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MAGNETITE DEPOSITS NEAR KLUKWAN AND HAINES, SOUTHEASTERN ALASKA

By

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ABSTRACT

Low-grade iron ore is found in magnetite-bearing pyroxenite bodies near Klukwan and Haines in Southeastern Alaska. An alluvial fan at Haines also contains magnetite-bearing rock of possible economic significance.

The Haines-Klukwan area is underlain by rocks of Mesozoic age including epidote diorite, quartz diorite, and alaskite of the Coast Range batholith, metabasalt (recrystallized lava flows and pyroclastic rocks), and, in the southern part, interbedded slate and limestone. Layering and foliation, where perceptible, generally strike northwest and dip steeply northeast. The iron deposits are found at or near the contact between the metabasalt and epidote diorite; they appear to represent highly altered lava flows that were metamorphosed during the emplacement of the batholith.

Several billion tons of rock containing about 13 percent magnetic iron are included in the pyroxenite body at Klukwan. Sampling and dip-needle data suggest the presence there of two or three tabular zones in which the rock has an average magnetic iron content of 20 percent or more. Pyroxenite bodies outcropping in three areas near Haines apparently are lower in grade than the Klukwan deposit; lack of exposures prevented thorough sampling but reconnaissance traverses with a dip needle failed to reveal important zones of high-grade iron ore.

An alluvial fan adjoining the pyroxenite body at Klukwan contains several hundred million tons of broken rock having a magnetic iron content of about 10 percent.

INTRODUCTION

This report describes a large low-grade magnetite deposit near Klukwan and smaller low-grade magnetite deposits near Haines in Southeastern Alaska (fig. 1). Haines is a town of about 500 people and a deep-water port with good docking facilities near the head of Lynn Canal. Klukwan is an Indian village of about 150 people 22 miles northwest of Haines along the paved portion of the Haines Highway (fig. 2). Gravel roads extend to the magnetite deposits from Haines and Klukwan.

The Haines district is similar in general geology to the Porcupine Creek district, a placer-gold area 12 miles west of Klukwan described by Wright (1904) and Eakin (1919), and to the Berners Bay area 30 miles to the southeast, described by Knopf (1911). The magnetite deposits at Haines and Klukwan were observed by prospectors on their way to the Porcupine and Yukon gold districts in 1899, but the first published descriptions were those of Knopf (1910) and Eakin (1919, p. 27-29). Thorne (1949) describes the results of a detailed investigation of the Klukwan deposit, and Wells and Thorene (1953) describe proposed methods of beneficiation of the magnetite-bearing rock.

Field investigations for this report were accomplished by

Geological Survey parties in 1950 and 1953. The author was assisted by O. E. Tolbert and R. Velikanje, geologists, and A. E. Nessett and R. Manuell, field assistants.

GEOGRAPHIC SETTING

The Haines-Klukwan area consists essentially of the Takshanuk Mountains, a steep-sided ridge rising 3,000 to 6,000 feet above the Chilkat River and extending 30 miles northwestward from Haines. The valleys of the Chilkat and Chilkoot Rivers separate the Takshanuk Mountains from other ranges to the west and east. The Chilkat Peninsula is a subdued continuation of the Takshanuk Mountains extending 18 miles southeastward from Haines. Tolson, Anyaka, Shikosi, and Kataguna Islands continue the topographic trend 6 miles farther southeastward down Lynn Canal.

The Haines-Klukwan area has been intensely glaciated; a few glaciers exist now in cirques on the northeast flank of the Takshanuk Mountains, and all cirques on that flank have small end moraines and pro-talus ramparts remaining from the last ice advance in Recent time. Oversteepened mountain sides, striated and grooved rock surfaces, erratic boulders on slopes above 3,500 feet altitude as well as in the Chilkat River flood plain, and the rounded forms of two hills, 1,250 and 1,755 feet high, on Chilkat Peninsula demonstrate the former presence of much larger glaciers that covered all except the highest ridges of the Haines-Klukwan area.

The vegetation of the Haines-Klukwan area consists of forest and brush at low altitudes and alpine tundra at high altitudes. The forest is composed of spruce, hemlock, cottonwood, and birch and is confined to altitudes below 1,500 feet. Alder, willow, dwarf maple, devil's-club, and berry bushes form dense underbrush in the forest and extend above timberline to altitudes of about 3,000 feet. Alpine tundra, consisting of mountain hemlock, grasses, and mosses, extends from the shrubline to the mountain tops.

The Haines-Klukwan area has warm summers and severe winters (table 1). Rainfall is moderate but snowfall is heavy. Severe cold and heavy snowfall are likely to hamper open-pit mining operations from November through March.

Table 1.--Climatic data for Haines and Klukwan, Southeastern Alaska.[1]

A. Mean monthly temperatures

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean Annual
Haines	24	26	32	40	49	55	57	56	50	42	32	25	41
Klukwan	12	19	27	38	48	55	57	55	49	38	25	16	37

B. Other data

	Last frost	First frost	Coldest winter temp. from avg. mo. min.	Warmest summer temp. from avg. mo. max.	Mean Ann. Precip.	Mean Ann. Snowfall
Haines	May 22	Sept. 21	-16° (Feb.)	90° (July)	60	123
Klukwan	June 2	Sept. 18	-36° (Dec.)	99° (July)	22	104

[1] Based on United States Weather Bureau records for Haines from 1925 to 1949 and for Klukwan from 1908 to 1922.

GENERAL GEOLOGY

Rocks of the Haines-Klukwan area are similar in lithology and structure to and represent a northwestward extension of rocks in the Berners Bay area described by Knopf (1911, p. 14-21). Coarse-grained igneous rocks of the Coast Range batholith underlie the northeastern part of the Haines-Klukwan area, and metabasalt consisting of metamorphosed basaltic lava flows and pyroclastic rocks underlies most of the southwestern part (fig. 2). Interbedded slate and limestone underlie a small area on the southwest side of Chilkat Peninsula. The magnetite deposits consist of masses of magnetite-bearing pyroxenite, which may be a more highly metamorphosed, more mafic, and coarser-grained facies of the metabasalt.

Sedimentary and volcanic rocks of Mesozoic age

Slate and limestone.--Interbedded slate and limestone underlie a small area on the southwest side of Chilkat Peninsula. The alternating layers of calcareous slate and shaly limestone have an average thickness of 1 inch. The rocks are isoclinally folded with vertical limbs, and the true thickness of the unit probably is much less than the outcrop breadth of 3,000 feet. The slate is bleached and baked to hornfels at the contact with the metabasalt to the east, indicating that the slate is older than the volcanic rocks. The slate-limestone unit lies on the general strike with, and may be equivalent to, the Berners formation of Berners Bay as used by Knopf (1911, p. 17) which he considered to be Upper Jurassic or Lower Cretaceous. No other evidence of the age of the unit was found in the Haines-Klukwan area.

Metabasalt.--Metabasalt underlies most of Chilkat Peninsula and occupies a narrow strip along the southwest side of the Takshanuk Mountains adjacent to the batholith. The metabasalt is dark green, fine grained, and amygdaloidal; it consists chiefly of pyroxene and feldspar with 1 to 3 percent magnetite. Beds of pyroclastic breccia and tuff are exposed locally, and pillow lava is found on the southwest side of Chilkat Peninsula. The flow rocks are massive, and bedding is generally obscure; a faint layering having a northwest strike can be discerned in places. The contact between the metabasalt and the igneous rocks of the batholith is sharply defined and dips moderately to steeply northeastward. The metabasalt occupies the same structural and stratigraphic position as similar rocks in the Berners Bay area (Knopf, 1911, p. 19-21) and is probably equivalent in age. Knopf considers the metabasalt at Berners Bay to be Jurassic or Cretaceous in age.

Pyroxenite.--Magnetite-bearing pyroxenite crops out in several areas clustered within a 2-mile radius of Haines and in another large body northeast of Klukwan (fig. 2). The pyroxenite is thought by the author to be a more highly metamorphosed and mafic facies of the metabasalt and therefore of the same age. The metamorphism to pyroxenite presumably took place during the emplacement of the Coast Range batholith in Cretaceous time. Similar rocks in the Berners Bay area are called hornblendik by Knopf (1911, p. 25-26); he considers the hornblendik there to be intrusive and to have been emplaced concurrently with the Coast Range batholith.

The pyroxenite of the Haines-Klukwan area is described in more detail under magnetite deposits (ms. p.10).

Sedimentary rocks of Cenozoic age

Conglomerate.--Well-indurated conglomerate makes up Kochu Island in Chilkat Inlet. It is composed of rounded pebbles and boulders of quartz diorite, quartzite, metabasalt, slate, limestone, and graywacke. The total thickness exceeds 300 feet. The conglomerate is tilted to a dip of 50° W. The degree of induration and tilting suggests that the conglomerate is older than Quaternary; the presence of quartz diorite boulders indicates an age younger than the batholith; therefore the conglomerate is believed to be of Tertiary age.

Alluvium and marine clay.--Unconsolidated sediments cover most lowlying areas. Sand and gravel alluvium comprise the floodplains of the Chilkat and Chilkoot Rivers, and marine clay is found near the town of Haines. The unconsolidated deposits are composed mostly of glacial sediments that have been reworked by streams and marine waters.

Alluvial fans.--Two large alluvial fans are on the southwest side of the Takshanuk Mountains, at Klukwan and at Mile 18 on the Haines Highway. The Klukwan fan is composed of fragments of pyroxenite and epidote diorite, and the fan at Mile 18 consists of fragments of epidote diorite and quartz diorite. Each fan has a radius of about one mile and a height at the apex of about 700 feet above the Chilkat River. Both fans are found below closely jointed zones in the rocks of the ridge.and probably originated by rapid erosion along these zones.

All the unconsolidated sediments are younger than the last major glaciation and therefore are of Quaternary age.

Intrusive igneous rocks

Quartz diorite.--Quartz diorite of the Coast Range batholith underlies the northeast half of the Takshanuk Mountains. It is medium grained, massive, and light gray; it consists of plagioclase, quartz, orthoclase, hornblende, biotite, sphene, and a few accessory minerals. Quartz diorite apparently continuous with this body is found in the Berners Bay and the Eagle River areas (Knopf, 1911, p. 22-26; 1912, p. 23-32) and in the Juneau gold belt (Spencer, 1906, p. 13-16). The batholith rocks there are considered to be Cretaceous in age.

Epidote diorite.--Light- to medium-green diorite occupies a belt 1 to 2 miles wide between the quartz diorite and the metabasalt in the Takshanuk Mountains. This darker variety of diorite is composed essentially of plagioclase, hornblende, epidote, and biotite. The epidote is a minor but ubiquitous constituent, and the rock is therefore called epidote diorite. In places the rock is perceptibly foliated; the foliation strikes northwest parallel to the contact with the metabasalt and dips moderately to steeply to the northeast. The contact between the epidote diorite and the metabasalt is sharp; the contact with the quartz diorite is gradational through a distance of fity to several hundred feet. The epidote diorite is a facies of the quartz diorite and therefore presumably is Cretaceous in age.

Alaskite.--A stock of alaskite about 4 miles in diameter makes up the northwest end of the Takshanuk Mountains. The alaskite is an equigranular, light gray, massive rock of medium grain size; it consists of quartz, orthoclase, albite, and muscovite. No contacts with the other batholith rocks were seen, but the alaskite is assumed to be Cretaceous in age because it lies within the batholith.

Dike rocks.--A few diabase dikes cut the slate and limestone on Chilkat Peninsula; they may be contemporaneous with the metabasalt. A few felsite dikes are found in the metabasalt on the ridge adjacent to the Chilkat River; presumably these were intruded with the batholith rocks.

Geologic structure

The rocks of Mesozoic age in the Haines-Klukwan area have the northwest regional strike and northeast dip characteristic of other rocks of Mesozoic age throughout southeastern Alaska (Buddington and Chapin, 1929, p. 289-298). A major fault is thought to underlie the lower Chilkat Valley and to separate the rocks of Mesozoic age in the Haines-Klukwan area from rocks of Paleozoic age in the mountains to the west.

Isoclinal folds with vertical limbs in the slate and limestone unit and minor faults in the pyroxenite and metabasalt are superimposed upon the regional structure. All the Mesozoic rocks display two pronounced steeply dipping joint systems, one trending northward and the other trending eastward, as well as a less pronounced joint system having a northwest strike and a gentle northeast dip.

MAGNETITE DEPOSITS

Most of the magnetite deposits in the Haines-Klukwan area consist of large bodies of magnetite-bearing pyroxenite (fig. 2). A subsidiary magnetite deposit at Klukwan consists of an alluvial fan composed largely of magnetite-bearing pyroxenite. The deposits are low-grade, but it may be economically feasible to concentrate the iron to commercial grades by magnetic or gravity processes in a large-scale mining and milling operation. An understanding of the geologic occurrence of these iron ore deposits is vital to the planning of such an operation.

Magnetite-bearing pyroxenite

General description.--The pyroxenite body at Klukwan is relatively well exposed and consists of a compact, irregular-shaped central mass, tongues and tabular lenses extending northwest and southeast from the central body, and a U-shaped lens lying north of the central body (fig. 3). The pyroxenite bodies near Haines are covered by dense forest and their boundaries cannot be determined in detail.

The pyroxenite is dark green, and the range in size of silicate grains is from one-eighth inch to several inches in length. It is composed principally of pyroxene and amphibole and of lesser quantities of feldspar, chlorite, epidote, calcite, magnetite, and ilmenite. Olivine was observed in one specimen. Augite generally predominates, but in places the rock consists chiefly of blades of hornblende intermixed with smaller quantities of actinolite. A layer of granular andesite, thought to be a tuff bed, is exposed in Canyon 2. [1]

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[1] The numbered canyon designations used in this report are those used by Barkdull and associates, owners of the claims at Klukwan.

Ore mineralogy.--The magnetite-ilmenite content ranges from 5 to 51 percent. The ore minerals occur in disseminated grains and in sparsely distributed irregular branching masses from one inch to several feet long.

The detailed relations of the ore minerals were studied by the examination of 7 polished sections, all cut from specimens collected in the Klukwan deposit.

Polished sections of the pyroxenite with disseminated magnetite show an intimate mixture of magnetite and ilmenite. The magnetite grains are not homogeneous, but are made up of two finely blended phases, a relatively pure iron oxide and a titanium-bearing iron oxide called titaniferous magnetite. Other metallic gangue minerals are hematite, chalcopyrite, pyrite, and leucoxene, but they are present only in very small amounts. Silicate gangue minerals are mostly pyroxenes and amphiboles. The grains of magnetite have an average diameter of 0.5 mm; they range in size from 0.01 to 5.0 mm. About half of the ilmenite occurs as tiny, lath-like grains about 0.003 mm long distributed in cubic and octahedral exsolution patterns in the magnetite, and the other half occurs as rounded grains 0.2 mm in diameter found within or adjacent to the magnetite grains.

Deleterious impurities and trace elements.--Chemical analyses by wet methods for deleterious impurities were made of ore from Canyon 2 at 1,350 feet altitude (sample 46, table 2) and from the cliff above Canyon 8 at 4,550 feet altitude (sample 81, table 2).

Table 2.--Partial chemical analysis of magnetite-bearing pyroxenite.[1]

Sample No.	Percent Magnetic Fe	Percent Total Fe	Percent TiO_2	Percent S	Percent P	Percent Fe in magnetic concentrates
46	11.0	18.4	1.7	.01	.013	65.0
81	8.8	18.3	2.2	.02	.017	62.5

[1] Analyses were made by M. Grasso, Sarah M. Berthold, and L. Shapiro of the U. S. Geological Survey.

Spectrographic analyses for trace elements were made of magnetite concentrates separated from these same two ore samples (table 3). About 7 percent of each magnetic concentrate was silicate gangue; the amounts of trace elements given in table 3 include constituents of the accompanying gangue minerals as well as those of the magnetite.

Table 3.--Spectrographic analyses for trace elements in magnetic concentrates.

Sample No.	Percent Cu	Percent Mn	Percent Ni	Percent Cr	Percent V	Percent Sc	Percent Al	Percent Mg	Percent Ca
46	.038	.17	.14	.004	.28	.0005	2.2	.70	1.22
81	.024	.26	.004	.001	.28	.0001	2.4	.52	.26

Looked for but not found: Ag, Au, Hg, Pt, Mo, W, Re, Ge, Sn, Pb, As, Sb, Bi, Zn, Cd, In, Co, Ga, Y, La, Ce, Th, Nb, Ta, U, Be, Sr, Ba, B.

The analyses were made by Richard S. Harner of the U. S. Geological Survey.

Structure and contact relations.--The pyroxenite at Klukwan is cut by closely spaced joints but the pyroxenite bodies appear otherwise massive and structureless when viewed close up. However, a distinct layering can be seen from a distance in pyroxenite in the upper, vegetation-free slopes of the Takshanuk Mountains. Layering is also suggested by the distribution of high-grade ore and high magnetic intensities in the pyroxenite body at Klukwan (ms. p. 18).

Minor faults were seen in the Klukwan deposit, but there are no large offsets.

The pyroxenite near Haines surrounds a small body of epidote diorite and is surrounded in turn by metabasalt. The pyroxenite at Klukwan is entirely surrounded by epidote diorite. Boundaries between the pyroxenite and the metabasalt are gradational and irregular; boundaries between the pyroxenite and the epidote diorite are sharp.

Klukwan lode deposit

History

Interest in the Klukwan magnetite deposit began in 1899 when prospectors, following the Dalton Trail along the Chilkat River to the placer-gold districts at Porcupine Creek and along the Yukon River in Canada and Alaska, observed the magnetite-bearing rock, presumably while visiting the Indians of Klukwan village. Claims were first filed on the Klukwan deposit in 1908 by W. S. Brown and associates of the Alaska Iron and Steel Company (later the Alaska Iron Company) of Portland, Maine. No development work was done. In 1910 H. B. Le Fevre restaked eight of the Alaska Iron Company claims, but he held them for only one year.

C. H. Barkdull and associates staked about 20 lode claims on the Klukwan pyroxenite body in 1916 and 1917, and eight placer claims on the alluvial fan in 1917 and 1919. No important development work was done at that time, and a hiatus of 27 years followed during which no interest was shown in the Klukwan deposits.

In 1946 Barkdull joined with C. E. Russell, C. Houson, H. Hartman, and A. E. Schrimpf in forming Alaska Iron Mines, Inc., of Seattle, Washington to exploit the Klukwan deposit. Claims were staked covering the pyroxenite body and the alluvial fan. The corporation built about 5 miles of access roads from the Haines Highway over the fan to the foot of the mountain slope and performed other minor development work and gravity concentration tests during 1949, 1950, and 1951.

In 1952, Takahashi, Upton, and associates took an option to buy the claims and sponsored a brief diamond-drilling program. Quebec Metallurgical Industries, Ltd., built additional roads on the fan and slopes of the ridge and did other development work during 1953 and 1954; this concern has participated as of about October 1954 as a stockholder with Alaska Iron Mines, Inc., in the Klukwan Iron Corporation, as owners of the property.

Distribution of magnetic iron

Three methods were employed to determine the distribution of magnetic iron in the Klukwan pyroxenite body: direct visual observation; traverses with a dip needle; and collection of samples for chemical analysis. The method of direct observation was most important and served to direct the use of the other two methods.

Visual estimation of magnetic content.--Iron ore minerals comprising 5 percent or more of a rock are visible to the eye, although experience is required to recognize grains of magnetite in pyroxenite. With experience it is possible to estimate the volume percentage of magnetite in pyroxenite and therefrom to determine the iron content in weight percent. In rocks containing less than 45 percent by weight of magnetic iron the volume percentage of magnetite is approximately equal to the weight percentage of magnetic iron (that is, the iron contained in the magnetite). The relationship applies whether the rock gangue is felsic or mafic and is due to a compensation for the difference in density of magnetite compared to country rock by the dilution of iron in the magnetite by its oxygen content:

$$(\text{Wt. \% mag. Fe in ore}) = \frac{(\text{Vol. \% mt in ore})(\text{Density mt})(\text{Wt. \% Fe in mt})}{(\text{Vol. \% mt in ore})(\text{Density mt}) + (\text{Vol. \% gangue in ore})(\text{Density gangue})}$$

A graph of this expression is given in figure 4 for two types of ores having gangue densities of 2.7 and 3.2 gm/cc. This method of estimating is appropriately used in sampling and mapping because magnetite ore is invariably beneficiated by processes depending on the high magnetic susceptibility or on the high density of the magnetite in order to obtain a satisfactory blast furnace ingredient; only the iron contained in the magnetite is recovered by either method.

Magnetic anomalies.--Dip needle traverses were run in several places across and beside the Klukwan pyroxenite body, relying on the assumption that a usable relationship can be found between the amount and location of adjacent magnetite and the strength of the magnetic field at each station. The dip needle used was of the Lake Superior type. (For the theory and practice of this magnetic method, see any textbook on geophysical prospecting, for example, Nettleton, 1940, Part II.)

Use of a dip needle or even a magnetometer is handicapped by high relief and steep slopes throughout much of the Klukwan deposit. Readings taken at the foot of declivities, especially in canyon bottoms, are as strongly influenced by nearby above-horizontal magnetite as by magnetite underfoot. The terrain problem casts doubt on the reliability of data obtained in the usual way by reading maximum swing or stationary positions of the dip needle. Therefore, a method employing an auxiliary magnet held at fixed distances (6 inches, 4 inches, and 3 inches) from the needle pivot was utilized to try to determine magnetic intensity more quantitatively. Horizontal and vertical intensity readings were made.

The magnetic data obtained were computed and plotted as profiles on a geologic outline map of the Klukwan deposit (fig. 5). The vertical intensity of the magnetic field is expressed in percent as the increment of intensity at the station divided by regional intensity:

$$100 \text{ X } \frac{\text{(Vertical intensity at station)} - \text{(Regional vertical intensity)}}{\text{(Regional vertical intensity)}}$$

The normal, regional vertical field intensity is taken as 0.54 oersteds. The inclination of the total intensity vector (fig. 5) with the horizontal is expressed as a difference in degrees from the normal regional inclination (which is taken as 84°) as follows:

(Inclination of total magnetic field at station) - (Inclination of total magnetic field of region)

Declinations determined with a sun dial compass also are shown in figure 5 wherever they were obtained, but they are too sparse to be significant.

At each station a comparison was made of the intensities calculated from the readings for the auxiliary magnet at the three distances, disclosing that replication was poor. The vertical intensity percentages in figure 5 may be in error by as much as half of their values, although most of them checked within 20 percent of their values. Stated in another way, the accuracy of a typical anomaly of 15,000 gammas was plus or minus 3,000 gammas. The maximum anomaly of observed vertical intensity from the regional vertical intensity (about 54,000 gammas) was 27,000 gammas.

Readings of the maximum position of the needle swinging from a horizontal starting position parallel to the magnetic meridian were obtained at each station also. It was found that these readings can be correlated very well with the vertical intensities determined with the auxiliary magnet. It is suggested that the maximum swing technique is adequate in such steep terrain, because in general only qualitative results are required anyhow.

The magnetic field intensities (fig. 5) in the canyons are considerably lower than those on the ridges, and generally show as negative percentages. However, this may be interpreted loosely to mean that the greater the negative percentage the nearer is above-horizontal rock of high magnetite content, and large negative percentages in the canyons may then be correlated with high positive percentages on the adjacent ridges.

Interpretation of the magnetic data in figure 5 must be qualitative, because the traverses are widely spaced and because the direct relation between the strength of magnetic anomaly and the magnetite content of the rock may be invalid in places due to unrecognized polarization effects. Northwest-trending zones of probable higher grade ore can be discerned by connecting the relatively high intensities (coupled with high chemical analysis) between adjoining traverses: high grade zones near the southwest edge and possibly across the middle of the pit body, and a lower grade zone near the northeast edge, located along a prominent layering in the body. The zone near the northeast edge of the body seems to be located along a prominent layering in the rock (fig. 6).

Sampling and chemical analyses.--The pyroxenite at Klukwan was sampled along several traverses where accessibility and cover permitted along canyon walls and cliff sides. Individual samples weighing about 25 pounds were obtained by taking chips at 3 to 5 feet spacings of fresh apparently homogeneous portions of the pyroxenite; the chips for each sample were collected over distances of one hundred to several hundred feet in length. The results of analyses of individual samples are given in table 4, and averages of groups of samples are shown in figure 5.

The iron samples were analyzed by the Geochemistry and Petrology Branch of the U. S. Geological Survey. They were crushed to minus 80 mesh, freeing most of the magnetite grains from the gangue minerals. The magnetic portion was then removed from each sample by using an ordinary hand magnet followed by a Davis Tube separation. Analyses were made of the undivided sample as well as of the magnetic concentrate in order to determine both the total iron content and the content of magnetic iron (table 3 and fig. 5). The average grade of magnetic iron for each sequence of samples was weighted for length of sample interval by dividing the sum of the products of the slope distances and the grades of the samples by the total slope distance.

Table 4.—Analyses of samples from Klukwan pyroxenite body.

Location	Approx. Elev. (feet)	Slope Dist. (feet)	Percent Magnetic Fe	Percent Total Fe	Percent TiO_2 *
Canyon 1, both walls from southwest to northeast	1450	150	13.2	18.2	1.8
	1500	160	13.2	19.8	1.7
	1550	250	6.3	19.4	1.3
	1600	250	12.7	19.3	1.8
Average grade			10.9		
Canyon 2, northwest wall from southwest to northeast	1300	250	11.5	15.5	1.8
	1350	400	11.0	18.4	1.7
	1400	200	18.4	24.3	1.9
	1450	170	16.3	22.1	2.0
	1600	300	5.9	14.0	1.6
	1700	450	11.4	18.0	1.8
	1900	200	18.0	24.9	1.9
Average grade			12.2		
Canyon 2, southeast wall from southwest to northeast	1350	110	11.8	19.0	1.7
	1350	110	14.2	19.5	1.8
	1400	210	13.7	19.2	1.6
	1600	300	6.7	14.4	1.8
	1700	450	11.4	18.0	1.8
Average grade			10.9		
Canyon 2, both walls, Average grade			11.7		
Canyon 3, at northwest rim, cliff outcrop	4400	200	9.9	18.1	1.9
Canyon 3, grab sample of talus	3100	-	13.4		1.2*
Canyon 4, northwest wall from southwest to northeast	1250	120	38.1		1.8*
	1300	110	29.0		1.4*
Average grade			33.6		
Canyon 4, southeast wall from southwest to northeast	1250	130	42.2		1.7*
	1300	125	38.7		1.9*
Average grade			40.5		
Canyon 4, both walls, from southwest to northeast	1350	260	12.1		1.1*
	1700	200	8.5		1.3*
	2000	440	17.8		1.3*
Average grade			14.1		

Table 4.—Analyses of samples from Klukwan pyroxenite body.—Continued

Location/	Approx. Elev. (feet)	Slope Dist. (feet)	Percent Magnetic Fe	Percent Total Fe	Percent TiO_2
Canyon 5, both	1400	1550	14.4	23.5	1.9
walls from southwest	1800	400	31.2	35.3	2.3
to northeast	1900	570	11.0	18.3	1.8
Average grade			17.3		
Canyon 5, cliff outcrop	4600	100	11.2		1.0*
Canyon 6, cliff outcrop,	4400	150	8.5	16.2	2.0
southwest to northeast	4600	180	7.4	15.1	1.8
Average grade			7.9		
Canyon 8, cliff outcrop,	4400	500	8.4	15.5	1.7
southwest to northeast	4550	400	8.8	18.3	2.2
	4600	300	5.5	13.8	1.9
Average grade			7.8		
East of Canyon 1, out-	4300	150	28.1	35.9	3.0
crops of two tongues of pyroxenite	4800	150	7.3	14.9	1.7

* TiO_2 determinations marked with asterisks were made on the magnetic concentrates. All other TiO_2 determinations were made on undivided samples.

_/ All analyses by M. Grasso, Sarah M. Berthold, and L. Shapiro of the U. S. Geological Survey

The results of sampling, dip-needle traverses, and geologic mapping are combined on a profile of Canyon 4 in figure 6 to illustrate their relationships. The magnetic anomaly of course, is affected by the adjacent steep walls of the canyon (ms. p. 16), but there is a correlation here of considerable content of magnetic iron with a large negative anomaly. High grade ore here is located at the contact of the pyroxenite with the epidote diorite, but pyroxenite at the contact elsewhere is low in magnetic iron; thus, the contact does not constitute a dependable ore guide.

Grade and reserves

Individual samples from the Klukwan pyroxenite body range in grade from 5.5 to 42.2 percent magnetic iron and from 13.8 to about 50 percent total iron according to analyses by the Geological Survey. Rock exposed through a slope distance of 255 feet in Canyon 4 and containing an average of 37 percent magnetite and 1.7 percent TiO_2 (fig. 5) probably is representative of the richer parts of the pyroxenite body.

Assuming an average depth of 1,000 feet, the Klukwan body contains between 1 billion and 5 billion tons of pyroxenite containing an average of about 13 percent magnetic iron. The average grade may be as much as 2 percent lower or 7 percent higher.

The analyses suggest that a zone of relatively high-grade iron ore extends across the lowest part of the pyroxenite body, outcropping at altitudes of 1,300 to 2,200 feet. Assuming an average width of

500 feet, a length of 10,000 feet, and an average depth of 1,000 feet, the zone contains 500 million tons of ore estimated to have an average grade of about 20 percent magnetic iron. The average grade may be 5 percent higher or lower.

Geologic aspects of mining, milling, and smelting problems

The magnetite-bearing pyroxenite body at Klukwan can be mined most easily by open-pit methods, if problems arising from the climate and terrain can be surmounted. Ore of better than average grade is available in the lowest part of the pyroxenite body, about 1,000 feet above the valley floor; however, the mountain side is very steep, and access roads to the deposit will be difficult to build. The climatic conditions that must be considered include heavy snowfall and low temperatures in the winter and heavy rainfall in September and October (table 1). The average rainfall during September and October is 3.5 and 2.5 inches, and the average maximum precipitation reported for 24 hours is 2.7 inches and 1.8 inches respectively. Occasional wash-outs of the Haines Highway occur at the alluvial fans at Klukwan and at Mile 18 during September and October. Access roads and open-pit mining facilities in the pyroxenite body would be difficult to maintain during these two months as well as during the winter.

In planning the beneficiation of the ore, consideration should be given to the effect of grinding upon the effectiveness of removing TiO_2 from the magnetic concentrate. At least one-fourth of the total TiO_2 is in leucoxene, sphene, or amphibole minerals;

these can be freed from adjacent magnetite grains by grinding to 80 mesh and will then be rejected in the magnetic concentration. Much of the remaining TiO_2 is in ilmenite of two size classes (ms. p. 11-12). The coarser grains, constituting about half of the ilmenite, can be freed from adjacent magnetite by grinding to 65 to 100 mesh, but the other half is in grains smaller than 200 mesh. It would be expensive to grind the ore to 200 mesh, and magnetic separation is ineffective in such fine-grained material. Consequently, the optimum degree of grinding is likely to be about 80 mesh. The magnetic concentrates from several samples ground to 80 mesh contained 1 to 4 percent TiO_2 (table 4).

The sulfur and phosphorus content in the pyroxenite is low and will be reduced even farther in magnetic concentration. The sulfur and phosphorus are contained principally in pyrite, chalcopyrite, and apatite; these have relatively low magnetic susceptibilities and would go into the tailings in magnetic beneficiation. It is concluded that the magnetic concentrates would not contain deleterious quantities of sulfur and phosphorus for use in either an electric or open-hearth furnace; this conclusion should be checked, however, by analyses for sulfur and phosphorus of a number of samples of magnetic concentrates.

Haines lode deposits

History

Magnetite-bearing rock was observed on the beach at Haines by the early settlers at Haines Mission in 1879. The first iron ore claims were staked on the pyroxenite body west of Haines (fig. 3) in 1906 by W. S. Brown and associates on behalf of the Alaska Iron and Steel Co. The Company drove a 100-foot tunnel in the pyroxenite body; the tunnel is now caved in. The Company abandoned its eight claims in 1911; they were restaked in 1912 by G. Franklin and others who relinquished them after one year. J. H. and A. S. Chisel staked a few claims on the pyroxenite body northeast of Haines in 1909, and other individuals staked claims on this body in the years through 1916; only a few, briefly held claims, have been staked on any of the pyroxenite bodies near Haines since 1916.

Distribution of magnetic iron

The Haines deposits were studied less thoroughly by sampling and by dip needle traverses than the Klukwan deposit, because it was obvious from visual examination that most of the pyroxenite croppings contain less than 10 percent magnetic iron. Eight widely spaced dip needle traverses were made, and only a few large magnetic anomalies observed (fig. 7). Heavy vegetation limited sampling to outcrops along the shore and along road cuts (table 5). The content of magnetic iron is considerably lower in samples from Haines than in samples from the Klukwan deposit; the averages range from 2 to 10 percent. The non-magnetic iron content of the pyroxenite is about 9 percent, somewhat higher than at Klukwan.

Grade and reserves

The sampling of the magnetite-bearing pyroxenite at Haines is not adequate to permit an estimate of the grade. Moreover, the areal extent of the pyroxenite cannot be determined accurately. Outcrops are limited to shoreline bluffs and road cuts; dense vegetation and a thick mantle of Quaternary sediments in intervening areas prevents an accurate delineation of the contacts; and the exact number of pyroxenite bodies present cannot be determined. Consequently, a calculation of possible ore reserves is not warranted. It can be said that the Haines deposits contain several billion tons of low-grade magnetite-bearing pyroxenite.

Table 5.—Analyses of samples from Haines pyroxenite bodies 1/

Location	Slope Dist. (feet)	Percent Magnetic Fe	Percent Total Fe	Percent TiO_2 *
Northeast of Haines, along road, at Nukdik Point, 1.6 to 2.3 miles from southwest to northeast	600	4.6	13.7	1.5
	1100	9.7	16.7	1.8
Average grade		7.9		
Southeast of Haines, 0.5 to 1.2 mi., southeast of Port Chilkoot, northeast side of Chilkat Peninsula, from northwest to southeast	300	8.1	15.6	1.8
	450	2.0	10.9	1.3
	400	9.6	19.0	1.8
Average grade		6.2		
South of Haines, 1.95 to 2.15 mi., on Cannery road, southwest side of Chilkat Peninsula, from north to south	500	7.2	15.2	1.8
	250	5.5	15.2	1.8
	400	3.7	13.6	1.8
Average grade		5.6		
Northwest of Haines, above collapsed tunnel of Alaska Iron and Steel Co., at 600 feet elevation	100	9.6		1.6*
Northwest of Haines, ½ mile west of tunnel site, several outcrops on cliff and in creek bed, from 500 to 850 feet elev.	-	8.0		2.3*

* TiO_2 determinations marked with asterisks were made on the magnetic concentrates. All other TiO_2 determinations were made on undivided samples.

1/ All analyses by M. Grasso, Sarah M. Berthold and L. Shapiro of the U. S. Geological Survey.

Klukwan alluvial fan deposit

History

The large alluvial fan at the mouth of Canyons 1 and 2 on which the village of Klukwan is built (fig. 3) has been proposed as a ready source of broken iron ore (oral communication, Barkdull, et al., of Alaskan Iron Mines, Inc.) because much of it was eroded from the magnetite-bearing pyroxenite body in the Takshanuk Mountains. A much smaller compound fan at the mouths of Canyons 4, 5, 6, and 7 is composed of similar material but is so small compared to the fan below Canyons 1 and 2 that it is not given further consideration here. The history of claim ownership and development on the alluvial fan is similar to that of the Klukwan lode deposit (ms. p. 14).

Description

The fan is shaped like half of a right circular cone with a flat slope (fig. 8). The surface contours are almost semicircular. The surface ranges in slope from 6° at the toe to 10° at the apex. It is covered with a forest of spruce, birch, balsam poplar, and western hemlock with considerable willow and alder.

Water flows all year round in the stream from Canyons 1 and 2 providing a supply for Klukwan village. The flow of water is highly variable; no discharge records are available, but the discharge is estimated by the author to range from less than 10 cubic feet per second during winter to more than 1,000 cubic feet per second after heavy rain storms in September and October. The debris of the fan is moved most effectively by the floods resulting from the immediate large runoff that follows the autumn storms. Channels 3 to 10 feet deep are cut in the fan during these periods. A considerable amount of material also is moved by mudflows, especially in zones on the fan where the underbrush and soil are sparse. One such zone extends straight out, S. 50° W., from the canyon mouth. The boulders on the lower part of the fan were probably rafted on mudflows to their present positions.

The detrital material of the fan ranges in size from silt to large boulders and consists of magnetite-bearing pyroxenite and epidote diorite. Detritus in the floor of Canyon 1 is composed of equal quantities of both rock types, and detritus in Canyon 2 consists almost entirely of pyroxenite. The confluence of the two streams lies 2,000 feet upstream from the apex of the fan, so that the rocks from the two canyons are well mixed and the pyroxenite diluted by epidote diorite in the fan.

Distribution of magnetite

Sampling procedure.--In order to evaluate the fan as a source of ore, a study was made of the approximate distribution of magnetite on the surface of the fan according to the size and weight of the enclosing rock fragments.

Twenty-nine samples were taken at irregularly spaced locations. The sampling was done in two ways and the results combined later by computation: a visual estimate was made of the volume percentage of cobbles and boulders larger than 4 inches in average dimension, and a grab sample was taken of the material smaller than 4 inches. Most of the samples were taken from vertical faces cut in the fan by bulldozer or by stream action, and the other samples were taken from a horizontal part of the fan surface. Each sample was taken from a horizontal or vertical area of 20 to 50 square feet.

The visual estimates were made by listing the sizes of all boulders and cobbles observed in the sample area. Boulders of epidote diorite and of pyroxenite were listed separately. For each pyroxenite boulder, an estimate was made of the percentage of magnetite contained, based on moderate experience with variations in the pyroxenite by detailed megascopic and microscopic examination. A visual estimate also was made of volume percentages of rock fragments larger and smaller than 4 inches in diameter. These visual estimates are admittedly subjective and of low precision, but because they were all made by one person, they should be at least internally consistent. Confidence was gained in the visual estimates when a fair compatibility with data from the sieved and weighed grab sample was observed in the cumulative weight and size distribution curves. Nevertheless, considering the lack of precision inherent in visual estimates and the initial and uneven sorting of the aggregate found on the fan, the overall accuracy of the data obtained in the study is probably rather low.

The grab samples weighed 20 to 30 pounds apiece and were taken by scraping off small portions of material at convenient intervals across each sample area. The samples were put through a nest of sieves, and the weight percentage determined for each size interval. The size classes used in classifying visually estimated and sieved material are listed in table 6 (the size classes are rather large and not quite standard):

Table 6.--Size classes and names for analysis of Klukwan alluvial fan

Class	Upper Size Limit	Lower Size Limit	Midpoint Size	Name
1	128 inches	32 inches	64 inches	Large boulders
2	32	8	16	Small boulders
3	8	2	4	Cobbles
4	2	.500	1	Coarse gravel
5	.500	.132	.250	Fine gravel
6	.132 (6 mesh)	.0331	.066	Coarse sand
7	.0331 (20 mesh)	.0083	.0166	Medium sand
8	.0083 (65 mesh)	.0029	.0042	Fine sand
9	.0029 (200 mesh)	-	.0015	Coarse silt

The data obtained by visual estimation and by sieving were combined by using the following densities:

Magnetic fraction from sieving	5.0 gm/cc
Non-magnetic fraction from sieving	3.0
Epidote diorite boulders and cobbles	2.7
Pyroxenite boulders and cobbles	3.3

Volume percentages of the sieved material were combined with volume percentages of visually estimated material, and then both were recalculated to weight percentages. The size distribution through all nine size classes given in table 6 for each sample was thus determined on a weight basis.

For each grab sample, each size class was crushed to minus 65-mesh, split on a Jones riffle, and a magnetic separation made with a hand magnet. The products were weighed, and the magnetite content of each class was calculated for each sample. The separation of magnetite from the diorite and pyroxenite minerals was about 95 percent effective, judging from a rather cursory microscopic examination of the products of several samples.

Size and magnetic separation data on samples 1 and 2 of Wells and Thorne (1953) also have been incorporated in the illustrations (figs. 8, 9, and 10).

The median size of each sample was obtained from curves of cumulative weight percentages of sizes. The median size divides the sample in half, so that 50 percent by weight of the sample has a larger size and 50 percent a smaller size.

Size distribution.--A contour map of median sizes of each sample (fig. 9) shows that the central portion of the fan is coarser than the sides. The explanation of this is not readily apparent, but the topographic contours indicate greater erosion in the central portion than at the sides, and this may be due to the presence of thick vegetation on the sides and to the fact that erosion results chiefly from sudden periods of large stream discharges after the autumn storms. These factors cause the stream to remain in the lower, central portion of the fan most of the time and to wash out the fine material there.

The spread (that is, the degree of sorting or bunching) of the sizes about the median size is measured by the sorting coefficient, which is the square root of the ratio of the quartile sizes taken from the cumulative curves (Krumbein, 1938, chap. 9). The sorting coefficient for sample E-1, taken from just above the apex of the fan, is 4.8, indicating poor sorting of the material there. In order to generalize about the local significance of sorting on the Klukwan fan, a sorting factor was calculated from the ratio of the sorting coefficient of each sample to the sorting coefficient for sample E-1; rough boundaries to zones of sorting factors above and below 2.0 (fig. 9) show that the sorting is better around the apex and at the wings than in the middle portion of the fan.

The median size according to magnetite content was determined from cumulative curves of weight percentage of magnetite and is that size which halves each sample by weight of magnetite. A contour map of median sizes according to magnetite content (fig. 10) shows about the same pattern of size distribution as for the total sample. But in general, at a given location, the median size according to magnetite content is smaller by about half than the median size of the total sample. This indicates that the rate of comminution of the pyroxenite is more rapid than that of the epidote diorite.

The rate of comminution of all detritus with distance from the apex, starting from sample G-2 (fig. 9) at 1,500 feet elevation in

No. 2 Canyon through samples E-1 and C-12 down to the foot of the fan at the site of sample A-1, is illustrated by the frequency distribution graphs in figure 11. The relative amount and the weight distribution of the magnetite in these samples is also shown.

The distribution of boulders over the surface of the fan was analyzed from the visual estimate data. In order to categorize the distribution, the fan was arbitarily divided into five segments of about equal volume by vertical surfaces along the following contours: 500-foot, 400-foot, 300-foot, and 200-foot; and the segments designated from highest to lowest as follows: 500-700, 400-500, 300-400, 200-300, and 100-200. Estimated average figures of amounts of boulders greater than four inches in each segment and the largest sizes observed are given in table 7. The percentage of magnetic iron in the boulders relative to the total magnetic iron contained in each segment is also given.

Table 7.--Distribution of boulders over 4 inches in diameter on Klukwan alluvial fan

Segment	Weight Percent Epidote diorite Boulders	Largest Epidote Diorite Boulder Observed (Diameter in inches)	Weight Percent Pyroxenite Boulders	Largest Pyroxenite Boulder Observed (Diameter in inches)	Percent Total Magnetic Iron
500-700	15	28	20	40	27
400-500	10	21	12	28	17
300-400	7	20	8	28	8
200-300	8	20	3	18	5
100-200	1	16	1	18	1

Grade and reserves

Grade calculations are based on the 29 samples collected on the alluvial fan at Klukwan by the author and on two other samples collected by Wells and Thorne (1953). The magnetic fraction is assumed to consist entirely of magnetite containing 72.4 percent magnetic iron; the combined content of measured magnetic iron in the fine fraction and estimated magnetic iron in the coarse fraction is given at the site of each sample on figure 8.

The distribution of the magnetite is irregular, but the samples from the fan have an arithmetical average of 10 percent magnetic iron; this agrees well with the average magnetic iron content of four samples from the floors of Canyons 1 and 2. Because of the limited and rather hasty sampling, this average may be as much as 3 percent too high or too low.

Estimation of the reserves in the fan is handicapped by the lack of information as to the position and shape of the base. It is assumed here that the base is horizontal at an altitude of about 100 feet, but it is possible that a considerable quantity of flood-plain sediments of the Chilkat River underlie the fan detritus at altitudes higher than 100 feet. A series of churn-drill holes would permit a more accurate delineation of the position of the base of the fan.

Calculation of reserves is based upon the assumption that the fan can be represented by a wedge-shaped section of a cone 700 feet high having a basal radius of 6,000 feet and a sectional arc of 167° (fig. 8). One ton of fan material is assumed to occupy about 20 cubic feet. Calculations based upon these assumptions indicate that the fan has a volume of about 10 billion cubic feet and that it contains between 350 million and 600 million tons of magnetite-bearing detritus, depending on the amount of dilution by river deposits and on depth to bedrock.

It is concluded that the alluvial fan at Klukwan contains 500 million tons of material containing an average of 10 percent magnetite.

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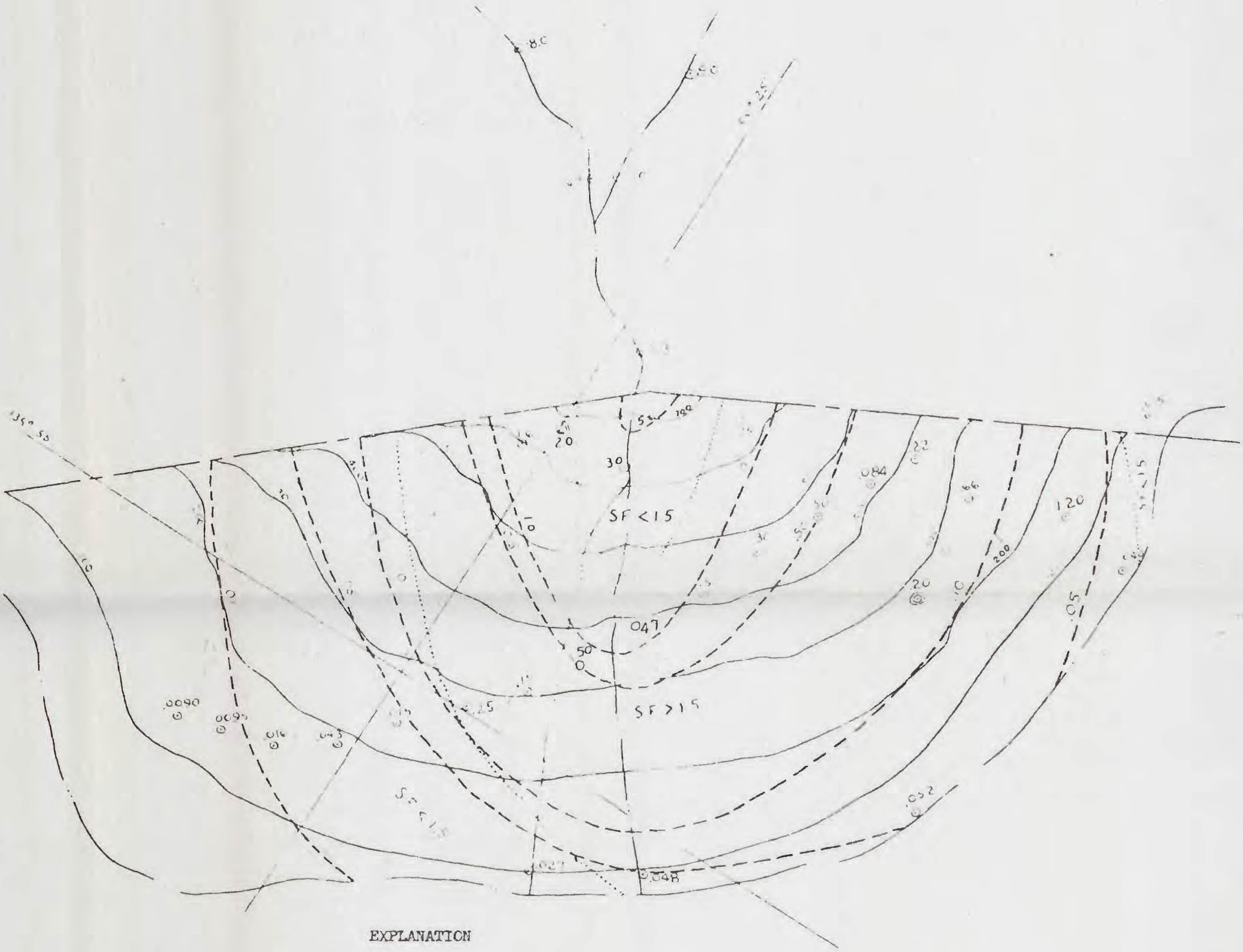
FIGURE 10

GRAIN SIZE AT THE MEDIAN OF MAGNETITE CONTENT IN ALLUVIAL FAN AT KLUKWAN



EXPLANATION

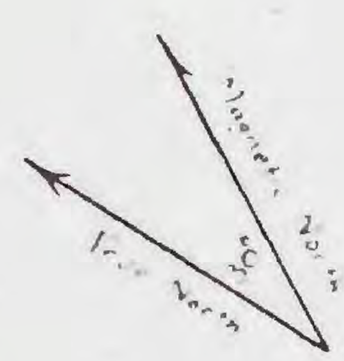
Grain size, inches, at sample locations

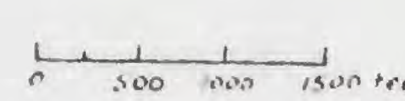
Contours of grain size, inches

Boundary of sorting factor

Drainage boundary

Arbitrary upper boundary of fan





This map is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

Topography. U.S.G.S., 195?

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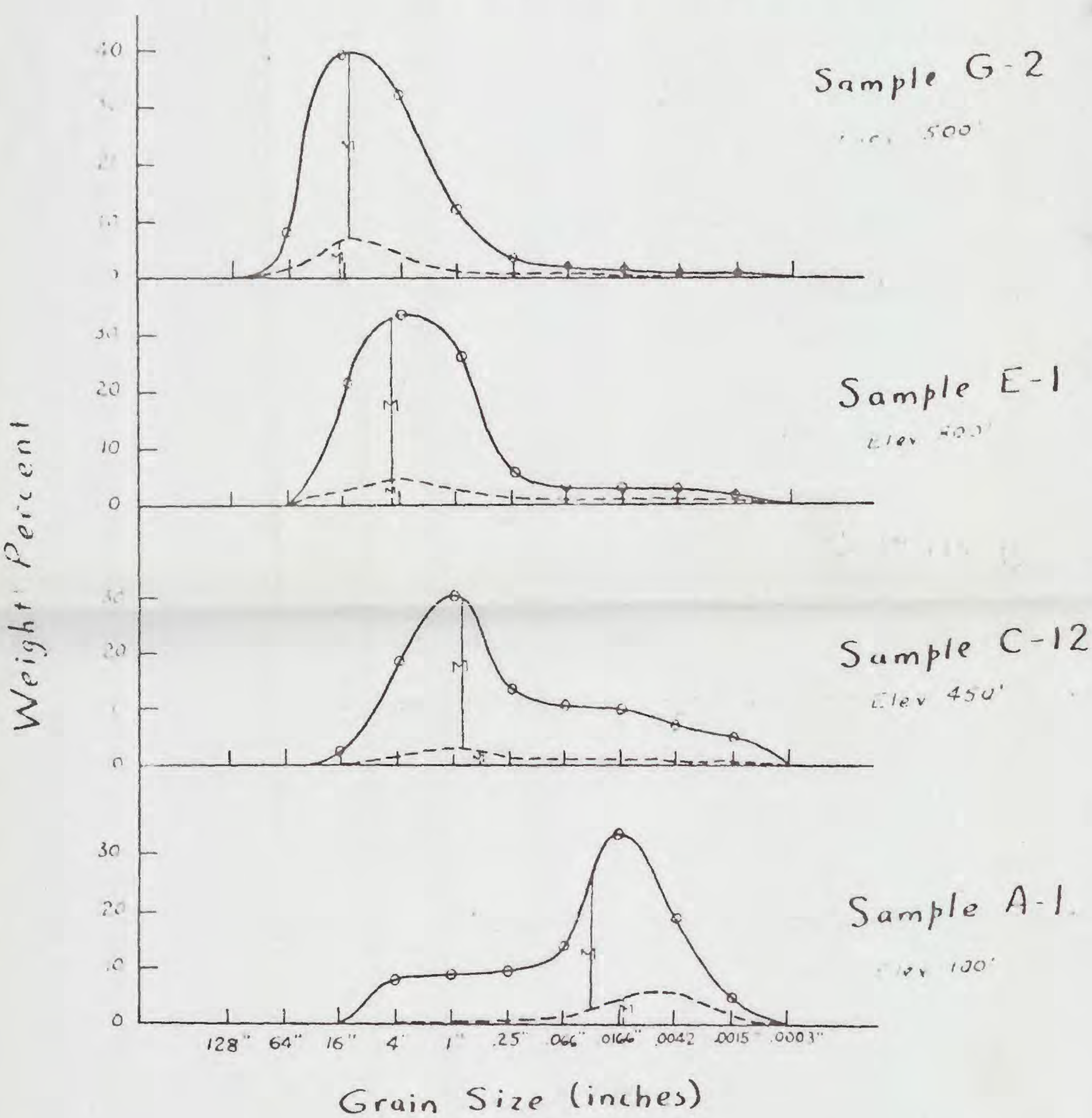
FIGURE II

REDUCTION IN GRAIN SIZE DOWN THE ALLUVIAL FAN AT KLUKWAN AS SHOWN BY FOUR FREQUENCY CURVES



EXPLANATION

Size distribution of total sample

Size distribution of % magnetic iron in sample

Median grain size

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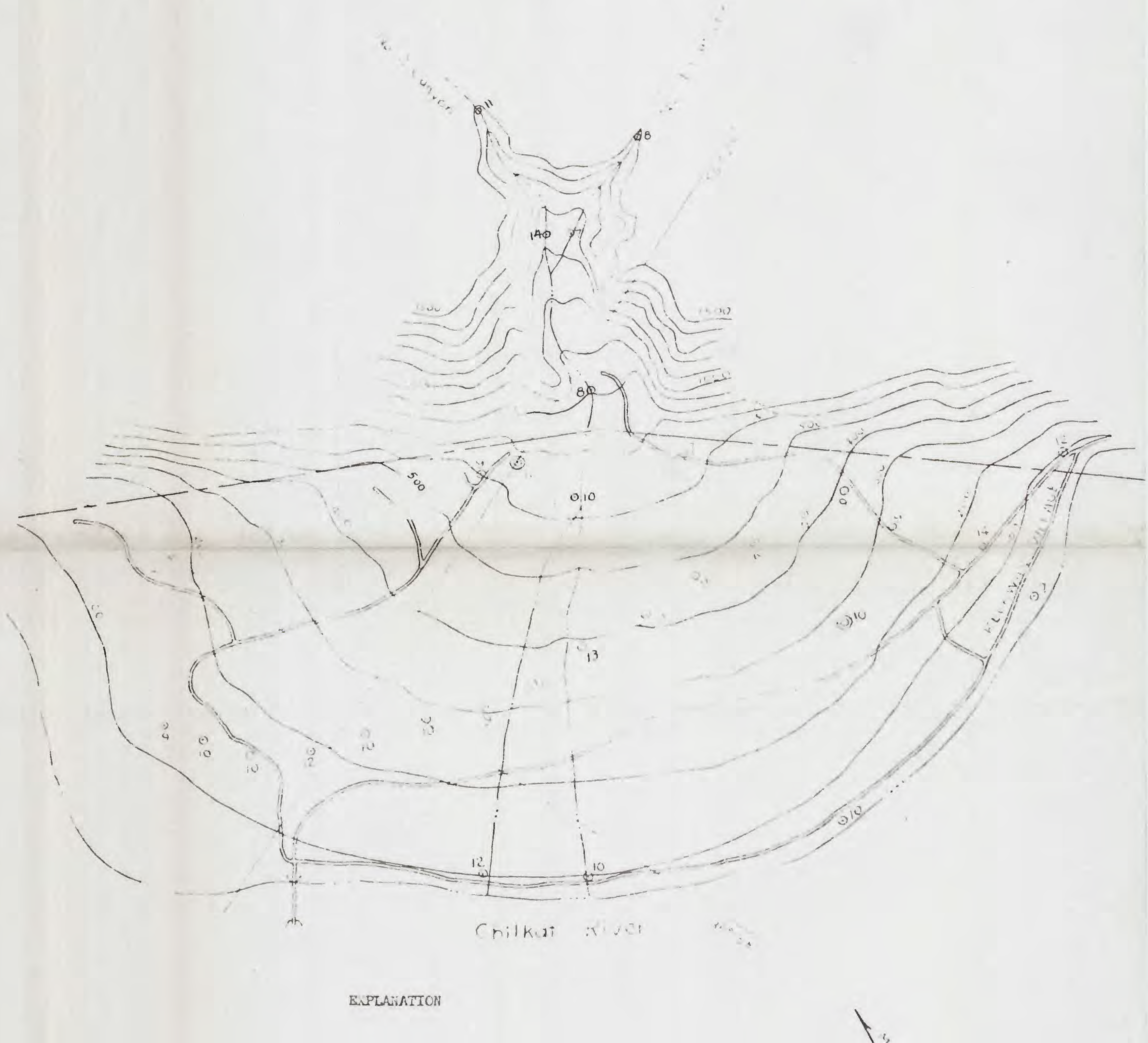
FIGURE 8

TOPOGRAPHY OF THE ALLUVIAL FAN AT KLUKWAN SOUTHEASTERN ALASKA



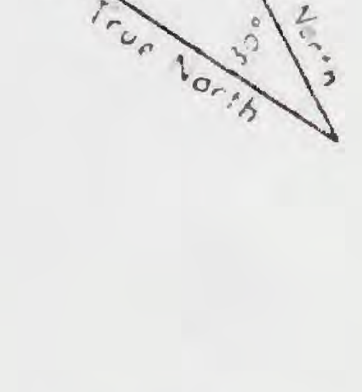
EXPLANATION

U.S.G.S. Sample locations with percent magnetic iron

U.S.B.M. Sample locations with percent magnetic iron

Drainage boundary

Arbitrary upper boundary of fan



0 500 1000 1500 feet

Topography, U.S.G.S., 1959

This map is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

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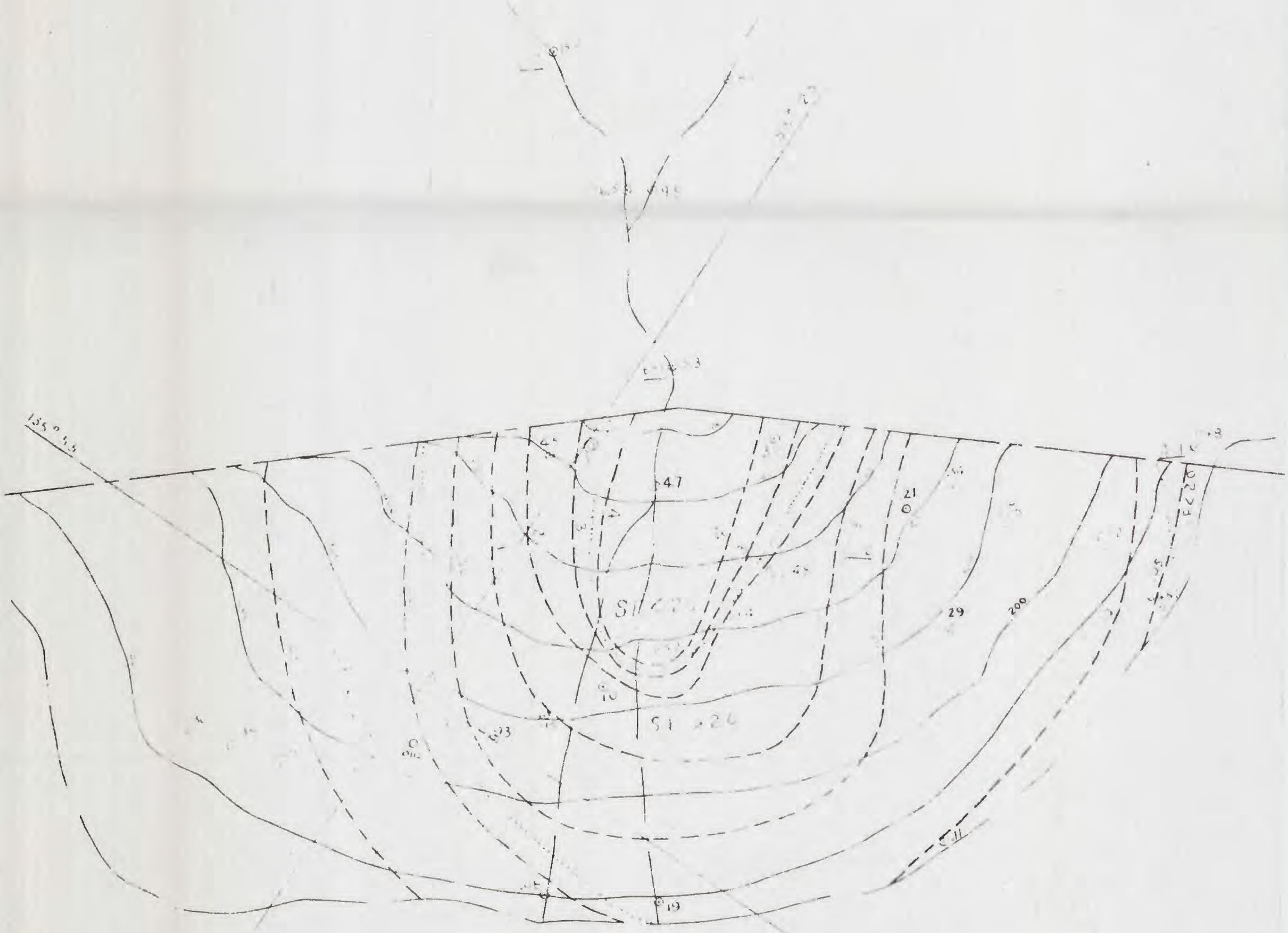
56-101 .

FIGURE 9

MEDIAN GRAIN SIZES OF MATERIALS COMPOSING THE ALLUVIAL FAN AT KLUKWAN



EXPLANATION

.05

Median grain size, inches, at sample locations

Contours of median grain size, inches

Boundary of sorting factor

Drainage boundary

Arbitrary upper boundary of fan

Topography, U.S.G.S., 1950

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