyon Lands Section). It essentially follows the Little Colorado River.

15. This border is the eastern edge of Carboniferous surficial rocks in the Grand Canyon Section.

16. This border is defined rather arbitrarily by the Puerco River.

a. This border segment is the northern portion of the Zuni Uplift area occurring in the Datil Section.

Provinces 7, 8, and 9

Figure C-7 shows the general location of the Rocky Mountain Provinces and Sections in the U.S. Although no specific border information is presented, many of the outer Province segments are described in the discussions of the adjacent Provinces.

Legend:
( )-Physiographic Unit Code
\ /-Border Segment Code
Note: Both Codes Keyed To Text

Figure C-3. Pacific Troughs Province/Section diagram. Source: Jenkins (31), *Raisz* (51), *Stose* (61).

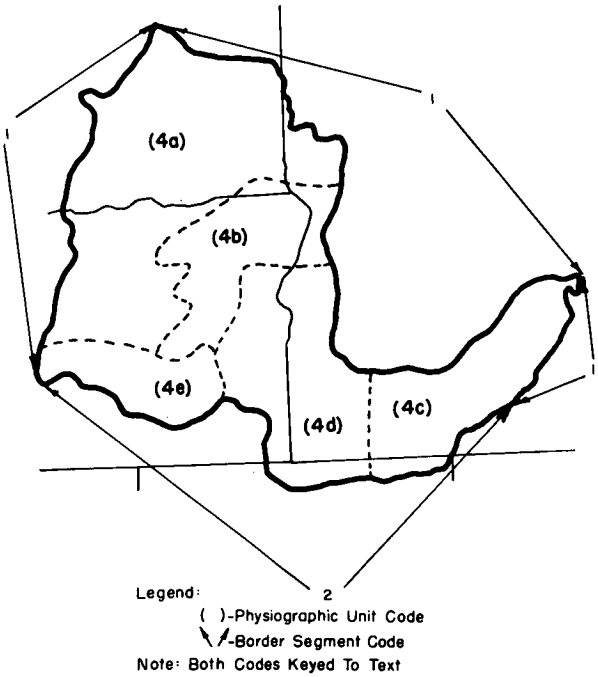


Figure C-4. Columbia Plateau Province/Section diagram. Source: Thornbury (65), Ref. 73.

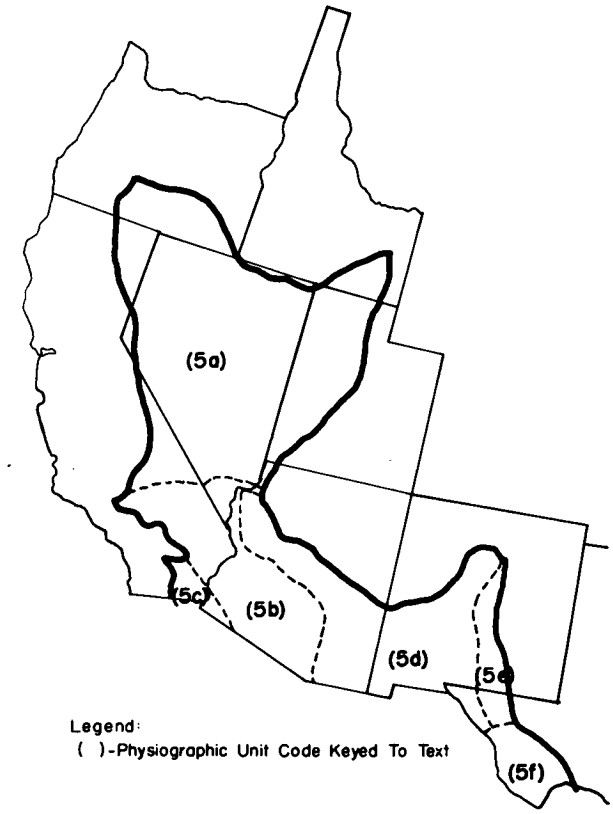


Figure C-5. Basin and Range Province/Section diagram. Source: Woods and Lovell (83).

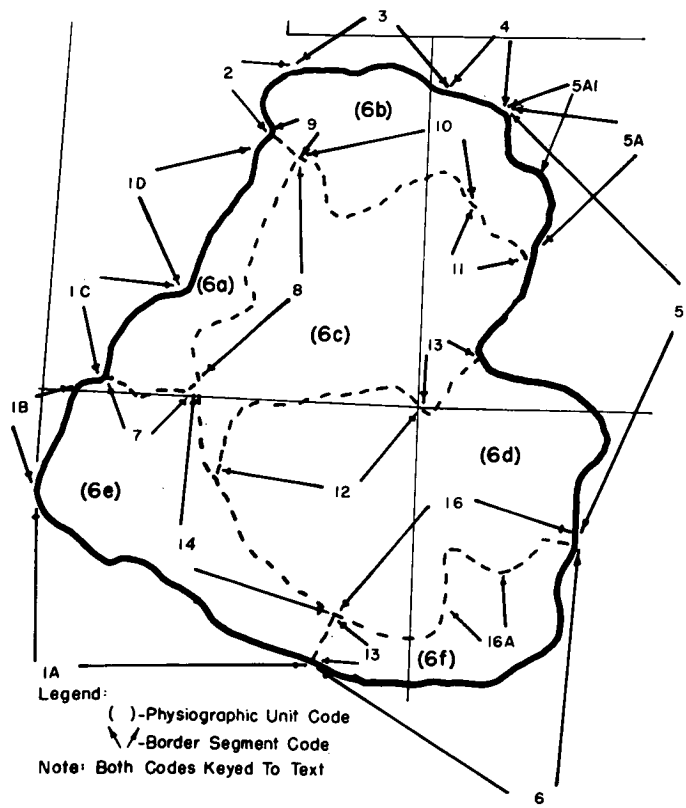


Figure C-6. Colorado Plateau Province/Section diagram. Source: Thornbury (65).

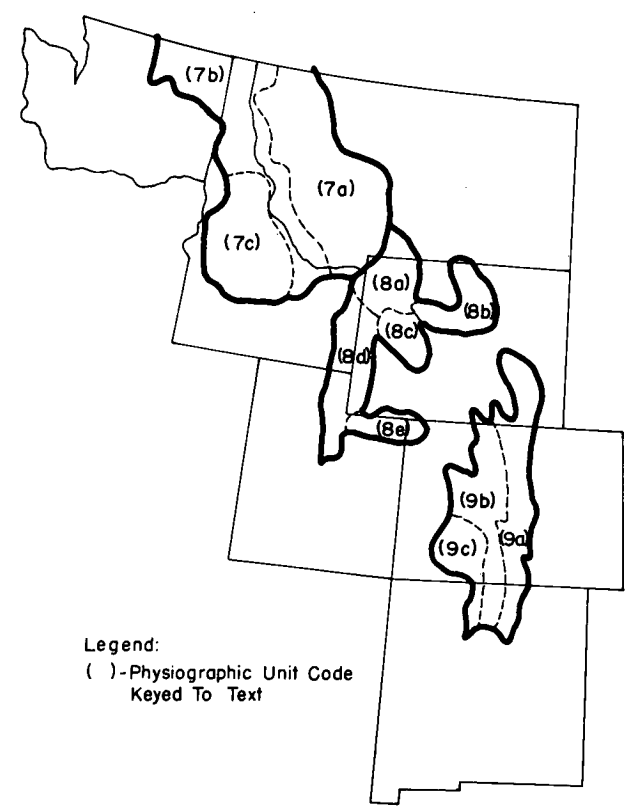


Figure C-7. Rocky Mountain System diagram. Source: Woods and Lovell (83).

Province 10

Figure C-8 shows the segments of the borders in and adjacent to the Great Plains Province. They are:

1. See Central and Eastern Lowlands Province.
2. See Ozark and Ouachita Province.
3. See Atlantic and Gulf Coastal Plain Province.
4. The western portion of the Stockton (Edwards)

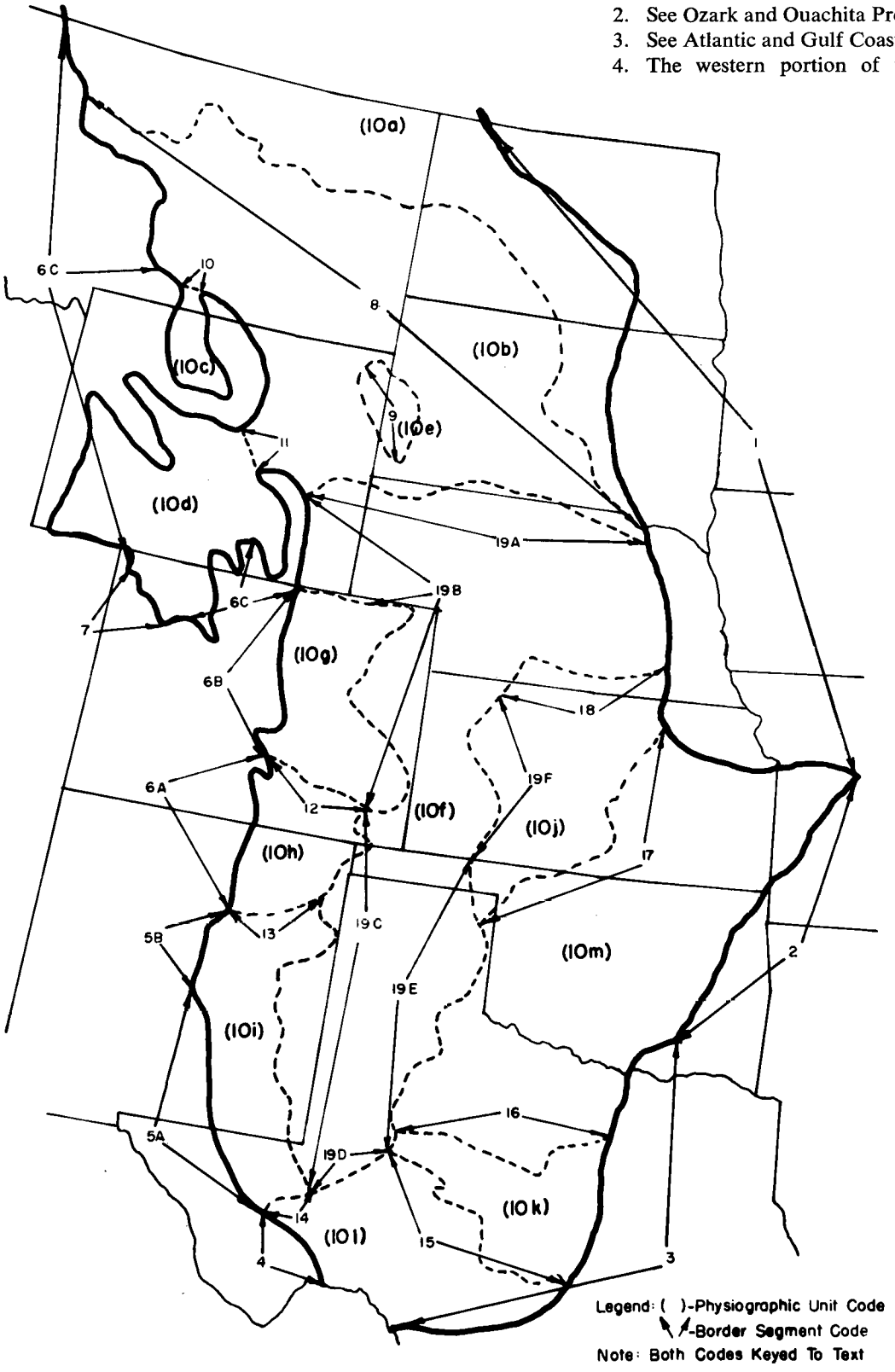


Figure C-8. Great Plains Province/Section diagram. Source: Ref. 73, Woods and Lovell (83).

Plateau terminates against the mountains of the Great Bend Highland Section.

5. This border separates the Pecos Valley Section from the Sacramento Highland Section.
   a. This portion is taken as the eastern edge of the Guadalupe and Sacramento Mountains. They exhibit a fairly definite topographic contrast.
   b. This portion does not afford any gross topographic boundary to distinguish the two Sections and, consequently, is very indefinite.

6. This border delineates the Rocky Mountain System from the Great Plains areas.
   a. This portion, as noted by Thornbury, presents a problem as to whether the border should be based on topography or geology. Similar bedrock types, age, and structure appear in both the Rocky Mountains portion and the Great Plains Section. The border is, however, based on topographic differences.
   b. The typical and distinctive western border of the Colorado Piedmont Section is the hogback ridges produced by the tilted Dakota sandstone formation.
   c. This border is generally, although not always, definite, in that it provides a strong topographic contrast.

7. See Colorado Plateau Province.

8. This border is taken as the southern limit of glacial deposits.

9. The border of this Section is taken as the outer rim of Triassic rocks (Spearfish formation) that comprise the Red Valley portion of the Black Hills. This border is contiguous and surrounded almost entirely by the Dakota formation which topographically overlooks the valley as a cuesta scarp on the west and as a hogback ridge on the east.

10. No apparent definite boundary has been established.

11. This border is taken as the Oil Mountain Anticline which connects the elbow of the Bighorn Range with the end of the Laramie Range. This anticline causes older Paleozoic rocks to outcrop in the form of monoclinal ridges for most of the border length.

12. No sharp line separates the adjacent Sections.

13. This border is the Canadian Escarpment (southern edge of Cretaceous rocks in the Raton Upland Section).

14. This border is a ragged escarpment, more than 1,000 ft high, rising to the Stockton (Edwards) Plateau. The escarpment overlooks the Toyah Basin in Texas.

15. This border is an escarpment marking the edge of where the horizontal limestone strata of the Edwards Plateau overlook the weaker, eroded rocks of the Central Texas Mineral Section.

16. The description of this border in available references is vague, and the border is difficult to ascertain from topographic, geologic, or soils maps. Fenneman describes it as an infacing (to Osage Plains Section) limestone escarpment. However, this east-west border butts across the northeast-southwest grain of Cretaceous, Permian, and Pennsylvanian outcrops found continuous in both Sections across the border line.

17. This is an arbitrary border and much difference of opinion exists as to which of the several cuesta scarps best serve as the boundary of the Section. Fenneman uses the east side of the Smoky and Red Hill areas.

18. This border, mainly in Nebraska, is very indefinite, as the erosion and dissection common to the Plains Border Section is veneered with loessial deposits that somewhat obscure the edge of the east-facing escarpments of the Section.

19. This border is primarily concerned with various modifications to the Tertiary alluvial mantle common to the High Plains Section.
   a. This portion is the north-facing Pine Ridge Escarpment capped by Tertiary (Arikaree formation) outwash. The escarpment locally attains heights of 1,000 ft.
   b. This boundary is generally taken as the outer (approximate) limits of the Tertiary alluvium (outwash) still existent in this area.
   c. This portion is capped by the resistant Ogallala formation that forms the Mescalero (Caprock) Escarpment.
   d. The Tertiary alluvium in this portion is thin and discontinuous, offering no significant topographic difference.
   e. This portion is similar in description to No. 19c. The escarpment is termed the "Break of the Plains" or Caprock.
   f. This portion is a continuation of the Break of the Plains escarpment of No. 19e. However, because of climatic differences as one proceeds northward, the escarpment loses its topographic prominence. Consequently, approximately north of Texas and in Kansas this border is not very definite.

Province 11

As Figure C-9 shows, 19 boundary portions are used to describe the border system of the Central and Eastern Lowlands Province. They are:

1. See Laurentian Upland Province.
2. See Appalachian Plateau Province.
3. See New England Maritime Province.
4. This border is taken as the west side of Lake Champlain.
5. This border, for purposes of describing physiography in the U.S. only, is an extension of Canadian Shield rocks that, in essence, connect the Adirondacks with the Southern Canadian Uplands Section (in Canada) of the Laurentian Upland Province. The border is actually an area occurring at the Thousand Islands.
6. The border is a relatively low moraine separating the Hudson and Champlain Valleys.
7. This border is a small east-facing escarpment passing northward near Schenectady, N.Y.
8. The border does not follow any one sedimentary outcrop; however, it does follow a fairly definite west foot of the high cuesta that slopes away from the Adirondacks (i.e., Tug Hill Cuesta).

9. This border is taken, as suggested by Thornbury, to essentially follow the Cary-Tazewell drift contact.

10. This border is marked by a fairly well-defined topographic contrast by the edge of a late Wisconsin terminal moraine. Small areas of outwash are included *within* the Driftless Section.

11. This border is the western edge of surficial Kansan drift. This strip of Kansan drift lies *within* the Driftless Section.

12. This border is taken as the edge of Illinoian drift. However, the topographic contrast is not great between the glaciated and the nonglaciated sections as the drift is fairly thin and considerably eroded.

13. This border is taken as the Ohio River between Louisville, Ky., and Cincinnati, Ohio. South of this area, minor known glacial deposits of Kansan drift have been recorded, but for general analysis this area has been included in the Interior Low Plateau Province. Note that this is a major exception to the border.

14. This border is the southern limits of Illinoian drift.

15. This border is the western edge of Illinoian drift. For practical purposes, the drift approximates the western boundary of the state of Illinois (Mississippi River).

16. This border is taken as the Missouri River within the state of Missouri. The exact border actually should be defined by the farthest southern extent of aeolian deposits in the Dissected Loessial and Till Plains Section. For most of its length, the Loessial boundary is slightly to the south of the Missouri River.

17. This border is the southern and western limits of Kansan drift that appears as surficial deposits in northeastern Kansas.

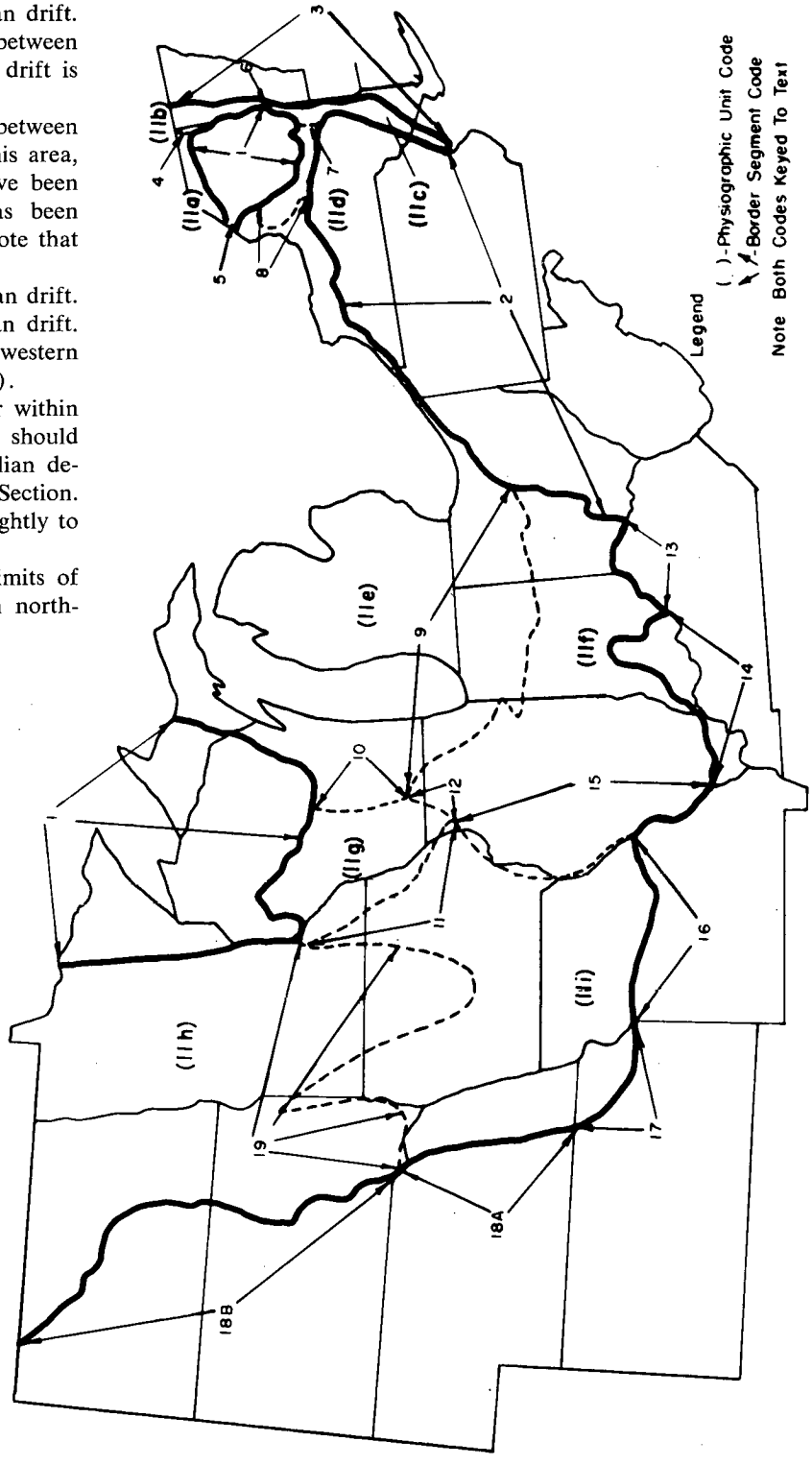


Figure C-9. Central and Eastern Lowlands Province/Section diagram. Source: Fenneman (18), Thornbury (65), Woods and Lovell (83), Wright et al. (84).

18. This border is the east-facing Missouri Escarpment.
    a. In Nebraska this escarpment is, in general, nonexistent. In North Dakota the escarpment is prominent and attains a height of 300 to 400 ft.
19. This border is placed at the Cary drift boundary of the Des Moines-Dakota ice lobes.

Province 12

Figure C-10 shows the border portions that are used to describe the Laurentian Upland Province. They are:

1. This border is apparent from topographic, geologic-age, and bedrock-type differences. In essence, the Adirondacks can be noted by the outer extent of old igneous and metamorphic rocks that contrast with sedimentary rocks in the adjacent lowlands.
2. This border agrees well with dividing the Precambrian rocks of the Superior Upland Section from the sedimentary rocks of the Central and Eastern Lowlands Province. In the upper peninsula of Michigan, the topography of the Superior Upland Section (relief and altitude) is markedly different from the adjacent area.
3. This border is indefinite in that Cambrian rocks common to the Driftless Section are placed in the Superior Upland Section because they are covered by thick drift.
4. This border is very arbitrary. It is taken as a line drawn northward from a location near St. Paul, Minn., along the 93rd meridian.

Province 13

As Figure C-11 shows, 10 segments are used to describe the borders of the Ozark and Ouachita Province. They are:

1. See Atlantic and Gulf Coastal Plain Province.
2. See Interior Low Plateau Province.
3. See Central and Eastern Lowland Province.
4. This border has little topographic contrast. The boundary is best located by geologic age difference between Mississippian-age rocks of the Springfield Plateau and the Pennsylvanian (Cherokee) clay and shale of the Osage Plains Section.

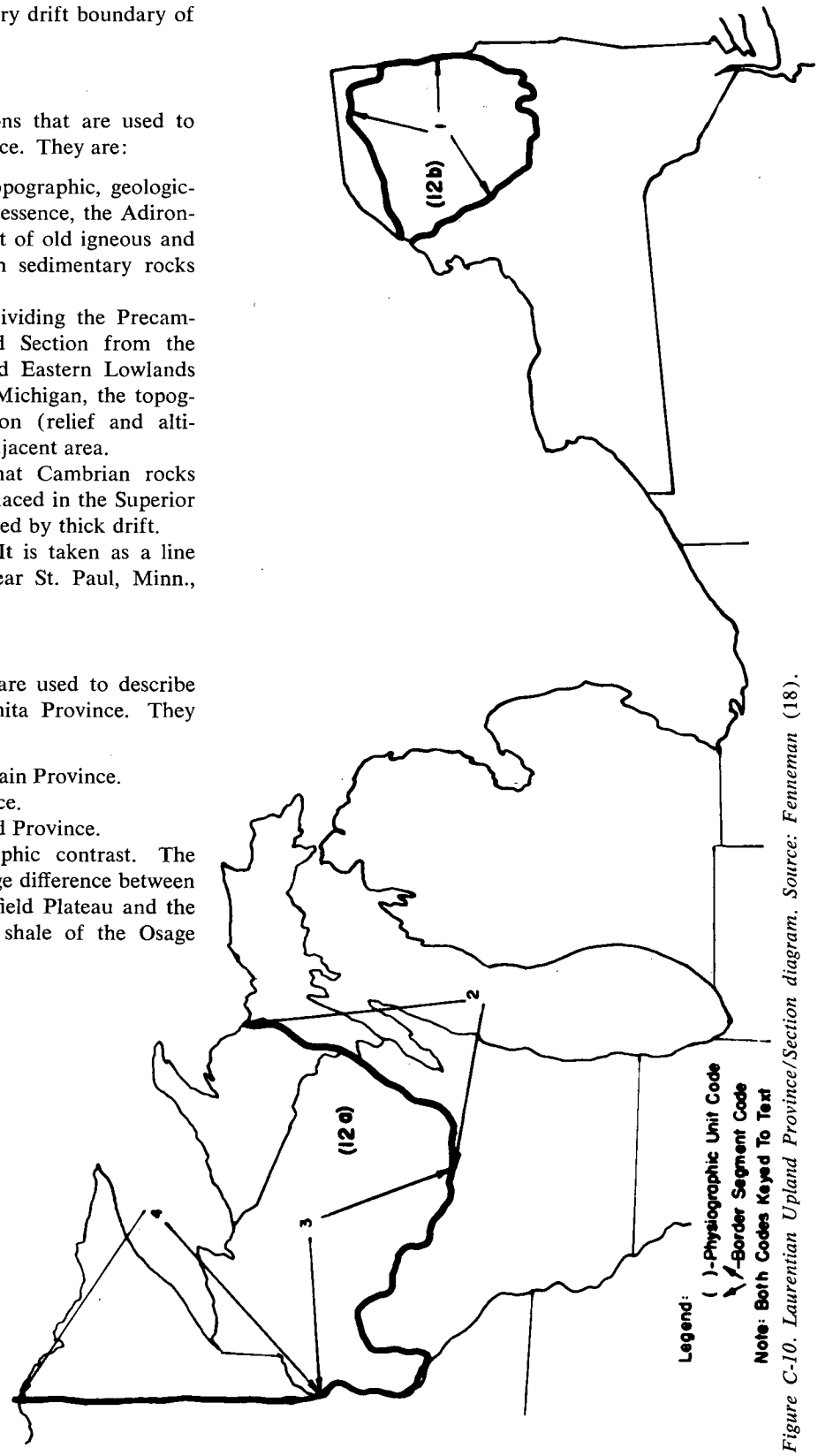


Figure C-10. Laurentian Upland Province/Section diagram. Source: Fenneman (18).

5. This border is recognizable by contrast between the east-west trending ridges of the Arkansas Valley and Ouachita Mountain Sections with the north-south trending cuestas of the Osage Plains Section. There is no outstanding contrast or difference in rock type and age between the two adjacent areas. Both areas are predominantly Pennsylvanian sandstone and shales.

6. This border is highly indefinite, owing to the partial exhumation of the Paleozoic sedimentary rocks that are also found in the Springfield-Salem Plateau Section. It appears that an attempt is made to enclose the outer limits of the Precambrian igneous rocks that have been exhumed. Consequently, Paleozoic sedimentary rocks that appear between the igneous outcrops may form a contiguous border with the Paleozoic rocks common to the Salem Plateau.

7. This border appears to differ considerably in location, particularly that portion in Missouri close to the Missouri River. The border is the Eureka Springs Escarpment, which is the retreating edge of the Mississippian strata found characteristically in the Springfield Plateau. The escarpment is prominent in southwest Missouri but decreases gradually as one goes north, until it disappears as a pronounced topographic expression near the Osage River Valley.

8. The boundary is the Boston Mountain Escarpment. Geologic age as well as difference in lithology can be used to determine this border.

9. This border, as described by Fenneman, occurs where the "mountainous upland of the Boston Mountains merges with the hills of the Arkansas Valley Section. At places the topographic break is abrupt, mainly where the boundary is against a local southdipping monocline, but at places the break in topography follows a fault."

10. The western portion of this border is the Chocktaw Fault that separates north-dipping beds of the Arkansas Valley with the south-dipping beds in the Ouachita Mountain area. In Arkansas, the border is described as following parts of the Petit Jean Creek, Dutch Creek, and Poteau River.

Province 14

Figure C-12 shows the border portions used to describe the Interior Low Plateaus Province. In general, the borders can be located either by marked topographic features or by differences in geology, except for the northern and western boundaries. All the remaining borders are noted by escarpments which are directly due to the structure of the bedrock in the area and surrounding Provinces. The border portions are:

1. See Appalachian Plateau Province.
2. See Central and Eastern Lowland Province.
3. See Atlantic and Gulf Coastal Plain Province.
4. This border is an in-facing escarpment (toward the Nashville Basin) known as the Highland Rim Escarpment. It essentially separates the Ordovician (minor Silurian-Devonian) limestone area of the basin from the younger (Mississippian) Fort Payne chert of the Highland Rim. The escarpment is several hundred feet high.

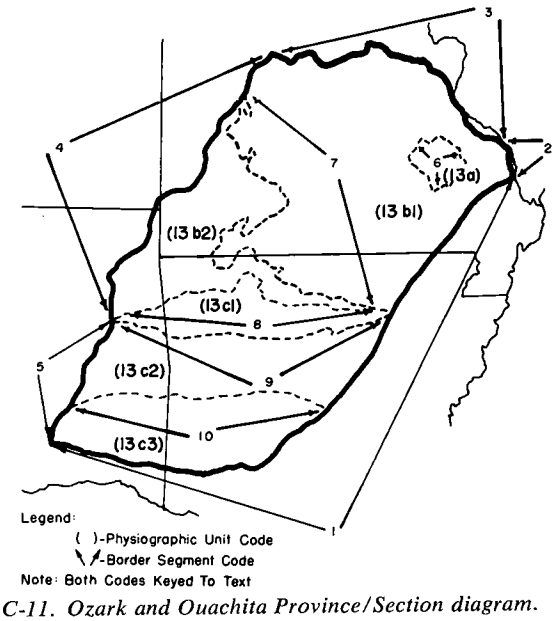


Figure C-11. Ozark and Ouachita Province/Section diagram. Source: USGS (75).

5. This border is determined by an escarpment overlooking the Highland Rim Section. In Indiana it is called the Chester Escarpment; in Kentucky it is called the Dripping Springs Escarpment.

6. Topographic contrast of this border is indefinite for, surficially, the area is veneered by unconsolidated aeolian and alluvial materials that gradually merge with adjacent Sections. In general, the border follows the western limit of Mississippian rocks within the Shawnee Hills Section

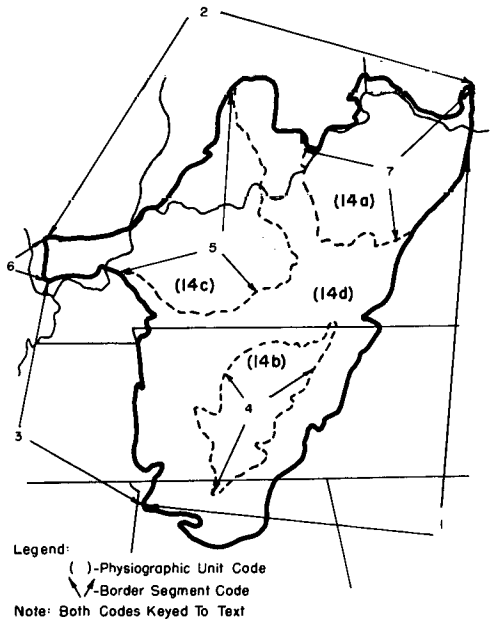


Figure C-12. Interior Low Plateaus Province/Section diagram. Source: USGS (75).

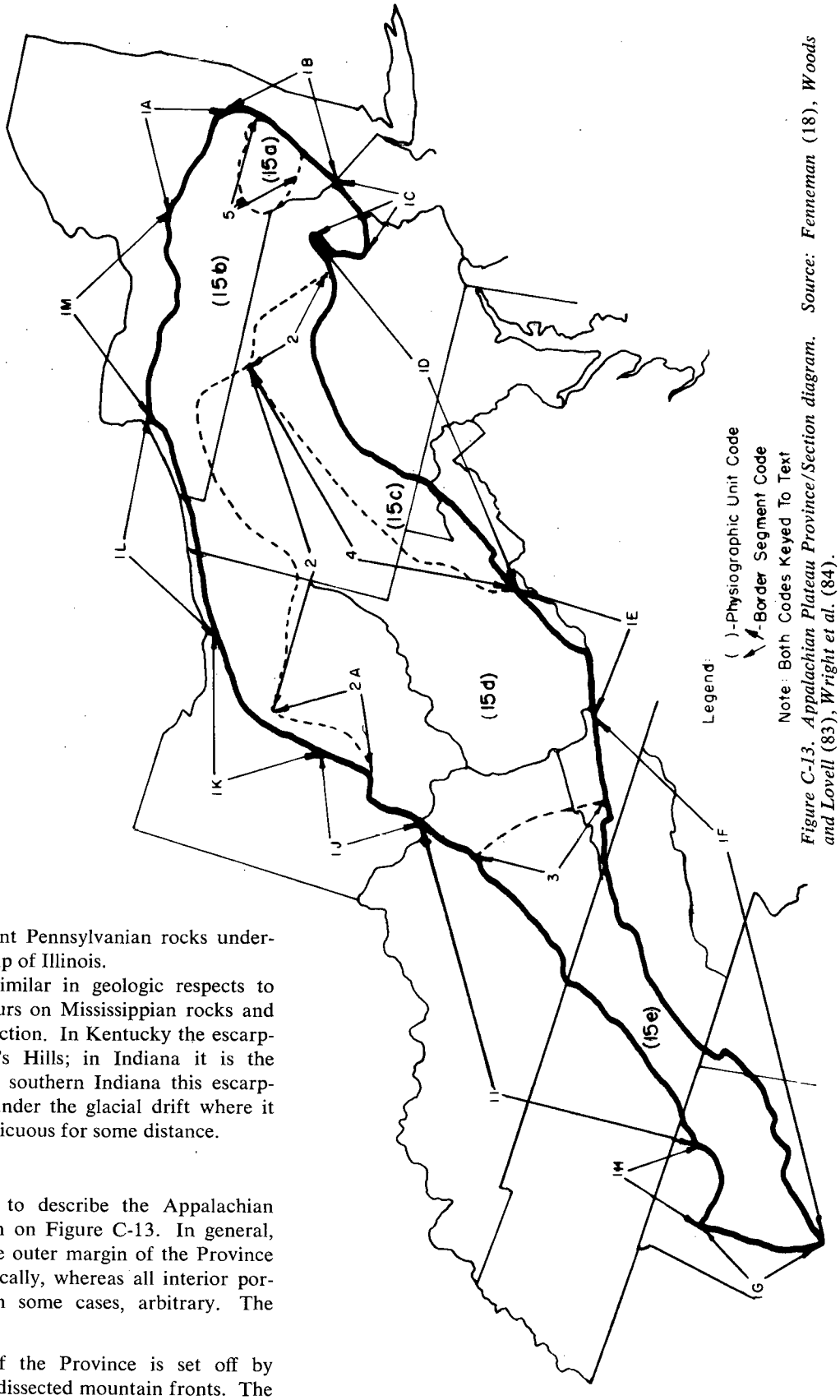


Figure C-13. Appalachian Plateau Province/Section diagram. Source: Fenneman (18), Woods and Lovell (83), Wright et al. (84).

and differs from the adjacent Pennsylvanian rocks underlying the extreme southern tip of Illinois.

7. This escarpment is similar in geologic respects to border No. 4 in that it occurs on Mississippian rocks and overlooks the Blue Grass Section. In Kentucky the escarpment is called Muldraugh's Hills; in Indiana it is the Knobstone Escarpment. In southern Indiana this escarpment proceeds northward under the glacial drift where it is still topographically conspicuous for some distance.

Province 15

The border portions used to describe the Appalachian Plateau Province are shown on Figure C-13. In general, the borders that describe the outer margin of the Province are very distinct topographically, whereas all interior portions are indefinite and, in some cases, arbitrary. The border portions are:

1. The outer margin of the Province is set off by marked outfacing scarps or dissected mountain fronts. The scarps in the east are generally higher and more clearly defined than the lower and more jagged scarps on the west.

a. This scarp is called the Helderberg Escarpment.

b. This scarp is called the Catskill Escarpment.
c. This border portion is contiguous with the Pocono Plateau.
d. This scarp is called the Allegheny Front.
e. In central West Virginia, the mountains of the Plateaus have the same altitude as those in the Ridge and Valley Province. However, the dendritic pattern in the Appalachian Plateau Province contrasts with the linear ridge-valley pattern of the Ridge and Valley Province.
f. This border portion is called the Cumberland Front.
g. This border offers no marked topographic contrast with the Atlantic and Gulf Coastal Plain Province. Hills of the Plateau Section are often capped by remnants of the coastal plain sediments and merge. (Also see geologic border discussion for Province 20.)
h. In Alabama the scarp portion is generally lacking. A generalized border separates the Pennsylvanian rocks of the Plateau from the Mississippian rocks in the Interior Low Plateau Province.
i. This border gives a fairly good topographic contrast, owing to the scarp that appears in southern Tennessee. The scarp is approximately 1,000 ft high. Geologic differences are similar to border No. 1h.
j. The border is noted by the west-facing scarp of Mississippian rocks in the Appalachian Plateau.
k. From Columbus, Ohio (slightly east), to Cleveland, Ohio, the west-facing escarpment is lost, but the contact of the till plain topography with the hilly terrain of the plateau is recognizable.
l. From Cleveland, Ohio, to an area south of Buffalo, N.Y., the scarp appears but does not follow any geologic boundary.
m. From Buffalo, N.Y., to near Utica, N.Y., the scarp is at the edge of the Portage sandstone and Tully, Onandago, and Helderberg limestones.

2. This border is taken as the southernmost limit of Wisconsin glaciation. (Note: older drift extends beyond this limit but is not topographically prominent.)

a. This border encloses an area not shown in Fenneman's diagrams. However, recent information indicates the presence of Wisconsin drift in this area.

3. This border is very arbitrary as it attempts to separate degrees of dissection between the adjacent Kanawha and Cumberland Plateau Sections.

4. In general, the Allegheny Mountain Section stands topographically higher and is dissected to a greater degree than the surrounding Kanawha Section. In West Virginia the altitude of both Sections is about the same and is difficult to denote.

5. This border may be thought of as arbitrary due to the facies change in resistant strata that protect and characterize the Catskill Mountains Section. These strata generally lose their resistance and character to the west and south and thus gradually merge with the New York Glaciated Section.

Province 16

As Figure C-14 shows, the border portions that describe the Ridge and Valley Province are as follows:

1. This border is based on the southern limits of Wisconsin glacial drift.
2. See Triassic Lowland Province.
3. This border, from a topographic viewpoint, is generally apparent. The mountainous upland terrain of the Blue Ridge and Reading Prong contrasts with the series of bordering lowland valleys developed on limestone in the Ridge and Valley Province.
4. This border has as a mutual Province the Piedmont Section of the Older Appalachians. The topographic difference between the two areas is not as pronounced as the border of No. 3. Difference in rock type exists between the areas.
5. See Atlantic and Gulf Coastal Plain Province.
6. The border is the prominent topographic escarpment of the Appalachian Plateau Province (Allegheny Front). In central West Virginia, ridges of the Ridge and Valley Province are at approximately the same elevation as the plateau areas of the Appalachian Plateau Province.
7. This border is arbitrarily taken as the drainage divide between the New and the Tennessee Rivers.

Province 17

Figure C-15 shows the border portions used to describe the Older Appalachian Province. They are:

1. See Ridge and Valley Province.
2. See Triassic Lowland Province.
3. See Atlantic and Gulf Coastal Plain Province.
4. This border is generally based on topographic differences of elevation and relief between the two Sections. The border, termed the Blue Ridge Escarpment, is not always well-defined. In many cases, particularly in the southern portion of the boundary, the Blue Ridge mountains gradually disappear into the Piedmont Plateau. Consequently, numerous Blue Ridge outliers are found in the Piedmont Section, making border placement difficult and indefinite.

Province 18

As Figure C-16 shows, four boundary portions are used to describe the Triassic Lowland Province. They are:

1. This border is distinguished by geologic age difference between the Triassic rocks and the older (Precambrian to Early Paleozoic) crystalline rocks. Topographically, the Triassic areas are lower than the crystalline areas that generally form the uplands.
2. The border is taken as the Ordovician limestone areas. Topographically they also are lower than the crystalline uplands.
3. This boundary is distinguished by geologic age difference between the Triassic rocks and the Cretaceous

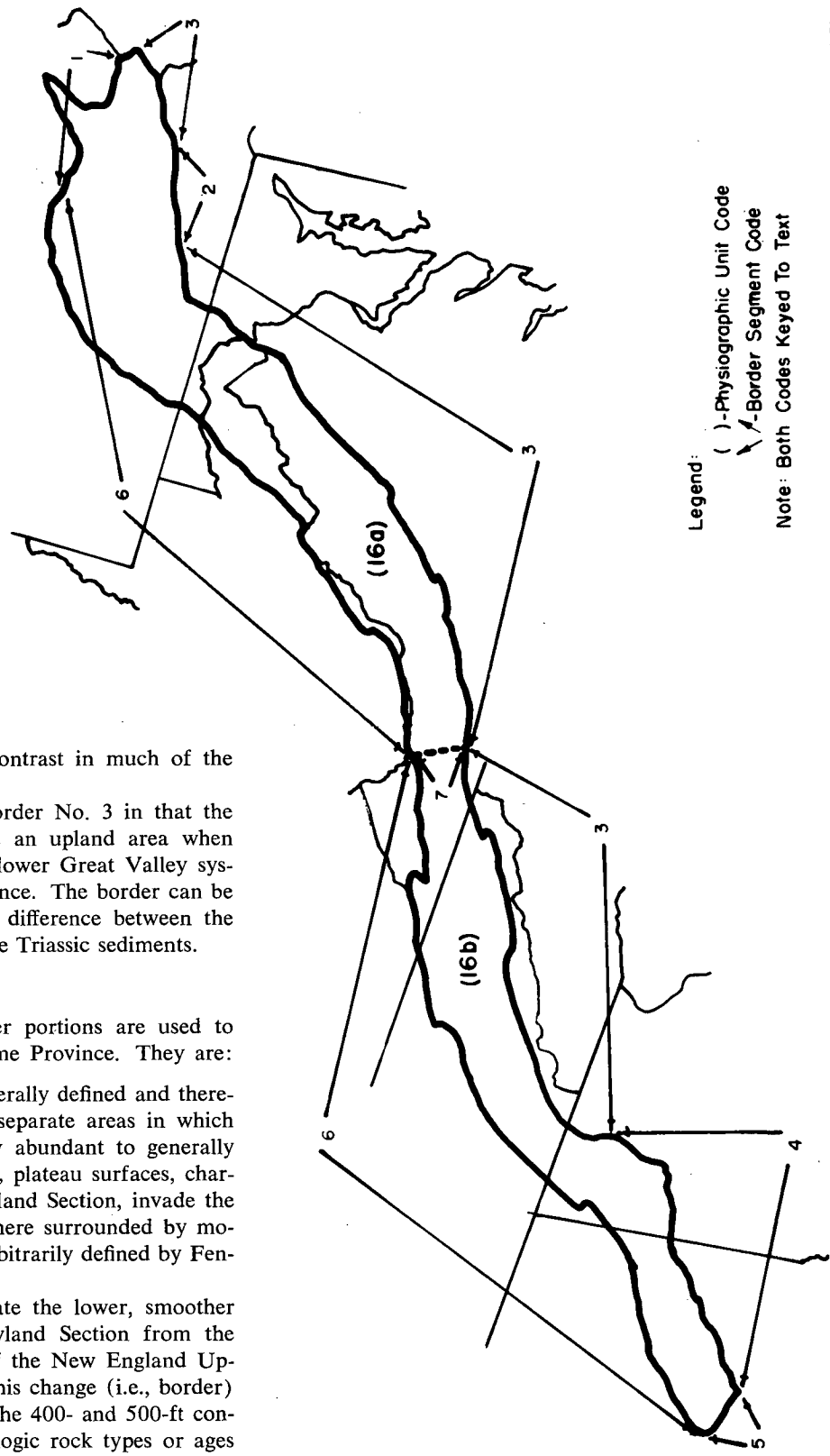


Figure C-14. Ridge and Valley Province/Section diagram. Source: USGS (75).

coastal sediments. Topographic contrast in much of the area is lacking.

4. This border is similar to border No. 3 in that the Triassic "Lowland" area becomes an upland area when contrasted to the topographically lower Great Valley system of the Ridge and Valley Province. The border can be distinguished by the geologic age difference between the Ordovician limestone valley and the Triassic sediments.

Province 19

As Figure C-17 shows, 11 border portions are used to describe the New England Maritime Province. They are:

1. This border can be only generally defined and therefore is indefinite. It attempts to separate areas in which mountainous terrain is sufficiently abundant to generally dominate the landscape. However, plateau surfaces, characteristic of the New England Upland Section, invade the margin of the area and are elsewhere surrounded by monadnocks. The border has been arbitrarily defined by Fenneman as the 1,500-ft contour.

2. This border tends to separate the lower, smoother topography of the Seaboard Lowland Section from the higher, less smooth topography of the New England Upland Section. Fenneman defined this change (i.e., border) in topography occurring between the 400- and 500-ft contour intervals. Differences in geologic rock types or ages cannot be used to obtain the boundary; consequently, this border is similar to border No. 1.

3. See Atlantic and Gulf Coastal Plain Province.

4. See Triassic Lowland Province.

5. This border is fairly definite from topographic and geologic standpoints. The lowland area developed on

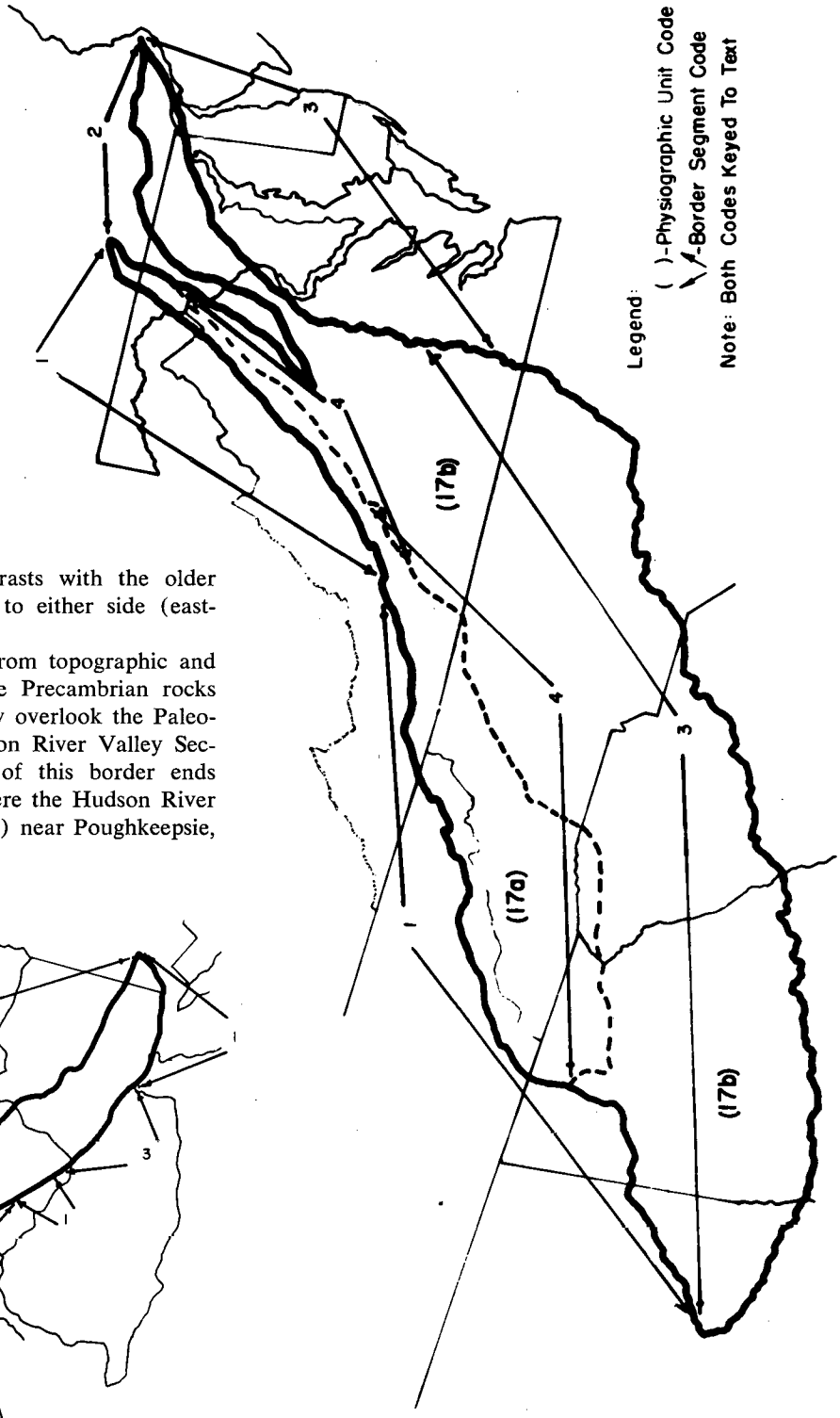


Figure C-15. Older Appalachian Province/Section diagram. Source: USGS (75).

relatively weak Triassic rocks contrasts with the older schists and granites of the uplands to either side (east-west).

6. This border is fairly definite from topographic and geologic standpoints. The crystalline Precambrian rocks of the Reading Prong topographically overlook the Paleozoic sedimentary rocks of the Hudson River Valley Section. Note: the northern portion of this border ends approximately 20 miles north of where the Hudson River enters the Highlands (Reading Prong) near Poughkeepsie, N.Y.

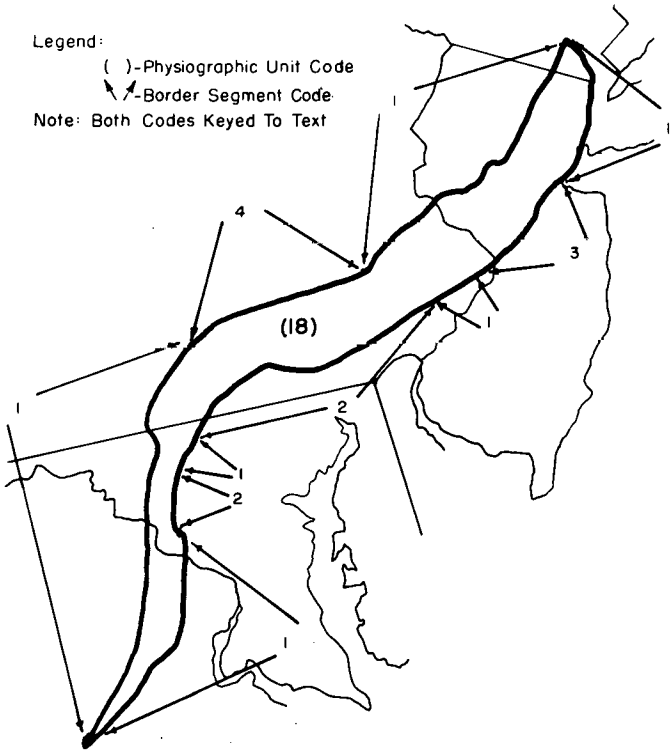


Figure C-16. Triassic Lowland Province diagram. Source: USGS (75).

7. This border is based primarily on differences in rock type attributed to the change of degree in metamorphism. The schists of the Taconics stand above and in a fairly definite linear trend compared to the slates of the Hudson Lowland.

8. The southern half of this border is definite topographically, as it appears as a nearly straight wall up to 500 ft high. The northern portion becomes indistinct, and a distinct line separating adjacent Sections is difficult to draw.

9. This border is ill-defined in available literature. It appears to be difficult to determine, particularly in the northern portion, as a gradual topographic merger between Sections occurs.

10. This border is separated by a series of valleys developed on carbonate rocks that are physiographically treated in the Taconic Section.

11. This border is not well-defined owing to the gradual change from the plateau-like topography of the New England Upland Section to the mountainous topography of the Green Mountain Section. The northern portion of the border is perhaps slightly more noticeable than the southern portion, as a terracing effect occurs in the north (due east of the Green Mountains).

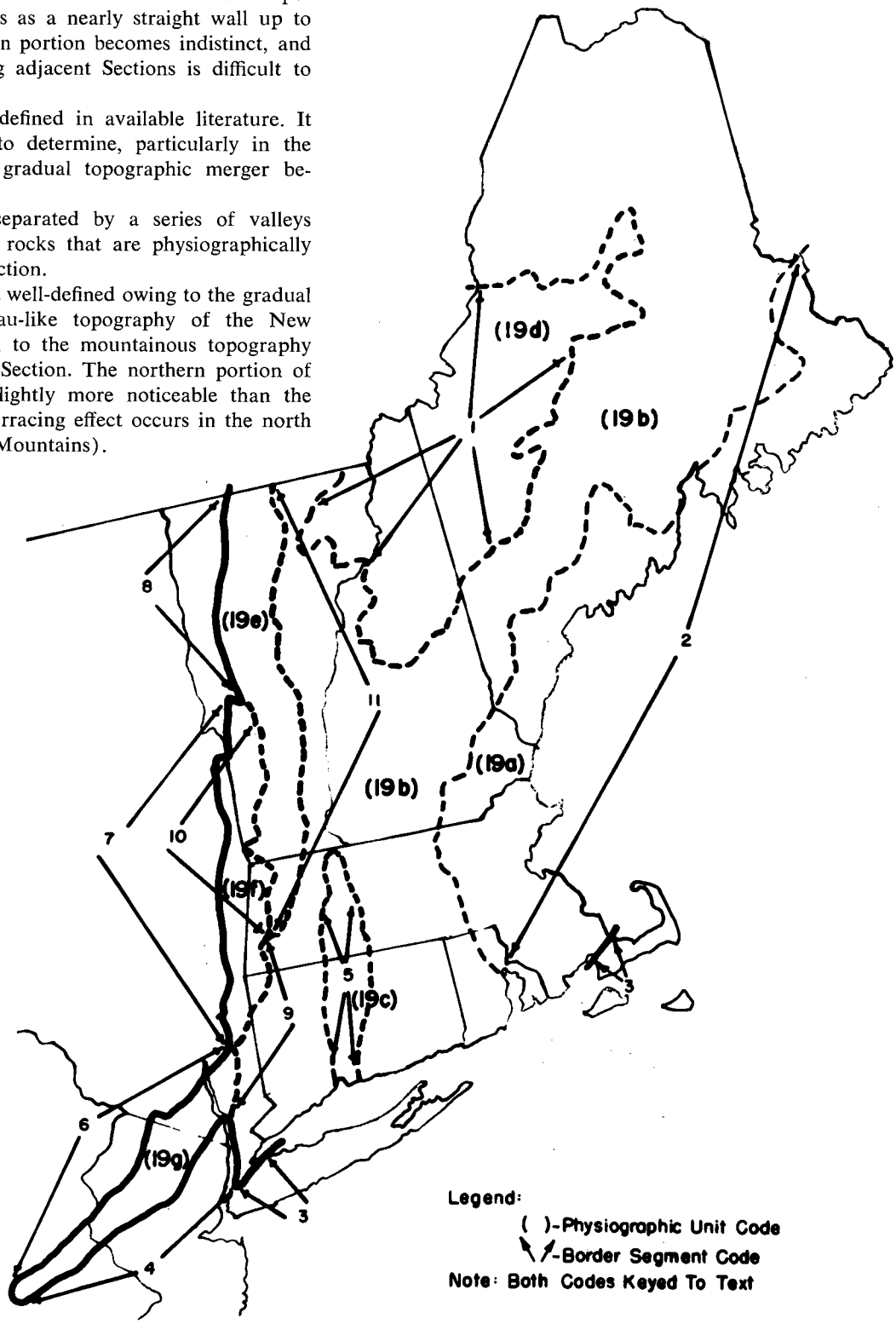


Figure C-17. New England Maritime Province/Section diagram. Source: USGS (18), *Woods and Lovell* (82).

Province 20

As Figure C-18 shows, eight boundary portions describe the Atlantic and Gulf Coastal Plain Province. They are:

1. This boundary occurs from Cape Cod, Mass., to Waco, Tex. The boundary is easily described as Cretaceous and younger sediments bordering the older consolidated materials of the uplands.
   a. Both Long Island and Cape Cod have been glaciated. As a result, the border must be based on the northern limit of Cretaceous rocks that underlie Pleistocene glacial sediments.
   b. In this area, topography is not significantly different where the coastal sediments border soft Triassic-age sedimentary rocks.
2. This border is generally the contact between Lower and Upper Cretaceous rocks. Lower Cretaceous rocks have been assigned to the Central Texas Mineral Section of the Great Plains Province because the dissected topography on the Lower Cretaceous rocks is more common to the Section of the Great Plains than to the Coastal Plains Province.
3. This border occurs approximately from Austin, Tex., to the Mexican border. The border is fairly definite, being distinguished by the Balcones Escarpment which divides Lower and Upper Cretaceous rocks.
4. The border is very indefinite as it is based primarily on topographic differences of the coastline (i.e., separates embayed areas of the Embayed Section from sea islands characteristic of the Sea Island Section).
5. This border is similar to No. 4 as it is indefinite. Topographic changes occur slightly west of the Georgia-South Carolina border.
6. The border is similar to No. 4 and No. 5 in that each Section (Sea Island, Florida, and East Gulf) has major differing modal characteristics. However, the location of the border dividing these characteristics is indefinite.
7. This boundary is based on the limits of surficial aeolian deposits. The eastern boundary, in many cases, is of a gradational variety.
8. This boundary is based on the border that separates the Mississippi alluvial deposits from the coastal sediments. The boundary can be easily located from geologic, pedologic, or soil origin maps of the area.

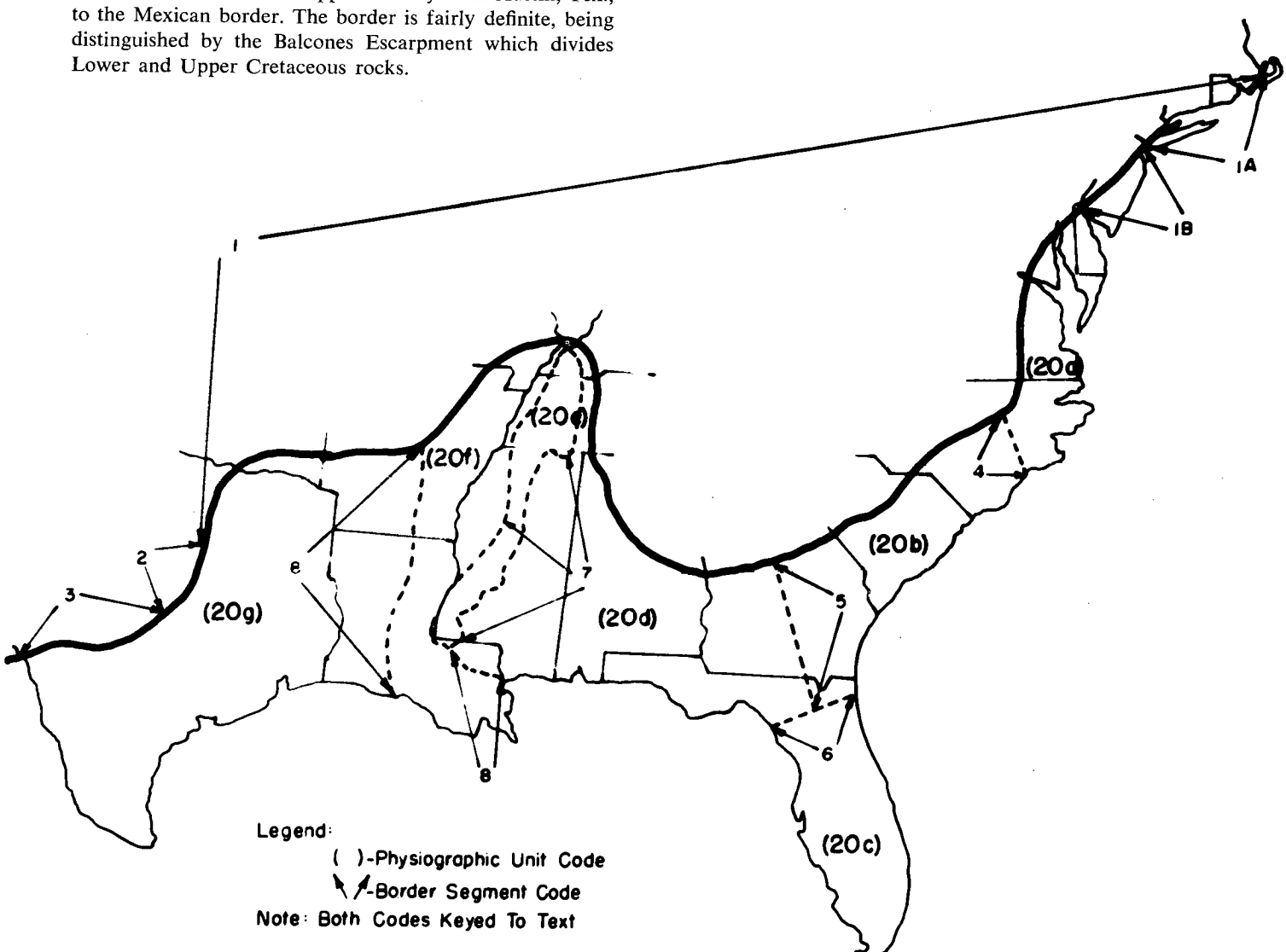


Figure C-18. Atlantic and Gulf Coastal Plain Province/Section diagram. Source: Woods and Lovell (83).

APPENDIX D

STATE AGGREGATE PRODUCTION DATA

TABLE D-1

SUMMARY OF AGGREGATE PRODUCTION RANKINGS, BY STATE

				Ranking[1]				
				Sand Gravel		Crushed Stone		Ratio
State	No.	Population	Area	(tonnage)	(ton. per Pop.-Area)	(tonnage)	(ton. per Pop.-Area)	(SG/CS)
Alabama	(1)	3,267,000	52,000	41	44	23	25	37-39
Arizona	(2)	1,302,000	114,000	14	25	39	43	8
Arkansas	(3)	1,786,000	53,000	26	23-24	24	13	31
California	(4)	15,717,000	159,000	1	40	16	38	17
Colorado	(5)	1,754,000	104,000	12	26-27	34-36	37	12
Connecticut	(6)	2,535,000	5,000	32	5	27	2	28
Delaware	(7)	446,000	2,000	48	3	44-48	44-48	1-5
Florida	(8)	4,952,000	59,000	38	46	3	10	45-46
Georgia	(9)	3,943,000	59,000	45	47	18-19	23	48
Idaho	(10)	667,000	84,000	13	15	34-36	29	16
Illinois	(11)	10,081,000	56,000	6	35	1	15	36
Indiana	(12)	4,662,000	36,000	10	19	14	11	32
Iowa	(13)	2,757,000	56,000	21-22	29	5	5	40-42
Kansas	(14)	2,179,000	82,000	25	33	18-19	19	34
Kentucky	(15)	3,038,000	40,000	40	36	12	7	45-46
Louisiana	(16)	3,257,000	49,000	23	30	26	26	23-24
Maine	(17)	969,000	33,000	24	10	42	41	7
Maryland	(18)	3,101,000	11,000	18	9	25	4	25-26
Massachusetts	(19)	5,149,000	8,000	11	6	28	8	20
Michigan	(20)	7,823,000	58,000	2	26-27	21	31-32	19
Minnesota	(21)	3,414,000	84,000	5	23-24	30	34	15
Mississippi	(22)	2,178,000	48,000	37	32	44-48	44-48	1-5
Missouri	(23)	4,320,000	70,000	27	43	7	16	43-44
Montana	(24)	675,000	147,000	17	17	37	36	11
Nebraska	(25)	1,411,000	77,000	19	20	33	31-32	18
Nevada	(26)	285,000	111,000	20	8	40	39	9
New Hampshire	(27)	607,000	9,000	34-35	2	44-48	44-48	1-5
New Jersey	(28)	6,667,000	8,000	15	11	20	3	29-30
New Mexico	(29)	951,000	122,000	34-35	31	32	30	21-22
New York	(30)	16,782,000	50,000	3	39	6	27	29-30
North Carolina	(31)	4,556,000	53,000	28	41	10	14	40-42
North Dakota	(32)	632,000	71,000	30	13	44-48	44-48	1-5
Ohio	(33)	9,706,000	41,000	4	4	8	1	27
Oklahoma	(34)	2,328,000	70,000	39	42	17	12	43-44
Oregon	(35)	1,769,000	97,000	13	28	11	9	35
Pennsylvania	(36)	11,319,000	45,000	16	45	4	22	40-42
Rhode Island	(37)	859,000	1,000	47	1	43	40	6
South Carolina	(38)	2,383,000	31,000	44	34	29	20	33
South Dakota	(39)	680,000	77,000	20-21	12	34-36	28	14
Tennessee	(40)	3,567,000	42,000	36	38	9	6	47
Texas	(41)	9,596,000	267,000	19	48	2	33	37-39
Utah	(42)	891,000	85,000	31	22	41	42	10
Vermont	(43)	390,000	10,000	46	7	44-48	44-48	1-5
Virginia	(44)	4,967,000	41,000	29	37	15	17	37-39
Washington	(45)	2,853,000	68,000	8	16	22	24	21-22
West Virginia	(46)	1,860,000	24,000	43	21	31	21	23-24
Wisconsin	(47)	3,952,000	56,000	7	18	13	18	25-26
Wyoming	(48)	330,000	98,000	42	14	38	35	13

Notes: 1. Ranking Number 1 is largest production factor; #48 is lowest production ranking.
2. Information concerning sand gravel obtained from reference (175) for 1964.
3. Information concerning crushed stone obtained from reference (189) for 1958.

TABLE D-2

SUMMARY OF STATE AGGREGATE PRODUCTION FACTORS, BY INCREASING MAGNITUDE

Sand Gravel Data		Crushed Stone Data		Ratio
Tonnage (Tons×10⁶)	Density (Tons / Pop.-Area ×10⁻⁶)	Tonnage (Tons×10⁶)	Density (Tons / Pop.-Area ×10⁻⁶)	(SG Tonnage / CS Tonnage)
1.2 (7)	11.3 (41)	0 (7)	0 (7)	0.5 (9)
1.6 (37)	17.2 (9)	0 (22)	0 (22)	0.6 (40)
1.8 (43)	24.0 (8)	0 (27)	0 (27)	0.7 (8)
4.2 (9)	31.3 (36)	0 (32)	0 (32)	0.7 (15)
4.6 (38)	34.2 (1)	0 (43)	0 (43)	0.8 (23)
5.5 (46)	36.4 (23)	.002 (37)	0.7 (2)	0.8 (34)
5.6 (48)	42.7 (34)	.04 (17)	1.1 (42)	0.9 (13)
5.8 (1)	45.4 (31)	.08 (42)	1.3 (17)	0.9 (31)
6.6 (15)	45.7 (4)	.09 (26)	2.0 (37)	0.9 (36)
6.8 (34)	46.5 (30)	0.1 (2)	2.8 (26)	1.2 (1)
7.4 (8)	53.2 (40)	0.3 (48)	3.7 (4)	1.2 (41)
7.8 (22)	53.9 (44)	0.6 (24)	4.4 (5)	1.2 (44)
8.0 (40)	57.0 (15)	0.8 (5)	6.0 (24)	1.3 (11)
8.8 (27)	62.0 (11)	0.8 (10)	7.8 (48)	1.5 (35)
8.8 (29)	67.5 (38)	0.8 (34)	8.7 (21)	1.6 (14)
9.6 (10)	73.0 (14)	1.5 (25)	9.3 (41)	1.7 (38)
10.1 (6)	76.2 (22)	1.6 (29)	13.7 (20)	2.4 (12)
10.2 (42)	77.5 (29)	1.7 (46)	13.7 (25)	2.5 (3)
10.5 (32)	88.0 (16)	2.5 (21)	13.8 (29)	2.6 (28)
10.6 (44)	91.0 (13)	2.9 (38)	14.2 (10)	2.6 (30)
11.2 (31)	105 (35)	3.3 (19)	15.3 (39)	2.8 (6)
11.4 (23)	115 (5)	3.6 (6)	18.3 (30)	2.9 (33)
11.7 (3)	115 (20)	4.0 (16)	25.1 (16)	3.4 (47)
13.0 (14)	121 (2)	4.4 (18)	28.0 (1)	3.4 (18)
13.5 (17)	126 (3)	4.8 (3)	29.5 (45)	3.5 (16)
13.6 (16)	126 (21)	4.9 (1)	34.0 (9)	3.5 (46)
13.8 (39)	131 (42)	5.7 (45)	36.2 (36)	5.6 (29)
13.8 (13)	133 (46)	6.2 (20)	37.8 (46)	5.6 (45)
14.1 (26)	137 (25)	7.0 (28)	39.2 (38)	6.4 (19)
14.6 (25)	143 (12)	7.9 (9)	44.0 (14)	8.4 (20)
15.1 (18)	154 (47)	7.9 (14)	45.2 (47)	10.0 (25)
16.0 (24)	160 (24)	8.7 (34)	45.6 (44)	12.3 (4)
16.2 (36)	165 (45)	9.2 (4)	46.0 (23)	12.5 (10)
17.7 (28)	178 (10)	9.3 (44)	46.5 (11)	14.4 (21)
18.1 (2)	187 (48)	9.9 (12)	48.8 (31)	17.5 (39)
18.3 (35)	244 (32)	10.0 (47)	50.5 (3)	24.0 (48)
20.7 (5)	269 (39)	10.4 (15)	53.3 (34)	26.3 (5)
21.3 (19)	368 (28)	11.7 (35)	59.2 (12)	26.7 (24)
24.4 (12)	437 (17)	11.8 (31)	67.7 (8)	125 (42)
29.2 (41)	441 (18)	13.2 (40)	68.5 (35)	167 (26)
31.9 (45)	468 (26)	13.3 (33)	80.5 (19)	180 (2)
34.3 (47)	500 (43)	13.9 (23)	85.0 (15)	350 (17)
34.8 (11)	512 (19)	15.3 (30)	88.0 (40)	1000 (37)
35.8 (21)	555 (6)	15.6 (13)	101 (13)	∞ (7)
37.7 (33)	950 (33)	18.5 (36)	129 (18)	∞ (22)
39.3 (30)	1000 (7)	19.8 (8)	143 (28)	∞ (27)
51.9 (20)	1800 (27)	23.8 (41)	200 (6)	∞ (32)
112.9 (4)	2000 (37)	26.3 (11)	333 (33)	∞ (43)

Notes: 1. Number in parenthesis refers to state description number
2. Information concerning sand gravel obtained from reference (175) for 1964
3. Information concerning crushed stone obtained from reference (189) for 1958

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