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MAGNETIC SURVEY OFF THE WEST COAST OF NORTH AMERICA, 32° N. LATITUDE TO 42° N. LATITUDE

Abstract: A ship-towed magnetometer survey of an area 250–300 miles wide off the foot of the continental slope along the coast of California has revealed a narrow pattern of anomalies of about 400 gammas magnitude trending north-south for more than 500 miles. The pattern is interrupted at the known faults and elsewhere; offset of the pattern at the Murray fault suggests a right-lateral displacement of about 84 nautical miles. The anomalies are such as might be expected of slablike structures underlying the ocean floor; geological possibilities include basic lava flows, topography of the main crustal layer, and intrusion of ultrabasic material from the mantle.

While making detailed hydrographic surveys off the west coast of North America, the Coast and Geodetic Survey ship PIONEER towed a total-field magnetometer and enabled us to survey an area 250–300 miles in width off the foot of the continental slope between latitudes 32° and 52° N., to a standard approaching that of air-borne magnetometer surveys over land.

A map of the section between latitudes 32° and 36° N., which includes part of the Murray fault, has already been published (Mason, 1958). This note presents a map of the area from latitude 32° N. to latitude 42° N., a little north of the Mendocino fault, and includes the section published previously. The geographical location and major physiographic features of the area are shown in Figure 1.

The area surveyed was covered with a regular grid of lines, normally about 5 miles apart (about twice the average depth of the water). Except in the vicinity of the Mendocino fault, where intersecting lines were run north–south and east–west, the lines were mostly east–west —*i.e.*, across the grain of the anomalous magnetic field. Sufficient lines were run in the other direction, however, to resolve any ambiguities that might otherwise have arisen in the contouring process. A radio-navigation system, using fixed beacons ashore, enabled positions to be determined about every 8 miles with a probable error of the order of 0.1 mile.

The magnetometer was a highly stabilized, self-orienting, total-field fluxgate. To reduce the effect of the ship's magnetism, the fluxgate mechanism was mounted in a streamlined fish and towed 500 feet behind the ship. The instrument was calibrated ashore, at approximately monthly intervals, by comparison with a proton-precession magnetometer. Taking into account the principal sources of error, namely inherent drift, inaccuracy of adjustment, and the effect of the ship, the standard deviation of a single observation from the absolute value is about 15 gammas. Provided that the instrument is kept in proper adjustment, the relative error between any two points on the same line is negligible.

The magnetic anomaly map (Pl. 1) is a plot of the observed field from which the regional magnetic field has been subtracted. The latter was derived from the map of the observed field by a smoothing process. No attempt was made to remove the effects of diurnal variation and magnetic storms. The daily range in hourly values of the total field at these latitudes is usually of the order of 30 gammas, and seldom exceeds 50 gammas, except during magnetic storms. It is unlikely, therefore, that the normal diurnal variation will have any significant effect on the positions and magnitudes of the more important anomalies, although individual contours may be distorted, particularly in areas of shallow magnetic relief. There were several magnetic storms during the survey, but the contours did not appear to be significantly affected by them. Long-term changes in the earth's magnetic field are automatically removed in the smoothing process for deriving the regional field.

The regional bathymetry has been described by Menard and Dietz (1952) and by Menard (1955). The area is crossed by two of the great east–west fault zones of the northeast Pacific,

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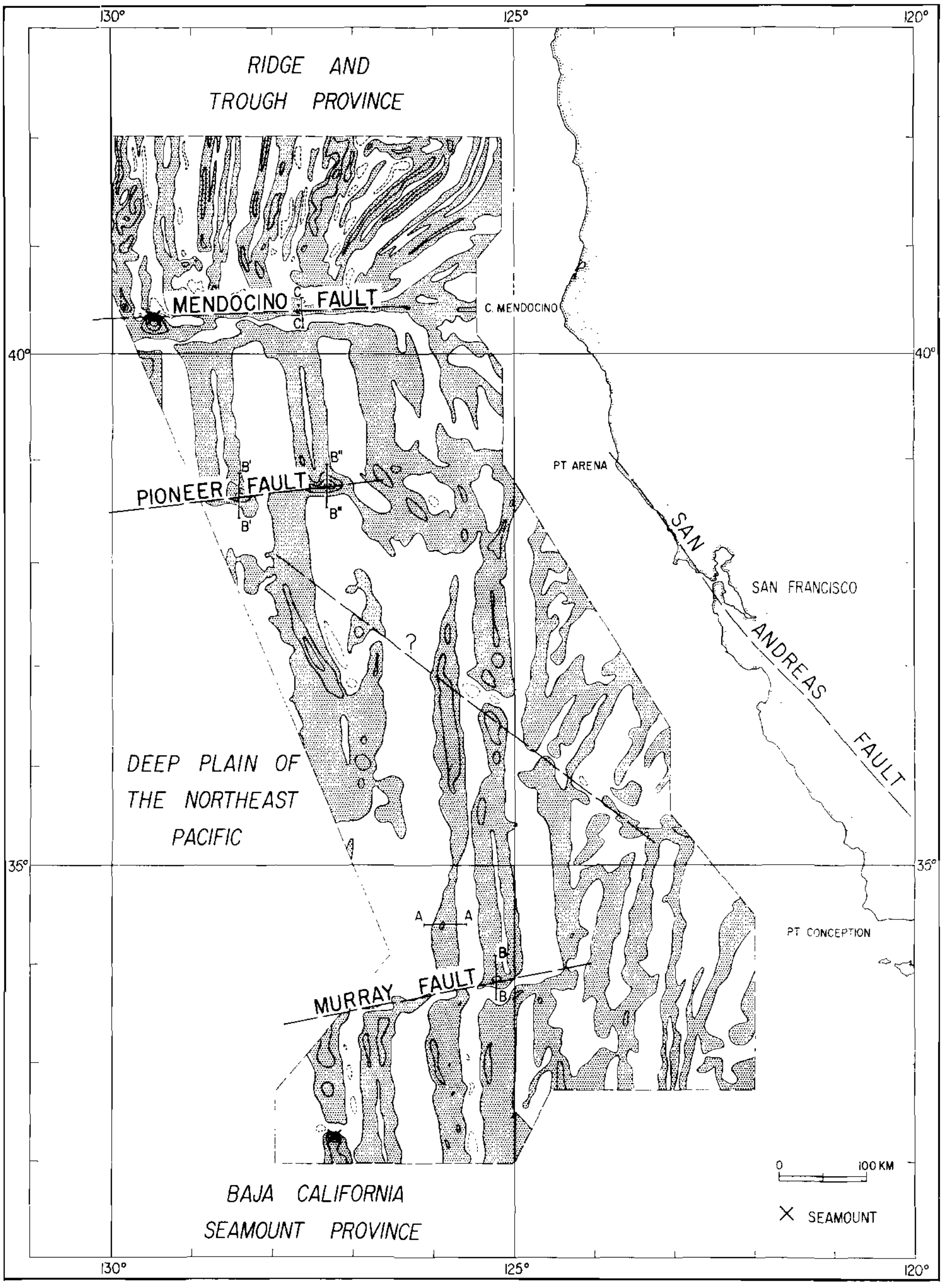

Figure 1. Skeleton magnetic map, showing geomorphic provinces, principal known faults, and locations of profiles. The contour interval is 250 gammas. Areas of positive anomaly are stippled. Negative contour lines are broken.

the Mendocino and the Murray. The former is by far the most spectacular topographic feature of the area; the bottom rises about 800 fathoms (1½ km) from south to north across it, and across most of the map it forms an asymmetrical ridge with a south-facing escarpment 5000–10,000 feet (1½–3 km) high. It marks the boundary between the Deep Plain of the Northeast Pacific, a comparatively smooth abyssal plain 2100–2600 fathoms (4–5 km) deep, to the south, and the shallower Ridge and Trough province, an area of narrow north or northeast trending ridges and troughs, to the north. The Murray fault, about 6° south of the Mendocino, divides the Deep Plain from the slightly shallower Baja California seamount province. A recently discovered topographic feature, the Pioneer Ridge, crosses the Deep Plain about 100 nautical miles (185 km) south of the Mendocino fault, marking the line of another major east–west fault.

Seismic-refraction measurements have been made at points widely distributed throughout the area. Results for stations south of the Mendocino fault are consistent with a normal oceanic crust (R. W. Raitt, personal communication). Thus at A–A (Fig. 1) the structure consists of 4.6 km of water, 0.3 ± 0.1 km of unconsolidated sediments, 1.4 ± 0.3 km of a second layer of velocity 5.4 ± 0.4 km/sec and commonly believed to be either volcanic rocks or consolidated sediments, and the main crustal layer 4.8 ± 0.5 km thick and of velocity 6.9 ± 0.1 km/sec. The M discontinuity is at a depth of 11.1 ± 0.6 km. North of the Mendocino fault, where the bottom is shallower, the structure appears to be distinctly different, but the exact nature of the difference has not yet been established.

The magnetic map is unusual in many respects. Although some correlation might have been expected between the magnetic field and the linear topography of the Ridge and Trough province, there were no grounds for anticipating either the strongly lineated character of the map over the Baja California seamount province and the relatively featureless Deep Plain, or the large horizontal displacements of the magnetic pattern that occur at the known faults and elsewhere. These lineations, and the horizontal displacements, far exceed in scale any that have been observed over the continents.

At the Murray fault, a 200-km section of the pattern on the north side can be matched against a similar section on the south side in a way that suggests a right-lateral displacement of about 84 nautical miles (155 km) (Mason, 1958). There is no obvious match of the pattern across either the Pioneer or the Mendocino fault, within the limits of the map. The survey has recently been extended westward on both sides of these faults, by ships of the Scripps Institution of Oceanography, to look for such a match and hence to determine the strike-slip movement along them. The results are reported elsewhere (Vacquier, 1959; Vacquier *et al.*, 1961). They are interpreted as indicating a left-lateral slip of about 140 nautical miles (265 km) across the Pioneer fault and about 640 nautical miles (1185 km) across the Mendocino.

At the Mendocino fault the character of the map changes abruptly. Some of the anomalies on the north side are so sharp as to place the top of the magnetic rocks no deeper than 3½ km (1900 fms) below sea level, which is shallower than the sea floor on the south side of the fault, and shallower therefore than the magnetic structures on that side. The change in character of the map is undoubtedly due in part to this factor. However, the seismic results, the change in elevation, and the fact that the line of the Mendocino fault marks the approximate boundary between various physiographic provinces of the neighboring continent (Eardley, 1951, p. 430) all point to a more general change in crustal structure. There is no significant change in the character of the map across either the Pioneer or the Murray fault.

The lineations of the anomalous magnetic field are remarkably straight. The principal north–south trending anomalies, for example, strike almost exactly N.5° W. from the southern edge of the map to the Mendocino fault, a distance of 500 nautical miles (900 km). This is surprising, in view of the very large relative displacements that have taken place at the intervening faults. They are also remarkably uniform in magnitude and width. Over most of the area they show little correlation with topography, and there is no indication of any systematic difference between seismic velocities in the anomalous areas and in the areas between, although the amount of data is not yet sufficient to demonstrate this point conclusively.

As to their immediate cause, the anomalies are such as might be expected of flat slablike structures approximately underlying the areas of positive anomaly. Figure 2 shows the observed anomalies along lines A–A and B–B of Figure 1, and superimposed on them theoretical anomalies computed respectively for an east–west line across an infinite north–south striking slab, and for a north–south line across the southern edge of a semi-infinite slab, both immediately underlying the ocean floor. The agreement is striking.

Two factors restrict the theoretically infinite range of possible depths and thicknesses of these slabs: (1) the sharpness of the anomalies places a limit on the depth to the magnetic rocks; and (2) since there is an upper limit to the polarization contrast that can reasonably be assumed, the bodies must be of a certain minimum thickness to produce anomalies of the observed magnitude.

The effect of these restrictions was investigated by comparing profiles from various parts of the map with theoretical anomalies computed for slabs of various depths and thicknesses. This investigation showed that the anomalies can be closely matched by slabs lying in the "second layer," and by slabs extending through the whole depth of the crust, but that, in general, anomalies computed for

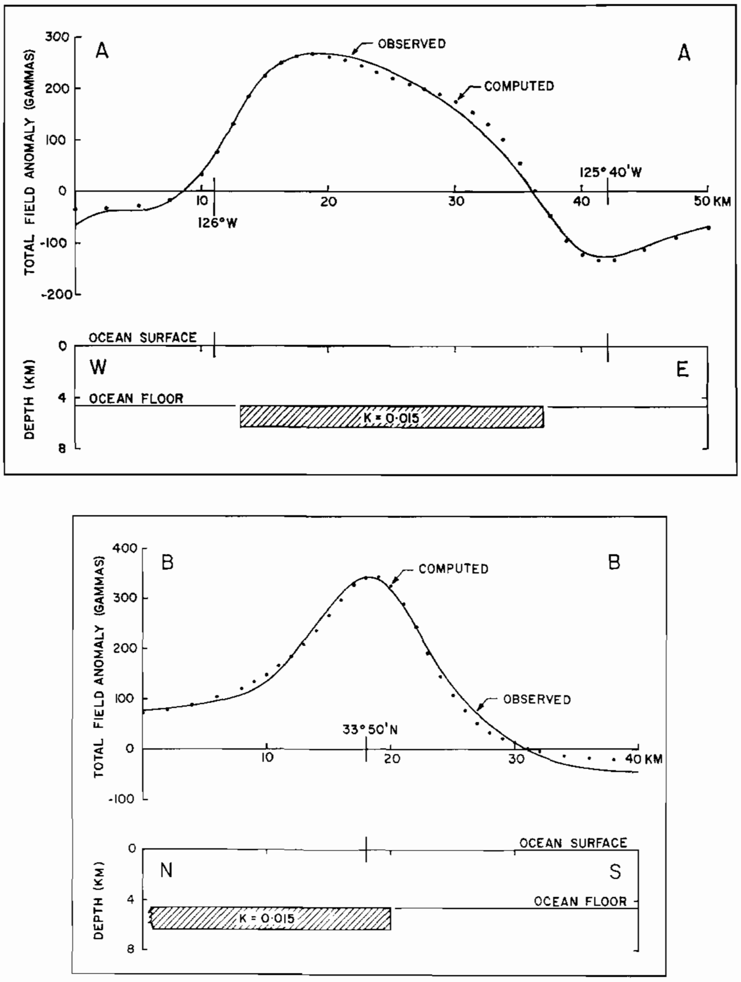

Figure 2. Observed anomalies along lines A–A and B–B of Figure 1. Superimposed on them are theoretical anomalies computed respectively for an east-west line across an infinite north-south striking slab, and north-south line across the southern edge of a semi-infinite slab.

slabs confined to the main crustal layer do not match the sharpness of the observed anomalies. Polarization contrasts corresponding to susceptibilities in the range 0.005–0.015 are necessary, which are values appropriate to the contrast between highly magnetic basalts and relatively nonmagnetic sediments.

both the second and the main crustal layers. Objection might be raised to all three on the grounds of lack of topographic and seismic expression. Figure 3 illustrates the three cases in terms of infinite north–south structures each of which has been adjusted by trial and error to fit the anomaly exactly (Mason, 1958).

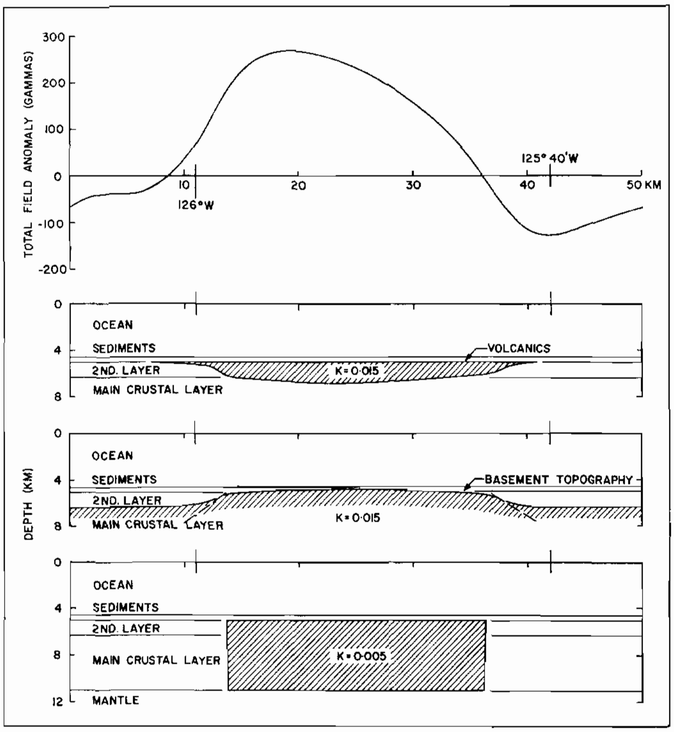

Figure 3. Possible interpretations of magnetic profile A–A. The theoretical anomaly computed for each of the three infinite north-south striking structures fits the observed anomaly almost exactly.

The geological possibilities fall into three categories: (1) isolated bodies of magnetically anomalous material, for example basic lava flows, within the "second layer"; (2) elevated folds or fault blocks of the main crustal layer; and (3) zones of intrusion of highly magnetic material from the mantle, extending from top to bottom of the crust. Category (1) would fit in well with current views about the somewhat enigmatic "second layer." Such lavas would constitute 10 per cent of the local crustal volume. For (2), a parallel might be drawn with the fault-block topography of the neighboring Basin and Range province. For (3), the anomalies might arise from magnetic contrasts within

On the magnetic map the Mendocino fault is marked by a narrow east–west anomaly of 300–500 gammas, almost symmetrical about the crest of the ridge. Figure 4 shows a typical section across the fault, along line C–C of Figure 1, and the observed anomaly along the same line. The question arises as to whether the anomaly is directly related to the ridge—*i.e.*, whether the magnetic rocks conform to the surface topography. Figure 4 shows a theoretical anomaly computed for uniform magnetization of the topographic section, assumed infinite in the east–west direction. The discrepancy between observed and computed anomalies suggests a deficiency of magnetic material on the south side of the fault. The stepped section, which has been adjusted by trial and error to approximately fit the anomaly, and which agrees closely with a possible interpretation of a nearby gravity profile (J. C. Harrison, personal communication), suggests a steeper and more abrupt discontinuity than might be expected from the topographic profile. For a polarization contrast of 0.007, a vertical displacement of about 3 km is indicated, or proportionately more or less for smaller or larger polarization contrasts.

The vertical relief across the Pioneer and Murray faults averages only a few hundred fathoms; the Pioneer fault forms a shallow ridge with a south-facing scarp, the Murray rises irregularly from north to south. On the magnetic map these faults are marked more by the effects of the transcurrent movements than by any persistent feature that could be ascribed to vertical displacements. The elliptical pattern of contours at B–B of Figure 1 on the line of the Murray fault, and the similar patterns at B′–B′ and B″–B″ on the line of the Pioneer fault, can be interpreted as the effects of south-facing ends of blocks intersected by the faults. The negative anomaly under the "A" of Murray in Figure 1 indicates a north-facing end.

This discussion has necessarily been based on very simple models. Not only are individual structures likely to be complex, but considerable heterogeneity of magnetic polarization is to be expected also. However, from their overall uniformity, the anomalous trends must clearly be considered part of a single homogeneous pattern. In the absence of any magnetic structures cutting across them, except neat the foot of the continental slope, where there is evidence for complex faulting with north–south components of slip, it must be concluded that the faults are more recent than the structures. Possibly the latter are relatively ancient features of the crust. A more significant discussion of both pattern and faults will be possible when the rest of the map, and projected extensions westward and over the continental shelf, have been completed, and when samples of the rocks have been obtained.

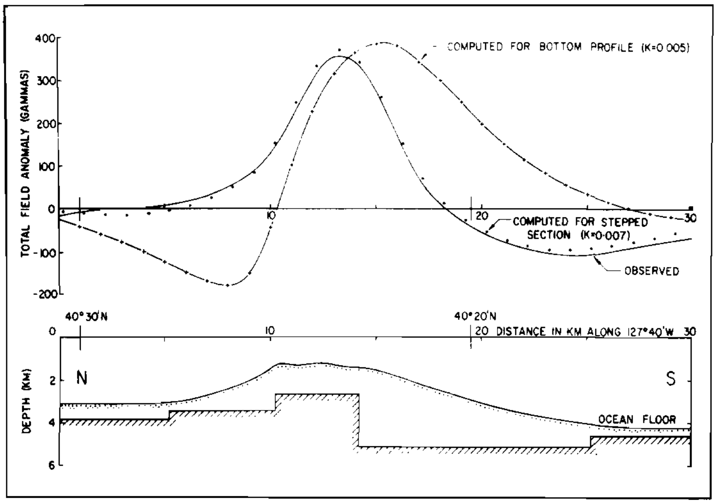

Figure 4. North-south profile across the Mendocino fault along line C–C of Figure 1, showing theoretical anomalies computed for uniform magnetization of topographic and stepped sections respectively, assumed infinite in the east-west direction

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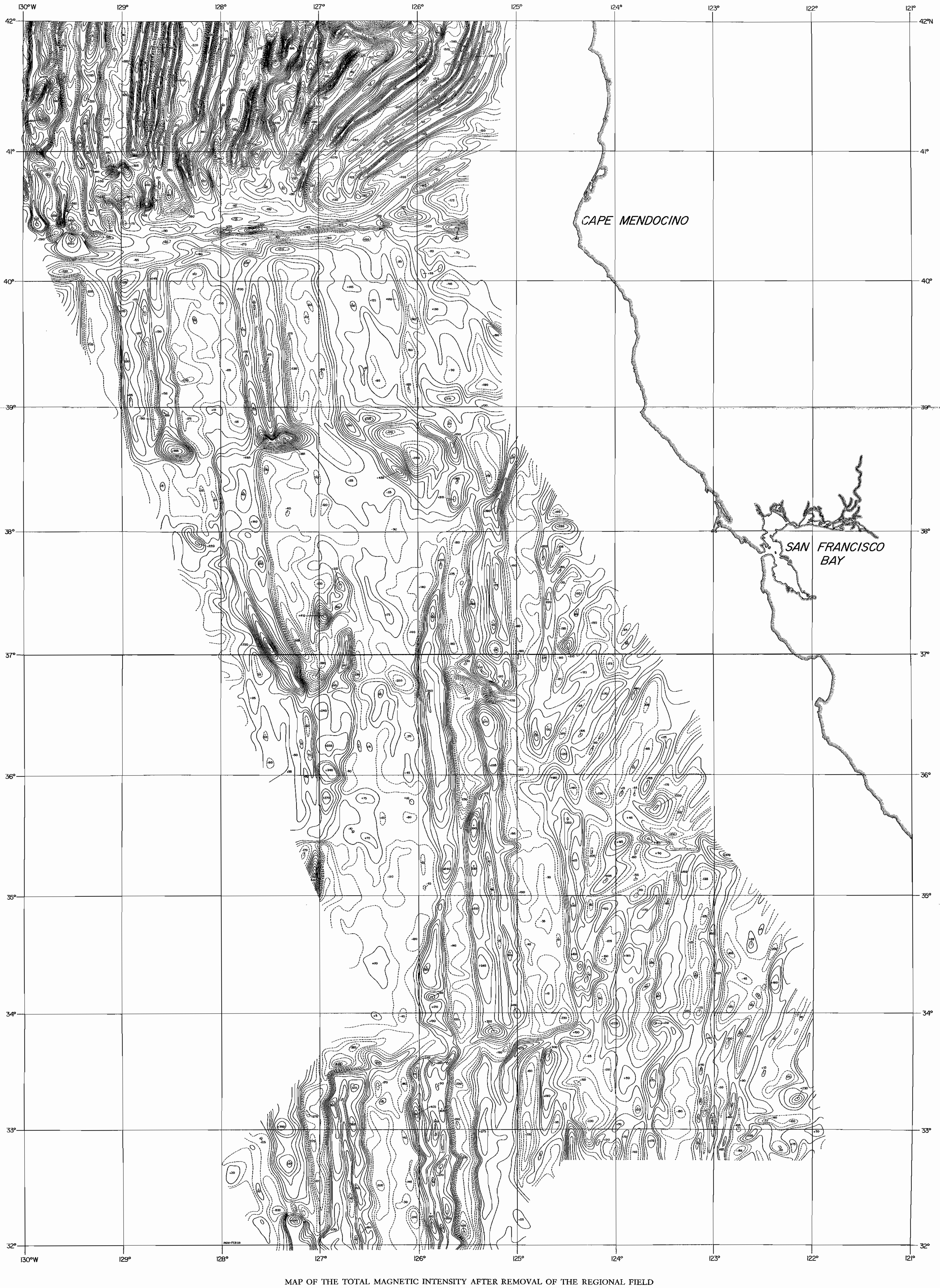

MAP OF THE TOTAL MAGNETIC INTENSITY AFTER REMOVAL OF THE REGIONAL FIELD

The contour interval is 50 gammas, and spot values are rounded off to the nearest 5 gammas beyond the extreme values recorded.

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