A GENERALIZED INVESTIGATION OF THE POTENTIAL AVAILABILITY OF AGGREGATE BY REGIONAL GEOMORPHIC UNITS WITHIN THE CONTERMINOUS 48 STATES

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The principal activity in this study was an examination of the potential availability of aggregate within the conterminous 48 states using an extant physiographic classification system. The classification selected was a modified version of the Woods-Lovell Physiographic-Engineering System, comprised of 97 physiographic sections. The estimated potential availability of aggregate was rated at four levels, ranging from abundant-to-adequate to severe-problem. Individual physiographic section ratings were assigned following an examination of the major aggregate type(s) used, their distribution within the section, and any quality limitations associated with their use. Information relative to aggregate types and characteristics was gathered from the literature, particularly bedrock and surficial maps, and from responses to a materials questionnaire sent to each state highway agency. The study shows that aggregates are potentially in short supply in about one-third of the conterminous 48 states, i.e., these areas have limited-to-severe-problem ratings. Such areas are primarily comprised of regional topography formed from predominantly sandstone and shale bedrock or from transported deposits deficient in either quantity or quality of sand-gravel and underlain by bedrock having little or no aggregate potential.

• ALTHOUGH engineering design and construction decisions are unique solutions to specific problems, such solutions depend strongly on the engineer's store of highly relevant experiences from which he can draw information, ideas, methodologies, etc. How does the engineer organize his experience so that the item appropriate to a particular job is retrieved? For example, are there geographic units within which general geotechnical conditions are unique and, accordingly, engineering solutions are similar?

The search for geographic units within which ground conditions, other environmental factors, engineering problems, and presumably design and construction practice demonstrate significant homogeneity has led to the study of the works of physiographers and regional geomorphologists. By using their three major classification factors of structure, process, and stage, which can be practically interpreted as parent material, origin, and age (9), physiographic units are mapped. Each unit has a unique mode of topographic expression, i.e., it differs from its neighbors in this respect. The units of greatest usefulness to engineers are, from largest to smallest, province, section, and subsection.

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The principal objective of this paper is to report a study of the practicability of using physiographic units to rate the potential availability of quality aggregate resources within the conterminous 48 states. The units were defined by a slightly modified version of the Woods-Lovell Engineering-Physiographic System presented in 1960 (8). This version resulted in the establishment of 97 unique areas, termed physiographic sections, to be investigated. Table 1 gives each province and section and provides a code for their location in Figure 1.

METHOD OF ANALYSIS

Data on the distribution of potential aggregate resources were sought in the literature and by questionnaires directed to the state highway agencies. Sources were mapped by aggregate type, and all quality problems reported for the sources were recorded.

Mapping

Aggregate sources were mapped as (a) crushed-stone sources (Fig. 2) and (b) sand-gravel sources (Fig. 4). The crushed-stone sources were subdivided into carbonate rocks, granitic and metamorphic complexes, and other igneous (primarily basaltic type) rocks. Certain references (1, 2, 4, 5, 6) were particularly valuable in providing state or regional maps of potential sources. Where such direct information was not located, the authors attempted to derive it from generalized state or regional geologic maps, origin-parent material diagrams, and aggregate production data.

In addition to regional potential aggregate areas, existing pits and quarries were mapped on a U.S. scale. These locations were grouped as sand and sand-gravel pits; crushed-stone quarries, regardless of major geologic rock type; and a miscellaneous category. Included within the latter group were slag, lightweight aggregate, caliche, clam and oyster shells, and coquina.

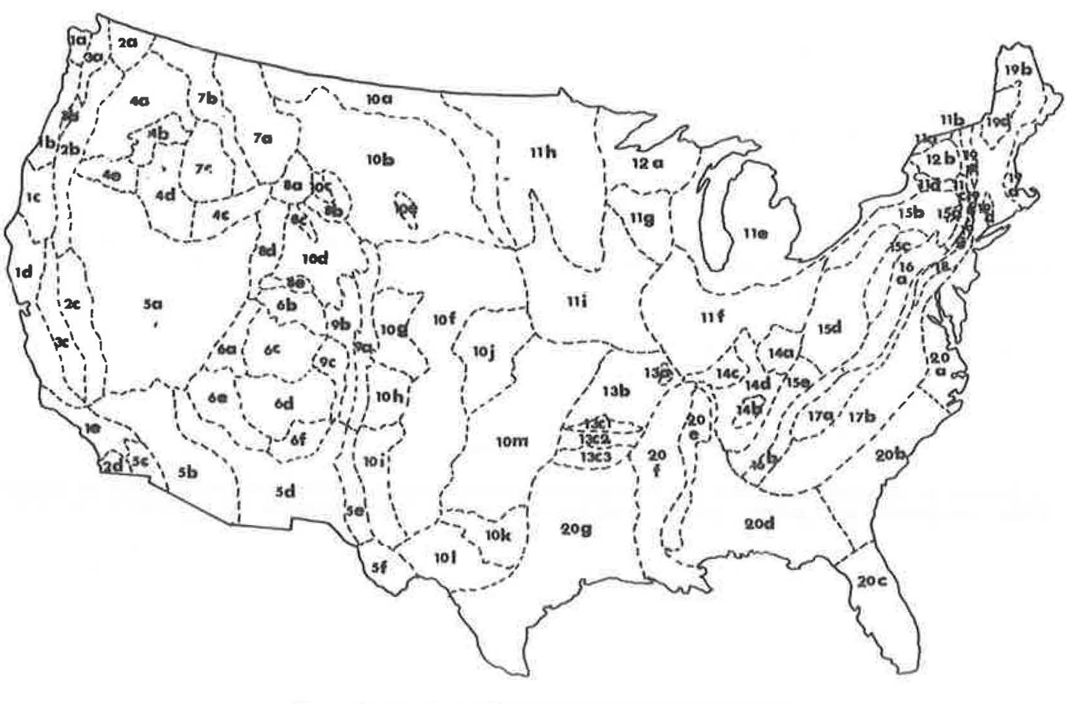

Figure 1. Physiographic diagram of the United States.

TABLE 1

PHYSIOGRAPHIC UNIT CODE

1. Western Mountains of the Pacific Coast Range
   a. Olympic Mountain
   b. Oregon Coast Range
   c. Klamath Mountain
   d. California Coast Range
   e. Los Angeles Range
2. Sierra-Cascade
   a. Northern Cascade Mountain
   b. Southern Cascade Mountain
   c. Sierra Nevada
   d. Lower California
3. Pacific Troughs
   a. Puget Sound
   b. Willamette Valley
   c. California Valley
4. Columbia Plateau
   a. Walla-Walla
   b. Blue Mountain
   c. Snake River Plains
   d. Payette
   e. Harney
5. Basin and Range
   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
   a. High Plateaus of Utah
   b. Uinta Basin
   c. Canyon Lands
   d. Navajo
   e. Grand Canyon
   f. Datil
7. Northern Rocky Mountain
   a. Montana
   b. Bitteroot
   c. Salmon River
8. Middle Rocky Mountain
   a. Yellowstone
   b. Bighorn Mountain
   c. Wind River Mountain
   d. Wasatch
   e. Uinta Mountain
9. Southern Rocky Mountain
   a. Front Range
   b. Western
   c. San Juan Mountain
10. Great Plains
   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
   a. St. Lawrence Lowland
   b. Champlain Lowland
   c. Hudson River Valley
   d. Mohawk River Valley
   e. Eastern Lakes and Lacustrine
   f. Central Till Plain
   g. Driftless
   h. Western Lakes and Lacustrine
   i. Dissected Loessial and Till Plain
12. Laurentian Upland
   a. Superior Upland
   b. Adirondack
13. Ozark and Ouachita
   a. St. Francois Mountain
   b. Springfield-Salem Plateau
   c1. Boston Mountain
   c2. Arkansas Valley
   c3. Ouachita Mountain
14. Interior Low Plateaus
   a. Blue Grass
   b. Nashville Basin
   c. Shawnee Hills
   d. Highland Rim
15. Appalachian Plateau
   a. Catskill Mountain
   b. New York Glaciated
   c. Allegheny Mountain
   d. Kanahwa
   e. Cumberland
16. Newer Appalachian (Ridge and Valley)
   a. Pennsylvania-Maryland-Virginia
   b. Tennessee
17. Older Appalachian
   a. Blue Ridge
   b. Piedmont
18. Triassic Lowland
19. New England Maritime
   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
   a. Embayed
   b. Sea Island
   c. Florida
   d. East Gulf
   e. Mississippi Loessial Upland
   f. Mississippi Alluvial Plain
   g. West Gulf

Note: Numbers represent physiographic provinces, letters represent physiographic sections.

Aggregate Problems

Many aggregate problems are identified and described in the literature (particularly 3). The distribution and magnitude of the problems were primarily defined by the responses to the materials questionnaire sent to each state highway department.

The materials questionnaire responses provided a current summary of aggregate types, uses, quality (problems), and availability for each state. The questionnaire responses were coded for convenience. Information was obtained for the specific physiographic sections within each state. Of particular importance to this report were the responses to a request to identify those physiographic sections where suitable aggregates were generally lacking.

RESULTS

Aggregate Distribution

Figures 2 through 5 partially summarize the results of the mapping effort for both the potential aggregate areas and the pit and quarry locations. Figure 2 shows the generalized potential crushed carbonate stone areas within the 48 states. [Diagrams showing the distribution of potential crushed granitic and metamorphic complexes, igneous (basaltic) rock, and the miscellaneous aggregate category are shown elsewhere (9).] It is the opinion of the authors that the mapping of the carbonate zones east of the Rocky Mountain-Great Plains border gives a relatively accurate pattern of the distribution. West of this border the carbonate sources are often quite local and scattered, which makes them very difficult to map at this scale. Figure 3 shows the location of crushed-stone quarries.

Figures 4 and 5 show the distribution pattern of potential and extant sand and sand-gravel sources. The relative accuracy of the sand-gravel map is quite variable due to the wide range of references interpreted to depict the total distribution.

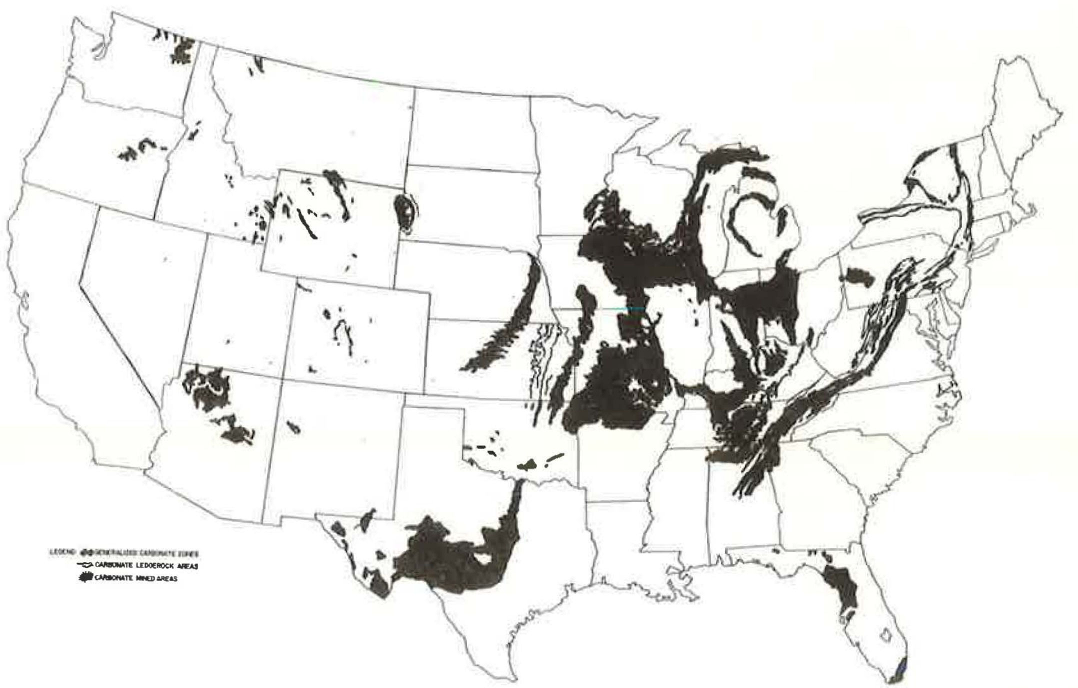

Figure 2. Distribution of generalized potential crushed carbonate stone areas.

Figure 3. Distribution of crushed-stone quarries in the United States.

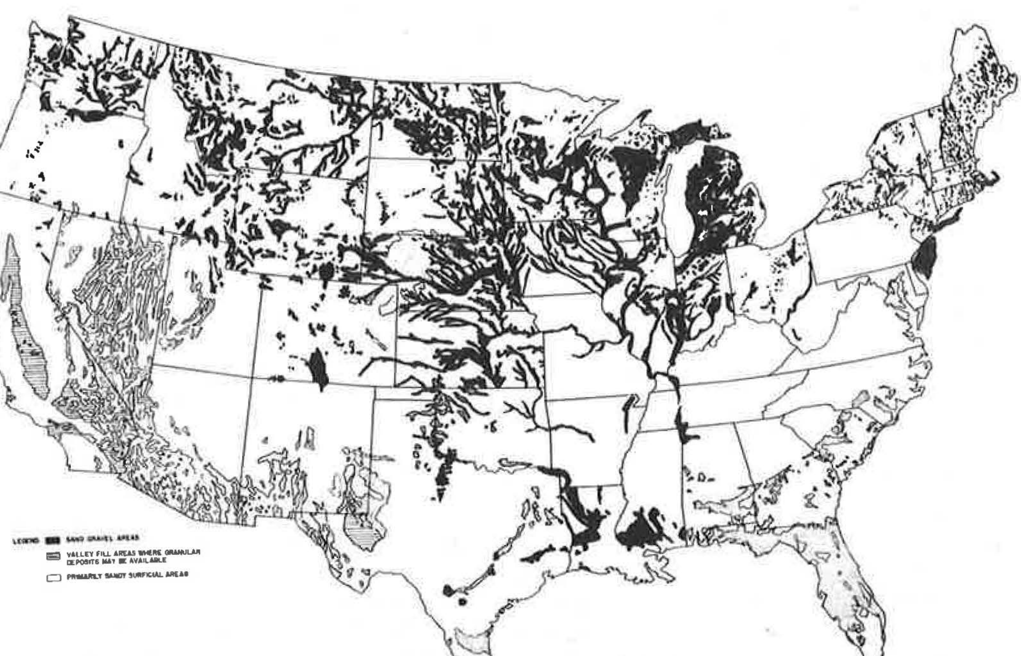

Figure 4. Distribution of generalized potential sand-gravel areas.

Figure 5. Distribution of sand and sand-gravel pits in the United States.

Aggregate Type Use

Aggregate Type Code—A wide variety of aggregates is used for highways; e.g., a total of 34 types are recognized in this study. Table 2 keys these aggregate types to a numerical code. The major groupings are sands and gravels, crushed stone, and miscellaneous. The last group consists primarily of artificial aggregates as well as the authors' interpretation of several "localized" sources, such as coquina and clam and oyster shells. The crushed-stone group is subdivided into sedimentary, igneous (extrusive and intrusive), and metamorphic. The relationship between the coded aggregate number and the general category of aggregate should be apparent (sedimentary crushed-stone types are the 10 series, igneous crushed stones are the 20 series, etc.).

Use—A summary of the major aggregate use by state and aggregate type is given in Table 3. This summary is based primarily on the responses to the materials questionnaire. Where states did not provide such information, input was obtained from available literature (3, 5, 6, 7) and is accordingly more tentative.

Table 4 is a summary of the aggregate types used for each physiographic section. Figure 6 shows areas reported by representative state highway officials to be deficient in quality aggregate sources.

Availability Ratings of Aggregate by Physiographic Section

The estimate of the potential availability of aggregate for each physiographic section was based on a four-level rating scale: (a) abundant-to-adequate, (b) adequate-to limited, (c) limited-to-problem, and (d) severe problem.

Ratings were assigned to the physiographic units by determining the major type or types of aggregates used, examining their relative distribution within the unit, and assessing their major quality problems. It was thus possible for an area possessing an abundant distribution of a potential aggregate type to receive a "compromised" rating due to the presence of a major problem with that particular type. On the other hand,

TABLE 2

AGGREGATE TYPE CODE

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

TABLE 3

SUMMARY OF GENERAL AGGREGATE TYPES USED BY STATE

State	Aggregate Type[a]	State	Aggregate Type[a]
Alabama	2,3,10,11,13,28,30, 33,42,47	Nebraska	1,2,3,10
Arizona	3,10,13,21,22,23, 28,31	Nevada*	3,10,13,21,28,30,31
Arkansas	3,10,11,13,14,29,31	New Hampshire	3,28,31
California*	3,10,13,21,28,47	New Jersey	1,3,10,11,15,21,22, 28,31,33,47
Colorado	3,10,13,21,28,30, 45,47	New Mexico	3,10,21,23,24,26, 31,49
Connecticut	3,21	New York	3,10,11,13,22,27, 28,30,31,47
Delaware	1,2,3,33	North Carolina	2,3,10,26,28,30,33
Florida	3,10,41,42	North Dakota	3,43
Georgia	3,10,12,28,30,31,33	Ohio	1,2,10,13,47
Idaho	1,2,3,10,11,21,31,47	Oklahoma	3,10,11,13,28
Illinois	3,10,11,47	Oregon	1,2,3,21
Indiana	3,10,11,47	Pennsylvania	3,10,13,22,28,47
Iowa	3,10,11	Rhode Island*	3,10,28
Kansas	3,10,11,12,13,48	South Carolina*	3,10,28
Kentucky	3,10,47	South Dakota	3,10,13,28,31
Louisiana	3,42,46	Tennessee	3,10,11,13,47
Maine	3,10,13,28,31	Texas*	3,10,13,21,28,30, 42,47,49
Maryland	1,2,10,27,28,30,32, 33,35,37	Utah*	3,10,13,28,30
Massachusetts	3,10,21,22,23,26,33	Vermont	3,10,11,25,28,31, 32,35
Michigan	1,2,3,10,11,13,21, 23,47	Virginia	3,10,11,13,21,22, 28,30,33,42
Minnesota*	3,11,21,28,31	Washington	3,10,13,21,28,31
Mississippi	3,42	West Virginia	1,3,10,13,47
Missouri	1,2,10,11,13,28	Wisconsin	1,3,11,13,21,28,31
Montana	3,10,13,15,21,28,31, 43,47	Wyoming	3,10,11,13,21,28,43

*For the states marked by an asterisk (*), information has been obtained through a literature search and is to be regarded as possible aggregate types only. For the states not marked with an asterisk, information has been obtained from the materials questionnaire.

[a]See Table 2 for key to aggregate type.

TABLE 4

SUMMARY OF GENERAL AGGREGATE TYPES USED BY PHYSIOGRAPHIC SECTION

Section Code	Aggregate Type
1a	3,13,21
b	1,3,13,21
c	3
d	3,10,11,13
e	3,10,11,28
2a	3,13,21,28
b	3,10,21
c	3,10,28
d	3,28
3a	3,13,21
b	3,21
c	3
4a	1,2,3,21
b	1,2,3,21
c	1,2,3,21,47
d	1,2,3,21
e	2,21
5a	1,2,3,10,11,21,31
b	3,21,23,28
c	3
d	3,10,13,21-24,28,31,44
e	3,10,31,49
f	3,10,21
6a	3
b	3
c	3,13
d	3,13,21
e	3,21
f	3,10,21,44
7a	3,10,13,15,21,28,31,34,47
b	1,2,3,10,15,21,28,31,34
c	2,3,21

Section Code	Aggregate Type
8a	3,28
b	3,10
c	3,10,34
d	3,10,11,13,34,47
e	3
9a	3,10,28
b	3,10,28,30
c	3,21,31
10a	3
b	1,3,10,13,43
c	3,10,11,13,21
d	3,10,13,28
e	10,28
f	1,2,3,10,11,13,28,49
g	3,10,21,47
h	3,10,21,26
i	3,10,49
j	1,3,11,13,48
k	3,10
l	3,10
m	1,2,3,10,11,12,13,28
11a	3,10,11
b	3,10,11,31
c	1,3,10,11,13,31,33
d	3,10,11
e	1,2,3,10,11,13,47
f	1,2,3,10,11,47
g	1,3,10,11,13,28,31
h	3,10,11,28,31
i	1,2,3,10,11,28,31,47
12a	1,2,3,21,23,30,31
b	3,27,28

Section Code	Aggregate Type
13a	1,2,10,11,28
b	1,2,3,10,11,13
c1	3,10,13
c2	3,10,13,29,31
c3	3,10,13,14
14a	1,2,3,10,11
b	3,10,47
c	3,10
d	3,10,11,13
15a	3,13
b	1,2,3,10,13,47
c	10
d	1,2,3,10,13,47
e	1,2,3,10,11,12,13,47
16a	1,2,3,10,11,13,22,47
b	1,2,3,10,11,12,13,30,47
17a	2,3,10,21,22,28,30,33
b	1,2,3,11,21,22,26-28,30-35
18	1,3,10,21,22,28
19a	3,10,13,23,26,28,31,33
b	3,10,11,21,22,25,26,28,31-33,35
c	3,21,22
d	3,28
e	3,25,28,32,35
f	3,10,11,31
g	1,3,10,11,15,22,28,30,31,33,47
20a	1,2,3,28,42,47
b	1,2,3,42
c	1,10,41,42,47
d	1,2,3,10,11,40,42
e	3
f	1,2,3,42,46
g	3,42

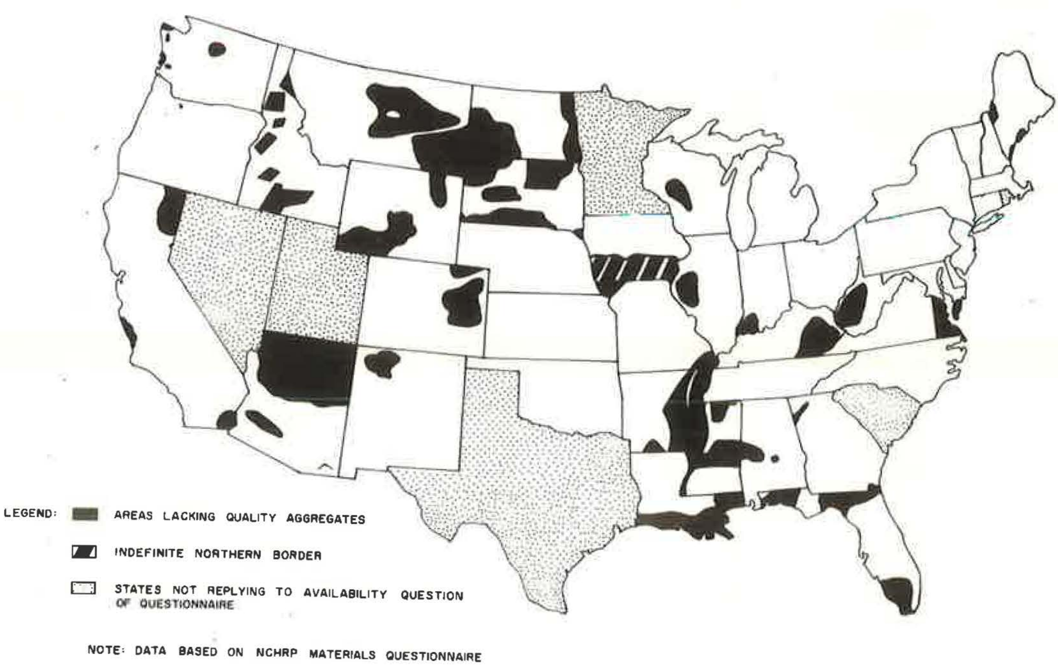

Figure 6. Questionnaire summary of areas lacking quality aggregates.

TABLE 5

SUMMARY OF ESTIMATED POTENTIAL AVAILABILITY RATINGS OF QUALITY AGGREGATES WITHIN SECTIONS

Abundant-to-Adequate		Adequate-to-Limited		Limited-to-Problem		Severe Problem	
Section Code	Area (square miles)	Section Code	Area (square miles)	Section Code	Area (square miles)	Section Code	Area (square miles)
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
Totals	1,061,610		1,004,180		787,520		169,090
Percentage of conterminous 48 states	35.1		33.2		26.1		5.6

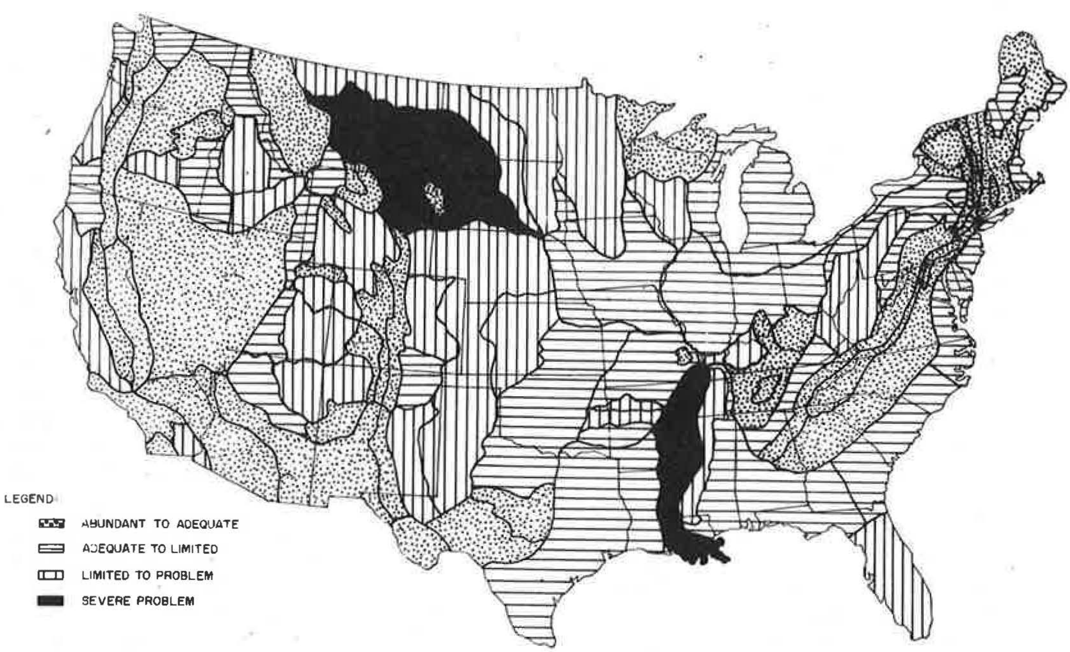

Figure 7. Estimated potential availability rating of quality aggregate resources by physiographic unit.

a more limited supply of a good-quality aggregate type, which was well distributed within a physiographic section, could produce a high (i.e., abundant-to-adequate) aggregate availability rating.

Table 5 summarizes the estimated potential availability ratings of aggregates by section, and Figure 7 shows these regions within the conterminous 48 states.

SUMMARY AND CONCLUSIONS

Aggregate Availability

This study shows that quality natural aggregate resources are not available over sizable areas of the United States.

As noted in Table 5, section areas comprising more than 26 percent of the total estimated aggregate availability have a poor potential for aggregate resources, while sections totaling almost 6 percent have a very restricted potential aggregate supply. In addition, the "true" or "realistic" (in contrast to potential) appraisal of aggregate resources may show an even more unfavorable situation.

For example, in many Western areas good potential aggregate sources exist (particularly crushed stone), but the regions are sparsely populated and in many cases the sources are practically inaccessible due to the extremely rugged, mountainous conditions. These aggregate resources are not only less needed, they are, by virtue of their location, less available.

In contrast, in the East, many of the areas possessing potentially adequate supplies may be quite restricted for exploitation due to urban development and the associated high population densities. This would likewise tend to reduce the real availability.

Geologic Summary of Sections Having Poor Aggregate Availability Ratings

Although each section possessing a limited-to-problem or severe-problem rating had its own unique combination of characteristics responsible for that rating, these sections can effectively be grouped into three types based on the causative geologic conditions. Table 6 gives the types and the grouping of aggregate-deficient sections within them.

One of the most significant factors, correlative with a lack of aggregate, was a widespread distribution of sandstones and shales. This, coupled with a relative lack of quality natural sand-gravel deposits, generally yields areas of extremely poor aggregate potential. From Table 6 it can also be seen that most of these areas (within the Type I grouping) have geologic ages that correspond to the Cenozoic, Mesozoic, Late Paleozoic (Permian and Pennsylvanian), and Early Paleozoic (Cambrian) eras. It is within the Paleozoic periods older than the Pennsylvanian that the majority of the crushed carbonate sources occur.

A modal bedrock pattern of sandstone and shale is not always associated with an overall poor aggregate availability rating for the section in question. Examples of sections that, in general, are characterized by relatively soft sandstone and shale bedrock but possess abundant-to-adequate potential for aggregates are the Bighorn Basin (10c), the Triassic Lowland Province (18), and the Connecticut Lowland Section (19c). Within these units, the widespread distribution of quality sand-gravels and/or crushed stone (obtained from variant bedrock types within the unit) is responsible for the rating.

Type II deficiency areas are those of poor quality igneous rocks (mostly extrusives), whereas in the Type III the bedrock is generally deeply buried by unconsolidated material deficient in the coarse sizes.

Although the examination of potential availability of aggregate in 97 physiographic sections produces a useful general perspective, the physiographic section is commonly too large and varied a region for the purpose. Subdivision of the conterminous 48 states into 242 subsections has been accomplished (9). Examination of this, or another engineering consideration, for these more homogeneous units would permit more specific regional predictions.

TABLE 6

GENERALIZED SUMMARY OF PREDOMINANT GEOLOGIC CONDITIONS EXISTENT WITHIN SECTIONS POSSESSING AN AGGREGATE AVAILABILITY RATING LOWER THAN ADEQUATE-TO-LIMITED

Section (Code)	Remarks
Type I: Sections possessing 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 Mountain (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 possessing 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 Plain (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 not suitable for use as highway aggregate.
Type III: Sections generally possessing a nonexistent-to-poor bedrock crushed-stone potential overlain by transported deposits either deficient in quantity or quality of granular materials	
Salton Trough (5c)	Widespread presence of fine-grained alluvial and lacustrine deposits characterize much of section.
Glaciated Missouri Plateau (10a)	Glaciated region possessing sand-gravel deposits of general poor quality underlain by bedrock similar to that found within unglaciated section (see 10b in Type I grouping).
High Plains (10f)	Crushed-stone potential nonexistent in section; major source of aggregates is from major rivers and tributaries. Higher concentration of rivers 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 possesses Cretaceous sandstones and shales similar in characteristics to those found in Type I grouping. Major areas void of aggregate associated with glacial lacustrine areas (Lakes Agassiz and Dakota).
Florida (20c)	Sandy unconsolidated coastal deposits veneer almost entire section. Regional carbonate zones present in portions of unit, but much of section lacks coarse aggregate.
Mississippi Loessial Upland (20e)	Widespread loessial deposits overlie areas lacking in crushed-stone potentials.
Mississippi Alluvial Plain (20f)	Widespread distribution of fine-grained alluvium throughout most of unit.

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