MAPS SHOWING AEROMAGNETIC SURVEY AND GEOLOGIC INTERPRETATION OF THE CHIGNIK AND SUTWIK QUADRANGLES, ALASKA

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INTRODUCTION

An aeromagnetic survey over part of the Chignik and Sutwik Island quadrangles, on the southern Alaska Peninsula, was flown in 1977 as part of the Alaska mineral resource assessment program (AMRAP). Maps at scales 1:250,000 and 1:63,360 have been released on open-file (U.S. Geological Survey, 1978a, 1978b). This report includes the aeromagnetic map superimposed on the topographic base (sheet 1) and an interpretion map superimposed on the topographic and simplified geologic base (sheet 2). This discussion provides an interpretation of the aeromagnetic data with respect to regional geology, occurrence of ore deposits and prospects, and potential oil and gas resources. The survey was flown along northwest-southeast lines, spaced about 1.6 km apart, at a nominal elevation of about 300 m above the land surface. A proton-precession magnetometer was used for the survey, and the resulting digital data were computer contoured at intervals of 10 and 50 gammas (sheet 1). The International Geomagnetic Reference Field (IGRF) of 1965, updated to 1977, was removed from the total field data.

Because of the ruggedness of the central and southeast parts of the Alaska Peninsula, it was difficult for the aircraft to maintain a constant height of 300 m above the terrain, particularly across deep narrow valleys or narrow marine inlets. Some apparent magnetic anomalies are therefore related to the geometry of the survey rather than to geologic features. Inclement weather during the survey contributed to the terrain clearance problem. More detailed discussions of anomalies related to "drape-flying" elsewhere in Alaska can be found in reports by Griscom (1975) and Case, Tysdal, Hillhouse and Grommé (1979).

The aeromagnetic map has a conspicuous northwest-southeast "grain", parallel to the direction of the flight lines, and a less prominent grain oriented northeast-southwest. This apparent orthogonal pattern may have an origin independent of geologic features: First, the Earth's diurnal field may have changed significantly between flying adjacent lines, and, second, the algorithm used for the computer-contouring process may introduce spurious lineaments parallel to the orientation of the grid. These possibilities introduce interpretive difficulties regarding the presence or absence of geologically significant lineaments, which may be related to segmentation of the volcanic arc that occurs along the Alaska Peninsula. We are confident that some of these lineaments, however, express geologic features.

Geologic descriptions of the Chignik and Sutwik Island quadrangles are provided in reports by Detterman, Miller, Yount, and Wilson (1979, 1981) and Burk (1965), and the generalized stratigraphy is summarized on figure 1. Briefly, this segment of the Alaska Peninsula is dominated by three large Quaternary volcanic centers of Mount Veniaminof, Black Peak, and Aniakchak Crater. Thick sequences of Tertiary marine and nonmarine sedimentary rocks occur in one or more basins along the Bristol Bay side of the peninsula and in northeast-trending basins or synclines south of Mount Veniaminof and Aniakchak Crater. Early Tertiary volcanic rocks and interstratified sedimentary rocks are exposed sporadically across much of the mountainous part of the area. Cretaceous continental and marine strata and Jurassic marine strata, mainly of shelf or upper slope facies, are exposed in several belts in complexly faulted anticlines that trend northeast from Chignik Lake and Aniakchak Crater. Folds in the area are generally broad and open, and the main deformational event in the area occurred after deposition of the Bear Lake Formation (Miocene). Most faults are high angle, and northwest-dipping reverse faults are common in the vicinity of Chignik anticline.

Numerous Tertiary dioritic to granodioritic plutons are scattered throughout the area and have associated copper and molybdenum mineralization of the porphyry type in both plutons and wallrock. Hypabyssal intrusive centers are common and range from leucobasalt to dacite in composition. Unless otherwise noted, ages of Cenozoic igneous rocks cited in this report were determined by F. H. Wilson, using K-Ar techniques. Detailed descriptions are provided in reports by Wilson (1978, 1980a, 1980b, 1980c) .

The age and lithology of the magnetic basement are uncertain. Northeast of the area, Triassic limestones are intercalated with basaltic breccias, agglomerates, and sills near Puale Bay (Burk, 1965), and a single locality of middle Permian limestone has also been reported near there (Hanson, 1957). Marbles containing early Paleozoic(?) corals occur north of Becharof Lake, in the Naknek quadrangle (Detterman, Case, and Wilson, 1979). The Gulf Oil Corporation #1 Port Heiden drill hole, near the north-central edge of the Chignik-Sutwik Island area, bottomed in granitic rock, presumably of Jurassic and(or) Cretaceous age (Brockway 1975; Reed and Lanphere, 1973), at a depth of about 4,570 m. Just north of the area, the Cities Service Corporation #1 Painter Creek hole bottomed in the Shelikof Formation of Middle Jurassic age at a depth of 2,412 m. Southwest of the area, the Pan Am #2 Hoodoo Lake hole (sec. 35, T. 50 S., R. 76 W.) bottomed in the Staniukovich Formation of Late Jurassic and Early Cretaceous age at a depth of 3,427 m (Brockway, 1975).

If corrections were made for the effects of low-density sedimentary rocks that occupy the basins, the entire Bouguer anomaly field of the Chignik-Sutwik Island part of the peninsula would be positive, with values in excess of +50 mgal in the north-central part of the ara. Such values are more characteristic of "oceanic" than "continental" crust (J. E. Case and others, in press, 1981). Thus, the magnetic basement in part may comprise Jurassic and(or) Cretaceous plutonic rocks and older rocks, especially northwest of the Chignik quadrangle, and pre-Jurassic oceanic or transitional crust in the central and southeastern part of the area.

GENERAL FEATURES OF THE AEROMAGNETIC MAP

The general level of the magnetic field increases by 700-800 gammas northeast across the mapped area, but it is uncertain whether this is an apparent regional long-wavelength anomaly that reflects a deep-seated crustal or mantle feature or whether it represents errors in the parameters of the IGRF.

Several broad groups of anomalies are superimposed on the regional field. 1) Anomalies of high amplitude and short wavelength are related to the young volcanic centers of Mount Veniaminof, Black Peak, and Aniakchak Crater. 2) Similar groups of anomalies form oval or partly oval patterns over older volcanic-plutonic complexes near Kujulik Bay, Chiginagak Bay, Sutwik Island, and Nakchamik Island. 3) Strongly positive oval anomalies occur over exposed or shallow Tertiary plutons. 4) Long-wavelength anomalies having gentle gradients reflect deep-seated features of the basement under the basin areas.

In the following descriptions, groups of anomalies shown on the aeromagnetic map (sheet 1) are numbered on the interpretation map (sheet 2) and keyed to the interpretive discussion where known or inferred rock types and ages have been indicated. Boundaries between areas are subjective and have been drawn on zones of steepened magnetic gradient that crudely define groups of anomalies. Locally, boundaries have been drawn that diverge from gradients in order to include rock units known from the geologic mapping.

AGE			THICKNESS meters	FORMATION	LITHOLOGY
QUATERNARY		Holocene and Pleistocene	10 - 1,000		Sand, gravel, and silt
QUATERNARY		Pliocene	300 - 1,500	Milky River Formation	Volcaniclastic sandstone and comglomerate
TERTIARY		Miocene	1,000 - 2,400	Bear Lake Formation	Sandstone, siltstone, conglomerate, shale, coal
TERTIARY		Oligocene and Eocene	500 - 1,500	Meshik Formation*	Sandstone, siltstone, conglomerate, shale, coal
TERTIARY		Eocene	1,000 - 1,500	Tolstoi Formation of Burk (1965)	Sandstone, siltstone, conglomerate, shale, coal
TERTIARY		Paleocene			
CRETACEOUS	Late	Maestrichtian	0 - 500	Hoodoo Formation	Dark siltstone, shale, minor shale, coal
CRETACEOUS	Late	Campanian	300 - 500	Chignik Formation	Sandstone, conglom erate, siltstone, shale, coal
CRETACEOUS	Late	Santonian			
CRETACEOUS	Late	Coniacian			
CRETACEOUS	Late	Turonian			
CRETACEOUS	Late	Cenomanian			
CRETACEOUS	Early	Albian			
CRETACEOUS	Early	Aptian			
CRETACEOUS	Early	Barremian			
CRETACEOUS	Early	Hauterivian			
CRETACEOUS	Early	Valanginian	0 - 30	Herendeen Limestone	Calcarenite
CRETACEOUS	Early	Berriasian	0 - 300	Staniukovich Formation	Feldspathic to arkosic sandstone
JURASSIC	Late	Tithonian			
JURASSIC	Late	Kimmeridgian	1,500 - 1,800	Naknek Formation	Upper part - dark siltstone Lower part - arkosic sandstone, conglomerate, siltstone
JURASSIC	Middle	Callovian	150 - 300	Shelikof Formation	Dark siltstone

*Recent potassium-argon and fossil data indicate that the age of the Meshik Formation, shown as Oligocene and Miocene by Detterman, Miller, Yount, and Wilson (1979), is Eocene and Oligocene (Detterman and others, 1981).

Figure 1.—Summary of thickness, lithology, and age of major rock units in the Chignik and Sutwik Island quadrangles. Modified from Wilson (1980b) and Detterman and others (1981)

Some of the larger and more conspicuous closed magnetic lows, generally having an amplitude greater than -50 gammas, are indicated by hachured lines. The origin of many lows cannot be determined from available data. Some may be (1) normal polarization lows, (2) effects of topography related to the drape-flying process or buried channels in the magnetic basement, (3) effects of alteration, or (4) reversed remanent magnetization. Only where the cause of the low can be postulated with some confidence has an origin been assigned. Identification of the sources of the anomalies is of special significance for two reasons: 1) if magnetic reversals are present over the volcanic centers, some of the rocks are older than 0.5 m.y. which is the approximate age of the first major reversal in the past; this would have major implications for the magnetostratigraphy of the Alaska Peninsula; 2) if lows indicate areas of alteration, particularly areas associated with granodioritic plutons, they may be guides to ore mineralization. Only a few areas of suspected alteration have been added to the interpretative map. Other areas of known alteration are shown on the geologic base.

Physical properties.--Although too few samples have been measured to adequately characterize the magnetic properties of the igneous rocks of the area, the measured values (table 1) indicate an expected wide range of magnetization and generally moderate to high values of susceptibility. Remanent magnetizations were not measured. Susceptibilities greater than 0.001 are large enough to produce many of the magnetic anomalies shown on sheet 1, provided that the bodies are of sufficient thickness (a few hundred meters or more). Similar values of susceptibility and attendant high magnetization have been found for volcanic rocks in the Aleutian Islands (Bath and others, 1972; Richards and others, 1967).

Table 1 - Physical properties of some samples from the Chignik and Sutwik Island quadrangles and vicinity (Measurements by Robert Morin)
K_T - Susceptibility (cgs units)

Sample		K_T	Rock type and map unit (see explanation for geologic base, sheet 2)
77ACE	25	0.00175	Diorite (altered) - Ti
	25B	.00038	Gabbro or diorite - Ti
	32	.00049	Gabbro or diorite - Ti
	33	.00088	Monzonite(?)-Ti
	44	.00358	Basalt-Tm
	45	.00188	Porphyritic diorite or dacite-Ti
	55	.00011	Diabase-Ti in KHc
	60	.00291	Amphibole dacite-Ti in Tm
	67A	.00003	Amphibole dacite-Ti
	69	.00291	Porphyritic dacite-Ti
	76	.00297	Porphyritic dacite-Ti in Khc
77AWS	40	.00348	Porphyritic leuco-basalt-Ti
77AWS	44	.00136	Porphyritic dacite-Ti
78ACE	11	.00220	Altered(?) basalt or gabbro-Tm
	13A	.00255	Altered basalt or andesite-Tm
	13B	.0000	Altered volcanic breccia-Tm
	14	.00080	Dacite-Tm
	15	.00099	Altered diorite-Ti
	16	.0000	Sandstone-Khc
	17	.00000	Sandstone-Khc
	20	.00003	Sandstone-Tt?
	21	.00010	Porphyritic dacite-Ti
	23	.00002	Sandstone-Khc
	38	.00390	Altered(?) diabase
	39	.00193	Dacite or diorite sill-Ti
	39A	.00002	Sandstone-Tt
	40	.00011	Porphyritic andesite or basalt-Ti in Tt
	42	.00200	Andesite or basalt-Tm
	43	.00246	Altered basalt or andesite-Tm
	44	.00286	Altered dacite-Tm
	44A	.00402	Altered basalt or diabase-Tm
	45	.00367	Porphyritic basalt-Ti in Khc
	47	.00009	Porphyritic andesite-Ti in Khc
	48	.00007	Porphyritic dacite or granite-Ti in Khc
	48A	.00002	Alaskite-Ti in Khc
	49	.00292	Basalt or andesite sill-Ti in Khc
	50	.00166	Dacite-Ti in Khc
	52	.00006	Arkosic Sandstone-Khc
	132	.00245	Andesite-Tv
	132A	.00000	Sandstone-KJhs
	138	.00219	Volcanogenic conglomerate-KJhs
	139	.00038	Porphyritic andesite-Qad
	140	.00000	Felsic pluton-Ti
	142	.00392	Porphyritic andesite or basalt-Qv
	144	.00317	Andesite rubble flow-Qv
	145	.00299	Dacite or andesite breccia-Qad

DISCUSSION OF SPECIFIC AREAS AND ANOMALIES

Bristol Bay lowlands.--Most of the mapped part of the Bristol Bay lowlands is underlain by a large sedimentary basin characterized by magnetic anomalies of gentle gradient and low amplitude, indicating relative great depth of 2 km or more to the magnetic basement.

In area 1, small oval highs and lows of a few tens of gammas are superimposed on anomalies related to deep-seated features. The Gulf Oil Corporation #1 Sandy River drill hole (T. 46 S., R. 70 W.) penetrated about 3,983 m of predominantly sedimentary strata and terminated in the Stepovak Formation of Burk (1965, Oligocene) at total depth (Brockway, 1975). Basalt flows and tuffaceous beds were intersected in shallow parts of the well, and interbedded volcanic rocks were common below 3,800 m. The small high-amplitude positive and negative anomalies are thus thought to be produced by volcanic materials interstratified in the shallower sedimentary sequence or by small concealed intrusive bodies.

A similar pattern of superimposed anomalies indicative of both deep and shallow sources occurs farther northeast in area 2. The magnetization of the basement appears to be higher than in area 1, or the basement is locally shallower, as inferred from the presence of broad positive anomalies of 50 to 150 gammas.

Several northwest-trending zones of steepened magnetic gradient occur in areas 1 and 2. The larger and more conspicuous zones probably represent faults because their direction closely parallels a belt of cinder cones on the north side of Mount Veniaminof, which is thought to indicate a major fracture zone (Nakamura, 1977). Many of these magnetic lineaments roughly parallel mapped cross-faults in surface exposures to the southeast. A north-south zone of steepened gradient in area 2 may also represent a buried fault or wrap. The Sandy River drill hole, located near one of the northwest-trending zones, cuts a probable fault zone of unknown trend at depths between 3,350 and 3,650 m.

Anomalies related to deep basement features are interrupted by a belt of northwest-trending, high-amplitude anomalies (area 31) related to the chain of Holocene(?) cinder cones and plugs of the Mount Veniaminof volcanic center.

Areas 3, 4, and 5, between the Mount Veniaminof, Black Peak, and Aniakchak volcanic centers, have anomaly patterns similar to those in areas 1 and 2 where anomalies related to basement features are of low amplitude and gentle gradient. These deep anomalies may be edge effects of a very large magnetic body at depth beneath areas 10 and 11. Small, high-amplitude anomalies are related to Quaternary ash and debris flows or to shallow volcanic materials in the sedimentary sequence. Basement may be deeper under anomaly area 4, near Black Lake, than under area 3. Farther north and northeast, anomaly area 5 is separated from more highly magnetic basement to the northwest in areas 10 and 11 by a major northeast-trending magnetic gradient that represents a lithologic contrast or step in the magnetic basement. The area 5 patterns are interrupted by a group of small, high-amplitude anomalies of area 6 that are probably caused by ash and debris related to the Black Peak complex. A nearby positive anomaly of about 100 gammas (area 7) is produced by a moderately magnetic body, buried at intermediate depths of perhaps 1 to 2 km, as estimated from the gradients on the flanks of the anomaly. The oval shape suggests a concealed pluton rather than a buried sequence of flows. However, an oval anomaly of about 400 gammas to the east (area 8) may overlie buried volcanic flows, which crop out nearby on the southwest flank of Aniakchak Crater volcano, although a concealed pluton cannot be discounted. Subdued magnetic gradients in anomaly area 9, northeast of the Black Peak volcanic complex, reflect the great depth to magnetic basement beneath the Meshik River syncline, whose axis parallels the upper course of the river.

Deep, moderately to strongly magnetic basement underlies area 10. Three large anomalies, areas 11, may represent more magnetic phases or discrete plutons in the basement. The Gulf Oil Corporation #1 Port Heiden well (T. 37 S., R. 59 W.), penetrated more than 4,550 m of Tertiary sedimentary and volcanic rocks above a granitic basement (Brockway, 1975). The age of the granitic rock has not been determined, but north of the area, in the Ugashik quadrangle, the General Petroleum #1 Great Basins well bottomed in a granite at a depth of 3,377 m, and an age of 177 m.y. has been reported (Brockway, 1975). Granodiorite from the Aleutian Range batholith near Becharof Lake has been dated at 163 to 176 m.y. by K-Ar methods (Reed and Lanphere, 1973). Anomalies of area 11 may represent a buried continuation of the Aleutian Range batholith, as proposed for the region by Reed and Lanphere (1973, p. 2606); however, abundant volcanic materials were found at depths of about 2,730 m in the Port Heiden well and persisted to the top of the granite at 4,550 m. It is therefore possible that the magnetic basement of areas 10 and 11 comprises a buried Tertiary (pre-Miocene Bear Lake) volcanic complex as well as a granitic basement.

Between areas 3 and 10 is a small anomaly (area 12) having an amplitude of more than 400 gammas and very steep gradients. The anomaly is similar to those over the cones and plugs that trend northwest from the Mount Veniaminof center and is inferred to be caused by a satellite volcano at shallow depth. The feature may actually crop out or be covered by thin glacial debris, but no geologic stations were occupied at the site of the anomaly.

Several northwest-trending zones of steepened magnetic gradient are prominent in parts of areas 3, 5, 10, and 11. Some are parallel to a set of satellite cinder cones of Mount Veniaminof, and others are parallel to or alined with fault zones exposed farther southeast near Chignik Lake. These features are believed to represent real geologic features of the basement rather than artifacts of the magnetic survey.

Southeast margin of Alaska Peninsula.--Other areas of relatively deep magnetic basement occur along the southeastern margin of the peninsula, mainly offshore. Southeast of the area, Bruns and von Huene (1977) have identified the Shumagin Basin offshore between the Semidi and Shumagin Islands, near lat 55°15'-55°45' N., long 157°15'-158°30' W., which contains as much as 2.5 km of presumed Cenozoic sedimentary strata. South of the area, in the Stepovak Bay quadrangle, the Phillips Oil Corporation Big River A #1 drill hole (sec. 15, T. 49 S., R. 68 W.) penetrated 3,436 m of strata and bottomed in the Naknek Formation of Late Jurassic age (Herrera, 1978).

Cretaceous and early Tertiary sedimentary rocks are exposed along the south-central edge of the Chignik-Sutwik Island area, near Ivan and Fishrack Bays. Magnetic basement is deep, as judged from gentle gradients of anomalies in area 13. Small anomalies with steeper gradients in area 14 probably represent small exposed and concealed granitoid plutons such as those exposed near Ivan Bay and Fishrack Bay (area 65).

The magnetic basement in area 15, near Kuiukta Bay, also appears to be generally deep, but topographic effects related to drape flying probably contribute to the magnetic low. Local anomalies of shallower source (area 16) and major positive anomalies (areas 66 and 67) related to granitic plutons interrupt the gentle anomalies related to the deep basement. Area 17 appears to have relatively deep magnetic basement, but a few small anomalies occur that are related to shallow igneous rocks. The deep basement persists northeastward across Chignik Bay into area 18. A prominent magnetic step of more than 50 gammas trends northwest and separates areas 17 and 18. Area 18 appears to be largely devoid of shallow-source anomalies. Deep to moderately deep magnetic basement continues to the northeast through areas 19 to 24, between the mainland and the volcanic complexes near Sutwik Island and Chigingak Bay. These areas are separated by northwest-trending zones of steepened magnetic gradient. Most of the areas include a few small anomalies suggestive of shallow sources, except area 23, which does not appear to contain significant shallow-source features. The magnetic basement in areas 13 through 24 is probably pre-Naknek (pre-Late Jurassic) in age, and it could lie at depths of 2 km or more beneath the flight elevation. Gentle magnetic gradients in area 25, near the head of Amber Bay, indicate a moderately deep magnetic basement, but a few small anomalies with steep gradients probably indicate the presence of small buried plutons. Somewhat larger magnetic anomalies in area 26 indicate larger buried plutons or overthrust Meshik rocks at relatively shallow depths.

The large positive anomaly in area 27 is caused partly by Tertiary volcanic rocks, but it may be of composite origin related also to a concealed pluton below the exposed Tertiary and Mesozoic sedimentary rocks. Similarly, broad magnetic anomalies of moderate amplitude and gentle to moderately steep gradients in areas 28 and 29 occur mainly over sedimentary and local volcanic rocks intruded by a few plutons. Most of these anomalies are probably caused by plutons at shallow to intermediate depth.

ANOMALIES RELATED TO QUATERNARY VOLCANIC CENTERS

The most conspicuous groups of magnetic anomalies of the region are those over the large active volcanic edifices of Mount Veniaminof, Black Peak, and Aniakchak Crater. Part of the Kupreanof volcanic complex lies astride the boundary of the Chignik and Stepovak Bay quadrangles, near long 159°45' W. The contractor was unable safely to obtain aeromagnetic data over Kupreanof because of inclement weather conditions. Some of the short-wavelength anomalies in areas 30 and 75 appear to overlie volcanic rocks emitted from Kupreanof but may also be related to older volcanic rocks or to flows from the Mount Veniaminof center.

Mount Veniaminof volcano.--The pattern of magnetic anomalies (area 31) over this large volcanic center is exceedingly complex, as it is over most composite volcanoes. Lava flows, air-fall tuffs, debris flows, and ignimbrites(?) have varying degrees of magnetization. Moreover, the Q-values, the ratio of remanent to induced magnetization, of island-arc volcanic rocks commonly vary dramatically (Blakely and Christiansen, 1978; Bath and others, 1972), leading to complex anomaly patterns. The volcanic edifices display prominent magnetic highs over flow units, plugs, and cones. Three specimens of andesite or basaltic andesite from this terrane have high susceptibilities--0.0024 to 0.0039 cgs units. In addition, numerous magnetic lows occur that may be related to topographic effects of drape flying, polarization effects, low original intrinsic magnetization, thick cover of ice or alluvium, hydrothermal alteration, or reversed remanent magnetization. We suspect, however, that relatively few of the negative anomalies over Mount Veniaminof are caused by reversed remanent magnetization because most of the edifice was probably constructed within the last 700,000 years, within the Brunhes normal polarity epoch.

Only a few specific anomalies within the complex are discussed here. An oval, ice-filled caldera occupies the central part of the center; a young intracaldera cone (area 32) causes a triangular positive anomaly of 2000 gammas. This high is surrounded by low or negative anomalies inside the rim of the caldera probably related to the topography. High positive anomalies surround the caldera and form a crudely arcuate pattern around the volcano. Those having an amplitude in excess of about 250 gammas have been labeled as a separate unit.

Cinder and spatter cones and volcanic necks form a conspicuous northwest-trending zone across the volcano, especially northwest of the caldera, and many of these appear to be associated with very prominent positive anomalies. One prominent cluster of cinder cones and an associated, rather obscure, positive anomaly (area 33) trend northeast rather than northwest.

Where the magnetic lows are clearly related to topographic lows, they are separately labeled, but many negative anomalies cannot be specifically determined to have an origin from topography, alteration, or remanent magnetization.

Black Peak volcano.--Black Peak volcano, about 54 km northeast of Veniaminof caldera, is a much smaller center than the Veniaminof and Aniakchak complexes. Quaternary flows are restricted to the north side of the caldera and cause erratic magnetic highs (area 34). Ash-fall tuffs and debris flows cause subdued highs and lows. The Tertiary volcanic flows exposed on the south and east flanks of the volcano likewise cause an erratic pattern of subdued highs and lows (areas 34 and 37). A general magnetic low occurs over the northern part of the caldera, but a prominent high (area 35) is present over the southern part and rim. The high may be related to the intra-caldera dome complex, or it may be the expression of a pluton such as those exposed farther south in areas 36 and 38 where a very prominent high (area 38) of more than 1000 gammas occurs over a large pluton. The pluton is a multiphase pyroxene and amphibole andesite or quartz diorite (hypabyssal) and has a K-Ar age of only 1.7 m.y. (Wilson, 1980a, 1980b). Positive anomalies of lower amplitude in area 36 near Range Peak probably have a composite source of Tertiary intrusive and extrusive rocks.

Aniakchak Crater volcano.--Anomaly patterns related to the Aniakchak Crater volcanic complex are associated with both Quaternary and Tertiary volcanic rocks. Anomalies caused mainly by Quaternary flows dominate the region around the caldera in area 39. The floor of Aniakchak caldera is studded with many cinder cones. A large magnetic high (area 40) of more than 2000 gammas occurs over the southwest part of the caldera. Magnetic lows in the east and south parts of the caldera are effects of topography and sedimentary rocks forming parts of the caldera wall. Strongly magnetized flows and associated volcanic rocks are the cause of lobate positive anomalies around the caldera. On the southerly slopes of the volcano, in area 41, small, short-wavelength anomalies are probably composite, related to both Quaternary and Tertiary volcanic materials and possibly to concealed plutons. In area 42, large positive anomalies, up to 400 gammas, occur over a terrane of Quaternary ash and debris flows and the Meshik Formation, and composite sources are suggested. Small anomalies in area 43 are mainly over a terrane of exposed Tolstoi Formation of Burk (1965), which is relatively nonmagnetic; hence small buried but shallow plutons are the suspected source.

OLDER VOLCANIC AND PLUTONIC CENTERS

Meshik River-Kujulik Bay center--A large area underlain by Tertiary volcanic rocks (Meshik Formation) and local intrusive rocks occurs around Kujulik Bay and along the northeast extension of the Chignik anticline. Anomalies over these rocks form crude oval patterns (area 44), similar in many respects to those over Mount Veniaminof and Aniakchak Crater volcanoes, and this group of anomalies is interpreted as an old volcanic center folded into a broad northeast-trending anticline. A caldera has not been identified in reconnaissance geologic mapping. If one exists, it might occur beneath Kujulik Bay. K-Ar ages of these rocks are about 30-35 m.y., and, on stratigraphic grounds, the Meshik is of Eocene and Oligocene age (Detterman and others, 1981).

Numerous magnetic highs in the area range up to more than 1000 gammas. Susceptibilities of three andesite and altered basalt samples are 0.002, 0.0025, and 0.0036 cgs units. A prominent low in area 45 is probably a normal polarization low related to the faulted northern contact of the volcanic complex. Many other magnetic lows in area 44 are caused by topography, but a few anomalies may be caused by reversely magnetized or altered rocks.

The Meshik occurs as a steeply dipping band along the northwest flank of Chignik anticline and around the north-plunging nose of the anticline. Anomalies related to these volcanic rocks, presumably the lowest part of the volcanic pile, have high amplitudes and short wavelength in areas 47 and 48. The anomalies over the Meshik Formation are interrupted and possibly reinforced by the large high in area 38 over the Quaternary pluton. On the southeast flank of the anticline, the Meshik evidently terminates near Dry Creek in the southwest part of T. 42 S., R. 57 W. and does not reappear until the vicinity of Chignik Lagoon, area 49. We do not know whether this outcrop pattern results from erosion or thrust faulting, or because the flows simply terminated. This is a critical point because the exposed core of Chignik anticline is composed mainly of nonmagnetic Jurassic and Cretaceous sedimentary strata, and only a few plutons have been mapped in the core in area 50. Yet the core region, area 51, is the site of many magnetic anomalies having very steep gradients indicative of shallow sources. They must be caused by either shallow but largely concealed plutons or by the Meshik beneath shallow thrust sheets. A similar conclusion applies to the small low-amplitude anomalies in area 52 on the southeast flank of the anticline.

Cape Kumlik-Sutwik Island Centers.--A group of high-amplitude, short-wavelength anomalies at Cape Kumlik (area 53) occurs over Tertiary volcanic rocks and small plutons, and it is distinct from those of the Meshik River-Kujulik Bay Center (area 44). Susceptibilities of three porphyritic dacite samples range from 0.0014 to 0.0035 cgs units. Ages from this area are in the range 32 to 39 m.y., similar to those from the Meshik River-Kujulik Bay Center, and could represent igneous activity satellitic to the main center. Another major volcanic-plutonic center appears to be present near Sutwik Island (area 54), but the size is unknown because magnetic coverage is incomplete. K-Ar ages from Sutwik Island range from 30 to 36 m.y., similar to those of the Meshik River and Cape Kumlik areas. Although the magnetic patterns suggest three discrete centers, perhaps only one larger center was present, and either erosion has stripped the volcanic rocks from local areas or deformation has depressed the volcanic rocks to great depth beneath water-covered areas between Cape Kumlik and Sutwik Island. Two areas of possible reversed remanent magnetization or alteration occur on Sutwik Island, where the anomalies do not correlate with topography. Magnetic lows north and northwest of the island are probably the combined effect of polarization and topography. Concealed Tertiary igneous rocks are inferred from the presence of small magnetic highs in area 55 to the northeast.

Chiginigak Bay Center.--An oval group of high-amplitude anomalies occurs at Chiginigak Bay (area 56) in the extreme northeastern part of the area. Some of the relative positive anomalies are as high as 1400 gammas. Rocks around the bay include the Meshik Formation and a variety of mafic to intermediate intrusive rocks, dikes, and sills. An age of 9.4 m.y. has been obtained from a mafic plug just north of the area. A negative anomaly at Cape Providence may represent alteration of exposed plutonic rocks.

In the northeastern corner of the map, around area 56, broad positive anomalies (area 57) are characterized by somewhat gentler magnetic gradients, probably produced by volcanic and plutonic rocks similar to those of the main Chiginigak Bay complex, but buried at shallow to intermediate depths offshore. Small plutons and volcanic rocks crop out at Cape Kuyuyukak (area 58) and near the head of Nakalilok Bay.

Other possible volcanic centers.--Other igneous centers probably occur in the vicinity of Unavikshak Island (area 59), and Chankliut Island (area 61). Each area is characterized by small, short-wavelength anomalies of moderate to high amplitude. The full size and extent of possible connections between areas 60 and 61 cannot be determined because the aeromagnetic coverage is incomplete. A hornblende-plagioclase porphyry from Nakchamik Island has an age of about 10 m.y., similar to those from the Chiginigak Bay area and the Devils Bay pluton.

Along the north edge of the quadrangle, complex high-amplitude anomalies in areas 62 and 63 occur over both plutons and Tertiary volcanic rocks, but some anomalies may be related to a recently discovered Holocene volcanic center near the head of Yantarni Creek, whose center is about 3 km north of the quadrangle boundary, along long 157°12' W. A magnetic high in area 64 is at the site of several small exposed plutons and probably overlies a larger one at relatively shallow depth.

ANOMALIES PRODUCED BY LARGER PLUTONS

Most of the exposed larger plutons in the area are moderately to strongly magnetic and cause conspicuous positive anomalies except where the plutons are hydrothermally altered. Recognition of magnetic patterns over the felsic to intermediate plutons has considerable significance in resource assessment because many of them contain associated copper and molybdenum deposits. Cox (1981) has identified 14 zoned clusters or "centers of mineralization" on the basis of evaluation of geochemical anomalies from panned concentrates of stream-sediment samples and drainage patterns (see Detra and others, 1978-1980). Most of these centers occur directly on or near the flanks of positive aeromagnetic anomalies, and many are near known or inferred plutons. Centers of mineralization occur near areas 14, 27, 36, 38, 50, 53, 58, and 64 discussed previously. Circular or oval features identified from satellite imagery occur on or near centers of mineralization in areas 14, 27, 50, 63, 68, 69, and 71 (LeCompte and Steele, 1981).

A granitoid pluton near Fishrack, Foot, and Fishhook Bays (area 65) causes a positive anomaly of about 300 gammas or more. A part of the body on the peninsula at the head of Fishrack Bay does not appear to cause a positive anomaly and may be altered.

A prominent north-trending anomaly in area 66 occurs over a multiphase plutonic complex near Warner Bay Devils and Bay that contains rocks of granodiorite to quartz diorite composition and several deposits or prospects of copper-molybdenum (Detterman and others; 1979, 1981; Wilson, 1980a; Cox, 1981). Three centers of mineralization occur along the magnetic high. Ages of this complex range from about 10 to 6 m.y. Relative magnetic anomalies range up to 1700 gammas in amplitude. Alteration occurs in and adjacent to the main pluton, and some alteration zones are expressed by flattened magnetic gradients. One such area is over the Warner Bay copper-molybdenum prospect.

The large composite magnetic high of about 900 gammas in area 67 is probably caused by both volcanic rocks and pluton of the same general complex as that in area 66, even though only a small pluton crops out at the site of the anomaly. An age on hydrothermally altered biotite of a granodiorite above the head of Mallard Duck Bay is about 21 m.y. The exposed pluton is hydrothermally altered, and it is the site of a steep magnetic gradient rather than a high. A center of mineralization occurs over the pluton; K-Ar ages of 21-27 m.y. have been determined for volcanic rocks in the area.

Prominent positive anomalies in areas 68 and 69 appear to have composite sources, and both are associated with centers of mineralization. Shallow volcanic rocks probably overlie a deeper pluton, and the two anomalies, which range up to 1200 and 1500 gammas in amplitude, are connected by an anomaly of lower amplitude in area 70 suggestive of a deeper or less magnetic pluton at moderate depth. These plutons were emplaced in a zone of northwest-trending magnetic lineaments, mentioned previously.

Positive anomalies of up to 900 gammas in area 71, north of Chignik Bay, appear to have a composite source of Tertiary volcanic rocks and shallow plutons. One sample of dacite from this area has a susceptibility of 0.0029 cgs units, but another is essentially nonmagnetic. A center of mineralization occurs on the northern flank of the magnetic high. A broad positive nose in area 72, offshore, may represent a more deeply buried segment of the pluton.

A magnetic high occurs over a Tertiary pluton in area 73, along Yantarni Creek (T. 37 S., R. 50 W.), but no center of mineralization has yet been identified from there.

MISCELLANEOUS ANOMALIES

A group of anomalies in area 74, in the southwest part of the quadrangle, is caused by largely concealed, but shallow volcanic rocks. Small anomalies in area 75 are caused by post-Bear Lake volcanic rocks. Composite sources of plutonic rocks and Quaternary and older volcanic rocks cause anomalies in area 76 and 77, southwest of Mount Veniaminof.

Although no large igneous bodies have been mapped in area 78, east of Mount Veniaminof, a terrane of Mesozoic sedimentary rocks and Quaternary ash and debris deposits, the small high-amplitude anomalies over Mesozoic strata suggest buried plutons or volcanic rocks at relatively shallow depth.

Anomalies in area 79, although on trend with the anomalies of area 48 over the Meshik Formation, appear to overlie a terrane of mainly Mesozoic rocks and must be caused by small plutons or volcanic plugs, a few of which have been mapped in the area.

MAGNETIC ANOMALIES AND RESOURCE APPRAISAL

The patterns of aeromagnetic anomalies in the Chignik and Sutwik Island quadrangles are directly pertinent to exploration for metallic mineral deposits and to exploration for oil and gas.

Most of the known mineral deposits in the area are associated with hypabyssal dioritic to granodiorite plutons of Cenozoic age. Most of the plutons cause oval positive magnetic anomalies of several hundred to more than 1000 gammas. Exposed or shallow plutons and accompanying magnetic highs, most with centers of mineralization, occur in areas 27, 36, 38, 50, 53, 58, 64, 65-69, 71, and 73. Local magnetic lows or flattened magnetic gradients superimposed on the highs may indicate zones of hydrothermal alteration and thus serve as direct exploration guides. Terrain clearance problems exist inthis rugged area, and suspected negative anomalies should be checked by ground magnetic surveys.

The aeromagnetic data have assisted in identification of areas where the magnetic basement is deep (2 km or more) and where shallow igneous sources are volumetrically minor--areas 1-5, 9, 10-13, 15 and 17-25. The core of Chignik anticline (area 51) is composed mainly of sedimentary rocks, but the presence of many small magnetic anomalies indicates that igneous bodies are present at shallow depth through much of the core region. Thus the anticline should not be considered a favorable site for drilling for oil and gas until additional geophysical investigations have been conducted. A similar situation exists in area 52 along the southern flank of Chignik anticline.

AEROMAGNETIC LINEAMENTS

Modern volcanic arcs are commonly segmented along lines or zones nearly perpendicular to trends of the arcs (Carr and others, 1973). Segmentation has been postulated from several different types of geologic and geophysical evidence: offsets in trends of colinear volcanic centers, changes in the dips of Benioff zones, mapped fracture and fault zones, etc. Some of these features in the Aleutian arc have been described by Marsh (1979), and those in the vicinity of the Alaska Peninsula by Fisher and others (in press). In the Chignik and Sutwik Island quadrangles and vicinity, volcanoes at Mount Kupreanof, Mount Veniaminof, Black Peak, and Aniakchak Crater trend N. 40° E., are colinear, and define an offset segment about 140 km long, with respect to other lines of volcanoes to the northeast and southwest having parallel or slightly different strikes. Northwest-trending aeromagnetic lineaments are spaced 5 to 25 km apart in the Chignik and Sutwik Island quadrangles. If they are faults related to segmentation of the volcanic arc, they are a much smaller scale feature than the main segmentation but presumably represent a strain pattern that formed in response to the same regional stress system. A key experiment is to determine the orientation of the aeromagnetic lineaments in other major segments along the Alaska Peninsula where the trends of the volcanic centers differ from those in the Chignik and Sutwik Island quadrangles.

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REFERENCES

Bath, G. D., Carr, W. J., Gard, L. M., Jr., and Quinlivan, W. D., 1972, Interpretation of an aeromagnetic survey of the Amchitka Island area, Alaska: U.S. Geological Survey Professional Paper 707, 25 p.

Blakely, R. J., and Christiansen, R. L., 1978, The magnetization of Mount Shasta and implications for virtual geomagnetic poles determined from seamounts: Journal of Geophysical Research, v. 83, no. B12, p. 5971-5978.

Brockway, Ron, Chairman, 1975, Bristol Bay region, stratigraphic correlation section, southwest, Alaska: The Alaska Geologic Society.

Bruns, T. R., and von Huene, Roland, 1977, Sedimentary basins on the Shumagin Shelf, western Gulf of Alaska: Proceedings, Offshore Technology Conference, 9th Annual Conference, Houston, Texas, May 2-5, 1977, p. 41-50.

Burk, C. A., 1965, Geology of the Alaska Peninsula--island arc and continental margin: Geological Society of America Memoir 99, 250 p.

Carr, M. J., Stoiber, R. E., and Drake, C. L., 1973, Discontinuities in the deep seismic zones under the Japanese arcs: Geological Society of America Bulletin, v. 84, no. 4, p. 2917-2930.

Case, J. E., Tysdal, R. G., Hillhouse, J. W., and Gromme, C. S., 1979: Geologic interpretation of aeromagnetic map of the Seward and Blying Sound quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-880-D, 2 sheets, scale 1:250,000.

Case, J. E., Barnes, D. F., Detterman, R.L., Morin, Robert, and Sikora, Robert, 1981, Gravity anomaly and interpretation map of the Chignik and Sutwik Island quadrangles: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-J, scale 1:250,000 [in press].

Cox, D. P., Detra, D. E., and Detterman, R. L., 1981, Mineral resource maps of the Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-K, scale 1:250,000 [in press].

Detra, D. E., Cooley, E. F., Day, G. W., O'Leary, R. M. Holloway, C. D., and Yount, M. E., 1978, Results and statistical summary from analysis of stream-sediment and heavy-mineral concentrate samples, Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Open-File Report 78-345, 96 p.

Detra, D. E., Cooley, E. F., Hopkins, R. T., Jr., O'Leary, R. M., Jefferis, D. R., 1978, Final results and statistical summary from analysis of stream-sediment and heavy-mineral-concentrate samples, Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Open-File Report 78-1090, 105 p.

Detra, D. E., and Cooley, E. F., 1980a, Distribution and abundance of copper in minus-80-mesh stream-sediment and nonmagnetic heavy-mineral-concentrate samples, Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-C, 2 sheets, scale 1:250,000.

______1980b, Distributrion and abundance of silver and arsenic in nonmagnetic heavy-mineral-concentrate samples, Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-G, 2 sheets, scale 1:250,000.

Detra, D. E., and Cooley, E. F., 1980c, Distribution and abundance of bismuth, tin, and tungsten in nonmagnetic heavy-mineral-concentrate samples, Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-H, 1 sheet, scale 1:250,000.

Detra, D. E., and Day, G. W., 1980, Distribution and abundance of molybdenum in minus-80-mesh stream-sediment and nonmagnetic heavy-mineral-concentrate samples, Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-F, 2 sheets, scale 1:250,000.

Detra, D. E., and Hopkins, R. T., Jr., 1980, Distribution and abundance of lead in minus-80-mesh stream-sediment and nonmagnetic heavy-mineral-concentrate samples, Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-D, 2 sheets, scale 1:250,000.

Detra, D. E., and O'Leary, R. M., 1980, Distribution and abundance of zinc in minus-80-mesh stream-sediment and nonmagnetic heavy-mineral-concentrate samples, Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-E, 2 sheets, scale 1:250,000.

Detterman, R. L., Case, J. E., and Wilson, F. H., 1979, Paleozoic rocks on the Alaska Peninsula, in Johnson, K. M., and Williams, J. R., eds., The United States Geological Survey in Alaska: Accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. B85-B86.

Detterman, R. L., Miller, T. P., Yount, M. E., and Wilson, F. H., 1979, Generalized geologic map of Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-A, scale 1:250,000.

Detterman, R. L., Miller, T. P., Yount, M. E., and Wilson, R. H., 1981, Geologic map of Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-1229, scale 1:250,000 [in press].

Fisher, M. A., Bruns, T. R., von Huene, Roland, Transverse tectonic boundaries near Kodiak Island, Alaska: Geological Society of America Bulletin, Part I [in press].

Griscom, Andrew, 1975, Aeromagnetic map and interpretation of the Nabesna quadrangle,Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-655-H, 2 sheets, scale 1:250,000.

Hanson, B. M., 1957, Middle Permian limestone on Pacific side of Alaska Peninsula: American Association of Petroleum Geologists Bulletin, v. 41, p. 2376-2378.

Herrera, R. C., 1978, Developments in Alaska in 1977: American Association of Petroleum Geologists Bulletin, v. 62, no. 8, p. 1311-1321.

Le Compte, J. R. and Steele, W. C., 1981, Maps showing interpretation of Landsat imagery of the Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-O, 2 sheets, scale 1:250,000 [in press].

Marsh, B. D., 1979, Island-arc volcanism: American Scientist, v. 67, no. 2, p. 161-172.

Nakamura, Kazuaki, 1977, Volcanoes as possible indicators of tectonic stress orientation-principle and proposal: Journal of Volcanology and Geothermal Research, v. 2, no. 1, p. 1-16.

Reed, B. L., and Lanphere, M. A., 1971, Generalized geologic map of the Alaska-Aleutian Range batholith showing potassium-argon ages of the plutonic rocks: U.S. Geological Survey Miscellaneous Field Studies Map MF-372, 2 sheets, scale 1:1,000,000.

______1973, Alaska-Aleutian Range batholith: geochronology, chemistry and relation to circum-Pacific plutonism: Geological Society of America Bulletin, v. 84, p. 2583-2610.

Richards, M. L., Vacquier, V., and Van Voorhis, G. D., 1967, Calculation of the magnetization of uplifts from combining topographic and magnetic surveys: Geophysics, v. 32, no. 4, p. 678-707.

U.S. Geological Survey, 1978a, Aeromagnetic map of Chignik and Sutwik Island quadrangle, Alaska, 1:250,000: U.S. Geological Survey Open-File Report 78-262, scale 1:250,000.

______1978b, Aeromagnetic maps of Chignik and Sutwik Island quadrangles, Alaska, 1:63,360: U.S. Geological Survey Open-File Report 78-263, 11 sheets, scale 1:63,360.

Wilson, F. H., 1978, Map showing preliminary results of K-Ar studies in the Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Open-File Report 78-1064, scale 1:250,000.

Wilson, F. H., 1980a, Late Mesozoic and Cenozoic tectonics and the age of porphyry copper prospects, Chignik and Sutwik Island quadrangles, Alaska Peninsula: Dartmouth College, Ph.D. thesis, 120 p.

Wilson, F. H., 1980b, Late Mesozoic and Cenozoic tectonics and the age of porphyry copper prospects: Chignik and Sutwik Island quadrangles, Alaska Peninsula: U.S. Geological Survey Open-File report 80-543, 94 p.

Wilson, F. H., Gaum, W. C., and Herzon, P. L., 1981, Map and tables showing geochronology and whole-rock geochemistry: Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-M, 3 sheets, scale 1:250,000, [in press].

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