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Discussion on: "Gravity Investigation in Mountainous Areas"

by P. Steinhauser, B. Meurers and D. Ruess, *Exploration Geophysics* **21** (1990), 161-168

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Firstly, it should be noted that Steinhauser et al.'s paper deals mainly with mapping gravity in mountains, not 'investigating' it, as their title suggests. Investigation implies analysis. But principally, I dispute the main thrust of their paper; the need to establish a regular distribution of stations at great cost, which includes placing some stations on the tops of all peaks, then having to terrain-correct all stations out to a distance of 167 km.

The problem is not so serious in Australia, as most of the continent is fairly flat. Terrain corrections were not applied to the first computerised map (Anfiloff et al., 1976), but tests showed that in the Australian Alps, the maximum correction of about 10 mGal, over very steep relief of 1400 m, operates over distances of only 10-20 km (Anfiloff, 1982a, Fig. 20). So I was surprised by Steinhauser et al.'s claim that a peak with a relief of 2-3 km necessitates a 5-mGal terrain correction out to a distance of 167 km.

I carried out some tests and found that the 2-D terrain correction for an escarpment 3 km high decreases to 1 mGal within 100 km, and for a sharp 3-km ridge, it reaches that value within 10 km. The 3-D equivalent situation, represented by a point on a flat plain encircled by mountains at a distance of 100 km, would require a terrain correction about four times greater. According to my calculations, at 167 km, this would require a correction of about 1 mGal.

The real issue is that over such large distances, such corrections represent a small long-wavelength change which is insignificant for local interpretation, and is also uninterpretable regionally, given the ambiguity of long-wavelength gravity features. But there is a much bigger problem in assuming a constant arbitrary density for all topography, as Steinhauser et al. have done. The density is neither constant nor known, and the higher the peak, the bigger the error introduced by this assumption.

My calculations show that a station on top of a 3-km peak has an error of about 11 mGal in terrain-corrected Bouguer anomaly for every 0.1 t/m^3 error in the assumed density. So there is every chance of having 20-mGal spikes in the finished map, and the highest peaks are therefore best omitted unless they can be processed properly using Nettleton's (1939) density profiling concept, applied in the 3-D sense. It is much more practical to avoid individual peaks and approach the problem in the 2-D sense.

So there is a real contradiction in insisting on the need to terrain-correct to 167 km, while assuming a constant topographic density over such a large distance, and I doubt whether Steinhauser et al.'s whole strategy is appropriate. Most of the effort should go towards establishing "prestige" traverses which can be analysed correctly. In mountainous regions, the two most serious factors affecting gravity interpretation are that the datum is far from flat, and topographic density is not known. There does not seem to be much point in producing, at great cost, a detailed picture of the gravity over mountains without having a modelling technique which takes account of these factors.

Steinhauser et al.'s statement that a 100-m error in position can affect gravity by 1 mGal reflects the old problem of what happens near the edges of steep topography, in what can be called the 'shadow zone'. The old approach was simply to avoid such zones. Now Steinhauser et al. point out that in attempting to include them, new problems appeared: the errors in positioning, together with errors in digitising topography, mean that some stations 'drift' around in the shadow zone, producing erratic terrain corrections. This demands more accuracy, and the implication is that the regular grid strategy has reached the point of diminishing returns.

It is better to channel much of the effort into quality traverses. By crossing mountains where they are reasonably two-dimensional, reduction and modelling can be carried out together in a combined process on the real datum. This has been done successfully many years ago using the 2-D Formal Interpretation Method of Anfiloff and Flavelle (1982), which is based on the automatic 2D Elevation Inversion Method of terrain correction over elongate topography (Anfiloff, 1976). It requires only a rough idea of the gravity trend directions, and in fact, the placement of traverses is governed wholly by the need to cross topography where it is most elongate. So when using this method, the local gravity grid is not used, which begs the question of how much of it is necessary at all.

The Formal Interpretation Method uses Nettleton's (1939) multiple-density profiling concept, and does not require the assumption of a topographic reduction density. It is axiomatic that whenever the topography is sufficiently steep to require a terrain correction, its bulk density can be assessed reasonably well from the gravity data itself, and this is one of the cornerstones of the method (Anfiloff, 1979). Conversely, when topography is not steep, it often cannot be determined from the gravity, and the interpretation can be very ambiguous (Anfiloff, 1982b)

The method was demonstrated over the 800-m Darai Escarpment in New Guinea (Anfiloff and Flavelle, 1982), and showed the formidable nature of problems confronting interpretation in mountainous regions for the 2-D case. These problems seem almost insurmountable for the 3-D case.

Figure 1 demonstrates the application to the Australian Alps along the same traverse used by Anfiloff (1982a, Fig. 20). The

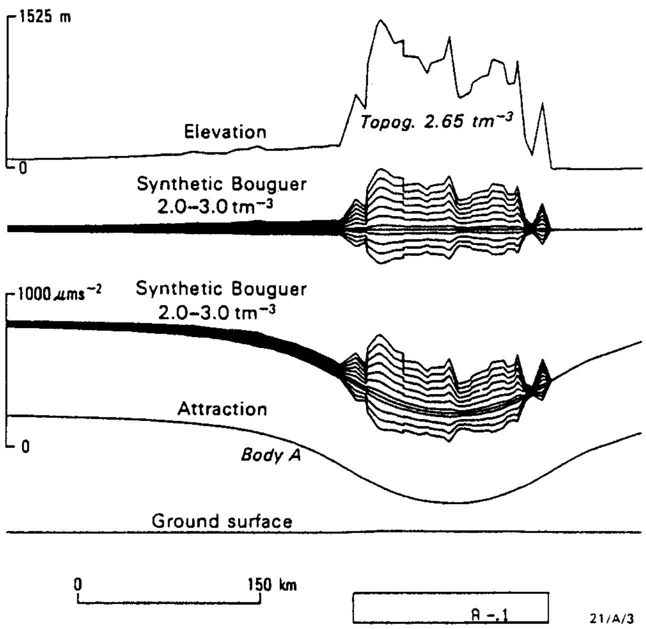

FIGURE 1
Demonstrating the 2-D Formal Interpretation Method of combined reduction and modelling across the Australian Alps along 360S.

key to interpretation is the production of a synthetic free-air profile which can be reduced to Bouguer anomaly with and without the interpreted body. And topographic density should be a by-product of a successful interpretation. Values which have been deduced in the past are 2.97 t/m³ (Anfiloff, 1976), 2.20 t/m³ (Anfiloff and Flavelle, 1982), 2.45 t/m³ (Anfiloff, 1983), and 2.6-2.7 t/m³ (Anfiloff, 1982b). Clearly, the arbitrary value 2.67 t/m³ has little chance of being being correct.

I expect there is no shortage of elongate topography in the European Alps where the method can be tried, using Steinhauser et al.'s 3-D terrain-correction system to 'improve' the two-dimensionality.

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Reply by B. Meurers and P. Steinhauser

First of all, we agree with Anfiloff's comment that the wording "gravity investigations" for the title of our paper is inappropriate. But first-quality gravity data is required for extensive interpretations in mountainous areas, while it makes no sense to use poor data.

Of course, a cost-benefit analysis should be done before designing a gravity survey in mountainous areas. If approximate information is sufficient, there will be no need for more advanced techniques – but one should always be aware that the results may be of only academic importance.

Our aim was to prove the possibility of obtaining gravity data of the same quality as in flat areas, even under highly mountainous conditions. And the problems are not as big as Anfiloff obviously assumes. For instance, terrain corrections to 167 km distance can readily be calculated using available geodetic data banks for the correction beyond 20 km.

Detailed gravity investigations in areas with rugged topography require application of high-resolution reduction procedures. For the determination of the gravity field in highly mountainous regions like the Alps, it is necessary to design a regular 2D station distribution. Owing to the complex geology, the gravity field cannot be described by 1D profiles. Two-dimensional modelling gives reliable results only in regional studies. Of course, station interval has to be chosen according to the problem to be solved. Also, when investigating the gravity field in a sub-regional to local scale, stations in extreme topographic situations have to be considered to obtain a regular station coverage.

As Fig. 6 of our paper clearly shows, the topographic effect of the distant range (20-167 km) increases strongly at stations higher than 1500 m, up to more than 5 mGal in

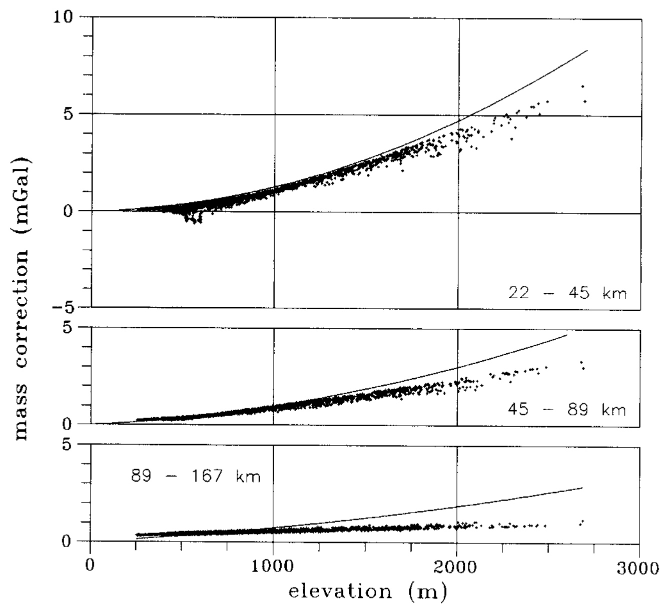

FIGURE 1
Contribution to mass corrections in far distant zones. Dots: Results for stations of an Eastern Alpine geotraverse. Solid line: Spherical Bouguer slab effect of the zone under consideration.

Table 1								
elevation [m]	topographic correction [mGal] radius of correction zones [km]							
	0-2.8	2.8-5.6	5.6-11	11-22	22-45	45-89	89-167	0-167
2662	60.55	15.12	7.96	3.54	1.77	1.96	1.33	92.23
2136	23.53	5.83	3.01	1.50	.97	.88	.80	36.51
1261	13.51	2.04	1.32	.61	.38	.24	.14	18.23
940	16.72	1.54	2.84	.98	.72	.15	–.03	22.93
739	5.95	3.73	3.82	1.87	.83	.17	–.11	16.27

TABLE 1
Contribution from different zones to the topographic correction for stations situated within an area of 25 km² at different elevations.

stations above 2000 m. If we assume a mean density error of 0.2 t/m³ in these zones, the maximum topographic correction error amounts to about 0.5 mGal. Accordingly, the problem of assuming a constant density is less severe in the distant range but very important in the zones close to the station, and therefore generally arises in gravity surveying independently of the maximum topographic correction radius. Hence the density problem cannot be an argument for restricting the topographic reduction area to 10 or 20 km only. In other papers we have discussed the effects considering the particular conditions in highly mountainous regions (Meurers et al., 1990). We have stressed this fact in the introduction to our paper.

The contribution of far distant zones to the mass correction, and especially to the topographic correction, can be seen in Fig. 1, which shows the situation for stations of an Alpine traverse (Meurers, 1992). The solid line marks the gravity effect of the spherical Bouguer slab, and the difference between this function and the dots defines the topographic reduction in the specified range. Figure 1 clearly proves the height dependence, which of course decreases with the distance of the reduction zone. Table 1 shows the topographic corrections from the different zones for some Alpine stations in partly steep topography. The stations are situated only within a small area of 5x5 km². Owing to the Earth's curvature, negative topographic corrections occur at low stations within the most distant range. The topographic correction of this zone differs by more than 1 mGal between the highest and lowest station. This difference increases to about 5 mGal if all zones from 22 to 167 km radius are included. Therefore, owing to its sensitivity to height, and the high-frequency content of the topography defined by the gravity stations, neglecting the contribution of the far distant zones also causes short-wavelength reduction anomalies. It should be stressed that the maximum value of the total topographic correction given by Anfiloff for the Australian Alps is far less than the mean value in the eastern European Alps. This can easily be seen in Fig. 11 of our paper, which shows the relation between station heights and topographic corrections.

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