Geology and Cement Raw Materials of the Windy Creek Area Alaska

GEOLOGICAL SURVEY BULLETIN 1039-D

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By R. M. MOXHAM, R. A. ECKHART, *and* E. H. COBB

INVESTIGATIONS OF CONSTRUCTION MATERIALS IN ALASKA

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Description of pre-Devonian to Late Cretaceous geology, including three limestone deposits

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CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGY AND CEMENT RAW MATERIALS OF THE WINDY CREEK AREA, ALASKA

By R. M. Moxham, R. A. Eckhart, and E. H. Cobb

ABSTRACT

The Windy Creek area, on the south flank of the Alaska Range, is within a geosynclinal belt that contains clastic and calcareous rocks ranging in age from pre-Devonian to Late Cretaceous. The major geologic structures in the area are oriented parallel to the regional easterly to northeasterly trend of the Alaska Range. Steeply dipping folded strata of Mesozoic age occupy the southern part of the area and have been downthrown against Devonian rocks on the north by a major fault zone that crosses the center of the area.

Two limestone deposits of Devonian and Devonian(?) age are of adequate size and chemical quality for cement-manufacturing purposes. They are located 7 and 11 miles, respectively, west of the Alaska Railroad. A third limestone deposit of large size but of inferior quality lies 1 mile west of the railroad. Argillaceous rocks, which occur in both the pre-Devonian, Devonian, and Jurassic(?) systems, are found in many parts of the area. Chert of Triassic age, possibly of some value as a high-silica component, occurs along the Alaska Railroad near Windy station.

INTRODUCTION

All the portland cement and other limestone products used by the construction industry in Alaska at the present time (1956) are imported from the continental United States. Interest has been shown in the possibility of local manufacture of these materials, particularly since the surge in construction that began in the early 1940's.

As the principal population centers and the most highly developed transportation systems are in south-central Alaska, the search for suitable raw materials for cement production has been concentrated in this region, especially in the Alaska Railroad belt. Three general localities in the railroad belt have received consideration as possible sources of cement materials (Waring, 1947; Rutledge and others, 1953; and Moxham and Eckhart, 1956), but the Windy Creek area, in the northern part of the belt, has been studied in more detail than the other potential sites, largely because of the proximity of limestone to the railroad.

The purpose of this report is to describe the principal geologic features of the Windy Creek area, with particular emphasis on those rock types of potential value in the manufacture of portland cement.

LOCATION OF AREA

The Windy Creek area is on the south flank of the Alaska Range, in south-central Alaska (fig. 13). The area lies across the Alaska Railroad and is in part within the southeastern limits of Mount McKinley National Park. Mount McKinley is about 70 miles southwest of the center of the area described in this report.

The limits of the Windy Creek area have been arbitrarily chosen; they are represented by lat 63°22′ and 63°29′30″ and long 148° 48′ and 149°18′ (pl. 11). About 145 square miles are included in this area.

PREVIOUS INVESTIGATIONS

In 1898, G. H. Eldridge (1900) and Robert Muldrow of the U. S. Geological Survey ascended Susitna River and its tributary drainage, crossed to Jack River at the east limit of the Windy Creek area, and traversed downstream along Jack and Nenana Rivers to Yanert Fork. Their brief descriptions of the rocks exposed along these streams were the first recorded geological observations made in the Windy Creek area.

The first systematic topographic and geologic survey was made in 1913. A party, under the direction of F. H. Moffit (1915), worked westward along the south flank of the Alaska Range from the Delta River country to Jack River, and mapped the geology on a reconnaissance scale.

In 1930 the geologic mapping of the south side of the Alaska Range was extended to the West Fork of Chulitna River by Capps (1932) who completed reconnaissance coverage of the area described in the present report.

The following year, Waring (1947) briefly examined and sampled four exposures of limestone between Little Windy Creek and the Alaska Railroad, west of Windy station, in connection with an investigation of nonmetallic minerals in the Alaska Railroad belt.

PRESENT INVESTIGATION

The present study of the Windy Creek area, for the purpose of investigating potential cement raw materials, began in 1947. In that year Cobb mapped in detail the limestones between Little Windy Creek and the railroad. Surface samples were collected from

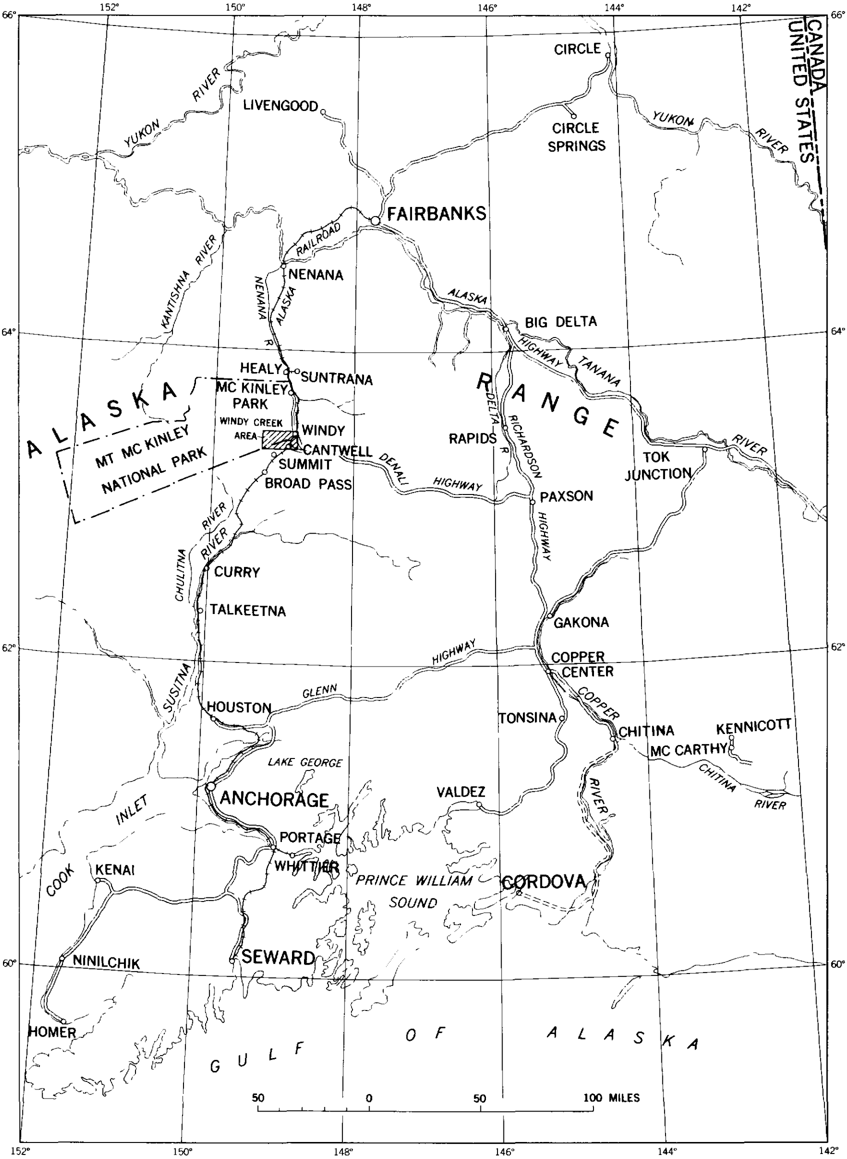

FIGURE 13.—Index map of south-central Alaska showing location of Windy Creek area.

two of the larger, more accessible limestone deposits. R. E. Fellows of the Geological Survey made a brief field investigation in 1949 to integrate coredrilling data, furnished by the U. S. Bureau of Mines, with the geological studies and to sample deposits of argillaceous materials that crop out near the railroad and in the lower Windy Creek basin.

Chemical analyses of the limestone samples and cores made by the Geological Survey and the Bureau of Mines, respectively, in 1947–49 indicated that the principal limestone deposits in the area east of Little Windy Creek are not of uniform chemical character. Although this condition might not preclude the use of restricted parts of the deposits for cement manufacture, it seemed desirable to determine whether other, more suitable limestone deposits exist elsewhere in the Windy Creek area. In July 1950, a brief reconnaissance of the Windy Creek drainage basin west of Little Windy Creek was undertaken, the principal objectives being to locate and sample all limestone bodies of potential commercial size and to sample the more accessible deposits of argillaceous materials. Two limestone deposits of adequate tonnage were mapped and sampled and several deposits of argillaceous materials were investigated. The present bulletin supersedes a brief open-file report describing this investigation (Moxham and others, 1951).

The geological investigations in the Windy Creek area described above were confined to detailed studies of relatively small portions of the eastern part of the area and reconnaissance surveys of the western part. Hence, in 1951, additional fieldwork was undertaken to determine more precisely the location and distribution of potential cement raw materials in the western part of the area, and, insofar as time permitted, to attempt to integrate the previous detailed studies with the areal geology. The fieldwork in 1951 was carried out between May 28 and July 10 by R. M. Moxham and R. A. Eckhart, geologists, and W. A. Bakke and R. A. Wilkens, field assistants. In the brief time available for this work it was possible only to map the major geologic units in reconnaissance fashion, and in many localities it was necessary to supplement direct field observations by photogeologic methods.

ACKNOWLEDGEMENTS

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GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The Windy Creek area includes parts of two physiographic divisions, the Alaska Range and the Broad Pass depression (Wahrhaftig, 1958). West of long 149°10′ W. the crest of the Alaska Range lies just south of the north boundary of the Windy Creek area. East of long 149°10′ W., it lies 1 to 3 miles north of the north boundary of the Windy Creek area. Despite the fact that Mount McKinley, 70 miles to the southwest, rises to 20,300 feet in altitude, the crest of the Alaska Range in the vicinity of the Windy Creek area is generally between 5,000 and 6,500 feet in altitude. The south flank of the Alaska Range is an interlocked mass of rugged peaks, sharp ridges, and U-shaped canyons. The peaks rise to altitudes of 5,000 to 6,000 feet, and the canyon floors range in altitude from 2,500 to 4,000 feet. Local relief is between 2,000 and 3,500 feet. The canyons were occupied by glaciers during the Pleistocene epoch; hence most of them are U-shaped, with flat floors and steep sides, and head in cirques. Locally the floors of the canyons are trenched by narrow steep-walled gorges.

The southeastern part of the mapped area is in the Broad Pass depression, an arcuate lowland 4 to 6 miles wide that lies along the south side of the central part of the Alaska Range. In the Windy Creek area this lowland has an average altitude of about 2,200 feet. A belt of valleys and low passes extends across the south flank of the Alaska Range in a S. 75° W. direction from the north side of the Broad Pass depression near Windy Creek. The line of valleys and passes is eroded along the trace of a great fault (pl. 11). It affords easy access to the more remote limestone deposits of the area.

The entire Windy Creek area is drained by the Nenana River and its tributaries. The Nenana River flows northward to a canyon through which it crosses the Alaska Range to flow into the Tanana River. At the point where it enters the canyon it is joined from the southwest by the Jack River, which flows northward and northeastward through the southeastern and eastern part of the Windy Creek area. The two main tributaries of the Jack River are Windy Creek and Cantwell Creek. Cantwell Creek drains the southern part of the Windy Creek area, including much of the floor of the Broad Pass depression, and a narrow strip along the west margin west of Foggy Pass. Windy Creek and its tributaries drain the largest part of the area, including the limestone deposits.

Windy Creek heads at the crest of the Alaska Range and courses southeastward through a U-shaped trough to its junction with its west fork (hereafter referred to simply as the West Fork) in the central part of the mapped area. The West Fork rises in the extreme northwestern part of the Windy Creek area in a glacial basin at the crest of the range and flows in a southerly and easterly direction through a glacier-scoured valley to its mouth. Beyond its junction with the West Fork, Windy Creek flows in an easterly

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direction across part of the Broad Pass depression to enter the Jack River.

Numerous boulders and a generally steep gradient prevent the use of boats of any kind on Windy Creek and the West Fork. During periods of high water in the spring and immediately after rainstorms in the summer months, Windy Creek below its junction with the West Fork may be difficult to ford on foot. Crossing during most of the rest of the summer, however, can be made without trouble.

CLIMATE

No weather records are kept at any locality in the Windy Creek area, but the data collected by the Civil Aeronautics Administration (U.S. Weather Bureau, 1955) at Summit, a short distance south of the area, give some indication of the climatic conditions that prevail in this region. The average annual temperature at Summit is 25°F with the average for the period June through August being 50°F and for the period December through February 5° F. Total precipitation is about 22 inches; an annual average of 113 inches of snowfall was recorded during the period 1950–54. Freezing temperatures may ordinarily be expected as late as May and as early as August, with the first ice occurring usually in October and the breakup in May.

The average seasonal temperatures in the Windy Creek area, as elsewhere in central Alaska, range widely, from the fifties in summer to the minus tens (°F) in winter. The Alaska Range forms a barrier across the path of the northward flow of Pacific air up the Susitna-Chulitna lowland, and as the moisture-laden air is driven upward, the seaward flank of the range receives an abnormal amount of precipitation. The dissimilar growth of glaciers on opposite flanks of the range reflect the difference in precipitation; those to the south of the crest are larger in size and number. However, the report area and its immediate environs are somewhat anomalous in that the development of glaciers is relatively poor, perhaps owing to the lower average altitude of the crest of the range in this vicinity or to some other local topographic condition that controls the airflow and precipitation.

VEGETATION

Timberline in the Windy Creek area is about 2,800 feet in altitude, so that the growth of timber, mainly spruce and cottonwood, is restricted largely to the lowlands in the southeastern part of the area and to narrow strips along Windy Creek and its principal tributaries. The junction of Windy Creek and the West Fork marks in general the westward extent of timber growth. Beyond this point, and locally above the 2,800-foot altitude, there is some scrubby growth, mainly cottonwood, willow, and alder. Most of the stream valleys below timberline are heavily overgrown with brush and shrubs, mostly willow and alder.

ACCESSIBILITY

The eastern part of the area is accessible by rail and air. Cantwell, in the southeastern part of the area, is 205 miles by rail from Anchorage and 151 miles from Fairbanks. A small airstrip at Cantwell will accommodate single-engine planes. Flagstop airline connection with Anchorage and Fairbanks is available at Summit, 7 miles by road south of Cantwell.

The eastern part of the Windy Creek area is accessible by road from Anchorage and Fairbanks. Two tractor trails give access to the valley of Windy Creek from Cantwell. One extends to the mouth of Windy Creek; the other runs westward to a National Park Service shelter cabin on Windy Creek, about 5 miles above its mouth. The valleys of Windy Creek and the West Fork offer no serious obstacle to tractor travel beyond the trail's end until the headwater gorges are reached.

GENERAL GEOLOGY

The area of this report is in the axial region of the Alaska Range geosyncline, a major arcuate tectonic element in a belt of subsidence that probably has been operative since early Paleozoic time. Sedimentary rocks in the area, predominantly clastic beds deposited in a marine environment, range in age from pre-Devonian to Late Cretaceous and are intruded by and interbedded with andesitic volcanic rocks of probable Triassic age. Granitic batholithic intrusives, sills, and dikes, emplaced during the Paleocene(?) orogeny, cut the sedimentary and volcanic units in the western part of the Windy Creek area.

PRE-DEVONIAN ROCKS

The oldest part of the geologic succession in the area mapped consists of pre-Devonian rocks that crop out on the south flank of the first ridge southwest of the junction of Windy Creek and the West Fork. Red, green, and buff argillite and shale are the predominant rock types and are quite dissimilar in appearance to any other strata observed in the report area.

On the south the pre-Devonian rocks abut the great fault zone that transects the entire Windy Creek area, and are upthrown against Jurassic(?) strata. The brightly colored pre-Devonian strata dip steeply southward, apparently constituting the south limb of an overturned fold, as they give way in a northerly direction to rocks of Devonian age. Evidence from which to determine the structural relationship adjacent to the great fault zone is concealed in the report area by alluvium and by glacial and glaciofluvial deposits. Capps (1932) made observations in the Chulitna River area to the west that led him to conclude that the narrow belt of rocks that include the highly colored argillite and shale immediately adjacent to the fault zone definitely underlie the Devonian rocks. Capps mapped an outcrop of the pre-Devonian rocks along the north side of Foggy Pass in the Windy Creek area, but the present writers have shown only Devonian strata here, owing to the presence of conglomerate that appears to be closely akin to the coarse clastic sediments found in the belt of Devonian east of Foggy Pass. The thickness of the pre-Devonian rocks in the mapped area is about 1,500 feet.

DEVONIAN SYSTEM

Closely folded metamorphosed marine strata of Devonian age crop out in a generally eastward-trending belt across the central part of the Windy Creek area. The rocks consist mainly of argillite, limestone, conglomerate, graywacke, slate, greenstone, and quartzite. The strata are characterized by abrupt lateral and stratigraphic discontinuities, so that in most localities individual beds are neither very thick nor laterally persistent. In the western part of the area the rocks are made up chiefly of conglomerate interbedded with argillite, graywacke, and a little limestone. Conglomerate beds that range from 2 to 60 feet in thickness are found throughout the section. Most of them are dark colored and are composed chiefly of black chert, argillite, and quartz particles, ranging in size from coarse grit to pebbles several inches in diameter, in a siliceous matrix. Toward the east the clastic sediments tend to become finer in texture, limestone becomes more abundant, and some greenstone, tuff, and quartzite are found.

Most of the limestone beds are relatively thin and discontinuous. In a few areas they are as much as 500 feet thick, but the average thickness is probably nearer 50 feet. The limestones are generally gray or, locally, buff on weathered surfaces and black or dark gray where fresh. The rock is mainly very dense and fine grained in texture, although locally it is coarser grained where recrystallized. The calcareous strata have been thoroughly shattered by intense dynamic metamorphic action, and the rock is reticulated by calcite-filled fractures. At most places the original bedding of the limestone is obscured by secondary structural features to such an extent that the rocks are massive.

Argillite is common in the eastern part of the area. The beds are brown to black and are generally thin. In many parts of the area the argillite has been crumpled, sheared, and intricately faulted both as a result of regional metamorphic action and, locally, as a result of stresses along the faults that bound the unit on the north and south.

Fossils are scarce in these strata, except for a few poorly preserved specimens in the limestone beds at several localities. Most of the fossils are sufficiently silicified to become etched in relief on weathered surfaces; very little of the freshly broken rock shows any trace of organic remains. Collections were made at two locations, shown on figure 2. The fossils consist largely of corals but also include stromatoporoids and bryozoa. The collections contain the following forms:

Locality	Collection	Fossil
1	47–ACb–76	*Tryplasma* sp., *Amphipora* sp.
2	50–AMx–101	*Cladopora* sp., pseudamplexoid coral, stromatoporoids.
	50–AMx–102	pseudamplexoid coral.
	50–AMx–103	*Coenites*? sp., unidentified horn coral.
	50–AMx–104	*Cladopora* sp., stromatoporoids.
	50–AMx–105	*Coenites* sp., unidentified bryozoan.

The fossil identifications were made by Jean M. Berdan, of the U. S. Geological Survey, who reports as follows:

Lot 47–ACb–76 differs from the other collections in containing the horn coral *Tryplasma*, which is most abundant in the Silurian but has been reported from the Middle Devonian of Germany (Etheridge, R., Geol. Survey of New South Wales, Mem. 13, p. 44, 1907). This collection also contains a block with different lithology from that containing the horn corals in which there are rodlike objects which appear to be *Amphipora*, a form of stromatoporoid occurring in the Middle and possibly also in the Upper Devonian. The * * * collection * * * was made from talus so that more than one horizon may be represented. Lots 50–AMx–101 through 105 contain horn corals which agree with the subfamily Pseudamplexinae described by Stumm (Geol. Soc. America Mem. 40, p. 47–48, 1949) in possessing subcylindrical corallites with radially arranged septa, no fossula, and a septal dilation which suppresses the dissepiments in the peripheral zone. However, this subfamily is described as containing simple corals only, and some of those in the material at hand appear to be weak faciculate. These corals are associated with the tabulate coral *Cladopora* and with lamellar and encrusting stromatoporoids. Two collections contains a tabulate coral referable to *Coenites* and one an unidentified bryozoan. All these forms range from Silurian through the Middle Devonian but * * * similar material (from this area) has been identified as Middle Devonian, and this is probably the best age assignment possible at present.

FIGURE 14.—Northwestward view across fault zone in Foggy Pass. The trace of the fault is marked by low scarp line in center of photo.

The structure of the rocks of Devonian age is very complex. The strata are intricately folded and faulted, but in general the strike is northeasterly and steep southerly dips predominate.

The southern extent of the Devonian strata, except where they are underlain by the pre-Devonian, is limited by a major fault zone that is perhaps the outstanding structural feature of the Windy Creek area. This zone cuts across the area in a northeasterly direction, following a remarkably straight trend. The trace of the fault is marked by springs, bogs and, locally, low scarps (figs. 14 and 15). The fault probably extends far beyond the limits of the report area, both to the east and to the southwest.

The existence of the fault zone in this area was first noted by Moffit (1915) who mapped a small part of it near Nenana River. Capps (1932) apparently was the first to recognize that the zone probably extended from Anderson Pass, 40 miles west of Cantwell, to Nenana Glacier, 35 miles east of Cantwell. He also pointed out topographic features that suggest its continuation beyond these limits. Geologic mapping in the eastern part of the Alaska Range (Moffit, 1912; 1954) indicates that the fault zone may extend many miles farther to the southeast.

In the Windy Creek area the fault zone probably is vertical or dips steeply to the north, dropping Jurassic(?) and Upper Cretaceous rocks on the south (downthrown) side into contact with Devonian strata on the north (upthrown) side.

FIGURE 15.—Aerial view of northeastern part of Windy Creek area. Limestone deposit 1 is located at *A*. The trace of the major fault zone between Devonian and Mesozoic rocks is discernible between points *B* and *C*.

The northern extent of the Devonian rocks west of Little Windy Creek probably is limited by another nearly vertical fault which has brought them into contact with younger beds of possible Devonian age. In the western part of the area, the line of displacement is clearly marked on the aerial photo (fig. 15) by northeastward- to eastward-oriented drainage, and an alinement of similarly oriented passes extends from a point at least several miles beyond the western limit of mapping eastward almost to the junction of Windy Creek and the West Fork. Eastward from this junction the structural relation is more obscure and the location of the fault between Windy and Little Windy Creeks has accordingly been questioned on figure 2. East of Little Windy Creek the aerial photos show no displacement of the Triassic rocks that presumably overlie the Devonian section, but whether the Devonian rocks are faulted beneath the Triassic is open to question. Indeed, the location of the Devonian-Triassic contact itself is questionable, as noted in the discussion of the Triassic system (p. 80).

Because of the complex folding and faulting, the thickness of the Devonian rocks can only be estimated to be about 3,000 feet.

DEVONIAN(?) SYSTEM

North of, and in fault contact with, the Devonian rocks west of Little Windy Creek is a succession of reddish-weathering, folded and metamorphosed thin-bedded shaly limestone, argillite, graywacke, and shale. This sequence is here referred to as of Devonian(?) age although no fossil evidence of this age has been found. East of Little Windy Creek recognized Devonian rocks are unconformably(?) overlain by sedimentary rocks of Triassic age. On the basis of the lithologic dissimilarity of the reddish-weathering sequence and the Triassic section and of the structural relationship of the reddish-weathering strata to Devonian rocks west of the Windy Creek area, an age designation of Devonian(?) seems most appropriate.

The Devonian(?) rocks crop out in the headwaters of the Windy Creek and the West Fork drainage basins. In contrast to the rocks of the accepted Devonian, the Devonian(?) strata appear to be nearly free of conglomerate and contain a greater percentage of calcareous rocks. The strata consist of closely folded, metamorphosed sedimentary beds, primarily limestone, graywacke, argillite, and shale. These beds, with the exception of the more massive limestones, are generally dark colored where fresh, characteristically weathering to shades of reddish brown. The limestone generally tend to be argillaceous and with one notable exception are thin bedded, locally schistose, strata.

The most impressive lithologic unit of the Devonian(?) strata is a massive limestone that crops out in an eastward-trending belt across the headwaters of the West Fork. It is quite persistent laterally along the strike, extending for at least 20 miles west of the West Fork and two miles eastward. The limestone is blue gray to black, is locally banded, and weathers to a light gray. Most of it is very dense and has a fine-grained texture. In some localities the rock is quite hard and breaks with a conchoidal fracture. Calcite reticulation is abundant.

Although wide variations occur in the attitude of individual beds the limestone body as a whole probably stands nearly vertical. The limestone attains a maximum thickness of about 2,600 feet in the valley of the West Fork; its outcrop thins markedly to the east and somewhat less so to the west.

North of the massive limestone and overlying it are interbedded limestone, argillite, and shale, which dip steeply to the north. Similar rocks, closely folded and faulted but generally dipping steeply to gently southward, lie south of the massive limestone; they probably belong to the same stratigraphic sequence as those north of the massive limestone. If this interpretation is correct, the major structural feature of the Devonian(?) strata in the headwaters of the West Fork is an eastward-trending anticline, although other complex folds are superimposed upon the major structure. The axis of the structure follows the outcrop of the massive limestone so that this geologic unit may represent both limbs of a closely compressed fold.

Only a rough estimate of the thickness of the Devonian(?) rocks can be made, but it appears that as much as 8,000 feet may be present in the western part of the Windy Creek area. The massive limestone is probably about 1,300 feet thick stratigraphically.

TRIASSIC SYSTEM

East of Little Windy Creek, rocks of Triassic age overlie the Devonian. Here the lower part of the Triassic section consists of 1,000 to 2,000 feet of argillite, limestone, conglomerate, chert, greenstone, and slate which strike in a northeasterly to easterly direction and dip steeply both to the north and to the south. The lithology of the lower part of the section is quite similar to the underlying rocks of Devonian age, so that the position of the boundary between the systems is open to question. The location of the boundary shown in plate 11 is based on the evidence of fossil collections 47–ACb–76 and 47–ACb–78 (p. 80) and the predominance of greenstone in the younger system. The stratigraphic and structural relationships of the Triassic rocks with the underlying rocks of

Devonian age are not clear, but the boundary is probably an unconformity.

No Triassic rocks had previously been mapped in this part of the Alaska Range, but they had been seen in adjacent areas. Near the crest of the range north and west of the Windy Creek area Capps recognized greenstone, slate, and chert between known Devonian rocks and overlying Cretaceous rocks, but in the absence of any evidence to the contrary he included them with underlying strata of Devonian age. Limestone of Triassic age interbedded with greenstone and other volcanic rocks has been found elsewhere on the south flank of the range. On the West Fork of Chulitna River, about 20 miles southwest of the Windy Creek area, Ross (1933, p. 298) mapped limestone and argillite of Triassic age which overlie rocks of Permian age, and in the Valdez Creek area, about 40 miles to the east, Moffit (1915, p. 33) found limestone of Triassic age interbedded with greenstone.

Greenstone, chert, and phyllite lie unconformably beneath the Cantwell formation in the headwater of Yanert Fork, northeast of the Windy Creek area. Apparently these rocks are similar in lithology to those that underlie the Cantwell formation west of Nenana River; they are probably Triassic in age (Wahrhaftig, 1958, pl. 4).

In 1947 E. H. Cobb made two collections of fossils from a limestone bed near the west end of the ridge between Bain and Windy Creeks. The identifications given below are by Ralph W. Imlay:

Locality	Collection	Remarks
3	47–ACb–78	Contains the pelecypods *Megalodus*(?) and *Mysidia* which are characteristic of the Upper Triassic.
	47–ACb–79	Contains a belemnite that is definitely Mesozoic but not well enough preserved to identify generically.

TRIASSIC(?) SYSTEM

The foregoing description of Triassic rocks outside of the Windy Creek area indicates that greenstone and other volcanic rocks are common constituents of the Triassic strata. In the area of this report, the narrow belt of predominantly sedimentary rocks of Triassic age is overlain on the north by a thick sequence of andesitic and basaltic greenstone sills and extrusive rocks that occupy the northeastern part of the mapped area and have been designated as Triassic(?) in age. In general they dip to the north at a moderate angle, perhaps averaging 20°–30°.

Altered greenstone extrusive masses interbedded with tuffs crop out in the area west of Cantwell. Their stratigraphic relationship to the Jurassic rocks on the north has not been established, as the bedding of both units appears to be nearly vertical in the contact areas. In the extreme southeastern part of the greenstone outcrop area, some of the flows when viewed from a distance appear to dip gently to the south and to strike northeastward. They are tentatively correlated with the Triassic(?) greenstone that crops out in the northeastern part of the area.

JURASSIC(?) SYSTEM

A belt of steeply dipping metamorphosed sedimentary strata, tentatively assigned a Jurassic(?) age, crops out between the major fault zone that trends northeastward across the central part of the area and the intrusive and volcanic rocks which border the Windy Creek area on the south. In the western part of the area the predominant constituents are argillite and slate, with some conglomerate, which are cut by felsic dikes and sills, although the igneous rocks are not abundant. The slate and argillite are mostly black; the conglomerate is dark brown to black; it is composed chiefly of black chert, dark argillite, and white quartz pebbles set in a dark brown matrix. In the eastern part of the Jurassic(?) belt, the clastic sediments become much coarser with graywacke predominating.

In most of the Windy Creek area the rocks of Jurassic(?) age are cut off on the north by the major fault zone, but in the extreme western part they are overlain by the Upper Cretaceous Cantwell formation. The complexity of the structure in this area obscures the stratigraphic relationship of the rocks of Jurassic(?) age with the Cantwell rocks, but there may be an angular unconformity between the Cantwell formation and the underlying strata, as found on the north side of the Alaska Range (Capps, 1932, p. 269).

In general the Jurassic(?) rocks strike slightly north of east and are closely folded, with steep dips to the north and south.

The total thickness of the Jurassic(?) system on the south side of the central part of the Alaska Range has been estimated to be as much as 5,000 feet (Capps, 1940, p. 111), but in all probability only the upper 4,000 feet is present in the Windy Creek area.

No fossils have been found in the Jurassic(?) rocks in the Windy Creek area, and in the absence of other conclusive evidence the age assignment remains the same as that determined by Capps (1940, p. 111); he based the age of these rocks on a relatively long range correlation with the argillite of known Jurassic age found near the West Fork of the Chulitna River.

CRETACEOUS SYSTEM

CANTWELL FORMATION

The Cantwell formation, a nonmarine sequence of Late Cretaceous age, has a relatively wide distribution on the south side of the Alaska Range in the region southwest of the area of this report. The belt that it occupies, however, narrows to the northeast so that only a small part of the lower Cantwell section, in the western Windy Creek area, represents the easternmost extent of the formation south of the major fault zone. The Cantwell formation in the Windy Creek area consists primarily of dark-colored coarse massive conglomerate and argillite, which are locally cut by sills and dikes varying widely in chemical composition. The conglomerate is composed chiefly of pebbles and cobbles of limestone, argillite, slate, and chert, that range in size to as much as 6 inches in diameter. The general trend of the beds of the Cantwell formation is N. 60°–80°E., and their attitude is nearly vertical.

On the north the rocks of the Cantwell formation are cut off by the major fault zone, and to the south they are underlain by black argillite of Jurassic(?) age. The total thickness of the Cantwell formation in the Windy Creek area probably does not exceed 1,500 feet.

No fossils were found in the rocks of the Cantwell formation in this area. Ten miles east of the mouth of Jack River, Moffit (1915, p. 48) collected fossil plants of Eocene age from shale and sandstone interbedded with conglomerate, which he considered to be part of the Cantwell formation. However, it is recognized that the Cantwell formation on the north side of the range is definitely older than coal-bearing sediments in that area that also are of Eocene age. In 1936, Capps collected fossil plants from rocks of the Cantwell formation on the north side of the range which were determined to be of Cretaceous age. Although the few fossil collections that have been made from the Cantwell formation present conflicting evidence, an age assignment of Late Cretaceous appears to be the most acceptable at the present time.

QUATERNARY SYSTEM

A detailed description of the Quaternary geology of the central part of the Alaska range is given by Wahrhaftig (1958).

The Pleistocene epoch marked the inception of widespread and intense glaciation of the Alaska Range, culminating in the accumulation of such an extent of glacial ice that only the higher peaks of the range protruded. The gradual wane from the last advance has continued into Recent time, although the remaining glaciers in the Windy Creek area are small in comparison to the impressive ice flows that occupy the valleys draining the range farther west.

The glaciers not only modified the preglacial landforms; they also laid down deposits of glacial and glaciofluvial material in the lowland of the lower Windy Creek drainage basin. At their western limit the deposits are probably only a few feet thick. Eastward the glacial deposits thicken markedly, attaining a thickness of about 60 feet in the Windy Creek Valley 3 miles downstream from the mouth of the West Fork. The full thickness of the glacial deposits, resting on Jurassic(?) bedrock, is well exposed at this locality.

In the extreme eastern part of the mapped area, about 1 mile west of the Alaska Railroad, travertine is being deposited by spring water emanating from the fault zone that limits the Devonian rocks on the south.

IGNEOUS ROCKS

The Triassic(?) greenstone has been described in the previous discussion of the bedded rocks (p. 80).

In the northwestern part of the area the Devonian(?) strata have been intruded by an igneous complex ranging in composition from medium-grained diorite to an ophitic gabbro, with the more mafic compositions predominating. The contact with the Devonian(?) rocks in most places is inclined steeply to the north. In the peripheral areas the intruded beds are cut by dikes and sills, mostly felsic, and the host rock is locally silicified.

In all probability more than one period of intrusion was involved, but the principal igneous activity of batholithic magnitude probably took place in post-Cantwell, that is, Late Cretaceous or Paleocene time. This conclusion is based upon observations made in the region north of the Windy Creek area, where the igneous mass cuts the Cantwell formation of Cretaceous age but is overlain by coal-bearing strata of Eocene age. Farther west, however, large masses of granitic rock are overlain by rocks of the Cantwell formation, indicating that major intrusive activity took place in the Alaska Range geosyncline both before and after the deposition of the Cantwell formation.

In the southwestern part of the area the Jurassic(?) argillites and slates have been intruded by a light-gray coarse-grained quartz diorite. The rock has a porphyritic texture in most places, with euhedral orthoclase crystals as much as 1½ inches in length. The contact with the host rock dips moderately to steeply southward, approximately parallel to the local attitude of the enclosing strata. This intrusion is correlated with the post-Cantwell igneous rocks in the northwestern part of the area.

CEMENT RAW MATERIALS

In order to evaluate the mineral resources of the Windy Creek area in relation to the problem of a cement supply, it will be necessary not only to examine the structure, lithology, size, and accessibility of the individual deposits of potential raw materials, but also to take into consideration their chemical composition. The cement industry today must manufacture a product that will meet exacting chemical and physical standards, so that detailed knowledge of the chemical composition of the raw materials is a fundamental requirement. Deleterious substances in any potential component may well eliminate it from further consideration, even though all other geologic factors pertaining to its exploitation are favorable.

The chemical restrictions that apply to the various cement raw materials are governed to a certain extent by the type of cement to be produced. The chemical requirements formulated by the American Society for Testing Materials (1950, p. 1–4) for portland cement type II (which is employed for general construction purposes) are given in table 1. It is possible to control cement composition in part, and within certain limits, through adjustment of the ratio of the raw components, adjustment of the burning time or temperature, or both, and the use of supplemental iron and silica components. However, magnesia and the alkalies, which have undesirable chemical characteristics, may require flotation or other special treatment to bring them within acceptable limits and therefore are usually regarded as undesirable substances as far as the raw materials are concerned.

As each component of the raw mix, including the fuel combustion residue, contributes to the composition of the end product, it would not be possible to arrive at an upper limit of magnesia or alkali content for any particular raw component that would be applicable in all instances. However, with raw components of the general chemical composition of those found in the Windy Creek area, an upper limit of magnesia content of 3 percent probably would be applicable to the limestone, which would ordinarily be the major contributor of this compound. The alkalies can be dealt with only in very general qualitative terms, inasmuch as they would volatilize to an unknown extent under actual kiln operation. The maximum permissible amount in the cement, according to Federal specifications (table 1), is 0.6 percent (total Na_2O plus 0.658 K_2O); this figure may be used as a guide in the evaluation of the ingredients.

LIMESTONE

Limestone occurs at several localities in the belt of Devonian, Devonian(?), and Triassic rocks that crosses the Windy Creek area in an eastward direction. Deposits of commercial size have been found in three general areas: (1) between the valley of Little Windy Creek and the Alaska Railroad, (2) on the ridge southwest of the junction of the West Fork with Windy Creek, and (3) in the headwater area of the West Fork. These three principal limestone deposits in the Windy Creek area are designated as deposits 1, 2, and 3. Their locations are shown on plate 11.

TABLE 1.—*Chemical requirements for type II portland cement*

[Specifications are those of the American Society for Testing Materials. Federal specifications are the same except that when the purchaser specifies "low alkali cement," the alkali content (Na_2O+0.658 K_2O) shall not exceed 0.6 percent. All values are maximum with the exception of SiO_2 which is minimum]

	Type II (percent)		*Type II (percent)*
SiO_2	21.0	Ignition loss	3.0
Al_2O_3	6.0	Insoluble residue	.5
Fe_2O_3	6.0	Tricalcium silicate	50.0
MgO	5.0	Dicalcium silicate	
SO_3	2.0	Tetracalcium aluminate	8.0

DEPOSIT 1

The area between Little Windy Creek and the railroad, by reason of its relative accessibility, received considerable attention during the previous investigations of the Windy Creek area. The limestone outcrops were mapped in detail by Cobb in 1947. His studies were devoted primarily to the most extensive deposit in this area, designated as deposit 1.

General description.—Deposit 1, a limestone in the Devonian rocks, is on the south side of the ridge between Windy and Bain Creeks (pl. 11). The easternmost exposure of the deposit is slightly less than 1 mile west of the nearest point on the Alaska Railroad. The deposit crops out between altitudes of 2,620 and 3,190 feet, the lower altitude being about 500 feet above the level of the nearest point on the railroad. Five claims, covering the greater part of deposit 1, were staked in October 1948 and were acquired by the following year by the Northern Empire Development Co. No private development work is known to have been undertaken.

The limestone of deposit 1 is typically quite dense and has a fine-grained texture. It is dark gray to black where fresh and weathers to lighter shades of gray and buff. The strata have been thoroughly shattered by intense mechanical metamorphic action, and the rock is reticulated with calcite-filled fractures. Where bedding is discernible the strata strike about N. 70° E. and dip 60°–70° SE., although many local variations are found.

Exposures of deposit 1 are found intermittently over a lateral (east-west) distance of about 3,200 feet. Drill holes penetrating the deposit indicate that it has a maximum thickness of about 600 feet near the midpoint between its east and west limits.

The southward extent of the limestone is concealed by talus, glacial deposits, and vegetation, but presumably the strata are terminated on the south near the major zone of faulting which brings the rocks of Devonian age into contact with those of Jurassic(?) age. On the north the limestone is underlain by greenish to black calcareous schist.

Sampling.—Fifteen samples were taken across exposures of deposit 1 along lines normal to the strike. Each sample consisted of fresh chips collected at 8-inch intervals. Locations of the samples are shown on plate 11, and results of the chemical analyses of the samples are given in table 2.

Core drilling.—Core drilling and chemical analyses to determine the subsurface continuity, extent, and composition of deposit 1 were undertaken by the U. S. Bureau of Mines in 1948–50. Eleven holes, totaling 3,048 feet, were drilled. The location of the holes is shown on plate 11. The diamond-drill cores were analyzed in great detail by the Bureau of Mines and the results have been reported by Rutledge and others (1953).

Chemical composition.—The magnesia content of deposit 1 is erratic and undesirably high in many of the surface samples (table 2). Analyses of the Bureau of Mines drill cores also show the magnesia to range from 0.3 to 17.15 percent. Some stratigraphic zoning of the magnesia is suggested by the distribution of the compound in the rocks penetrated by drilling, but a comparison of the core analyses with those of the surface samples shows little correlation when the suggested zoning at the drill-hole level is projected to the surface. In the area tested by drilling, more than half the limestone has an average magnesia content exceeding the arbitrary 3 percent limit.

TABLE 2.—*Chemical analyses of surface samples of limestone deposit 1*

[Analyst. R. K. Bailey]

Sample	HCl insolubles	R_2O_3	CaO	MgO	CO_2 [1]	P_2O_5	Total
53	0.76	0.26	44.76	9.66	45.37	0.04	100.85
54	.96	.18	47.08	7.52	45.07	.02	100.83
56	1.38	.25	46.46	7.66	45.15	.03	100.93
58	.84	.18	51.92	3.29	44.29	.02	100.54
59	.84	.24	49.26	4.94	44.18	[2].01	99.47
60	.76	.26	44.84	9.04	44.94	[2].01	99.85
61	1.94	.24	46.06	7.64	44.40	[2].01	100.29
62	1.04	.12	49.32	5.30	44.37	[2].01	100.16
63	.80	.24	46.50	7.92	45.00	[2].01	100.47
64	4.90	.24	52.58	.68	42.04	[2].01	100.45
65	4.86	.30	51.96	1.02	42.61	[2].01	100.76
66	2.84	.30	53.22	1.05	42.84	[2].01	100.26
67	2.42	.20	51.96	2.33	44.04	[2].01	100.96
68	1.78	.22	53.24	1.58	43.52	[2].01	100.35
69	1.72	.18	52.20	2.42	43.43	[2].01	99.96

[1] Calculated from CaO and MgO.
[2] The P_2O_5 may be less than .01 percent but was present in appreciable amounts and was designated as being 0.01 percent.

FIGURE 16.—Limestone deposit 2 (left foreground) looking westward.

Perhaps a suitable calcareous component could be obtained from deposit 1, but, other factors being equal, this limestone is generally inferior to deposits 2 and 3.

DEPOSIT 2

General description.—Deposit 2 crops out along the summit of the west end of the ridge southwest of the junction of the West Fork with Windy Creek (fig. 16). Its western limit is approximately 7.8 miles, measured along Windy Creek and the West Fork, west of the Alaska Railroad. Outcrops of the deposit are found mainly between altitudes of 3,300 and 3,550 feet. The lower altitude is about 1,180 feet above the railroad at the Windy Creek bridge.

In physical appearance the limestone of deposit 2 is very similar to that of deposit 1. It is dark gray to black on fresh surfaces and weathers to a light gray. The original bedding is almost entirely obscured, but the trend of the body as a whole is about N. 70° E. and the strata dip 65°–75° SE.

The overturned beds of brightly colored pre-Devonian calcareous argillites and shales lie above the limestone. Beneath the limestone are dark cherty conglomerates and black shales of the Devonian system. Plate 11 shows a cross section of deposit 2 along a prolongation of sample line 38.

Sampling.—Six samples composed of fresh chips taken at 5-foot intervals were collected along lines normal to the strike. Sampled localities are shown on plate 11.

Chemical composition.—Results of the chemical analyses of the samples (table 3) indicate that the deposit is remarkably uniform in composition. Sample 30, taken across the west end of the deposit, contains 3.2 percent magnesia, which is slightly in excess of the arbitrary limit, but the weighted-average magnesia content of all the samples is only 1.3 percent. The weighted average of the alkali content is 0.16 percent.

If the surface sampling is representative of the deposit as a whole, it would appear that the deposit would be chemically acceptable as far as content of magnesia and alkalies is concerned.

Estimated available limestone.—Deposit 2 is assumed to have an average thickness of 300 feet over a lateral extent of 4,800 feet and to dip 70° S. It is estimated that about 6 million short tons of limestone could be removed by quarrying to a 50-foot depth.

TABLE 3.—*Chemical analyses of samples of limestone deposit 2*

[Analysts: L. I. Shapiro, L. E. Reichen, and S. M. Berthold. Na_2O, K_2O, and P_2O_5 determined by flame photometer; all other determinations by rapid colorimetric and titrimetric procedures]

Sample	Laboratory No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	Ignition loss	Total
30	----------	1.4	0.00	0.2	3.2	51.2	0.1	0.1	0.1	------	43.3	99.6
32	1911 C	1.5	.30	.16	1.1	52.8	.29	.12	.00	0.08	43.3	99.7
34	1912 C	1.4	.30	.30	.07	54.1	.16	.11	.02	.06	43.5	100.0
36	1913 C	2.2	2.4	.30	1.5	51.5	.17	.14	.01	.08	42.8	101.1
38	1914 C	1.5	.46	.32	.07	54.0	.11	.13	.02	.08	43.1	99.8
39	----------	1.1	.00	.2	2.5	52.0	.1	.1	.1	------	43.4	99.5
Volume-weighted average		1.5	0.5	0.2	1.3	52.8	0.1	0.1	0.04	0.08	43.2	99.8

DEPOSIT 3

General description.—Deposit 3 includes part of a bed of massive limestone that is thicker and of greater lateral extent than any others in the Windy Creek area. It crops out along an eastward-trending belt that crosses the valley of the West Fork at the junction of the principal headwater tributaries (pl. 11 and fig. 17). This massive limestone unit of the Devonian(?) system was first mapped on a reconnaissance scale and described by Capps (1932, p. 253), who traced its outcrops from the head of Windy Creek westward along the crest and southern slopes of the Alaska Range for a distance of about 20 miles.

A sketch map of the deposit was made by the Geological Survey in 1950 (Moxham and others, 1951, fig. 10), and samples of the principal outcrops were collected and analyzed. The boundaries of

FIGURE 17.—Headwaters of West Fork of Windy Creek looking northward. Deposit 3 is in the left and right middle ground in the thicker limestone beds (Dll) which are bounded by Devonian limestone, graywacke, and shale (Dl).

deposit 3 were mapped on a new base map (pl. 11) in 1951. The deposit was subsequently sampled by the U. S. Bureau of Mines (Rutledge and others, 1953).

Deposit 3 consists of that part of the massive limestone which is generally accessible from the valley of the West Fork (pl. 11). Outcrops of deposit 3 are found from creek level (altitude 3,200 feet) to the 5,000- to 6,000-foot summits of the steep serrate ridges that form the valley walls. The lowest outcrops, at creek level, are about 11.2 miles (measured along Windy Creek and the West Fork) west of the Windy Creek crossing of the Alaska Railroad and are about 1,100 feet above the level of the railroad bridge.

The more accessible part of the deposit is on the east side of the West Fork. Here the bedrock of the eastern part of the valley floor and of the lower slopes of the valley wall is mantled with talus which has accumulated in vast quantities at the base of the more precipitous slopes. Nearly continuous exposures are found on the steep slopes from the upper limit of the talus to the top of the ridge that forms the eastern valley wall of the West Fork.

The limestone in deposit 3 is very dense and fine grained in texture. Fresh surfaces are dark to bluish gray, weathering to a light gray. Locally, particularly in the central part of the deposit, the limestone exhibits a banded coloration due to thin alternating layers of dark bluish-gray and light-gray material. The calcareous strata are closely folded and locally are intricately contorted, but in general the degree of shattering appears to be less than that seen in deposits 1 and 2. The attitudes of individual beds vary greatly, but the general impression is that the limestone body as a whole stands nearly vertical. The general trend of the deposit is easterly.

Deposit 3 has an outcrop width of about 3,000 feet at its widest extent in the valley of the West Fork, but a stratigraphic thickness of not more than half that figure if the structural interpretation is correct—that is, that both limbs of a closely compressed fold are represented.

Plate 11 includes a longitudinal section through deposit 3.

Sampling.—In 1950 the U. S. Geological Survey collected samples of the limestone along lines generally normal to the strike near creek level in the valley of the West Fork. The material comprised fresh chips collected at about 5-foot intervals. Additional samples were taken at higher altitudes, where accessible, on the east side of the valley. The sampled localities are shown on plate 11.

That part of deposit 3 east of the West Fork was sampled in detail by the U. S. Bureau of Mines in 1951 and the results are given in the report by Rutledge and others (1953).

Chemical composition.—The bedrock of deposit 3 on the east side of the West Fork is not as uniform in chemical composition as deposit 2. The alumina and iron vary over a considerable range as does the ratio between these two compounds in particular samples. The average magnesia and alkali content is well within the required limits. The Bureau of Mines analyses indicate that the belt of talus at the foot of the east valley wall is of similar character to the bedrock throughout approximately the northern half of the talus deposit. South of the midway point the chemical composition tends to be somewhat erratic, with a generally lower lime content prevailing. Samples collected on the west side of the West Fork are generally more uniform chemically than those on the east; the alumina and iron content is lower as is the alumina:iron ratio.

Estimated available limestone.—The estimated available limestone has been divided into two categories, talus and bedrock. The approximate distribution of the talus and its inferred cross-sectional configuration are given in plate 11. By use of these data the northern half of the talus deposit is estimated to include about 8 million tons of limestone. The bedrock on the east side of the West Fork between creek level and an arbitrarily chosen altitude of 4,000 feet would comprise roughly 180 million tons of limestone, based upon the longitudinal section shown in plate 11. Probably about 10 million short tons lie west of the West Fork above creek level.

TABLE 4.—*Chemical analyses of samples of limestone deposit 3*

[Analysts: L. I. Shapiro, L. E. Reichen, and S. M. Berthold, Na_2O, K_2O, and P_2O_5 determined by flame photometer; all other determinations by rapid titrimetric and colorimetric procedures]

Sample	Laboratory No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	Ignition loss	Total
491	501920 C	7.1	2.3	0.19	1.4	48.5	0.22	0.11	0.03	0.84	38.8	99.5
492	501921 C	3.5	2.3	.78	2.9	47.9	.30	.12	.01	.32	42.4	100.5
493	1922 C	2.1	.80	.32	1.4	53.0	.50	.13	.01	.24	42.6	101.1
494	1923 C	8.6	2.5	.80	1.0	47.7	.83	.28	.03	1.16	38.2	101.1
495	1924 C	6.2	.95	.40	1.0	50.0	.38	.13	.02	.41	40.6	100.1
496	1925 C	5.4	1.1	.46	1.8	50.3	.62	.19	.01	.35	40.4	100.6
497	1926 C	6.0	.64	.45	1.3	50.1	.37	.19	.02	.51	40.4	100.0
498	1927 C	25.5	5.6	2.1	2.0	33.5	1.3	.70	.06	.64	28.2	99.6
499	1928 C	6.6	1.1	.41	1.9	50.1	.59	.20	.00	.61	39.6	101.1
501	1929 C	3.2	.31	.34	.83	53.1	.21	.07	.01	.19	41.9	100.2
502	1930 C	7.9	1.3	.85	2.4	46.9	.63	.16	.03	.30	39.4	99.9
503	1931 C	5.2	.80	.78	8.0	43.4	.33	.08	.01	.11	41.8	100.5
504	1932 C	5.9	1.0	.64	2.1	48.4	.18	.09	.02	.16	40.5	99.0
541	1933 C	3.9	.59	.19	2.0	50.7	.23	.15	.01	.18	42.1	100.0
542	1934 C	2.7	.29	.19	.77	53.1	.20	.11	.01	.08	42.6	100.0
543	1935 C	2.2	.00	.18	.76	53.7	.20	.10	.01	.12	42.8	100.1
544	1936 C	2.2	.21	.30	.51	53.6	.20	.08	.01	.08	42.5	99.7
545	1937 C	3.0	.83	.30	.75	52.8	.24	.08	.01	.09	42.4	100.5
546	1938 C	5.9	.69	.40	1.6	50.3	.37	.11	.01	.33	40.7	100.4
547	1939 C	4.3	1.9	.27	1.1	50.7	.32	.10	.01	.30	42.6	101.6
548	1940 C	4.2	1.4	.19	1.2	51.0	.28	.09	.01	.12	42.0	100.5
549	1941 C	4.0	1.6	.24	1.2	51.0	.26	.08	.01	.13	42.1	100.6
5410	----------	3.8	.79	.16	1.0	51.8	.30	.11	.01	.10	41.8	99.9
5411	----------	4.9	1.4	.11	.60	51.4	.26	.08	.01	.29	41.3	100.4
551	1952 C	16.2	2.5	1.2	1.2	43.6	1.1	.31	.09	.68	34.6	101.5
555	1953 C	12.5	2.4	1.3	1.3	45.9	.60	.47	.04	.43	35.0	99.9
559	1954 C	16.4	3.3	2.0	1.2	42.3	.82	.62	.04	.10	32.2	99.0
561	1942 C	6.5	.4	.4	1.6	49.6	.3	.1	.1	.00	41.0	100.0
562	1943 C	7.7	.6	.4	1.3	48.8	.3	.1	.1	.2	39.6	99.1
563	1944 C	6.1	1.3	.6	1.9	49.0	.3	.2	.1	.4	40.0	99.9
564	1945 C	5.5	.6	.4	2.5	49.5	.3	.1	.1	.2	41.3	100.5
565	1946 C	4.2	.6	.3	1.1	51.4	.2	.1	.1	.2	41.6	99.8
566	1947 C	7.3	.4	.3	1.0	49.4	.4	.1	.1	.3	40.0	99.3
567	1948 C	2.4	.3	.2	.6	53.2	.2	.1	.1	.1	42.6	99.8
568	1949 C	4.3	.4	.1	1.3	52.0	.2	.1	.1	.00	42.2	100.7
569	1950 C	2.6	.1	.1	.4	54.2	.1	.1	.1	.00	43.1	100.8
5610	1951 C	3.4	.5	.2	1.8	51.0	.3	.1	.1	.2	42.1	99.7

OTHER DEPOSITS

Limestone deposits have been found in many other localities in the Windy Creek area but they are generally regarded as inferior to deposits 2 and 3, owing to some aspect of their chemical quality, size, or accessibility.

A deposit comparable in size to deposit 1 is intersected by the valley of Little Windy Creek (pl. 11). The material was sampled by Cobb in 1947 and by the Bureau of Mines in 1949. The Geological Survey sample locations are shown on plate 11. The analytical results, given below, indicate that about half of the limestone contains excessive amounts of magnesia.

[Analyst: R. K. Bailey]

	In sample C55	*In sample C56*		*In sample C55*	*In sample C56*
Insolubles	3.88	2.64	CO_2	42.56	43.86
R_2O_3	.39	.18	P_2O_5	.05	.01
CaO	52.04	50.14			
MgO	1.66	3.98	Total	100.58	100.81

Several other deposits shown on plate 11 in the area between Little Windy Creek and the railroad were sampled by the Bureau of Mines in 1949 and some appear to be acceptable, insofar as the magnesia content is concerned, but the quantity of material is generally regarded as insufficient or the deposits are relatively inaccessible.

Two limestone beds averaging 40 feet in thickness crop out along the upper valley slopes on the north side of Windy Creek, west of Little Windy Creek. A chemical analysis of sample 5, which was taken across the thickest part of one of the beds (pl. 11), is given below:

[Analyst: L. I. Shapiro]

SiO_2	4.3	K_2O	.1
Al_2O_3	.1	P_2O_5	.2
Fe_2O_3	.5	Ignition loss	44.4
MgO	15.8		
CaO	34.4	Total	99.9
Na_2O	.1		

ARGILLACEOUS MATERIALS

The argillaceous component of a cement manufactured from materials available in the Windy Creek area probably would constitute 15 to 20 percent of the raw mix.

Argillaceous rocks of pre-Devonian, Devonian, and Jurassic(?) age at several localities were examined and samples were collected during the present investigation. A brief description of the various lithologic types is included in table 5, which summarizes the results of the investigation. The locations of the deposits are shown on plate 11 and chemical analyses of the samples are given in table 6.

PRE-DEVONIAN ROCKS

Samples 43 and 45 represent a red, green, and yellow mottled calcareous argillite of pre-Devonian age which crops out on the submmit of the ridge southwest of the mouth of the West Fork. The strata are south of and adjoin the limestone of deposit 2 and dip moderately to steeply to the southeast. They are exposed for a lateral distance of about 2,000 feet along the crest of the ridge. It is estimated that the beds are about 200 feet thick. Only a very thin soil mantle covers the bedrock in most of the area.

DEVONIAN SYSTEM

The abrupt lateral and stratigraphic discontinuities that characterize the rocks of Devonian age are such that most lithologic units are not very persistent. A few exceptions, however, were found in the central and western part of the outcrop area of rocks of Devonian age.

Samples 6 and 17 (possibly from the same part of the section) were collected from a brown to black crumpled argillite that crops out in two gullies cut into the steep north valley slopes of Windy Creek (pl. 11). The strata in general dip steeply to the southeast, although there are many local variations. The maximum exposed thickness at locality 6 is about 400 feet. The lateral extent of the beds is concealed by soil and vegetation, but the overburden is probably not more than 2 or 3 feet thick in most places.

TABLE 5.—*Summary of data pertaining to argillaceous materials*

Sample	Year collected	Description	Attitude of beds	Stratigraphic thickness (feet)	Estimated material available (tons)
C-1, C-2	1948	Shale	N. 80° E.; 35° N.		
302	1949	Dark-gray fine-grained sandstone with pyrite in small cubes and irregular grains.	N. 55° E.; 55° SE.	10	6,500
304	1949	Gray argillaceous sandstone; claystone with small carbonate veinlets and pyrite cubes.	N. 55° E.; 55° SE.	145	266,000
305	1949	Black platy siliceous claystone; limonite on cleavage faces.	N. 55° E.; 55° SE.	50	163,000
307	1949	Black sandy claystone, somewhat platy, with limonite on cleavage faces.	N. 60° E.; 85° SE.	20	10,600
308	1949	Black claystone	N. 70° E.; 55° SE.	50	67,000
309	1949	Dark-gray platy siliceous claystone.	N. 62° E.; 55° SE.	25	19,500
310	1949	Dark-gray siliceous claystone	N. 50° E.; 55° NW.	60	37,000
311	1949	Black siliceous claystone	N. 70° E.; 67° NW.	45	16,000
318	1949	Dark-gray sandy iron-stained claystone.	N. 60° E.; 60° SE.	70	77,000
6	1950	Black crumpled shale	N. 75° E.; 80° NW.	400	100,000
17	1950	Brown to black crumpled shale.	E. W.; 70° SE	100	40,000
26	1950	Black shale and slaty argillite	N. 80° E.; 75° SE.	100	40,000
43, 45	1950	Red, green, and yellow-mottled calcareous argillite.	N. 50° E.; 70° SE.	200	450,000
48	1950	Brown to black argillite	N. 55° E.; 20° SE.	140	130,000
51	1950	Black slaty argillite	N. 74° W.; 80° S.	400	300,000

TABLE 6.—*Chemical analyses of argillaceous materials*

[Analysts: A. A. Hanks, Inc.*; A. C. Vlisidis and L. I. Shapiro. Na_2O, K_2O, and P_2O_5 determined by flame photometer; all other determinations by rapid colorimetric and titrimetric procedures]

Sample	Laboratory No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	Ignition loss
C-1		60.61	15.74	7.81	4.59	1.17	0.91	0.59	0.20		
C-2		62.09	16.36	7.38	5.15	1.29	.97	.75	.21		
302*	10372	77.30	9.58	5.41	2.51	.90	.65	.43		0.55	2.21
304*	10373	70.59	13.37	6.43	2.72	.51	.71	.57		.30	4.20
305*	10374	70.91	13.73	6.09	2.40	.40	.46	.37		.35	4.75
307*	10375	64.86	16.63	6.71	1.76	1.59	2.53	.61		.12	4.58
308*	10376	64.58	16.37	5.07	4.56	1.66	1.16	.72		.10	5.25
309*	10377	61.85	18.15	7.28	3.80	.81	1.42	.65		.15	5.27
310*	10378	60.61	14.79	6.60	5.60	3.20	1.25	.70		.18	6.51
311*	10379	62.90	17.75	7.44	4.10	.96	1.55	.68		.07	4.17
318*	10380	70.31	15.94	4.06	2.93	.41	.28	.21		.67	4.85
6	1937 C	62.4	14.8	4.8	1.9	3.8	.85	2.2	.14		7.9
17	1938 C	64.2	16.8	5.7	1.3	.72	.94	2.4	1.4		5.9
26	1939 C	62.9	17.9	6.0	1.3	1.0	.84	2.7	.13		6.6
43	1940 C	41.8	11.2	4.3	2.1	19.9	1.7	1.5	.14		16.9
45	1915 C	47.6	12.6	4.2	2.6	14.5	1.2	2.2	.12	.19	14.2
48	1916 C	69.3	14.7	3.8	.80	.72	.92	2.6	.11	.99	5.4
51	1917 C	64.4	15.6	6.0	1.0	2.0	1.4	2.7	.15	.34	4.5

Sample 48 was collected from a brown to black argillite which crops out for a distance of about 300 feet along the south side of the West Fork from creek level to an altitude of about 2,900 feet. The beds strike N. 55° E. and dip 20° SE. A stratigraphic thickness of about 140 feet is exposed.

JURASSIC(?) SYSTEM

The largest deposit of argillaceous material in the Windy Creek area is represented by the argillite of Jurassic(?) age which underlies the conglomerate of the Cantwell formation at locality 51 in the western part of the area. Here the argillite of Jurassic(?) age is well exposed in a northward-flowing tributary which enters the West Fork near the east end of Foggy Pass (pl. 11). The strata are primarily black argillite but include a few layers of graywacke and conglomerate; the beds have been cut by felsic dikes in a few localities; the strata strike about N. 75° W. and dip 80° S. Sample 51 represents a stratigraphic thickness of about 400 feet of argillite. This general lithology persists laterally at least as far as the western limit of the mapped area. To the east the sedimentary beds become increasingly coarse and contain much more graywacke.

Rocks of Jurassic(?) age crop out immediately west of the Alaska Railroad between Windy Creek and Cantwell. The beds are composed chiefly of metamorphosed argillaceous sediments and minor amounts of limestone. In several localities the beds have been cut by dikes of granitic or dioritic composition. The strata of Jurassic(?) age dip moderately to steeply northward and strike about N. 80° E. In 1948, Gates and Cobb sampled a shale member exposed in an outcrop along the west side of the Alaska Railroad (localities C–1 and C–2, pl. 11) 1 mile southeast of Windy Creek. The sample was composed of material collected at 2-foot intervals over a distance of 375 feet along the railroad.

An additional sample of this material (311) was collected by R. E. Fellows in 1949.

Other outcrops of argillaceous rocks, rather limited in size, are along lower Windy and Little Windy Creeks and the Alaska Railroad. At most of these localities the deposits are mantled by a thick overburden of glacial outwash except where they are exposed by the stream erosion. The locations of samples collected by Fellows in 1949 are shown on plate 11 and briefly described in table 5.

CHERT

Modern cement-manufacturing processes require very close control of the chemical composition of the raw mix in order to produce a uniform product that will meet rigorous specifications. The most common practice is to adjust the composition of the raw mix by the addition of a high-iron and (or) a high-silica component in appropriate quantities to attain a cement of desired chemical composition. Mill scale and pyrite cinder are commonly used as high-iron components; silica sand, quartz, and quartzite comprise the principal high-silica materials.

No high-iron materials are known in the Windy Creek or adjacent areas, but chert that occurs in the northeastern part of the area might be chemically suitable as a high-silica component. The chert beds, probably of Triassic age, crop out adjacent to the Alaska Railroad about two-thirds of a mile north of Windy station. The rock is black, locally weathering to a rusty hue. To the north the chert is overlain or intruded by greenstone.

The beds have a stratigraphic thickness of about 60 feet and are exposed along the strike for at least 100 feet in a southwesterly direction from the railroad right-of-way.

Sample 100, consisting of fresh chips collected at 5-foot intervals across the width of the outcrop, was taken along the railroad right-of-way. Results of the chemical analysis of the sample are given below:

[Analyst: Harry M. Hymen]

SiO_2	96.31	H_2O+	0.05
Al_2O_3	1.59	H_2O-	.31
Fe_2O_3	.40	TiO_2	.06
FeO	.18	CO_2	.04
MgO	.07	P_2O_5	.15
CaO	.23	MnO	.00
Na_2O	.05		
K_2O	.35	Total	99.79

POTENTIAL CEMENT COMPOSITION

A discussion of the potential composition of cements that might be manufactured from the raw materials available would involve many aspects of physical chemistry and economics that are not within the scope of this paper; furthermore, as a prerequisite to any serious discussion on the subject, a great deal more would have to be known of the chemical character of the raw materials. However, some comments are thought warranted on the basis of the data that are available.

In the absence of a supplemental high-iron component, the alumina: iron ratio in the raw materials is of importance in keeping the tricalcium aluminate content of the finished product within the 8 percent maximum.

The limitation of a maximum of 5 percent magnesia in cement has been discussed (p. 84); the relationship between the amount of this compound in the raw materials and the cement composition is straightforward. The extent to which the alkali content of cement is harmful is a matter of controversy. In addition, because the alkalies will volatilize to a certain extent during burning, the alkali content in the raw ingredients is difficult to assess. In the computations given below no such losses are assumed, so the alkali content of the cements shown probably approaches maximum values.

It has been pointed out that the magnesia content of deposit 1 varies widely and in many localities is excessive (p. 86). The usefulness of this deposit will depend on various economic factors and will not be discussed further here.

Deposit 2 is remarkably uniform in chemical composition if the few surface samples taken are representative of the deposit as a whole. The material is probably superior in this respect to any other in the Windy Creek area. The alumina: iron ratio of the weighted average of the samples is 2.5:1, but the amounts of these compounds are very low. The magnesia and alkalies are likewise low.

The massive Devonian(?) limestone, of which deposit 3 is a part, offers enormous reserves, but is the most remote from the Alaska Railroad and the present highway network. The magnesia presents no problem and for the most part the alkalies are within reasonable limits, although there may be local exceptions.

On the east side of the West Fork, the alumina and iron content of the limestone is somewhat varied and computations of potential cement composition based on the weighted average of the samples, with different argillaceous components, indicated a slightly excessive tricalcium aluminate content. Computations based on the average composition of the samples from the central part of the deposit (locality 561–560) showed the limestone was satisfactory.

Generally, the argillaceous materials are satisfactory except for their alkali content. Except at locality 302 the alkali content is somewhat high, but for reasons mentioned above (p. 84) the extent to which this is undesirable will not be discussed here.

Two potential cement compositions are given below. Mix 1 consists of 78 percent limestone from deposit 2 (weighted average of samples), 20 percent shale from locality 302 (table 6), and 2 percent Healy River coal ash. The composition of the coal ash is the average of five samples from the New Suntrana mine (Selvig and Gibson, 1945). Mix 2 is 83 percent limestone from deposit 3 (average of samples 561–5610), 15 percent shale from locality 302, and 2 percent coal ash. The computations were made in accordance with the method of Bogue (1947). The amounts of the synthetic compounds were computed as required by the American Society for Testing Materials (1950).

TABLE 7.—*Calculations of potential cement composition*

	In mix 1	In mix 2		In mix 1	In mix 2
SiO_2	25.9	24.7	Ignition loss	.6	.6
Al_2O_3	4.1	3.4			
Fe_2O_3	2.0	1.6	Total	99.8	99.5
CaO	62.4	64.1			
MgO	2.3	2.3	Tricalcium silicate	21.3	42.3
Na_2O	.3	.5	Dicalcium silicate	58.2	39.0
K_2O	.3	.3	Tetracalcium	7.5	6.3
P_2O_5	------	------	Tetracalcium alumino-		
SO_3	1.9	2.0	ferrite	6.1	4.9

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INDEX

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CONTENTS

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