DIGITAL AEROMAGNETICS IN PETROLEUM AND MINERAL EXPLORATIONS

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ABSTRACT

The digital High Sensitivity Caesium Magnetometer provides greater resolution than may be obtained with previously available equipment.

Digital recording in the field permits rapid reduction of the data and the use of automated computing and mapping procedures. The data may be further enhanced by the application of non-linear filtering techniques.

More than two years have elapsed since the introduction of the digital High Sensitivity Caesium Magnetometer to the North American exploration industry. Still, many soft rock and hard rock geophysicists are unaware of the advantages of this new equipment over the more familiar Fluxgate and Proton Precession instruments. The following is designed to familiarize the general exploration community with the system, and to review new developments in digital data handling and interpretation.

Twenty years ago, magnetic data was used primarily to provide oil companies with an appreciation of regional basement structures and section thickness in order that seismic crews might be directed to areas most suited to petroleum accumulation. Mining companies made similar use of the data but with different objectives or goals in mind. Equipment in use was capable of resolution of approximately one gamma.

Large features or those with a high magnetic content either at basement level, within the section or near the surface, were easily detected by the equipment of this kind. However, small structures also play important roles in petroleum accumulation or mineralization and may not produce anomalies large enough to be "seen" by conventional equipment. The high sensitivity digital caesium magnetometer, which measures in units of 0.01 gammas, now makes it possible to detect these small structures. Considering that the smallest anomaly "seen" by older magnetometers is one gamma, and the new high sensitivity equipment will resolve to 0.1 gamma, the effective sensitivity has been increased by a factor of 10, resulting in recordings containing much more detail. Where before, one gamma anomalies did not allow reliable depth estimates — if any at all — today, higher resolution permits depth to origin to be determined with greater certitude.

Digital recording on magnetic tape of aeromagnetic data is now available to a computer oriented industry. To the petroleum geophysicist using stacked, filtered, and deconvolved profiles together with frequency analysis or power spectra, computerized techniques constitute a major breakthrough in data handling. To management, digital techniques mean not only more accurate interpretation but also accelerated results. With aeromagnetic data, the same advantages apply.

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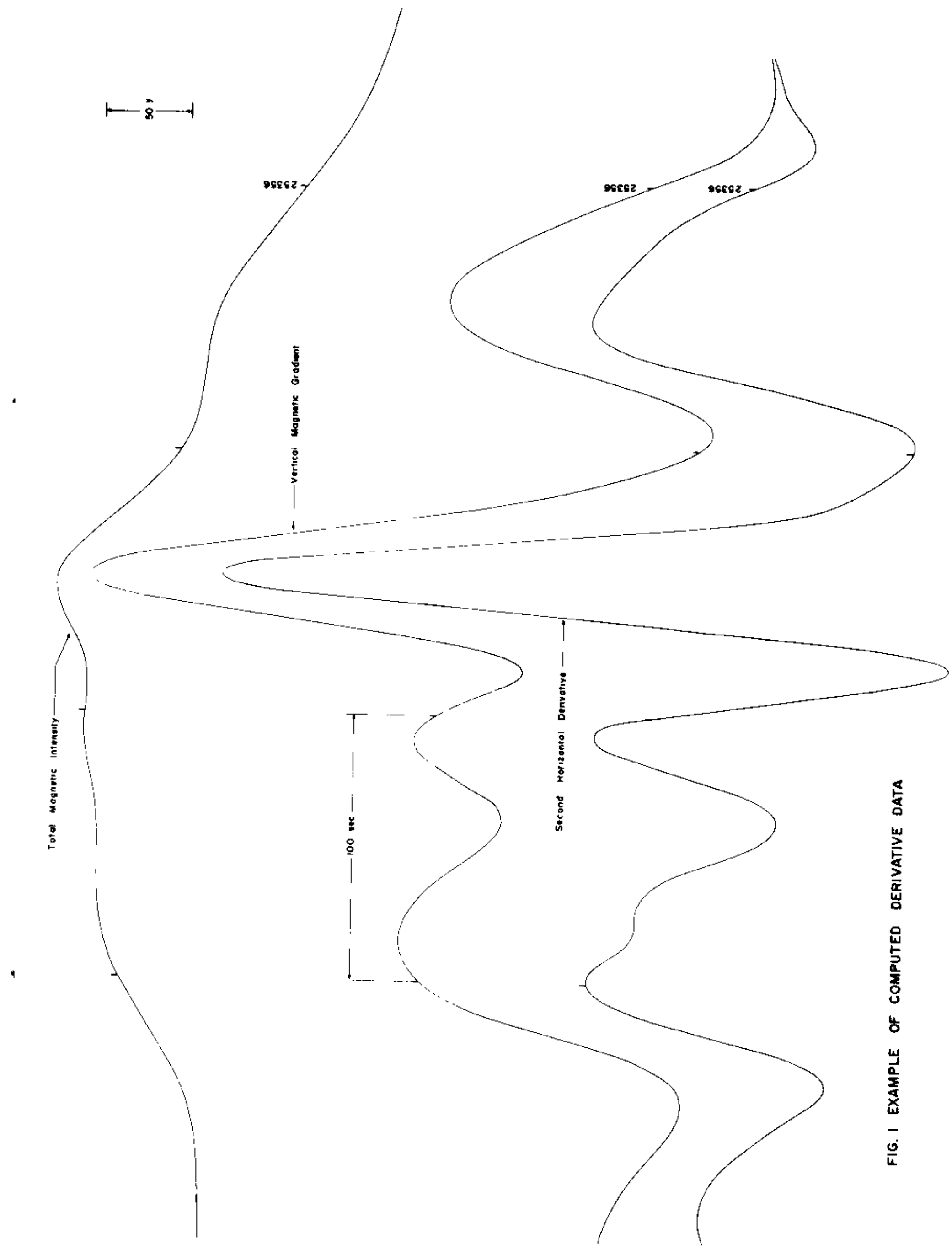

FIG. 1.—Example of computed derivative data.

To supplement the high sensitivity digitized magnetic data, computer programs permit rapid and accurate calculations of horizontal and vertical derivatives from total intensity measurements. In some cases, anomalies that are not detectable by measuring the gradient can be recognized by computing vertical derivatives from total intensity measurements. The cost of obtaining gradient data directly usually is more expensive than computing it on a high-speed digital computer. Enhancement of anomalies hidden either by regional trends or by the contiguity of other anomalies is the prime motive behind derivative calculations. Fig. 1 illustrates the desirability of developing derivative data for enhanced resolution.

As it does in seismic processing, filtering has a profound role to play in processing magnetic data. Aeromagnetic anomalies are mainly the result of magnetization contrasts existing anywhere from the surface of the earth to within the basement. Shallow and deep structures can coexist and both can be structurally significant, therefore it becomes desirable to separate their magnetic expressions, thus facilitating depth estimates.

Digital high sensitivity magnetic data lends itself well to filtering techniques. A non-linear filtering method has been developed which utilizes the width of anomalies as the basis for determining filter parameters. In this manner, the application of several filters can reduce most profiles to their component parts. It is well known that the width of an anomaly and its depth to source do not enjoy a one to one ratio, but the two characteristics are sufficiently interdependent that the width can be considered as a valid parameter for filtering. By selecting anomalies originating from different horizons, the geophysicist can break down his total intensity or derivative profile into profiles showing the magnetic expression of structures lying within certain gross depth limits, i.e. near surface, in section or basement. He can validate, or invalidate for that matter, his selection by determining a depth estimate on the residual profile.

Figure 2 shows an example of non-linear filtering. Profile 1 is the original data. The first computer run filtered out small anomalies. The result is shown by profile 2. By increasing the sampling interval, anomalies C, F and H are removed as shown on profile 3. Finally, by subtracting profile 3 from 1, the residual profile is obtained. Obviously, the improved definition of anomalies on the filtered and residual profiles allows more accuracy in determining depth estimates than could be obtained from the original profile.

Figure 3 shows the result of several passes of the filtering program. Curve 1 is the original data. Curve 2 is the output of the final pass and can be considered as a regional or deep-seated anomaly.

Digital recording of the total magnetic field makes automatic contour mapping possible. The original data are processed in a preliminary operation, the result of which is a levelled coherent network of data from which time variations of the magnetic field have been removed.

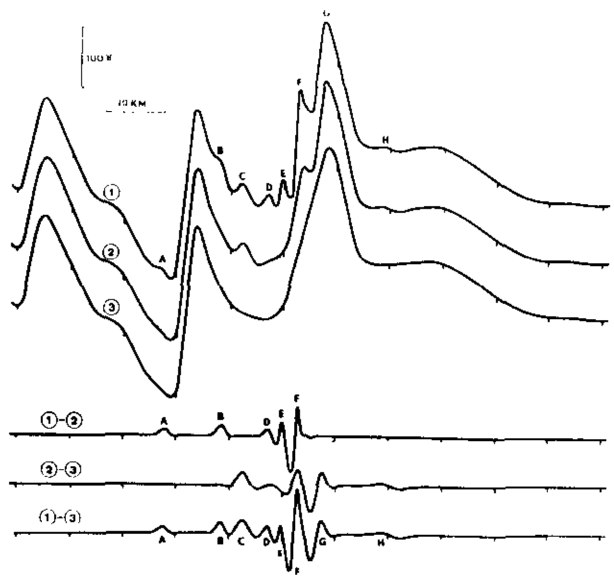

FIG. 2.—Example of filtering.

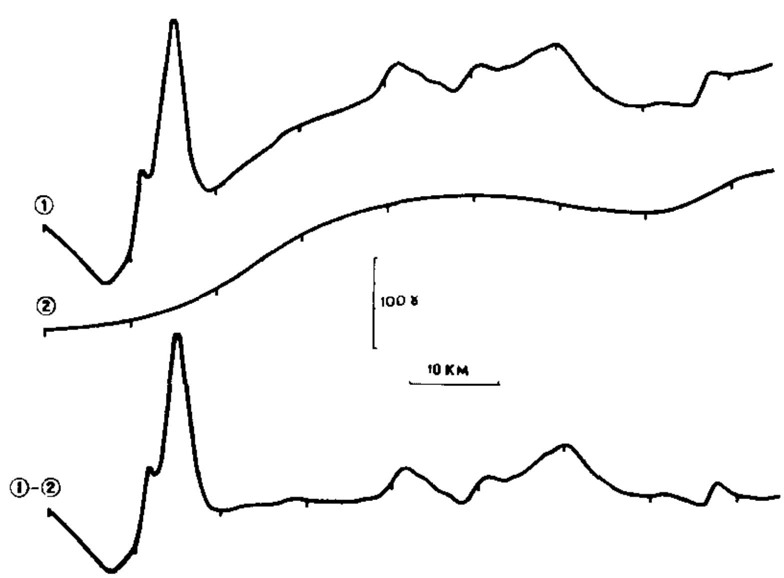

FIG. 3.—Example of filtering.

The sampling interval, i.e. the gap between data points, is small enough to represent the anomalies precisely (1 sec. for mineral surveys, 5 sec. for petroleum surveys). Each point on each profile is characterized by its X and Y coordinates and by the corresponding value of the total field.

Following the data reduction a mapping process can be carried out either manually or automatically, the latter being many times faster. One method for automatic mapping is to split the operation into two different parts: interpolation and contouring. Interpolation is the calculation of the total magnetic value at points of a square grid, the side of the grid unit being of the same order of magnitude as the spacing between computed points on profiles (200 ft. for a mining survey and 1000 ft. for an oil survey).

Using the grid values and a formula which excludes ambiguity, mapping contours are computed and then drawn automatically using a tracer plotter, each contour being a succession of very small portions of straight lines.

Digital high sensitivity aeromagnetic data together with sophisticated computer programs definitely constitutes an important method in oil and mineral exploration. The relatively high cost of seismic shooting necessitates a preliminary screening of target zones and any possible structures in any area to be surveyed.

Of concern to the seismologist and to management is how well does the interpretation of aeromagnetic data compare with that of seismic, the most reliable tool in the industry.

Figure A_1 shows the total magnetic field contours for an area covered by both seismic and digital aeromagnetic exploration systems. A technique known as 'reduction to the pole' has been applied to the original data and a new set of magnetic contours produced. The polar residual map, Figure A_2, is much richer in anomalies than the total intensity map. Lineations become more prominent. Interpretation of the aeromagnetic data is shown by Figure A_3, which when compared with the seismic interpretation, Figure A_4, locates common structures.

Figure B_1 shows total field contours, the interpretation of which is shown by Figure B_2. The seismic coverage in the area is not as extensive as the magnetic coverage but the interpretation of the seismic data correlates rather well with the magnetic interpretation.

Figures C_1 and C_2 illustrate the advantage of non-linear filtering. Interference effects have been reduced by filtering, thus allowing more accurate depth calculations.

REFERENCES

1. Baranov, V., 1953, Calcul du gradient vertical du champ de gravite ou du champ magnetic mesure a la surface du sol: Geoph. Prosp., V. 1, P. 171-191.
2. Giret, R., 1965, Some results of aeromagnetic surveying with a digital cesium-vapor magnetometer: Geophysics, V. 30, No. 5, P. 883-890.
3. Naudy, H., et Dreyer, H., 1965, Essai de filtrage non-lineaire applique aux profils aeromagnetic: Geoph. Prosp., V. 15, No. 2.

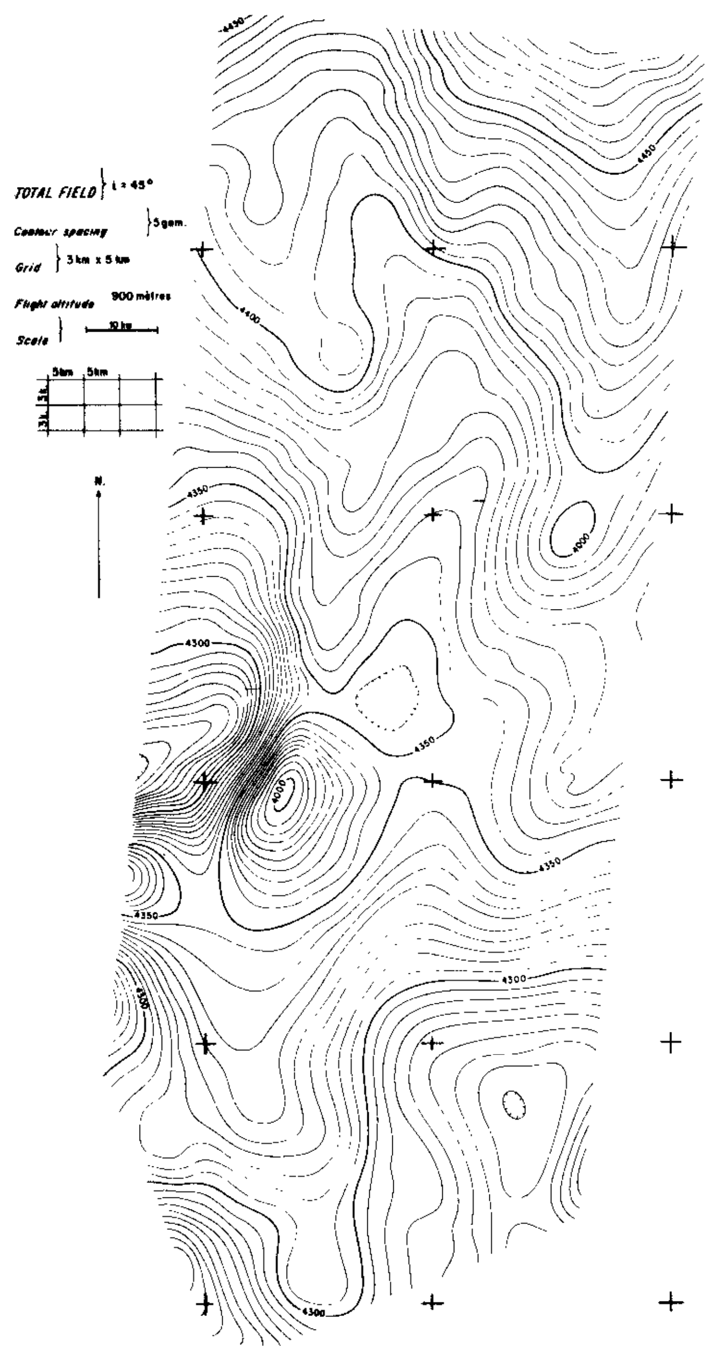
TOTAL FIELD
i = 45°
Contour spacing
5 gam.
Grid
3 km x 5 km
Flight altitude
900 mètres
Scale
10 km
5km
5km
N.
4450
4400
4350
4300
4000

FIG. A1.

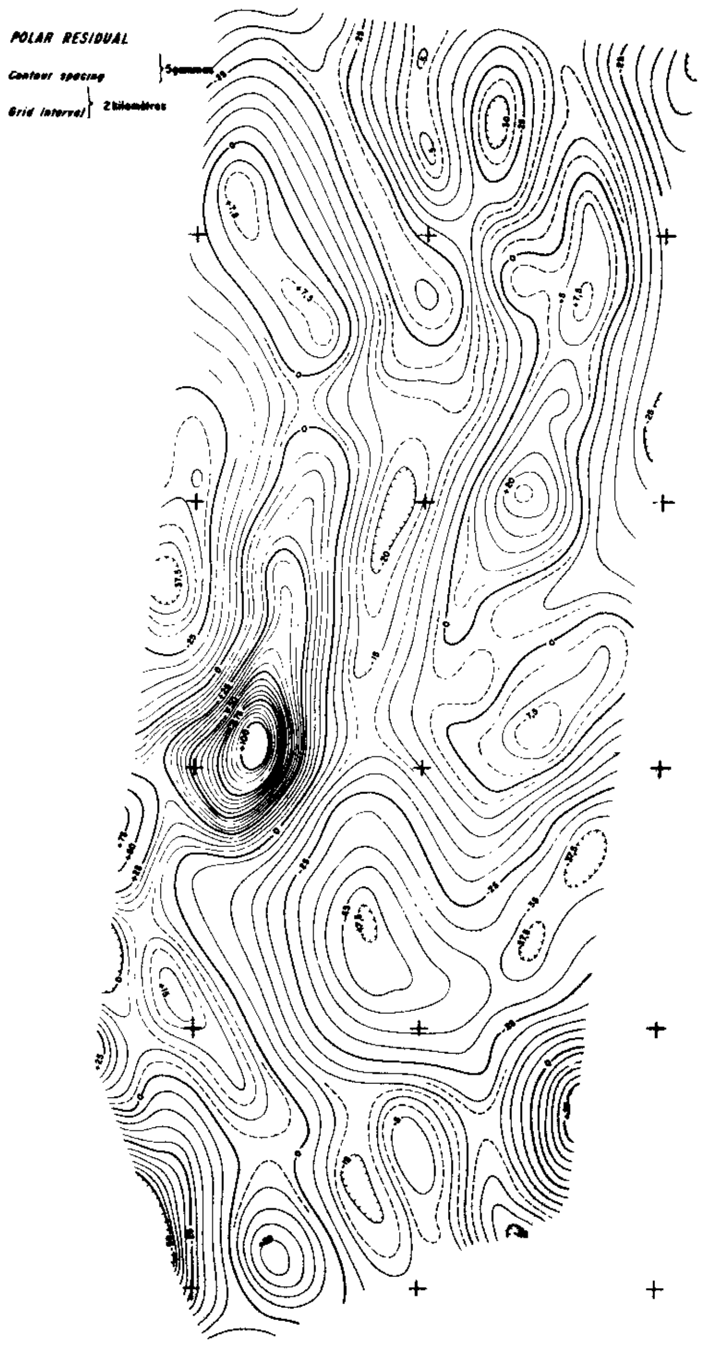
POLAR RESIDUAL
Contour spacing } 5 gammas
Grid interval } 2 kilometres

FIG. A2.

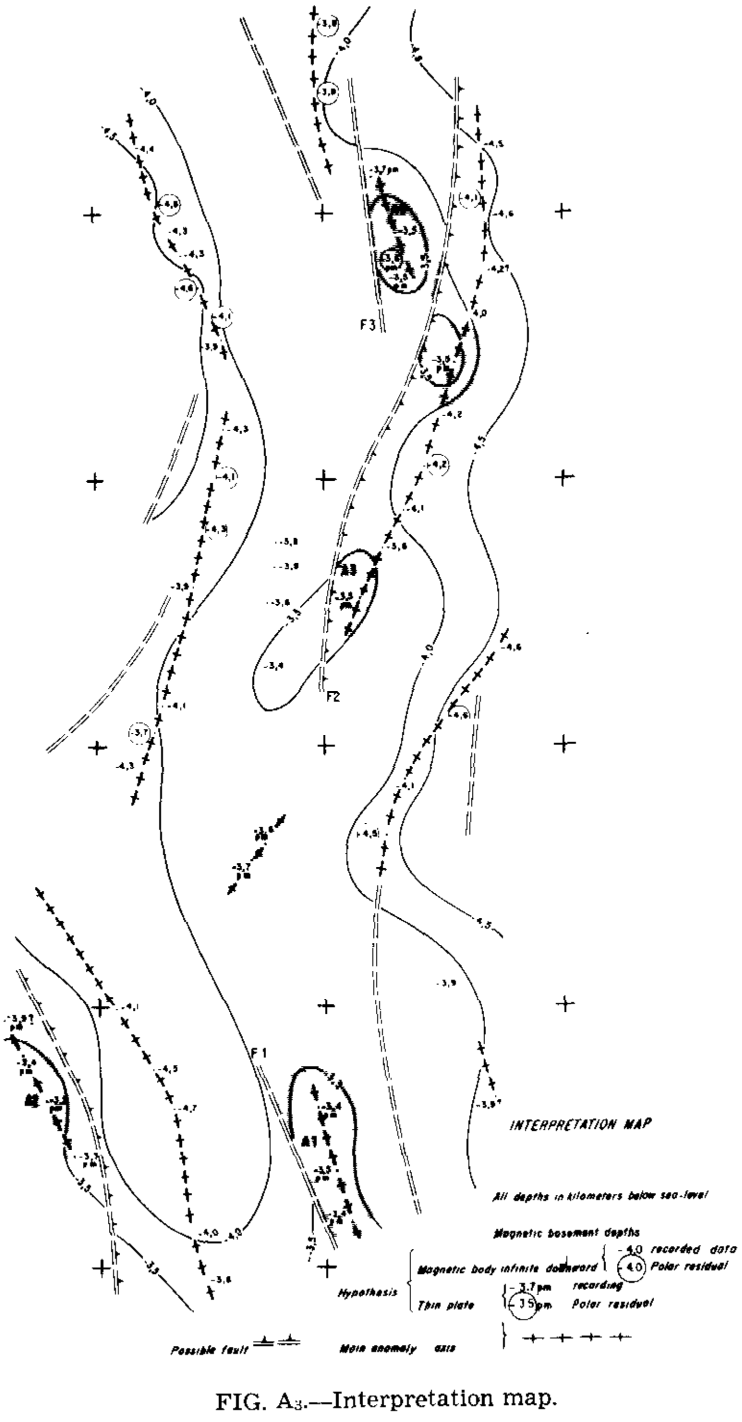

FIG. A3.—Interpretation map.

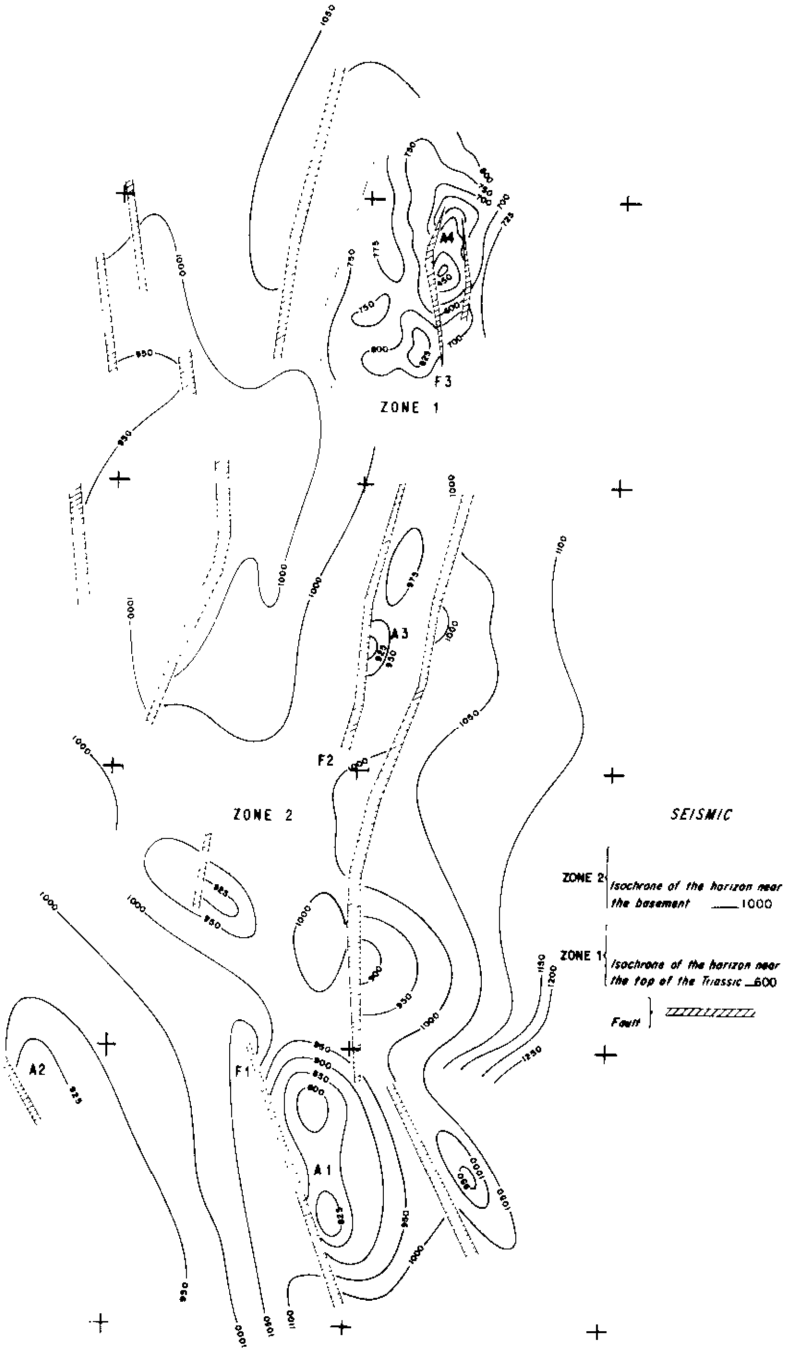

FIG. A4.—Seismic.

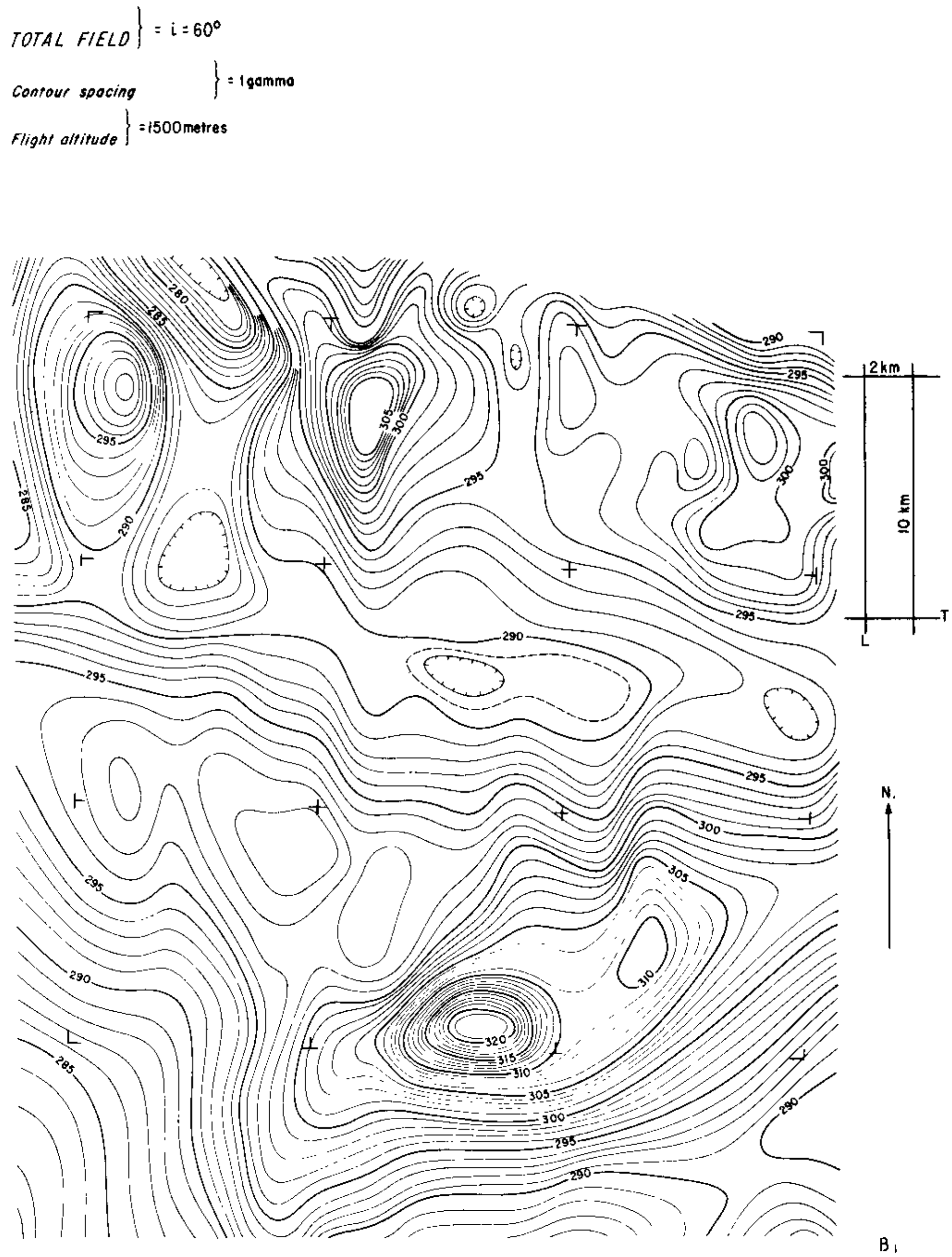
TOTAL FIELD } = i = 60°
Contour spacing } = 1 gamma
Flight altitude } = 1500 metres
280
285
295
305
300
290
2 km
10 km
T
L
N.
310
320
315
B1

FIG. B1.

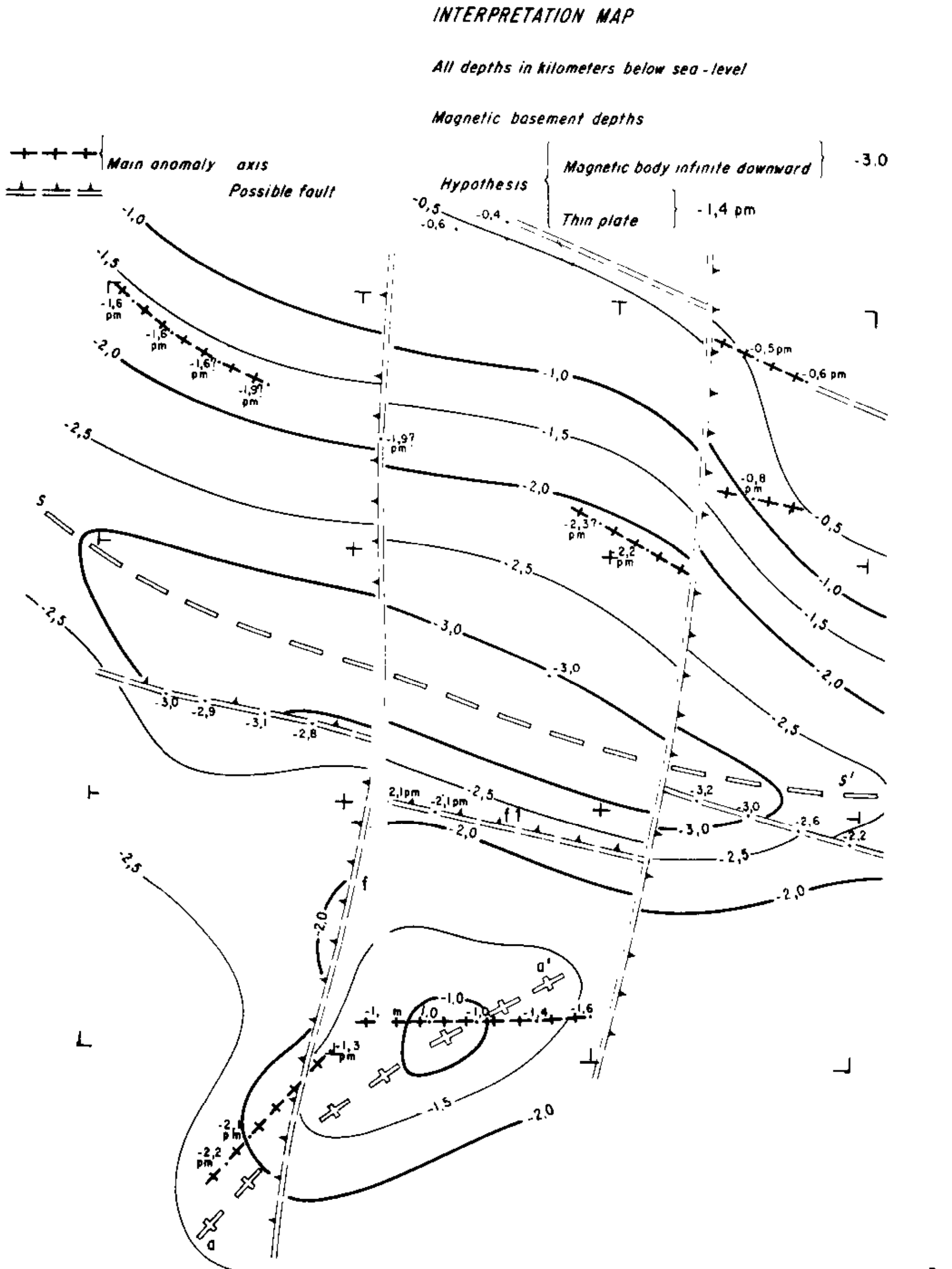

FIG. B2.—Interpretation map.

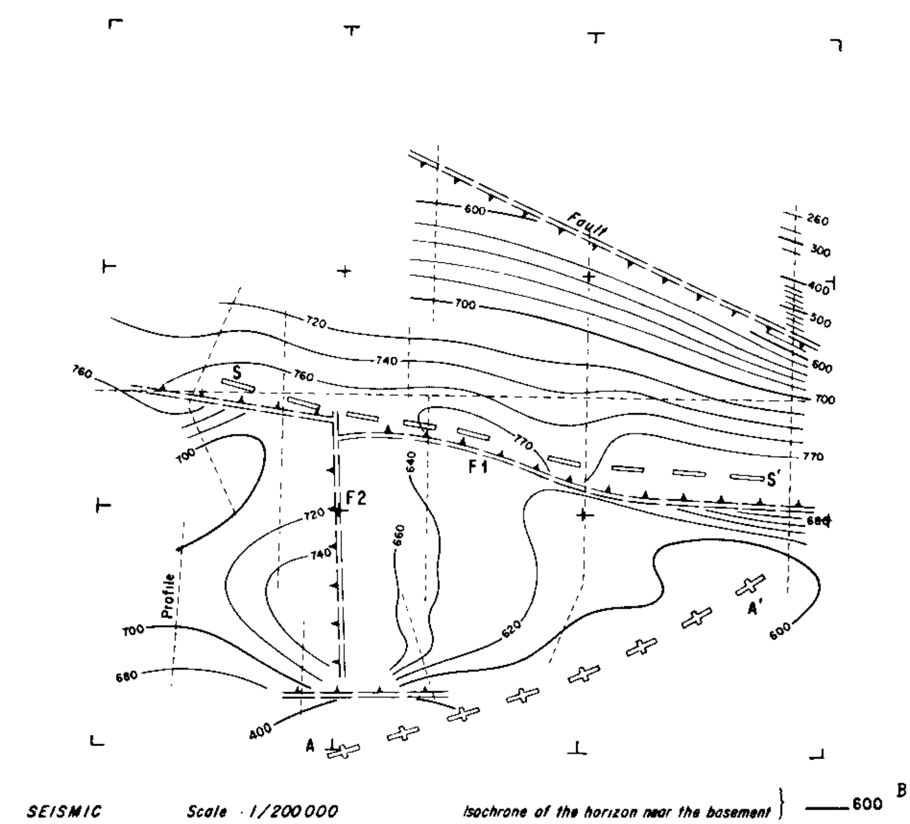
Fault
600
700
720
740
760
760
770
700
640
660
720
740
F1
F2
S
S'
620
600
700
680
400
A
A'
Profile
260
300
400
500
600
700
770
680
SEISMIC
Scale 1/200 000
Isochrone of the horizon near the basement
600
B3

FIG. B3.

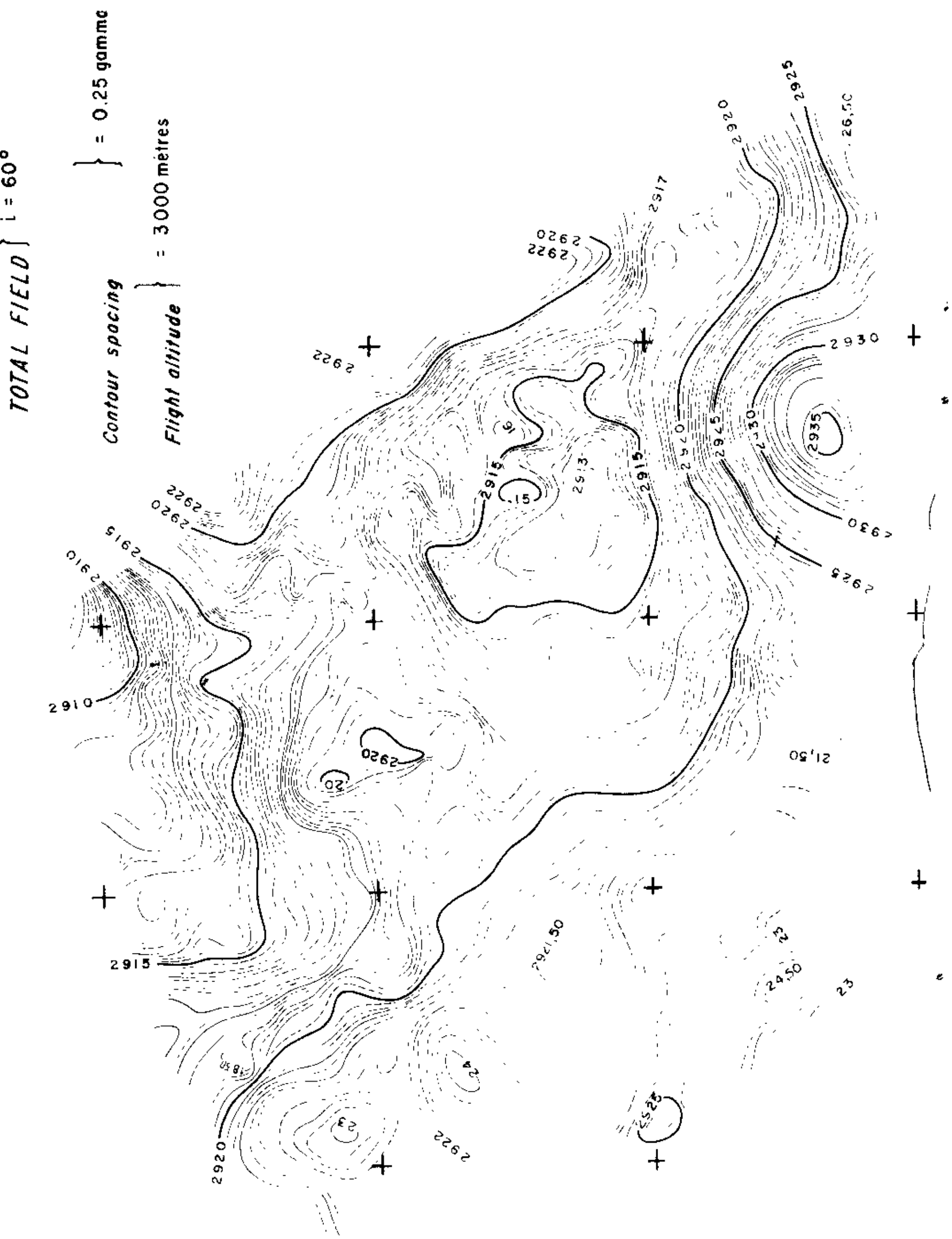
TOTAL FIELD } i = 60°
Contour spacing } = 0.25 gamma
Flight altitude } = 3000 metres
2910
2915
2920
2922
2925
2930
2935

FIG. C_1.

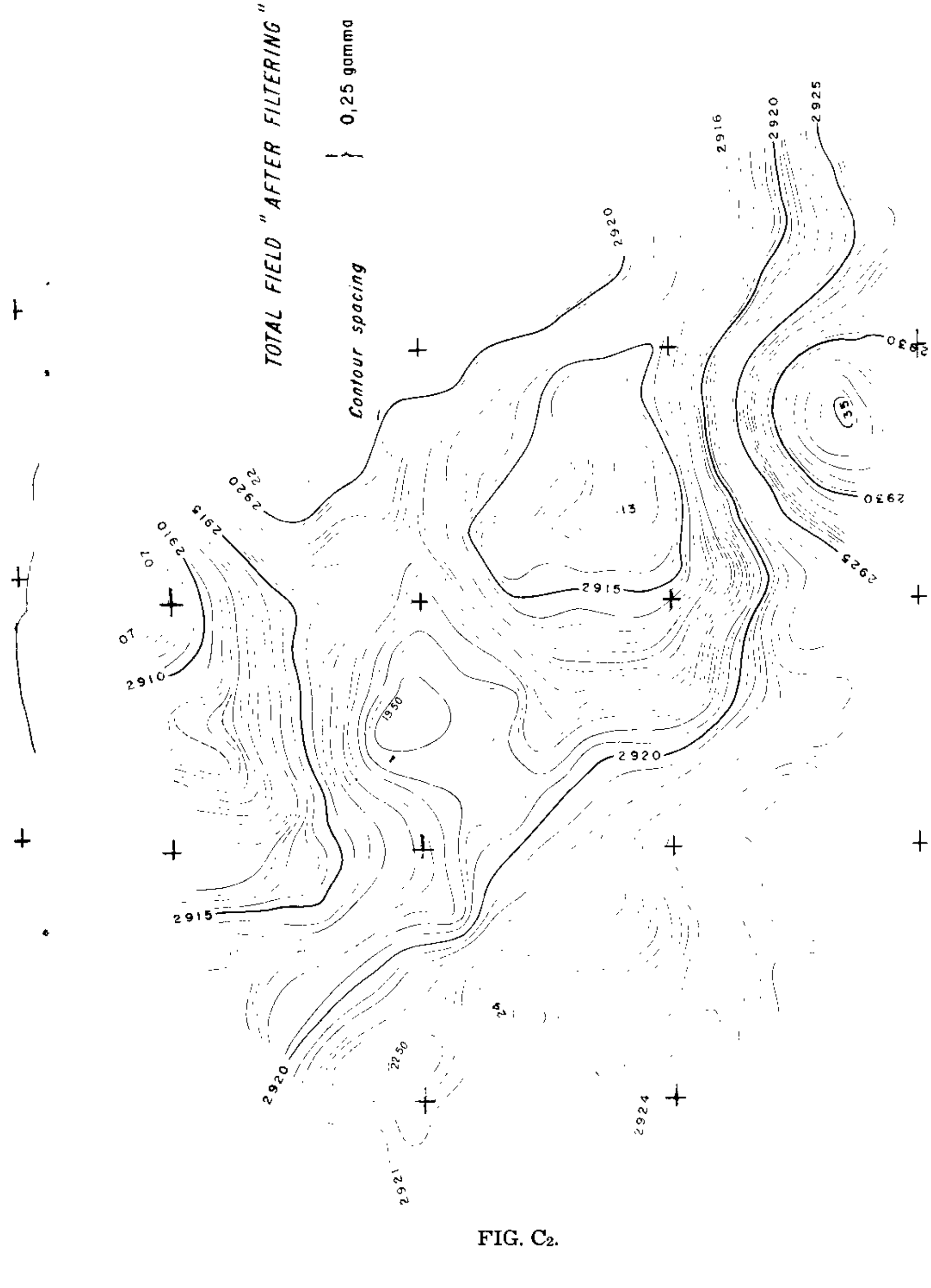
TOTAL FIELD "AFTER FILTERING"
Contour spacing
0,25 gamma
2915
2920
2910
2925
2930

FIG. C2.