GEOPHYSICAL EXPLORATION IN ALASKA*

H. R. Joesting†

In all parts of the world, geophysical exploration is concerned with the composition, form, and structure of the crustal rocks, with the search for minerals, mineral fuels, and ground water, and with problems of civil engineering and construction. In Alaska it is also concerned with permafrost, which has a marked modifying effect on the properties and distribution of near-surface materials, especially of unconsolidated deposits. Permafrost can usually be identified and mapped by geophysical methods, and it has therefore become a major field for geophysical investigation in Alaska.

In this paper I have attempted to review geophysical investigations in Alaska of geologic and related problems and to indicate problems worthy of future investigation. The earlier investigations are emphasized because relatively little information on them has been published. Permafrost investigations are also emphasized because of their importance in cold regions. Conversely, the recent extensive petroleum explorations in northern Alaska are treated more briefly than their importance might seem to warrant, because they are generally similar to petroleum explorations in other regions. In some instances it has been necessary to distinguish rather arbitrarily between geologic and geophysical endeavours, which are usually complementary. The paper is not intended to be exhaustive or complete, and discussions of investigations in fields of geophysics not closely related to geology have been omitted.

Permafrost and related problems

The earliest systematic attempts to use geophysical methods in interior Alaska were apparently all made by the U.S. Smelting, Refining, and Mining Company in the Fairbanks district. In 1928 magnetic surveys were carried out under the direction of E. E. Maillot, assisted by J. C. Boswell,[1] to determine their usefulness in tracing buried gold placer channels. The gold occurs on or near bedrock in gravels covered by as much as 200 feet of silt and muck. (Muck is dark-coloured silt, high in organic and water content and is usually frozen). Boswell concluded that the placers investigated did not contain sufficient magnetic black sands to affect a field balance.

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†Staff Geophysicist, U.S. Geological Survey.
[1]Boswell, J. C. 1929. "Application of geomagnetics to placer exploration". Unpublished thesis for B.S. in Mining and Geology, University of Alaska.

In 1933 the same company, using electrical resistivity and potential-drop-ratio methods, made systematic efforts to outline areas of permafrost and determine thickness of unconsolidated material over bedrock. On the whole these tests were not successful,[1] possibly because of the complex stratigraphy and permafrost relations of the partly frozen overburden.

In the summer of 1938 experimental seismic refraction surveys were made under the direction of L. D. Leet and H. G. Taylor for the same company. On the basis of this work, Taylor[2] concluded that the schist bedrock underlying the frozen muck and gravel in the Fairbanks district could not be mapped, because seismic velocities in frozen gravel were almost as high as in bedrock. Bedrock under frozen muck usually could not be mapped, because of variations in velocities in both bedrock and overburden, the latter resulting from thawed spots. Difficulty was generally experienced in determining depths to bedrock and to top of gravel in areas of discontinuous permafrost because of complex velocity relationships. In thawed areas it was usually possible to determine thickness of muck and gravel overlying the schist bedrock, though the accuracy was low in areas of deeply weathered bedrock. Considerable information was obtained on velocities of propagation in the formations in the Fairbanks district, and the following figures were recorded:

Light muck	1,000– 1,650 f.p.s.
Thawed muck	1,800– 4,000
Frozen muck	4,250–10,000
Thawed gravel	2,000–10,000
Frozen gravel	13,000–15,250
Bedrock (schist)	7,500–20,000

Light muck is evidently unfrozen, tan-coloured silt of aeolian origin (Tuck, 1940, pp. 1,299–306).

The rather wide variations in these velocities may have resulted in part from the discontinuous nature of permafrost in much of the Fairbanks district, so that measurements in completely frozen or completely thawed material were not always possible. Thus the lower velocity given for frozen muck (4,250 f.p.s.) may actually be for muck that was largely thawed, and the higher velocity for thawed gravel (10,000 f.p.s.) may result from an "island" of permafrost in otherwise thawed material. It is also likely that the higher velocity recorded for bedrock (20,000 f.p.s.) may result in part from irregularities of the surface of bedrock as well as from complex permafrost conditions.

In spite of the wide variations, Taylor's figures indicate that the velocities in frozen material are in general higher than in their thawed counterparts. This is substantiated by results obtained later in northern Alaska,[3] where velocities in continuous permafrost range between 8,000 f.p.s. in frozen

[1]Crawford, J. R. and E. E. Maillot. 1954. Personal communications.

[2]Taylor, H. G. 1939. "Report on geophysical work by the seismic method in the placer deposits of the Fairbanks district of Alaska". In files of U.S. Smelting, Refining, and Mining Company.

[3]Unpublished reports of United Geophysical Company to Director of Naval Petroleum and Oil Shale Reserves, 1950.

alluvium and 13,500 f.p.s. in frozen Tertiary sediments. The vertical velocities in northern Alaska were slowest and the velocity increased as the travel path approached the horizontal. Barnes[1] found horizontal velocities in frozen alluvium in the Fairbanks district to be comparatively high—of the order of 7,000 to 13,000 f.p.s. He states that a high seismic velocity is an almost sure indication of frozen ground (alluvium) and can only be misinterpreted as bedrock. He also noted that frozen alluvium is markedly anisotropic to the propagation of seismic waves.

Other experimental work includes the studies made by Matthews[2] in 1937 to test the use of the electrical resistivity method in exploring for gold placers in the Fairbanks district, and the more comprehensive investigation by the Territorial Department of Mines during 1938 to 1940 of magnetic and resistivity methods as aids to prospecting, mining, and geologic investigations in interior Alaska (Joesting, 1941). Magnetic surveys were found to be useful in prospecting for buried gold placers under favourable conditions, that is where moderate to large amounts of magnetic black sands were concentrated with the gold in comparatively shallow pay streaks, and where the effects of the black sands were not masked by bedrock anomalies. *In situ* determinations of resistivities of unconsolidated and consolidated rocks in the Fairbanks, Livengood, and Circle districts showed that in general the resistivities of frozen rocks are considerably higher than of comparable thawed materials and that these differences are sufficient to indicate the extent and approximate thickness of frozen unconsolidated deposits. Determinations of depth to bedrock were possible under favourable circumstances but were generally unsatisfactory in areas of discontinuous permafrost. It was also found that the contrast in resistivities between frozen and thawed unconsolidated deposits could facilitate the search for ground water.

In 1944 a brief study of the application of geophysical methods to permafrost problems was made by the U.S. Bureau of Mines and the Corps of Engineers, U.S. Army. Shallow resistivity surveys were made at Northway on the upper Tanana River, at Wolf Creek in the Fairbanks district, and at Galena on the Yukon River; and one seismic refraction station was occupied at Northway. On the basis of these surveys Swartz and Shepard[3] concluded that the top of the permafrost can usually be determined by both resistivity and seismic methods, and that areas of thawed and frozen ground can likewise be mapped by both methods. They also concluded tentatively that the bottom of the permafrost can be determined by resistivity, but not by seismic refraction because of unfavourable velocity ratios, and that ice lenses could be indicated by resistivity.

[1]Barnes, David F. 1954. "Preliminary report on tests of application of geophysical methods to arctic ground-water problems". Unpublished report in files of U.S. Geological Survey.

[2]Matthews, Ted C. 1938. "Application of geo-resistivity to placer exploration". Unpublished thesis for Batchelor of Mining Engineering, University of Alaska.

[3]Swartz, J. H. and E. R. Shepard. 1946. "Report on a preliminary investigation of the possible application of geophysical methods to studies of permafrost problems in Alaska". Unpublished report in files of U.S. Geological Survey.

More extensive experimental resistivity surveys were made in the Fairbanks district in 1948 by the U.S. Geological Survey under the direction of J. H. Swartz. This work substantiated earlier conclusions concerning the use of resistivity in permafrost areas, and the data are being incorporated in a report in preparation. In 1952 the Survey made an evaluation of electrical and seismic methods in the search for ground water in permafrost areas at the request of the Engineer Research and Development Laboratory, Corps of Engineers.[1] Following recommendations in this report, further surveys were made during the summer and fall of 1952. The geophysical work was coordinated with physiographic and ground-water studies and with a limited amount of drilling.

During the summer of 1953 experimental surveys were made by the U.S. Air Force Cambridge Research Center to determine the thickness of permafrost by measuring the frequency dispersion of flexural waves propagated through the permafrost layer. These experiments were made in continuous permafrost in the Farmers Loop area near Fairbanks. According to Hansen[2] records of flexural waves were obtained at distances of 3,000 feet to several miles using large charges placed in the permafrost. The method is based on one used by Press *et al.* (1951) to measure the thickness of sea ice.

Seismic reflection and gravity surveys were made in 1951 by Allen and Smith (1953) on the Malaspina Glacier, northwest of Yakutat Bay, to determine ice thickness and configuration of the subglacial floor. The information was obtained to aid in the study of structural relationships and flow within the glacier. Seismic refraction and gravity profiles were also run in 1952 on the Juneau Ice Field in southeast Alaska in connection with glaciological studies and to determine ice thickness (Miller, 1953a).

Geothermal investigations

In 1949 long-term geothermal studies were initiated in northern Alaska by the U.S. Geological Survey with the support of the Office of Naval Research and the Bureau of Yards and Docks of the Department of the Navy, and later of the Snow, Ice and Permafrost Research Establishment of the Corps of Engineers. These studies, which are still underway, aim to determine the temperatures and thermal properties of perennially frozen and other sub-surface materials in arctic Alaska and to relate them to the geology. Precise measurements of temperature have been made in both deep and shallow holes, most of them drilled in exploring for oil, and thermal conductivity measurements have been made of near-surface materials. The work has been coordinated with the extensive exploration program of the Office of Naval Petroleum and Oil Shale Reserves; the geothermal studies were in fact made feasible by the exploration program (MacCarthy, 1951, 1952).

[1]MacCarthy, Gerald R. and others. 1952. "Geophysical methods of prospecting for ground water in permafrost regions". Unpublished report in files of U.S. Geological Survey.

[2]Hansen, Roy E. 1954. Personal communication.

Temperature measurements in shallow boreholes have also been taken in the Umiat area of northern Alaska by a group from Boston University and in the Fairbanks district by the U.S. Geological Survey and the Corps of Engineers. Other temperature measurements were made in the boreholes in the Juneau Ice Field in southeastern Alaska in connection with glaciological studies (Miller, 1953b).

Sedimentary geology and oil exploration

During the period 1944 to 1953 extensive geophysical surveys were carried out in Naval Petroleum Reserve No. 4 and in much of the rest of northern Alaska on behalf of the Office of Naval Petroleum and Oil Shale Reserves of the Navy Department. Included were regional gravimetric surveys over much of the reserve, seismic reflection and refraction surveys in selected areas by the United Geophysical Company, aeromagnetic surveys of most of the reserve and the area eastward to Flaxman Island by the U.S. Geological Survey, and smaller-scale gravimetric surveys during 1945 by the Bureau of Yards and Docks. These have been discussed in reports by the United Geophysical Company[1] and Payne and others (1951). Additional reports and technical data are available for public inspection in the offices of the U.S. Geological Survey in Washington and the Inspector, Naval Petroleum Reserve, Fairbanks, Alaska.

These large-scale investigations exceed in magnitude the combined total of geophysical exploration already carried out in the remainder of Alaska. They were coordinated with extensive geologic investigations and by considerable test drilling. They were preceded by geologic and other explorations in northern Alaska, largely by the U.S. Geological Survey, over a period of many years, and conditions favourable to the occurrence of petroleum had been indicated by Smith and Mertie (1930), Smith (1939), and Ebbley and Joesting.[2]

As a result of the combined investigations it has been established that the region north of the Brooks Range is a single asymmetric sedimentary basin with its axis parallel to the range. Its deepest part is apparently within the foothills province of the region and not near the coast of the Arctic Ocean as was previously supposed. This sedimentary basin has been broadly defined, and a band of folding at least 30 to 50 miles wide and extending east more than 250 miles across the central part of the reserve has been outlined. In addition several anticlinal folds were examined in detail by seismic methods, especially along the northern part of the folded zone where exposures are insufficient to permit surface mapping of geologic structure (United Geophysical Company, 1954, *see* footnote 1, below); Gates, 1953; Gryc, Miller, and Payne, 1951).

[1]United Geophysical Company. 1954. "Final report on geophysical exploration of Naval Petroleum Reserve No. 4 and adjoining areas of Alaska, 1945 to 1953". Official report to Director, Naval Petroleum Reserve.

[2]Ebbley, Norman, Jr. and H. R. Joesting. 1943. "Report of investigation of petroleum seepages, Arctic Slope area, Alaska". Unpublished report in files of U.S. Bureau of Mines.

Renewed interest has been shown by private concerns in the oil resources of southern and southwestern Alaska during the past few years. In this connection seismic surveys were carried out on the Kenai Peninsula north of Homer during 1954 in areas where exposures of consolidated rocks are scarce.

In addition, the recent discovery of marine fossils in interior Alaska points up the possibility that other parts of the Territory may also contain oil (Payne, 1953; Péwé, 1954). The fossils were found in basal Quaternary deposits near Fairbanks, at the north edge of the middle Tanana basin. They are believed to have been derived from marine Tertiary rocks deposited in the Yukon–Tanana plateau region and removed during the Pliocene uplift, according to Payne. Payne further points out that under favourable conditions marine Tertiary rocks might be preserved in the middle Tanana basin and also in other basins in Alaska. Such rocks would be potential sources of petroleum, especially if considerable thicknesses are present.

Reconnaissance aeromagnetic surveys were flown by the U.S. Geological Survey in several parts of Alaska during 1954 to gain information on the approximate thickness of sedimentary rocks in the basins and also on regional structural trends and buried intrusive rocks. Among the areas flown over were parts of the Koyukuk geosyncline and of the Bethel, Nushagak River, Cook Inlet, Copper River, Yukon Flats, and Tanana River basins.

Metalliferous lodes

The first use of geophysical methods in prospecting for metalliferous lode deposits in Alaska was probably in 1930, by the Schlumberger Geophysical Company. The work was done at the Fidalgo-Alaska mine, on Prince William Sound south of Valdez. The problem was to find additional deposits of chalcopyrite and pyrite, or to extend known deposits. Spontaneous potential, equipotential, and electrical resistivity methods were used and several conducting zones were outlined that may have been related to deposits of sulfide minerals, but no commercial deposits are known to have been found.

No other geophysical prospecting for lode deposits seems to have been done until the period 1941 to 1943, when the Territorial Department of Mines carried out magnetic surveys for tungsten deposits in the Fairbanks district[1] (Joesting, 1943, p. 22), and for chromite deposits at Claim Point on the Kenai Peninsula.[2] Additional geophysical work in 1952 by the Territorial Department of Mines in the Lost River area of the Seward Peninsula, attempted to locate tin-bearing granite cupolas in limestone by use of magnetic and electrical resistivity methods. Negative results were obtained, partly because

[1]Joesting, H. R. and Eskil Anderson. 1941. "Preliminary report on scheelite deposits in the Fairbanks district, Alaska". Unpublished report available for public inspection at Office of Commissioner of Mines, Juneau, Alaska.

[2]Joesting, H. R. 1943. "Geologic and magnetic survey of chromite deposits, Claim Point, Alaska". Unpublished report available for public inspection at Office of Commissioner of Mines, Juneau, Alaska.

of the disturbing effect of permafrost, and of buildings and mining equipment.[1] Reconnaissance magnetic surveys were flown in the tin-bearing areas of Seward Peninsula in 1954, but attempts to locate granite cupolas were again unsuccessful. In the summer of 1954 an electromagnetic survey was made by private interests of the chalcopyrite and pyrite deposits at Horseshoe Bay on Latouche Island, Prince William Sound. Favourable results were reported (Territorial Dept. of Mines, 1954).

A number of dip-needle and magnetic-declination surveys for magnetic iron deposits were made in southeastern Alaska during the period 1942 to 1944. Records are available of surveys in several localities on Prince of Wales Island: on the Kasaan Peninsula (Erickson, 1948, p. 4), in Jumbo basin (Wright and Fosse, 1946, p. 6; Kennedy, 1953, pp. 36–8), and in the Mt. Andrew area.[2]

Several aeromagnetic surveys have also been made in connection with prospecting for metallic minerals. Among those in southeastern Alaska are a survey by the U.S. Geological Survey of southern Prince of Wales Island to obtain geologic information in an area containing deposits of magnetite and associated copper minerals,[3] and surveys by private interests of parts of the Mansfield Peninsula for nickeliferous deposits and of the Snettisham area for magnetic iron deposits.[4]

A reconnaissance aeromagnetic survey was flown in 1954 by the U.S. Geological Survey in the Snag River area, north of the Nutzotin Mountains, to relate magnetic and geologic features and to determine the magnetic effect of a mineralized zone that had been mapped in the adjoining area in Canada.

Radioactive minerals

Reconnaissance surveys for deposits of radioactive minerals have been made during recent years in many parts of Alaska both on foot, by car, and by aircraft using Geiger and scintillation counters. Most of these investigations have been made by the U.S. Geological Survey; their scope is indicated in publications by Gault *et al.* (1953), Moxham and Nelson (1952), Wedow,[5] and Wedow and others (1953).

Other investigations have been made by the Territorial Department of Mines, and recently there has been increasing activity by prospectors.

[1]Williams, J. A. and R. H. Saunders. 1953. "Geophysical exploration at the Lost River tin deposit, Alaska". Unpublished report available for public inspection at Office of Commissioner of Mines, Juneau, Alaska.

[2]Goddard, E. N., L. A. Warner and Matt Walton. 1944. "The copper-bearing iron deposits of the Mt. Andrew–Mamie area, Alaska". Unpublished report available for inspection in office of U.S. Geological Survey, Washington, D.C.

[3]Henderson, John, and others. 1954. "Aeromagnetic map of the southern part of Prince of Wales Island, Alaska". Open-file map available at offices of U.S. Geological Survey in Washington, D.C., Los Angeles, Menlo Park, San Francisco, and Denver, and in Anchorage, College, and Juneau in Alaska.

[4]Holdsworth, Phil. R. 1954. Personal communication.

[5]Wedow, Helmuth, Jr. 1951. "Adaptation of portable survey meters for airborne reconnaissance with light planes in Alaska". U.S. Geological Survey TEMR 323, released by Technical Information Service, U.S. Atomic Energy Commission, Oak Ridge, Tenn.

Additional airborne surveys were made in 1954 by the U.S. Geological Survey in the following areas: Buckland–Kiwalik, Nixon Fork, Tyonek, Yakataga Beach, and Nutzotin (Snag River).

Volcano research

A program of volcanological research in the Aleutian Islands was prompted by the eruption in June 1945 of Okmok volcano near Fort Glenn on Umnak Island. Geologic and geophysical investigations were started by the U.S. Geological Survey in 1946 at the request of the War Department. The geophysical investigations, which were terminated in 1954, were supported jointly by the Office of Naval Research and the U.S. Geological Survey (Swartz, 1951).

In connection with the geophysical investigations seismographs were set up on Adak and Great Sitkin islands to record earthquakes related to volcanic activity in the Aleutian Islands and tectonic activity in the Aleutian Trench. Measurements of earth tilt and of changes in the earth's magnetic and electrical fields were also made near Great Sitkin volcano.

Problems for future investigation

Except for problems related to permafrost, problems of geophysical exploration in Alaska are generally comparable to those in the western United States and western Canada. As these problems are practically infinite in number and variety, this discussion is restricted to those that appeal to me as interesting and important.

Permafrost

Permafrost—its distribution, physical properties, and origin; its relation to climate, vegetation, and animal life; and its effect on human activities—remains a field for investigation of first importance in northern regions, and one that has been pursued more assiduously in the U.S.S.R. than in Alaska. Geophysical methods, usually in combination with other methods of investigation, provide an effective means of adding to our knowledge of the distribution, physical properties, and origin of permafrost.

The distribution and upper surface of permafrost, for example, can now ordinarily be determined rapidly by electrical resistivity and seismic refraction surveys, supplemented by drilling and temperature measurements. The lower surface of permafrost may also be defined by resistivity, provided the frozen and thawed materials occur in suitably uniform, horizontal layers. Such ideal conditions are seldom found in nature, however, consequently the development of better means of obtaining and interpreting resistivity data in terms of depths to the bottom of permafrost is highly desirable. Seismic refraction methods are usually not suitable for defining the lower surface of permafrost, because unfavourable velocity relationships usually exist between permafrost and the underlying thawed material, especially where the thawed material is unconsolidated. Seismic reflection methods in theory do not have this limitation. Successful tests of shallow reflection equipment have recently been made by the U.S. Geological Survey (Pakiser and Mabey, 1954; Pakiser, Mabey, and Warrick, 1954) and this equipment may eventually be useful in defining the lower boundaries of permafrost.

Information on the decay or growth of permafrost and of heat flow from the earth can be gained from measurements of thermal conductivities and temperatures. Precise temperature measurements in boreholes could also conceivably be used to give information on climatic changes during the fairly recent past. In this connection Henderson[1] has computed the effect of a temperature increase of 10°C at the surface, assuming that changes as small as 0.005°C per year or 0.05°C per 10 years can be measured (this is about the limit of present-day equipment). Using reasonable values for thermal diffusivity, on which depends the rate of propagation of a thermal wave, it was found that such a wave could not be detected later than 490 years after it started from the surface. The maximum detectable depth of penetration would be about 800 feet after the lapse of 300 years, if the diffusivity were 0.01, and 1,100 feet after 300 years if it were 0.02. The simplifying assumption of a step-function temperature increase doubtless gives values somewhat greater than would be found experimentally. Field laws governing thermal processes in permafrost have been developed by Redozubov (1946).

More quantitative information on the physical properties of perennially frozen materials, their interrelationships, and their dependence on such factors as temperature, porosity, and permeability is required as a basis for an adequate understanding of permafrost. Electrical, elastic, and probably thermal properties are markedly affected by temperature. Ananian (1945), Dostovalov (1947), and others in the U.S.S.R. have shown that the resistivity and dielectric constant of perennially frozen materials depend on temperature as well as on other factors, but no quantitative investigations along these lines have yet been made in Alaska.

Adaptation or development of geophysical equipment for use in low temperatures is also desirable, especially as winter is the most favourable season for surface travel in many parts of Alaska. Adaptation of electrical resistivity equipment would require, for example, improved means of generating electrical power, of introducing current into the frozen ground, and of measuring current and potentials, and an insulation that would remain flexible. Development of electromagnetic induction equipment would probably also be worthwhile, as it would eliminate many of the practical difficulties of using electrodes in contact with the frozen surface and would permit more rapid mapping of permafrost. Weasel-mounted equipment could doubtless be developed for continuous cross-country traverses during the winter. Inductive methods have apparently been used to a considerable extent by the Russians in permafrost studies (Petrovsky, 1947; Petrovsky and Dostovalov, 1947 a,b) but little information is available on recent results.

Russian investigators have also noted spontaneous electrical currents at the interface between the thawed active layer and the permafrost layer

[1]Henderson, R. G. 1954. Personal communication.

(Kozin, 1936; Enenstein, 1947). Casual observations have failed to corroborate this phenomenon in Alaska. Systematic studies under known conditions would be worthwhile.

Sedimentary basins and oil exploration

If the Copper River region, Tanana River, Yukon Flats, and similar regions in Alaska prove to be basins of marine deposition as well as physiographic basins, they would become of great interest as potential sources of oil, and intensive geologic and geophysical investigations would be warranted. Such investigations would initially be concerned mainly with stratigraphic and structural relationships and would follow the same general pattern as in other parts of the world. It is probable, though, that airborne surveys would be used to a greater extent, at least in the initial stages of exploration, because of difficulties of surface travel.

Effect of earth's crust on terrestrial magnetism and electricity

In connection with the International Geophysical Year of 1957 to 1958, during which simultaneous observations will be made in many parts of the world of geophysical phenomena such as cosmic radiation, the aurora, geomagnetism, and ionospheric activity, it would seem desirable to carry out a series of magnetic and electrical investigations in which the modifying effects of the earth's crustal rocks are taken into account. More specifically, these should be concerned with the effects on the earth's magnetic and electrical fields, especially during periods of magnetic and auroral disturbance, of spatial variations in the magnetic and electrical properties of the crustal rocks due to differences in their structure and composition. These investigations should preferably be made in areas of high auroral activity, such as the Fairbanks district.

A start along these lines was made in Canada by Morley (1953), who measured two simultaneously operated stations, placed initially 130 miles apart and later 87 miles apart, during periods of severe magnetic disturbance. No attempt was made, however, to compare the amplitude of the disturbances with the magnetic susceptibility of the underlying rocks.

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