Transverse Gradient Theory

geoMetrics

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The transverse gradiometer is merely two magnetometers spaced horizontal and transverse to the direction of flight. The difference in intensity divided by the distance is approximately equal to the gradient (within l% if sensor spacing is less than one tenth of the distance to anomalies). The objective of this configuration is to obtain total intensity *data* of extremely high accuracy throughout the survey area, especially in the large unmapped region between adjacent profile lines. The data are normally unknown in such a region and is perhaps the principal reason for a) inaccuracies in slopes as applied to depth-to--basement estimates for petroleum exploration; b) unmapped anomalies which occur between flight lines for mineral exploration; c) anomalies which close around flight lines and other such errors in maps in the location and shape of the anomaly sources, and d) the requirement to fly closely spaced lines to adequately portray the data.

There has been a. continuing discussion among geophysicists on which interpolator works best to estimate the value of the total field in the region between alight lines, This region does represent most of the area of any man and so is of great importance. Obtaining this data more accurately with a, higher density of profile lines and tic lines does not necessarily achieve this goal because of the inherent inaccuracies in navigation, compilation, contouring and normal survey errors. The resultant gradient derived from such error sources would be inaccurately computed or mapped as the small difference between 2 large, inaccurate numbers.

The use of the transverse gradient can be evaluated by starting with a top (attached) and assuming for this purpose that the data on the map are perfectly accurate or "true". On this map are drawn widely-spaced flight lines, typical of an aeromagnetic survey. The lines are sampled at appropriate points which are used to form a maximum order surface, in this case third order, as one would normally do to form a map. For comparison of results, profiles (attached) are drawn across the flight lines and across the original map. The values, of course, agree very well near the points where the data are sampled. They diverge, however, sometimes considerably, at points between the flight lines. This is a simple exercise and one that could be performed on one's own data to evaluate just how accurate, or rather how inaccurate, the data might be on a typical survey.

The transverse gradient is then measured on the "true" map at each of these points where the total intensity was sampled. The gradient is measured transverse to the lines as would be measured by a transverse wingtip-to-wingtip gradiometer. In addition, the total intensity profile is used to compute He horizontal gradient along the lines as is normally observed on distance-corrected profile from chart records. These two

orthogonal gradients are used in a mathematical Taylor series expansion to involve terms of the gradient in an interpolation scheme. Many schemes can be employed which utilize the transverse gradient and this is only one selection. Again, a third order surface is fit to these points so obtained, but now instead of just the total intensity or absolute value of the. field, we also have the slope or second order terms between the profile lines. Profiles axe drawn across the flight lines as above and the data compared to the corresponding profiles from. the total intensity alone and the original "true" data from the map. Comparison of these profiles (attached) is just a method for comparing the corresponding surfaces. The profiles obtained from the transverse gradient. agree remarkably well with the original data., even though the lines are very far apart. The errors in the region between the originally sampled "flight" lines are reduced using the transverse gradient in some cases by almost a factor of 10 from those data, obtained using the total intensity alone.

This method demonstrates a method utilizing the transverse gradient by which one may obtain a very accurate total intensity survey at essentially the same logistic efforts and cost as a. standard survey. Conversely, one may wish to reduce the line spacing and hence the total line miles and still obtain the same map as one would have had using total intensity alone. The relative advantages of using the transverse gradient depend to a, large extent on the wavelength of the anomalies being measured. For a relatively constant gradient, the transverse gradient is already measured accurately using the absolute values of the total field as one normally measures in an aeromagnetic survey. On the other hand, if the wavelength of the anomalies is extremely short compared to the spacing of the flight lines, then the measured transverse gradient may not be the appropriate transverse gradient, but only the locally anomalous one. In this case, the measured transverse gradient would be misleading and erroneous in an interpolation scheme. Such spacing of flight lines, even for total intensity, would obviously be too large for anything but a coarse regional survey and too large to discern a shallow source.

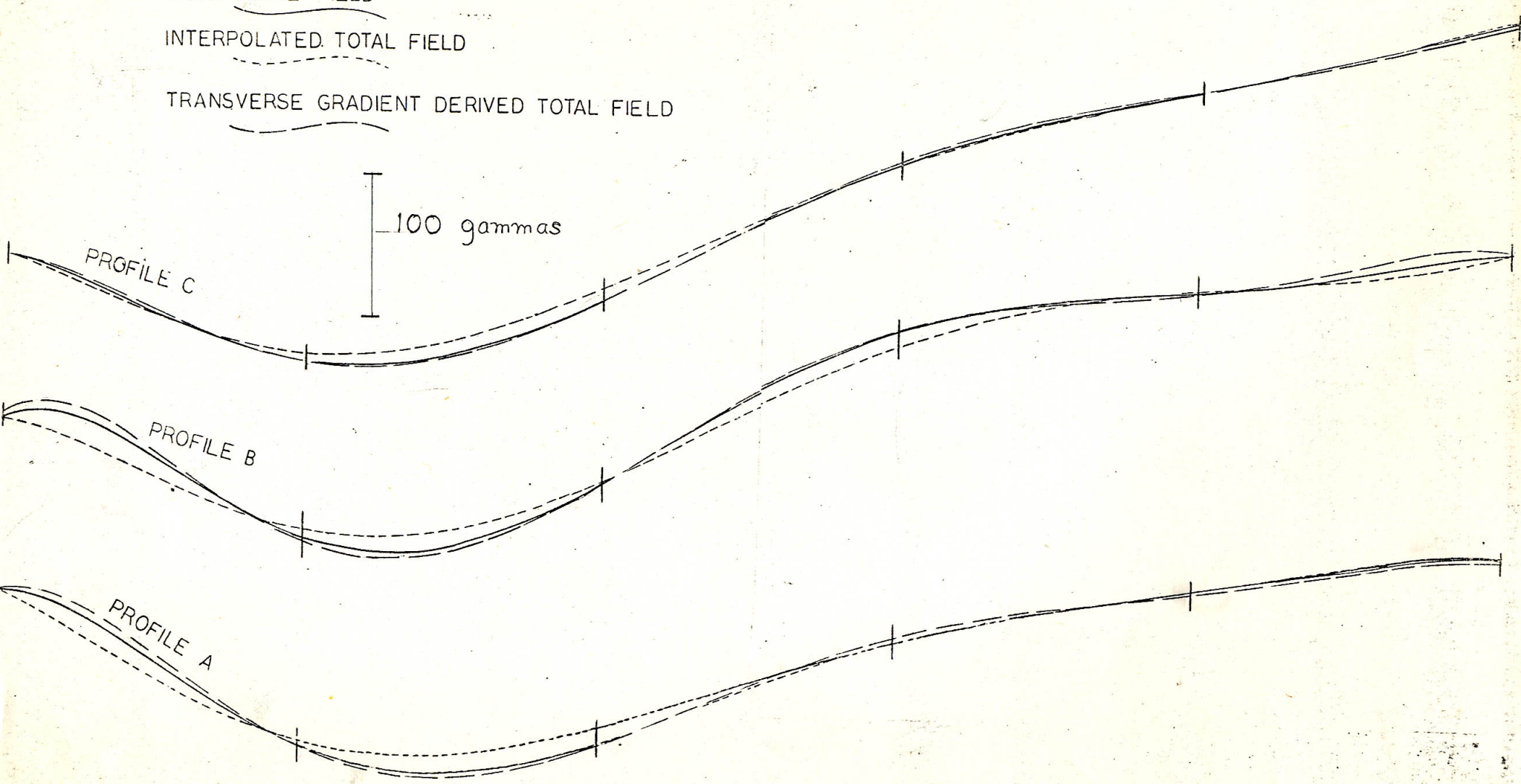
The sensitivity of a gradiometer necessary to produce usable transverse gradients is not necessarily extremely high, as one might think. It is not a question of detecting very small anomalies but rather of sensing the slope of the field transverse to the flight direction, even to an approximate value. If one sere to know even the sense of the slope, it would be better than not knowing it at all. The typical sensitivities that would be very useful would range from 3×10^{-2} gammas per meter .o 5×10^{-3} gammas per meter for mineral and petroleum surveys, respectively. These sensitivities can be obtained with a 0.5 gamma sensitivity and a 0.1 gamma, sensitivity gradiometer over a 16 meter sensor-to-sensor wing span, respectively, if the magnetic compensation of the aircraft is sufficiently good. A high sensitivity proton magnetometer now being flown has produced a sensitivity of 0.05 gammas with a reading every 0.9 seconds and at the high repetition rate, 0.5 gammas five times per second. Records of this performance are attached.

The doppler-related motion effects of a proton magnetometer are largely canceled in the rigid wingtip installation of a transverse gradiometer. There is common mode rejection of the identical angular rotation effects on a rigid platform when one measures the differential between the sensors, assuming that there are not extremely large vibrational characteristics of the wingtips. There are no micropulsation or diurnal time variation errors on the gradiometer because it is a differential magnetometer. Also, the data corrected according to the recorded yaw

(crab) angle will allow yet another variable to aid in adjusting or tieing the adjacent or tie lines for a more accurate map.

If there are serious wingtip mounting problems, one may also consider the possibility of birds suspended from pulleys at the two wingtips and brought up into cradles at the wingtips themselves, the two cables passing beneath the wing and into the fuselage. This is certainly not as desirable as the fixed installation, but might be required for an aircraft with large engines near the end of the wings, whose wing areas cannot be compensated sufficiently well, or where one does not desire wingtip extensions. The ideal installation is the extended wingtip sensor as shown on the enclosed printed data sheets. These can be extended to perhaps 2 meters or more on larger aircraft, but is 1 meter as a standard length. Whatever the configuration, good results will depend strongly upon the care in replacing ferromagnetic hardware, compensating the remaining effects, and, in general, attention to detail.

Effective use of the transverse gradiometer depends not only upon the differential but also the total intensity at one sensor. In some cases, the total intensity is affected more by the magnetic moment of a fuselage located engine than is the differential between *two* diametricallyopposed sensors. (Note: A magnet varying either in direction or amplitude will not bee detected at the midpoint of the line of a gradiometer.) For extremely high sensitivity work, it is also possible that: one might require a, towed bird or stinger-mounted high sensitivity magnetometer for total field and two 0.5 gamma wingtip sensors for the transverse gradient. This configuration, although more complex, is the ultimate in high sensitivity reconnaissance work for both petroleum and mineral exploration.
See attachments that follow.


TRUE TOTAL FIELD
INTERPOLATED TOTAL FIELD
TRANSVERSE GRADIENT DERIVED TOTAL FIELD
100 gammas
PROFILE C
PROFILE B
PROFILE A

PROFILE A
PROFILE B
PROFILE C

06.00
07.00
06.46 Beginn des Profils Nr.
3. JUNI 1978
06.42 Ende des Profils Nr.
3. JUNI 1978