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SEA MAGNETOMETER SURVEYS OFF SOUTHWESTERN NOVA SCOTIA, FROM SABLE ISLAND TO ST. PIERRE BANK, AND OVER SCATARI BANK

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(Report and 6 figures)

Margaret E. Bower

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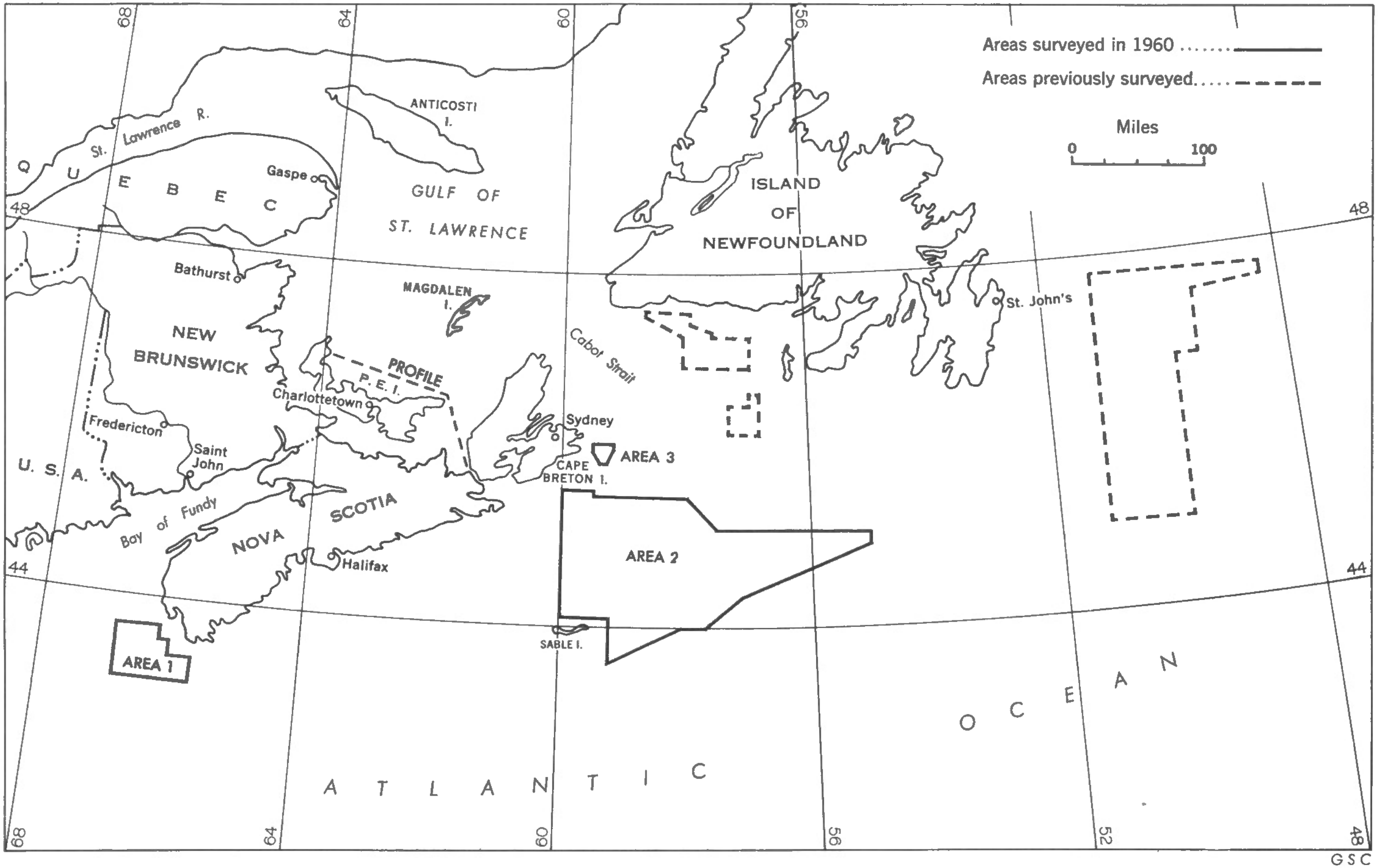

Figure 1. Areas surveyed with sea magnetometer

SEA MAGNETOMETER SURVEYS OFF SOUTHWESTERN NOVA SCOTIA, FROM SABLE ISLAND TO ST. PIERRE BANK, AND OVER SCATARI BANK

In 1960, sea magnetometer surveys were carried out jointly by the Geological Survey of Canada, the Canadian Hydrographic Service, and the Oceanographic Research Institute. Magnetometers were installed on two Canadian Hydrographic ships, the "Baffin" and the "Kapuskasing". These ships were making depth soundings and taking bottom samples in various areas to the south and east of Nova Scotia. The installation and operation of the magnetometer equipment was under the technical direction of the Geological Survey. Areas for which magnetic data have been compiled are shown in Figure 1.

FIELD WORK

C.G.S. Baffin (Area 1)

The Baffin surveyed an area of about 1,700 square miles between Yarmouth and Cape Sable, Nova Scotia during May and June, 1960, the magnetometer being in operation for 26 days.

The area was traversed on a series of parallel paths, in much the same manner as an aircraft doing aeromagnetic work. The traverses were run approximately northeast-southwest at intervals ranging from 1/3 to 2/3 mile. A Decca navigation system was used to determine the ship's position. Because positions obtained from the established Decca chain were not sufficiently accurate, the Baffin used its own Decca transmitters. The master station was carried on the ship and two slave stations were set up on shore. The Decca fixes and numbers were recorded automatically on the magnetometer tapes.

A GSC Model 60 magnetometer was used to measure the magnetic field strength. This is a direct-reading proton precession magnetometer (Serson, 1961)[1] that was developed by the Geological Survey. It records the absolute total magnetic field in gammas, taking a reading every 10 seconds. At the Baffin's normal operating speed of 13 knots, the magnetic readings were at approximately 220-foot intervals. The detecting unit was towed in a 'fish' about 400 feet behind the ship. At this distance magnetic effects from the ship were negligible.

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[1]Names and dates in parentheses refer to publications listed in the References.

C.G.S. Kapuskasing (Areas 2 and 3)

The Kapuskasing worked mainly in the area to the north and east of Sable Island, surveying about 18,000 square miles. In addition, some small areas were surveyed along the east coast of Cape Breton Island. The survey was in progress from May to October, 1960, the magnetometer being in operation for 70 days.

Most traverses in the western part of Area 2 were run in a north-south direction; those in the eastern part, east-west. Area 3 was traversed in a similar manner, except that the north-south and east-west traverses overlapped in the northern part of the area. Line spacing ranged from 1 mile to 2 1/2 miles, with closer spacing over shoals. The established Decca chain was used to determine the ship's position.

The magnetometer equipment was of the same type as that used on the Baffin. The Kapuskasing has a normal operating speed of 11 knots, so magnetic readings were taken at about 180-foot intervals.

Ground Station

A ground station was set up at Glace Bay, Nova Scotia, using a Varian station magnetometer. This unit started recording on June 10, 1960, and was in operation almost continuously for the rest of the field season. These records were used to provide magnetic control for the sea magnetometer data.

COMPILATION

A plotted chart of the ship's course was supplied to the Geological Survey by the Hydrographic Service staff on each of the ships. Corrections had already been made for known position errors. The accuracy of the Decca fixes varies with the distance of the ship from the Decca transmitters. Because the Kapuskasing was at times a great distance from both the Newfoundland and Nova Scotia Decca chains, the probable position error may vary from 200 to more than 1,000 yards. The Baffin on the other hand carried its own master station and its position error should be much less, probably not more than 100 yards. In addition to this known error, both magnetic and ionospheric storms have been observed to cause distortion of the Decca lanes and result in large position errors.

No corrections have been made for regional gradient, which is different for each area. In general, it increases toward the northwest at a rate of 6 to 8 gammas per mile.

The data from the two surveys were compiled somewhat differently, and will therefore be considered separately.

Area 1

The proton precession magnetometer is assumed to have no instrumental drift, and, as the survey had been completed before the ground station was in operation, no corrections could be made for diurnal drift. However, the Agincourt records of the Dominion Observatory were checked for all times during which the ship was in operation, and sea magnetometer records taken during magnetic storms were not used. Intercept values were taken on the magnetometer records at 50-gamma intervals, and these values were used to produce the contour maps (Figures 3 and 4).

Most of the uncontoured areas on these maps are due to magnetic storms. On 6 days there were disturbances of the order of hundreds of gammas, and the sea magnetometer records taken on at least parts of these days were not used. On several other days there were variations of 20 to 100 gammas, of both the gradual-drift and short-burst types of disturbance. These variations interfered with the contouring, but not enough to result in gaps in the map.

Some trouble developed in the magnetometer equipment, and the records taken on 2 days could not be used. So many spurious counts were recorded that the true magnetic variation could not be determined. This may have been caused by electronic trouble within some part of the equipment, water leaking into the 'fish', or interference from electrical equipment on the ship.

Areas 2 and 3

Most of the magnetometer records for these areas have been corrected for diurnal variation. The Glace Bay ground station went into operation a few days after the Kapuskasing surveys started, and, except for occasional breakdowns, was in continuous operation until the end of the survey. When the ground station was not in operation the Agincourt records were checked for magnetic storms.

The sea magnetometer records were corrected for diurnal variation in the following manner. The ground-station tapes were examined to determine the normal, undisturbed magnetic level. This 'base level' was found to be 55,150 gammas. The magnetic values were determined at 15-minute intervals on the tape, using a scale that converts the Varian counts into gammas. The diurnal variation was the difference between these values and the base-level value. The sea magnetometer records were then divided into corresponding 15-minute intervals, and the diurnal variation marked on the tapes. This provided a datum line from which corrected magnetic readings could be obtained. Intercept values were taken on the magnetometer records at 50-gamma intervals for Area 2 and at 100-gamma intervals for Area 3, and the contour maps compiled from them (Figures 5 and 6).

Neither magnetic storms nor equipment trouble were major problems on these surveys. Although parts of some traverses could not be used, no blank areas were left on this account. Gaps in Figure 6 are from a different cause, to be discussed later.

RESULTS AND INTERPRETATION

Area 1 (Figures 3 and 4)

This survey covers German Bank and adjacent areas. The ocean there is mostly shallow, and depths of more than 100 fathoms were recorded only along the western edge. To the east and north the water becomes shallower and in many places is less than 20 fathoms deep. The ocean floor consists mainly of sand, gravel, and shell fragments, but rock was found in a few places, mostly on shoals where the water is less than 10 fathoms deep.

The geology of the adjacent land is fairly well known. According to the Geological Map of the Maritime Provinces (Alcock, 1947), the rocks are mainly metamorphosed sediments of Precambrian or early Palaeozoic age, intruded by Palaeozoic granite (Figure 2). Recent detailed mapping by Taylor (1960) reveals the presence of volcanic rocks in the vicinity of Yarmouth. This region was greatly folded during the Acadian orogeny, and steep dips are common. Nothing seems to be known about the rocks off shore, as no samples were secured during hydrographic surveys.

All adjacent land and part of the Bay of Fundy have been surveyed with the airborne magnetometer (Geol. Surv., Canada). Volcanic rocks at the surface commonly cause magnetic anomalies of 300 to 500 gammas, but there is no absolute correlation between volcanic rocks and anomalies. In Figure 4 some aeromagnetic data has been included to show the continuation on land of magnetic trends established by the sea magnetometer.

In 1948 and 1951 the Lamont Geological Observatory made a series of seismic refraction measurements in the Gulf of Maine and east to Yarmouth, Nova Scotia (Drake, Worzel and Beckmann, 1954). By measuring the velocities of the seismic waves in the different strata, they could distinguish between unconsolidated sediments, consolidated sediments, and basement. A higher-velocity sub-basement was also detected at some points. The term 'basement' is generally defined as crystalline rock, probably of Precambrian age. In the seismic work, however, the term is used to describe rocks in which the velocity is around 15, 000 to 18, 000 feet per second. Such velocities may be obtained from rocks other than those usually thought of as basement, and it is possible that the higher-velocity sub-basement layer is more likely that which is usually considered as basement.

One of the seismic profiles was run between 43° 35'N, 66°42'W, and 43°40'N, 66° 20'W, a distance of 19 miles. This is near the north end of Area 1. At the east end of this profile the calculated depth to basement is 180 feet below sea-level. This is approximately the depth of the water, so that the rocks are apparently close to the surface of the ocean floor with little or no sedimentary cover. The sub-basement layer was detected 3, 770 feet below basement. At the west end of this profile the basement is overlain by 1, 120 feet of water and unconsolidated sediment, and the sub-basement is 9, 820 feet farther down. Still farther west, beyond Area 1, the basement levels out and the sub-basement rises fairly steeply to the surface of the ocean floor, pinching out the basement.

The gradient of the magnetic field may often be used to determine the distance from the plane of observation to the rock causing the anomaly. There are various methods of doing this, but the one used here is the 'half-slope' graphical method (Peters, 1949). Although depths calculated on the sea magnetometer data are not as accurate as those done on aeromagnetic maps, they should at least give the correct order of magnitude of the depths to the source rocks. For convenience, anomalies will arbitrarily be described as having shallow (less than 1,000 feet), intermediate (1,000 to 5,000 feet), or deep (greater than 5,000 feet) sources. Rocks causing anomalies are generally within the crystalline basement, but some may be intrusions or lava flows above the basement. The trend of anomalies is of as much interest as their depth. Where the anomaly source is shallow, the trend, if it exists, is generally obvious. Where the source is deep, the trend may be masked by the regional gradient.

Depth calculations were made on many of the anomalies in Figures 3 and 4, and the results were all in the 300-to-1,100-foot range. No other reliable depth determinations could be made. Probably some rocks are closer to the surface than 300 feet, but the cycling rate of the magnetometer was such that much shallower sources would not be recorded as distinct anomalies.

The most conspicuous feature in Figures 3 and 4 is the strong, linear trend of anomalies in the northeastern part of the area. Individual north-trending anomalies persist for as much as 14 miles, but the distance from one peak to the next across the trend is as little as 1/4 mile. To the northeast of the sea magnetometer survey, aeromagnetic flights to Gannet Rock and Green Island show similar north-trending anomalies, although magnetic gradients are not as steep on the aeromagnetic profiles because of the greater distance to the rocks. Farther north, in the vicinity of Yarmouth, northeasterly-trending anomalies (Geophysics Paper 601G) coincide with exposed volcanic rocks. It is a reasonable hypothesis that the volcanic rocks extend south from Yarmouth under the ocean, and are the cause of the linear anomalies.

An interesting feature of these linear anomalies is the close spacing of the magnetic highs and lows. There are two possible explanations for this:

1. The lava flows may occur in distinct, narrow bands, separated by less-magnetic material.

2. The magnetic effect may be due to folding. It has been observed in aeromagnetic work that the intensity of an anomaly is at times affected by the attitude of the rock. A flat-lying bed may have little magnetic expression, whereas the same bed tilted at a steep angle may produce a strong anomaly. The rocks in this part of Nova Scotia have been intensely folded, and the fold axes are generally parallel with the magnetic trends. The rocks off shore have probably undergone the same deformation.

At 43° 33'N on Figure 3 there is some evidence of faulting. The anomalies seem to be offset along a line running south of west. The apparent horizontal displacement is to the right.

In the south-central part of Area 1 some of the magnetic trends change abruptly to a westerly or southwesterly direction. These anomalies have shallow sources, but the narrow banding is not as prominent as it is farther north. If the volcanic rocks are still present there, the change in trend may be due to structural control of the older rocks, or to disturbances during the Acadian orogeny. The anomalies may however be caused by other rocks, such as an intrusion like that on the southern tip of Nova Scotia. A southwesterly magnetic trend is predominant in much of southern Nova Scotia (Geol. Surv., Canada).

The northwestern part of Area 1 has little magnetic variation, other than the regional gradient. In areas of such low magnetic relief, the contours are likely to be distorted by diurnal variation, and a change of a few gammas between traverses may completely change the contour pattern. Little can be said about this area except that either the basement rock is non-magnetic or there is a thick layer of sedimentary material over the basement.

The presence of volcanic rocks casts some doubt on the interpretation of the seismic data. In calculating the velocities and depths it is generally assumed that the velocity of the seismic waves increases with depth. But in this case the situation is reversed. The presence of the volcanic rocks means that there is a relatively thin high-velocity layer at the top of the section. This reversal of the velocities would not be detected in a refraction survey, and the computed depths to basement from the seismic data would be too shallow. Therefore the dipping basement layer postulated by Drake, Worzel and Beckmann (1954) may well be dipping less steeply than calculated, or not at all. The low magnetic relief in the northwest corner of the area does confirm the suggestion of a deep basement. There the magnetic effect may be due to the sub-basement rock referred to in the seismic report.

Some of the data in the southeastern part of Area 1 have not been contoured (Figure 4). The magnetometer records for this area contain a rapid succession of small anomalies, as many as five in a mile. Most of the anomalies have intensities of less than 50 gammas, few are greater than 200 gammas, and from one traverse to the next there is no suggestion of any trend or continuity. The values could be contoured but the results would be meaningless and misleading. The cause of the difficulty is shallow water; the depths there range from 7 to 20 fathoms. The magnetometer was so close to the rocks that it recorded small localized variations in magnetic susceptibility contrast that do not persist from one traverse to the next.

The uncontoured data does, however, give some information about the probable nature of the rock. The presence of the large number of small anomalies indicates that slightly magnetic material is very close to the surface of the ocean floor as smaller anomalies like these would not be detected through a few hundred feet of non-magnetic or flat-lying material. Bottom samples were taken in this area, and rock was found where water was less than 10 fathoms deep. On the adjacent land, metamorphic rocks are intruded by granite. Either of these rock types can produce an erratic magnetic pattern with low relief and few persistent trends. In the southeast corner of Area 1 the magnetic pattern is somewhat similar, but there the ocean is deeper and the smaller anomalies are not resolved. There is no evidence to suggest that the rocks in these areas are different from those on land.

Strongly negative anomalies are uncommon enough to warrant some mention. One was detected near the south end of Area 1 at 43° 07'N, 66° 10'W (Figure 4). At its lowest point this anomaly has a value of 53,700 gammas, which is 1,800 gammas below the general magnetic level of the surrounding area. Most strong positive anomalies have a complementary weak negative anomaly in the direction of the north magnetic pole, but here the relative intensities are reversed. A small positive anomaly occurs to the south of the large negative one. Negative anomalies are common over ilmenite-hematite deposits. These tend to have a strong remanent magnetization and if this magnetization is in a direction opposite to that of the present earth's field, a negative anomaly will result. However, the cause of this particular anomaly cannot be determined without a sample of the rock responsible.

Near the eastern edge of Area 1 a small elliptical anomaly of 1,000 gammas intensity was detected (Figure 4). It is peculiar because it occurs only on one traverse, and no sign of a peak can be found on either of the adjacent lines. Temporary equipment trouble may have been the cause and perhaps no anomaly actually exists, but there is no proof of this. If there really is an anomaly it is probably caused by a small body of basic rock.

The data in Area 1 is insufficient to define the structure and nature of the rocks completely, but the rock types known on land appear to continue out to sea. The general picture seems to be one of near-surface volcanic rocks with little sedimentary cover, underlain by a relatively non-magnetic basement.

Area 2 (Figure 5)

This survey covers the Banquereau and Misaine Banks, and extends east to the St. Pierre Bank. The depth of the ocean is mainly 20 to 100 fathoms over the banks, and greater than 200 fathoms in the Cabot Strait trough. The southern boundary of the area is over the continental slope; there the depth increases to more than 1,000 fathoms.

Most of this area is too far from land to permit correlation of the magnetic data with geology. On the southeast coast of Cape Breton Island the rocks are granitic, sedimentary, and volcanic. The southern part of the island has been surveyed with the airborne magnetometer and the main trend of the contours is south-westerly, with little magnetic relief over most of the area. The volcanic rocks are relatively non-magnetic, and where they do coincide with anomalies the source rocks appear to be at least 1,000 feet deep. Over the metamorphic rocks, anomalies commonly coincide with fold axes.

The Lamont Observatory did seismic work in this area in 1951 (Press and Beckmann, 1954). One of the profiles was run from 44°52'N, 57°50'W, to 45°00'N, 57°32'W. Depths to basement were calculated to be 8,250 feet at the west end and 8,780 feet at the east end, but even at these depths the velocity is rather low for a basement type of rock. In 1950 another series of profiles was run from Halifax southeast across the continental shelf and slope (Officer and Ewing, 1954). The basement depths were found to increase from 200 feet near the coast to more than 20,000 feet at a point 160 miles off shore. Even greater depths were obtained from other profiles that extend south from the Grand Banks, just beyond the eastern boundary of Area 2 (Bentley and Worzel, 1956).

The magnetic data does nothing to contradict the depths found in the seismic surveys. Over part of the area the magnetic variation is so small that only the regional gradient is apparent. The depth to the ocean floor seems to have no effect on the magnetic pattern, for some of the straightest contours occur where the depth is only 20 fathoms. This is strong evidence for a great thickness of non-magnetic (probably sedimentary) material. There is no evidence of intrusive rocks above the basement. Some magnetic activity is shown in the northwest corner on Figure 5. A depth calculation made on one anomaly gave a value of 5,500 feet below sea-level. This anomaly could be caused by a lithological contrast within the basement.

Along the southeastern boundary of Area 2 the regular decreasing intensity of the magnetic field is interrupted, the pattern being more of a 'shoulder' than a normal anomaly. In effect a few contours there show an easterly loop. If the regional gradient were disregarded this shoulder would appear as a broad low-intensity anomaly. It occurs at the edge of the continental shelf where the ocean bottom drops rapidly from 100 to more than 1,000 fathoms. Magnetic anomalies at the edge of the shelf have been recorded on aeromagnetic flights made by the United States Geological Survey (Keller, Meuschke and Alldredge, 1954). Their cause is not known, but one theory is that a large intrusion parallels the edge of the continent. Such a body, if buried beneath thousands of feet of non-magnetic material, could produce the magnetic effect observed in Figure 5.

Much of Area 2 is so far from land that some of the Decca positions are probably inaccurate. It is also possible that the diurnal variation differs from that at the Glace Bay ground station. This is particularly true of that part of the area east of 57°W. There the contours take some rather peculiar bends, and it is debatable whether these are the expression of deeply buried rock structure or are merely errors in the data. All that is certain is that there is a great thickness of sedimentary or other non-magnetic material.

The magnetic data give little information about the composition of the basement rock, as only the more intense anomalies could be detected through the thick layer of non-magnetic material. It is likely, however, that the basement rock under Area 2 is a continuation of the older rocks on the adjacent land. These generally have low magnetic relief, and at depth could produce a magnetic pattern of the type observed in Figure 5.

Area 3 (Figure 6)

This is a survey of the Scatari Bank, which is about 9 miles east of Scatari Island, Cape Breton. The traverse spacing is 1/8 to 1/4 mile, with three additional lines extending beyond the main area. The contour interval is 100 gammas, and no correction has been made for diurnal variation.

The depth of water over the Scatari Bank ranges from 13 to 70 fathoms, the shallowest part being in the northeast corner. (The revised hydrographic chart for this area has not yet been published.)

In part of Figure 6 no contours have been drawn, as a very complex magnetic pattern was recorded. In part it seemed to be a rapid succession of small anomalies, but much of the data was an almost random series of values. This was true mainly in the northeastern and southeastern parts of the area, and to a lesser extent around the main anomaly peak, and did not always coincide with the shallower water. Broken-line contours have been used where there is some doubt as to their accuracy, both in the anomalous areas and between the widely spaced traverses beyond the main survey area.

The rocks on the adjacent land are mainly volcanic, and on the extreme eastern point of land they are intruded by small bodies of gabbro (Weeks and Cameron, 1960). As mentioned previously, the magnetic relief there is low except in localized patches.

Although the anomaly is not completely defined by the available data, it appears to be approximately circular. At the northwest corner, the magnetic intensity rises in a smooth, steady manner, with very few small anomalies superimposed on the main one. In contrast, on the south and east sides, there are so many small anomalies that accurate contouring is impossible. The highest intensity recorded was more than 56,500 gammas, and the undisturbed magnetic level in this area is about 54,900 gammas.

A considerable amount of magnetic rock must be present to produce an anomaly of this size and intensity, and the many small sharp anomalies indicate that some of the rock is very close to the surface. Steep magnetic gradients, such as those occurring on the northwest side of the main anomaly, are generally caused by bodies having steeply dipping sides. If the rocks there are similar to those on the adjacent land, the anomaly may be caused by a circular-shaped gabbro intrusion, or perhaps a small sea mount such as those found in other parts of the Atlantic Ocean. As the rock is so close to the surface, the magnetic susceptibility contrast need not be extremely high to produce an anomaly of this magnitude. Several different rock types could have such a susceptibility contrast, and, as no samples were obtained, the intrusive or extrusive character of the body cannot be determined.

CONCLUSIONS

The chief problems encountered in these sea magnetometer surveys were:

1. Magnetic storms and diurnal variation.

2. Uncertainty of the ship's location.

3. Inadequate coverage in regions of shallow water.

4. Ambiguous data where the magnetometer was too close to magnetic rocks.

The data taken in shallow water could probably be improved by speeding up the cycling rate of the magnetometer. Most of the other problems are inherent in this type of survey and little can be done to solve them, and it must be remembered that the primary purpose of these surveys was to obtain hydrographic information.

The contoured maps must be used with some forethought as they are less accurate than aeromagnetic maps. This is particularly true in areas of little magnetic relief. The sea magnetometer data may, however, be correlated with other geophysical and geological information to give a generalized picture of the geology beneath the ocean.

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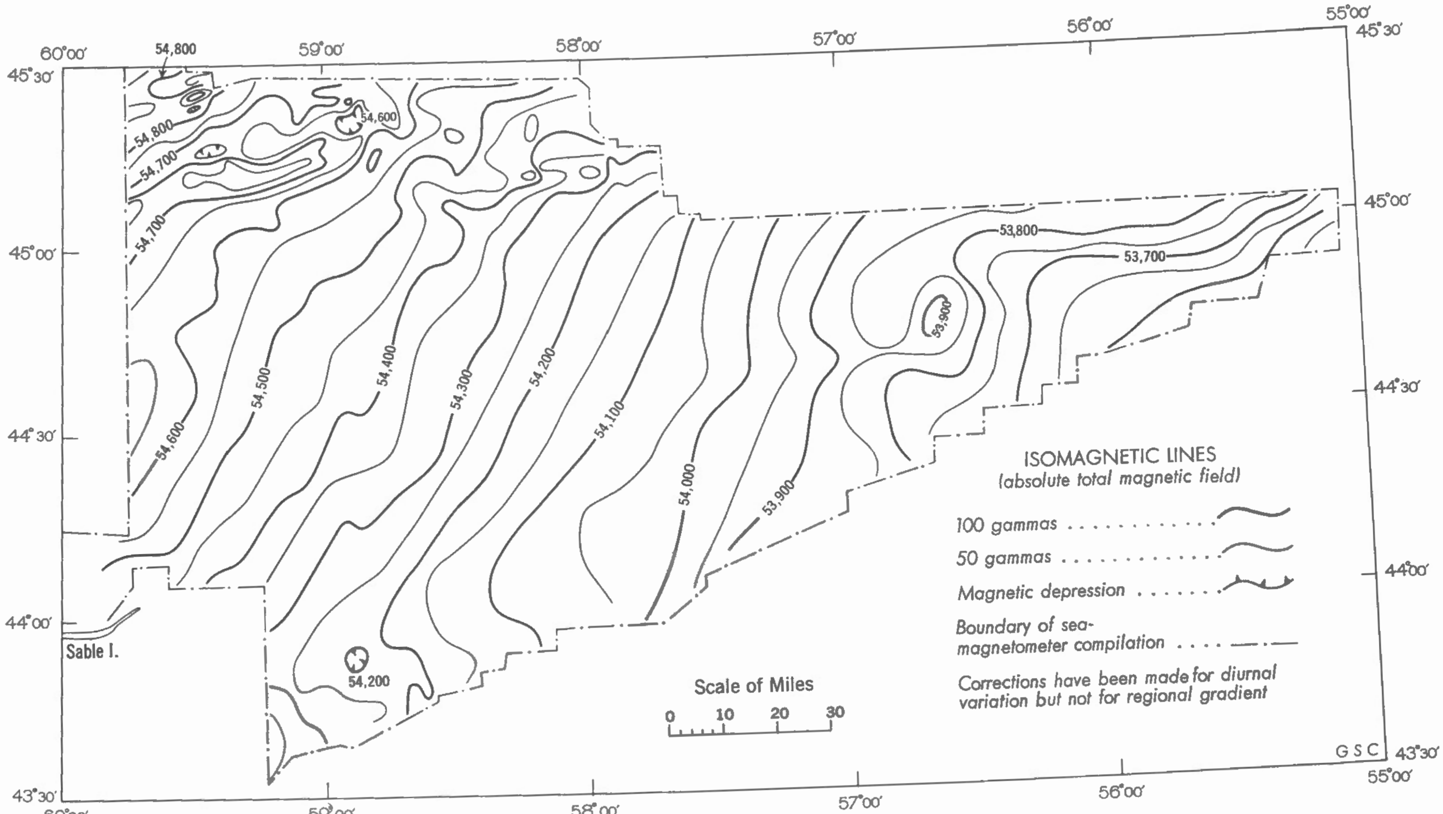

Figure 5. Sea magnetometer survey from Sable Island to St. Pierre Bank (Area 2)

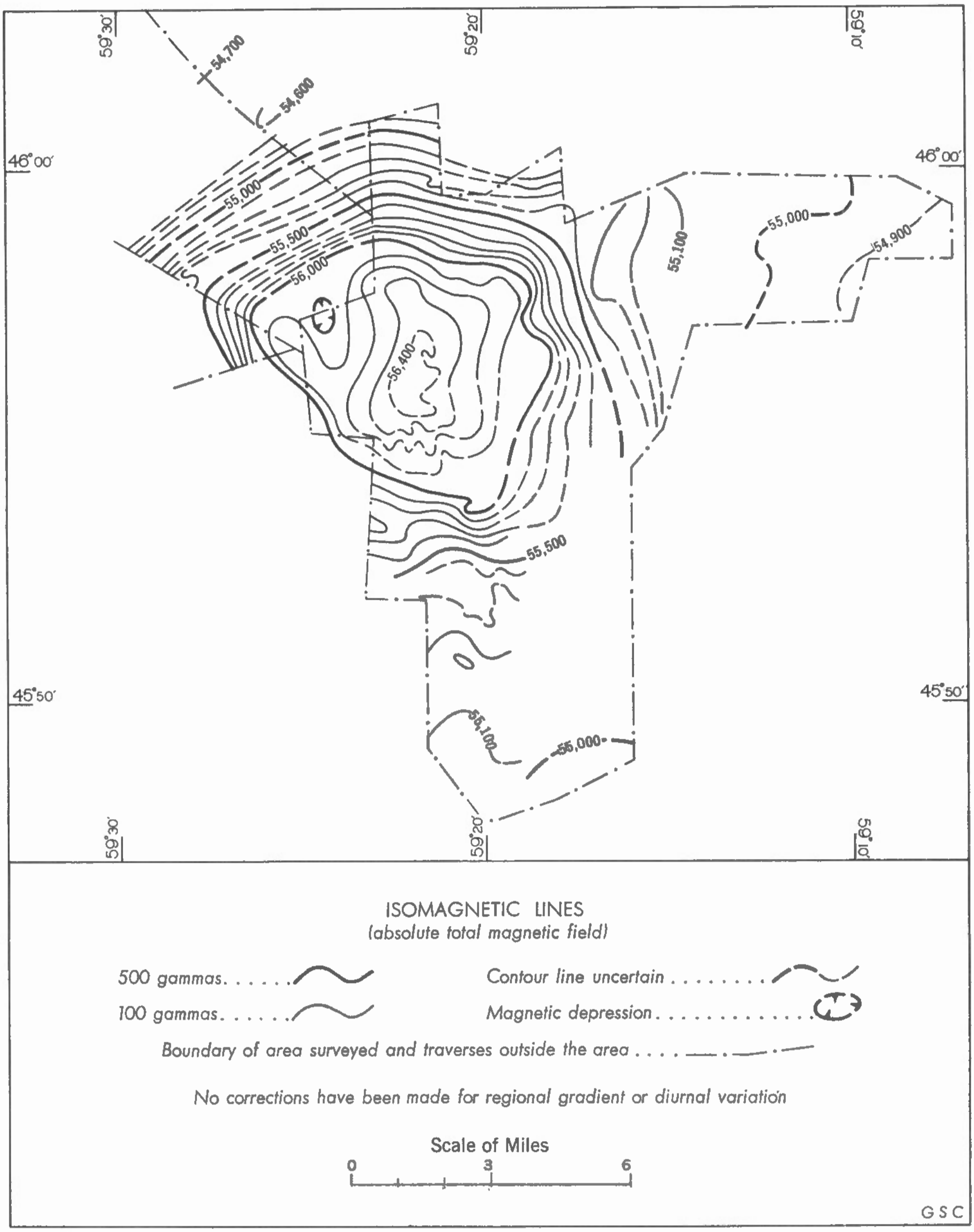

Figure 6. Sea magnetometer survey of Scatari Bank (Area 3)