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AEROMAGNETIC INTERPRETATION OF THE TALKEETNA QUADRANGLE, ALASKA

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AEROMAGNETIC DATA AND INTERPRETATION

In 1975 the U.S. Geological Survey acquired additional aeromagnetic data to fill the gap in the 1973 survey. This 1975 data block covers the rectangular area lat 62°30' to 63° N. and long 151°45' to 152°30' W. Both data sets were collected along north-south flight lines, the 1973 traverse at intervals of 1.2 km the 1975 at 1.6 km. The flight altitude was a nominal 300 m above the ground. Compilation was originally in the form of 30- by 15-minute quadrangles at a scale of 1:63,360; these quadrangles have been combined and reduced to form the present map. The contour interval is 10, 20, 100, or 500 gammas, depending on the steepness of local gradients in the Earth's magnetic field. Before the map was contoured, a regional field (updated IGRF, 1965) was removed from the data by computer and 5,000 gammas arbitrarily added to all values.

The local topographic relief for the northern part of the map area and the west half is very large, exceeding 4,000 m at Mount Foraker on the north border of the quadrangle and commonly exceeding 1,000 m throughout half the area. The fixed-wing aircraft used for the survey flew approximately 300 m above the ridge crests and descended only as far as safety permitted into the intervening valleys. Continuous recording altimeter data are available for each traverse. Because the rocks making up the topographic features of this map area are not in general highly magnetic, the high relief does not cause local magnetic anomalies due to topography. The few exceptions are specifically described under "Rock units."

The magnetic anomalies and patterns on the magnetic map are caused by variations in the amount of magnetic minerals, commonly magnetite, in the various rock units and are therefore closely related to geologic features. The magnetic anomalies in the map area are caused by igneous rocks, both plutonic and volcanic, by serpentinized ultramafic rocks, and by the contact-metamorphosed rocks in the metamorphic aureoles of certain plutons.

The aeromagnetic interpretation map (sheet 2) was compiled by the following procedure: a preliminary interpretation map was constructed using only the magnetic map and not referring to the geologic map; the interpretation was then compared with the geologic map and refined by modification of boundaries and the addition of a few more anomaly boundaries and interpreted faults. At this latitude, boundaries between magnetic and relatively nonmagnetic rock units are in general located on the flanks of the magnetic anomalies, approximately at the steepest gradients. The aeromagnetic interpretation map contains many such interpreted boundaries drawn around characteristic magnetic anomalies. In addition, a few boundaries are drawn to separate relatively flat magnetic areas from rather irregular areas. Some of these interpreted boundaries correspond approximately to mapped geologic contacts shown on the generalized geologic map. Other boundaries may represent rock units that have not yet been located by geologic mapping. Many of the boundaries are concealed by extensive Tertiary and Quaternary alluvial deposits, particularly in the northwestern and southeastern parts of the area and in the broad river valleys of the central part. In general, these boundaries are believed to be exposed at the top surface of the bedrock. Long linear magnetic boundaries that may truncate other magnetic features are interpreted as faults and are so indicated on the interpretation map. Minor discrepancies between mapped geology and aeromagnetic interpretation are to be expected at this map scale; they may arise from errors in aircraft location, from the semiquantitative nature of the magnetic interpretation, and from the reconnaissance nature of the geologic mapping.

Certain magnetic lows on the map are interpreted to be the result of reverse remanent magnetization of the associated volcanic, plutonic, and metamorphic rock units; they are indicated by a subscript capital letter "R." These lows are relatively isolated and are considered to be below the local background level of the magnetic field, which on this map is set arbitrarily at 5,000 gammas. Other magnetic lows, particularly those on the north, northeast, and northwest sides of the major magnetic highs, are produced by edge effects and have nothing to do with reverse remanent magnetization.

In the following sections, the magnetic expression of the various rock units is discussed.

ROCK UNITS

Volcanic rocks

A number of small masses of volcanic rocks of various ages are exposed in the Talkeetna quadrangle. Commonly these volcanic units are associated with magnetic anomalies, but not all such masses produce anomalies.

In the northwest corner of the map area, a discontinuous linear magnetic high is associated with a pillow basalt unit along the northwest side of the Denali fault. A few anomalies in the extreme northwest corner whose sources are concealed beneath Quaternary sedimentary deposits are interpreted to be caused by volcanic rocks but could be caused by plutonic rocks. Six anomalies no more than 12 km southeast of the Denali fault are interpreted to be caused by volcanic rocks, but two of these anomalies are not associated with mapped exposures of such rocks.

In the extreme northeast corner of the quadrangle, a distinct magnetic low (V_R) is associated with an area of volcanic rocks. These rocks must have reversed remanent magnetization to explain the sharp low.

At Happy River Valley in the southwest corner of the area, exposures of Tertiary volcanic rocks provide an explanation for at least two small magnetic highs. The larger high underlying the entire valley in this area is believed to be caused by a concealed source, probably a granitic pluton (P_{C2}).

Two linear magnetic highs (V), one about 40 km long, are recorded in the north center of the map area. The source of these anomalies is unknown, but their form indicates a steeply dipping tabular mass of magnetic rocks, possibly a dike or a sill and also possibly a thin layer of volcanic rocks. The country rocks here are nonmagnetic graywacke, argillite, and shale of Jurassic and Cretaceous age and strike generally northeast, parallel to the Denali fault in this area. Similar anomalies (labeled V_C) are seen at the south center of the area; one is about 25 km long. These two anomalies vary in strike by about 60° but are near the southeast margin of the belt of Jurassic and Cretaceous rocks (see section on concealed magnetic rocks of the southeast corner) and are approximately parallel with the northeast-striking south margin of the graywacke belt. Although the source of these anomalies is concealed, the depth to source is in general estimated to be no greater than 500 m below the surface and therefore possibly at the unconformity below the Tertiary

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sedimentary deposits and at the top of the Jurassic and Cretaceous graywacke (B. L. Reed, written commun., 1978, estimates that the Tertiary rocks here may be thicker than 500 m). The cause of these linear northern and southern sets of anomalies may be the same and seems to bear some relation to the regional structure of the graywacke basin as a whole.

Other volcanic rocks interpreted to be present in the subsurface of the southeast corner are discussed in the last section.

Ultramafic rocks

Serpentinized ultramafic rocks commonly produce large aeromagnetic anomalies because secondary magnetite develops in such rocks in the process of serpentinization. All known ultramafic rocks in this area cause aeromagnetic anomalies, labeled "U" on the interpretive map.

Anomaly U_1, in the northwest part of the map area, is clearly associated with a mapped ultramafic body. The anomaly is on strike with a small high 5 km northeast, also tentatively interpreted as caused by serpentinite.

A series of three magnetic highs, U_2, U_3, U_4, connect several isolated areas of exposed ultramafic rocks and indicate that they may form a more continuous rock unit. Anomaly U_3, composed of both mafic and ultramafic rocks, has wide gradients extending 3 to 4 km southwest of any exposed mafic or ultramafic rocks mapped; the anomaly form and the gradients suggest that a large mass is present in the subsurface. The measured magnetic susceptibilities of six samples from this rock mass range from 3.38×10^{-3} to 8.60×10^{-3} emu/cm^3 and average 5.40×10^{-3}. Corresponding densities for the six samples range from 2.46 to 2.77 g/cm^3 and average 2.57. The magnetic susceptibilities are large and help explain the amplitude of magnetic high U_3. The densities are low and indicate a marked degree of serpentinization.

Because podiform chromite is associated with these ultramafic rocks (Reed and others, 1978), the aeromagnetic data indicate additional areas to prospect for chromite.

Intrusive rocks

Many plutons of Late Cretaceous and Tertiary ages (Reed and Lanphere, 1973) cut the layered rocks of the Talkeetna quadrangle. Most of these intrusive rocks must be essentially nonmagnetic because the associated magnetic field is commonly as smooth as that over the nonmagnetic layered rocks. Some of these nonmagnetic plutons are locally rimmed by contact-metamorphosed country rocks that are magnetic (see following section) and that at some places provide an outline defining the approximate position of the pluton (for example, the pluton at lat 62°25' N., long 152°40' W. and pluton P_4). These approximate positions are shown as dashed lines on the interpretation map, which outlines the two exposed plutons in the west half of the map and an inferred third concealed pluton (P_C) in the southeast part of the central map area (lat 62°15' N., long 151°00' W.).

In the west half of the map area, a series of small plutons (P_1) or small areas within plutons (P_1) display small subcircular magnetic anomalies. Since two of these anomalies (one at lat 62°32' N., long 152°10' W. and one lat 62°30' N., long 152°30' W.) occur over known mafic phases of the pluton, many or all of the anomalies may indicate the presence of such phases. A group of three such anomalies is associated with the Kichatna plutons, a cluster of granodiorite masses in the hills between the Kichatna River and the Happy River. The magnetic pattern near these plutons is one of many small local closures; and this area of irregular magnetic field is interpreted to indicate a concealed larger pluton (P_{C1}).

Near the west edge of the map at lat 62°30' N., a small intrusion of biotite-pyroxene gabbro corresponds in location with a much broader circular magnetic high (P_2), whose marginal gradients indicate outward-dipping contacts of a much larger concealed mass. This pluton displays copper mineralization (Reed and others, 1978).

In the northwestern part of the map area, a series of magnetic highs (P_3) are associated with certain small gabbro and quartz diorite dikes. Where the magnetic plutons form topographic highs, proximity of magnetic rocks to the aircraft accentuates the anomalies.

Pluton P_4, though itself nonmagnetic, is outlined by various magnetic anomalies produced by several causative rock types and is associated with several kinds of mineralization (tin, silver, beryllium).

Three magnetic highs (P_5) shown in the north center of the aeromagnetic map are associated with small plutons that appear to be somewhat different from the surrounding larger plutons.

Concealed plutons may be inferred from several different kinds of evidence. If a pluton is magnetic with near-surface extension, it may give rise to an area of irregular magnetic field (pluton P_{C1}). Or a body or bodies may produce a broad anomaly with wide marginal gradients that indicate a source at depth below the surface. Anomalies P_{C2}, P_{C3}, and P_{C4} in the southwest part of the quadrangle are of this type; judged by the width of the magnetic gradients, the sources of P_{C2} and P_{C4} are at a depth probably no greater than 2 km; the source depth of P_{C3} is somewhat deeper, though continuous with P_{C2} and P_{C4}. Another kind of evidence for a concealed pluton is a magnetic anomaly caused by contact-metamorphosed country rocks (see following section). For example, anomalies M_{R2} and M_{R3}, associated with pluton P_{C4}, are good supporting evidence for the existence of this pluton, independently inferred from its associated broad magnetic high. Magnetic anomalies such as M_{R4} and the several anomalies labeled M_{R5} indicate concealed subsurface plutons in this way. All of these concealed plutons may be of economic interest because of the high metal content in stream-sediment and pan-concentrate samples collected in some of these areas (Curtin and others, 1978a, 1978b).

Other possible concealed plutons are discussed in the section dealing with concealed rocks of the southeast corner.

Contact metamorphosed sedimentary rocks

Rimming many of the plutons that intrude the central belt of Jurassic and Cretaceous graywacke and argillite are magnetic anomalies over the adjacent layered rocks. On the map, such features are especially visible in the northeast part of the quadrangle and in the western third. Most of these anomalies are lows (labeled M_R) and therefore thought to be caused by rocks with reverse remanent magnetization. A few anomalies are highs (labeled M). Examination of thin sections from rocks associated with certain of these magnetic anomalies discloses graywackes and argillites contact-metamorphosed to biotite and andalusite grades of metamorphism. Heating experiments by C. S. Grommé indicate that pyrrhotite is the only significant ferromagnetic mineral present. Examination of polished sections discloses abundant pyrrhotite (to 5 percent by volume) in the samples but no appreciable amounts of other opaque minerals. Measurements of magnetic properties from oriented metamorphosed graywacke samples yielded reversed remanent magnetizations of about 5×10^{-4} emu/cm^3 and magnetic susceptibilities of about 5×10^{-5} emu/cm^3; the stronger reversed remanent magnetization indicates that large rock masses of this material will cause aeromagnetic lows. It is believed that the original sulfide in the graywackes is pyrite (FeS_2) and that contact metamorphism has locally altered the pyrite to pyrrhotite, causing development of the remanent magnetization in these rocks.

Major magnetic lows with irregular outline that range from 10 to 25 km in maximum dimension are recorded throughout the central area of Jurassic and Cretaceous graywackes, but these anomalies are not adjacent to any large exposed masses of plutonic rocks. Thin sections from two of these anomalous areas (M_{R1}, M_{R2}) indicate metamorphism of the graywackes to biotite grade or higher. These magnetic rocks are taken to be the product of contact metamorphism whose causative plutonic rocks are concealed at relatively shallow depth (1-3 km) beneath the surface. Such areas may be favorable for prospecting for gold deposits.

Magnetic highs associated with contact-metamorphosed rocks occur in the southwest corner of the area of the aeromagnetic map. The ridge south of Johnson Creek (anomaly M_1 on south edge of map) is composed of metamorphosed graywacke (biotite zone) associated with several ground magnetic anomalies caused by magnetic rocks at the surface. Anomaly M_2 (lat 62°15' N., long 152°50' W.) is of interest because the anomaly on the opposite (southeast) side of this small pluton is reversed.

On the southwest end of reversed anomaly M_{R1} and the east end of reversed anomaly M_{R2}, the magnetic rocks are metamorphosed graywacke of the biotite and andalusite zones, respectively. Anomaly M_{R3} is considered to have the same cause as M_{R2}, namely, a concealed pluton (P_{C4}) at shallow depth. At the north end of anomaly M_{R4} (lat 62°30' N., long 151°05' W.), the degree of metamorphism of the graywackes increases at lower elevations (B. L. Reed, written commun., 1976; Reed and Nelson, 1977). Both anomalies M_{R2} and M_{R3} are accentuated by topographic highs composed of magnetic rocks.

The various anomalies labeled M_{R5} are all considered to indicate concealed plutons beneath or beside them, depending on lateral extent. Anomaly M_{R6} at the east edge of the map is probably caused by a concealed pluton (P_C) adjacent on the west side. Association of two small lows, M_{R7} and M_{R8} with graywacke outcroppings in the south center of the map area, provides evidence that most of the concealed anomalies in this general area are probably caused by the same effect, namely, contact metamorphism from a shallow pluton concealed beneath the overlying Quaternary sediments. The shallow depth (less than 200 m) to the sources of these concealed reversed anomalies ($M_{R,C}$) suggests that the thickness of Tertiary rocks must here be small, if in fact such rocks are present at all. An alternative and less convincing hypothesis is that these reversed anomalies are caused by concealed volcanic rocks at shallow depth, possibly within the Tertiary sedimentary rocks.

Concealed magnetic rocks of the southeast corner

The magnetic patterns in the southeast corner of the Talkeetna quadrangle are strikingly different from those elsewhere on the map and imply that an entirely different geologic terrane is concealed beneath the Tertiary and Quaternary sedimentary rocks, which here extend to a depth of at least 2.2 km according to the log of an exploration well (Union Texas Petroleum 1 Pure Kahiltna River-State) drilled in section 33 of T. 23 N., R. 8 W.

The aeromagnetic patterns can be analyzed to yield certain information. Three prominent subcircular magnetic highs with relatively wide marginal gradients are located on the northwest border of this magnetic province. These anomalies are interpreted to be caused by plutons, probably located within the magnetic basement. The remaining patterned area (divided into three large sections) displays the irregular discontinuous highs and lows that are generally caused by volcanic rocks. The southeast section, labeled $V_{R,C}$, is caused by an extensive area of rocks having reverse remanent magnetization and thus appears to be caused by a layer of relatively flat-lying volcanic rocks. A few kilometers east in the Talkeetna Mountains quadrangle (oral commun., Bela Csejtey, Jr., 1977), Tertiary basalt crops out through the Quaternary sediments and is associated with an extension of this area of reversed magnetic anomalies (Alaska Division of Geological and Geophysical Surveys, 1973b). The magnetic pattern of area $V_{R,C}$ is interpreted as caused by concealed reversely magnetized Tertiary basalt.

Depth determinations to the magnetic rocks can be calculated from the horizontal extent of the steepest magnetic gradients (Vacquier and others, 1951). Griscom has not made careful measurements from the original flight-line data but for the purposes of this study has made depth estimates from the original contoured aeromagnetic maps at a scale of 1:63,360. Depth estimates in the area labeled $V_{R,C}$ range from about 300 m along the east border of the map area to about 1,000 m at the west edge of area $V_{R,C}$. Depth estimates in area V_{C1} are rather small. At the northeast tip of area V_{C1} south of the Yenlo Hills, the magnetic rocks are thought to be essentially at the surface. A private company geologist (oral commun., 1978) states that altered volcanic rocks (age unknown) have recently been observed at the extreme south end of the Yenlo Hills so perhaps these rocks are predicted outcrops of magnetic basement. But as the exploratory well penetrated small amounts of Tertiary volcanic rocks in the lower 500 m of the hole, the altered volcanic rocks of the Yenlo Hills may be Tertiary, rather than older basement rocks. Elsewhere in area V_{C1}, the estimated depths to magnetic rocks are no greater than a few hundred meters. It is not clear whether the anomalies here are caused by older basement rocks or Tertiary volcanic rocks, but I favor basement rocks.

Estimated depths to magnetic rocks in area V_{C2} are somewhat greater. In general, the shallowest depth about 1 km, occurs along the north margin of this section. The three small circular areas labeled $V_{R,C}$ (lat 62°15' N., long 150°15' W.) give much shallower depths (100-200 m) but are probably caused by small amounts of Tertiary volcanic rocks overlying other Tertiary layered rocks. Maximum depths of 1.5-2 km are estimated along the south border of this section at the quadrangle bounday. These results compare reasonably with the 2.2-km depth at the exploratory well in section 33 of T.23 N., R.8 W. Again, I interpret these anomalies are being caused by older basement rocks rather than by Tertiary volcanic rocks.

The geology of the concealed magnetic rocks can be better understood by considering the geology of the area east of the V_C area, where magnetic basement rocks are exposed in the Talkeetna Mountains quadrangle. Extending through the northern part of this quadrangle is the same belt of nonmagnetic Jurassic and Cretaceous graywacke observed in the Talkeetna quadrangle. In contact with the south side of this belt is a terrane of crystalline rocks, Paleozoic and Triassic volcanic and sedimentary rocks intruded by younger granitic rocks (Beikman, 1974; Csejtey, (1976). These rocks are magnetic, forming an irregular pattern of intense aeromagnetic anomalies (Alaska Division of Geological and Geophysical Surveys, 1973b). The boundary between the magnetic crystalline rocks and the belt of nonmagnetic graywacke is reasonably well delineated by both the geologic mapping and the aeromagnetic data and is somewhat linear, striking S. 60° W. such that, if extended farther southwest, it would pass through the south end of the Yenlo Hills near area V_{C1}. The north boundary of the magnetic crystalline rocks of the Talkeetna Mountains quadrangle is thus approximately colinear with the north boundary of the concealed magnetic rocks in the Talkeetna quadrangle. It seems very likely that the concealed magnetic rocks are the same as those of the exposed crystalline terrane east of them, specifically, Paleozoic and Triassic volcanic rocks intruded by younger

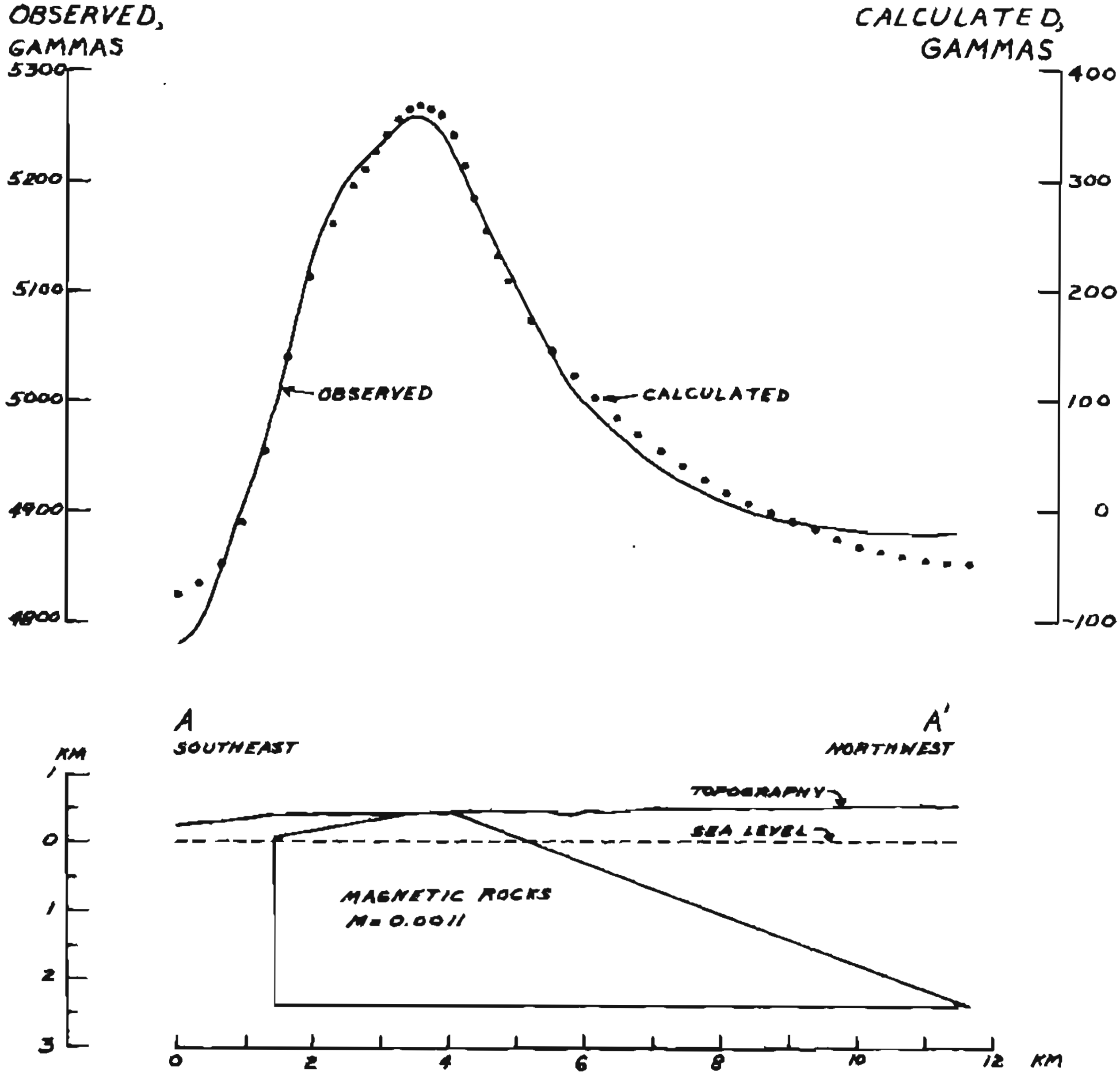

Figure 1.--Calculated and observed magnetic profiles across a two-dimensional model simulating a concealed magnetic rock mass in the southeast corner of the Talkeetna quadrangle. Cross-section A-A' is located on Sheet 2 and the magnetic data are projected from the flight line shown on Sheet 2. Northwest contact dips 20° and is interpreted as an unconformity. See discussion in text.

granitic rocks. Another complication is that concealed magnetic Tertiary volcanic rocks overlie the magnetic crystalline rocks (as in area $V_{R,C}$), but any magnetic effects of such rocks are considered to be relatively unimportant in areas V_{C1} and V_{C2}.

The nature of the contact between the crystalline rocks and the northern graywacke belt is tectonically of considerable regional interest. In the Talkeetna Mountains quadrangle, this contact is generally concealed by younger layered rocks or intruded out by younger granitic rocks (Béla Csejtey, oral commun., 1977) and in one locality appears to be a thrust dipping to the south. In a regional sense, the contact is considered to be a south-dipping thrust (Csejtey and others, 1978). The magnetic data of the Talkeetna quadrangle provide important structural information because only three relatively small, concealed plutons appear to interrupt the magnetic boundary. The smooth wide magnetic gradient sloping down to the northwest indicates that the boundary of the magnetic rocks of the crystalline terrane dips gently northwest beneath the nonmagnetic rocks of the graywacke belt. The relations at the south end of the Yenlo Hills are critical, because here the graywacke belt is exposed and here also the magnetic crystalline rocks are very near the surface and possibly crop out. A magnetic profile across the boundary in this locality was compared with a profile (location on sheet 2) calculated from a model of a cross section projected across the boundary (fig. 1). The simple model agrees well with the observed data and indicates that the magnetic boundary is reasonably smooth, dipping about 20° to the northwest beneath the sedimentary rocks of the graywacke belt. This dip is typical for the boundary in the Talkeetna quadrangle, and the contact inferred from it is most probably an unconformity, locally interrupted by a few faults, as indicated at the south edge of the interpretive map. This geophysical interpretation of the contact is in apparent contradiction with the geologic interpretation of the contact in the Talkeetna Mountains quadrangle.

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