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MAP SHOWING GEOLOGIC INTERPRETATION OF AEROMAGNETIC DATA FOR THE CHUGACH NATIONAL FOREST, ALASKA

by

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STUDIES RELATED TO WILDERNESS

The Wilderness Act (Public Law 88-577, September 3, 1964) and related acts require the U.S. Geological Survey and the U.S. Bureau of Mines to survey certain areas on Federal lands to determine their mineral resource potential. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a geophysical survey of the Chugach National Forest, Alaska, including the Nellie Juan-College Fiord Wilderness Study Area established by Public Law 96-487, Dec. 2, 1980.

INTRODUCTION

The aeromagnetic map of the Chugach Wilderness area is a composite of four maps prepared by government contractors supporting this project and three projects of the Alaskan Mineral Resource Assessment Program (AMRAP). Aeromagnetic surveys were flown between 1975 and 1979 by two separate contractors, whose results were published and interpreted separately as components of the following AMRAP quadrangle (or extended quadrangle) projects: Seward-Blying Sound (U.S. Geological Survey, 1978; Case and others, 1979b); Valdez (U.S. Geological Survey, 1979b; Case and others, 1988); Cordova-Middleton Island (U.S. Geological Survey, 1979a); and Anchorage (U.S. Geological Survey, 1980). The published interpretations of components of the Chugach survey provide somewhat fuller treatments of the data and multiple maps, which permit readers to make comparisons between the aeromagnetic data and topography as well as geologic interpretations. The map in this report is a composite of the aeromagnetic data, printed on a topographic base showing only shorelines, culture, and drainage, to which have been added overprints of the generalized geology plus the framework for a simplified aeromagnetic interpretation. Aeromagnetic data are not yet available for two small areas on the northern and eastern sides of the national forest, which were late additions to the study area. The three southernmost refraction profiles of the Trans Alaska Crustal Transect (TACT, Page and others, 1986), lie within the mapped area, and consideration of the combined data sets should improve both the magnetic and seismic interpretations. The recorder and shot point locations of these 1984 and 1985 seismic measurements are thus shown on the Chugach gravity map (Barnes and Morin, 1990). The text also mentions two magnetic features, the interpretation of which should be aided by the seismic results.

AEROMAGNETIC DATA

The primary specifications of 1-mi flightline separation and 1,000-ft above-mean-terrain flight elevation were identical for all components of the survey, but differences in equipment, in flightline orientation, and especially in the contractor's treatment of the data caused significant differences between individual parts of the aeromagnetic map. Data for the southern two-thirds of the map were acquired by Geometrics Inc., which used a proton-precession magnetometer on north-south flightlines and then contoured the difference between the observed magnetic field and the International Geomagnetic Reference Field data of 1965 (IGRF) updated to 1976 (Fabiano and Peddie, 1969). Thus both halves of the southern part of the map (Seward-Blying Sound and Cordova-Middleton Island) have the same datum, and the contours are continuous across the two southern parts of the map.

Data for the northern one-third part of the map were acquired by LKB Resources, Inc., which used a model ANASQ-10 fluxgate magnetometer on N. 30° W. and S. 30° E. flightlines in the west (Anchorage quadrangle) and north-south to N. 15° E. or S. 15° W. flightlines in the east (Valdez quadrangle). Regional gradients determined from mean values of IGRF data were removed from the magnetic field values, but constants of 56,000 and 57,000 gammas were then added to the residual values to approximate the mean total-intensity magnetic field in each quadrangle.

These differences in flight and data-reduction procedures cause significant differences in contour values, magnetic datum, and even contour form across the quadrangle boundaries of the two northern surveys. Attempts to eliminate the differences by redrawing and relabeling the contours would involve either complete data reprocessing or unjustified assumptions, but the mean datum differences between the surveys can be estimated. Labeled magnetic field strengths in the Anchorage quadrangle are about 57,290±30 gammas higher than the labels of contours in the Seward quadrangle to the south; and those in the Valdez quadrangle are about 57,540±30 gammas higher than adjoining labels in the Cordova quadrangle. Thus the labeled field strengths in the Valdez quadrangle are about 250±10 gammas higher than those in the adjoining Anchorage quadrangle. The contour interval is 5 gammas throughout the map except where dropped in regions of high gradient and in the Valdez quadrangle, where the contour interval is 10 or locally 20 gammas because of much steeper gradients in other parts of the quadrangle.

Nominal flight elevations for all parts of the survey are stated as 1,000 ft terrain clearance (t.c.) or above mean terrain (amt), but in practice the aircraft could not maintain a constant elevation above the ground surface over topography as rugged as that of much of the Chugach National Forest. Over the ocean and areas of subdued topography the aircraft was probably close to 1,000 ft above the terrain, but over rugged topography the aircraft's height was significantly greater than 1,000 ft above valley floors and it was probably closer than 1,000 ft to ridge and hill crests. Furthermore, when climbing toward the higher parts of a mountain range, the aircraft's ability to parallel the underlying terrain was probably less than on a return leg while descending to lower elevations. The effects of these departures from perfect "drape flying" varied somewhat depending on the magnetic properties of the rocks forming the topography. Where the rocks are magnetic and the field is normally induced, the ridges tended to produce magnetic highs and the valleys produced magnetic lows. However, when in valleys the aircraft is closer to deep sources of magnetic anomalies and to the center of the Earth's dipolar

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magnetic field. At this latitude the Earth's magnetic field has a vertical gradient of about -8 gammas per 1,000 feet of elevation increase, so an aircraft descent of 3,000 ft can cause a 25-gamma increase. Although topographic contours are not shown on the present map, the principal valleys are indicated by river and glacier drainage, and some topographic or flight-elevation anomalies are mentioned in the discussion of regional anomalies. Combined aeromagnetic and topographic maps are published in the aeromagnetic interpretations of the individual quadrangles forming parts of the study area (Case and others, 1979b and 1986); and longer discussions of topographic and flight-elevation effects on Alaskan aeromagnetic data can be found in Griscom (1975) and Cady (1978).

GEOLOGY, LITHOLOGY, AND MAGNETIC CHARACTERISTICS OF GENERALIZED ROCK UNITS

A separate map in this series (Nelson and others, 1985) summarizes the regional geology and descriptions of the rock units of the Chugach National Forest; a generalized geologic map derived from it is part of the base map for this aeromagnetic map. Other recent summaries of the geology of some of the component quadrangles have been published by Tysdal and Case (1979; Seward and Blying Sound), Winkler and Plafker (1981, Cordova and Middleton Island); and Winkler and others (1981, Valdez).

The predominant rock type of the region is a flysch sequence that ranges in age from Cretaceous through early Tertiary, with its older more metamorphosed rocks on the north and west. This flysch sequence has traditionally been divided into the Orca and Valdez Groups. Throughout the past century geologists have debated both the distinguishing characteristics of these two units and the placement of the contact between them (Moffit, 1954). The two groups show no magnetic distinction, because all sedimentary rocks of the flysch have a very low content of magnetite. However, many associated mafic volcanic rocks and some plutons have relatively stronger magnetic expression and are the main features interpreted in this report. Most geologists now believe the Contact fault (and its strands and extensions, the Jack Bay, Landlocked, Gravina, and Bagly faults) is the probable boundary between the Orca and Valdez groups, but geophysical trends are continuous across these faults. Near the extreme western boundary of the national forest, the flysch sequence is in fault contact with an older melange known as the McHugh Complex, which has strong magnetic expression west of the project boundary. The only other stratigraphic sequence within the study area is a series of Eocene and Oligocene formations that are in probable fault contact with the flysch in the southeastern corner of the national forest.

The generalized geologic map that forms part of this map has been simplified from Nelson and others (1985). Many lithologic units have been combined into simplified units with nearly equivalent geophysical properties. The map explanation shows which units from the detailed map are included in each of the simplified units. Outlines of most of the alluvial cover have been omitted except in areas where the alluvial cover obscures other geologic boundaries. Lineaments, structure symbols, field localities, and other details have been omitted from this generalized geologic base.

Case and others (1979b) reported the magnetic properties of hand and shallow-drill-hole specimens from the mafic-ultramafic complexes of Knight Island and Resurrection Peninsula. These complexes probably contain the most magnetic rocks within the national forest. However, Case and others (1979) also recognized that near-surface weathering had probably lowered the magnetite content of most specimens and that many of the measured susceptibilities were probably too low to explain the aeromagnetic anomalies. Only 20 percent of the 89 random, unoriented hand specimens had susceptibilities greater than 1×10^{-4} cgs (centimeter-gram-second) units, and the maximum susceptibilities measured for basalt, diabase, and greenstone were all in the range of 3×10^{-3} to 4×10^{-3} cgs. Nearly 400 oriented samples from 9 sites on Resurrection Peninsula and Knight Island yielded similar susceptibilities and additional information about remanent magnetization. In this latter group, the sheeted dikes had slightly larger susceptibilities and remanent magnetizations than the pillow basalts had. Values of Q, the Koenigsberger ratio of remanent to induced magnetization, varied generally in the range of 0.5-1.0 so that remanent components only locally dominate the induced components. Virtually all the sedimentary rocks, their metamorphosed phases, and the granites had measured susceptibilities of less than 1×10^{-4} cgs units.

AEROMAGNETIC INTERPRETATION

Correlation of the aeromagnetic features with the geologic units permits the interpretation of the causes of some of the anomalies and the drawing of possible unexposed boundaries of the magnetic rock units. However, much judgment is involved in locating these boundaries, which should be used with care. Many boundaries have been copied directly from previous maps of Case and others (1979b, 1986).

The regional gradient based on IGRF-65 seems to have adequately approximated the lateral variations of the Earth's main magnetic field over most of the project area. Residual anomaly contours in the range of 120±50 gammas (or nanoteslas) are typical of background field strengths over most of the southeastern part of the Chugach National Forest (Cordova, eastern Seward and adjoining parts of Middleton Island, Blying Sound, and Bering Glacier quadrangles). However, strong regional gradients seem to be present near both the northern and western edges of the map in higher parts of the Chugach Mountains. The contours representing these gradients trend almost east-west in the north and north-south in the west. Both of these gradients have magnitudes of about 2 gammas per mile, which is about 50 percent of the removed IGRF parameters. However, localization of the gradients to the more mountainous parts of the Chugach area and the near right-angle change in their directions suggest a geologic explanation involving deep parts of the crust or mountain system. Perhaps the gradient could be an expression of a slab of magnetic material dipping down to depths below the Curie-point isotherm (the temperature above which rocks cease to be magnetic). The change in direction of the aeromagentic contours is somewhat similar to changes in direction of geologic fold axes (Hellwig and Emmit, 1981) and dip of planes formed by the loci of earthquake hypocenters (Lahr, 1975). However, such ideas are speculations; other features of the magnetic map represent shallower structures that can be better correlated with mapped geologic features.

Apart from the regional gradient on the northern and western parts of the map, the magnetic field of much of the mountainous part of the Chugach National Forest is remarkably flat and suggests a great depth to magnetic basement. This flat field is typical of most of the thick flysch sequences in the national forest. Case and others (1979b) estimate depths of 3-6 mi to sources of some of the steeper gradients in these areas.

The most prominent feature of the aeromagnetic map is an arcuate belt of high-amplitude anomalies that extends northeast across the map from near Evans Island and forms a natural nearly diagonal partition of the map. This aeromagnetic belt closely parallels or coincides with a belt of gravity highs that Case and others (1966) referred to as the Prince William Sound high; the same geographic name could also be applied to this belt of aeromagnetic anomalies. The remaining features of the aeromagnetic map are more local in nature and can be discussed in two groups, depending on their position relative to the diagonal Prince William Sound belt of anomalies. The discussion begins with the anomalies in the northwestern part of the map, proceeds to the Prince William Sound belt which is considered as a unit, and concludes with anomalies southeast of the belt.

NORTHWESTERN ANOMALIES

Near the extreme northwest corner of the map a positive aeromagnetic anomaly, indicated by westward deflection of the magnetic contours (anomaly 1) over

Turnagain Arm, is probably caused by the low elevation of the aircraft as it flew over Turnagain Arm. The 5- to 15-gamma amplitude is approximately the increase that would result from the 500- to 2,000-ft decrease in flight elevation. The anomaly is largely outside the national forest boundary and is a good example of the possible topographic effects in aeromagnetic interpretation.

Farther south along the western side of the map, a series of small magnetic highs and lows with amplitudes of a few gammas (anomalies 2 and 3) seem to be associated with small plutonic bodies in the McHugh Complex west of the Eagle River fault. The largest of these (anomaly 3) coincides with some mafic and ultramafic rocks reported by Case and others (1979b).

Some similar features (anomalies 4 and 5) extend farther south into the Valdez flysch, and some of these lows (labeled 4R) are the result of reversed remanent magnetization. These are not associated with known outcrops of igneous rocks but probably represent small, shallowly buried igneous bodies. The largest of these (anomaly 5R) probably represents the source of some geochemical anomalies (Goldfarb and Smith, 1987).

East of these anomalies along the western boundary of the national forest, the magnetic field flattens and shows primarily the regional gradient and the relatively smooth field associated with the Valdez flysch sequence. However, the regional gradient is not constant from west to east but is broken into three north-south belts of steepened gradient (anomalies 6, 7, 8 and 9). These might result from diurnal variations between flightlines or erroneous flightline recovery in rugged topography, but most belts are wider than a pair of flightlines and they parallel the regional structural trend. Case and others (1979b) suggested that they could result from steps in the depth of magnetic basement or from magnetization variations within it or possibly within the overlying flysch. The gentle gradients suggest that the source is probably at depths of 5-10 km. A few local anomalies that interrupt the belts probably represent small bodies of igneous rocks. One possible volcanic dike or stock, represented by anomaly 10, interrupts gradient belt 9 and may be a cause of geochemical anomalies (Goldfarb and others, 1984).

South of Portage townsite a long magnetic high (anomaly 11) follows the belt of schist along the Placer River, which Case and others (1979b) considered a high-grade metamorphic unit (chiefly biotite-zone greenschist) of the Valdez Group and which may include small amounts of tuff and other volcanic rocks. Other higher amplitude anomalies (12 and 13) along this belt may coincide with even higher grade metamorphic rocks and possible increased proportions of volcanic rocks. Case and others (1979b) reported amphibolite-grade rocks in the vicinity of anomaly 12. A lower amplitude high (anomaly 14) west of the schist outcrop along the Placer River and approximately above the valley of Lower Trail Lake, could suggest more higher grade metamorphic rocks at depth or, as Case and others (1979b) suggest, a possible very deeply buried northward extension of mafic and ultramafic rocks on the Resurrection Peninsula. Another explanation of anomaly 14, however, is that it may represent another area where the aircraft's low elevation caused higher measurements of the Earth's primary field. The fact that significant anomalies follow the trend of metamorphic rocks along the Placer River does suggest that the same rocks at depth might cause some of the subtle, low-amplitude anomalies and steepened gradients observed to the west.

Farther south along the west side of the Placer River fault, one of the larger and more geologically significant features of the aeromagnetic map (anomalies 15-19) is associated with the mafic complex of the Resurrection Peninsula. A complex pattern of high-amplitude highs and lows (area 18) correlates with the outcrops of the sheeted dike complex and pillow basalts near the center of the peninsula, but the breadth of the anomaly pattern shows that the rocks are much more extensive than the outcrop. Most of the anomalies are positive, although a few lows over topographic peaks (area 19) clearly suggest locally reversed remanent magnetization. Case and others (1979b) sampled a single site from the most southern of these areas and found positive inclination, although reversed specimens were found at other sites on the peninsula. The anomalies clearly extend offshore to both the south and west. Two anomalies (area 17) along the northern and eastern sides of the group, however, have lengths and magnitudes that suggest a difference in character and origin from the remainder of the group. Their peaks coincide with flysch areas outside the edge of the mafic-ultramafic outcrop area, so a buried but probably related source is suggested. Case and others (1979b) compared the anomalies to similar ones mapped over serpentinite bodies in California and suggested a similar origin or possibly a large shallowly buried, serpentinized dunite. They prepared a two-dimensional model of a buried serpentinite mass that could explain a magnetic profile across the center of the large northern anomaly, but their model is not a unique explanation. The proposed body was a trapezoidal mass (about 1,500 ft thick and 5 mi wide) with a susceptibility of 0.003 cgs units that was buried at a depth of less than 500 ft. The sloping sides suggest that much of the anomaly source is much deeper, so that a thin serpentinite slab might be as deep as 2,000 ft beneath parts of area 16, representing the deeper margin of the body causing the broad anomaly. Anomaly 15 at the northern end is probably a separate mafic or ultramafic body although it could be a metamorphic feature like anomaly 13.

Immediately east of the Placer River fault the magnetic field is fairly flat and featureless over a very broad area of flysch. Within this large area Case and others (1979b) identified two broad lows (anomalies 20 and 21), which they speculated might represent thicker flysch or higher aircraft elevation above the high peaks. Furthermore, the southern anomaly may in part be only a dipole polarization effect of the adjacent Resurrection Peninsula magnetic high.

On the mainland east of the Placer River fault, the most prominent anomaly (22) is a long arcuate north-to-south belt of contours representing a steeper gradient, which Case and others (1979b) named the Sargent lineament for the icefield that it transects. Field strengths on the east side of the lineament are 20-50 gammas higher than on the west, and the slope of the gradient suggests a probable depth of 5-10 km for its source. Logical explanations might be a shallowing of the magnetic basement or an increase in the magnetization to the east. Granitic plutons seem more abundant east of the lineament, but this could be either coincidental or a consequence of changes in magnetic basement. The lineament may also in part represent a change in elevation of the topography and flight elevation along much of its length. For example, in the center of the Sargent Icefield the glaciers on the west side of the lineament are at least 1,000 ft higher than those on the east, which would probably cause a 10- to 15-gamma magnetic gradient because of the change in aircraft elevation. The gradient is steepened on the southeast by a series of small magnetic highs (anomaly 23). Small outcrops of greenstone on the shore of Whidbey Bay suggest that these highs might represent buried bodies of mafic rock.

A variety of subtle anomalies near and east of the Sargent lineament can probably be correlated with various plutons. One of the more obvious ones interrupts the lineament near the middle of the area where it causes an eastward flexure of the contours (anomaly 24) that correlates with the outcrop of the Nellie Juan granitic pluton. This pluton thus causes a small magnetic low, which suggests reversed magnetization. Other plutons have even weaker expression, for example the Passage Canal pluton (anomaly 25), where the contour flexures cannot be clearly correlated with the outcrop. This is, however, the only pluton clearly west of the Sargent lineament. Farther north between College Fiord and upper Unakwik Inlet, another group of low-amplitude anomalies, combined with a northward flexure of the contours (anomaly 26), is interpreted as suggesting a granitic pluton, which is only exposed in a samll outcrop south of Yale glacier. Farther east, gentle contour flexures (anomalies 27, 28, and 29) seem to correlate with outcrops of the mafic pluton near Miners Bay and granitic plutons near Cedar Bay and Columbia Glacier. The available magnetic data do not, however, permit exact delineation of the boundaries of such weakly magnetic plutons. Deeply buried granitic rocks could underlie a broad area of the southern Anchorage and northern Seward quadrangles plus adjacent corners of the Valdez and Cordova quadrangles. The dashed line (anomaly 30) is a speculative outline of an area of small low-amplitude anomalies that might be expressions of a single or composite buried pluton, but other outlines are also possible. A more distinct magnetic low (anomaly 31) was mapped south of College Fiord and north of Esther Passage over a topographic high. It was considered an expression of a small, concealed and reversely magnetized pluton by Case and others (1979b). South of this distinct anomaly, a gentle eastward flexure of the magnetic contours indicates a small low over the granitic pluton of Esther Island (anomaly 32). The anomaly could represent weak reversed remanant magnetization or a lower susceptibility than adjacent rocks. However, a much more prominent positive anomaly (33) coincides with a gabbroic phase at the southeast corner of the island, and the marginal lows are evidence of the dipolar nature of the magnetization.

Farther south, the magnetic field mapped over Perry Island (anomaly 34) shows the most prominent magnetic expression of any granitic pluton in the national forest. Steep gradients coincide with mapped contacts of the granite on both the north and south sides of the island, which suggests that the granite is the source of the anomalies. However, susceptibilities measured on a few hand specimens were low, and the cause of the unique magnetic expression of this pluton is uncertain. Proximity to the previously discussed plutons on Esther Island, where a gabbro body is associated with the granitic pluton, suggests that gabbro or other mafic rocks may underlie the granite of Perry Island at shallow depth. As another explanation, Case and others (1979b) suggested that this granite may have been emplaced through a considerable thickness of mafic rocks that contaminated it with magnetic minerals. Lower amplitude versions of these anomalies extend westward (anomaly 35) across Perry Passage and are mapped over outcrops of the Culross granitic pluton and nearby sedimentary rocks on both shores of Culross Passage (anomaly 36). The magnetic field over the pluton outcrop is flatter than that over much of the area occupied by sedimentary rocks and includes a few prominent anomalies near the western margin of the pluton (anomalies 37). This variety of magnetic expression suggests that these Culross anomalies (35, 36, and 37) may, like the Perry and Esther Island anomalies (32, 33, and 34), have composite sources that include both granitic and mafic rocks and possibly metasedimentary rocks (Case and others, 1979b).

Farther south, a prominent linear magnetic low (anomaly 38) follows the coastline between Foul and Falls Bays. No plutonic rocks crop out along this anomaly but strong reversed remanent magnetization of a near-surface intrusion body is suggested. Still farther to the south, the Eshamy pluton seems to have little magnetic expression on its eastern and western sides, but two prominent magnetic anomalies (39) correlate well with a central gabbroic phase. The Eshamy pluton thus appears to be composite with both granitic and mafic phases. Still farther to the southwest, another group of small magnetic highs and lows (area 40) occurs at the northern end of anomaly 23 and by similarity to other anomalies suggests a granitic, mafic, or composite pluton. In this group, two small magnetic lows coincide with high topography and suggest reversed remanent magnetization.

In the extreme northern part of the national forest, north of the granitic and composite plutons, the magnetic contours in the Anchorage quadrangle trend northwest-southeast (anomalies 41). These trends parallel the flightlines and represent narrow highs and lows; a few of the axes have been drawn on the map for emphasis. Most of these highs and lows have amplitudes of 5-15 gammas and widths of one or two flightline spacings. The trends do not extend beyond the quadrangle boundary into the Valdez quadrangle, where the flightline directions were north or south. The narrow highs and lows are thus believed to be a result of either the data collection or data compilation in the high mountains. Perhaps the aircraft had greater problems in maintaining an accurate ground-clearance elevation when climbing toward the higher peaks of the Chugach Mountains than on a reverse flightline when flying toward a lower elevation. Perhaps a problem was encountered in recovering correct flight elevation for a tieline flown along a serrated ridge line so that location could be more accurately checked. Whatever their cause, these northwest trends are not considered an expression of geology, and the true magnetic field is probably very smooth as in most of the mountainous flysch areas to the east in the Valdez quadrangle.

In the northern and northeastern parts of the national forest (area 42), the magnetic field is very flat and suggests a great thickness of flysch (probably 3-5 mi). One pair of small anomalies (area 43) occurs near outcrops of Valdez Group volcanic rocks, which probably cause the anomalies. A few other smaller anomalies may have similar causes, although no associated volcanic outcrops have been mapped. Other almost identical anomalies (area 44) were mapped south of the Jack Bay strand of the Contact fault, but these anomalies nominally represent volcanic rocks of the Orca Group. There is no significant difference in the anomalies and probably little difference in the causative rock bodies.

PRINCE WILLIAM SOUND BELT

Southeast of the granitic and composite plutons is a belt of complex and high-amplitude anomalies that are the most prominent feature of the Chugach National Forest aeromagnetic map. This arcuate belt of anomalies follows outcrops of predominantly mafic volcanic rocks and minor gabbro and ultramafic bodies north-northeastward along the trend of Elrington, Evans, Knight, Eleanor, and Glacier Islands and then eastward south of Bligh Island, Ellamar, and the mountainous spine that includes Mt. Denson, the cirques of Wortmanns, Woodworth, and Schwan Glacier, and Cordova Peak. Copper mines and deposits are found along or close to this belt of anomalies. The character of the anomalies along the trend varies, and the reasons for some of the variations are poorly understood. In spite of discontinuities and variations, the anomalies along the belt are best discussed as parts of a unit, beginning with the zone of best development and outcrops, then southward to the most important mineralization, then northward and eastward into zones where the anomalies are poorly developed and could be discontinuous.

On Knight Island (anomaly 45) the highest-amplitude anomalies approximately coincide with the contact between the sheeted dike complex and the pillow basalts. Measurements on hand specimens suggest that the sheeted dikes are slightly more magnetic than the basalts, but the amplitude of the anomalies may be more a function of thickness of the sequence of magnetic rocks than of their magnetic properties. The mafic assemblage includes sheeted dike complexes, pillow basalts, pillow breccias, mafic sills, small gabbroic bodies, and three smaller ultramafic units of dunite and peridotite. The largest negative anomalies occur over low topography, but some magnetic lows are probably the result of reversed remanent magnetization. On the eastern side of the island, lower amplitude anomalies are present over the sheeted dikes, pillow basalts, associated sedimentary rocks, and offshore areas (anomaly 46). These lower amplitudes can result from a possible higher degree of metamorphism, increased proportion of interbedded sedimentary rocks, sea-floor alteration, or an overall thinning of the magnetic section. The contours suggest that all the anomalies of northern Knight Island and adjacent islands may be superimposed on a broad almost oval high. Case and others (1979b) have suggested that this broad anomaly could represent a deeply buried volcanic center or local seamount, although they knew of no supporting geologic evidence.

The anomaly belt is widest and the amplitudes are highest near Knight and Chenega Islands, which have the largest variety of rocks interpreted as causes of the anomalies. Here both the anomalies and the causative rock units resemble those of the Resurrection Peninsula, although the latter are considered older because of the postulated age of the adjacent rocks. The highest amplitudes of the belt (800 gammas) in area 47 were measured over Chenega Island, where most of the mafic outcrops consist of greenstones with low susceptibilities. However, very steep gradients and large anomalies were measured on the ground surface (Case and others, 1979b) so the causative magnetic rocks (probably pillow basalts and sheeted dikes) may be buried at very shallow depths. A magnetic low over the deep water of Knight Island Passage between Chenega and Knight Islands is probably more than a topographic effect. Magnetic modeling by Case and others (1979b) suggests that magnetic rocks are probably absent under the passage or at least buried at very great depths. The model also indicates that the anomalies could be explained by thicknesses of 0.6-1 mi of magnetic rock. However, much larger thicknesses are required to explain the observed gravity anomalies (Barnes and Morin, 1990), which suggests that the magnetization of the dense rocks varies greatly.

On Bainbridge, Evans, Elrington, and Latouche Islands (anomaly 48), the anomalies have small amplitudes, and few mafic rocks are exposed. There are no exposed sheeted dikes or ultramafic rocks, but outcrops of pillow basalts and anomalies with gentle dips suggest that other magnetic rocks could be buried at depths of 1 mi or less. Inverse correlation between topography and magnetic field suggests that at least one of the anomalies (marked R) is an expression of reversed remanent magnetization. On Latouche Island small anomalies suggest the presence of deeply buried mafic rocks near some copper mines. A sharp shallow anomaly (anomaly 49) was recorded close to where one flightline crossed the Beatson fault trace. A single steep-gradient anomaly (anomaly 50) measured over Knight Island Passage south of the Pleiades Islands shows that the mafic rocks are probably continuous across the southeast arm of the passage.

At the north end of Knight Island Passage a belt of anomalies (anomaly 51) extends from the northeast corner of the passage near Crafton Island northward through Lone Island, and the Axel Lind Island group. Mafic rocks crop out on Crafton and Lone Islands where steep gradients indicate the source rocks are close to the surface. However, gentler gradients near the Axel Lind Island group suggest that the mafic rocks are buried 1 mi or less beneath the exposed flysch. Here the belt bends sharply eastward toward Glacier Island. Many other features of the geologic and geophysical maps also reflect this oroclinal bending, but the bend in the belt of magnetic anomalies is particularly abrupt.

Both sheeted dikes and pillow basalts crop out on Glacier Island, where the highest anomalies (anomaly 52) occur a short distance north of the contact between the two geologic units, perhaps where their thickness is greatest. The anomalies extend westward almost to Little Axel Lind Island and suggest that the mafic rocks are very close to the bottom of Prince William Sound. Outpost Island within this anomaly pattern consists of greenstones. The shallow anomalies also extend northeastward to the entrance of Valdez Arm and Point Freemantle, where more Orca Group volcanic rocks crop out. However, the anomaly trend is not continuous across Valdez Arm, although the interruption is more of an offset and change in anomaly character than a real break in the magnetic belt.

The high amplitude anomalies associated with the sheeted dikes and pillow basalts of Knight Island do not extend north of pillow basalt outcrops on Eleanor Island, and a much flatter field between Eleanor and Glacier Islands suggests that a thick flysch sequence breaks the continuity of the magnetic rocks. However, gravity highs on Knight and Glacier Islands do seem to be connected by a trend of lower but distinctly high gravity that extends along the channel between Naked and Lone Islands, through western Storey Island, and northeast to Glacier Island (Barnes and Morin, 1990). The flatness of the magnetic field along this trend indicates absence of, or great depth to, magnetic rocks and suggests that nonmagnetic rocks such as a structural or basement high may be partly responsible for the high gravity.

A broad magnetic high (anomaly 53) between Naked Island and the deeper water to the east suggests a very deeply buried magnetic object. Case and others (1979b) estimate that the feature has a depth of about 6 mi and probably represents a large body of serpentinite, although a granitic pluton could be another possibility. A similar feature (anomaly 54) is mapped southeast of Knight Island and is centered on Green Island.

The character of the anomaly belt changes in several ways at Valdez Arm. Over the arm itself (anomaly 55) the anomaly field is fairly flat and suggests either very deep water or a thick flysch sequence. Bathymetry alone, however, cannot explain the flatness because a high-amplitude negative anomaly is present over equally deep water at the entrance to Port Fidalgo (anomaly 58). East of the arm on Ellamar Peninsula and northeastern Bligh Island (anomaly 56), pillow basalts interbedded with sedimentary rocks are abundant, but the magnetic anomalies are much smaller than those over similar outcrops along the belt. The anomaly amplitudes actually increase where no volcanic rocks are exposed in southwestern Bligh Island and adjacent offshore areas (anomaly 57). Some of the anomalies seem to be continuous across the Landlocked Bay strand of the Jack Bay fault, which suggests that the source rocks are either younger than the fault movement or below its dipping fault plane. The most pronounced offshore anomalies are two pair of lows (anomaly 58), which are south of the island and have amplitudes of more than 100 gammas. These almost certainly manifest some feature of remanent magnetization—perhaps a sill of reversely magnetized volcanic rocks. However, the anomalies coincide with a belt of gravity contours that are on the south side of the regional gravity high and which represent a steep gradient to the north. Flows with strong remanent magnetization probably could explain the observed magnetic lows if they are folded or draped over a major geologic structure so that they dip steeply or are overturned. These well-developed lows are part of a much longer magnetic low (anomaly 59) that follows the anomaly belt from Knight Island Passage (between Knight and Chenega Islands) northward and around Naked Island and then eastward through northern Port Fidalgo to a termination near the Jack Bay fault. For most of its length the low follows the southeast side of the gravity high, but in Knight Island Passage it lies west of the area with the highest gravity. In Knight Island Passage the long low can be explained merely by the absence of magnetic rock, but south of Bligh Island it seems to represent a structure that deforms rocks that have remanent magnetism. Such variation of probable causes suggests that the apparent continuity of the low may be more coincidental than structurally significant.

Between Ellamar and the Jack Bay fault (anomaly 60) the magnetic field is almost as flat as it is over Valdez Arm. However, the contours trend almost east-west and seem to represent a feature 1-3 mi deep with continuity across the fault. East of the fault the anomaly character changes again, and more equidimensional, higher amplitude anomalies predominate over a broad area that extends to the Copper River (area 61). The steeper gradients bounding most of the anomalies within this area suggest shallow sources, and many anomalies coincide with outcrops of metavolcanic rocks of the Valdez Group. The assymmetry of most of the anomalies suggest that the causative rock bodies dip northward, and some of their northern boundaries are probably 1-3 mi deep. Most of the magnetic lows are on the northern or eastern sides of the anomalies and probably are the result of the dipolar edge effects, but a few lows are topographic effects. Most of the anomalies are close to outcrops of the Valdez Group but a few large ones (for example, anomaly 62) have no associated outcrops although volcanic rocks must be present at shallow depths beneath the flysch or glacier ice. Most of the anomalies occur in the high mountains near the Wortmanns, Deserted, Tasnuna, Woodworth, and Schwan Glaciers. One ultramafic body northwest of anomaly 62 crops out between two flightlines and did not seem to affect the contouring, so its dimensions are probably small. This part of the long belt of aeromagnetic anomalies lies south of a gravity high (Barnes and Morin, 1990) that has been mapped between the highest peaks and the Tasnuna River to the north, but the apparent northward dip of the sources of the anomalies suggests that the gravity and magnetic anomalies could have related sources. One TACT refraction profile follows the south side of the Tasnuna River Valley, and its analysis should aid the interpretation of these anomalies.

The eastern end of this group of anomalies is marked by a flattening of the magnetic field and a decrease in anomaly amplitude approximately 10 mi west of the Copper River (anomaly 63). Most of the gradients in this area are steep enough to indicate shallow sources, and there are many outcrops of Valdez Group volcanic rocks. The decreased amplitudes may suggest thinner flows interbedded with sedimentary rocks or a decrease in magnetization, perhaps as a result of metamorphism or hydrothermal alteration. Farther south (anomaly 64) the amplitudes are even smaller and more uniform, although many outcrops of the same volcanic rocks have been mapped. However, the contours on the northern side of anomaly 64, near Allen Glacier, have a uniform gradient that seems to suggest a magnetic boundary that is probably at least 2 mi deep. Another pronounced magnetic lineament (anomaly 66) forms the southwestern boundary of anomaly 64 and suggests a southern boundary of magnetic rock at a shallow to medium depth of 0.5-1.5 mi; this lineament almost coincides with the Bagley fault. North of the lineament the low-amplitude, shallow-source magnetic anomalies in area 65 closely resemble the anomalies in areas 63 and 64, where they probably indicate the Valdez Group volcanic rocks. Such rocks do not crop out in area 65, but the similarity between the anomalies suggests that they may be present at shallow depths. If such rocks are present, the Contact fault probably coincides with the Bagley fault for a longer distance than that indicated by recent geologic mapping (Winkler and Plafker, 1981; and Nelson and others, 1985), and it could be almost continuous with the Jack Bay fault as shown by the dashed line.

East of anomalies 63 and 64 the amplitudes again increase near the Copper River in area 67. Here the anomalies represent a complex combination of the effects of topography, varied flight elevation, near-surface volcanic rocks, and deep fill of weakly magnetic sediments in parts of the river valley. Near Miles Lake volcanic rocks of the Valdez Group crop out on both sides of the river valley, and the anomaly pattern suggests that they are extensive under Miles Lake, the termini of Miles and Allen Glaciers, Baird Canyon, and adjacent parts of the Copper River valley and bordering hillsides. North of the terminus of Allen Glacier the contours closely parallel the walls of the valley, and the gradients probably represent a complex combination of flight-elevation, topographic, and sedimentary-fill effects. One low in the center of the valley suggests that at least part of the sedimentary fill is even less magnetic than the adjacent flysch and sedimentary rocks, although lower flight elevations in the valley cause most of it to appear as magnetic high. Furthermore, the steepness and amplitude of the gradients along the valley walls seem too large to be explained by flight-elevation changes and suggest that other parts of the river-valley sedimentary fill may be magnetic. Many of these steep gradients are outside the national forest boundary so their detailed analysis is beyond the scope of this report.

East of the Copper River Valley the map does not show any of the high-amplitude, steep-gradient anomalies associated with the volcanic rocks of the Valdez Group that occur west of the river, and no outcrops of these rocks have been mapped on the east side. The most prominent magnetic feature east of the river is a broad high (anomaly 68) that suggests that a large magnetic body is buried at great depth beneath the mountains south of the Wernicke Glacier. One possible explanation for the anomaly is a large mass of serpentinite or peridotite buried at a depth of 2-5 mi. Magnetic lineaments (anomaly 69) north and south of the anomaly may be part of the anomaly or could represent bordering and perhaps shallower features. The gneissic rocks of the Valdez Group and granites of the Miles Glacier pluton that crop out near anomaly 68 have no detectable magnetic expression. East of the Copper River the gravity high continues to lie north of the magnetic highs that are here represented by anomaly 68; the parallelism of the regional gravity and magnetic trends suggests that they are structurally related. Farther east only reconnaissance gravity and magnetic data are available, but a preliminary interpretation of the limited gravity data (Barnes, 1977) suggests that the high may have a total length of more than 500 mi and that it connects with a similar feature near Glacier Bay to the southeast.

SOUTHEASTERN ANOMALIES

Near Latouche and Elrington Islands, the Prince William Sound belt of high-amplitude anomalies coincides with the northwest end of an even broader high (area 73 and approximate boundary 73), which marine magnetic surveys have shown extends many miles southeastward. The anomaly was previously discussed by Taylor and O'Neill (1974), who referred to it as the "continental margin" anomaly because it follows the top of the continental slope and truncates magnetic stripes observed in surveys over the Gulf of Alaska. Most of it lies both offshore and outside the boundaries of the Chugach National Forest.

The magnetic field is fairly flat over most of Montague Island and suggests another thick flysch sequence. A very weak magnetic low (anomaly 74) resulted because the aircraft had to climb to higher elevations to clear the peaks on the island. Two small offshore magnetic highs (anomaly 75) are on a trend that also passes through small outcrops of volcanic rocks of the Orca Group on Neck and Jeanie Points, so the anomalies probably represent submarine accumulations of similar rocks, although the map does not show anomalies near the outcrops. Although no volcanic or intrusive rocks have been mapped near another group of small anomalies (area 76) west of Patton Bay, the proximity to Jeanie Point suggests that these anomalies represent shallowly buried mafic volcanic rocks of the Orca Group.

Over the center of Prince William Sound the magnetic field is very flat and suggests a thick flysch sequence with a probable 3- to 6-mi depth to magnetic basement. The broad low (anomaly 77) approximately coincides with the deepest water and may suggest that underlying sediments and flysch have a slight but very low susceptibility. Farther east a small anomaly (78) at the point south of Port Gravina coincides with an outcrop of Orca Group volcanic rocks and interbedded sedimentary rocks. A similar anomaly (79) just offshore to the west undoubtedly represents similar rocks. There are some small contour flexures (anomaly 80) near the large Sheep Bay pluton east of Port Gravina, but the magnetic susceptibility of these granites must be very low to cause such minimal magnetic expression.

A small outcrop of Orca Group mafic volcanic rocks at Johnstone Point on northern Hinchinbrook Island suggests that similar rocks probably cause the small magnetic high mapped just offshore to the west (anomaly 81). Three other anomalies (82) close to the western shore of the island are also probably caused by mafic rocks. A much larger complex of anomalies (83) extends from near the center of the island northeastward through Hawkins Island and the adjacent Hawkins Island Cutoff and Orca Inlet to the vicinity of Shephard Glacier on the mainland. Several outcrops of Orca Group mafic volcanic rocks and interbedded sedimentary rocks are mapped along the trend and near the highest amplitude anomalies. Dipolar edge effects cause several bordering magnetic lows (anomaly 84). The southwestern end of these shallow-source anomalies is superimposed on a much broader magnetic low (anomaly boundary 85) that has approximately the same shape and size as Hinchinbrook Island. This low is too broad to be an edge effect of these anomalies and probably represents a deeply buried feature. It could be a reversely magnetized object such as a pluton or flysch-covered seamount or it might represent a pluton or other rock unit with magnetization even lower than that of the surrounding flysch. One TACT refraction profile crosses this large anomaly and should aid its interpretation.

Many magnetic anomalies with amplitudes and dimensions similar to those of anomalies caused by the Orca Group volcanic rocks were mapped over the lowlands, river channels, and offshore islands of the Copper River Delta, but no nearby outcrops of the mafic volcanic rocks have been found. Nevertheless, the similarity of the anomaly pattern strongly suggests that mafic volcanic rocks buried at shallow depths below the delta sediments are the cause of these anomalies in this area (86). However, other possible causes might involve large accumulations of magnetite in the delta sediment or irregular topography of an underlying basement surface. A few magnetic lows (anomaly 87) are adjacent to magnetic highs and have amplitudes and dimensions that suggest that they represent dipole edge effects. However, a few other lows (anomaly 88) in this area are more isolated and have large enough amplitudes and dimensions to suggest that they represent mafic rock units with reversed remanent magnetization. North of the delta a broad magnetic high (anomaly 89) follows the valley of the Copper River south of Miles Lake. This rather linear high has an amplitude of about 25γ, which could be explained by the fact that the aircraft was about 3,000 ft lower (closer to the Earth's center) over the river valley than it was over the adjacent hilltops. The gradient on the eastern side of the valley has a higher amplitude and probably represents some bordering mafic volcanic rocks. Small contour flexures over the McKinley Peak pluton (anomaly 90) are the only indication of these very weakly magnetic intrusive rocks on the western side.

Similarly, the only indication of the weakly magnetic Miles Glacier pluton in the mountains east of the Copper River are three broad lows (anomaly 91), which could also be explained by the high flight elevations over the mountains. The tuffaceous sedimentary rock unit south of the Martin fault has a much stronger magnetic expression as shown by the string of highs (anomaly 92) that follows much of the outcrop belt. This unit of the Orca Group has a varied lithology that includes sedimentary rocks, volcanic breccias, pillow basalts, and porphyritic dikes. The relative abundance and magnetic properties of these lithic units are unknown, but the latter two are considered the more probable cause of the magnetic anomalies. Farther south another group of high-amplitude anomalies (anomaly 93) follows the string of Orca Group pillow basalts and associated volcanic rocks that are exposed in a north-south belt near the Ragged Mountain fault. The asymmetry of the anomalies indicates that the volcanic rocks dip westward, and the string of lows to the east (anomaly 94) is a combination of topographic and dipole edge effects. The southern end of the anomalies is offshore and suggests that the same rocks extend about 5 mi offshore although buried at shallow depths beneath the Gulf of Alaska.

Farther east a very broad magnetic high (anomaly 95) is centered over the lower Bering River. This feature indicates a large deep magnetic object below the upper Tertiary sedimentary rocks that crop out in the Don Miller Hills and adjacent lowlands. The gravity minimum associated with these sedimentary rocks (Barnes and Morin, 1990) is less than 10 mGal and is nearly centered over the magnetic high. The density and thickness (at least 6,000 ft) of these sedimentary rocks (Plafker, 1967) are such that a much lower gravity anomaly might be expected, so the deep magnetic object may have a density high enough to compensate for the gravitational effects of the overlying sedimentary rocks. This suggests that the deep magnetic object could be a peridotite or gabbro, although lower density rocks such as serpentinite are other possibilites.

The highest amplitude anomalies (anomaly 96) on the Chugach National Forest magnetic map were measured offshore of Wingham and Kayak Islands near the southeast corner of the map. A few outcrops of volcanic rocks of the Orca Group on Wingham Island suggest that such rocks are the probable cause of the anomalies. The asymmetry of the anomalies suggest that the rocks have a westerly dip, and the string of lows to the east (anomaly 97) indicates another dipole edge effect. Other rocks that might cause the anomalies are the volcanic rocks of the Poul Creek Formation that crop out on the northern end of Kayak Island, where they have little magnetic expression; but offshore flows might be much thicker and more magnetic. Low-amplitude lineaments to the northwest and east suggest possible structural connections to the Ragged Mountains and some possible offshore anomalies.

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