REPORT OF COMMITTEE ON CORRELATION OF RESEARCH IN MINERAL AGGREGATES

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SHALE IN AGGREGATES[1]

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SYNOPSIS

Discussion of the origin and characteristics of shale and of its metamorphosed equivalents, slate, phyllitte and schist Clay is derived from the weathering of igneous rocks and of sedimentary rocks, especially limestone and shale Shale is consolidated clay The change is accompanied by crystallization, dehydration, and cementation The process is readily reversed by alternate wetting and drying In the change from the clay to schist there is a progressive loss of water and CO_2, and an increase in silica resulting in rocks which are resistant to weathering A comparison of the specific gravity of shale with those of other rocks indicates difficulty in effecting complete separation of shale in gravel by any method that depends upon relative specific gravities

Nearly all specifications for concrete aggregates directly or indirectly place shale in the list of deleterious substances In Minnesota the tolerance is not more than 2 5 per cent by weight in sand and in coarse aggregate not more than 0 4 per cent by weight of the portion between 2 and ¾ inches in size and not more than 0 7 per cent by weight of the entire sample These limits were developed from observation of the effect of shale in concrete Michigan permits up to 3 per cent of shale in concrete coarse aggregate

It has appeared to the Committee on Correlation of Research in Mineral Aggregate that the geological aspects of shale should be considered This paper, therefore, will discuss the derivation and characteristics of shale and its metamorphic equivalents from the standpoint of highway aggregates

[1] This report has been carried over from the Proceedings of the Eleventh Annual Meeting in order that it may accompany the report on "Shale in Concrete Aggregates" by Walker and Proudley, which discusses the subject from the standpoint of engineering use

DERIVATION OF SHALE

Clay is the fine-grained product of rock weathering Twenhofel (1)[2] defines clay on the basis of grain size as having particles less than $\frac{1}{256}$ mm in diameter and silt as consisting of particles between $\frac{1}{256}$ mm and $\frac{1}{16}$ mm in diameter The primary source of clays is weathered igneous rock Clay is produced also by the decomposition of sedimentary rocks especially shale and impure limestone "The minerals of the clays consist of hydrous aluminum silicates of the kaolin group, containing more or less of absorbed alkalies and alkaline earths, minerals of the chlorite group, hydrous iron oxide, secondary quartz, and opal, carbonates of calcium, magnesium, and possibly iron, small amounts of sulphate (probably largely gypsum), fine-grained fragmental quartz, feldspar, micas, and ferromagnesian minerals, and very small amounts of original unaltered accessory mineral" (2)

SHALE

In the sense generally employed shale is a consolidated clay, forming a close-grained rock which may be laminated with excellent parting parallel to the bedding or it may be nearly massive Consolidation is accompanied by cementation which may be due to the crystallization of colloidal envelopes surrounding the minerals The change is a progressive one In the early stages, before much crystallization and dehydration have taken place the process of hardening may be reversed by soaking in water As a rule shale slakes more readily after it has been air dried The cretaceous shale at Red Wing, Minnesota, slakes readily in three minutes (3) Some exposures of the Coldwater (Lower Mississippian) shale of Michigan slake more slowly The term shale is loosely employed as a structural term to describe not only true shale but also other thin bedded rocks, particularly sandstone and limestone Since the original sediment was not in all cases pure clay, there are all gradations, with increasing sand content, between shale and argillaceous sandstone With an increasing proportion of calcareous material shale grades into argillaceous limestone Shales are usually soft, cut readily and are brittle They vary greatly in color but shades of gray are the most common Geologically shales are important since it has been estimated that 80 per cent of the sedimentary rocks are shale Outcrops, however, are not common owing to rapid weathering The average clay (4) has a mineral specific gravity of 2 68 and the average shale a mineral specific gravity of 2 71 Porosity of the clay is largely eliminated by compression The average porosity of clays is 27 per cent and that of shales is but 13 per cent The average mineral composition of shales is shown in Table I (5).

[2] See list of references at end of paper

"There are, of course, wide variations from this average The shales have a much smaller proportion of amorphous constituents than clays The colloidal substances have largely disappeared Kaolin and the ferric hydrates have decreased to a marked extent The fine-grained matrix or paste of the shales consists of finely granular quartz or chert, containing considerable quantities of white mica and locally rutile Much of the iron is reduced to the ferrous condition in combination with silicates (principally chlorite) and as carbonate It may be combined with sulphur, which is often present under these conditions, to form pyrite. The presence of carbonaceous matter favors this reduction, as shown by the common association of iron carbonate and sulphides with granitic shales The result is often a change of color of the rock from yellowish or reddish to greenish gray or black" (6)

TABLE I

	Per cent
Quartz	31 91
Kaolin	10 00
White Mica	18 40
Chlorite	6 40
Limonite	4 75
Dolomite	7 90
Gypsum	1 17
Orthoclase	12 05
Albite	5 55
Rutile	0 66
Apatite	0 40
Carbon	0 81

SLATE

A shale becomes a slate through one or more of the following (a) long continued pressure, (b) contact metamorphism or dynamic action or (c) through the effects of high temperature and pressure The change is marked by a development of the platy minerals, principally muscovite and to a less extent chlorite A parallel arrangement of the mineral constituents may develop cleavage, which is generally at an angle to the bedding. The process of alteration may be only partial, resulting in a clay slate, having as its chief constituents clay, mica and chlorite If the process is carried still further a mica slate results In this little or no clay remains, the chief constituents being mica, quartz and chlorite The most abundant mineral is white mica (sericite) Argillaceous rocks may be transformed into massive rocks, devoid of cleavage, which chemically and mineralogically are slates

PHYLLITE AND SCHIST

The word phyllite means leaf stone Phyllites are metamorphosed slates, characterized by excellent cleavage, by means of which they split into thin sheets The surface is sometimes flat, sometimes wavy and irregular Mica may constitute more than 50 per cent of the weight of the rock. Mica schists may represent a continuation of the recrystallization process which developed the slate, resulting in a foliated rock with a coarser grain The individual folia are mineralogically alike and the principal minerals are so large as to be visible to the naked eye

TABLE II

	Percentage			
	A	B	C	D
SiO_2	54 28	58 38	61 90	65 74
Al_2O_3	14 51	15 47	16 54	17 35
Fe_2O_3	6 25	4 03	2 73	1 90
FeO	0 77	2 46	3 63	3 35
MgO	2 99	2 45	2 99	1 90
CaO	5 04	3 12	1 07	1 25
Na_2O	1 21	1 31	2 57	1 78
K_2O	2 12	3 25	3 15	3 28
H_2O	8 41	5 02	3 84	2 01
TiO_2	0 42	0 65	0 82	0 55
CO_2	3 53	2 64	0 59	None
P_2O_5	0 09	0 17	0 04	0 12
SO_3	0 08	0 65	0 03	0 03
Cl	0 02		Trace	Trace
F			Trace	0 07
MnO	0 08	Trace	Trace	0 03
SrO		None	Trace	Trace
BaO		0 05	0 01	0 05
Li_2O		Trace	Trace	Trace
FeS			0 11	
C	0 24	0 81	0 22	0 58
	100 04	100 46	100 24	99 99

A Average of 12 analyses of clays and soils
B Average of composite analysis of 78 shales
C Average of 22 analyses of slates
D Average of 5 analyses of schists

SUMMARY OF CLAY, SHALE, SLATE AND SCHIST RELATIONSHIP

Shales, slates, phyllites and mica schists, therefore, form a continuous series of rocks which can be derived from clay by progressive metamorphism (dehydration and crystallization) The general order of change from clay to schist is shown by the analyses in Table II (7)

There is a progressive loss of water and carbon dioxide in the change from clay to schist Carbon dioxide has been replaced by silica which has proportionally increased as a cementing material Ferric iron is partly reduced to the ferrous state and there is an apparent gain in alumina

WEATHERING

Rocks of this series, derived from clay, the end-product of the weathering of pre-existing rocks, are chemically stable and break down under weathering largely through physical processes The susceptibility of each type to destruction by weathering is determined by the degree of metamorphism The shales having been least metamorphosed weather most rapidly Since shale is exceedingly fine-grained, the pore spaces are subcapillary in size, water is confined and the destructive effect of freezing is much greater than in a porous sandstone A shale consolidated by pressure decrepitates and weathers to clay A shale consolidated by cementation as well as pressure weathers more like a slate forming angular platy fragments To the extent that any shale is composed of soluble or incompletely weathered minerals, that shale and its metamorphosed equivalents are susceptible to chemical change As mica slates are more resistant to absorption, and are, therefore, more resistant to weathering than clay slates, they have long been considered one of the most durable of building materials Bowles (8) reports a slate roof in good condition after 1200 years of service

SHALE IN AGGREGATES

Gravel Since shale weathers rapidly, outcrops are uncommon in spite of the fact that it is a very important sedimentary rock Weathered shale is an important constituent of glacial till in shale areas In areas underlain by shale, it is a relatively common constituent of gravel The better gravels have been subjected to such vigorous abrasion that the soft unstable constituents have disappeared and only the hard and durable materials remain Gravels, derived in part at least from areas of shale outcrop, contain a proportion of shale fragments determined by the distance transported and the amount of abrasion experienced en route The shale in glacial gravel has been subjected to grinding within the ice, and to abrasion before deposition by a glacial stream A wave cut exposure of shale furnishes pebbles to the beach If wave action is vigorous, these pebbles are worn out during relatively short transportation along shore The percentage of shale pebbles in stream gravels decreases rapidly upon transportation away from the ledge

A study of the aggregate in the weathered zone of gravel exposures gives many data regarding shale Here all of the material has been subjected to a service test An original shale pebble may be represented by small chips or by a mass of clay In recently worked portions of the deposit, the shale pebbles may appear quite hard and sound, since they have not been exposed to alternate wetting and drying and to freezing and thawing

With shale present in gravel there is some possibility of removing it in the plant, but the data in Table III regarding specific gravity of various types of rock indicate that there will be considerable difficulty in effecting complete separation by any method that depends upon relative specific gravities

A system of grinding which would destroy the shale and the friable particles might be effective, providing the cost were not excessive This would reproduce in the plant, Nature's method of destroying such material

TABLE III

Rock	Specific gravity		
	Average	Maximum	Minimum
Wisconsin Stone (9)			
Granite	2 655	2 713	2 629
Dolomite	2 808	2 856	2 740
Sandstone	2 631	2 660	2 524
Average of Rock Samples (10)			
Basalt	2 86		
Granite	2 66		
Limestone	2 65		
Sandstone	2 56		
Mica Schist	2 77		
Slate	2 76		
Dolomite	2 76		
Shale			
9 Samples (11)	2 56	2 70	2 50
18 Iowa Shales (12)	2 45	2 64	2 25

Quarries If a limestone quarry is under consideration the weathered ledge should be carefully examined for evidence of shale Thin beds of limestone or dolomite are usually separated by thin laminae of shale Even massive beds decrepitate upon weathering because of paper thin shale partings Loughlin (13) ascribes the failure of a western Pennsylvania limestone to clay and organic matter in irregular spots The clay mineral was beidellite Chemical analyses of lime stone are a valuable indicator of the clay content By a studied selection it is possible to eliminate in quarrying the undesirable stone, thus bringing the crushed product up to requirements The service history of quarried stone is a valuable source of information Many quarries have been in use for many years and buildings of long standing indicate the quality of the stone It must be remembered that care has usually been exercised in selection so that only the more durable beds were utilized.

SLATES AND SCHISTS AS AGGREGATES

Slates and schists are composed of minerals very resistant to atmospheric weathering These rocks are, therefore, sound, but are usually undesirable as road materials for structural reasons Tests of Pennsylvania slate (14) showed the following results

Porosity, per cent	0 196
Tensile strength, lbs per sq inch	3,625
Compression strength, lbs per sq inch	10,250
Abrasion, per cent of wear	5 12
Abrasion, French coefficient	7 81
Toughness	11 5
Hardness coefficient	11 0

The tendency of these rocks to produce flat and elongated fragments is considered objectionable Thin bedded limestones and standstones are subject to the same objection

REFERENCES

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(2) Leith and Mead, Metamorphic Geology, p 102
(3) Grout, Frank F , Clays and Shale of Minn , U S G S Bull 678, p 169
(4) Leith and Mead, Metamorphic Geology, p 108
(5) Leith and Mead, Metamorphic Geology, p 76
(6) Leith and Mead, Metamorphic Geology, p 104
(7) Clarke, F W , Data of Geochemistry, U S Geol Sur Bull 770, p 631
(8) Oliver Bowles, The Technology of Slate, Bureau of Mines, Bull 218, p 7
(9) Buckley, E R , Building and Ornamental Stones, Wis Geol Sur , Vol 4, p 371
(10) Bulletin, 348, U S Dept of Agriculture, Table 1
(11) Reis and Watson, Engineering Geology, p 601
(12) Iowa Geol Survey, Vol. 14, p 116
(13) Loughlin, G E , Qualifications of different kinds of natural stone for concrete aggregate, Am Con. Inst , Proc , Vol 23, pp. 319–351
(14) Oliver Bowles, Technology of Slate, Bureau of Mines, Bull 218, p 7.

DISCUSSION

ON

SHALE IN AGGREGATES

Abstracted

PROF F C. LANG, *Engineer of Tests and Inspection, Minnesota State Highway Department* Although Dr Bean's statement that "A comparison of the specific gravity of shale with that of other rocks indicates difficulty in effecting complete separation of shale in gravel by any method that depends upon relative specific gravities" is undoubtedly true of many shales, there are many in Minnesota and Iowa in which the specific gravity is rarely over 1 75 When the shales are as light as this the difference in specific gravity between the shale and other particles is being used as a basis for commercial reduction of shale content of gravel to about one per cent There is considerable variation in the specific gravities of shales in gravel deposits in different localities which may explain the difference which is permitted in the amount of shale in concrete aggregates in the States of Minnesota and Michigan In Minnesota the shale is so light that in the manipulation of the concrete it works toward the surface In Michigan the shale is considerably heavier and they do not get the concentration near the surface

PROF W J EMMONS Two methods besides hand picking are used in Michigan for the elimination of shale and other soft particles from gravel The first is a ball mill device, consisting of a long inclined revolving cylinder, inside of which are perforated cones holding shot which are of greater diameter than the holes The gravel flows from one cone to the next, the softer particles being ground by the abrasive charge of shot Water is applied at the discharge and to remove the worn material Another mechanical device is a rapidly rotating horizontal disc upon which the gravel flows It is immediately thrown by centrifugal force against a surrounding steel plate The impact is sufficient to reduce a great many of the soft particles and even fracture the hard ones

MR H S MATTIMORE A specification of allowable shale content in any aggregate does not give a definite designation What should be specified is the allowable percentage of detrimental or unsound shale The soft unsound kind of shale can be readily identified