DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-1594-D
PAMPHLET

BOUGUER GRAVITY AND AEROMAGNETIC MAPS OF THE WILDERNESSES AND ROADLESS AREAS OF THE WHITE MOUNTAINS NATIONAL FOREST, NEW HAMPSHIRE

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1986

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 Great Gulf and Presidential Range-Dry River Wildernesses; the Dartmouth Range, Wild River, Pemigewasset, Kinsman Mountain, Mount Wolf-Gordon Pond, Joblidunk, Carr Mountain, Sandwich Range, and Dry River Extension Roadless Areas; and the intervening and immediately surrounding areas in the White Mountain National Forest, Coos, Grafton, and Carroll Counties, N.H. The Great Gulf Wilderness was established when the Wilderness Act was passed in 1964, and the Presidential Range-Dry River Wilderness was added by public law 93-622, January 3, 1975. The Dartmouth Range, Wild River, Pemigewasset, Kinsman Mountain, Mount Wolf-Gordon Pond, Carr Mountain, and Joblidunk Roadless Areas were classified as Further Planning Areas, and the Dry River Extension and Sandwich Range Roadless Areas were classified as Proposed Wildernesses during the Second Roadless Area Review and Evaluation (RARE II) by the U.S. Forest Service, January 1979.

INTRODUCTION

The wildernesses and roadless areas of the White Mountain National Forest in north-central New Hampshire occupy approximately 315 mi^2 (approximately 800 km^2). Twelve individual and often unconnected parcels of variable size have been combined within a larger, contiguous area (hereinafter called the study area) covering about 1,300 mi^2 (approximately 3,300 km^2) to provide continuity for geological, geochemical, and geophysical description, analysis and interpretation.

GEOLOGIC SETTING

The study area is located in the central New England crystalline belt of the northern Appalachian Mountains almost entirely in New Hampshire (Index map). It is bounded on the west and northwest by the Bronson Hill anticlinorium. The majority of the area to the east lies within the Kersarge-Central Maine synclinorium (Lyons and others, 1982), a large northeast-trending structure in New England referred to previously as the Merrimack synclinorium by Billings (1956). The central feature cutting both major structures is the White Mountain batholith of Jurassic age (Index map). This composite body and the outlying central complexes of plutonic and volcanic heritage dominate the geological and geophysical maps.

The Bronson Hill anticlinorium exposes the oldest rocks in the region. Metasedimentary and metavolcanic Ordovician rocks (the latter of some economic interest) generally conformably overly the Middle Ordovician Oliverian gneiss domes which form a linear north- to northeast-trending belt from south-central Connecticut to west-central Maine. Only two of the gneiss domes are exposed within the study area: the northern part of the Moody Ledge Dome (now considered a Silurian felsic intrusive body; R.H. Moench, USGS, oral commun., 1984) and large part of the Jefferson Dome. Both are flanked by the Middle Ordovician Ammonoosuc Volcanics, although these rocks are mostly cut out by the Mahoosuc fault along the southeast side of the Jefferson Dome.

The Kearsarge-Central Maine synclinorium is defined by the distribution of Silurian and early Devonian metasedimentary and minor metavolcanic rocks. The youngest is the fossil-based Early Devonian Littleton Formation (Billings and Cleaves, 1934). They collectively form a broad synclinal tract that trends north-northeast through the region. The metamorphic rocks have been polydeformed and lie almost entirely within the sillimanite plateau of central New England (Thompson and Norton, 1968).

Igneous rocks, representing three of the four plutonic suites of northern New England (Billings, 1956), intrude both regional structures. The calc-alkaline granitic core gneisses of the Oliverian

Plutonic Suite and slightly younger, mildly alkalic syenites (just north of the study area in the Pliny Range) represent magmatism during and just following the Middle Ordovician Taconic orogeny (Naylor, 1968, 1969; Leo, 1980; Foland and Loiselle, 1981). Stratified rocks overlying the Oliverian Plutonic Suite, and to a lesser extent the gneisses of the Oliverian, are in turn intruded by the largely peraluminous granitic rocks of the New Hampshire Plutonic Suite. These intrusive rocks are generally syntectonic semiconcordant sheets 1 to 3 km thick (Neilson and others, 1976; Carnese and others, 1982) to post-tectonic discordant stocks and represent nearly continuous magmatism during the Acadian orogeny, 415-360 Ma (Lyons and Livingston, 1977).

Nearly one-half of the study area is underlain by various members of the mildly alkalic, post-tectonic White Mountain Plutonic-Volcanic Suite. A mean K/Ar age of 180 Ma (Foland and Faul, 1977) is reported for the dominant Conway Granite. The range for the discordant complexes, the composite batholith, ring dikes, and foundered volcanic rocks is 230-110 Ma, and varies from complex to complex (see Hatch and Moench, 1984 for a more complete discussion and pertinent references).

GEOPHYSICAL STUDIES

A number of geophysical studies have been carried out in central New Hampshire over the last thirty years that cover the study area wholly or in part. Gravity work includes that of Bean (1955), Joyner (1963), Osberg and others (1978), and Wetterauer and Bothner (1977). These data, combined and corrected by Bothner and others (1980), plus about 200 new stations occupied as part of this study and the Conterminous United States Mineral Assessment Program (CUSMAP) for the Lewiston-Sherbrook 1^{o}x 2^{o} quadrangle, were used in the compilation of the gravity map of the study area.

Published aeromagnetic maps (U.S. Geological Survey, 1973a,b) with east-west flight lines at approximate 1 km spacing, were digitized at 30-second intervals and combined at a common flight altitude (5,500' barometric) by Hassemer and others (1979); these digital data were used to prepare a 305 m draped map. A very small area in the northwestern corner of the study area (Moosilauke 15-minute quadrangle) remains unflown.

Aeroradioactivity data are also available for about the southern third of the map area (Portland 1^{o} x 2^{o} quadrangle) as flight-line profiles. These were acquired during the middle 1970's as part of the National Uranium Resource Evaluation (NURE) program (Texas Instruments, 1976). Analysis of these data is not discussed herein.

Bouguer Gravity Map

About 1,650 gravity stations are located within the area outlined by 43°45'-44°30' N and 70°45'-72°00' W and were used for the generation of the complete Bouguer gravity map (fig. 1). Standard U.S. Geological Survey reduction methods (G.I. Evenden and R.R. Wahl, USGS, written commun., 1977) using a Bouguer slab density of 2.67 g/cm^3 were followed. Only that part of the map covered by the study area was drafted, eliminating all edge effects. All data are terrain corrected to a distance of 0.895 km of the station using digital terrain data (Plouff, 1977; R.H. Godson, USGS, written commun., 1978).

Most features of the Bouguer gravity field can be accounted for by mapped igneous and metamorphic rocks. Closed negative anomalies are clearly associated with granitic bodies of the White Mountain Plutonic-Volcanic Suite, and in one case with a mass of granitic gneiss of the Oliverian Plutonic Suite. Modest negative deflections in gravity contours occur over mapped bodies of the New Hampshire Plutonic Suite granites. Closed positive anomalies occur over isolated bodies of denser quartz syenites (as stocks or ring dikes of the White Mountain Suite) or masses of still denser metamorphic rocks generally isolated within or between intrusives of both the White Mountain and New Hampshire Suites.

The gravity field in the study area is dominated by a broad low over the White Mountain composite batholith. The low is a major feature of north-central New England and extends to the east into Maine (Kane and others, 1972; Bothner and others, 1980). The batholith is approximately outlined by the -50 to -60 milligal (mgal) contours, deflected variably by satellitic stocks and central complexes, most notably the Profile (P) and Mad River (MR) plutons and the Cherry Mountain (CM) stock (fig. 1). Minimum values of -72 mgal occur within the central part of the batholith near or over stocks of Mount Osceola Granite (**Mzo**). Within and marginal to the batholith, interruptions in an otherwise smoothly decreasing gravity field are related to ring dikes and/or volcanics of the White Mountain Suite or to inlying bodies of older igneous and metamorphic host rocks.

Outside the batholith, isoanomaly contours approximately parallel the major structural trends of the Bronson Hill anticlinorium and the Kearsarge-Central Maine synclinorium best seen on smaller scale maps referenced above. Along the southern margin of the study area, north- and northeast-trending, low-amplitude gravity ridges and troughs, with few closures, broadly conform to mapped metasedimentary and felsic igneous rocks, respectively. From the southwestern corner to the north, a broad, pronounced gravity ridge is centered over metasedimentary rocks of the Littleton Formation (**Dl**). This anomaly decreases to the north over the Bethlehem Gneiss (**Dbgn**) and flattens over the metagraywacke and metavolcanic members of the Littleton Formation. Only slight (2-4 mgal) negative deflections occur to the east of the gravity ridge over the Kinsman Quartz Monzonite (**Dkqm**), supporting the view of Nielson and others (1976) that plutons of the New Hampshire Plutonic Suite are thin semiconcordant sheets. Too little of the core rocks of the Bronson Hill anticlinorium are exposed within the map area to show the modest gravity lows associated with the gneiss domes.

The northwest corner of the map is dominated by a large (10 mgal) high centered over the Cherry Mountain (CM) syenite (informal usage, Chapman, 1937) and a smaller (4 mgal) low over the Jefferson Dome consisting of coarse-grained granitic gneiss (**Oog**) of the Oliverian Plutonic Suite. Metavolcanic rocks of the Ammonoosuc Volcanics, partly cut out by the Mahoosuc fault, have no effect on the gravity field.

The north-central and northeastern area of the study area is characterized by a northeast-trending gravity high reaching a maximum value of -50 mgal largely over sillimanite-grade metasedimentary rocks of the Presidential Range. A small body of gabbro of the White Mountain Plutonic-Volcanic Suite is exposed near Crawford Notch, N.H. and may account for the extension of the elongate high to the southwest.

Gravity modeling using 2-, 2 1/2-, and 3-dimensional techniques, and appropriate density contrasts of the intrusive bodies within the study area indicates that granitic rocks of both the Oliverian and New Hampshire Plutonic Suites are thin (generally <2.5 km), semiconcordant sheets (Nielson and others, 1976; Carnese and others, 1982). By contrast, most intrusives of the post-tectonic White Mountain Plutonic-Volcanic Suite are steep walled, discordant plugs that extend to depths of 3 to 7 km, the thickest in the center and western portions of the White Mountain batholith (Wetterauer and Bothner, 1977) generally in areas underlain by the Mount Osceola Granite. Outlying stocks (P, MR) tend to be thinner (≤3 km).

Aeromagnetic Map

Interpretation of the aeromagnetic data is limited to a qualitative discussion of the major anomalies and gradients and their sources. Correlation between rock units and magnetic anomalies was aided by the analysis of 182 samples from 11 rock groups for magnetic susceptibility using a Soiltest Inc. Model MS-3[1] magnetic susceptibility bridge. The results of these measurements indicate that the Albany Porphyritic Quartz Syenite (**Mzqs**), Robbins Ridge granite (**Mzp**) (informal usage, Wetterauer, 1983) and Moat Volcanics (**Jmv**) are the units most likely to be anomaly sources; the Conway Granite (**Mzc**), Mount Osceola Granite (**Mzo**) and Littleton Formation (**Dl**) may offer secondary sources. One of the unclassified dikes ($6,309 \times 10^{-6}$ cgs units) and one sample of Na-amphibole granite ($2,519 \times 10^{-6}$ cgs units) show anomalously high susceptibilities. Because no anomalies related to these units are shown on the aeromagnetic map at this scale, it is suggested that rocks of such susceptibilities are limited in extent.

The magnetic anomalies on the map are keyed to the text by letter and subscript. Ten groups of anomalies are distinguished based upon probable anomaly source: A, Ordovician Bronson Hill rocks; B, Mesozoic syenite (**Mzs**); C, Conway Granite (**Mzc**); D, Devonian granite and quartz monzonite (**Dtg**); E, Silurian and Devonian metasedimentary rocks and related gneisses (**Sr, Spm, Ssf, Sm, DSg**); F, Mount Lafayette Granite Porphyry (**Mzl**); G, Moat Volcanics (**Jmv**); H, Mount Osceola Granite (**Mzo**); I, metavolcanics of the Littleton Formation (**Dlmv**); and J, Porphyritic quartz syenite (**Mzpqs**). In addition, two linear magnetic anomalies, the Bronson Hill Gradient and Mad River-Carter Trend, are identified (fig. 2).

The Bronson Hill anticlinorium, as exposed in the map area, contains three basic lithologies of Ordivician age: Ammonoosuc Volcanics (**Oam**), granites and syenites (**Oog**) of the Oliverian Plutonic Suite, and hornblende quartz monzonite (**Oohq**) of the Oliverian Suite. The Ammonoosuc Volcanics show strong positive anomalies (A_1, A_2) of 100-300 nanoteslas (nT) on the western edge of the map area that are probably related to the more mafic portions of this unit. It is unclear whether the 200^{+}nT anomaly labeled A_2 is the result of the granite or the Ammonoosuc Volcanics. In areas west of the study area, granites of the Oliverian Suite show only small positive anomalies. The 100^{+}nT anomaly labeled A_3 occurs over rocks mapped as Devonian Bethelehem Gneiss. As the Bethelehem Gneiss shows no anomalies in other areas, and because this anomaly is spatially near the Ammonoosuc Volcanics, it is postulated that the anomaly is caused by volcanic rocks at depth. The contact between the Ammonoosuc Volcanics and Bethelehem Gneiss is interpreted as intrusive and is consistent with the possibility of Ammonoosuc Volcanics lying at shallow depth. Ammonoosuc Volcanics on the north edge of the map area east of the Mahoosuc fault shows very little anomaly. Because ore deposits in the Ammonoosuc Volcanics are often associated with magnetic metachert horizons and magnetic mafic volcanics, the above anomalies may warrant further investigation.

Between the complex positive anomaly associated with the Bronson Hill anticlinorium and the low magnetic values associated with the Devonian and Silurian and Devonian metasedimentary and igneous rocks lies the Bronson Hill Gradient. Magnetic values decrease eastward across this gradient (10-20 nT/km) and are interrupted by satellite stocks of the northwestern margin of the main batholith.

The Cherry Mountain syenite (CM) (informal usage) intrudes Oog and has a strong positive anomaly (B_1) of 600^{+}nT. This roughly circular stock is one of a series of syenites and quartz syenites that have high magnetic susceptibilities (avg. 720×10^{-6} cgs units) and well-defined anomalies. Anomalies B_2-B_5 show well defined positive anomalies of approximately 300-1100 nT. Anomaly B_6 shows a much weaker positive anomaly.

Anomaly C_1 interrupts the Bronson Hill Gradient on the western border of the map area. The Conway Granite has a measured mean susceptibility of 215×10^{-6} cgs units, but values as high as 1090×10^{-6} cgs units and as low as 10×10^{-6} cgs units were measured. This broad variability is very typical of the Conway Granite and is seen in the close spatial relationship between anomaly C_4, a weak negative anomaly, and anomaly C_3, which shows a moderate 100^{+}nT anomaly. Other areas underlain by Conway Granite show flat magnetic fields with no recognizable anomalies, with the exception of C_2 which is a small negative anomaly. As C_1 is offset from the circular granite body, it is possible that much of that anomaly results from some as yet unidentified alteration at the contact between the Conway Granite and the Kinsman Quartz Monzonite. It is also possible that C_1 results entirely from the Kinsman Quartz Monzonite, as is seen at D_1. There are known ore deposits at the Iron Mountain Mine (magnetite), located at the margin of one body of Conway Granite (imm, fig. 2), northeast of Bartlett, N.H. As suggested by Barton and Goldsmith (1968), other Conway Granite contacts should be investigated in detail, especially those showing positive magnetic anomalies. Three positive magnetic anomalies which may be the result of alteration in the contact zones of the Conway Granite are C_1, G_2, and T_2. Anomaly C_1 is discussed above; G_1 and G_2 and probably emanate from the Moat Volcanics, but may be localized at the contact with Conway Granite; I_1 and T_2 show anomalies that may be related to

[1]The use of trade names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

exposures of porphyritic quartz syenite, or may be related to the contact between the quartz syenite and the Conway Granite. Since the Iron Mountain mine shows no anomaly at the flight elevation and spacing used to construct the map, it is possible that contact zones of the Conway Granite other than those listed above may contain ore deposits of the Iron Mountain type. A more detailed aeromagnetic survey and field checks of the more prominent anomalies would be necessary to properly evaluate this potential resource.

The anomalies found over bodies of Devonian quartz monzonite (**Dkqm** and **Dnmq**) indicate complex variations of magnetic susceptibilities within these bodies. The majority of areas underlain by Devonian quartz monzonite show weak or no anomalies. Where anomalies do occur, the anomaly is positive and local in extent. Anomaly D_1 is approximately the same size areally as a Mesozoic gabbro (**Mzg**) body mapped 3 km to the west. This aroused suspicion that the flight lines over this area were misplaced. Anomaly D_1 was field checked with a portable proton precision magnetometer and it is apparent from the additional data that the anomaly is correctly located.

Positive anomalies related to Silurian and Devonian metasediments and related gneisses are generally low in amplitude. Two larger positive anomalies have been identified (E_1 and E_2), and because these metasedimentary rocks do show high background amounts of copper (Moench and others, 1984) they should be investigated further. Anomaly E_1 is offset slightly (about 0.5 km) from a small (0.5 km^2 exposed area) mapped gabbroic stock north of the main batholith. Many complex, 20-200 nT anomalies are found in this area, and it is unclear whether E_1 can be attributed to the gabbroic stock. A similar gabbroic stock located near anomaly D_1 shows no magnetic signature. Anomaly E_2 occurs along the Mad River-Carter Trend and as such bears further investigation. The Smalls Falls Formation (**Ssf**), one of the Silurian and Devonian metasedimentary units (Hatch and Moench, 1984), is a rusty-weathering, sulfidic schist that often has a magnetic signature. Smalls Falls lithologies do occur in proximity to E_2, but there is no correlation between these rocks and the magnetic anomalies.

The Mad River-Carter Trend, named for the Mad River and Carter-Moriah Ranges, is located over the Silurian and Devonian metasedimentary terrain and is characterized by a N30°E trending, generally 40-200$^+$nT positive anomaly. The anomaly extends both south and north of the study area and is interpreted here to be related to a possible fracture system. Several faults have been identified to the south along this trend; none, however, have been identified to the north. The often magnetic Smalls Falls Formation does occur in proximity to the Mad River-Carter Trend but, as with anomaly E_2, there is apparently no direct correlation between them.

A strong geochemical tin anomaly is associated with the White Mountain batholith. Fracture-controlled tin deposits may be as important in this area as they are in the Nigerian tin district (Olade, 1980). The Jackson tin mine is located in rocks similar to those along the Mad River-Carter Trend (Moench and others, 1984), and further field studies should investigate the possibility of fracture-controlled mineralization in these rocks.

The series of complex anomalies labeled F correlate with two semicircular exposures of the Mount Lafayette Granite Porphyry (**Mzl**), though it is found to contain accessory magnetite (Hatch and Moench, 1984). The highly variable nature of the anomalies is probably the result of an irregular distribution of magnetite within this unit.

Anomalies labeled G vary from approximately 100-500 nT, and are related to the Moat Volcanics. The Moat Volcanics have an average susceptibility of 506 x 10^{-6} cgs units but vary from 10 x 10^{-6} cgs units to 1,364 x 10^{-6} cgs units. Anomaly G_1 and G_2 have both been discussed earlier regarding a possible relationship with the Conway Granite. The high susceptibility of volcanic rocks clearly are the cause for the greater portion of anomalies labeled G.

The Mount Osceola Granite (H_1, H_2, and H_3; average susceptibility 113 x 10^{-6} cgs units) shows a wide variation of susceptibility and shows well-defined positive anomalies in only three locations. The specific cause of these anomalies is not known, but they are most likely attributable to local variations in granite composition.

The negative anomaly labeled J occurs over the northern end of the metavolcanic rocks of the Littleton Formation (**Dlmv**) near the contact with the gneisses of the Oliverian Plutonic Suite. About 10 km southwest within the same belt lies the Coppermine Brook mine (cmb, fig. 2), but no association of the mine and this anomaly is possible. An anomaly over the mine area, if present, is strongly masked by C_1. The remaining area underlain by Littleton metavolcanic rocks shows no magnetic anomalies and it appears unlikely that the potential for additional deposits is high.

CONCLUSIONS

Bouguer gravity and aeromagnetic maps of the wildernesses and roadless areas of the White Mountain National Forest in central New Hampshire serve to characterize the distribution of major intrusive bodies of both the New Hampshire Plutonic Suite and White Mountain Plutonic-Volcanic Suite, and to provide at this scale more limited information on the older metamorphic rocks. Broad anomalies (both positive and negative) in the gravity field can be correlated with mapped intrusions whose effect is a function of density contrast and mass. It is difficult to distinguish subsurface extent at the contacts between granites of either series because of insufficient density contrast. Maximum thickness of the New Hampshire Plutonic Suite appears to be about 3 km or less; for the White Mountain Suite, no more than 7 km.

Magnetic anomalies emphasize surface and near-surface variations in magnetic susceptibilty, making that map more useful in assessing contact relationships and tracing specific rock units or structures (some of which have known or potential mineralizaton) in areas of poor exposure. Trends are identified for which more detailed geophysical surveying, in conjuction with companion geologic and geochemical maps, may be warranted.

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