Haydite Raw Material in the Kings River, Sutton, and Lawing Areas, Alaska

GEOLOGICAL SURVEY BULLETIN 1039-C

Haydite Raw Material in the Kings River, Sutton, and Lawing Areas, Alaska

By RICHARD A. ECKHART *and* GEORGE PLAFKER

INVESTIGATIONS OF CONSTRUCTION MATERIALS IN ALASKA

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A geologic study of three areas that contain raw material for haydite, a lightweight vesicular construction material

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INVESTIGATIONS OF CONSTRUCTION MATERIALS IN ALASKA

HAYDITE RAW MATERIAL IN THE KINGS RIVER, SUTTON, AND LAWING AREAS, ALASKA

By Richard A. Eckhart and George Plafker

ABSTRACT

Argillaceous rocks and associated graywacke of the Matanuska formation, of Late Cretaceous age, are exposed in much of the Matanuska Valley. At the confluence of the Matanuska and Kings Rivers, and on the Matanuska River about 3 miles west of Sutton, there are deposits of argillaceous shale of the Matanuska formation that are possible sources of raw material for haydite. Clays and shales that are a suitable raw material for haydite must bloat when heated, produce a glassy phase viscous enough to trap a gas, and contain a material that will evolve a gas at or slightly above the temperature at which the glassy phase is produced. Bloating tests of the argillaceous material from the Kings River and Sutton areas indicate that the shale meets these qualifications and is a good source of raw material for haydite. Large reserves are available, and both localities are close to transportation, fuel, and a market.

North of Lawing, along The Alaska Railroad and the Seward-Anchorage highway, interfingering argillite, slate, and graywacke of probable Mesozoic age crop out. Bloating tests of the argillite indicate that it is a suitable source for haydite raw material.

GENERAL INTRODUCTION

The present large demand for construction materials and their high cost have emphasized the need for local supplies of lightweight aggregates in Alaska. The high cost of transportation precludes shipping such low-cost bulky products into the State; likewise the development of suitable deposits of raw materials in Alaska that are not easily accessible to rail or highway transportation probably would be uneconomical.

Several raw or processed materials, including haydite, pumice, perlite, and diatomite, may be used as lightweight aggregates. "Haydite" is the commercial term applied to a vesicular, lightweight, expanded product, similar to coal cinders, that results from the controlled heating of suitable clays or argillaceous rocks in a rotary kiln to temperatures generally between 1,000° and 1,300°C. The term is synonymous with the terms "expanded shale" and "expanded clay."

From 1946 to 1949 pumice was mined on Augustine Island and shipped to Anchorage for the manufacture of lightweight building blocks. This material is at present (1952) being mined at Geographic Harbor in Katmai National Monument and shipped to Anchorage for the same purpose. As far as is known no other lightweight aggregates are being produced in Alaska.

Haydite produced in Alaska could be used to make lightweight concrete blocks. It might also be used as a high-strength lightweight aggregate in structural concretes; the use of such concretes in some structures in the United States has resulted in considerable savings in more expensive materials, particularly structural steel. Haydite has greater compressive strength, lower water absorption, and better particle shape than pumice. For these reasons it would generally be a more favorable concrete aggregate. Most concretes using pumice, however, have better insulation value than those using haydite (U. S. Housing and Home Finance Agency, 1949, p. 21, 25). The choice of aggregate, therefore, would depend largely on the specifications of the concrete required.

Two reports are combined here to describe three areas in which haydite raw materials have been found. The report on the Kings River and Sutton areas is the result of a special investigation made by the U. S. Geological Survey to study the argillaceous rocks in these areas and to determine their suitability for the manufacture of haydite. The report on the Lawing area is based on a brief examination and sampling undertaken after U. S. Bureau of Mines tests of a sample from the area showed promising results.

HAYDITE RAW MATERIAL (BLACK SHALE) IN THE KINGS RIVER AND SUTTON AREAS OF THE MATANUSKA VALLEY, ALASKA

By Richard A. Eckhart

INTRODUCTION

LOCATION OF AREA

Both the Kings River and Sutton areas are in the valley of the Matanuska River, which flows into Knik Arm, in south-central Alaska (fig. 9). One area is near the mouth of Kings River, about 67 miles northeast of Anchorage via the Glenn Highway. The other is between Sutton and Moose Creek, near mile 16 (measured from Matanuska) on the Sutton Subdivision of The Alaska Railroad.

PREVIOUS INVESTIGATIONS

The areas here described are near the coal deposits in the Matanuska Valley. Considerable work has been done by the Geological Survey in this region, primarily in connection with coal investigations. Mendenhall (1900, p. 265–300) gave the first general geologic and geographic description of the valley after making a traverse from Cook Inlet to the Tanana River in 1898. In 1905, Martin (1906) made a reconnaissance study of the coal in part of the valley. Since that time, the area of coal deposition and adjacent regions has been studied by numerous workers (see Capps, 1940, p. 68–86).

The haydite potentiality of the shale in the Kings River area was first recognized by the Anchorage Sand and Gravel Co. Early in 1950, this company sent samples of the rock to Mr. W. G. Bauer, consulting engineer, Seattle, Wash., for testing. Mr. Bauer reported that the samples were suitable haydite raw material, and a company called Basic Building Products, Inc., was then formed in Anchorage to undertake the development of the deposit.

In July 1950, G. O. Gates of the U. S. Geological Survey briefly investigated the geology of the areas here described. He recognized the similarity of the shale in the Sutton area to that in the Kings River area, and recommended that the former be sampled and tested to determine its suitability for the manufacture of haydite. Later in the summer of 1950 the Bureau of Mines sampled the shale in the Kings

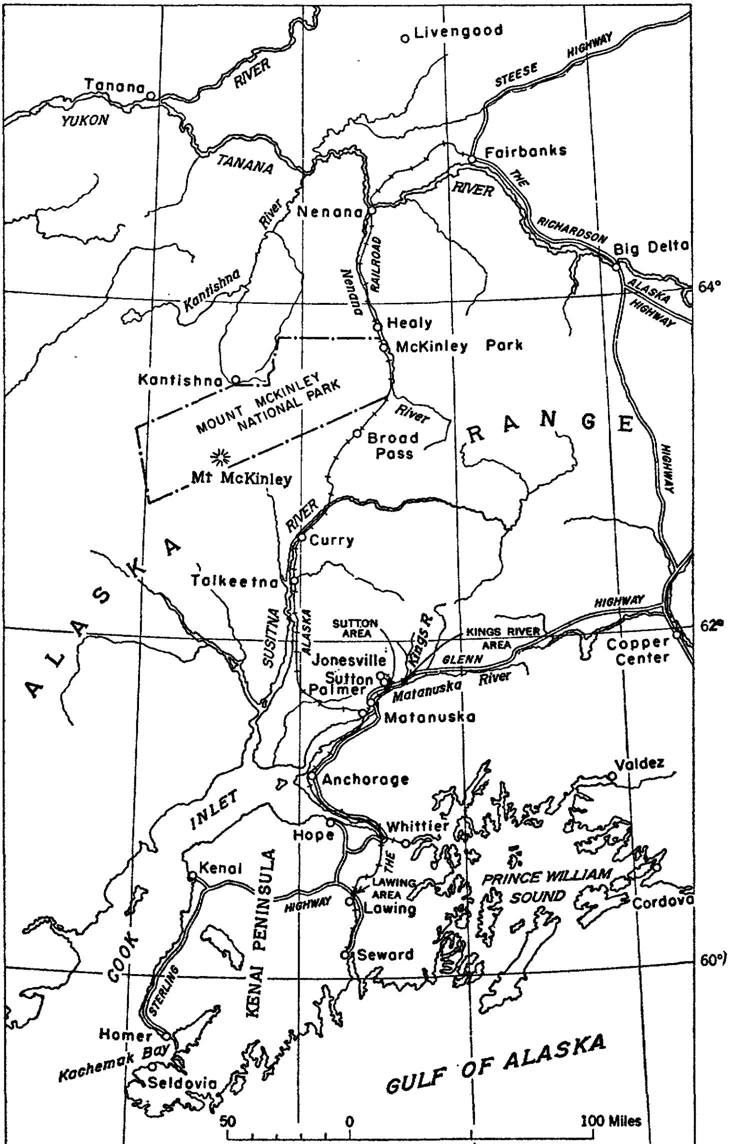


FIGURE 9.—Index map of south-central Alaska showing locations of deposits of haydite raw material.

River and Sutton areas and subsequently ran tests on these samples (Rutledge, F. A., 1953). Results of the tests are included in this report.

PRESENT INVESTIGATION

During August 1951 a party of the U.S. Geological Survey examined the Kings River and Sutton areas to determine the distribution, structure, lithologic characteristics, and accessibility of the argillaceous rocks in each locality. A detailed topographic and geologic map (pl. 7) of the Kings River area was made by planetable and alidade methods. The geology in the Sutton area was plotted on a base map compiled by the Topographic Division, U.S. Geological Survey (pl. 8).

GEOGRAPHY

The valley of the Matanuska River is about 5 miles wide and lies between roughly parallel eastward-trending mountain fronts. The valley is bordered by the Talkeetna Mountains to the north and the Chugach Mountains to the south. Within the valley are rounded hills, some of which attain altitudes of 3,500 feet above the level of the gravel flats in the floor of the valley. The Mantanuska River is about 85 miles long and has a drainage basin of about 1,000 square miles (Martin and Katz, 1912, p. 10).

The Glenn Highway, extending from Anchorage to the Richardson Highway near Glennallen, follows the north side of the valley. Most of the south side of the valley is inaccessible except on foot. A spur line of The Alaska Railroad, called the Sutton Subdivision, extends from the main line at Matanuska to Moose Creek and Jonesville, serving the valley's coal-mining industry.

The Kings River area as referred to in this report includes about one-fourth of a square mile at the confluence of the Matanuska and Kings Rivers. The latter, which heads in the Talkeetna Mountains, borders the area on the north, whereas the Matanuska River forms the south and west boundaries. To the east the area is bordered by low hills forming the divide between the two rivers. The principal topographic feature of the area is a small, northeastward-trending ridge, about three-fourths of a mile long and half a mile wide, which attains an altitude of about 1,060 feet. The remainder of the area consists of a thin strip of gravel flats between the ridge and the rivers. The Glenn Highway parallels the Matanuska River in this locality and crosses the west and south margins of the area.

The Sutton area as referred to in this report includes an area of about six-tenths of a square mile, situated on a conspicuous bend in the Matanuska River about 3 miles west of Sutton. The river lies along the south and most of the east boundary of the area which consists of a depression-marked bench with steep cliffs, up to 225 feet high, facing the river. A low gravel bench locally 700 feet wide lies between the cliff and the river on the south side of the area. The Glenn Highway crosses the northern part of the area, and The Alaska Railroad (Sutton Subdivision) crosses the area at the base of the cliffs.

Vegetation in both the Kings River and Sutton areas includes grasses, devilsclub, alder, cottonwood, birch, and a small amount of spruce.

Although the summers are mild and the winters are moderate, as compared with most of Alaska, year-round quarrying operations in the Kings River and Sutton areas would be affected by the climate. Snowfall during the winter is not heavy, but the many drifts and low temperatures would probably hamper operations.

GEOLOGY

Folded and faulted sedimentary rocks of Mesozoic and Tertiary age comprise the major part of the bedrock in the Matanuska Valley. The sedimentary units are cut by numerous small bodies of intrusive rocks of acidic and basic composition. On the north the sedimentary units are bordered by granitic rocks of the western Talkeetna Mountains, sedimentary rocks of Mesozoic age, and volcanic rocks of the eastern Talkeetna Mountains. On the south they are bordered by the metamorphic and granitic rocks of the Chugach Mountains. General structural trends within the valley are oriented in a northeasterly or easterly direction. Most geologic boundaries of the valley are marked by zones of faulting.

MATANUSKA FORMATION

The argillaceous rocks and associated graywacke in the Sutton and Kings River areas are part of the Matanuska formation. This formation has a wide distribution in the Matanuska Valley (fig. 10), cropping out in irregular areas and belts extending from a few miles below the mouth of Moose Creek eastward to the headwaters of Caribou Creek (Capps, 1940, p. 77). As described by Martin and Katz (1912, p. 34–36), the Matanuska formation consists essentially of dark shale and greenish-gray graywacke with a subordinate amount of conglomerate. On Granite Creek, where the most complete section known is exposed, the formation has a thickness of at least 4,000 feet of which the lower half is almost all shale and the upper half consists of alternating graywacke and shale, the graywacke predominating (Martin and Katz, 1912, p. 34–35).

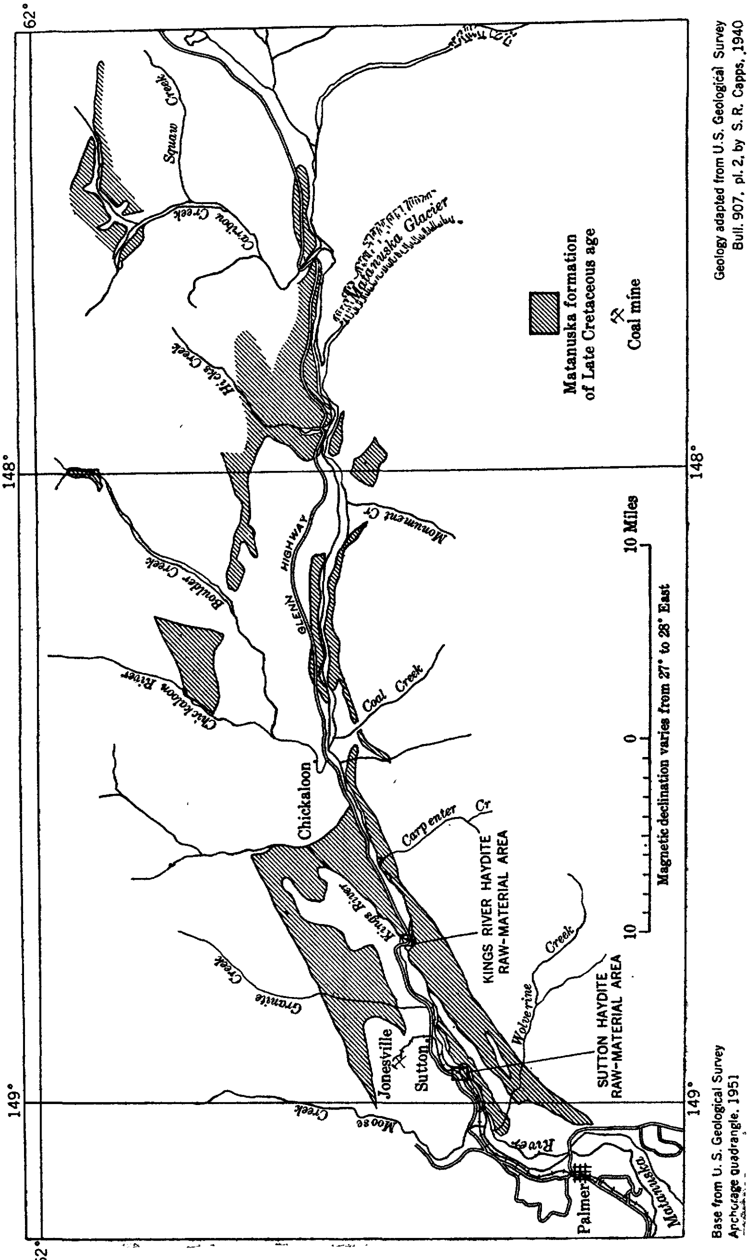


FIGURE 10.—Geologic map showing distribution of the Matanuska formation in the Matanuska Valley.

The base of the formation has not been observed, but it probably rests unconformably upon an erosion surface that truncates rocks ranging in age from Early Jurassic to Early Cretaceous. The Matanuska formation is unconformably overlain by coal-bearing rocks of Tertiary age. *Inoceramus* and other fossils have been collected from the shale and graywacke of the Matanuska formation. On the basis of these, the formation is definitely assigned to the Upper Cretaceous (Capps, 1927, p. 37–40).

KINGS RIVER AREA

The Matanuska formation is believed to underlie the ridge and gravel flats comprising the Kings River area. Although exposures are not plentiful, outcrops examined indicate that the ridge may be divided into two major units on the basis of lithologic characteristics. One unit underlies the northern third of the ridge and consists largely of shale. The other underlies the remaining portion of the ridge and consists of interbedded graywacke and shale (pl. 7).

The shale is almost continuously exposed from the road cut about 1,000 feet south of the Kings River bridge, northeast along the Kings River. Along the south side of the river it is exposed in a steep cliff (pl. 9*A*), but at the northeast end of the map area and beyond, it is concealed by river gravel. A few small exposures suggest that the shale underlies the vegetation and soil at higher elevations in the northern part of the ridge.

The shale is black, rather hard, and massive; jointing is common. Locally the shale contains a few thin beds and lenses of graywacke that are rarely more than a few feet thick. No graywacke, however, was observed in the shale exposed between the road cut and point *Z* (pl. 7) on the Kings River. Owing to the lack of bedding in this exposure the thickness of the grit-free portion of the unit is unknown. The thickness of the entire shale unit likewise could not be determined because of the lack of bedding, the large amount of shearing and faulting, and the generally indefinite location of its contact with the graywacke to the south. The stratigraphy of the Matanuska formation, described by Martin and Katz (1912, p. 34–35), suggests that the shale unit in the Kings River area is near the base of the formation, but no direct evidence of the sequence in this area was noted.

The petrographic character of the shale was studied in some detail, as this material is of primary interest as a source of haydite. Thin sections prepared from specimens collected at the north end of the road cut show that the rock consists of clay and very fine subangular mineral fragments. The clay is probably illite. This identification is based on a comparison of stain-test reactions of the clay with known clay and the results of differential thermal analyses. The mineral fragments are largely quartz and feldspar, with subordinate amounts of muscovite, biotite, chlorite, epidote, pyrite and (or) marcasite, amphibole and (or) pyroxene, and possibly opal. The presence of organic matter in the shale was determined by differential thermal analyses and the loss of color due to heating during the analyses. The feldspar includes plagioclase and probably orthoclase. Calcite was identified in only one thin section. Its presence may be due either to calcite stringers that locally cut the shale or to small limy nodules. Such nodules occur in the rock at the northeast corner of the map area.

The southern two-thirds of the ridge is underlain by interbedded graywacke and shale with graywacke predominating. Two distinct graywacke zones containing very little interbedded shale are exposed south of the main shale units. In the road cut a thin band of shale separates these zones, and their contacts are marked by vertical or nearly vertical faults. Several exposures of graywacke near the highest elevation on the ridge suggest that these zones may be continuous across the ridge. The outcrop on the south end of the ridge (pl. 7) consists of intimately interbedded shale and graywacke in about equal proportions.

The graywacke is dark greenish gray, fine grained, and well cemented. A thin section of a specimen collected at the road cut shows that the rock is composed of poorly sorted and sized angular to subangular fragments. These fragments consist largely of quartz and feldspar with subordinate amounts of muscovite, calcite, chlorite, rock fragments, biotite, epidote, zoisite, clinozoisite and apatite, in order of decreasing abundance. The feldspar includes plagioclase (largely oligoclase), orthoclase, microcline, and perthite, with the first two minerals being most abundant. Much of the orthoclase shows alteration to sericite and clay, whereas the oligoclase is very fresh. Quartz fragments are fractured and strained. Rock fragments appear to represent andesite and (or) basalt lava flows or dike rocks. Most of the calcite occurs as irregular masses filling the interstices between allogenic grains, but some of it may be detrital. A cement of sericite, clay, and chlorite is probably the principal bond between the constituent fragments of the graywacke, although some of the calcite contributes to the cementation.

Locally the graywacke contains small lenses of conglomerate. The conglomerate consists of well-rounded quartz, granite, chert, greenstone, and quartzite cobbles, up to 4 inches across, in a graywacke matrix. The matrix is shaly in some places. In the easternmost outcrop mapped along the highway, the conglomerate contains limestone fragments set in a calcareous graywacke matrix.

Individual beds of graywacke average between 2½ to 3 feet in thickness, and the thickest is about 5 feet. In most exposures, shale layers in the graywacke zones are several feet or less in thickness. This shale is black, rather soft, and thinly laminated. Joints are generally lacking. Mineralogically the shale is similar to that described above.

The section along line *A–A′* in plate 7 shows the structure in the western part of the Kings River area where exposures are abundant enough to warrant an interpretation. The attitudes of the strata south of the main shale unit suggest an anticlinal structure whose axis trends roughly northeastward. Although this structure is not well exposed, it is believed to be faulted along or near its axis. This is suggested by the fact that what may be the westward extension of the same fold appears in the graywacke and shale that form the cliff on the west bank of the Matanuska River. As observed from the Glenn Highway, the anticline exposed in the west bank appears to be faulted and sheared along its axis. No data were obtained concerning movement along the fault. The strata on the north flank of this structure dip moderately northward. The attitude of the shale along section *A–A′* is unknown as no bedding was observed. Farther east, along the Kings River (point *Z* in pl. 7), several graywacke layers in the shale dip steeply southward, but the westward projection of this attitude would be subject to question.

A great amount of shearing and faulting has taken place in the graywacke and shale. Not all the fault and shear zones are shown in plate 7, and, also, for the sake of simplicity shear zones are shown as faults. Slickensides and grooves are abundant along the faults, and their surfaces are locally coated with calcite. Movement along the zones is believed to be largely horizontal, although at some places a vertical displacement of 2 or 3 feet was observed.

Slickensides and grooves on the vertical fault between the shale and graywacke in the road cut indicate that movement has been horizontal, but no evidence was found as to the direction and amount of displacement. The eastward extension of this fault was not found.

A well-defined joint system, striking northeastward and dipping 40°–70° N., was observed in the shale between the road cut and point *Z* (pl. 7) along the Kings River. In shale exposures farther up the river, Martin and Katz (1912, p. 36) found that the jointing is perpendicular to the bedding and to a minor set of joints. They believe that the minor joints are also perpendicular to the bedding.

SUTTON AREA

The Matanuska formation probably forms the bedrock of the Sutton area, although exposures are found only in the cliffs along the railroad. The formation there consists of interbedded black shale and graywacke, with individual beds ranging from less than a foot to about 4 feet in thickness. Both the shale and graywacke are about the same in lithologic character as that in the Kings River area. There are, however, zones in the formation in the Sutton area in which either shale or graywacke predominate. Because of the possible economic value of the shale it seemed desirable to map these zones as distinct units. The stratigraphic section in the Sutton area is, therefore, divided on the basis of lithologic characteristics into 10 units, arbitrarily designated as units A through J in descending order (pl. 8).

Units A through F represent a normal stratigraphic sequence. Units G through J may include part of the overlying units, but the lack of marker beds and the presence of several faults with unknown displacements precludes such a correlation. Quaternary deposits unconformably overlie all the units.

Unit A crops out at the north end of the cliff along the railroad. Its northern extent is concealed by unconsolidated Quaternary deposits. The unit is largely black shale with an estimated 10 percent interbedded graywacke. A few thin layers of dark siltstone and gritty shale, less than 2 feet thick, also occur in the unit. The shale is finely laminated for the most part, and rather soft. It is cut by numerous thin calcite stringers and locally contains subrounded calcareous nodules up to about 4 inches in diameter which give the shale a conglomeratic appearance from a distance. The unit is cut by two sets of joints that occur in the black shale of unit A. These strike about N. 15° E. and dip about 75° NW. and 40° SE. The top of the unit is not exposed. It has a thickness of more than 490 feet, and is conformably underlain on the south by unit B.

Unit B is estimated to consist of about 50 percent black shale and 50 percent graywacke, the 2 rock types being interbedded in layers averaging between 2 to 3 feet in thickness. The shale has the same appearance as that in unit A; the graywacke contains numerous black shale fragments and streaks up to about 2 inches long. The unit has a thickness of 230 feet and is conformably underlain by unit C.

Unit C consists of graywacke with an estimated 10 percent interbedded black shale. Both rock types are similar to those in units A and B. The unit has a thickness of 700 feet and is conformably underlain by unit D.

Unit D is similar to unit A, as it consists of black shale with an estimated 10 percent interbedded graywacke and siltstone. Some of the clastic material occurs in small irregular masses within the shale. The thickness of this unit is 230 feet. It is conformably underlain by unit E.

Unit E is similar to unit C, as it consists of graywacke with an estimated 10 percent interbedded black shale. This unit has a thickness of 160 feet and is conformably underlain by unit F.

Unit F consists of black shale free of any interbedded graywacke or siltstone (pl. 9*B*). The unit, however, contains numerous thin impure limestone layers, less than a foot thick, which form resistant layers in the shale.

The calcareous beds are estimated to compose less than 10 percent of the unit. The limestone is fine grained and blue black and weathers to a dark brown. Impurities include small angular fragments of quartz, chert, feldspar, mica, chlorite, clinozoisite, and apatite. A thin section shows forms having circular cross sections that may be radiolaria. Unit F has a thickness of more than 360 feet. The base of the unit is not exposed.

Unit G consists of interbedded black shale and graywacke, in about equal amounts. Layers of each rock type average 3 to 4 feet in thickness. The stratigraphic position and thickness of the unit are unknown, as neither the base nor the top of the unit is exposed. Its lateral extent is believed to be limited on the east and west by faulting.

Unit H consists of graywacke and appears to be free of black shale. The graywacke is similar to that in the units described above. Neither the base nor the top of the unit is exposed. The lateral extent of the unit is limited by faulting.

Unit I is similar to units A and D, as it consists of black shale with an estimated 10 percent interbedded graywacke. The eastern extent of the unit is limited by a fault which according to F. F. Barnes (oral communication) has displaced this unit and unit J southward. Unit I may be the stratigraphic equivalent of unit D. Unit I has a thickness of more than 240 feet, and is conformably underlain by unit J. The top of the unit is not exposed.

Unit J consists of graywacke with an estimated 10 percent black shale. This unit is similar lithologically to units C and E, and it may be that the sequence formed by units I and J is the stratigraphic equivalent of the sequence formed by units D and E. Unit J has a thickness of more than 240 feet. The base of the unit was not observed.

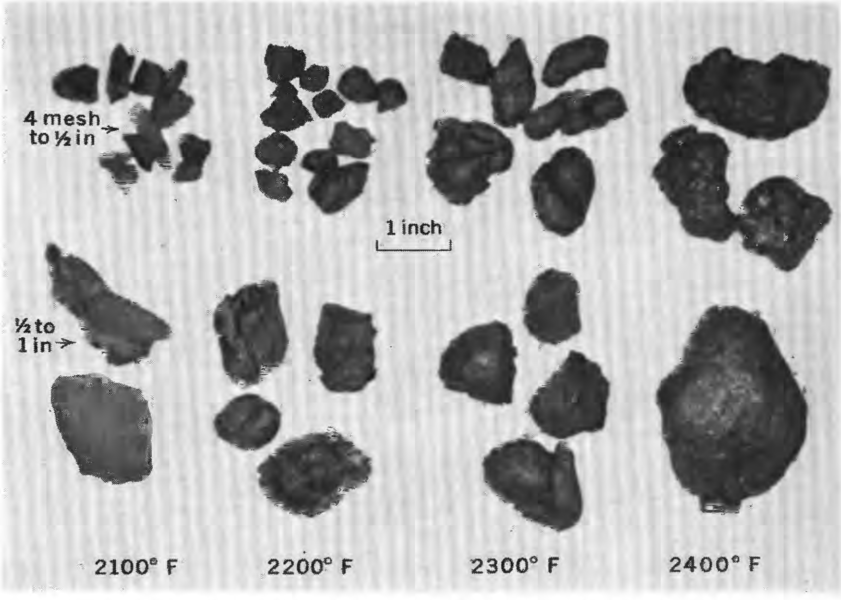
The section along line *A–A′* in plate 8 shows that the Sutton area is underlain by a homoclinal succession of steeply northward-dipping strata. Beds in this structure strike N. 80°–85° E. and dip 78°–88°

A. CLIFF OVERLOOKING KINGS RIVER

B. BLACK SHALE OF UNIT F AT SUTTON AREA

A. HAYDITE MADE FROM A SHALE SAMPLE FROM KINGS RIVER AREA

Bloating temperature was 1,052°C



B. CHANGES IN ARGILLITE SAMPLES WITHIN BLOATING RANGE

N. Bedding is very distinct, although locally it is slightly contorted. The homoclinal structure is cut by numerous faults and shear zones. Most of the surfaces along which movement has taken place are coated with calcite. Not all the faults and shears observed are shown in plate 8. The most noticeable fault is a small thrust which is exposed in the cliff along the east side of the area. It strikes roughly west, dips about 10° S., and has a horizontal displacement of about 6 feet.

SURFICIAL DEPOSITS

Gravel of the Matanuska River and Kings River makes up the Quaternary surficial deposits of the Kings River area. The gravel, which rests unconformably upon the Matanuska formation includes silt, sand, cobbles, and boulders from most of the various rock types found in the Matanuska Valley.

Quaternary deposits consisting mostly of river gravel and loess unconformably overlie the Matanuska formation in the Sutton area. Locally, the loess is up to 10 feet thick. At several places the alluvium may be of glacial origin.

FACTORS AFFECTING DEVELOPMENT

PROPERTIES OF LIGHTWEIGHT AGGREGATE

Standard specifications for lightweight aggregates for concrete, including haydite, have been adopted by the American Society for Testing Materials (1950, p. 720–722). Both chemical and physical tests are necessary to determine the suitability of a particular material. In the absence of such tests, some of the generally desirable properties of lightweight aggregates (Conley and others, 1948, p. 7–8) are described below. This list may serve as a guide to evaluate the shale in the Sutton and Kings River areas. The following properties pertain to a lightweight aggregate to be used in concrete, but most of them also would apply to aggregate used in building blocks:

Lightweight.—The aggregate should not weigh more than half as much as the standard aggregate it replaces. Because rock or gravel aggregates have a bulk density of approximately 100 pounds per cubic foot, the ideal light aggregate should have a bulk density of less than 50 pounds per cubic foot.

High strength.—The individual particles of the aggregate should be as strong as possible. Concrete with a strong aggregate will require less cement than one with a weaker aggregate, thus resulting in savings of cost and weight.

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Well-rounded particles.—The ideal aggregate should have well-rounded, preferably spherical, surfaces. This quality promotes good workability.

Low water absorption.—The individual particles should have closed pores; otherwise, water from the concrete mix will fill the pores, thus dehydrating the concrete and giving a poor set. High absorption may be compensated to some extent by presoaking the aggregate.

Uniform particle-size gradation.—The aggregate must be composed of a range of sizes, including a sufficient quantity of fine-grained particles. This size gradation promotes workability.

Chemical inertness.—The aggregate should not contain compounds that would tend to react with the cement and affect its setting.

Low production cost.—The production cost of the lightweight aggregate is the ultimate factor that determines its acceptability, for the aggregate must compete with other lightweight aggregates and heavy aggregates such as sand and gravel. This means that the raw material must be easily mined, located near markets and a source of fuel, and processed with a minimum of technological difficulty. Although their production costs are higher, lightweight aggregates may favorably compete with heavy aggregates if the initial extra production costs are offset by one of the following factors: a saving in weight that permits elimination of some reinforcing steel, use of lighter weight forms which results in reduction of labor costs, or the attainment of better thermal and sound insulation qualities.

BLOATING TESTS

The conditions and results of tests made by the U. S. Bureau of Mines on samples of argillaceous material collected by the bureau from the Kings River and Sutton areas are shown in tables 1, 2, 3 and 4. The tests were run at the Bureau of Mines' Electrotechnical Laboratory, Norris, Tenn. (Rutledge, 1953).

For the stationary-kiln tests, the samples were crushed to pass an 8-mesh sieve, and small briquets, approximately one-half inch by 1 inch by 2 inches, were formed by hand-tamping dampened particles into a mold. The briquets were artificially dried for about 12 hours at 100°C, or air-dried for several days before firing.

A laboratory kiln was heated to 1,150°C and a series of samples inserted on a silicon carbide slab. Sufficient time was allowed for the kiln to come to equilibrium after loading, and the samples were held at the maximum temperature for 15 minutes before removing for visual inspection. The kiln temperature for other heats was then adjusted upward or downward, in steps of 50°C, as indicated by the condition of the specimens. A sufficient number of heats were run to indicate the bloating range and optimum bloating temperature of the material.

TABLE 1.—*Results of stationary-kiln bloating tests on samples from Kings River area*

Sample	Temperature (°C)	Bloating results			Remarks [1]
		Poor	Fair	Good	
3	1, 100	------	X	------	Temperature too low.
	1, 150	------	------	X	
	1, 200	------	X	------	Temperature too high.
4	1, 100	------	X	------	Temperature too low.
	1, 150	------	------	X	
	1, 200	------	X	------	Temperature too high.
5	1, 100	------	X	------	Temperature too low.
	1, 150	------	------	X	
	1, 200	------	X	------	Temperature too high.
6	1, 100	------	X	------	Temperature too low.
	1, 150	------	------	X	
	1, 200	------	X	------	Temperature too high.
7	1, 100	X	------	------	
	1, 150	X	------	------	
	1, 200	X	------	------	
8	1, 100	X	------	------	
	1, 150	X	------	------	
	1, 200	X	------	------	
9	1, 100	X	------	------	
	1, 150	------	X	------	
	1, 200	------	X	------	

[1] See pl. 7 for locations of samples 3–8. Location of sample 9 is described on p. 54.

TABLE 2.—*Results of stationary-kiln bloating tests on shale samples from Sutton area*

Sample	Temperature (°C)	Bloating results			Remarks	Locations of samples [1]
		Poor	Fair	Good		
53	1, 100	X	------	------	------------	Sample length 80 ft. Cut normal to strike and dip of beds adjacent to railroad.
	1, 150	------	------	X	------------	
	1, 200	X	------	------	Bloated [2] ----	
54	1, 100	X	------	------	------------	Sample length 50 ft. Cut approximately normal to strike and dip of beds near upper contact adjacent to railroad.
	1, 150	------	------	X	------------	
	1, 200	X	------	------	Bloated [2] ----	

[1] Channel samples spaced 400 feet apart along strike of beds in unit F (see pl. 8).
[2] Large cellular structural bubbles ⅛ to ¼ inch in diameter.

The product of the rotary-kiln test of shale from the Kings River area had fine uniformly spaced pores, indicating excellent vesicular structure. It showed an expansion of 100 percent and tended to clinker and form logs in the kiln. The temperature of the kiln, which was difficult to control or read closer than 50°C, was slightly high for best results.

TABLE 3.—*Specifications of raw material and product in rotary-kiln test of shale from Kings River area*

Particle size:	
Minimum ....mesh..	4
Maximum ....in..	1
Weight of feed:	
Cu ft ....lb..	94½
Total ....lb..	280
Weight of product:	
Cu ft (<⅜ in diameter) ....lb..	43
Total ....lb..	215
Bulk specific gravity:	
Fine	0.89
Coarse	0.84
Bulk specific gravity, saturated surface, dry basis:	
Fine	1.29
Coarse	1.12
Apparent specific gravity:	
Fine	1.66
Coarse	1.16
Absorption:	
Fine ....percent..	33.2
Coarse ....percent..	44.5

TABLE 4.—*Kiln-operation conditions for rotary-kiln test of shale from Kings River area*

Time (a.m.)	Temperature (°C)	Remarks
10:10		Start fire.
10:40	1,190	Off to load.
10:45		Loaded and fired.
11:20	1,200	Off.

Screen analysis of the product after crushing to minus ⅜-inch size is shown by the following tabulation:

Mesh	Percent
−2 +4	19.0
−4 +6	15.5
−6 +8	11.1
−8 +18	23.4
−18 +30	5.0
−30 +70	9.0
−70 +100	3.0
−100	14.0

Mr. A. F. Waldron, president, Basic Building Products, Inc., has kindly made available to the author a report of tests on Kings River shale samples by W. G. Bauer (written communication, Oct. 23, 1951). After preliminary tests on the samples, Mr. Bauer made five followup firings on one of the samples to determine optimum heating rates, temperatures, kiln atmospheric conditions, bloating range, glaze coating, heat spalling, and sticking tendencies. All firings were made in a gas-fired rotary kiln. Firing schedules were held to those employed in commercial-size kilns using similar raw material. The kiln was correlated to a large rotary kiln used in a commercial plant that treated similar raw material and, therefore, Mr. Bauer believes the test results can be duplicated on a commercial scale.

The tests showed that the maximum temperature required for bloating is 1,980°F (about 1,080°C). The weight of the product was judged to be about 42 pounds per cubic foot when the full range of required sizes is obtained. It was necessary to crush the kiln product in order to obtain the required fines.

Summarizing the results of his tests, Mr. Bauer states,

the shale forms a good ceramic glaze or coating which is harder than steel at a temperature of 1,870°F and which takes place just prior to bloating. The bloating range is not wide, although the pores become too large if the material is held at the maximum temperature too long. Some sticking occurs in the kiln, especially when particle size range of the feed is large and much fine material is present. There are operational and equipment-design techniques, however, to overcome this to a large extent.

Mr. Bauer concludes that the shale sample produces

a haydite-equivalent product and there are no special processing difficulties. There are definite indications that considerable further improvement in uniformity, strength, and absorption can be achieved in a correctly designed commercial installation.

DISCUSSION OF BLOATING

Grim and Bradley (1940); Austin, Nunes, and Sullivan (1942); Conley and others (1948); Riley (1951); and other investigators have done valuable work on the bloating properties of clay and shale. The following discussion is based largely on the works cited above.

The mechanisms by which some clay and shale bloat when heated are not fully understood. There appears to be no direct correlation between chemical composition and bloating properties. Probably the mineralogic composition governing the chemical combinations in the raw material is of basic importance. It is known, however, that the following conditions must be fulfilled to produce a bloat (Conley and others 1948, p. 10): (1), The material, when heated sufficiently, must produce a pyroplastic or glassy phase which is developed by fluxes to the point of incipient fusion. The viscosity of the phase must be great enough to trap a gas. (2), Some constituent or constituents of the material must evolve a gas at or slightly above the temperature at which the pyroplastic phase is produced. The gas is then trapped by the viscous melt and produces a cellular structure. The gas must not be readily soluble in the melt.

By plotting a large number of chemical analyses of bloating and nonbloating clay, Riley (1951) was able to define the limits of bloating on a composition diagram. He states,

The "area of bloating" on this diagram showed desirable compositions of clays which satisfy the first necessary condition for bloating. As a test of the area of bloating, silica and alumina were added to nonbloating clays to give them compositions conforming to points within this area. When fired these mixtures bloated.

It should be emphasized that the bloating would not have taken place if the second condition for bloating was not satisfied; that is, if gas-producing constituents were not present.

The impurities of some clay and shale are potential sources of gas for bloating. Some of these are carbonaceous matter, iron compounds, carbonates, and sulfates. Conley and others (1948, p. 98) state that, "these need be present only in small proportions (1–2 percent) to effect extensive bloating." Riley (1951, p. 121), in a study of a shale from Minnesota, demonstrated that hematite, pyrite, and dolomite are the only accessory minerals that dissociated and produced gas at the proper temperature.

Conley and others (1948, p. 30) concluded from their studies that if the combined impurities of clay or shale are less than 5 percent, the rock is almost certainly a nonbloating type. However, Grim and Bradley (1940) bloated purified samples of illite and montmorillonite clay. Riley (1951, p. 124) also bloated a purified sample of illite.

Many samples of nonbloating clay and shale may be made to bloat by using admixtures such as sulfur, carbon, hydrocarbons, and sulfates; some clay and shale that is nonbloating at normal temperatures will bloat at temperatures higher than those now employed commercially (1,000°–1,300°C). The use of admixtures or higher kiln temperatures, however, increases production costs.

Table 5 shows the chemical composition of a shale sample collected at the north end of the road cut at the Kings River area. It is interesting to note that this composition falls within the "area of bloating" on Riley's composition diagram. The analysis shows no sulfur in the sample, but pyrite and (or) marcasite (both are iron sulfides) were observed in a thin section of the same sample and identified by microchemical tests, suggesting that they are sparsely disseminated in the shale but were not present in the portion of the sample anaylzed.

Precise quantitative mineralogic analyses of the Kings River and Sutton haydite raw materials are not available, but the chemical analysis, thin-section studies, and stain tests indicate that the shale from the Kings River area has the following mineral composition: 50–60 percent quartz and feldspar, 10–15 percent illite, 15–20 percent mica, 5–10 percent calcite, opal, chlorite, epidote and other ferromagnesian minerals, 1 percent or less pyrite and (or) marcasite and organic matter. The shale of unit F at the Sutton area is believed to have roughly the same chemical and mineral composition.

The bloated shale from the Kings River area has a cellular structure with a sealed outer surface (pl. 10*A*). A thin section shows that the cell walls consist of glass with many embedded fragments of unaltered quartz and feldspar. Within the cells are a few small fragments of quartz, feldspar, and an unidentified mineral that occurs in isotropic and anisotropic grains and has a negative relief. Refractive indices of this mineral are unknown, as specimens of the bloated shale are not available. It is possibly a glass, but it is unlike the glass of the cell walls.

From the thin-section study it appears that quartz and feldspar are the only minerals in the shale that survive the bloating process, and that glass and an unidentified mineral, which may also be glass or an artificial mineral, are the only new substances formed in the kiln.

TABLE 5.—*Chemical analysis of shale sample from Kings River area*

[Analysis by H. M. Hyman, U. S. Geological Survey]

Chemical constituent	Percent	Chemical constituent	Percent
SiO_2	60.17	H_2O+	3.78
Al_2O_3	16.02	TiO_2	.73
Fe_2O_3	1.29	CO_2	.77
FeO	5.14	P_2O_5	.29
MgO	3.17	S	.00
CaO	2.33	MnO	.15
Na_2O	2.22		
K_2O	2.72	Total	[1] 99.42
H_2O-	0.64		

[1] Sample contains some organic matter.

The quartz and feldspar apparently play no part in the bloating process. The other constituents of the shale behave as follows: Some melt to a glassy phase; others are dissolved in the glassy phase once it has formed, as the temperature increases; still others evolve a gas or gases which vesiculate the glass. Which minerals participate in each of these functions is unknown, but the physical and chemical characteristics of some of the minerals present are at least suggestive.

Purified samples of illite were bloated experimentally by Grim and Bradley (1940, p. 8–10). They found that at a temperature of 850°C, illite has lost all of its water; from 850° to 1,300°C, spinel forms from illite; and at 1,100°C, mullite forms from illite. No attempt was made to explain the bloating phenomenon. It is possible, however, that a dissociation of Fe_2O_3 in the spinel takes place, providing oxygen as the gas for bloating. Hydrogen and water vapor could not be responsible for the bloating because water is lost at a temperature much lower than that needed to produce the pyroplastic phase. The shale from the Kings River area and the shale comprising unit F in the Sutton area are estimated to contain 10–15 percent illite, but no mullite or spinel were observed in the haydite from the Kings River area. It is probable that the reaction of illite with the other ingredients of this rock does not yield mullite or a spinel and, therefore, whether or not the illite could be responsible for the bloating gas is not known.

Biotite when heated to temperatures around 1,200°C yielded leucite, Fe_2O_3, and spinel (Grim and Bradley, 1940, p. 9). As with illite, a dissociation of the Fe_2O_3 and the spinel might produce oxygen. The argillaceous rocks in the Kings River and Sutton areas contain biotite but, as stated above, the haydite does not contain spinel and no leucite was identified. Therefore, it is not known whether or not biotite could be responsible for the bloating gas. Biotite also contains water, but all of it would probably be driven off by the time the bloating temperature is reached.

It has been demonstrated that pyrite will evolve gas, probably sulfur dioxide, at a temperature within the bloating range. Marcasite should do the same. The shale in the areas here described probably contains less than 1 percent iron sulfide minerals. If gas-producing constituents must be present in the amount of 1–2 percent, it is considered unlikely that iron sulfide minerals are of major significance in the production of gas in these rocks during bloating. This conclusion is based on the lack of sulfur in the chemical analysis shown in table 5. More analyses are needed, however, to support this conclusion.

The Sutton and Kings River haydite raw materials contain a small amount of calcite. This mineral may be responsible, at least in part, for the bloating. It dissociates at temperatures below those at which bloating takes place, but Riley (1951, p. 127) believes that calcite may react with other ingredients to form compounds that dissociate at temperatures high enough for bloating. He suggests cancrinite and potassium carbonate as possible intermediate compounds. Part of the calcite may also act as a flux in the formation of the glassy phase.

It is possible that no single mineral constituent of the argillaceous rocks in the Kings River and Sutton areas is the sole gas-producing agent, but, rather, that the pyroplastic phase and bloating gas or gases are the result of reactions largely among illite, mica, ferromagnesian minerals, and calcite. Intensive laboratory study would be needed to explain fully the bloating of the shale. One valuable contribution would be quantitative analyses of the gas or gases evolved during bloating.

PROPERTIES DESIRED OF HAYDITE RAW MATERIAL

The following properties are listed by Conley and others (1948, p. 76, 81–82) as desirable in raw material that will bloat in a rotary kiln. These properties have been briefly applied to the shale unit in the Kings River area and unit F in the Sutton area. It is assumed that all the material in these units bloats under the same conditions and with the same results as obtained in bloating tests on samples.

Short bloating time.—Fast-bloating material requires less time in the kiln and, therefore, the kiln may be operated at a greater capacity. Tests by the U. S. Bureau of Mines (table 4) and Mr. Bauer indicate that the Kings River shale possesses this property. Samples of the Sutton shale were not tested in the rotary kiln.

Wide range between temperature of bloating and temperature of agglomerating.—Materials that agglomerate at temperatures near those at which they bloat cause serious kiln operating difficulties. Not only does this property cause the material to stick to the kiln lining and to form "logs," but it impedes the movement of the feed through the kiln and may prevent part of the feed from receiving the proper amount of heat. Generally, the finer the particle size of the feed, the greater the tendency to agglomerate. There are, however, remedies for this problem. Both the U. S. Bureau of Mines (Rutledge, 1953) and Mr. Bauer observed that the shale from the Kings River area showed some tendency to agglomerate. They do not, however, consider this tendency to be serious. As the shale from the Sutton area was not tested in the rotary kiln, it is not known whether or not the shale possesses this property.

Low bloating temperature.—Because of fuel costs, a material that bloats at temperatures greater than about 1,300°C in the rotary kiln is generally considered undesirable as a raw material unless there are other strong factors in its favor. Tests indicate the shale from the Kings River area bloats in the rotary kiln at temperatures less than 1,200° C and that the shale from the Sutton area also bloats below that temperature in a stationary kiln. It is believed that the shale from the Sutton area would bloat at 1,200°C or less in a rotary kiln.

Presence of free carbon.—A substantial amount of free carbon is desirable. The exothermal reaction of its combination with oxygen reduces the amount of fuel required for bloating. Differential thermal analyses indicate an exothermic reaction in the shale from the Kings River area up to about 400°C.

OTHER ECONOMIC FACTORS

Coal from the mine at Jonesville is a potential source of fuel for a haydite plant using shale from either the Kings River area or the Sutton area.

The part of the shale unit at the Kings River area exposed from the road cut to point *Z* (pl. 7) along the Kings River appears free of graywacke and, therefore, is considered the best source of haydite raw material in the Kings River area. The remainder of the exposed part of the unit contains 10 percent or less graywacke. The effect this impurity would have on the bloating of the shale is unknown. It occurs in beds up to several feet thick and, therefore, much of it might be excluded from the raw material in quarrying. If included in the feed and passed through the kiln the graywacke would not bloat and probably would only add weight to the product.

The interbedded graywacke-and-shale unit in the Kings River area is not considered a potential source of haydite material, for samples of the shale (7 and 8, table 1) did not bloat satisfactorily in stationary-kiln tests. A shale sample (9, table 1) from the easternmost outcrop along the highway also did not bloat satisfactorily (Rutledge, 1953). The large proportion of graywacke and the fact that none of the shale beds observed are thick enough for mining are other factors that rule out this unit as a source of haydite raw material.

The shale from the Kings River area is easily accessible from the Glenn Highway, and enough working room exists for quarrying operations (pl. 7). Much of the shale unit is free of overburden, and where present the overburden probably does not exceed 3 feet in thickness. Locally considerable brush and timber would have to be stripped before quarrying.

Unit F is considered the best potential source of haydite raw material in the Sutton area. The limestone that occurs in thin beds within the unit is apparently not a contaminating constituent, for it undoubtedly made up parts of the samples collected and successfully bloated by the Bureau of Mines (see location column in table 2). Unit F is easily accessible from the railroad and enough working room is available for quarrying operations (pl. 8). Very little soil and brush cover the western part of the unit on the side of the bench. At the top of the bench, Quaternary material as much as 10 feet thick covers the shale, but this is true in only a small area which is not included in the reserves.

Units D and I are other possible sources of haydite shale in the Sutton area, but lack of room for quarrying between these units and the railroad is a disadvantage. Their graywacke content is also an undesirable feature. According to F. A. Rutledge (oral communication) a sample of unit A tested by the Bureau of Mines did not bloat satisfactorily.

RESERVES

All calculations of reserves are based on the assumption that the specific gravity of the black shale is 2.65; that is, 12 cubic feet of ore weighs 1 short ton.

Reserves in the Kings River area were calculated only for the main shale unit. Calculations were made by constructing five vertical sections across the unit, oriented S. 35° E. An altitude of 560 feet was assumed as the bottom of each section, as this is the approximate altitude of the base of the cliff along the Kings River and, therefore, probably the lowest practical working limit in quarrying. The south contact of the shale is assumed to be vertical. Graywacke layers in the shale are included in the reserves. These layers probably comprise less than 10 percent of the unit. The inferred reserves are 34,900,000 short tons.

Reserves of the graywacke-free shale exposed from the road cut to point *Z* (pl. 7) along the Kings River are estimated to comprise 20 percent of the total reserves of the unit, or 7,980,000 short tons.

Reserves in the Sutton area were calculated only for unit F. Calculations were made by constructing four vertical sections across the unit, oriented N. 40° W. An altitude of 425 feet was assumed as the bottom of each section. The part of the unit that underlies Quaternary material at the top of the bench is not included in the reserves. The indicated reserves are considered to be 24,900,000 short tons.

MINING CLAIMS

At the time this investigation was made, several mining claims were held by A. F. Waldron and Jack Harrison of Anchorage on part of the shale unit in the Kings River area. The claim marker shown in plate 7 represents the northwest corner of discovery No. 1 claim held by these men. No other claims were known to be staked on this unit.

According to the U.S. Bureau of Land Management no mining claims had been staked on or near the bedrock exposures in the Sutton area as of August 1951.

OTHER POTENTIAL SOURCES OF HAYDITE RAW MATERIALS

Other potential sources of haydite shale in the Matanuska formation are suggested by extensive exposures along the highway between Kings River and Chickaloon and along the highway between Hicks Creek and Caribou Creek. The latter locality, however, has the disadvantage of being a considerable distance from a market and a source of fuel. The former area might compare favorably with the Kings River area. A sample of shale collected between Kings River and Chickaloon at mile 71.5 yielded a satisfactory bloat in stationary-kiln tests by the Bureau of Mines (Rutledge, 1953).

A sample of shale of the Matanuska formation exposed near the north abutment of the Matanuska River bridge, near Palmer (see fig. 10) was collected and tested in a stationary kiln by the Bureau of Mines (Rutledge, 1953). The sample did not bloat satisfactorily.

CONCLUSIONS

The graywacke-free portion of the shale unit in the Kings River area and unit F in the Sutton area appear to be the best sources of haydite raw material considered in this report. These units have relatively large accessible reserves and, if all the shale bloats as successfully as tests on samples indicate, a large tonnage of raw material is available. Both localities are favorably located with respect to year-round rail and truck transportation, source of fuel, and market.

In view of the limited exposures at each locality, additional methods of exploration, such as trenching, drilling, or sampling are needed to determine the reserves of shale in the Kings River and Sutton areas suitable for the manufacture of haydite.

HAYDITE RAW MATERIAL (BLOATING ARGILLITE) NEAR LAWING, ALASKA

By GEORGE PLAFKER

INTRODUCTION

The argillite described in this report is 2½ miles north of Lawing along both The Alaska Railroad and the Seward-Anchorage highway (fig. 9). The area is 89 miles by rail from Anchorage and 25½ miles from Seward. In 1952 the writer collected a grab sample of the argillite exposed in a highway cut at this locality and submitted it to the U. S. Bureau of Mines for a bloating test. On the strength of promising results from the initial test, the area was revisited in 1953 for 1 day and the argillite exposed in road cuts for a distance of 1,800 feet north of the outlet of Lower Trail Lake was mapped and systematically sampled.

The U. S. Bureau of Public Roads made available a highway line-change map (scale 1:1,200) which was used as a base for this work.

GEOLOGY

GENERAL DESCRIPTION

The argillite sampled near Lawing is part of a thick series of slightly metamorphosed clastic sedimentary rocks of probable Mesozoic age that underlies a large part of the Kenai Mountains. Bedrock in the Lawing area consists almost entirely of well-indurated dark gray to black thinly bedded argillite and slate interfingering in varying proportions with lenticular beds of fine- to medium-grained hard massive graywacke. Interstratified with the argillaceous beds and graywacke, but in very minor amounts, are lenticular bodies of conglomerate less than 10 feet thick. In a few places the argillaceous beds and graywacke are cut by veinlets and irregular masses of quartz.

In general, structures in the area are characterized by closely appressed isoclinal folds which strike approximately north and are, in part, overturned to the west. Everywhere, jointing is well developed in the graywacke, and an imperfect cleavage is present in the fine-grained rock. Although local deviations are numerous, cleavage as a rule is parallel to the bedding.

All low-lying parts of the Kenai Peninsula were glaciated during the Pleistocene epoch. Unconsolidated deposits of glacial and postglacial age are found overlying bedrock throughout the area.

LAWING ARGILLITE DEPOSIT

Lithologic characteristics.—The argillite mapped on figure 11 is a hard black fine-grained rock with a smooth silky sheen on fresh surfaces. The rock breaks along bedding planes into thin slabs with irregular sharp edges. No mappable beds of sandstone or other impurities were found in the deposit.

In thin sections the rocks are seen to consist of approximately 25–50 percent silt-sized particles less than 1 mm in diameter, embedded in a very fine grained dark-colored matrix. Clear angular fragments of quartz and plagioclase feldspar predominate, with subordinate amounts of detrital muscovite flakes. The flakes of mica generally lie parallel to the bedding and, in combination with chlorite, give the rock its characteristic platy parting. Sections cut normal to the stratification show an aggregate positive elongation due to parallelism of the mica flakes. A very finely laminated structure is caused by streaks and minute lenticles of carbonaceous material and magnetite, which clouds and masks the fine-grained matrix minerals.

The matrix consists largely of clay-sized particles predominantly of a colorless flaky mineral with very low birefringence and relatively high refractive index ($\beta = 1.58$). The X-ray diffraction pattern indicates that the clay-sized minerals are predominantly chlorite with subordinate amounts of illite. This probably represents incipient recrystallization to chlorite of original clay minerals, due to low-grade regional metamorphism.

Accessory minerals are abundant magnetite and scant epidote, garnet, tourmaline, carbonate, zircon, and sphene. Iron sulfides are conspicuously absent.

Structure.—Both the bedding and cleavage in the argillite deposit strike uniformly north to N. 15° E. and dip about 55° E. to southeast. The road cuts of the Seward-Anchorage highway are excavated essentially along bedding planes in the argillite. A single fault trending N. 45° W., and dipping 43° SW. cuts the argillite. It is filled with 2–3 inches of quartz. Thin quartz stringers less than 1 inch thick occur in 1 area (fig. 11) as a swarm of conjugate sets trending N. 60° W. and N. 80° W., and dipping 60° NE. and 33° S., respectively.

Unconsolidated deposits.—Steep slopes in the vicinity of the deposit are mantled by a veneer of loose argillite slide rock. Most of the material along The Alaska Railroad is fill derived from outside the mapped area.

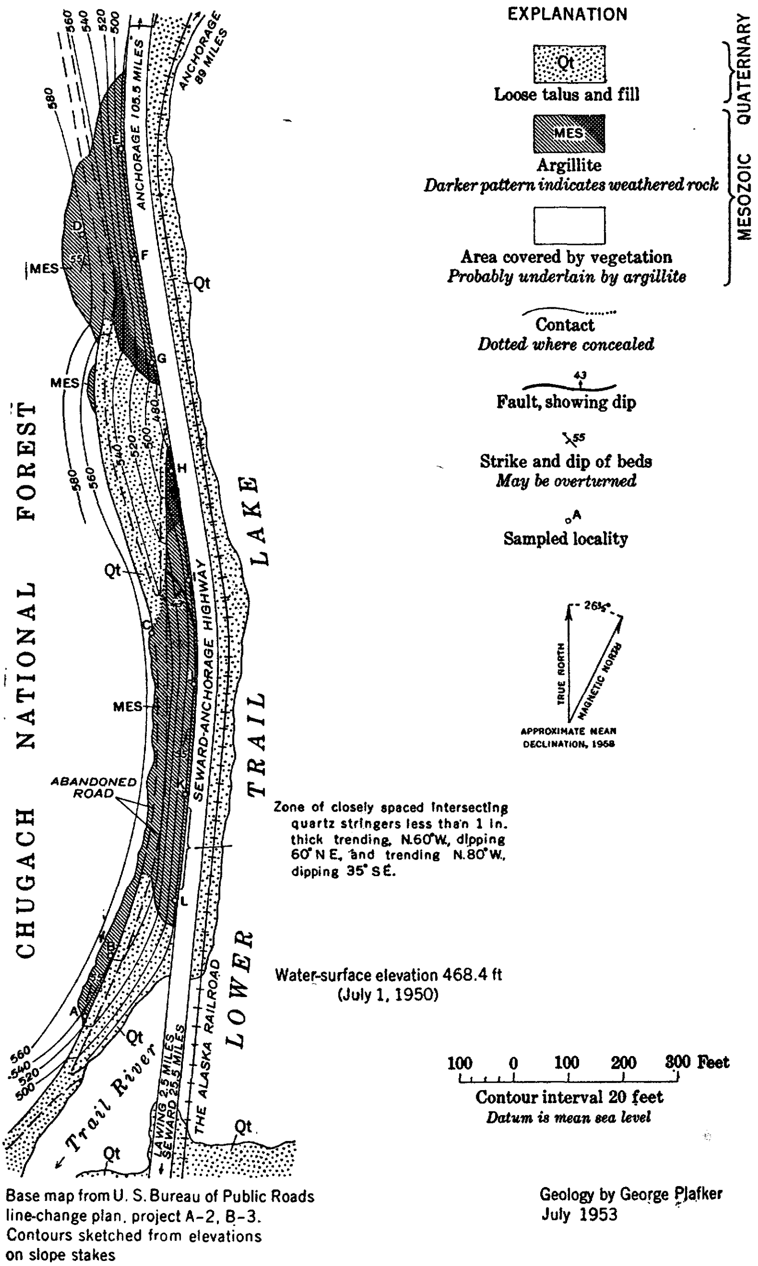

FIGURE 11.—Geologic map of argillite deposit near Lawing.

BLOATING CHARACTERISTICS

Twelve samples of argillite were taken at the localities shown on figure 11. These were paired to give a total of six samples that were submitted to the U. S. Bureau of Mines Electrotechnical Laboratory at Norris, Tenn., for bloating tests. The absorption and weight for each of the paired samples at regular temperature intervals in the bloating range are tabulated in table 6; averages of these figures for the six samples are shown graphically as figure 12.

The tests were made in a stationary kiln using a fast fire (15-minute bloat). Because only small samples were available, the tabulated weight figures were obtained by using the water displacement method to obtain apparent specific gravity. These weight figures are approximately 15 pounds per cubic foot higher than would be obtained by the usual commercial container method described by the American Society for Testing Materials (1955, p. 1241–1242). The estimated average weights that would be obtained in the bloating range by using the container method are also shown graphically in figure 12.

TABLE 6.—*Water absorption and weight of six argillite samples*

[Symbols: C, coarse (½–1 in); F, fine (4 mesh–½ in)]

Temperature (°F)	Sample											
	AB		IJ		CH		FG		DE		KL	
	C	F	C	F	C	F	C	F	C	F	C	F
	Water absorption (lbs per cu ft of argillite)											
2,000	4	5	3	3	4	3	3	4	3	4	3	3
2,100	7	8	7	7	7	8	7	6	6	6	6	7
2,200	10	12	11	10	17	12	13	14	9	9	12	11
2,300	13	13	18	23	32	23	26	24	11	11	16	12
2,400	14	17	26	27	31	27	36	45	24	23	19	19
	Weight of argillite (lbs per cu ft)											
2,000	160	160	159	157	159	142	159	158	160	155	158	160
2,100	133	133	125	127	127	119	125	123	133	120	129	129
2,200	56	66	49	51	44	55	59	56	45	44	62	59
2,300	32	37	21	29	25	27	24	25	36	24	25	30
2,400	25	30	21	24	27	28	25	19	28	26	23	27

The six samples tested showed little or no differences in bloating properties. The change in particle shape through the bloating range for a typical sample is shown as plate 10. The samples reach the 60-pound, or floating, stage at a temperature ranging from 2,175°F to 2,200°F. At 2,000°F the particle surface has a dull light-brown-

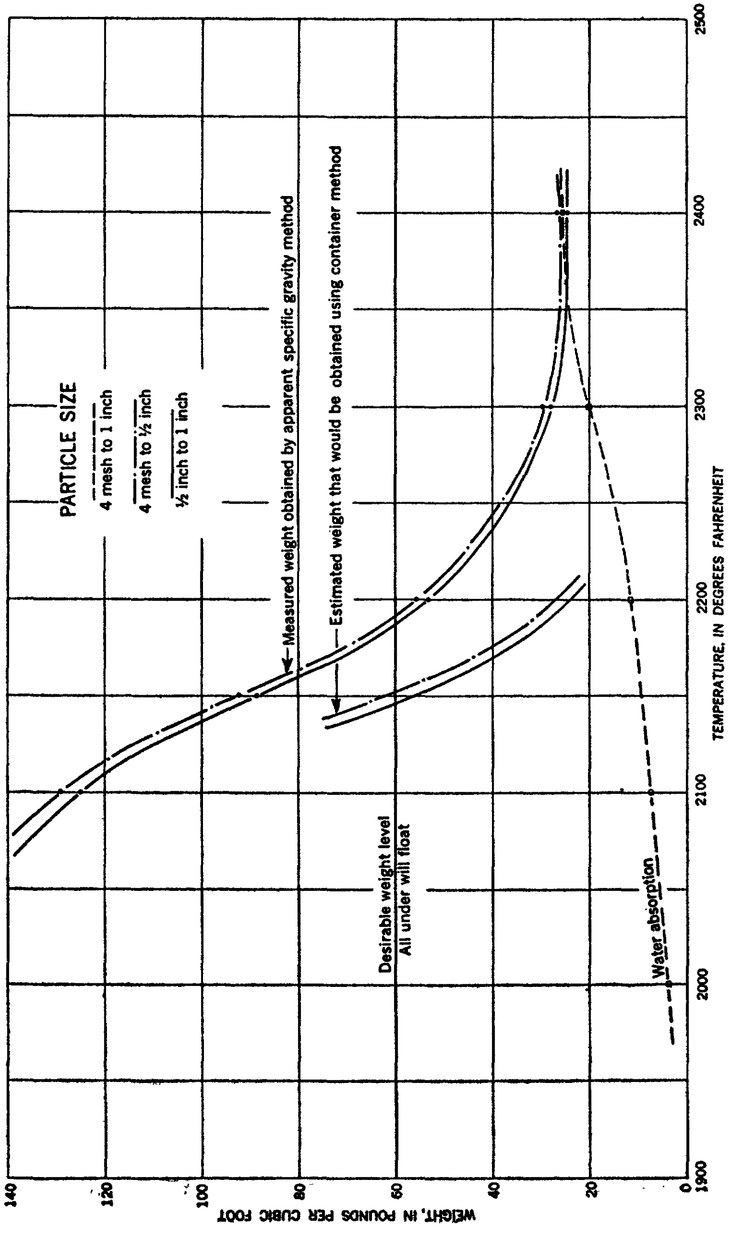

FIGURE 12.—Average water absorption and weight of six argillite samples from Lawing area.

ish-orange glazed surface harder than steel and a soft dark-gray interior with a dull luster. Thin sections show that the average grain size is smaller than in the natural material, and that there is some glass formed in the outer 0.6 mm. Magnetite near the surface has been oxidized to blood-red hematite. The interior of the grains appears to be essentially unchanged except that the muscovite has been destroyed. X-ray diffraction gives a pattern for quartz and plagioclase indicating that the matrix has changed to glass.

At 2,100°F the particle surface is a glazed light brown. The centers of the particles are hard and dark red, with a faint vitreous luster. Slight spreading of the bedding planes is noticeable in the particles, and a few elongate holes are visible. In thin section the interior of the particle is seen to be shot through with long narrow openings as much as 0.1 mm wide that are parallel to bedding planes. The interior is almost entirely glass (refractive index=1.54) except for the silt-sized quartz and plagioclase and a few scattered specks of magnetite.

By 2,200°F, the specimens have a moderate-brown outer surface with a medium-dark-gray interior. All of the material is now harder than steel. Thin sections show a definite cellular structure with discrete holes slightly elongated parallel to the bedding and as much as 3.5 mm in the longer dimension. X-ray diffraction patterns show that only quartz remains in a matrix of glass. In thin section the quartz grains have irregular margins due to reaction with the glass matrix.

By 2,300°F, the particles assume a dusty moderate-brown cellular, and a brownish-gray interior. The material is now highly cellular, with thin vitreous brownish-gray glass membranes between the vesicles. A thin section shows that the glass is almost black and is still charged with quartz particles. The vesicle walls are now extremely thin, and many of them have been distended to the point of rupture, forming large aggregates of vesicles or small connections between the vesicles. At this point the strength of the particles begins to drop markedly and the water absorption increases correspondingly.

The results of the bloating test were summarized by T. A. Kleinfelter (1954, written communication), Chief of the Raw Materials Branch for the U. S. Bureau of Mines at Norris, Tenn., as follows:

With all of them the best all-round bloat occurs at 2,300°F. By 2,400°F, all of them had reached the over-bloated stage, and would probably cause trouble in the kiln by sticking and thus forming rings and ball-like masses in the kiln. On the whole this gives us a bloating or firing range of not over 150°F for good operating conditions, which is a bit on the narrow side.

However, with a well-controlled kiln, and especially if the firing procedure in the length of time the material is subjected to the top heats is worked out properly a good first class product should result. The material from 2,200° through 2,300°F is quite good, shows no signs of stickiness and has good strength.

RESERVES

The lack of adequate topographic and geologic control uphill from the road-cut exposures described in table 1 makes impossible anything but a general statement on the amount of argillite in the area. Relatively pure argillite with less than 1 percent quartz as thin stringers makes up all of the deposit shown on figure 11. This section represents a stratigraphic interval of 375 feet (assuming a constant 55° dip), and is exposed along the strike for 1,750 feet and for a vertical distance of more than 100 feet. The uniform character of the argillite indicates that similar material may also be present uphill from the road cuts. This material could be readily sampled from shallow pits dug to bedrock or by means of low-angle core holes drilled into the hillside from the highway or from the abandoned road above the highway.

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