DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEOPHYSICAL INVESTIGATIONS
MAP GP-956

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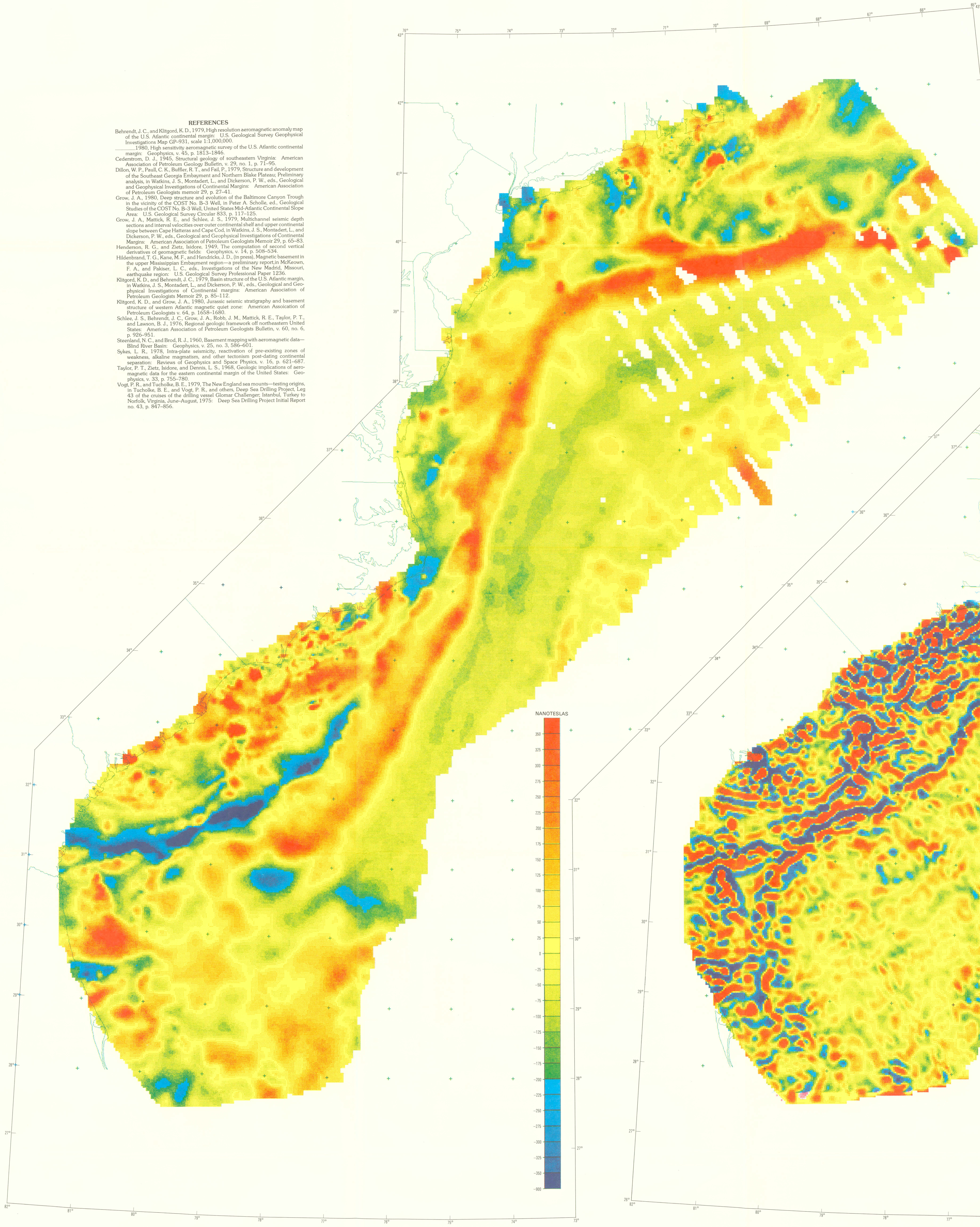
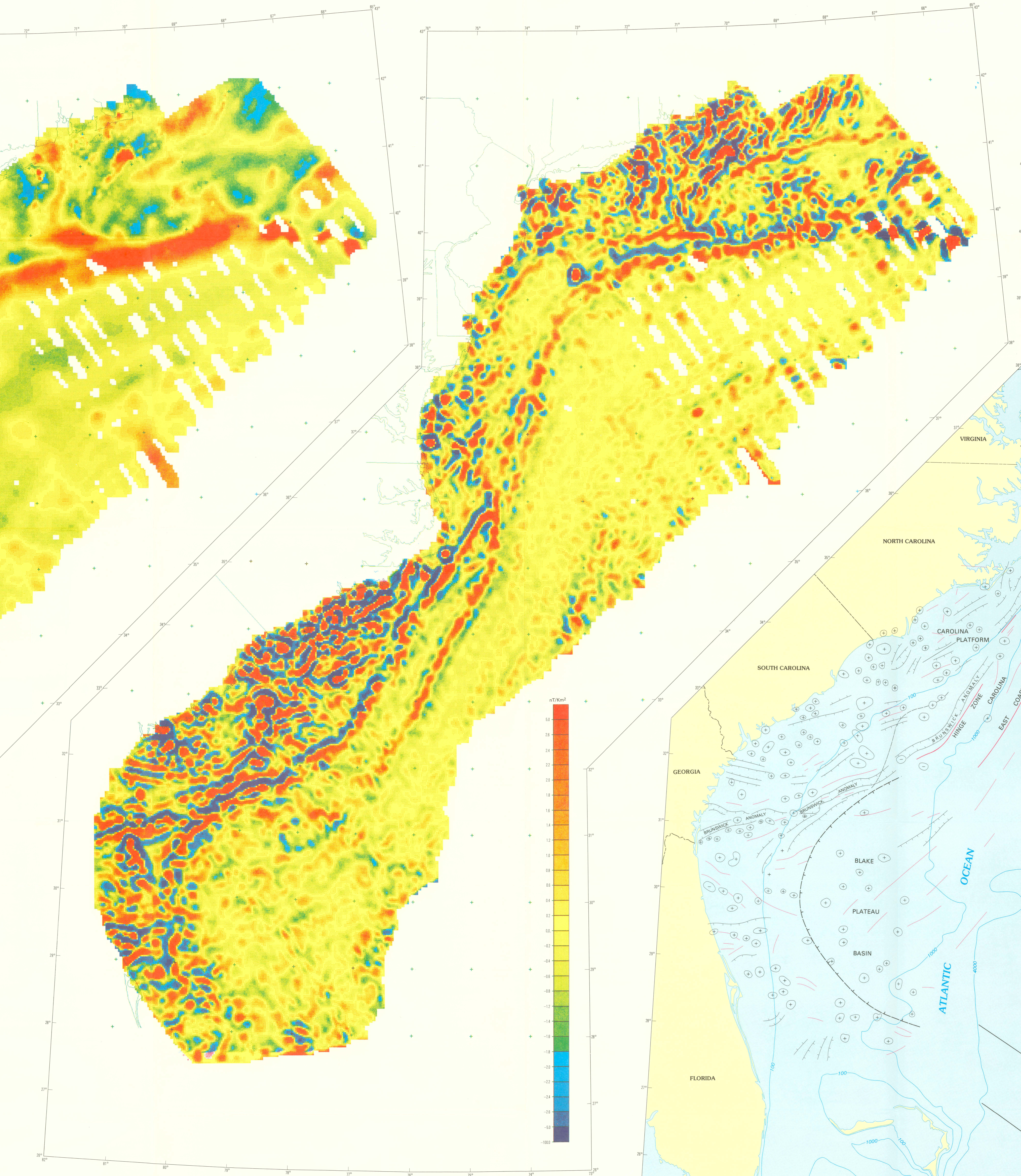
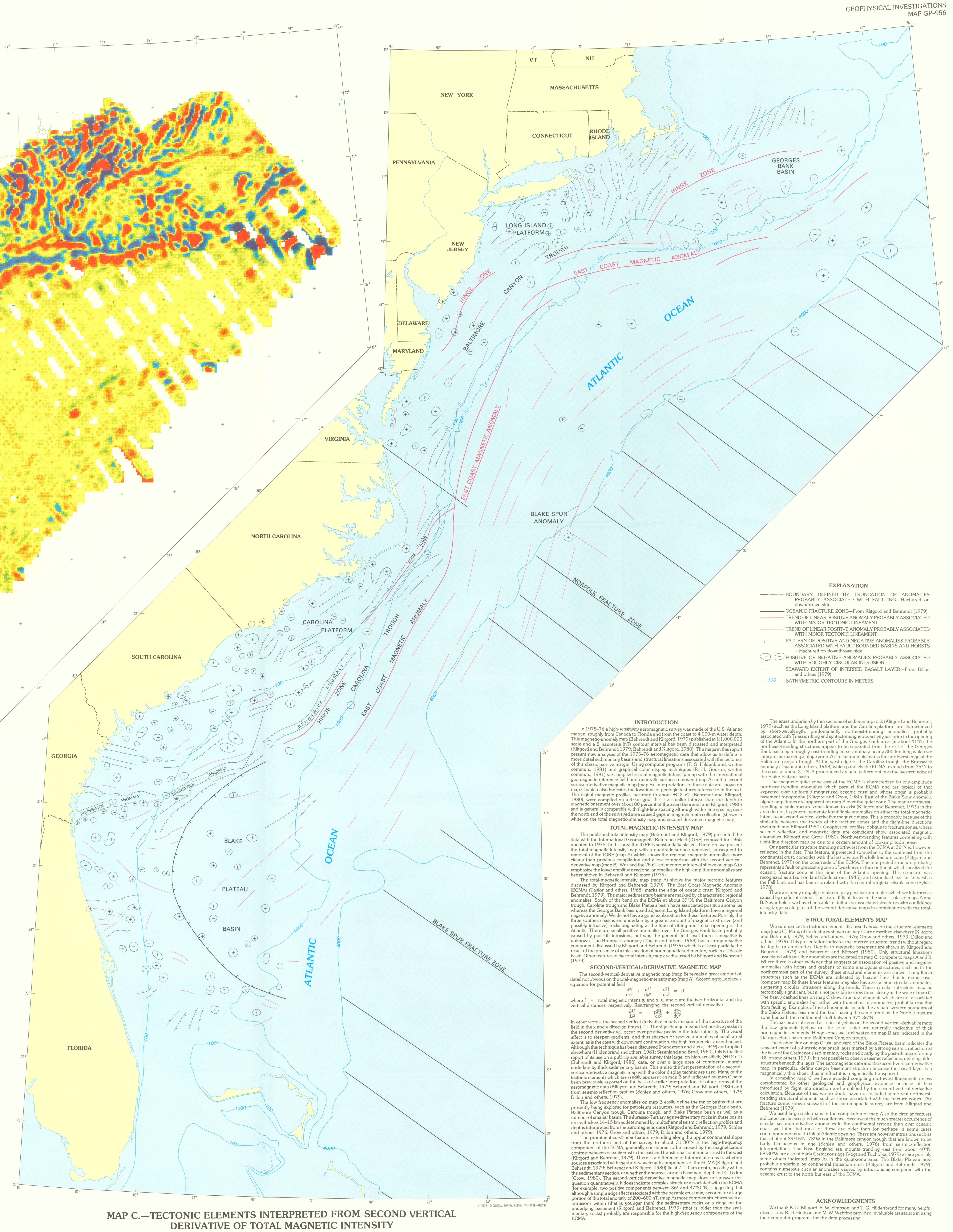


MAP A.—TOTAL-MAGNETIC-INTENSITY MAP WITH INTERNATIONAL GEOMAGNETIC REFERENCE FIELD AND QUADRATIC SURFACE REMOVED
CONTOUR INTERVAL 25 nT



MAP B.—SECOND-VERTICAL-DERIVATIVE MAGNETIC MAP
CONTOUR INTERVAL 0.2 nT/Km²



MAP C.—TECTONIC ELEMENTS INTERPRETED FROM SECOND VERTICAL DERIVATIVE OF TOTAL MAGNETIC INTENSITY

SCALE 1:2 500 000
50 0 50 100 150 200 250 MILES
50 0 50 100 150 200 250 KILOMETERS
UNIVERSAL TRANSVERSE MERCATOR PROJECTION
BASE LATITUDE 0°, CENTRAL MERIDIAN 74°

INTRODUCTION

In 1975–76 a high-sensitivity aeromagnetic survey was made of the U.S. Atlantic margin, roughly from Canada to Florida and from the coast to 4,000-m water depth. This magnetic-anomaly map (Behrendt and Klitgord, 1979) published at 1:1,000,000 scale and a 2 nanotesla (nT) contour interval has been discussed and interpreted (Klitgord and Behrendt, 1979; Behrendt and Klitgord, 1980). The maps in this report present new analyses of the 1975–76 aeromagnetic data that allow us to define in more detail sedimentary basins and structural lineations associated with the tectonics of this classic passive margin. Using computer programs (T. G. Hildenbrand, written commun., 1981) and graphical color display techniques (R. H. Godson, written commun., 1981) we compiled a total magnetic-intensity map with the international geomagnetic reference field and quadratic surface removed (map A) and a second vertical-derivative magnetic map (map B). Interpretations of these data are shown on map C which also indicates the locations of geologic features referred to in the text. The digital magnetic profiles, accurate to about ±0.2 nT (Behrendt and Klitgord, 1980), were compiled on a 4-km grid; this is a smaller interval than the depth to magnetic basement over about 80 percent of the area (Behrendt and Klitgord, 1980) and is generally compatible with flight-line spacing although wider line spacing over the north end of the surveyed area caused gaps in magnetic-data collection (shown in white on the total magnetic-intensity map and second derivative magnetic map).

TOTAL-MAGNETIC-INTENSITY MAP

The published total intensity map (Behrendt and Klitgord, 1979) presented the data with the International Geomagnetic Reference Field (IGRF) removed for 1965 updated to 1975. In this area the IGRF is substantially biased. Therefore we present the total-magnetic-intensity map with a quadratic surface removed, subsequent to removal of the IGRF (map A) which shows the regional magnetic anomalies more clearly than previous compilation and allow comparison with the second-vertical-derivative map (map B). We used the 25 nT color contour interval shown on map A to emphasize the lower amplitude regional anomalies; the high-amplitude anomalies are better shown in Behrendt and Klitgord (1979).

The total-magnetic-intensity map (map A) shows the major tectonic features discussed by Klitgord and Behrendt (1979). The East Coast Magnetic Anomaly (ECMA) (Taylor and others, 1968) marks the edge of oceanic crust (Klitgord and Behrendt, 1979). The major sedimentary basins are marked by characteristic regional anomalies. South of the bend in the ECMA at about 39°N, the Baltimore Canyon trough, Carolina trough and Blake Plateau basin have associated positive anomalies whereas the Georges Bank basin, and adjacent Long Island platform have a regional negative anomaly. We do not have a good explanation for these features. Possibly the three southern basins are underlain by a greater amount of magnetic extrusive (and possibly intrusive) rocks originating at the time of rifting and initial opening of the Atlantic. There are small positive anomalies over the Georges Bank basin probably caused by post-rift intrusions, but why the general field level there is negative is unknown. The Brunswick anomaly (Taylor and others, 1968) has a strong negative component discussed by Klitgord and Behrendt (1979) which is at least partially the result of the presence of a thick section of nonmagnetic sedimentary rock in a Triassic basin. Other features of the total intensity map are discussed by Klitgord and Behrendt (1979).

SECOND-VERTICAL-DERIVATIVE MAGNETIC MAP

The second-vertical-derivative magnetic map (map B) reveals a great amount of detail not obvious on the total-magnetic-intensity map (map A). According to Laplace's equation for potential field

$$\frac{d^2f}{dx^2} + \frac{d^2f}{dy^2} + \frac{d^2f}{dz^2} = 0,$$

where f = total magnetic intensity and x, y, and z are the two horizontal and the vertical distances, respectively. Rearranging, the second vertical derivative

$$\frac{d^2f}{dz^2} = - \left(\frac{d^2f}{dx^2} + \frac{d^2f}{dy^2}\right).$$

In other words, the second vertical derivative equals the sum of the curvature of the field in the x and y direction times (−1). The sign change means that positive peaks in the second derivative will occur over positive peaks in the total intensity. The visual effect is to steepen gradients, and thus sharpen or resolve anomalies of small areal extent; as is the case with downward continuation, the high frequencies are enhanced. Although this technique has been discussed (Henderson and Zietz, 1949) and applied elsewhere (Hildenbrand and others, 1981; Steenland and Brod, 1960), this is the first report of its use on a publicly available survey this large, on high-sensitivity (±0.2 nT) (Behrendt and Klitgord, 1980) data, or over a large area of continental margin underlain by thick sedimentary basins. This is also the first presentation of a second-vertical-derivative magnetic map with the color display techniques used. Many of the tectonic elements which are readily apparent on map B and indicated on map C have been previously reported on the basis of earlier interpretations of other forms of the aeromagnetic data (Klitgord and Behrendt, 1979; Behrendt and Klitgord, 1980) and from seismic-reflection profiles (Schlee and others, 1976; Grow and others, 1979; Dillon and others, 1979).

The low frequency anomalies on map B easily define the major basins that are presently being explored for petroleum resources, such as the Georges Bank basin, Baltimore Canyon trough, Carolina trough, and Blake Plateau basin as well as a number of smaller basins. The Jurassic-Tertiary age sedimentary rocks in these basins are as thick as 14–15 km as determined by multichannel seismic reflection profiles and depths interpreted from the aeromagnetic data (Klitgord and Behrendt, 1979; Schlee and others, 1976; Grow and others, 1979; Dillon and others, 1979).

The prominent curvilinear feature extending along the upper continental slope from the northern end of the survey to about 31°30′N is the high-frequency component of the ECMA, generally considered to be caused by the magnetization contrast between oceanic crust to the east and transitional continental crust to the west (Klitgord and Behrendt, 1979). There is a difference of interpretation as to whether sources associated with the short-wavelength components of the ECMA (Klitgord and Behrendt, 1979; Behrendt and Klitgord, 1980) lie at 7–10 km depth, possibly within the sedimentary section, or whether the sources are at a basement depth of 14–15 km (Grow, 1980). The second-vertical-derivative magnetic map does not answer this question quantitatively. It does indicate complex structure associated with the ECMA (for example, two positive components between 36° and 37°30′N), suggesting that although a simple edge effect associated with the oceanic crust may account for a large portion of the total anomaly of 200–600 nT, (map A) more complex structures such as intrusions within (that is, younger than) the sedimentary rocks or a ridge on the underlying basement (Klitgord and Behrendt, 1979) (that is, older than the sedimentary rocks) probably are responsible for the high-frequency components of the ECMA.

The areas underlain by thin sections of sedimentary rock (Klitgord and Behrendt, 1979) such as the Long Island platform and the Carolina platform, are characterized by short-wavelength, predominantly northeast-trending anomalies, probably associated with Triassic rifting and syntectonic igneous activity just prior to the opening of the Atlantic. In the northern part of the Georges Bank area (at about 41°N) the northeast-trending structures appear to be separated from the rest of the Georges Bank basin by a roughly east-trending linear anomaly nearly 300 km long which we interpret as marking a hinge zone. A similar anomaly marks the northwest edge of the Baltimore canyon trough. At the west edge of the Carolina trough, the Brunswick anomaly (Taylor and others, 1968) which parallels the ECMA, extends from 35°N to the coast at about 31°N. A pronounced arcuate pattern outlines the western edge of the Blake Plateau basin.

The magnetic quiet zone east of the ECMA is characterized by low-amplitude northeast-trending anomalies which parallel the ECMA and are typical of that expected over uniformly magnetized oceanic crust and whose origin is probably basement topography (Klitgord and Grow, 1980). East of the Blake Spur anomaly, higher amplitudes are apparent on map B over the quiet zone. The many northwest-trending oceanic fracture zones known to exist (Klitgord and Behrendt, 1979) in the area do not, in general, generate identifiable anomalies on either the total-magnetic-intensity or second-vertical-derivative magnetic maps. This is probably because of the similarity between the trends of the fracture zones and the flight-line directions (Behrendt and Klitgord 1980). Geophysical profiles, oblique to fracture zones, where seismic reflection and magnetic data are coincident show associated magnetic anomalies (Klitgord and Grow, 1980). Northwest-trending features correlating with flight-line direction may be due to a certain amount of low-amplitude noise.

One particular structure trending northwest from the ECMA at 36°N is, however, reflected in the data. This feature, if projected somewhat to the southeast from the continental crust, coincides with the less obvious Norfolk fracture zone (Klitgord and Behrendt, 1979) on the ocean side of the ECMA. The interpreted structure probably represents a fault or preexisting zone of weakness in the continent, which localized the oceanic fracture zone at the time of the Atlantic opening. This structure was recognized as a fault on land (Cederstrom, 1945), and extends at least as far west as the Fall Line, and has been correlated with the central Virginia seismic zone (Sykes, 1978).

There are many roughly circular (mostly positive) anomalies which we interpret as caused by mafic intrusions. These are difficult to see in the small scales of maps A and B. Nevertheless we have been able to define the associated structures with confidence using larger scale plots of the second-derivative maps in combination with the total-intensity data.

STRUCTURAL-ELEMENTS MAP

We summarize the tectonic elements discussed above on the structural-elements map (map C). Many of the features shown on map C are described elsewhere (Klitgord and Behrendt, 1979, Schlee and others, 1976; Grow and others, 1979; Dillon and others, 1979). This presentation indicates the inferred structural trends without regard to depths or amplitudes. Depths to magnetic basement are shown in Klitgord and Behrendt (1979) and Behrendt and Klitgord (1980). Only structural lineations associated with positive anomalies are indicated on map C; compare to maps A and B. Where there is other evidence that suggests an association of positive and negative anomalies with horsts and grabens or some analogous structures, such as in the northernmost part of the survey, these structural elements are shown. Long linear structures such as the ECMA are indicated by heavier lines, but in many cases (compare map B) these linear features may also have associated circular anomalies, suggesting circular intrusions along the trends. These circular intrusions may be tectonically significant, but it is not possible to show them clearly at the scale of map C. The heavy dashed lines on map C show structural elements which are not associated with specific anomalies but rather with truncation of anomalies, probably resulting from faulting. Examples of these lineaments include the arcuate western boundary of the Blake Plateau basin and the fault having the same trend as the Norfolk fracture zone beneath the continental shelf between 37°–36°N.

The basins are observed as tones of yellow on the second-vertical-derivative map; the low gradients (yellow on the color scale) are generally indicative of thick nonmagnetic sediments. Hinge zones well delineated on map B are indicated in the Georges Bank basin and Baltimore Canyon trough.

The dashed line on map C just landward of the Blake Plateau basin indicates the seaward extent of a Jurassic-age basalt layer marked by a strong seismic reflection at the base of the Cretaceous sedimentary rocks and overlying the post-rift unconformity (Dillon and others, 1979). It is not possible to observe seismic reflections defining older structure beneath this layer. The aeromagnetic data and the second-vertical-derivative map, in particular, define deeper basement structure because the basalt layer is a magnetically thin sheet, thus in effect it is magnetically transparent.

In compiling map C we have avoided compiling northwest lineaments unless corroborated by other geological and geophysical evidence because of bias introduced by flight line direction and amplified by the second-vertical-derivative calculation. Because of this, we no doubt have not included some real northwest-trending structural elements such as those associated with the fracture zones. The fracture zones shown seaward of the aeromagnetic survey are from Klitgord and Behrendt (1979).

We used large scale maps in the compilation of map A so the circular features indicated can be accepted with confidence. Because of the much greater occurrence of circular second-derivative anomalies in the continental terrane than over oceanic crust, we infer that most of these are older than (or perhaps in some cases contemporaneous with) initial Atlantic opening. There are however intrusions such as that at about 39°15′N, 73°W in the Baltimore canyon trough that are known to be Early Cretaceous in age (Schlee and others, 1976) from seismic-reflection interpretations. The New England sea mounts trending east from about 40°N, 68°30′W are also of Early Cretaceous age (Vogt and Tucholke, 1979) as are possibly some others indicated (map A) in the quiet-zone area. The Blake Plateau area probably underlain by continental transition crust (Klitgord and Behrendt, 1979), contains numerous circular anomalies caused by intrusions as compared with the oceanic crust to the north but east of the ECMA.

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STRUCTURAL ELEMENTS OF THE U.S. ATLANTIC MARGIN DELINEATED BY SECOND VERTICAL DERIVATIVE OF AEROMAGNETIC DATA

By
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