DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

AEROMAGNETIC RECONNAISSANCE AND GENERALIZED GEOLOGIC MAP OF THE SAN ANDREAS FAULT BETWEEN SAN FRANCISCO AND SAN BERNARDINO, CALIFORNIA

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GEOPHYSICAL INVESTIGATIONS
MAP GP-815

PUBLISHED BY THE U. S. GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242
1972

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INTRODUCTION

The San Andreas fault is one of the most conspicuous geologic structures in California, and it separates crustal blocks of strikingly different lithology. Its tectonic significance is indicated by an aggregate horizontal displacement measurable in hundreds of miles, by its long history of past movements, spanning at least the past 25 million years and possibly much longer, and by its historic and present rates of movement and seismicity which rank it with the world's most active tectonic features. A right-lateral strike-slip fault or fault system, it trends southeastward from Cape Mendocino, near lat 40°30′ N., to the Gulf of California, a distance of nearly 800 miles. Although it generally trends N. 30°-50° W., it assumes a more westerly trend in the Transverse Ranges where it is joined by the Garlock and Big Pine faults. North of the Transverse Ranges, the fault is essentially a single break except in the San Francisco Bay area where it branches into the Hayward and Calaveras faults; south of the Transverse Ranges, numerous splays form a more complex system of faults that extend the San Andreas trend southeastward to the Gulf of California. Topography adjacent to the fault varies markedly in both elevation and maximum relief. Elevations in the Coast Ranges (strips A and B) range from sea level to about 4,500 feet near the fault and in the Transverse Ranges (strip C) from about 3,000 feet to as much as 8,000 feet.

AEROMAGNETIC SURVEY

A regional aeromagnetic survey consisting of seven flight lines about 250 miles long and 4 miles apart was made by the U.S. Geological Survey along the San Andreas fault between San Francisco and San Bernardino, California. The main purposes of the survey were to delineate major magnetic trends which may relate to gross basement lithologies and geologic structures along the fault and to outline areas of special geophysical and geological importance for more detailed future work.

The aeromagnetic survey was flown in three segments; from northwest to southeast, these were: (1) San Mateo, about 15 miles southeast of San Francisco proper, to Peach Tree Valley, about 15 miles east of King City (strip A); (2) Peach Tree Valley to Elkhorn Hills, about 7 miles southwest of Maricopa (strip B); and (3) Elkhorn Hills to Cajon, about 15 miles northeast of San Bernardino (strip C). The middle flight line is approximately coincident with the main fault trace; the remaining six flight lines cover about 12 miles on either side of the fault. The northern and central segments of the survey were flown at a barometric elevation of 6,500 feet, the southern segment at an elevation of 9,000 feet. Total intensity magnetic data were obtained by recording the digital output of an ASQ-10 fluxgate magnetometer along flight paths tracked with an APN-147 Doppler system, checked with a strip film camera. A latitude-dependent regional magnetic field gradient averaging 9 gammas per mile in the direction N. 16° E. has been removed from the original data. The contoured aeromagnetic data are shown on base maps of generalized geology (strips A, B, and C).

In general, the longitudinal flight line spacing is too great to allow accurate quantitative analysis of source rocks of an anomaly with dimensions of less than about 10 miles except where auxiliary flight lines used to tie the main longitudinal flight lines provide additional control. More detailed analysis is also possible near Palo Prieto Pass and near Wrightwood where ground magnetic surveys were made to identify local features of regional anomalies pointed up in the reconnaissance survey. Qualitative evaluation of the major anomalies with respect to lithology and structure of the mapped surface rocks is possible in most places. This report emphasizes such qualitative interpretations.

Interpretation of anomaly sources is based in part on computer programs for 2-dimensional and 3-dimensional magnetic models. These programs were used together with generalized rock magnetic data of DuBois (1963), Burch (1965), Saad (1968), Hanna and others (in press), and unpublished data of the U.S. Geological Survey. Rock magnetic properties of only a few of the anomalously magnetic rocks within the surveyed area have been measured, and one of the main purposes of the aeromagnetic survey is to indicate which lithologic units are significantly magnetic for more detailed future analysis. The aeromagnetic data alone suggest that most sources of anomalies are polarized at least approximately in the direction of the earth's present magnetic field and that most sources have total magnetizations in the range 10^{-4} to 10^{-3} electromagnetic units per cubic centimeter.

GEOLOGIC UNITS

Regional geologic data used in aeromagnetic interpretation were compiled mainly from 1° × 2° sheets of the Geologic Map of California, including the San Francisco (Jennings and Burnett, 1961), San Jose (Rogers, 1966), Santa Cruz (Jennings and Strand, 1959), San Luis Obispo (Jennings, 1958), Bakersfield (A. R. Smith, 1964), Los Angeles (Calif. Div. Mines and Geology, unpublished), and San Bernardino (Rogers, 1969) Sheets. The surface geologic data shown here are generalized, and some units shown on the state geologic map are combined or somewhat modified to facilitate interpretation of the aeromagnetic data. The units shown are: (1) gabbro, (2) anorthosite, (3) schist, (4) granitic and gneissic rocks, (5) sedimentary rocks of the Franciscan Formation, (6) volcanic rocks of the Franciscan Formation, (7) ultramafic rocks, (8) Cenozoic volcanic rocks and related intrusive bodies, and (9) Mesozoic and Cenozoic sedimentary rocks and alluvium. Aeromagnetic features are assessed in terms of these units using as additional control the basement well data of M. B. Smith (1964).

Gabbro

A layered gabbro-anorthosite complex of Precambrian age in the western San Gabriel Mountains consists of medium- to coarse-grained gabbroic rocks that are composed of variable proportions of plagioclase and pyroxene and lesser amounts of olivine and metallic opaque minerals. Much of the original pyroxene has been replaced by hornblende. Some layers are rich in, or almost entirely composed of, ilmenite and magnetite.

Anorthosite

Part of the layered gabbro-anorthosite complex of the San Gabriel Mountains (strip C) is virtually pure andesine anorthosite. These rocks grade by addition of dark minerals through a transition rock into gabbro. Many small bodies and layers rich in ilmenite and magnetite are found near the margin of the anorthosite and in some of the rocks transitional to the gabbro.

Schist

Large masses of mica-albite-quartz schist, locally rich in actinolite, epidote, and chlorite and with lesser thin beds of quartzite and marble, are present near Cajon Pass, south of Lancaster, and west of Tejon Pass along the San Andreas fault, as well as northeast of Tejon Pass along the Garlock fault (strip C). These schist masses, generally referred to collectively as the Pelona Schist, were derived from a thin-bedded sequence of graywacke, siltstone, and shale with interbedded mafic volcanic rocks, chert, and limestone. Long considered Precambrian(?) in age, largely on the basis of their degree of metamorphism, these schists are now suspected to be Mesozoic and possibly temporal and environmental equivalents of the Franciscan assemblage.

Granitic and gneissic rocks

The basement southwest of the San Andreas fault in the Coast Ranges and on both sides of the fault in the Transverse Ranges is dominated by a variety of granitic rocks and gneiss. The granitic rocks mostly range in composition from quartz monzonite to quartz diorite; granodiorite is probably the average composition for the whole region. Gneiss is abundant in the Transverse Ranges basement but more localized in the Coast Ranges; it is dominantly quartzo-feldspathic and generally has a compositional range between quartz monzonite and quartz diorite—similar to that of the granitic rocks. The gneiss and granitic rocks are intricately mixed in outcrop over much of the Transverse Ranges, in part migmatitically. In contrast, the largest masses of granitic basement in the Coast Ranges—Montara Mountain, Ben Lomond Mountain, the Gabilan Range, the La Panza Range—are granitic rocks with discrete roof pendants of marble, schist, hornfels, and quartzite. These pendant rocks and similar rock types in the Transverse Ranges have not been differentiated on the geologic base as they cover relatively small areas and probably cause no significant variation in the regional magnetic pattern.

Sedimentary rocks of the Franciscan Formation

Moderately to intensely deformed graywacke, siltstone, bedded chert, and conglomerate that crop out northeast of the San Andreas fault comprise a major part of the Franciscan Formation. These sedimentary rocks are interbedded and structurally intermixed with pillow lava, flow breccia, and small intrusive masses of basaltic composition. On the geologic map accompanying this report, the sedimentary and volcanic facies of the Franciscan are shown separately wherever possible, but some areas shown as sedimentary rock may contain unmapped bodies of volcanic or intrusive rock.

The Franciscan rocks are exposed in anticlinal cores and on the relatively upthrown sides of major faults, and they are commonly separated from the rocks that structurally overlie them by major bedding-plane faults. The most extensive areas of Franciscan rocks lie structurally beneath a thick sequence of marine Cretaceous strata that is widely exposed in the Diablo Range and extends eastward in the subsurface beneath the San Joaquin Valley to the western border of the Sierra Nevada. These marine Cretaceous rocks presumably overlap a lateral contact between Franciscan rocks and Sierran crystalline basement rocks at an unknown distance east of the map area. In other parts of the California Coast Ranges, Franciscan rocks are structurally overlain by similar marine strata that are as old as Late Jurassic.

The Franciscan sedimentary rocks are recognized by their crushed or cataclastic texture, their degree of physical deformation, and by their structurally low position. The lithologic character of these rocks ranges from chaotic tectonic breccia, through semi-schist and phyllonite, to only a slightly deformed graywacke and siltstone. Locally they are recrystallized and contain such minerals as glaucophane, lawsonite, and pumpellyite. Although true glaucophane schists form a very small percentage of the exposed Franciscan sedimentary terrane, minor recrystallization may be widespread.

The Franciscan is commonly treated as a stratigraphic unit. Although it is clearly a mappable lithologic unit, its recognition and mappability depend more on superimposed structural and metamorphic effects (especially cataclasis and closely spaced faulting) than on original lithology and stratigraphic relations. For this and other reasons, the "age" of the Franciscan is controversial, but it has produced fossils indicative of ages ranging from Late Jurassic to Late Cretaceous. Much of the Franciscan is evidently a cataclastically deformed facies of the marine clastic Mesozoic sequence which structurally overlies it and extends northeastward beneath the San Joaquin and Sacramento Valleys.

Because of its structurally low position and because its base is nowhere known, the Franciscan is considered as basement in the northernmost part of the Temblor Range, the Diablo Range, and in the northern Coast Ranges. In all these areas the exposed Franciscan rocks are found on the northeast side of the San Andreas fault zone and as slivers within it. In the northernmost part of the Temblor Range and in the Gabilan, La Panza, and Diablo Ranges, Franciscan rocks northeast of the fault are juxtaposed against granitic rocks and against metamorphic rocks southwest of it.

Volcanic rocks of the Franciscan Formation

Pillow lava, flow breccia, tuff, and small diabase bodies are commonly associated with Franciscan sedimentary rocks and in some areas may be the predominant lithology of the Franciscan Formation.

Lithologically these rocks range from nearly textureless, nondescript "greenstones" to well-crystallized little-altered basalts and diabases and to microcrystalline or glassy variolitic pillow basalts. Like the Franciscan sedimentary rocks, they are locally metamorphosed to glaucophane schists, but these are both rare and of local extent; minor recrystallization into glaucophane schist minerals may be more widespread than currently available data indicate. Many of the volcanic rocks are sheared or otherwise cataclastically deformed, but few exhibit the degree of cataclasis shown by Franciscan sedimentary rocks. The Franciscan volcanic rocks are interbedded or structurally intermixed with Franciscan sedimentary rocks, and they therefore crop out in similar structural settings. The volcanic rocks are considerably less abundant than their sedimentary counterparts except in the area north of the San Benito River where mapped volcanic sequences within the Franciscan are several thousands of feet thick.

Indirect evidence, derived largely from Franciscan volcanic outcrop areas elsewhere in California, suggests that these rocks were extruded or emplaced in Late Jurassic or Early Cretaceous time.

Ultramafic rocks

Serpentine crops out at many localities in the northern Temblor Range, in the Diablo Range, and in the southeastern part of the Santa Cruz Mountains. In all of these areas it is found in place only on the northeast side of the San Andreas fault, and most of it is closely associated with Franciscan rocks. Although many serpentinite bodies are intensely sheared and altered, a few retain bastite textures and remnants of an original mineralogy that indicates derivation from peridotite, dunite, and other ultramafic rocks. Field evidence at many places has demonstrated that most, and perhaps all, of the exposed serpentinite was emplaced not as a hot magma but as a relatively cold plastic mass that was incapable of producing contact metamorphic effects in the enclosing rocks. The plasticity of the serpentine and either current or very recent crustal deformation, coupled with gravity sliding, has locally produced a thin surface mantle of serpentinite which largely masks the shape and dimensions of the parent serpentinite body at depth. The mapped distribution of serpentinite is therefore an imperfect indication of its subsurface structural relations and extent. Most serpentinite bodies, however, do crop out in structurally controlled belts, especially along bedding-plane faults or faulted anticlinal crests. The age of the serpentinite and the age of its primary ultramafic ancestor are unknown. Although time of emplacement of serpentinite can be approximated for some bodies, the evidence now available suggests a continuing process of emplacement that began at least as early as the late Mesozoic for some serpentinite bodies and that is probably still continuing for others.

Some bodies mapped as ultramafic rocks or serpentinite are in part composed of various kinds of gabbro and pyroxenite. For example, small masses of hornblende-quartz gabbro and anorthositic gabbro along the San Andreas fault zone at Logan, near Hollister (strip A), and at Gold Hill, near Cholame (strip B), and exposures of gabbro, quartz gabbro, and pyroxenite at the west end of the San Emigdio Mountains are probably related to the ultramafic suite.

Cenozoic volcanic rocks

Volcanic rocks are rather widespread in the Coast Ranges on both sides of the San Andreas fault zone, but only locally do they form large areas of outcrop. The Pinnacles, in the southern part of the Gabilan Range, are made of a thick sequence of volcanic breccia, agglomerate, flows, and intrusives. The compositional range in this volcanic center is from rhyolite to basalt, but rhyolitic material seems to be most abundant. In the Diablo Range, as much as 4,000 feet of flows and agglomerate is present—the Quien Sabe Volcanics of Taliaferro (1949). These rocks are dominantly andesite and basalt, but rhyolite is present locally. Andesitic intrusive bodies are also common in this area. In the Santa Cruz Mountains, basaltic flow-breccia, pillow lava, and lithic tuff (Mindego Basalt) are interstratified with a sequence of mudstone, sandstone, and carbonate rocks. Sills and irregular dikes of diabase are also included. Other small layers and bodies of Cenozoic volcanic material that are shown in the geologic compilation are probably too small to affect the regional magnetic picture.

In the Transverse Ranges, along the north side of the San Andreas fault near the west end of the Mojave Desert (Antelope Valley), is a thick series of porphyritic and glassy flows ranging in composition from andesite to rhyolite and associated with minor amounts of interbedded tuff, agglomerate, sandstone, and limestone. South of the San Andreas fault in the Soledad Pass area is a section of volcanic flows, tuffs, and breccias with associated terrestrial sedimentary rocks (Vasquez Formation). These volcanic rocks range from dacite to basalt but are mostly andesite.

Mesozoic and Cenozoic sedimentary rocks and alluvium

Stratified marine and nonmarine sedimentary rocks with an aggregate thickness of nearly 40,000 feet structurally overlie the Franciscan rocks northeast of the San Andreas fault. The sedimentary rocks are predominantly siltstone and sandstone with minor amounts of conglomerate and local concentrations of water-laid volcanic debris. Locally they are interbedded with thick volcanic lenses. The sedimentary rocks range in age from Late Jurassic to Holocene and in mode of origin from deep-water marine deposits to those of present-day alluvial fans and flood plains. More than half the total thickness of these rocks occurs as offshore marine deposits of late Mesozoic age—part of a widespread and homogeneous sequence of sandstone and siltstone that is found throughout the California Coast Ranges and that, at depth, underlies much of the Sacramento and San Joaquin Valleys. These indurated and well-lithified rocks of Mesozoic age are overlain by marine and nonmarine strata of Tertiary age that are much more heterogeneous, more localized, and more subject to facies changes. Despite these variations, lithology and stratigraphic relations in the Tertiary rocks record a trend from predominantly open-sea marine conditions of Paleocene time to nonmarine conditions at the close of the Tertiary. Sandstone, siltstone, and conglomerate, or their unlithified equivalents recur throughout this stratal record, and the only lithologic characteristics exhibiting reasonably consistent trends are degree of induration and compaction which are greater in the older rocks. Even so, some relatively old rocks are highly porous and friable and some relatively young rocks are compact and well indurated.

Southwest of the San Andreas fault, a much thinner sedimentary rock section overlies granitic basement rock, and the strata are chiefly of Miocene age or younger. These rocks differ in detail from their counterparts across the fault to the northeast chiefly because unlike facies have been juxtaposed by strike-slip movement on the San Andreas fault, but they are otherwise grossly similar.

ANOMALIES BETWEEN SAN MATEO AND PEACH TREE VALLEY

The most conspicuous magnetic features shown on the northwestern map segment (strip A) are an elongate positive anomaly (locality 3) centered between the Santa Cruz Mountains and Ben Lomond Mountain, about 11 miles north of Santa Cruz, and a broad magnetic ridge (localities 7, 9, 10, 11, 12) that lies between the Diablo and Gabilan Ranges and extends northwestward for about 65 miles from a zone of high magnetic intensity in the southeastern corner of the area. Less prominent magnetic highs occur near Palo Alto (locality 1) in the northern part of the map and near the Pinnacles National Monument (locality 8) in the southeastern part of the Gabilan Range.

The elongate anomaly (locality 3) has an amplitude of about 120 gammas and is centered over Cenozoic sedimentary rocks and alluvium between the northwest-trending Zayante and Butano fault zones. Magnetic gradients indicate that the top of the anomaly source lies at a depth of as much as a mile. If the anomaly source is magnetically polarized approximately parallel to the earth's field, the magnetic material is probably confined somewhere within a 3-mile wide zone between imaginary planes extending downward from the Zayante and Butano fault traces and extending for a longitudinal distance of at least 10 miles. The Zayante and Butano faults dip northeast and southwest respectively at ground surface; the anomaly source may be in large part deeper than the wedge formed by the downward extensions of these faults.

Because the source of this anomaly is covered by as much as a mile of sedimentary rocks and alluvium, its nature is unknown. The anomalously magnetic rocks may be Franciscan volcanic rocks, serpentinized ultramafic rocks, gabbro, intermediate granitic and gneissic rocks, or Cenozoic volcanic and intrusive rocks, all of which crop out within about 10 miles of the anomaly center. However, geologic and other geophysical evidence favors certain of these possibilities and renders others unlikely. Gravity data of Chapman and Bishop (1968) and J. D. Rietman (pers. commun., 1969) indicate that the area between the Zayante and Butano fault systems is associated with the northwest extremity of a major northwest-trending gravity trough. This gravity low (centered near locality 4) is principally caused by low-density Cenozoic sedimentary rocks of the Santa Cruz Basin (Gribi, 1963), not shown on map, in contact with a variety of higher density basement rocks including Salinian plutonic rocks. Because the gradients of the northwest extension of this gravity trough (near locality 3) are not significantly interrupted, we infer that the magnetic basement rocks beneath the sedimentary cover have an average density similar to nearby Salinian plutonic rocks at Ben Lomond Mountain (about 5 miles southwest of locality 3). However, the anomaly source rocks appear to be more strongly magnetic than the plutonic rocks at Ben Lomond Mountain.

Assuming that the rocks in question have densities similar to nearby plutonic rocks, it remains to inquire about the high magnetization required for the anomaly source. It is pertinent to note that about 25 miles southeast of the magnetic anomaly, gravity data of Bishop and Chapman (1967) and J. D. Rietman (pers. commun., 1969) and detailed aeromagnetic data furnished by the Gulf Oil Company show a coincidence between a gravity high and a magnetic high just southwest of the gabbro cropping out southeast of Logan (locality 6). Density and rock magnetic data for gabbro obtained by two of us (Ross and Hanna) from the Logan quarry, not shown on map, suggest that these positive anomalies are associated with gabbro extending southwest in the subsurface from the exposed rock near Logan. Judging from gravity data, this magnetic gabbro is similar in density to Salinian plutonic rocks in the exposed massif of the Gabilan Range (northwest of locality 8) to the southwest. The plutonic rocks of the Gabilan Range, like those of Ben Lomond Mountain, are not strongly magnetic, judging from aeromagnetic data, but are quite dense. Thus, the density and magnetization relationships between the partially exposed magnetic gabbro near Logan and the plutonic rocks of the Gabilan Range may be similar to the relationships between the buried magnetic rocks of locality 3 and plutonic rocks of Ben Lomond Mountain. On the basis of this argument, we infer that the magnetic anomaly source rocks of locality 3 may be gabbro, similar to exposed gabbro near Logan.

A possible alternative interpretation of the aeromagnetic anomaly is that its source is similar to rocks producing similar anomalies studied by Griscom (Zietz and others, 1969, p. 1704-1705) at the continental margin west of the map area. The inferred sources of these offshore anomalies are Salinian basement rocks. However, unless such Salinian rocks are appreciably more magnetic than those exposed at Ben Lomond Mountain and in the Gabilan Range, it would be difficult to interpret such rocks as the anomaly source. Because the anomaly source is apparently too dense to be serpentinite, another potentially magnetic source rock, we infer that a gabbro source rock is most likely.

The somewhat irregular 65-mile-long magnetic ridge (localities 7, 9, 10, 11, and 12) between Watsonville and Peach Tree Valley is associated with various amounts of exposed serpentinized ultramafic rocks near Priest Valley (locality 12), Laguna Mountain (locality 10), and Santa Rita Peak (locality 11) in the southern part of the map segment. The anomaly source rocks are covered by Mesozoic and Cenozoic sedimentary rocks northwest of Laguna Mountain, but thin sheets of serpentinite are exposed within fault zones in this area, and, on the basis of evidence afforded by mapped structural and stratigraphic relations, we assume that serpentinite underlies much of the area beneath the anomaly and northeast of the San Andreas fault. The depth to most of the buried magnetic rocks associated with that part of the magnetic ridge between San Benito Valley (locality 7) and Bear Valley (locality 9) may be as great as 1.5 miles. The conspicuous constriction and closing of anomaly contours between San Juan Bautista and Hollister (locality 7) appears to be influenced by the northwest-trending Calaveras fault. The abrupt northwest termination of the anomaly (between localities 6 and 7) suggests that the Sargent fault (north of locality 6) does not separate large volumes of magnetic serpentinite in the subsurface.

Throughout much of this part of the Diablo Range there is a remarkably strong correlation between negative gravity anomalies (Bishop and Chapman, 1967) and positive magnetic anomalies. Although the negative gravity features are in many places associated with low-density sedimentary rocks, in other places they appear to reflect subsurface concentrations of serpentinite, the presumed source rock of the positive magnetic anomalies. The subsurface serpentinites seem in general to increase in volume southeastward from San Juan Bautista. A very large diapiric serpentinite body near Santa Rita Peak (locality 11), which generates a high-gradient anomaly at the edge of the map, is associated with mercury deposits at the famous New Idria mining district (Eckel and Meyers, 1946; Coleman, 1957).

The small indicated 40-gamma ppsitive closure (locality 1) centered over the southern part of San Francisco Bay, near the northeast edge of Palo Alto, has a source which generates a local gravity high according to data of Oliver and Chapman (1966) and Chapman (Calif. Dept. of Water Resources, 1967, plates 8, 9, and 10; Chapman and Bishop, 1968). These positive anomalies are associated with an uplifted block of Franciscan rocks between northwest-trending faults inferred from well data (Calif. Dept. of Water Resources, 1967, plate 3). The source of the magnetic high may be Franciscan volcanic rocks or serpentinized ultramafic rocks; a single well 1 mile east of Coyote Hills, about 4 miles northeast of Dumbarton Point, reached "serpentine" at a depth of less than 400 feet (Calif. Dept. of Water Resources, 1967, plate 3).

Apart from the conspicuous though minor contour flexure at Monte Bello Ridge (locality 2), about 10 miles south of Palo Alto, attributable to topographically high Franciscan volcanic rocks or serpentinite, the only other important minor anomalies occur as a positive nose between San Juan Bautista and Pajaro Mouth (locality 5) and a broad 40-gamma high (locality 8) in the Gabilan Range, just west of Pinnacles National Monument. Neither the known geophysical nor geological data provide good evidence for the sources of these anomalies.

The aeromagnetic data show that the plutonic and metamorphic massifs at Ben Lomond Mountain and in the Gabilan Range are generally less magnetic than serpentinite bodies across the fault to the northeast. The data also indicate that exposed Franciscan volcanic rocks and Cenozoic volcanic and intrusive rocks do not generally produce significant magnetic anomalies.

ANOMALIES BETWEEN PEACH TREE VALLEY AND ELKHORN HILLS

The central segment (strip B) of the aeromagnetic survey is characterized by five major anomalies near the San Andreas fault: two northeast of the fault, one almost directly over the fault, and two southwest of the fault.

The anomalies northeast of the fault occur near Priest Valley (locality 12) in the northern end of the map segment and include Table Mountain (locality 14) to the southeast. The northwest part of the Priest Valley anomaly reaches an amplitude of 250 gammas. It extends southeast for some 25 miles where its ridgelike extension turns eastward to follow the axis of Table Mountain. The 150-gamma magnetic ridge that follows the axis of Table Mountain is associated with a serpentinite extrusion mapped by Dickinson (1966). This magnetic high also coincides with a conspicuous gravity trough according to data of S. H. Burch, and the main source of the anomalies is interpreted to be a tabular serpentinite body 2 to 3 miles thick and dipping steeply to the northeast (Hanna and others, in press). The elliptical high at Priest Valley does not directly correlate with outcrops of magnetic rocks, although the feature is part of a pronounced high associated with ultramafic rocks on Santa Rita Peak, and considerable amounts of serpentinite are exposed at the southwestern flank of the anomaly. Gravity data of Bishop and Chapman (1967) do not clearly indicate whether the magnetic source has an anomalous density; part of the area is characterized by a weak gravity high and part by a weak low. Magnetic gradients and continuity of the magnetic anomaly with the magnetic ridge at Table Mountain suggests that the anomaly source is serpentinite covered by no more than half a mile of Cenozoic sedimentary rocks.

The single magnetic anomaly most prominent in amplitude and areal extent within the magnetic survey spans the San Andreas fault near Palo Prieto Pass (locality 15) in the central part of the segment. The characteristics of this elliptical 400-gamma anomaly, together with Bouguer gravity data of S. H. Burch, suggest that the magnetic source is a serpentinite-rich mass with a roof 2 to 3 miles below ground surface and a floor as much as 10 miles deep. The inclination of the assumed magnetization, parallel to that of the earth's field, causes a pronounced southwestward displacement of the anomaly so that the aeromagnetic feature is centered directly over the main fault trace. Judging from the geophysical data, the mass is bounded on the southwest by the vertical San Andreas fault, bounded on the northeast by a northeast-dipping surface, possibly a fault zone within Franciscan rocks, and bounded on the northwest and southeast by steeply dipping surfaces of unknown structural significance (Hanna and others, in press). The inferred source of this anomaly probably represents the southernmost large concentration of serpentinite along the San Andreas fault.

Two anomalies southwest of the San Andreas fault are centered near the northwest part of the Cholame Hills (locality 13) and over part of the Carrizo Plain (locality 16) in the northwestern and southeastern parts of the map segment, respectively. The source of the asymmetrical high near the Cholame Hills remains an enigma. The steep gradient at the southwest flank of the anomaly is similar to the corresponding gradient of the anomaly near Palo Prieto Pass and probably reflects the presence of a buried steep-walled source. The gentle northeast flank of the anomaly presumably reflects the influence of abundant magnetic serpentinite between Priest Valley and Table Mountain, northeast of the San Andreas fault. The prominent western nose of the anomaly partly coincides with a structural low and a south-facing structural scarp within Salinian basement rocks near the San Ardo oil field, as expressed by well data (M. B. Smith, 1964). Granitic rocks occur as isolated outcrop patches about 5 miles east-southeast of the anomaly center and in a single basement well about 5 miles southeast of the anomaly center. The presence of plutonic rocks near the edges of the anomaly suggest that its source is part of the Salinian basement complex covered by sedimentary rocks less than 1 mile thick.

It is of speculative interest to note the possibility of a correlation between this anomaly source and the buried anomaly source at Palo Prieto Pass. Relations consistent with such a correlation include (1) the strong magnetization, depth of burial, and proximity to the fault zone of both sources, (2) the relative locations of the two anomalies consistent with right-lateral offset along the San Andreas fault, and (3) the amount of offset corresponding to a 25-mile post-late-Pliocene fault displacement (as suggested by Galehouse, 1967), implying emplacement of serpentinite contemporaneous with diastrophism in the Diablo and Temblor Ranges. Observations inconsistent with such a correlation include (1) no major occurrences of serpentinite are known from geologic mapping or well-hole data southwest of the fault within the map area and (2) gravity data of Burch and others (1970, in press) suggest that the source rocks have higher densities than serpentinite. The inconsistencies of correlation across the San Andreas fault appear to outweigh the consistencies. We conclude that the anomaly source southwest of the fault consists of plutonic rocks.

A narrow northwest-trending 100-gamma magnetic anomaly (locality 16), similar in shape to the magnetic ridge near Table Mountain, extends for a distance of about 25 miles over the Carrizo Plain, southwest of the San Andreas fault. Although the anomaly is controlled chiefly by a single flight line, the constraints of nearby anomalies controlled by two or more flight lines give assurance that the anomaly has the general shape depicted. Based on deep well data (M. B. Smith, 1964), the anomaly correlates with an uplift of Salinian basement rocks. A limited number of gravity data of W. F. Hanna in the area suggest that the gravity field is higher over that part of the Carrizo Plain concealing the magnetic source than elsewhere on the plain. The inferred anomaly source is believed to be plutonic rocks uplifted as much as a mile above surrounding basement rocks in the subsurface and concealed by as much as half a mile of Cenozoic sedimentary rocks.

ANOMALIES BETWEEN ELKHORN HILLS AND CAJON

The magnetic pattern in the third segment of the survey (strip C) shows a large positive anomaly near Blue Ridge (locality 17) in the northwest part of the segment, prominent highs over the Clearwater fault (locality 22) and near Acton (locality 24) in the central part of the segment, high-gradient anomalies near Pacific Mountain (locality 25) and Cucamonga Peak (locality 28) in the southeast part of the survey, and a sharp-crested high over the fault (locality 27) on the northeast side of the San Gabriel Mountains. The anomaly near Blue Ridge has a maximum of 200 gammas centered on the northeast side of the San Andreas fault in the western part of the San Emigdio Mountains. This anomaly is superposed on a much broader magnetic high of about 100 gammas which extends on both sides of the San Andreas fault in approximate coincidence with a major 55-mgal gravity high (Hanna, 1968). The broad magnetic anomaly is associated with a generally mafic basement terrane of dense plutonic and metamorphic rocks on both sides of the San Andreas fault northwest of the Big Pine and Garlock faults. The maximum at Blue Ridge is associated with a body of hornblende quartz gabbro and related mafic plutonic rocks, partly exposed about 2 miles north of Blue Ridge. This gabbroic complex may be oceanic-type basement rocks associated with the Franciscan assemblage.

About 40 miles southwest of the Blue Ridge anomaly, an elongate, somewhat curved, 100-gamma high (locality 22) is almost directly superposed over the trace of the Clearwater fault near Elizabeth Lake Canyon, southwest of the San Andreas fault. This anomaly is coincident with a broad gravity high which rises 50 mgal in a distance of 15 miles southward across the San Andreas fault from Antelope Valley (W. F. Hanna, unpub. gravity data). The main source of the magnetic anomaly may be gneisses and amphibolites largely confined between the Clearwater fault and a southeastward extension of the Liebre fault zone that lies to the north. The magnetic data suggest that exposed plutonic and metamorphic basement rocks northeast of the Clearwater fault zone and Cenozoic volcanic rocks immediately northeast of the San Andreas fault are less magnetic than the anomalous source rocks to the southwest, although the volcanic rocks may merely be insufficient in volume to produce a major anomaly. The pronounced negative anomaly centered along the San Andreas fault in the western part of Antelope Valley (locality 21) is interpreted to be a polarization low; however, part of this negative expression could arise from reversed remanent magnetization in exposed volcanic rocks. The source rocks of the positive anomaly are generally exposed along the Clearwater fault but are concealed possibly by as much as a mile of Cenozoic sedimentary rocks near the northwestern flank of the anomaly.

Twenty miles southeast of the anomaly near the Clearwater fault, an asymmetrical, east-west-trending, 100-gamma high (locality 24) is centered near Acton, southwest of the San Andreas fault. This anomaly occurs over exposures of volcanic rocks, gabbro, anorthosite, and intermediate plutonic and metamorphic rocks, as well as sedimentary rocks which cover the basement rocks in many places. Inasmuch as the anomaly is centered over many lithologic units, its source is not readily apparent. Because positive magnetic anomalies are not generally associated with exposures of Cenozoic volcanic rocks, Precambrian gabbro, or Precambrian anorthosite elsewhere in the map segment, it is suggested that intermediate to mafic plutonic and metamorphic rocks, such as granodiorite and diorite gneiss (Payne and others, 1967), may provide a sufficiently magnetic source for the anomaly.

Equally puzzling are source rocks of two anomalies which occur over the terrane of plutonic and metamorphic rocks between Pacific Mountain (locality 25), about 15 miles south-southeast of Palmdale, and Cucamonga Peak (locality 28), about 10 miles southwest of Cajon. The narrow north-south-trending 150-gamma anomaly near Pacific Mountain appears to have a hidden, nearly vertical, dikelike source no more than 1 mile wide. The anomaly may mark an intrusive body confined within part of a subsurface fault system. The 250-gamma equidimensional high centered 2 miles southwest of Cucamonga Peak has a magnetic source which is bounded on the south by the Cucamonga fault zone, on the west by a major northeast-trending fault zone, and on the north by the contact between the Pelona Schist and the plutonic and metamorphic rocks. The east boundary of the anomaly is undefined in the survey. Here, as in the anomalously magnetic areas near Pacific Mountain, Acton, Elizabeth Lake Canyon, and much of the San Emigdio Mountains, the magnetic source rock is interpreted to be plutonic and metamorphic rocks that are extensively exposed in this part of the Transverse Ranges. It is likely that each of these anomalies is accentuated to some extent by sharp topographic relief because the anomalies tend to peak where distances between magnetometer and source rocks become minimal.

Among the most perplexing problems in the area surveyed is the source of a narrow elongate magnetic anomaly (locality 27) which straddles the San Andreas fault over a distance of 25 miles between Valyermo and Wrightwood, near the southeastern end of the map segment. This anomaly is in part controlled by an auxiliary flight line, and most of the anomaly has been verified in a local vertical-intensity ground magnetic survey. Here, as in other anomalous areas within this map segment, the source is believed to be plutonic and metamorphic rocks, perhaps hornblende diorite, gabbro, and related gneisses. In contrast to most other anomalous areas, however, the source rocks are located on the northeast side of the San Andreas fault, probably in contact with the fault zone. The main source, like that of the anomaly near Pacific Mountain, is inferred to be a nearly vertical dikelike body no more than 1 mile wide over most of its extent. Although the San Andreas fault apparently bounds the anomaly source on the southwest, no known fault system confines the body on the northeast. If the source rocks are interpreted as a tectonic slice within the San Andreas fault zone, the great depth to which the slice apparently extends suggests that it is an unusual fault zone feature.

Very likely the presence of nonmagnetic Pelona Schist attenuates the expression of underlying magnetic rocks within this map segment and plays an important, though passive, role in determining the continuity of magnetic anomalies. Subsurface abundance of the Pelona Schist near the San Jacinto fault zone south of Wrightwood helps to dissect what would otherwise be a nearly continuous positive magnetic feature between Cucamonga Peak and Wrightwood. The Pelona Schist also interrupts an otherwise nearly continuous positive anomaly between Acton and Elizabeth Lake Canyon.

The unexplained magnetically inert areas of plutonic and metamorphic rocks southwest of the San Andreas fault between Cucamonga Peak and Pacific Mountain, between the San Gabriel and Big Pine fault zones near Alamo Mountain (south of locality 19), also northeast of the San Andreas fault between Valyermo and Quartz Hill (Palmdale area), and between Lake Hughes and Lebec (locality 21) may be partly attributable to subsurface abundances of Pelona Schist and other nonmagnetic rocks comprising an intruded terrane.

At least four other magnetic highs incompletely defined near the margins of the map segment appear to be generated by buried and exposed plutonic and metamorphic rocks. Gradients of three of these anomalies northeast of the San Andreas fault are expressed near Wheeler Ridge (locality 18), northeast of Fremont and Antelope Buttes (locality 23), and northeast of Lovejoy Buttes (locality 26). The gradient of a fourth anomaly (locality 20) is expressed near San Rafael Peak, southwest of the San Andreas fault. The local 60-gamma circular high near Frazier Mountain (locality 19), 10 miles north-northeast of San Rafael Peak, is associated with topographically high bodies of mafic gneisses.

ANOMALIES AND LITHOLOGIC UNITS

Most of the aeromagnetic relief on the northern and central map segments appears to be associated with large quantities of known or inferred serpentinite northeast of the San Andreas fault. The absence of magnetic expression over several exposed serpentinite bodies suggests that these ultramafic rocks occur as relatively thin sheets or discontinuous pods which lack sufficient volume to cause an anomaly. Most aeromagnetic anomalies on the southern map segment appear to be associated with intermediate to mafic plutonic and metamorphic rocks. One major anomaly is produced by a Franciscan-type gabbroic body; however, the Precambrian gabbroic-anorthositic complexes generally do not seem to be highly magnetic. The occurrence of many conspicuous anomalies over terranes of plutonic and metamorphic rocks in the surveyed area do not relate to known distinctive petrologic types. Some of these anomalies may reflect minor variations of magnetic iron oxide content within igneous and metamorphic rocks that are petrologically very similar. Franciscan and Cenozoic volcanic rocks throughout the area do not produce significant anomalies. Part of their weak magnetic expression may be attributable to chemical changes of magnetic oxides accompanying metamorphism of Franciscan rocks, although part is probably due to the felsic nature of many Cenozoic volcanic rocks and to a lack of significant volumes of those Franciscan or Cenozoic volcanic rocks which are magnetic.

ANOMALIES AND MAJOR STRUCTURE

The axes of many major anomalies throughout the area trend conspicuously northwest, approximately parallel to the overall structural pattern. The magnetic source rocks of many anomalies are bounded by one or more faults that are expressed at the surface; other source rocks may be controlled by subsurface zones of weakness not exposed at the surface. Even the curvature of some anomaly contour lines may be related to changes of strike of major fault systems, as suggested in anomaly patterns near the San Andreas fault in the San Emigdio Mountains and near the Clearwater fault farther south. Only in the San Gabriel Mountains, near the southern end of the surveyed area, do anomalies trend north to east; here, too, the anomalies conform to a major northeast structural alinement.

ANOMALIES AND TECTONIC MOVEMENT

It is of interest to compare areas of major magnetic anomalies along the San Andreas fault with those of special tectonic behavior as a possible means of correlating gross crustal lithologies with seismicity and crustal movement. Measurements of recent surface faulting, tectonic creep, microearthquakes, and major earthquakes (Allen, 1968; Brown and Wallace, 1968; Wallace, 1968; California Dept. Water Resources, 1964; Bolt and others, 1968; Eaton, 1967; Tocher, 1958, 1960; Rogers and Nason, 1967; Brown and others, 1967; Brune and Allen, 1967; Howard, 1968; Burford, 1966; Niazi, 1964; Whitten and Claire, 1960; Allen and others, 1965; Bonilla, 1967; Meade and Small, 1966; Steinbrugge and Zacher, 1960) suggest that localities north of Los Gatos and south of Cholame within the map area have infrequent earthquakes of large magnitude with little tectonic creep, whereas the zone between Los Gatos and Cholame has more frequent earthquakes of small magnitude with much tectonic creep (Wallace, in press). The aeromagnetic data, supported by gravity surveys, show that an extraordinary abundance of subsurface serpentinite extends upward to shallow depths or to ground level between Los Gatos (about 7 miles northeast of locality 3, strip A) and Cholame (about 12 miles northwest of locality 15, strip B) on the northeast side of the San Andreas fault. This association of abundant near-surface serpentinite with an area of more or less continuous slippage along the fault suggests that the serpentinites in the uppermost crust are on the average mechanically weaker than adjacent rocks. It is supposed, in accordance with experimental observations of Raleigh and Paterson (1965) that such a mechanical weakness of near-surface serpentinite is an expression of a high interstitial water content at shallow depths. Inferred deeply buried serpentinite, such as the presumed anomaly source at Palo Prieto Pass (locality 15) southeast of Cholame, may be deficient in interstitial water and, as a consequence, may be mechanically competent, partly accounting for the absence of creep in this area.

ANOMALIES AND ECONOMIC DEPOSITS

The aeromagnetic data are generally too sparsely distributed to be of much use in locating specific mineral commodities, an effort usually requiring detailed geophysical and geologic information. However, the data are important insofar as they help outline major structure in basement rocks and concentrations of magnetic rocks; these may indirectly relate to economic mineral deposits.

For example, regional anomalies near Indian Valley, southeast of San Ardo, and on the Carrizo Plain, north of Cuyama, presumably reflect, in part, elevated basement rocks in the subsurface. Structure in overlying sedimentary rocks may take the form of oil traps where the sediments are sufficiently petroliferous. Near Indian Valley this structure comprises part of the major source of the San Ardo oil field; on the Carrizo Plain this structure may be unimportant as an oil trap due to a deficiency of petroleum source rocks.

Regional anomalies reflecting abundances of serpentinized ultramafic rocks within Franciscan terrane may signal potential occurrences of mercury, asbestos, chromite, magnesite, and nickel sulfide minerals, which are associated with these rocks in many parts of the California Coast Ranges (Davis, 1966).

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