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ABSTRACT

A magnetic anomaly map produced from Pogo data for North America and adjacent ocean areas is presented. At satellite elevations anomalies have wavelengths measured in hundreds of kilometers, and reflect regional structures on a large scale. Prominent features of the map are 1) a large east-west high through the mid-continent, breached at the Mississippi Embayment, 2) a broad low over the Gulf of Mexico, 3) a strong gradient separating these features, which follows the Southern Appalachian-Ouachita curvature, and 4) a high over the Antilles-Bahamas Platform which extends to northern Florida. A possible relationship between the high of the mid-continent and the 38^{th} parallel lineament is noted.

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INTRODUCTION

NASA Goddard Space Flight Center and the U.S. Geological Survey are jointly engaged in analysis of OGO 2, 4, and 6 (Pogo) satellite magnetometer data. An element of this program is the identification of magnetic anomalies arising from crustal sources, and the development of procedures for modeling them. Regan et al. (1975) presented a global magnetic anomaly map based on 1° averages of the Pogo data between 50° north and south latitudes; an account of data selection and reduction procedures can be found in that paper. A refined version of a portion of that map, North America and adjacent ocean areas south of 50° north, is presented here (Figure 2). The data provides a new constraint on regional tectonic models involving large-scale structures and variations in gross crustal magnetic properties.

PROCEDURES

While the major anomalies are well defined in the 1° average map of Regan et al. (1975), the anomaly contours tend to be aligned north-south, reflecting the direction of the polar orbits of the Pogo satellites. This effect is shown in Figure 1 for the area of the present study.

The north-south striping is partly due to averaging over the 400-700 km elevation range of the data as well as over 1° squares. However, in many cases individual profiles over nearly the same area, and at the same elevation agree poorly; in such cases an obvious difference in level and overall trend is present. In effect, each profile has its own "regional," which is evidently an external field effect. This is the second, and in many cases the more important, source of north-south elongation of contours in the 1^{o} world map. We describe below a possible reason for this effect and a means of bringing the data into internal agreement. An important external field effect is the DS variation arising from ring current flow in the magnetosphere during storm time (Langel and Sweeney, 1971). The effect is most pronounced in more intense storm times, but is present during most of the satellite passes to some extent. The effect was modeled by Cain and Davis (1973) and Davis and Cain (1973), who developed a procedure for correcting each satellite profile for the effect by fitting data over a satellite half-orbit to the first term of a zonal harmonic series. This correction allowed the use of data obtained during relatively disturbed external field conditions (up to $Kp = 2^{+}$), and was systematically applied to data over each satellite half-orbit used in the 1^{o} world map of Regan et al. (1975). Coefficient values for the correction determined by least squares for a particular profile will be influenced somewhat by external field variations not modeled by the correction and by magnetic anomalies; this would have the effect of leaving a small residual in each profile. The correction appears on a given profile as a very broad bell-shape curve having a prominent minimum at the magnetic equator, but over the latitude range of Figure 2 it is very nearly linear. The residual effect in each profile should, then, itself be linear, and in fact adjacent profiles can be brought into good agreement simply by subtracting a least-squares best-fit linear function independently from each. Examples of this additional correction are shown in Figure 3 for three groups of three closely adjacent profiles. The satellite tracks for these profiles are shown in Figure 4. The top line of Figure 2 shows the uncorrected data, the middle line is data with the correction applied, and the bottom line is data with a best-fit linear function subtracted from the corrected data. Experiments with removing a variety of other functions indicate that the straight-line approximation to the external field residual is nearly optimal.

The linear correction improves the internal agreement of the data considerably; even for adjacent profiles over quite different elevation ranges, agreement often improves dramatically. It should be noted, however, that an overall level difference or broad north-south variations would go undetected, and it is possible that such effects are present in Figure 2. Also, the linear correction is not applicable over a wider latitude range.

In making the map of Figure 2 only those profiles containing data across at least 30^{o} of latitude were used in order to insure that a valid best-fitting linear function could be determined. Roughly half the available data was thus not used. Further, only that data below 550 km was used; this cut the data set in half again. Figure 5 indicates those satellite tracks containing data used in Figure 2. A data point was taken approximately every 1-1/2 degrees of latitude along each track, which is every third point. The resulting data subset contains over 4000 values.

In order to effectively bring the data to a constant elevation, the anomaly field was fit by an equivalent source field, the equivalent source being a dipole array at the earth's surface spaced at 4° intervals of latitude and longitude and oriented in the direction of the main field. The main field was modeled simply as an inclined dipole core field. A set of magnetic moments were determined for this array such as to give a least squares best fit to the observed field. The field was then computed at 450 km using these coefficients. The result of this computation is Figure 2. The overall standard deviation between observed and computed fields is about 1-1/2 gammas, most of which is attributable to the high-frequency noise in the data evident in Figure 4. The distribution of the dipole sources is such as to border the map area, the geographic limit of the data. The magnetic moments determined for the dipole array vary irregularly, and by two orders of magnitude, the greatest variation generally occurring near the map border. The moment values themselves have no particular physical significance, and are simply chose so as to produce a magnetic field which closely approximates the observed field.

The 4° dipole grid spacing appears to be nearly optimal in that the more localized anomalies cannot be fit well by a much coarser array, while computational instability results with a finer array where data is thin in the vicinity of individual sources. While the dipole sources were specified to lie along an inducing field vector, an equally good fit can be obtained by fixing their orientation in some arbitrary direction.

DESCRIPTION OF ANOMALIES

Whereas the near-surface anomaly field is dominated by a large number of localized anomalies, the field at 450 km consists of a relatively few very broad, very low amplitude anomalies, some of which have an apparent association with certain large-scale tectonic elements (Figure 6).

Perhaps the most striking anomaly is a large east-west high in the U.S. mid-continent, the axis of which parallels the "38th parallel lineament" as drawn by Heyl (1972). We suggest the possibility that the low-amplitude high over the mid-Atlantic shelf is a continuation of this high; the picture is then of a continuous east-west high crossing the continent, overprinted or otherwise reduced in amplitude in three places: on the west at the Rockies, on the east at the Appalachians, and in the middle at the northern Mississippi Embayment, a tectonically active zone, and the site of a hypothesized Precambrian rift reactivated in the Mesozoic (Ervin and McGinnis, 1975). Kutina and Carter (1976) have hypothesized two discontinuous transcontinental lineament zones around 40^{o} north and 34^{o} north, and note that these zones follow in a general way the gradients north and south of the magnetic high, as seen in the map of Regan et al. (1975).

To the south of this anomaly is a deep low over the Gulf of Mexico. Although the low has an apparent association with the Gulf basin, its western flank extends with diminished amplitude to the western margin of Mexico; by contrast, its eastern flank ends sharply at the Florida Platform.

A high at the Central American margin is largely confined to the Cocos Plate; it passes across the arc to a low in the Caribbean, which is separated from the Gulf low by a relative high over the Yucatan Peninsula.

A high following the Antilles arc and Bahamas Platform continues north over eastern Florida and dies out at a relatively localized low in the transition zone between the Florida Platform and the Appalachians.

A low in the western Atlantic follows the belt of Keathley anomalies (Vogt et al. 1971), but broadens over the Blake-Bahama Basin. Note that by contrast the Pacific is magnetically dead.

The Northern Rockies-High Plains boundary appears to be marked by a weak relative high. This is probably real; a transition near this boundary has been noted in long low-pass filtered aeromagnetic profiles by Caner (1969).

A few tracks indicate that a local high is present in the vicinity of the Michigan Basin. Unfortunately, the data are sparse in this area, and the anomaly is not well defined by the data used in Figure 2; the dashed contour line simply suggests its apparent position and amplitude.

DISCUSSION

The magnetic anomaly field measured at satellite elevation gives a new perspective on the earth which we have not yet learned to interpret. Some particular problems are discussed below.

First, we would like to know that the core field has been entirely removed from the data, and that the anomaly field arises from lithosphere sources only. It is, perhaps, not possible to be entirely sure of this; certainly, the spatial frequency spectra of the fields, while largely distinct, do overlap to some extent (Alldredge et al.,1963). One might suspect, for example, that the apparent western extension of the high in the mid-continent and the Gulf low across major tectonic features simply reflects residual core field still in the data. There are, however, certain convincing, if not entirely compelling, arguments against this. 1) A field model represented by spherical harmonic terms up to maximum order and degree 13, designed to model wavelengths longer than about 3000 km (Regan et al., 1975) has been removed from the total field data; removal of successively higher order field models from the data, up to order and degree 22, leave the apparent anomaly field little changed. 2) Unrealistically high fields in the core would be required to produce the relatively high-frequency core field components with the observed amplitudes (Regan et al., 1975). 3) The anomalies cited above close east of the western continental margin, which a core component would ignore. 4) Most of the anomalies of Figure 2 appear to correspond in some way with large-scale tectonic features.

Second, one must be cautious about associating anomalies with structural features, since the polarization effect of magnetic anomaly fields causes anomaly extrema to be displaced considerably with respect to the sources giving rise to them.

Third, even relatively localized sources produce very broad anomalies at satellite elevations; the anomaly field at any point is thus the sum of contributions from many sources distributed over a very wide area, and as a result we can expect an extreme superposition problem.

Fourth, we do not yet understand the nature of the sources giving rise to the anomaly field, and are just beginning to learn how to model them. At least three views may be taken. One is that the anomalies arise from structures or magnetization variations in a continuous crustal layer, possibly a lower crustal layer as advocated by Hall (1974). Another is that the anomalies are due to discrete bodies or zones within the crust. Some of the more localized anomalies may be of this kind. It should be noted, however, that some features, such as the mid-continent rift system (King and Zietz, 1971; m in Figure 6), which have intense geophysical expression on the ground, are not seen at satellite elevations. A third view is that the anomalies result from Curie isotherm variations where it is within the crust; the damping of the high in the mid-continent west of the Rockies may be such an effect. Shuey et al. (2973), modeled Curie isotherm variations across the western Rocky Mountain transition in this way, using in part data from the Soviet satellite Cosmos-49 presented by Zietz et al. (1970). In fact, all these effects may be present to some extent in some regions.

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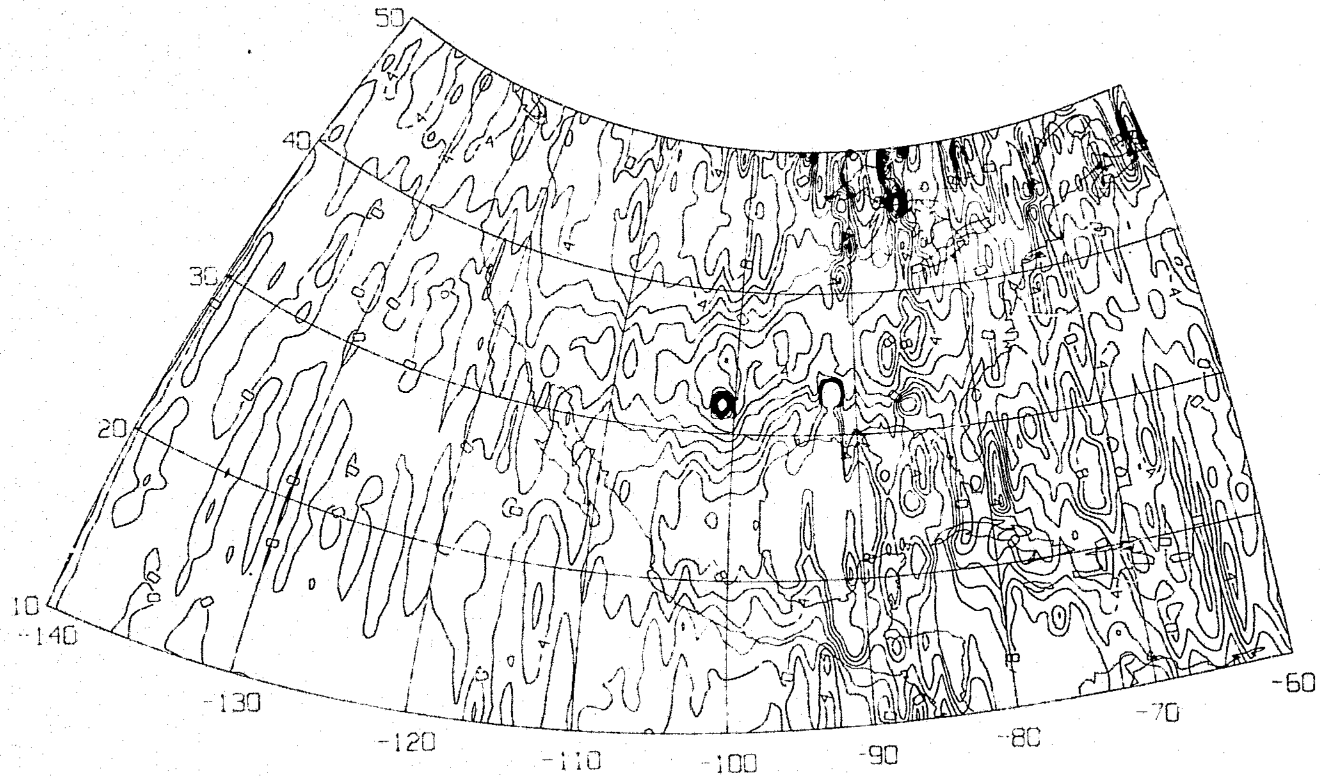

gure 1. Apparent magnetic anomalies which result from averaging all Pogo data over 1° squares. Contour interval is 2 gammas.

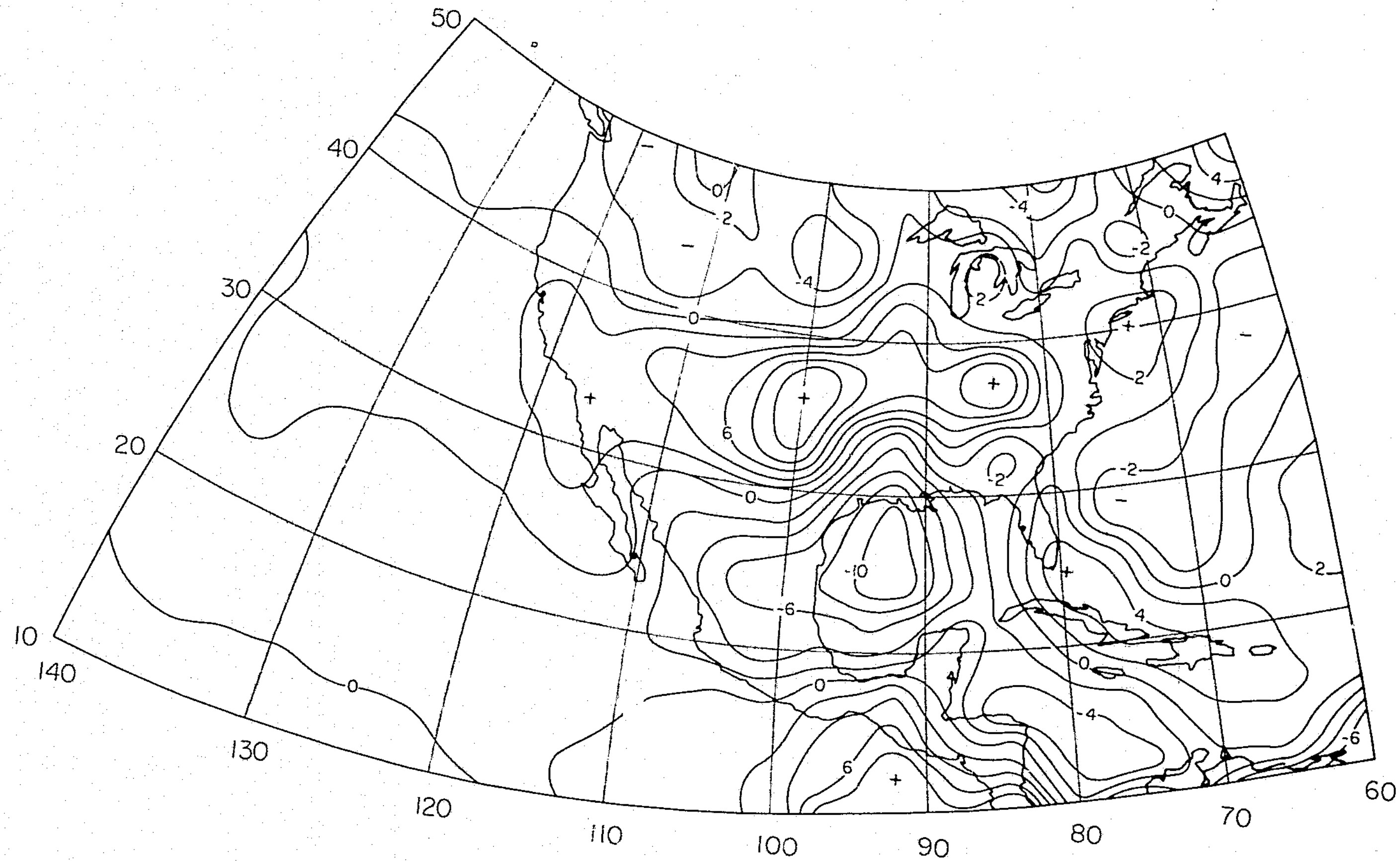

Figure 2. Anomaly in the total magnetic field at 450 km elevation. Contour interval is 2 gammas. Base map is tectonic map of North America of King and Edmonston (1972).

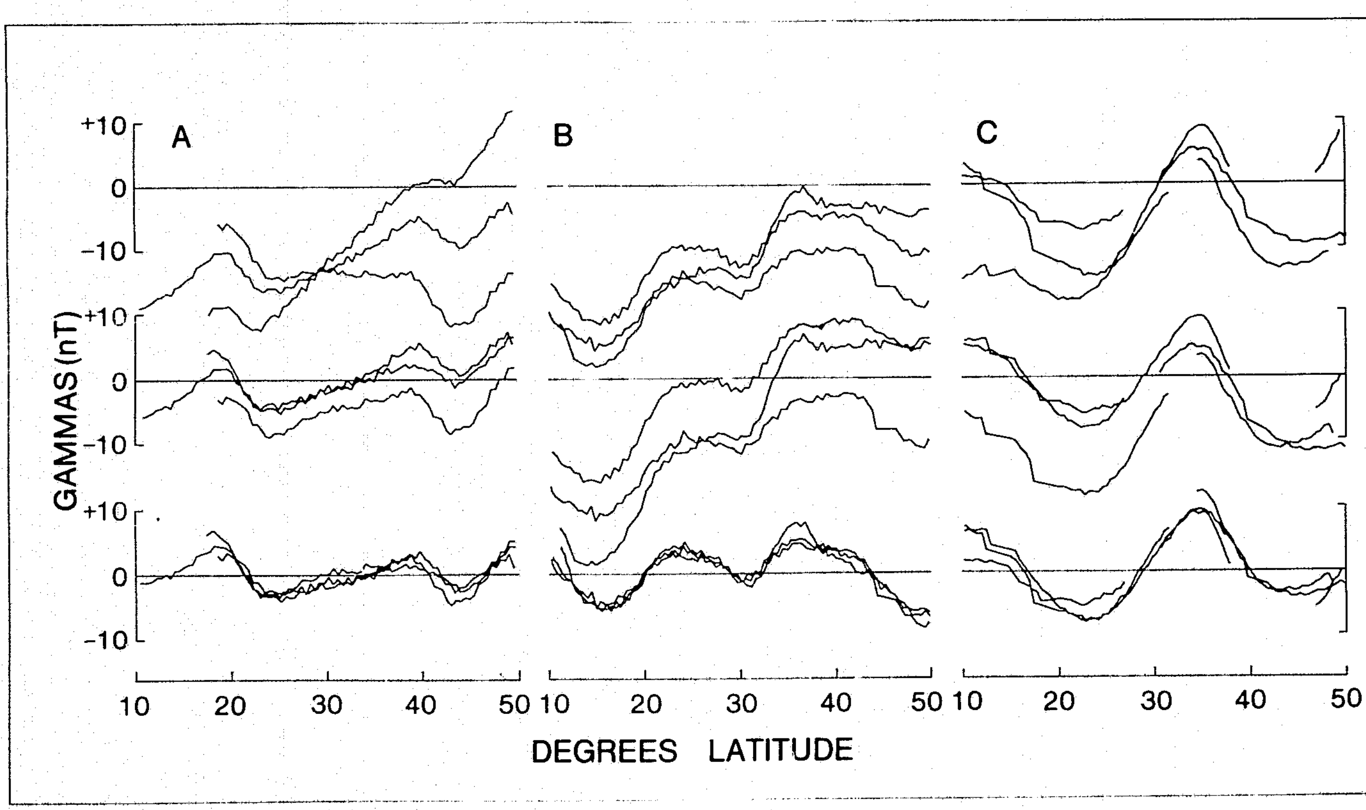

Figure 3. Profiles along three groups of tracks shown in Figure 3. Upper line shows uncorrected profiles. Middle line shows profiles corrected for DS variation. Lower line shows corrected profiles with linear function removed.

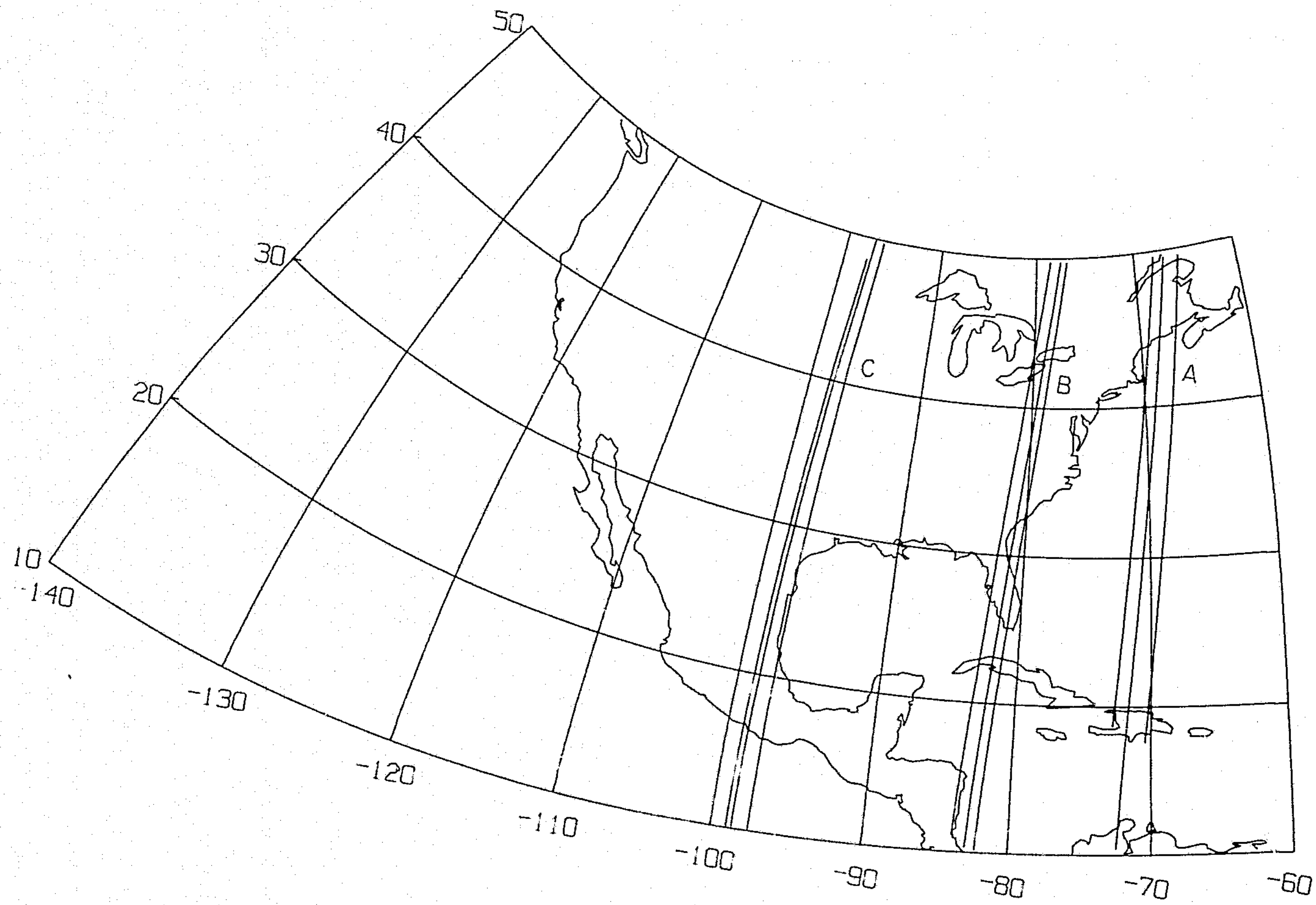

Figure 4. Satellite tracks of profiles shown in Figure 2.

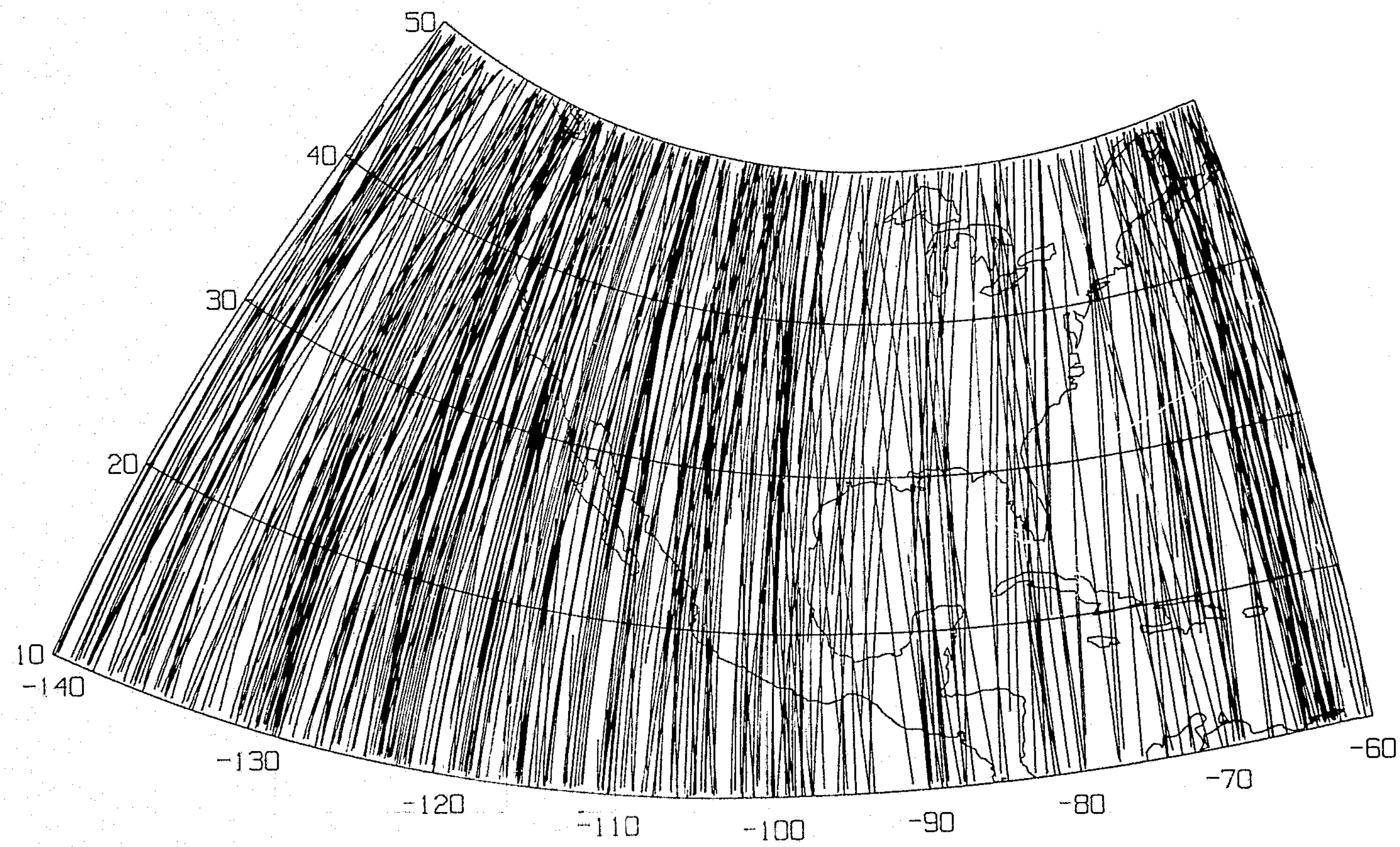

Figure 5. Track chart of all satellite passes containing data used in Figure 2. Data selection described in text.

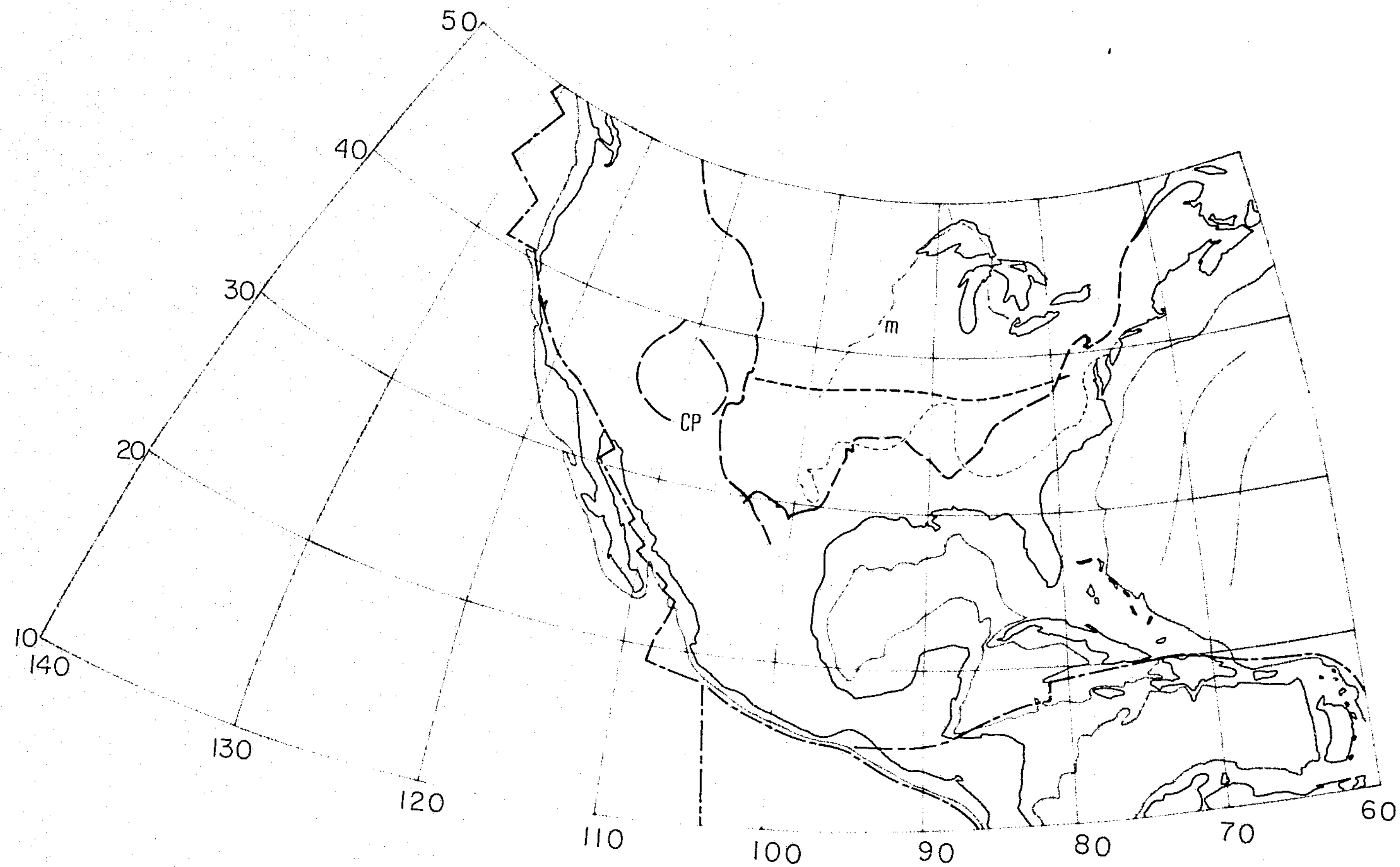

Figure 6. Selected tectonic elements in North America taken primarily from King and Edmonston (1972). Heavy long dashed line is Appalachian-Ouachita and eastern Rocky Mountain front and Colorado Plateau. Heavy short dashed line is 38th parallel lineament of Heyl (1972). Heavy short-long dashed lines are generalized plate boundaries. Light short dashed line is coastal plain boundary. Light double line in western North Atlantic is approximate region of Keathley anomalies (Vogt et al., 1971).