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Chapter C

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Scientific notes and summaries of investigations prepared by members of the Geologic and Water Resources Divisions in the fields of geology, hydrology, and related sciences

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FOREWORD

This collection of 46 short papers is the second of a series to be released as chapters of Geological Survey Research 1964. The papers report on scientific and economic results of current work by members of the Geologic, Conservation, Water Resources, and Topographic Divisions of the U.S. Geological Survey. Some of the papers present results of completed parts of continuing investigations; others announce new discoveries or preliminary results of investigations that will be discussed in greater detail in reports to be published in the future. Still others are scientific notes of limited scope, and short papers on techniques and instrumentation.

Chapter A of this series will be published later in the year, and will present a summary of results of work done during the present fiscal year.

Thomas B. Nolan

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Director.

CONTENTS

GEOLOGIC STUDIES

Structural geology

Stratigraphy and paleontology

Mineralogy and petrology

Geochemistry

Geophysics

Economic geology

Geomorphology and Pleistocene geology

Glaciology

Analytical techniques

HYDROLOGIC STUDIES

Ground water

Quality of water

Engineering hydrology

Theoretical hydrology

TOPOGRAPHIC MAPPING

Photogrammetry

INDEXES

OCCURRENCE AND ORIGIN OF LAUMONTITE IN CRETACEOUS SEDIMENTARY ROCKS IN WESTERN ALASKA

By J. M. HOARE, W. H. CONDON, and W. W. PATTON, JR.,
Menlo Park, Calif.

Abstract.—Laumontitized sedimentary rocks of Cretaceous age which are easily recognized by their distinctive mottled or spotted appearance crop out over an area of at least 2,000 square miles in western Alaska. Most of the laumontite is thought to have formed diagenetically through the reaction of water rich in calcium carbonate with tuffaceous material of acid or intermediate composition.

In the course of regional mapping in western Alaska, laumontitized[1] sandstones have been mapped over an area of at least 2,000 square miles. This is probably the largest known occurrence of this calcic zeolite in North America. Deposits of similarly zeolitized sedimentary rocks of probable comparable size have been recognized in Russia (Zaporozhtseva, 1960). The zeolitized rocks discussed here form part of a thick sequence of clastic sedimentary rocks which were deposited in the Koyukuk geosyncline (fig. 1) in mid-Cretaceous (Albian and Cenomanian?) time.

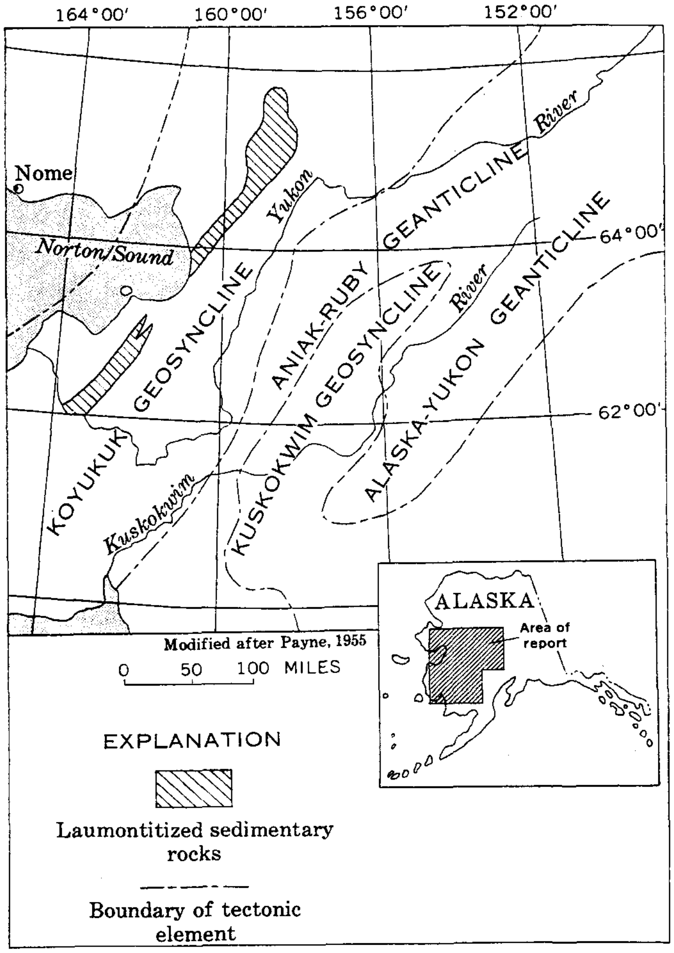

FIGURE 1.—Map showing occurrence of laumontitized sedimentary rocks in west-central Alaska.

Geophysical data indicate that the sedimentary section in the deeper parts of the geosyncline may be as much as 20,000 to 30,000 feet thick. The section consists of dark-gray, fine-, medium-, and some coarse-grained graywacke sandstones interbedded with equal or greater amounts of siltstone and shale. In the southwestern part of the geosyncline this thick sequence of rocks can be divided into three mappable lithologic units on the basis of whether the sandstones are calcareous, noncalcareous, or laumontitized (fig. 2). Most of the rocks mapped as calcareous effervesce freely when treated with cold dilute hydrochloric acid, but many rocks in the unit are noncalcareous or slightly calcareous. Conversely, the rocks mapped as noncalcareous include some rocks that are at least weakly calcareous. The laumontitized unit contains an equal or greater amount of calcareous and noncalcareous sandstone that contains little or no laumontite. The thickness of the laumontitized strata cannot be determined accurately because the

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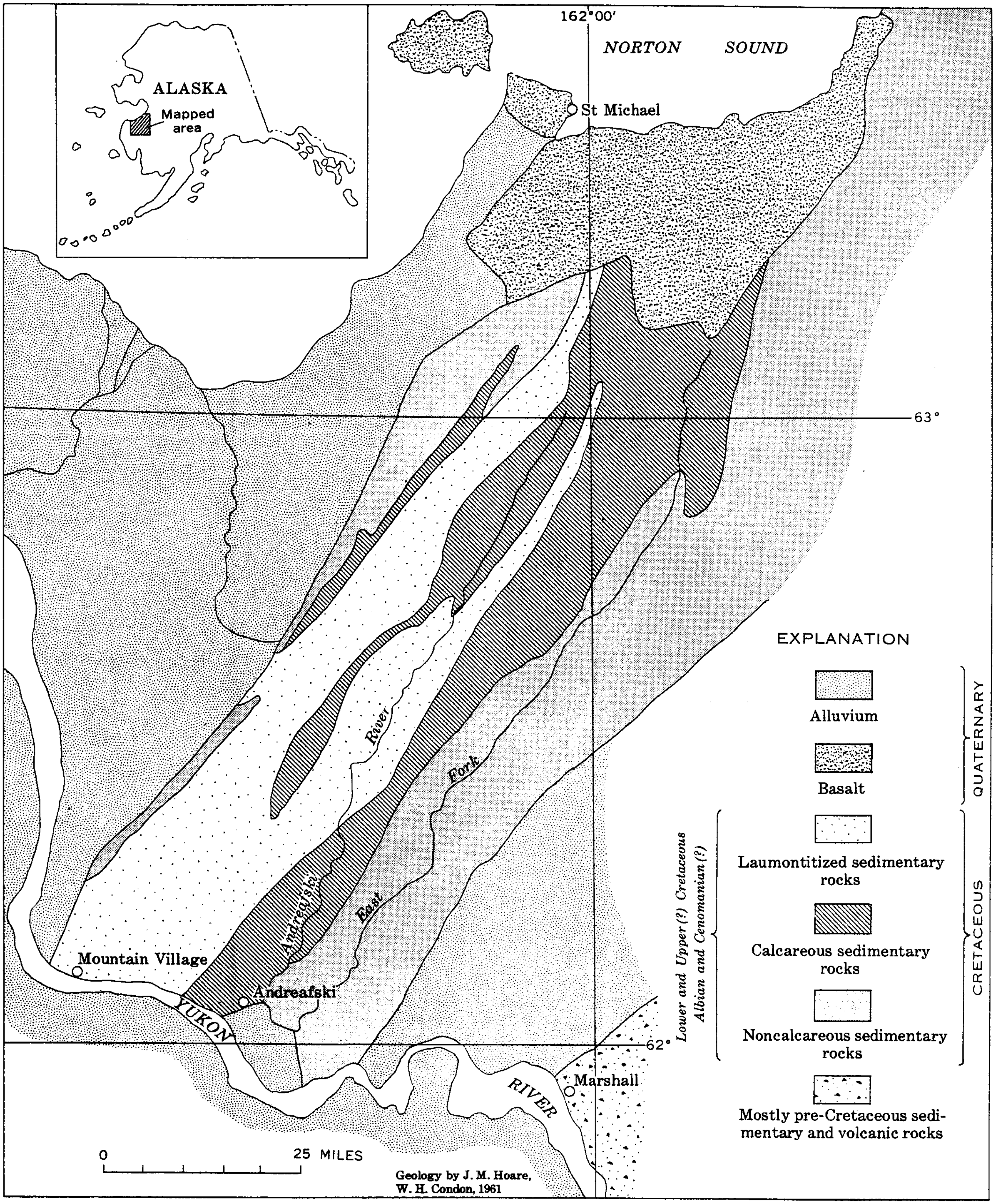
[1] The ideal, alkali-free formula for laumontite is $Ca_4Al_8Si_{16}O_{48} \cdot 16H_2O$ (Coombs, 1952, p. 825); however, it usually also contains some sodium and potassium.

U.S. GEOL. SURVEY PROF. PAPER 501-C, PAGES C74-C78



Geology by J. M. Hoare, W. H. Condon, 1961

FIGURE 2.—Map showing distribution of laumontitized sedimentary rocks in the southwestern part of the Koyukuk geosyncline, western Alaska.

rocks are highly deformed and poorly exposed, but they probably are 2,000 to 5,000 feet thick. These three mappable units form northeast-trending belts parallel to the regional strike. The stratigraphic and structural relationships of these belts of strata are uncertain. In many places the laumontitized sandstones appear to overlie the calcareous sandstones. However, the intimate association of laumontitized and calcareous sandstones near the head of Andreafski River suggests that they may also in part grade into each other and that the laumontitized sandstones are at least locally a facies of the calcareous sandstones.

DESCRIPTION OF LAUMONTITE-BEARING ROCKS

Medium- to coarse-grained sandstones in the laumontitized sequence are generally more highly altered than are the finer grained sandstone and siltstone. This fact suggests that porosity and permeability may be important factors in determining the amount of alteration in these clastic rocks.

The laumontitized sandstones are fairly well sorted mixtures of subangular and subrounded mineral and rock fragments in a poorly defined matrix containing chloritized biotite, sericite, and laumontite. The clasts are chiefly quartz, albite, chert, and fragments of finely porphyritic volcanic detritus. Epidote, apatite, pyroxene, and sphene are very minor constituents. Much of the matrix and many of the fragments could not be identified. Some of the albite is partly replaced by laumontite, but most of the laumontite occurs as cement.

Carbonitized plant debris is common in the laumontitized rocks as well as in the nonlaumontitized rocks. The occurrence of fragile vertical plant stems in highly laumontitized calcareous tuff suggests that the tuff was deposited in a shallow-water environment. Shallow-water deposition is also suggested by local occurrence of mud cracks in shales which are interbedded with the altered sandstones.

The laumontitized rocks are recognizable in the field because the dark-gray sandstones are spotted or mottled with lighter gray areas. In finer grained rocks the lighter gray spots are well-defined ovoids less than 1/4 inch in greatest dimension. In coarser grained rocks the spots are less well-defined; they merge with the surrounding dark-gray matrix and with each other. In more highly altered strata the spots make up practically all the rock and the result is a light gray or buff rock with an earthy appearance, mottled with vague darker areas. The spots or ovoids are oriented with their long dimensions parallel to the bedding. In more massive strata the orientation of the spots may be the only apparent indication of bedding.

X-RAY STUDIES

A number of representative specimens from each of the three lithologic units were studied by X-ray diffraction methods. The purpose of this study was first to determine if laumontite was present, and if present, to obtain semiquantitatively the relative amounts of laumontite, quartz, calcite, and plagioclase in the rocks.

No special techniques were used in preparing and analyzing the diffraction samples. The laumontite undoubtedly lost much of its water, and the diffraction peaks are probably those of leonhardite rather than laumontite. The spacing of the diffraction lines obtained from the Alaskan material (see accompanying table) agrees quite well with the data obtained by Coombs (1952, p. 822), except for the strongest peak at 9.41, (110) face. Coombs' data were obtained using a powder camera which apparently did not record this low-angle peak that is shown on later diffractographs (Neumann and others, 1957, pl. I).

X-ray diffraction data for laumontite (leonhardite)

[Only the 7 most intense lines shown]

Air-dried leonhardite [1]		Air-dried laumontite [2] (leonhardite?)	
d (A)	I [3]	d (A)	I [3]
------------	------------	9. 41	10
6. 88	6	6. 81	6
4. 18	10	4. 15	7
3. 67	4	3. 65	3
3. 52	10	3. 51	4. 5
3. 28	3	3. 25	3. 5
3. 04	4	3. 03	3

[1] Coombs, 1952, p. 822, specimen 192, Hungary. Analysis was by means of a powder camera which apparently did not record the highest intensity line (9.41) because of its low angle.

[2] Specimen 61AHr 1010, lat 62°16′ W., long 163°5′8″ N., Kwiguk 1:250,000-scale quadrangle, Alaska. X-ray powder not purified, contains minor amounts of quartz, albite, chlorite, and carbonized plant detritus. Analysis on wide-range diffractometer, Ni-filtered CuKα radiation, (λ=1.54050 Å).

[3] Line intensities do not compare well because the line of strongest intensity, 9.41, was not recorded for the Hungarian specimen, and the Alaskan specimen contains crystalline impurities.

Data from X-ray analysis of whole-rock diffraction powders show that, almost without exception, the presence of laumontite is indicated by the development of light-gray ovoids in the dark-gray sandstones and siltstones or by more complete alteration of the dark-gray rocks to light-olive-gray rocks. None of the dark-gray sandstones that are not mottled appear to contain more than 2 percent laumontite and most of them none at all. Several of the weakly laumontitized and nonlaumontitized specimens came from beds lying between strongly laumontitized strata. Separate X-ray analyses of the light- and dark-colored fractions of the laumontitized rocks show that most, if not all, of the laumontite is in the light-colored fraction. Thin sections show that the darker fraction contains relatively more chlorite and biotite.

The X-ray data also show that albite and oligoclase are the only feldspars plentiful enough to be detected by this method of analysis. Of these, albite is by far the more common feldspar in both altered and unaltered rocks. The anorthite content of the feldspar in selected specimens was estimated from the spacing of the (131), ($1\bar{3}1$), and (220) reflection peaks (Smith and Yoder, 1956, p. 634). Oligoclase was identified only in the unaltered rocks. The composition of the albite is variable, but in general it appears to be less calcic in rocks containing appreciable amounts (10 to 20 percent) of laumontite. Coombs (1954, p. 71) points out that lime-free albite in sediments may owe its composition to albitization of andesine. Some of the albite in these rocks may be derived from older volcanic rocks which are commonly albitized, but the close correlation between the occurrence of laumontite and albite suggests that much of it formed in place.

ORIGIN

The laumontitized rocks of western Alaska appear to be similar in many respects to rocks recently described (Zaporozhtseva, 1960) in the Lena coal basin, Russia, where laumontitized sedimentary rocks are developed on a regional scale. Laumontitized rocks form three separate stratigraphic intervals in a sedimentary sequence 2,500 to 3,000 meters thick for a distance of more than 1,000 km (Zaporozhtseva, 1960, p. 58). In discussing the diagenetic origin of the laumontite, Zaporozhtseva emphasizes the chemistry of the formative medium and either ignores or tacitly assumes such important factors as availability of reactive volcanic glass, porosity, and depth of burial. She believes that the laumontite formed while the sediments were still unconsolidated and concludes (Zaporozhtseva, 1960, p. 58) that

> The widespread occurrence of laumontite * * * is attributable to the uniform circumstances of sedimentation over a vast territory, where the formation of calcic zeolite took place in silt deposits of a desalinized basin, as well as in alluvial (?) deposits, during the diagenetic stage.

She points out (Zaporozhtseva, 1960, p. 56) that

> The availability of the starting material for the formation of zeolites in the ooze of reservoirs is a fairly frequent phenomena. Yet, it is common that zeolites do not always crystallize thereby. It may be assumed that they are very sensitive to the formative medium, the details of which are unclear (concentration of the components in solution, chemical activity, the amounts of organic matter, carbonic acid, oxygen, the concentration of hydrogen ions, and so on).

It is probable that the laumontitized sandstones of western Alaska developed in a manner analogous to that described by Zaporozhtseva.

Staining with sodium cobaltinitrite solution reveals that the laumontitized rocks contain no more than a trace of potash feldspar. However, many of the nonlaumontitized rocks contain as much as 5 percent potash feldspar and a few as much as 20 percent.

The writers believe that the laumontite formed through the interaction of unstable volcanic debris, probably glass, with water of the appropriate composition. This manner of formation has been suggested by Bradley (1929, p. 2–5) for the analcime in the Tertiary Green River Formation, by Coombs (1954, p. 79) for analcime and heulandite in the Taringatura sediments in New Zealand, and by Hay (1963, p. 246) for authigenic zeolites in late Pleistocene sediments.

The following observations suggest that tuffaceous material of siliceous or intermediate composition is a prime requisite to the formation of laumontite in these rocks: (1) mottled laumontitized sandstone beds grade laterally into laumontitized tuffs; (2) the intercalation of laumontitized and nonlaumontitized strata within the laumontitized unit is more easily explained by intermittent incorporation of tuffaceous material of pyroclastic or epiclastic origin in the sandstone than by postulating differential effects of load metamorphism; (3) the apparent lack of laumontite and tuffs in the underlying(?) calcareous and noncalcareous units, although they do contain abundant albite and calcic feldspars and were deeply buried, suggests that the laumontite formed at the expense of tuffaceous material rather than by the hydration of plagioclase.

Of equal importance in the genesis of laumontite is the composition of the water in which the volcanic debris was deposited. Bradley's (1929) observations indicate that the formative medium was alkaline. His observations are supported by experimental evidence showing that (1) alkaline waters are capable of reacting with siliceous volcanic material, and (2) zeolites can be synthesized under alkaline conditions. However, Coombs (1960, p. 348) reports that zeolites exist at Wairakei, New Zealand, in waters made slightly acid by carbon dioxide and that zeolites have been formed artificially from obsidian in waters of the same composition.

These contrasting facts are made more understandable by Hemley's work (Hemley and others, 1961, p. 340), which points out the fundamental importance of equilibrium constants or critical ion ratios (in this instance the activities of Ca^{+2} and Na^{+1} relative to H^{+1}). Thus, the reaction by which laumontite was formed could have taken place in either alkaline or slightly acid solutions, depending upon the concentrations of the reacting ions. However, in this specific environment the combined effects of solution of calcareous material and of hydrolysis of unstable volcanic ash could be expected to lead to somewhat alkaline conditions even in the presence of acid-forming decaying plant material.

Laumontitized strata have not been recognized in sedimentary deposits of about the same age which were laid down in the adjacent Kuskokwim geosyncline (fig. 1). The apparent lack of laumontite in these deposits is largely attributed to the fact that they contain few calcareous strata and little or no tuff or tuffaceous sandstone. That the Kuskokwim geosynclinal deposits are mostly deeper water deposits containing relatively little carbonitized plant trash is probably also significant in explaining why laumontite is so abundant in the Koyukuk geosyncline and apparently lacking in the Kuskokwim geosyncline.

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ORE CONTROLS AT THE KATHLEEN-MARGARET (MACLAREN RIVER) COPPER DEPOSIT, ALASKA

By E. M. MacKEVETT, JR., Menlo Park, Calif.

Work done in cooperation with the Defense Minerals Exploration Administration

Abstract.—The Kathleen-Margaret copper prospect, near the terminus of the MacLaren Glacier on the southern flank of the Alaska Range, explores north-striking quartz veins that cut greenstone and contain subordinate bornite and chalcopyrite. The quartz veins are near an eastward-striking fault zone. Copper values in the largest and richest known vein apparently diminish northward away from the fault zone–vein intersection.

This article supplements and updates a report by Chapman and Saunders (1954), who described the Kathleen-Margaret copper prospect during the early stages of its development, and is largely an outgrowth of investigations made under the auspices of the DMEA (Defense Minerals Exploration Administration). The article is based mainly on geologic mapping of the underground workings at a scale of 1 inch equals 20 feet and on examination of several thin sections and polished sections. The writer participated in three brief examinations of the prospect in 1957 and 1958 for the DMEA and made an additional 2-day examination in 1960. Emphasis in this article is placed on the structure and local geologic setting of the ore deposit as determined from exposures in the underground workings. Little new information concerning the areal geology at the prospect has been obtained since the work of Chapman and Saunders (1954).

Information in the DMEA files has been drawn upon freely, and grateful acknowledgment is made to those who participated in the DMEA program at the prospect, particularly to R. M. Chapman, Fred Barker, and A. E. Weissenborn of the U.S. Geological Survey, and to E. W. Parsons of the U.S. Bureau of Mines.

The prospect is in the southern part of the central Alaska Range, about 10 miles north of the Denali Highway (fig. 1). It is in the Mount Hayes B–6 quadrangle (U.S. Geological Survey 1:63,360 topographic series, 1951), approximately 1 mile west of the terminus of the MacLaren Glacier, at an altitude of about 4,000 feet. Access is most practical by small aircraft, which can utilize a landing strip on the flats of the MacLaren River about 1½ miles southeast of the prospect. The prospect is also accessible from the Denali Highway by foot or amphibious vehicle.

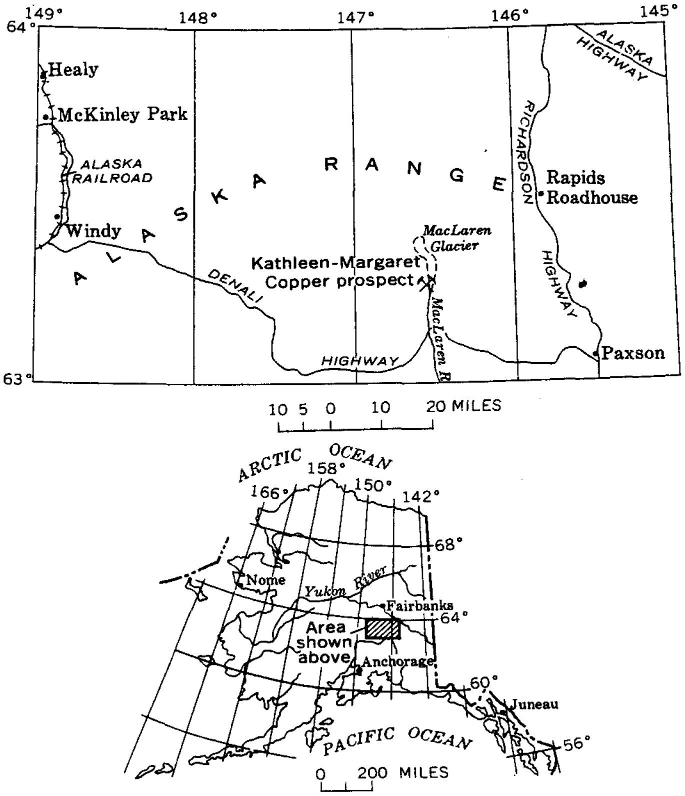


FIGURE 1.—Index map showing the location of the Kathleen-Margaret copper prospect.

U.S. GEOL. SURVEY PROF. PAPER 501-C, PAGES C117-C120

A road, approximately 1½ miles long and suitable for tractors and four-wheel-drive vehicles, connected the prospect with a base camp on the river flats about half a mile northwest of the airstrip. Both the road and the camp buildings are now in disrepair (R. M. Chapman, written communication, 1963).

The MacLaren River copper deposit probably has been known since 1918 (Martin, 1920, p. 20), but its early history is sketchy. F. S. Pettyjohn, Jr., relocated the copper-bearing quartz veins in 1952 while associated with E. O. Albertson in a prospecting venture. The prospect was explored, partly under DMEA sponsorship, between 1953 and 1959, by an adit and connecting underground workings totaling about 800 feet (fig. 2), by diamond drilling, and by shallow trenching. Most of the trenches sloughed and became partly filled with surficial debris soon after they were excavated. Approximately 2 tons of ore, estimated to contain between 1 and 2 percent copper, was stockpiled at the property in 1960.

The Kathleen-Margaret prospect is in the altered volcanic rock (greenstone) that is extensively distributed along the southern flank of the central part of the Alaska Range and throughout nearby terranes (Moffit, 1912, pl. 2). This rock constitutes a thick sequence, mainly of lava flows, and was considered by Moffit (1912, p. 30) to be of late Carboniferous or Early or Middle Triassic age. Little geologic mapping has been done in the region since Moffit's pioneering reconnaissance. Undoubtedly, detailed geologic mapping would reveal more complicated geology than has been recognized by reconnaissance methods and would disclose diverse lithologies and structures. Most of the ground at the prospect is covered by low vegetation and by unconsolidated surficial debris.

The dominant rock at the prospect is greenstone that forms a flow sequence dipping southward gently. The greenstone is greenish gray, very fine grained, and is composed largely of secondary minerals. Most of it is cut by numerous veinlets and some is porphyritic and (or) amygdaloidal. Thin sections of the greenstone consist largely of altered plagioclase, epidote, and chlorite. Quartz, calcite, and actinolite are less abundant, and sphene, opaque minerals and their alteration products, and prehnite(?) are uncommon. Scattered specks of chalcopyrite are rare constituents of some of the greenstone. The amygdules and veinlets contain epidote, chlorite, calcite, and quartz. The porphyritic greenstone consists of phenocrysts of altered plagioclase, as much as 2 mm long, in a felty groundmass that is rich in altered plagioclase less than 0.1 mm long. The primary texture in much of the greenstone has been obliterated during alteration.

The greenstone is cut locally by hypabyssal rocks, by several discontinuous quartz veins (some containing copper minerals), and by numerous faults.

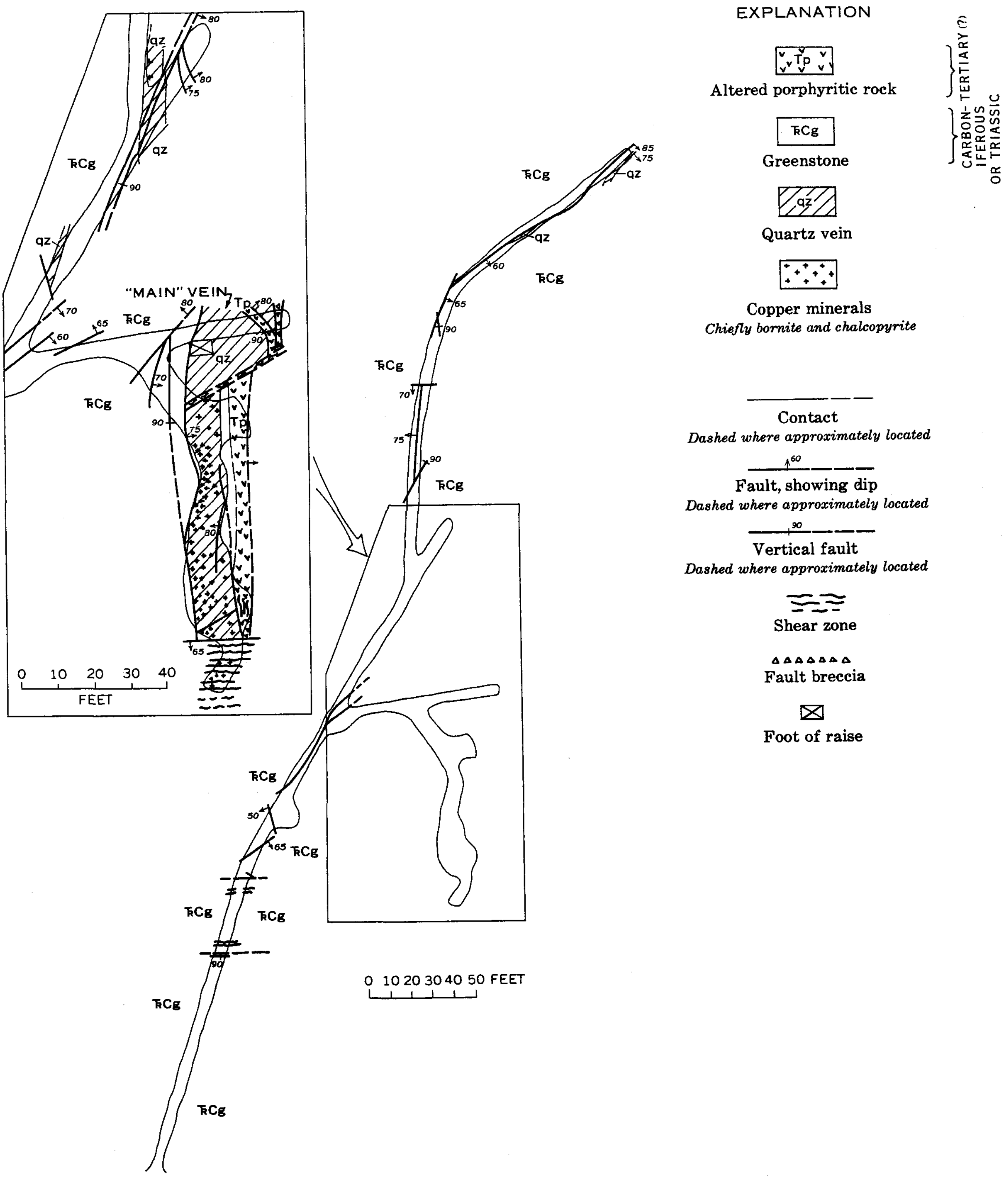
The hypabyssal rocks consist of diabase and a highly altered porphyritic rock. The diabase is known only from a few outcrops where it commonly forms sills as much as 20 feet thick and is slightly altered. It is fine grained, has a diabasic texture, and consists chiefly of pyroxene (augite?), plagioclase, and uralitic hornblende in nearly equal amounts. Its lesser constituents are secondary iron oxides that are mainly alteration products of opaque minerals, and clay minerals. Quartz-chlorite-epidote veinlets cut some of the diabase.

A narrow altered porphyritic dike is exposed in the underground workings along a fault a few feet from a mineralized quartz vein, the "main" vein (fig. 2). Rock making up the dike is light gray and contains medium-grained phenocrysts of altered feldspar in a fine-grained groundmass that is rich in plagioclase and calcite. Phenocrysts constitute about 25 percent of the rock's volume. They are largely altered to calcite, chalcedony, epidote, and clay minerals. Subordinate constituents in the groundmass are apatite, altered opaque minerals, and chlorite. The rock is cut by numerous veinlets containing epidote, calcite, iron oxides, and quartz. Both the diabase and the porphyritic dike are probably Tertiary in age, although field evidence for their age assignment is meager.

Faults are numerous and well exposed in the underground workings, but little is known of their areal distribution.

A steep fault zone, which strikes eastward and whose component fractures dip between 65° S. and vertical, and several steep subsidiary faults that strike northeastward are exposed in the underground workings (fig. 2). The fault zone is about 35 feet thick and is characterized by abundant gouge and breccia. The subsidiary faults commonly contain minor gouge and, uncommonly, breccia. The "main" quartz vein is cut by the fault zone and is partly bounded by north-striking faults that dip nearly vertically.

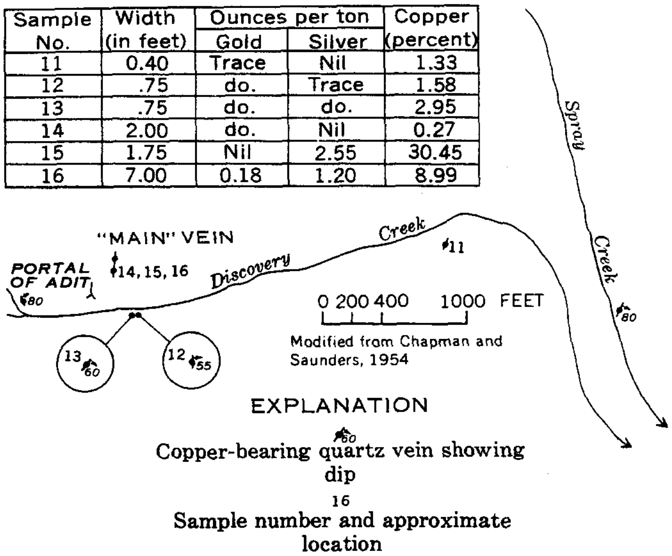
Several copper-bearing quartz veins crop out at the prospect (fig. 3), but they commonly are not traceable along strike for more than 100 feet because of inherent discontinuities or poor exposures. Most of the veins strike nearly north, dip vertically or steeply east or west, and range from a few inches to about 20 feet in thickness. Only one of the veins, the "main" vein, is large enough and rich enough to have encouraged exploration. It has been explored by both the underground workings and by some of the surface cuts. The copper content of the "main" vein diminishes northward from the intersection between the vein



Base map from MacLaren River
Copper Corporation, 1957

Geology mapped by A. E. Weissenborn,
E. M. MacKevett, Jr., G. O. Gates, and
E. W. Parsons, 1957, 1958

Figure 2.—Geologic map of the level workings, Kathleen-Margaret prospect.



Sample No.	Width (in feet)	Ounces per ton		Copper (percent)
		Gold	Silver	
11	0.40	Trace	Nil	1.33
12	.75	do.	Trace	1.58
13	.75	do.	do.	2.95
14	2.00	do.	Nil	0.27
15	1.75	Nil	2.55	30.45
16	7.00	0.18	1.20	8.99

Modified from Chapman and Saunders, 1954

FIGURE 3.—Location and sampling data of outcrop samples, Kathleen-Margaret prospect.

and the fault zone (fig. 2). The small quartz bodies that are exposed in the northern part of the adit may be parts of the "main" vein, in which case a size diminution of the vein to the north is also indicated. The "main" vein is not known with certainty south of the fault zone, although the two small quartz veins south of Discovery Creek that were sampled by Chapman and Saunders (fig. 3, Nos. 12 and 13) may be branches of an offset segment of the "main" vein.

The veins consist largely of quartz in the form of strained anhedral crystals between 1 and 2 mm in diameter. Much of the quartz is fractured and cut by a system of calcite veinlets that intersect approximately at right angles. The veinlets contain minor quantities of quartz along with the calcite. Most of them are less than 0.1 mm thick. Irregular masses of chalcopyrite and bornite, mostly a few millimeters but as much as several centimeters across, cut and replace the early quartz, and are also cut by the calcite veinlets.

Bornite and chalcopyrite are intimately associated throughout most of the ore, with chalcopyrite forming irregular blebs in bornite-rich samples and the converse prevailing in the chalcopyrite-rich samples. Bornite is the most abundant sulfide mineral in most of the ore. Surface coatings of malachite are conspicuous in some of the vein outcrops and also on breccia fragments within the pervious fault zone.

The grade of ore ranges from a few tenths of a percent to about 30 percent copper, but commonly it is between 1 and 5 percent. The ore also contains minor values in silver and traces of gold. The zone of richest ore, about 60 feet long, 5 feet wide, and 100 feet high, extends northward from the fault zone and is adjacent to the west wall of the "main" vein.

The diminution in copper values in the "main" quartz vein northward from the fault zone suggests that the fault zone may have been significant in the ore genesis. Possibly the copper-bearing solutions ascended a conduit formed at the intersection between the fault-controlled "main" vein and the incipient fault zone and found receptive hosts in the adjacent fractured vein quartz. The copper minerals may have been derived from late-stage fluids associated with the porphyry dike. The process of ore formation probably was part of a sequence involving (1) the formation of the "main" vein and similiar veins by quartz deposition in open spaces formed by previous fracturing; (2) fracturing of the vein quartz; (3) intrusion of the porphyry dike; (4) deposition of chalcopyrite and bornite in the quartz vein near the fault zone during the initial stage of development of the fault zone; (5) additional faulting, particularly along the fault zone; (6) deposition of calcite-rich veinlets in the quartz vein; and (7) mobilization and deposition of the secondary copper minerals in the fault zone and outcrops of the veins contemporaneous with recurrent movements along the fault zone.

All the known copper-bearing veins at the prospect are near the projection of the east-striking fault zone, which tends to strengthen the belief that the fault zone had a role in the ore formation. However, additional field and laboratory work should be done before a theory on the genesis of the MacLaren River deposits can be advanced with reasonable assurance.

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