# GEOLOGICAL SURVEY RESEARCH 1970

# Chapter D

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*Scientific notes and summaries of investigations in geology, hydrology, and related fields*

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## GEOLOGIC STUDIES

# GEOLOGICAL SURVEY RESEARCH 1970

This collection of 45 short papers is the third published chapter of "Geological Survey Research 1970." The papers report on scientific and economic results of current work by members of the Geologic, Water Resources, and Topographic Divisions of the U.S. Geological Survey.

Chapter A, to be published later in the year, will present a summary of significant results of work done in fiscal year 1970, together with lists of investigations in progress, reports published, cooperating agencies, and Geological Survey offices.

"Geological Survey Research 1970" is the eleventh volume of the annual series Geological Survey Research. The ten volumes already published are listed below, with their series designations.

| *Geological Survey Research* | *Prof. Paper* |
|---|---|
| 1960 | 400 |
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# INDUCED POLARIZATION AND RESISTIVITY SURVEYS ON CLEARY SUMMIT, ALASKA

By LENNART A. ANDERSON and GORDON R. JOHNSON,
Denver, Colo.

*Abstract.*—Induced polarization and resistivity surveys were made on the north flank of Cleary Summit about 16 air miles north-northeast of Fairbanks, Alaska. Data were obtained along three traverses that were positioned to transect some of the known vein structures that have produced gold, silver, and other metallic minerals. Two disseminated sulfide concentrations of possible economic interest, one deep seated and the other about 75–150 feet beneath the surface, were detected.

From 1903 into the mid-1950's lode gold was mined from narrow quartz veins in the Cleary Summit area, which is about 16 air miles north-northeast of Fairbanks, Alaska (fig. 1). Sulfide minerals were also found in the fractures that contained the gold-quartz veins. Stibnite was mined for antimony when the market price for that mineral warranted independent production (Killeen and Mertie, 1943). At the time the present survey was made, mining was being carried on as a one-man operation which involved the extraction of fault gouge primarily for its lead content and secondarily for its small silver content.

The quartz veins strike approximately eastward and generally dip to the south. The mineral-bearing veins are confined to the north slope of Cleary Summit and are thought to be related to igneous rocks that intrude the schistose country rock (Killeen and Mertie, 1943).

To test the area for possible new sources of sulfide minerals, we made induced polarization and resistivity surveys along three traverses that were positioned to transect the trend of two of the known vein structures.

## METHOD, RESULTS, AND INTERPRETATION

The dual-frequency method was used to measure induced polarization. In this method, a set of current and potential electrodes placed directly in contact with the earth are used to measure resistivity at two discrete frequencies. If conductive or polarizable minerals are present in disseminated form, the resistivity will decrease as the frequency is increased. This effect can then be considered a measure of induced polarization and is expressed as percent frequency effect (PFE) where PFE $= (\rho_l - \rho_h) \times 10^2 / (\rho_l \rho_h)^{1/2}$; $\rho_l$ and $\rho_h$ are the resistivities measured at the low and high frequencies, respectively. For a detailed discussion of the dual-frequency method, see Keller and Frischknecht (1966).

The induced polarization surveys were made with the pole-dipole or half Schlumberger electrode configuration in which one current electrode is placed at a distance at least 10 times greater than the maximum separation between the near-current electrode and the measuring dipole. A 100-foot dipole was used, and measurements were made at frequencies of 0.05 and 1.0 Hz. Five in-line measurements were made for every current electrode emplacement at distances of 100–500 feet in multiples of 100 feet.

Traverses *A–A′*, *B–B′*, and *C–C′* were made across the major trend of the mineralized zone on Cleary Summit (fig. 1). Traverse *A–A′* was positioned to transect the Jamesonite vein near the site of the old Keystone mine, where fault gouge associated with the vein was mined during 1967–68 for its lead-silver content. The gouge is significantly more conductive, electrically, than the surrounding schist and therefore can be detected easily with the induced polarization method.

The contoured resistivity data obtained along traverse *A–A′* (fig. 2) indicate the presence of a narrow conductive zone which can be associated with the vein gouge. The high resistivity anomaly

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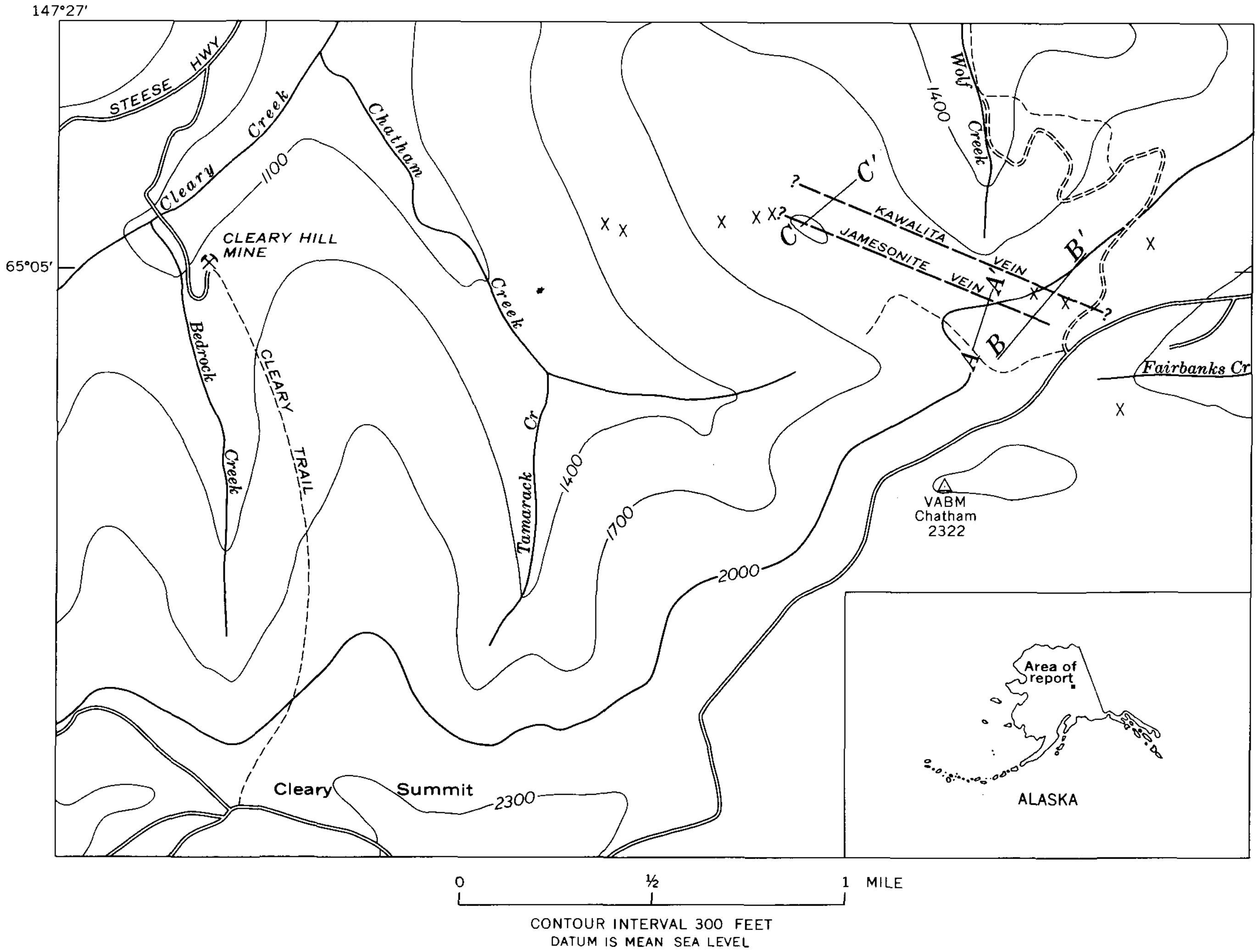


FIGURE 1.—Location of induced polarization-resistivity traverses (*A–A′*, *B–B′*, and *C–C′*) on Cleary Summit. X, mine or prospect. Contour interval, 300 feet. Base from U.S. Geological Survey Livengood A-1 quadrangle, 1951, scale 1 : 63,360.

immediately south of the fault is characteristic of the three-electrode or pole-dipole array when profiling across a near-vertical conductive boundary (Keller and Frischknecht, 1966; Dakhnov, 1959). The lowest apparent resistivities were found in the near-surface rock, indicating that some degree of weathering has occurred in the upper layer.

The contoured induced polarization data taken along traverse *A–A′* do not produce a pattern that can be related directly to the distribution of conductive gouge within the vein. The polarization values obtained over the unaltered schist average about 5.0 PFE near the surface and increase slightly with depth. This increase can be caused by either an increase in the volume fraction of conducting minerals or a subtle variation in clay content.

In the vicinity of the Jamesonite vein, the increase in the polarization values probably is caused by the combined effects of clay and sulfide minerals within the fault zone. These minerals are well concentrated and occupy only a relatively small volume compared with the gross volume taken in by any one field measurement, which may account for the rather minor change in the observed PFE values. The PFE values near the vein increase with depth, possibly because the gouge interval becomes wider or because the polarizing minerals are more disseminated at depth.

Traverse *B–B′*, positioned about 700 feet east of traverse *A–A′*, was carried out to a greater length than traverse *A–A′* in order to test for other mineralized veins on the north flank of Cleary Summit as well as to transect the Jamesonite vein. A resistivity pattern similar to the principal resistivity anomaly noted on the plot of traverse *A–A′* data can be seen beneath field stations 6 and 7 (fig.

2, *B–B′*). Despite the absence of an observable low resistivity zone, the pattern is sufficiently similar to the anomaly of traverse *A–A′* to identify the source as the easterly extension of the Jamesonite vein.

Farther north, in the vicinity of station 12, the resistivity plot shows a low resistivity zone. The cause of the anomaly may be the Kawalita vein, which parallels the Jamesonite vein to the north according to Forbes, Pilkington, and Hawkins (1968). Their description of the Kawalita vein indicates that it is similar to the Jamesonite vein in

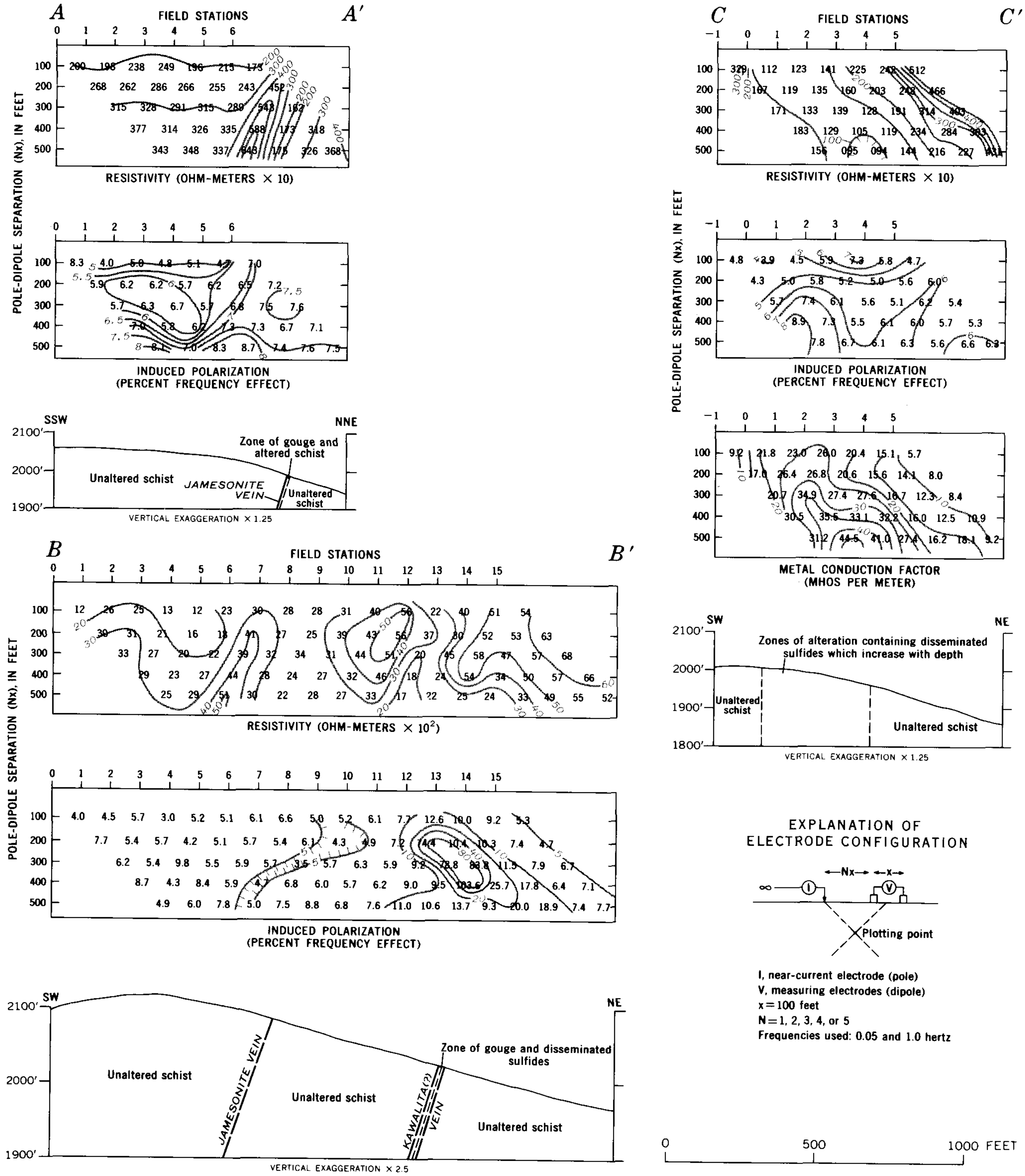


FIGURE 2.—Induced polarization and resistivity data obtained on Cleary Summit. Lines of traverses shown on figure 1.

that it contains quartz veins, gouge, and sulfide nodules. The vein possibly broadens with depth; the most conductive material is estimated to be in excess of 125 feet below the surface.

The corresponding induced polarization data show no polarization anomaly associated with the Jamesonite vein. In contrast, the Kawalita(?) vein produces a fairly strong polarization anomaly with values as much as 20 times the background level. The anomaly possibly is caused by disseminated sulfides within or near the main vein located at an estimated depth of 75–150 feet below the surface.

Traverse *C–C′* (fig. 2) was positioned about 3,000 feet northwest of traverse *A–A′* in the expectation of surveying across the main mineralized zone as determined from the alinement of mine workings and prospect pits on Cleary Summit (fig. 1). The contoured resistivity data indicate that the traverse apparently was well placed, although the southern limit of the low resistivity zone is not well defined. A low resistivity anomaly detected at depth beneath station 4 is the only source of interest on the resistivity plot.

The induced polarization data plotted as percent frequency effect show small variations within the section, but the pattern created by the contours shows no strong evidence of mineral concentrations. To enhance the diagnostic qualities of the induced polarization data, a parameter known as metal factor was calculated by using the formula $2\pi \times 10^3 (\mathrm{PFE}/(\rho_h \rho_l)^{1/2})$ where $\rho_h$ and $\rho_l$ are the high and low resistivities, respectively. Metal factor has the units of conductivity and is shown in contour form below the PFE data (fig. 2, *C–C′*).

The plot of these data indicates a single anomaly which coincides with the low resistivity anomaly detected at depth beneath station 4. The anomaly has a peak metal factor value of 45, which signifies only a small amount of sulfide mineralization within the rock (Keller and Frischknecht, 1966).

How this mineralized zone relates to the recognized mineral veins on Cleary Summit is unknown. The principal source of the resistivity and induced polarization anomalies is buried much deeper than those found along traverses *A–A′* and *B–B′*, and the zone of mineralization or alteration is much broader and better defined than elsewhere. Although the suggested sulfide content is not of economic interest, the apparent increase in the volume fraction of sulfides with depth may possibly lead to significant metal concentration at depths greater than 200 feet.

## CONCLUSION

Interpretation of the electrical resistivity and induced polarization surveys obtained on Cleary Summit, Alaska, indicates that narrow zones of conductive minerals exist in conjunction with known vein structures. The economic significance of the conductive zones may be difficult to assess on the basis of these investigations, but the data may be useful for selecting locations at which further study is warranted. It seems that the induced polarization anomaly near the north end of the *B–B′* traverse and the deep-seated mineralized zone beneath the *C–C′* traverse, in particular, may be worthy of additional investigation.

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# GEOLOGIC INTERPRETATION OF A RESIDUAL AEROMAGNETIC MAP OF THE NIXON FORK DISTRICT, ALASKA

By LENNART A. ANDERSON[1], BRUCE L. REED[2], and GORDON R. JOHNSON[1],

[1] Denver, Colo.; [2] Menlo Park Calif.

*Abstract.*—A residual aeromagnetic map covering approximately 480 square miles was compiled for the Nixon Fork district located about 35 miles northeast of McGrath, Alaska. The aeromagnetic survey was flown in search of concealed intrusive rocks similar to the quartz monzonite stocks that have produced contact metamorphic deposits in limestone, the principal source of gold in the district. Negative magnetic anomalies are associated with quartz monzonite stocks, establishing a useful criterion for locating favorable prospecting areas. Some new localities of possible economic interest in this area are discussed.

In 1968, an aeromagnetic survey was made of a 480-square-mile area lying between Nixon Fork and the North Fork Kuskokwim River in Alaska, in conjunction with mineral-resource investigations by the U.S. Geological Survey (fig. 1). The survey was flown by Lockwood, Kessler, and Bartlett, Inc., and compiled by the U.S. Geological Survey. The objectives were (1) to determine the magnetic characteristics of the intrusive rocks in the vicinity of the Nixon Fork mines, and (2) to delineate other areas where similar concealed intrusive rocks may occur.

The Nixon Fork district, located approximately 35 miles northeast of McGrath, is a region of rugged hills that range in elevation from 400 to 2,800 feet above sea level. Gold placers were discovered in the area in 1917, but lode deposits soon became the chief source of gold. The gold lodes at the Nixon Fork mines occur as small contact metamorphic deposits in limestone, generally within a few hundred feet of the quartz monzonite contact. The chief ore minerals are auriferous pyrite and chalcopyrite. Locally, extensive oxidation has resulted in the release of gold from the sulfide minerals and consequent enrichment in the oxidized zone. Although the data are incomplete, the total production, through 1942, from the several lodes in the area was valued at approximately $1.3 million (Herreid, 1966). The mines have been virtually inactive since 1942, although limited operations were attempted in 1960.

## GEOLOGIC SUMMARY

The geology of the Nixon Fork district (fig. 1) and descriptions of the lode and placer deposits are given in reports by Martin (1922), Brown (1926), Mertie (1936), White and Stevens (1953), Jasper (1961), and Herreid (1966). A brief summary, based largely on those reports, follows.

The oldest and most common rock type in the area is complexly folded Paleozoic limestone which forms most of the higher hills between the Nixon Fork and North Fork Kuskokwim River. The limestone, 5,000–7,000 feet thick, is white to dark gray, thin to thick bedded, and contains thin interbeds of shale, chert, and calcareous sandstone. Near contacts with quartz monzonite and granitic stocks the limestone is metamorphosed to a calc-silicate marble.

Cretaceous rocks in the area consist of a monotonous sequence of medium- to dark-gray graywacke, arkosic sandstone, shale, and siltstone, and local beds of conglomerate. These rocks are at least 5,000 feet thick, have a conspicuous slaty cleavage, and are hornfelsic near contacts with intrusive stocks.

Tertiary stocks of quartz monzonite and granite cut the Paleozoic and Cretaceous rocks. Quartz latite porphyry is found within and along the borders of the quartz monzonite stock at the Nixon Fork mines. These porphyry phases are believed to represent chilled border zones (Brown, 1926) or late differentiates of the magma (Herreid, 1966).

Quaternary deposits of unconsolidated gravel, sand, and silt occupy the flat lowlands along the

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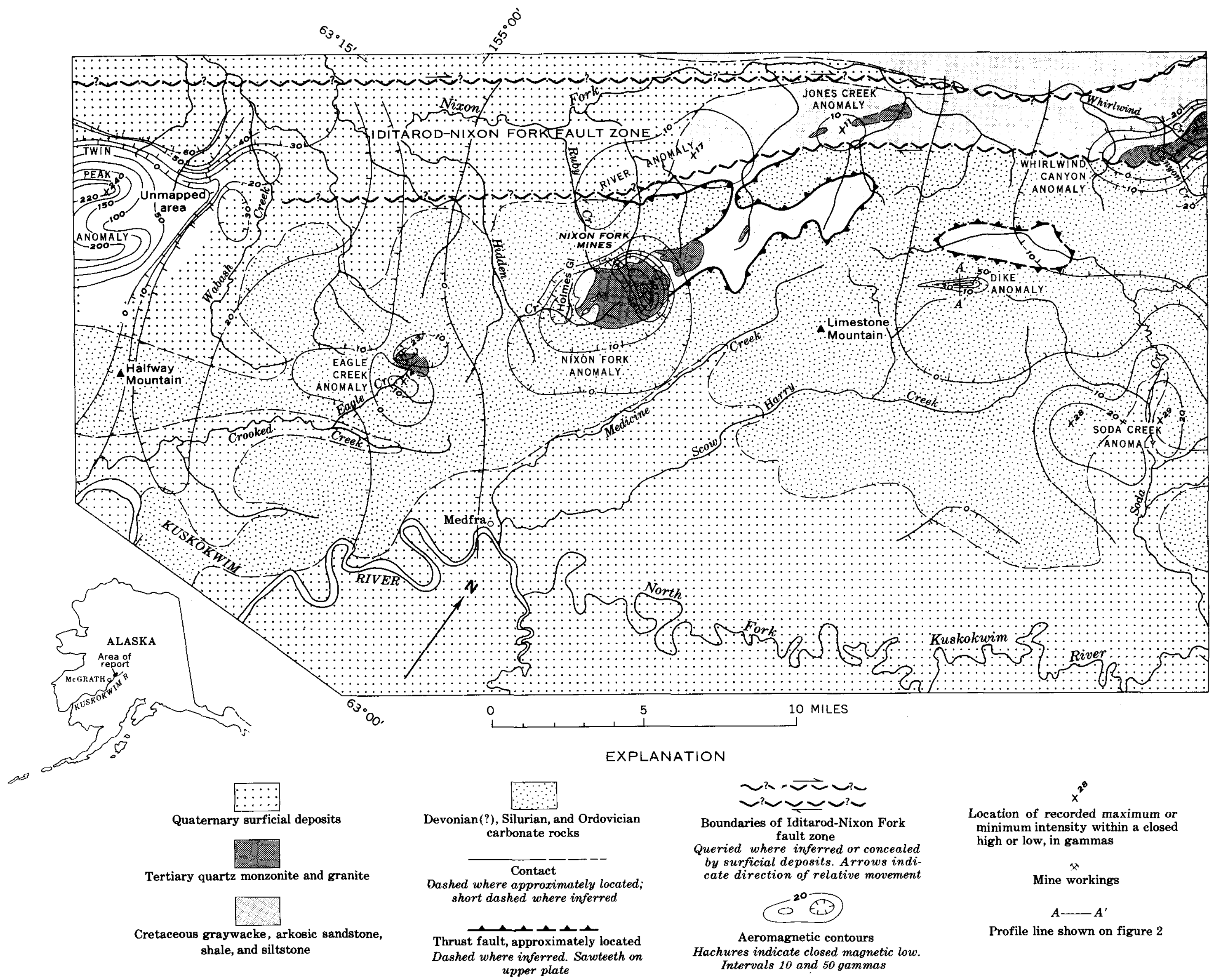


FIGURE 1.—Geologic reconnaissance and residual aeromagnetic map of the Nixon Fork district, Alaska. Geology is based on the early work of Brown (1926) and is supplemented by aerial-photograph interpretation. Base from parts of U.S. Geological Survey quadrangles, scale 1:63,360: Medfra B–4, 1953; A–3, A–4, A–5, 1954; B–3, 1955.

North Fork Kuskokwim River and the Nixon Fork.

The Paleozoic limestones have been thrust northwestward over the Cretaceous rocks (Brown, 1926, p. 120–123). These Paleozoic rocks were subsequently folded and pierced by acidic intrusive stocks, and therefore the possibility that a mineralized thrust plate occurs at the base of the limestone near intrusive contacts should be considered. Subsequent erosion has formed fensters exposing Cretaceous rocks below the thrust plate (fig. 1). To the north, the thrust plate appears to be terminated by the Iditarod-Nixon Fork fault zone—a major fault zone in south-central Alaska with probable right-lateral movement (Grantz, 1966).

## AEROMAGNETIC SURVEY

The aeromagnetic survey consisted of 40 northwest-southeast traverses approximately 12 miles long and spaced 1 mile apart. The traverses were flown at a barometric flight elevation of 2,500 feet, except where topography required higher flight elevations. A fluxgate magnetometer was used to obtain a total intensity magnetic profile along each traverse.

The magnetic data in figure 1 are in the form of a residual magnetic map, which was constructed from the total field magnetic map of Anderson, Reed, and Johnson (1969) by removing the earth's normal total magnetic field using a computer technique employing the method of least squares as described by Oldham and Sutherland (1955). There is little difference between the two maps except that some of the magnetic features are somewhat more prominent in the residual magnetic data.

## AEROMAGNETIC DATA

The larger known intrusive bodies in the Nixon Fork district can be correlated with either a negative or positive magnetic anomaly. Although each exposed igneous body has been mapped as a "granitic" intrusive, including quartz monzonite, a marked difference in magnetic properties from one body to another is indicated by the variety of magnetic expressions. Other magnetic anomalies shown in figure 1 are produced by intrusives, unknown prior to this survey, which possibly may be identified as to rock type by the polarity of the anomaly.

### Negative anomalies

The known gold lodes and prospects in the district are related to a quartz monzonite stock at the Nixon Fork mines and a similar stock located about 7 miles southwest at the headwaters of Eagle Creek (Brown, 1926; White and Stevens, 1953). A negative anomaly, labeled Nixon Fork anomaly on figure 1, delineates the Nixon Fork stock. The reason for the negative signature of the anomaly is unknown, but because the quartz monzonite shows little alteration (Herreid, 1966) and the shape and amplitude of the anomaly do not indicate reversed magnetization of the rock, we believe that the quartz monzonite has no magnetic expression. The negative anomaly is most likely the result of the intruded stock replacing a more magnetic unit at depth, thereby distorting the magnetic field so as to lessen the relative magnetic intensity over the area of the stock.

Within the Nixon Fork anomaly and west of the exposed quartz monzonite, a small negative anomaly lies over the valley of Hidden Creek which is underlain by limestone. This anomaly may correlate with a cupola of the main stock located within the ridge that parallels Holmes Gulch. The depth to the source of the anomaly as determined from the magnetic profile over the proposed cupola is less than 300 feet.

The Eagle Creek stock is also delineated by a negative anomaly that occurs in close association with a positive anomaly to the south, jointly labeled Eagle Creek anomaly on figure 1. The magnetic properties of the quartz monzonite probably are similar to those of the Nixon Fork stock although the magnetic high and low conceivably can be caused by magnetic differences within the exposed quartz monzonite. A depth estimate determined from the profile crossing the stock, however, indicates that the source of the positive magnetic anomaly is approximately 1,500 feet beneath the ground surface. The depth to the source and the location of the magnetic high and low suggest, therefore, either that the stock is more magnetic at depth or that a magnetic rock unit occurs along the south flank of the stock.

Two broad negative magnetic features, not labeled as anomalies on figure 1, are present in the mapped area. One, which is located immediately east of the Twin Peak anomaly and which trends northward, may be caused by a ridge of quartz monzonite that is fairly close to the surface, but it is more likely caused by a structural depression in the magnetic basement rock. The other feature, which is in the northeastern part of the mapped area, possibly indicates the existence of a large intrusive similar to the quartz monzonite at the Nixon Fork mines.

### Positive anomalies

The two most prominent positive magnetic features in the mapped area (fig. 1) are the Whirlwind Canyon anomaly, at the northeast corner, and the

Twin Peak anomaly, near the southwest boundary. The Whirlwind Canyon anomaly is caused by an elongate body of exposed granite which forms the southwest extension of Whirlwind Ridge (Brown, 1926, p. 117). The Twin Peak anomaly coincides with a pair of rounded, isolated hills having a relief of about 1,000 feet. The hills are extensively covered by vegetation, and the bedrock geology is not known. The intensity of the Twin Peak anomaly is similar to that of the Whirlwind Canyon anomaly, suggesting the presence of an igneous mass like that found on Whirlwind Ridge.

Within the broad negative anomaly in the northeast section of the map, a small elliptical magnetic high, labeled Dike anomaly on figure 1, occurs over a northeast-trending ridge. The ridge (crossed by section line *A–A′* on fig. 1) probably consists of steeply dipping limestone as determined from inspection of aerial photographs. The relatively steep gradient of the magnetic anomaly suggests the presence of an intrusive that is not deeply buried. To test this observation, a theoretical magnetic body was constructed using a two-dimensional magnetic-profile computer program. A theoretical model that generates a magnetic anomaly similar to that observed on profile *A–A′* is shown in figure 2. The theoretical magnetic body is 250 feet wide, dips 70° NW., and extends to an infinite depth. The magnetic susceptibility contrast was chosen to be $6.4 \times 10^{-3}$ cgs units. A physical counterpart to the model structure having an equivalent magnetic susceptibility would be a mafic body which is dikelike in form. The top of the dike lies near the surface of the limestone ridge. If the dike exists in association with quartz monzonite, then the limestone in the vicinity of the dike provides a favorable environment for lode deposits similar to those found at the Nixon Fork mines (Brown, 1926, p. 135).

North of the Nixon Fork intrusive, two low-intensity positive anomalies, labeled River anomaly and Jones Creek anomaly, possibly correlate with granitic bodies surrounded by Upper Cretaceous rocks. The contacts between Cretaceous sedimentary rocks and Tertiary intrusive bodies, however, are not considered as favorable as contacts with limestone for contact metamorphic deposits, and the intrusives along the Iditarod-Nixon Fork fault zone offer little encouragement to the prospector (Brown, 1926, p. 140). Likewise, the broad double-peaked magnetic feature named Soda Creek anomaly, located near the northeast boundary of the surveyed area, is too deeply buried to be of economic interest.

## SUMMARY AND CONCLUSIONS

The intrusives associated with known mineral deposits appear on the map as negative magnetic anomalies. If this observed relation is used as a criterion for locating new prospecting sites, then the area associated with the small negative anomaly within the Nixon Fork anomaly southwest of the Nixon Fork mines and the area in the vicinity of the Dike anomaly may be of interest to the prospector. In the vicinity of the Dike anomaly, in an area possibly underlain by quartz monzonite, a feature that is inferred to be a dike is clearly defined by the magnetic data. This proposed dike is near the surface in a limestone ridge, and the difference in elevation between the top of the ridge and the thrust (mapped from aerial photographs), which has the fenster that exposes Cretaceous rocks to the north (fig. 1), is about 1,000 feet. Thus the depth to the

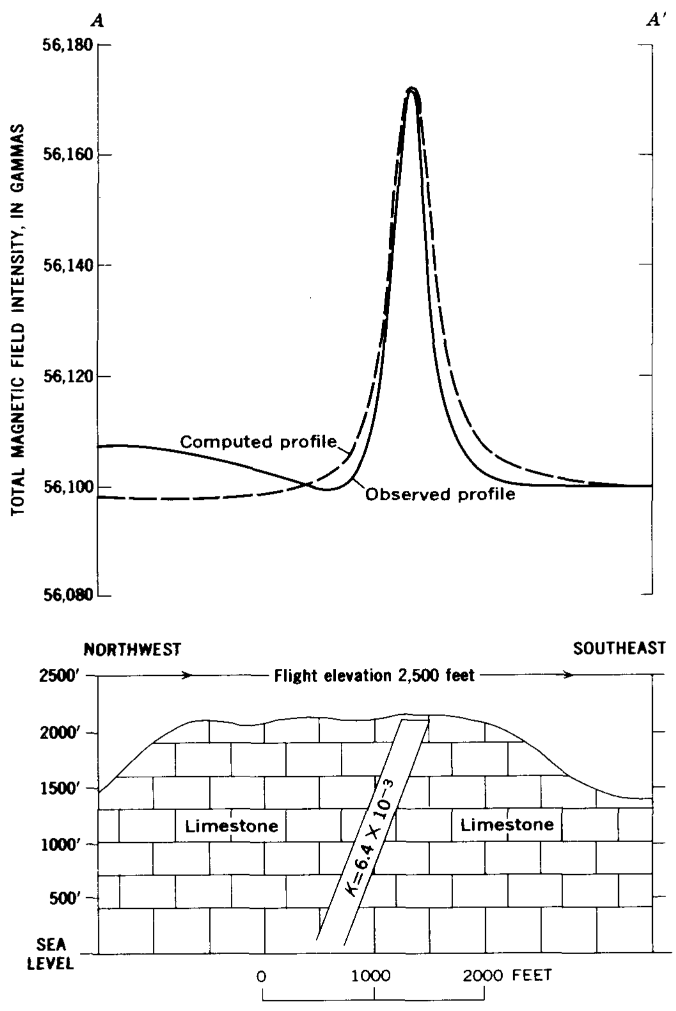


FIGURE 2.—Observed and computed magnetic profiles along line *A–A′* (fig. 1) over an assumed dike of infinite depth. Magnetic susceptibility (*K*) in cgs units.

thrust in this area cannot be great, and the thrust probably would have been pierced by the inferred dike and possibly by the inferred body of underlying quartz monzonite.

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# GOLD RESOURCE POTENTIAL OF THE DENALI BENCH GRAVELS, VALDEZ CREEK MINING DISTRICT, ALASKA

By THOMAS E. SMITH[1], Reno, Nev.

*Abstract.*—Recent investigations of the bench gravels near Denali, Alaska, including seismic refraction measurements, have defined a deposit of more than 35 million cubic yards of auriferous gravel. More than three-fourths square mile in area and at least 45 feet thick, it extends north and south of Valdez Creek. The sample data that are available indicate that the gravel contains from 50 cents to $1.20 of gold per cubic yard (at $35 per ounce) and that gold is distributed throughout the deposit. Although mining has been confined largely to rich pockets in bedrock depressions or incised channels, gold disseminated through the gravels constitutes the primary economic potential of the district. Potential resource value at 50 cents per cubic yard is in excess of $17 million.

The Valdez Creek placer deposits were discovered in 1903 and have been mined and explored intermittently up to the present. Gold production until 1936 was estimated at $1,250,000 (at $35 per ounce), nearly all of which came from placers (Tuck, 1938, p. 113).

The area was reexamined in 1968–69; this report describes only the placer deposits near the abandoned town of Denali and integrates earlier published information with new seismic refraction data to give resource estimates for the gold-bearing gravels.

The Denali placer area is approximately midway between the towns of Paxson and Cantwell, in east-central Alaska, near the confluence of Valdez Creek with the Susitna River. An unimproved road extends into the area and joins the Denali Highway 5 miles to the south, near milepost 77. Two unimproved airstrips in the area are also accessible to light aircraft (fig. 1).

## GEOLOGY

The Denali bench gravels (fig. 1) are underlain by metamorphic rocks that grade from dark-gray argillite and greenish graywackes at the south end of the area to dark lineated phyllites north of Denali. Locally, interbed shearing and minor folding have produced slaty cleavage within both phyllites and higher grade argillites. In the extreme northern end of the area, the phyllites are distinctly spotted with clots of poikiloblastic biotite. The gradational bedrock sequence lies in the lower grade part of a regional metamorphic terrane. Bedding and foliation dip gently northward across the area, but are complicated locally by small folds and numerous faults. The metamorphic zonation is important to the present study because suballuvial seismic velocities vary with the degree of recrystallization. Slight velocity differences along profiles may also in part reflect variations in foliation attitude.

The Denali bench gravels, as referred to informally in this report, include both the auriferous alluvium on the bedrock bench adjacent to Valdez Creek and local channel fillings deposited in a canyon deeply incised within the bench. The deposits are distributed in a broadly curved belt extending northeast and southwest of Valdez Creek (fig. 1). The alluvium on the bedrock bench is a broad blanketlike deposit consisting of well-bedded auriferous gravels. It has been mined for gold intermittently since 1940, in the south wall of Valdez Creek across from Denali (fig. 2) and near Peters Creek.

Early mining in the gravels surrounding Denali was mainly concentrated along a deeply incised bedrock canyon cut by the ancestral Valdez Creek. (For detailed discussion see Moffit, 1912; Ross, 1933; and Tuck, 1938.) This buried canyon—the Tammany channel—and its downstream extension —the Dry Creek cut—were filled by beds of moderately sorted fluvial gravel, much of which has been removed by hydraulic mining. Subrounded boulders are locally concentrated near the channel bottom,

[1] Mackay School of Mines, University of Nevada, Reno, Nev. 89507.

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point potassium chloride crystallizes. The potassium chloride is separated from the liquor, which is rich in magnesium and can be used to manufacture either refractory grade magnesia (MgO) and hydrochloric acid or metallic magnesium and chlorine. The multistage process may be represented in a simplified form by the following equations in which the concentrate is shown as kainite:

$$MgSO_4 \cdot KCl \cdot 3H_2O + CaCl_2 + 5H_2O \rightarrow MgCl_2 \cdot KCl \cdot 6H_2O + CaSO_4 \cdot 2H_2O$$

$$MgCl_2 \cdot KCl \cdot 6H_2O \rightarrow MgCl_2 \cdot 6H_2O + KCl$$

$$MgCl_2 \cdot 6H_2O \rightarrow MgO + 2HCl \text{ in } 5H_2O$$

In accordance with the reactions outlined above, a ton of kainitic concentrate requires the use of only 0.45 ton of calcium chloride to produce 0.69 ton of gypsum, 0.30 ton of potassium chloride, 0.16 ton of magnesia, and 0.66 ton of hydrochloric acid.

Another substance of value that can be produced from the versatile kainitic concentrate is potassium sulfate. The production of this substance involves reactions between brine and solids in the reciprocal salt-pair system magnesium sulfate-potassium chloride-water, and it can be accomplished by employing a two-stage base-exchange process such as that used by the Italian potash industry to exploit kainitic ores from the Caltanisseta deposits in central Sicily. The process consists of treating a kainitic concentrate with magnesium sulfate liquor to form picromerite ($K_2SO_4 \cdot MgSO_4 \cdot 6H_2O$). The picromerite is separated from the magnesium-rich liquor, which can then be used as a source of magnesia and hydrochloric acid. The picromerite is digested in water, at which point potassium sulfate crystallizes. The potassium sulfate is separated, and the magnesium sulfate liquor is used to treat the kainitic concentrate at the start of the process. The process may be represented in a simplified form by the following equations:

$$2MgSO_4 \cdot KCl \cdot 3H_2O \rightarrow K_2SO_4 \cdot MgSO_4 \cdot 6H_2O + MgCl_2$$

$$K_2SO_4 \cdot MgSO_4 \cdot 6H_2O \rightarrow K_2SO_4 + MgSO_4 \text{ in } 6H_2O.$$

With this process, a ton of kainitic concentrate can be expected to yield 0.35 ton of potassium sulfate and sufficient magnesium-rich liquor to produce 0.13 ton of magnesia and 0.55 ton of hydrochloric acid.

## CONCLUSIONS

The deposits of potassic rocks found in the Salt Range Formation at Khewra and elsewhere in the eastern Salt Range appear to offer great promise of development. The deposits could become the basis of important new fertilizer and chemical industries greatly needed in Pakistan, but they require study, testing, and sampling to determine whether or not their distribution, grade, composition, and tonnage are sufficient to fulfill all requirements for commercial development.

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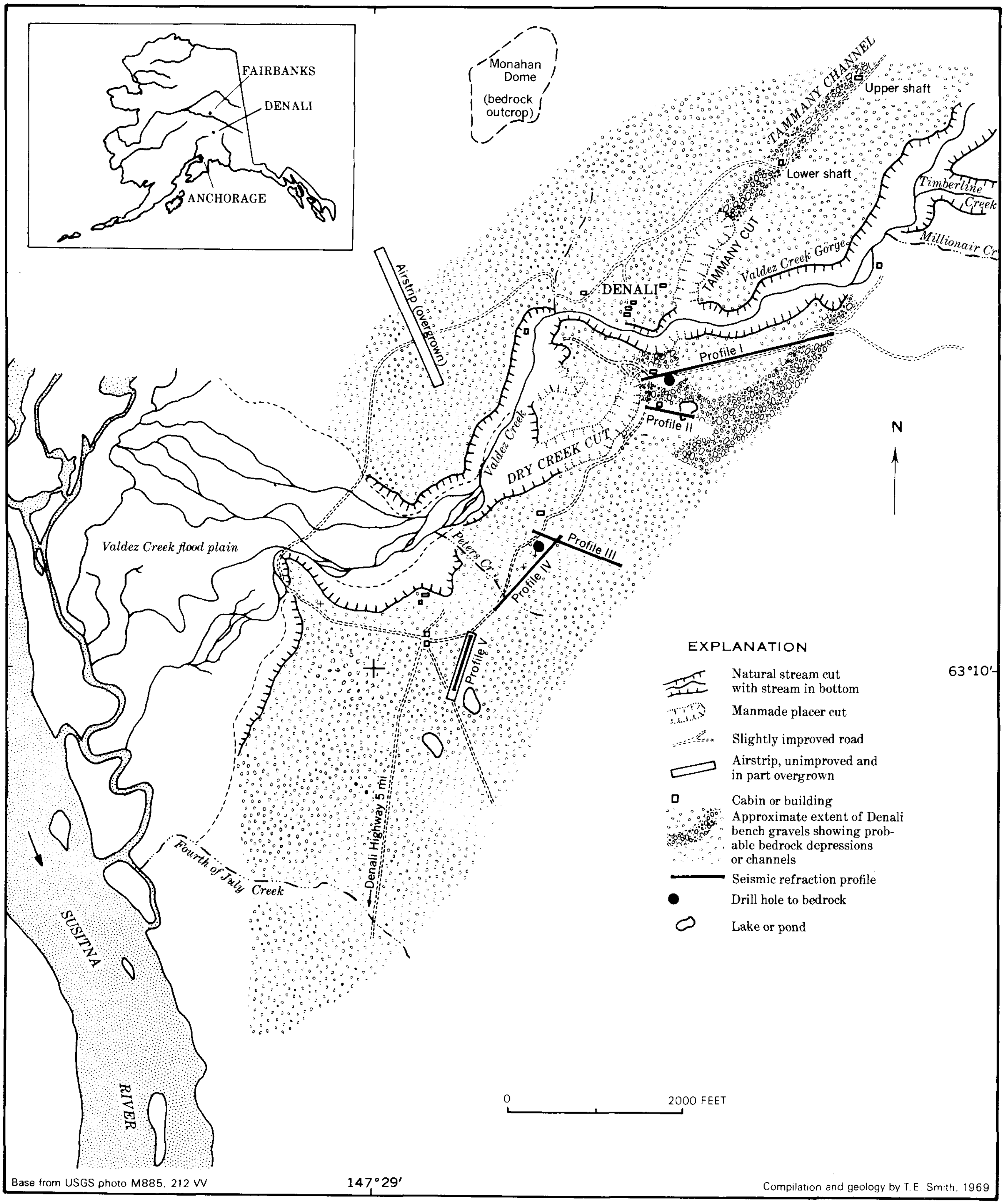


FIGURE 1.—Denali placer area, northwestern part of the Healy A-1 quadrangle (1:63,360), Alaska.

FIGURE 2.—Placer cut in bench gravels across Valdez Creek from Denali. (Photograph taken in 1946, courtesy of L. B. Kercher.) View south.

and quartz diorite, schist, and argillite represent the most abundant lithologies in the gravels. In underground workings along the channel bottom north of the Tammany cut, a thin layer of decomposed phyllite and slate bedrock yielded most of the gold recovered (J. Herman, oral commun., 1969), although all the fill reportedly contained fine gold (Ross, 1933, p. 450). Scour-and-fill structures are prevalent in the lower part of the channel but give way to evenly bedded material near the top. Numerous discontinuous layers of rounded or subrounded cobbles are present throughout the gravels. All detritus appears to be derived from the Valdez Creek drainage; there are no exotic lithologies to suggest that glacial debris from other drainages has been incorporated in the deposits.

The V-shaped cross section and large rounded boulders in the buried channel record a period of vigorous erosion, perhaps during an early Pleistocene interglacial stage. Downcutting during this time was to a base level near the present floor of the Susitna valley. A subsequent local rise in base level, probably due to an advance of the Susitna glacier, initiated a long period of aggradation during which the canyons were filled and surrounding benches covered by bedded fluvial gravels. Within the gravels, such characteristics as a general absence of scour-and-fill structures except in the deeper channels, presence of distinct bedding and dips lower than 2°, and lack of bedding relation to the irregular bedrock surface all suggest moderate-energy deposition on a gentle alluvial plain. In view of their areal configuration parallel to the Valdez Creek valley and their internal character, the gravels are interpreted as a broad proglacial outwash deposit or valley train that formed below the stationary or retreating terminus of the Valdez Creek glacier. The western side of the aggradational outwash plain was apparently bounded and obstructed by the Susitna glacier, deflecting the proglacial deposits southward along the mountain front.

A final advance and rapid retreat of the Valdez Creek glacier mantled the outwash plain with a thin, irregular ground moraine containing abundant angular boulders of lithologies indigenous to the Valdez Creek basin. The moraine is rarely more than 10 feet thick, although locally its surface is undulatory and marked by numerous low ridges and potholes, whose vertical relief also is on the order of 10 feet. This heterogeneous unit, which makes up the present surface, is the greatest source of difficulty in obtaining seismic records from the area.

Valdez Creek, rejuvenated by a drop in base level when the Susitna glacier withdrew, began cutting the deep gorge through which it now flows—approximately 20 feet lower than the floor of the ancestral creek, exposed in the Tammany cut.

## SEISMIC REFRACTION STUDIES

### Methods of data collection

Shallow seismic refraction measurements were made to aid in estimating the total volume of gravel on the Denali bench and to determine whether other buried channels, comparable to the Tammany, are incised into the bench nearer the mountains. The locations of the profiles are shown on figure 1.

An Electro-Tech 12-channel portable refraction unit was used. The PRA-2-12 amplifier bank, SDW-100 oscillograph, and power supply were mounted on an enclosed, tracked vehicle, providing off-road capability in locating the profiles. Twelve 4.5-cps geophones (EUS-8) were placed at 50-foot intervals along all spreads.

In order to minimize near-surface velocity variations in thawed swamps and morainal debris, the data were recorded in late May, before active-zone ground ice had thawed below a few inches. Almost all the geophones were emplaced directly in the frozen surface layer. A satisfactory acoustic coupling was obtained by similarly placing all shots in holes dug into the frozen layer or in shallow ponds on the frozen surface. One to eight sticks of standard 40-percent dynamite were used, depending on record quality and offset distance to the spread. All profiles were reversed and, with the exception of profile V, were shot at least twice in the same direction from different offsets; this technique provided the necessary redundancy for establishing bedrock velocities and local departures from linear time-distance curves.

Wherever possible, as at the west end of profiles I and II, shots were placed directly on bedrock in old placer cuts, thus allowing a direct comparison of computed and actual thicknesses. Two drill holes (fig. 1) provide additional control on interpretations.

### Interpretation

Time-distance curves and geologic sections inferred from the curves are shown in figures 3 to 6. On all reversed profiles permitting a good estimate of suballuvial velocities, the standard time-intercept method (discussed by Dobrin, 1960, p. 82) was applied to establish the planar bedrock model shown. Only the innermost data between shotpoints were utilized in these computations; redundant data from greater offsets were used merely to check suballuvial velocities and local variations from the linear model. After the data were corrected for surface topography (plotted only on inner data actually used), all departures from a linear traveltime curve were interpreted as variations of the bedrock surface. These are shown as undulations in the basic planar models.

On profile II and the end spreads of profile I, the data do not permit a good choice of traveltime slope. These spreads were interpreted using the method of differences (Jakosky, 1961, p. 725), corrected for appropriate critical propagation angles. The solutions so obtained accord well with the adjacent planar solutions.

Seismic velocities in unfrozen parts of the gravel blanket ranged from 3,000 to 3,800 feet per second

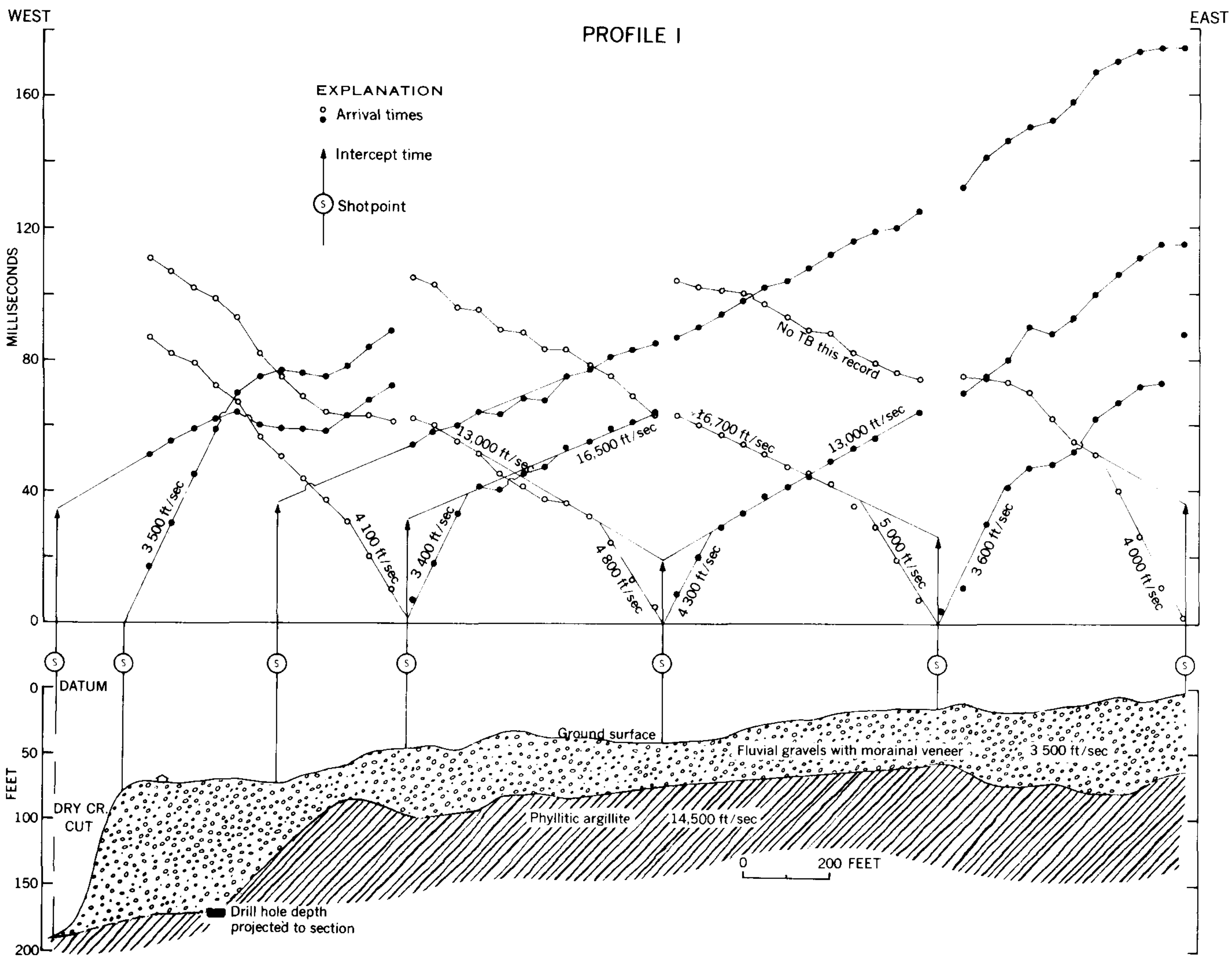


FIGURE 3.—Time-distance curves and geologic section, profile I. TB, time break (instant of shot detonation).

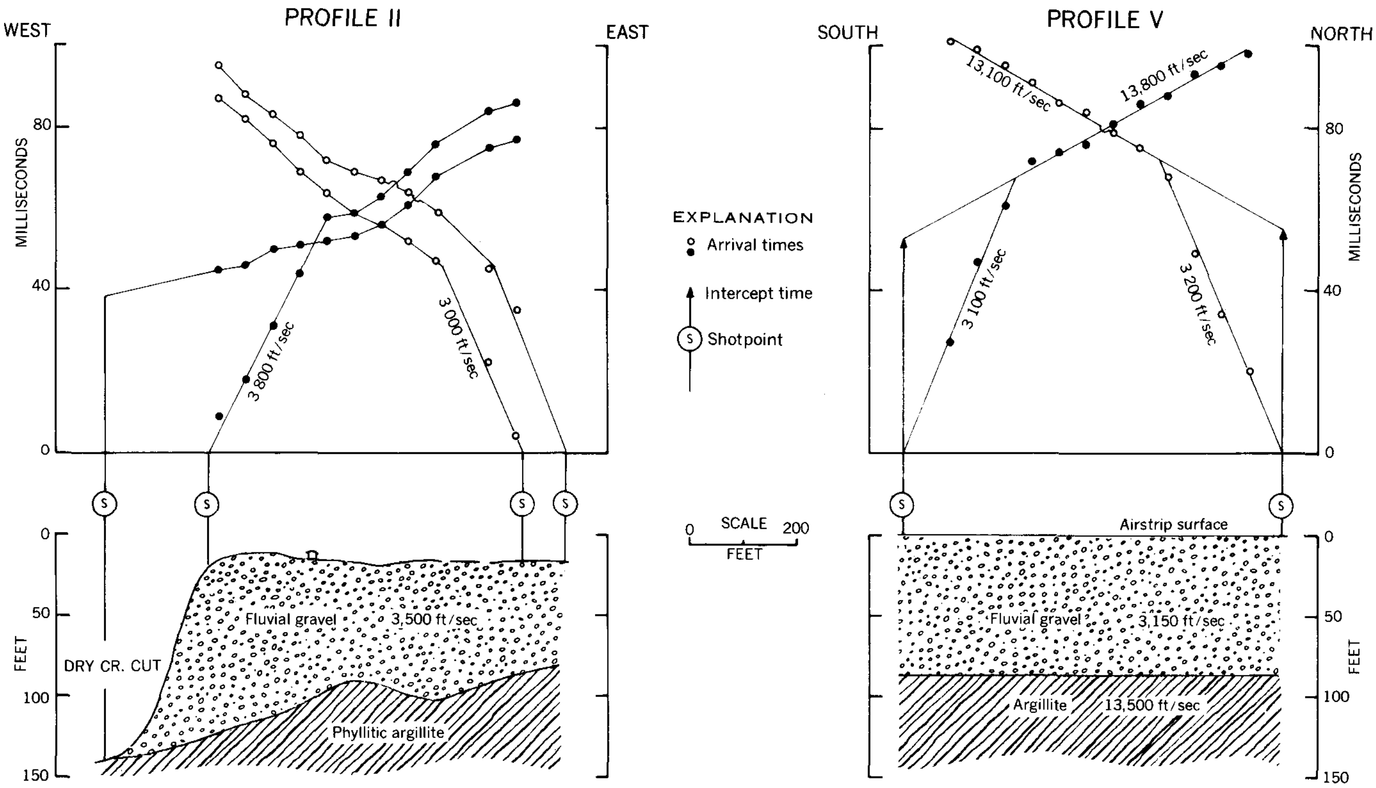


FIGURE 4.—Time-distance curves and geologic sections, profiles II and V.

The presence of a thin frozen layer complicates to some extent the choice of a representative velocity for the gravels and creates a corresponding element of ambiguity in the interpretations. In water-saturated swamp material, the first energy arrived at a velocity characteristic of the frozen surface—6,300 fps in the center of profile III. However, in the better drained areas, as along profile I, the frozen layer velocities ranged from 3,500 to 5,000 fps, depending on content of ground ice. An average lower velocity of 3,500 fps was observed along all profiles except in well-drained areas in the extreme south; this is interpreted as characteristic of the thawed ground. Computational models based on this velocity are in reasonable agreement with drill-hole data (M. J. Wall, written commun., 1969; L. B. Kercher, oral commun., 1969) and with bedrock exposed in the cuts.

The ambiguity arises in the center of profile III, where the velocities in the frozen surface cannot be distinguished from those that permafrost would produce. If the gravels were entirely frozen, the solution would require the bedrock to be deeper than shown in order to satisfy the higher velocity, thus doubling the total amount of gravel estimated for this part of the bench. However, several lines of evidence suggest that permafrost is not present here: (1) solutions which use the high apparent surface velocity place bedrock much deeper than drill-hole data indicate, (2) no time differential occurs between the area of possible permafrost and the thawed material (velocity 3,500 fps) near the west end of profile III, (3) similarly, no change of bedrock velocity is observed between the area in question and the thawed region, and (4) the center of the profile is relatively dry between rainfalls in late summer, but a permafrost lens would probably contribute melt water throughout the dry season. In view of these observations, interpretations in the center of profile III are based on a gravel velocity of 3,500 fps.

Any further attempts to apply seismic methods to the bench gravels, as for example in support of an exploration program, should include a comprehensive evaluation of surface velocities. This could be done with a portable seismic unit in late summer, after seasonal ground ice has melted. With the resulting velocity control at hand, a very accurate compilation of bedrock configuration might be obtained by using the techniques and timing of this investigation.

The inferred geologic sections show that the

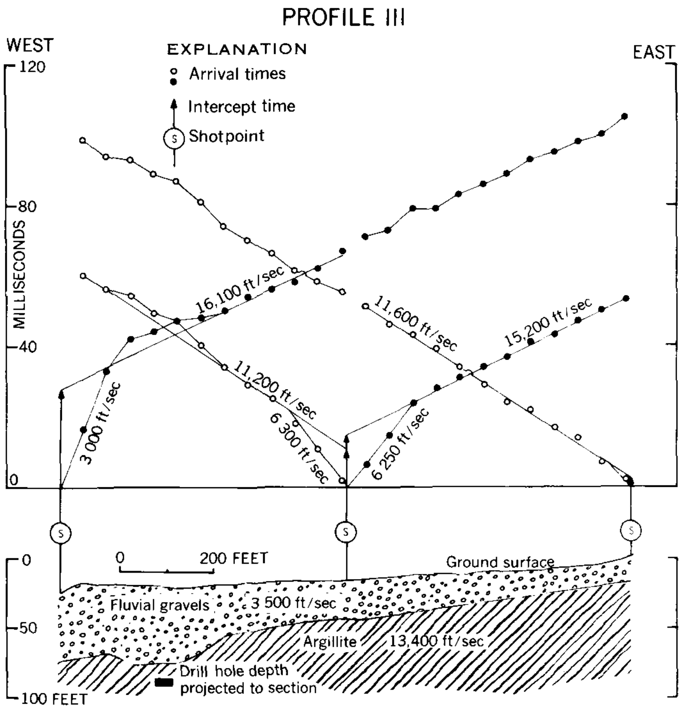


FIGURE 5.—Time-distance curves and geologic section, profile III.

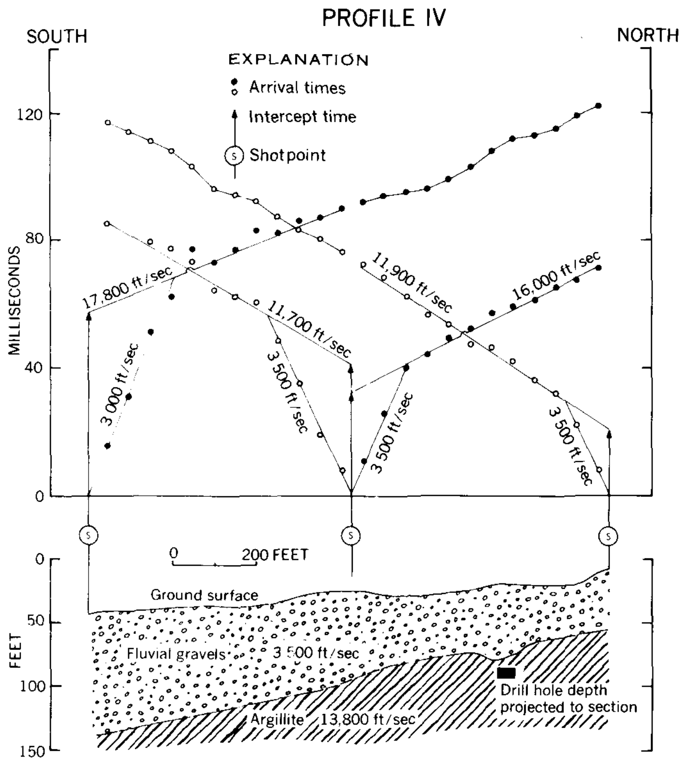


FIGURE 6.—Time-distance curves and geologic section, profile IV.

Denali bench is a relatively smooth bedrock surface. Its relief is characterized by gentle undulations and shallow depressions, rather than deeply incised channels such as the Tammany. Deposits are thickest along the Dry Creek cut. Profiles I and II reveal that mining operations in the cut did not extend to the edge of the buried channel; a considerable volume of channel fill still remains at this location. The seismic data indicate that elsewhere on the bench the thickness of the gravel blanket ranges from 45 feet in the north to nearly 75 feet in the south. These figures are in good agreement with thicknesses observed along the Valdez Creek gorge and with data from the drill holes.

## POTENTIAL RESOURCE VALUE

In describing the older workings, Ross (1933, p. 451) reported that by 1931 placer operations in the Tammany channel had processed approximately 500,000 cubic yards of material, yielding some 6,750 ounces of gold ($236,000 at $35 per ounce). The average value for all gravel, including the bedrock concentration, was about $1.10 per cubic yard (at $35 per ounce). Ross also reported that on the south side of Valdez Creek, downstream from Denali, 100,000 cubic yards of bench material yielded 2,850 ounces of gold, excluding that in the sluice boxes at the time of his examination. His estimate of bulk value, recomputed at $35 per ounce, is near $1.20 per cubic yard.

More recent estimates have been made for the gravels near Peters Creek (see fig. 1). There, complete panning of a vertical channel sample, totaling about 16 cubic yards, gave an average value of 50 cents per cubic yard, with little variation throughout the blanket (L. B. Kercher, oral commun., 1969).

Data from a drill hole to bedrock near profile III suggested also that gold is distributed uniformly in the gravels and averages about $1.27 per cubic yard, although some allowance should be made for inadvertent "salting" in the open hole (M. J. Wall, written commun., 1969; L. B. Kercher, oral commun., 1969).

During the present investigation, numerous small samples were panned from various vertical cutbanks in the gravels. Small amounts of gold, visible to the eye, were found in all these samples except those taken at the very top of the gravel blanket. However, the samples were too small to enable an estimate of bulk value. They do, however, verify the extensive distribution of gold throughout the gravels.

A conservative estimate of total value may be extended to the entire blanket by using the lowest bulk value mentioned above and the minimum indicated dimensions of the gravel deposit. Figure 1 shows that the blanket covers an area of at least 3,000 by 7,000 feet, about three-fourths square mile or more, and seismic measurements suggest a minimum thickness of 45 feet. Thus, at least 35 million cubic yards of auriferous detritus may cover the Denali bench. At 50 cents per cubic yard, the Denali bench gravels would have a resource value of more than $17 million. This figure, based on physical measurements and sample data from a small area near previous placer mining, must be considered an estimate of potential value. Further exploration is needed to verify that the bulk values reported here are representative of the entire gravel deposit.

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