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Relation of Gravity to Elevation in Zambia

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Abstract. Relations of gravity anomalies to elevation are derived for Zambia using different correlation methods with increasing mode of smoothing. Regression parameters derived are not consistent and thus cannot be compared to each other. Results are discussed and a preliminary interpretation is proposed.

Key words: Free-air anomaly – Bouguer anomaly – Elevation.

1. Introduction

Linear relations of free-air anomalies to elevation (FA-H relations) are sometimes used for the interpolation and/or extrapolation of gravity data (Heiskanen and Moritz, 1967; Groten and Reinhart, 1968) whereas linear relations of Bouguer anomalies to elevation (BA-H relations) are proposed to investigate isostatic compensation of the crust on a regional scale (Woollard, 1969; Qureshy, 1971).

The aim of this present study is to investigate whether relations of gravity anomalies to elevation in Zambia are suitable as gravity "predictors" and/or whether Woollard's model of a "normal", compensated crust does also hold for Zambia.

2. Data Collection and Processing of Data

The area of Zambia is 752600 km^2 (i.e. three time the size of FRG) and was covered by 1698 gravity stations (Strojexport, 1973; Mazac, 1974; Cowan, 1976). This amounts to a mean station density of 0.0023 field stations per km^2 or one station per 443 km^2. Moreover the station density is rather inhomogeneous,

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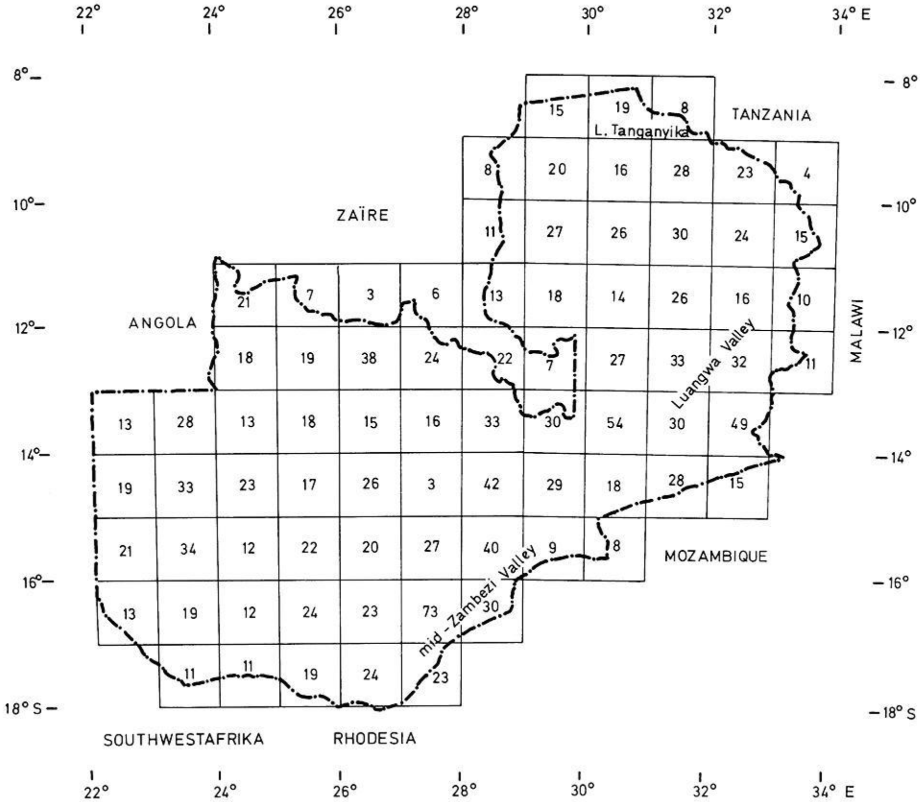

Fig. 1. Spacial distribution of gravity stations in Zambia

ranging from 3 station per $1° \times 1°$ unit area (1 station per 4107 km^2) to 73 stations per $1° \times 1°$ unit area (1 station per 169 km^2), see Figure 1.

Zambia is part of the Central African Plateau at an average altitude of about 1200 m above sea-level. In general the plateau is gently undulating although topographic highs (1600 m and even over 1900 m in the N and NE) and topographic lows (500–600 m in the Luangwa and mid-Zambezi Valleys and as low as about 300 m in the Feira District) do exist. The distribution of available gravity data (n) as function of elevation (H) is inhomogeneous too and clearly reflects the topography in Zambia, see Figure 2.

Free-air anomalies are correlated to elevation by least squares linear regression to result in a relation of the form

$$FA = a + bH. \tag{1}$$

The BA-H relation is of the form

$$BA = a + cH. \tag{2}$$

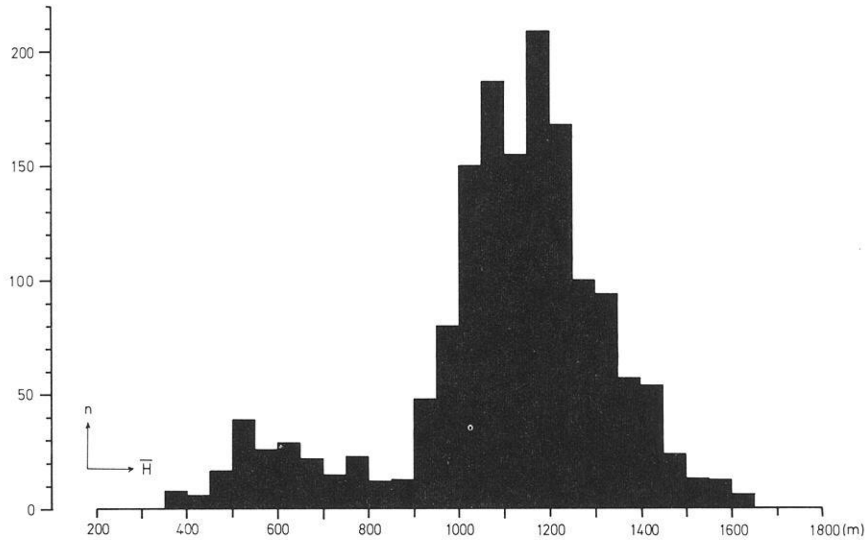

Fig. 2. Available gravity data in relation to elevation in Zambia

Strojexport (1973) estimates that topographic corrections for Zambia do not exceed 2 mgals and therefore no topographic corrections were applied to gravity data. Thus

$$(FA\text{-}BA) = (b\text{-}c) = +0.1119 \text{ (mgals/m)} \tag{3}$$

since a constant density of $\sigma = 2.67$ gcm^{-3} was used to calculate Bouguer anomalies.

It follows from Equations (1), (2) and (3) that FA-H relations can be derived from BA-H relations and vice versa. The author of this paper nevertheless calculated individual *FA-H* and *BA-H* relations and used Equation (3) to test the reliability of gravity data input to the computer. All computations were done on a Compucorp desk computer, model 425/44.

3. Results

Four different correlation techniques are undertaken and are listed below in order of increasing mode of smoothing:

a) correlation of individual pairs of *FA-H* and *BA-H* data within areas of $1° \times 1°$;
b) correlation of pairs of *FA-H* and *BA-H* data averaged over elevation intervals of 50 m;
c) correlation of $1° \times 1°$ mean values;
d) correlation of $3° \times 3°$ mean values.

Linear regression results are summarized in Table 1.

Table 1. Relation of gravity anomalies to elevation in Zambia

Method	Remarks	FA versus elevation				BA versus elevation			
		Elevation (m) from – to	Intercept (mgals)	Slope (mgals/m)	*r*	Elevation (m) from – to	Intercept (mgals)	Slope (mgals/m)	*r*
Corr. for	Average	1118 ± 196	−108 ± 177	+0.090 ± 0.20	–	1118 ± 196	−108 ± 177	−0.022 ± 0.17	–
ind. unit	max. intercept	1027 – 1057	+911	−0.885	−0.69	1027 – 1057	+911	−0.996	−0.74
areas of 1° × 1°	min. intercept	930 – 981	−908	+0.933	+0.84	930 – 981	−908	+0.825	+0.82
Mean values	Average	300 – 1700	−102	+0.081	+0.96	300 – 1700	−102	−0.030	−0.81
aver. over 50 m	max. intercept	300 – 800	− 70	+0.019	+0.39	300 – 800	− 71	−0.092	−0.90
intervals	min. intercept	800 – 1700	− 75	+0.062	+0.97	800 – 1700	− 75	−0.049	−0.95
1° × 1°	Average	400 – 1500	− 73	+0.057	+0.58	400 – 1500	− 73	−0.055	−0.55
mean values	max. intercept	600 – 1500	− 42	+0.034	+0.44	600 – 1500	− 42	−0.078	−0.73
	min. intercept	400 – 1500	− 79	+0.034	+0.97	400 – 1500	− 79	−0.078	−0.98
3° × 3°	Average		− 42	+0.029	+0.37		− 42	−0.083	−0.74
mean values	max. intercept	800 – 1400	+ 25	−0.027	−0.57	800 – 1400	+ 25	−0.136	−0.95
	min. intercept		− 44	+0.024	+0.65		− 44	−0.092	−0.94

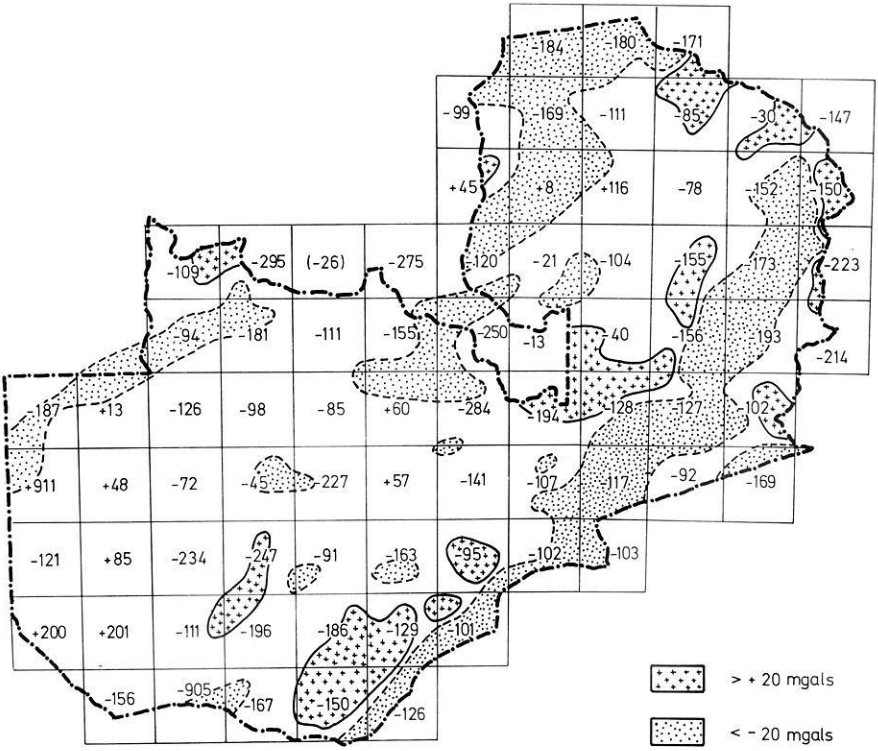

Fig. 3. Simplified free-air anomaly map and intercepts as derived from *FA-H* relations within $1° \times 1°$ unit areas of Zambia

3.1. Correlation of Individual Pairs of FA-H and BA-H Values within Unit Areas of $1° \times 1°$

Figure 3 shows intercepts as derived from the correlation of free-air anomalies to elevation for unit areas of $1° \times 1°$. Because of Equations (1) and (2) theses intercepts are also representative for *BA-H* relations. Intercepts vary over a wide range from +911 mgals to −908 mgals, the average being −108 mgals.

Superimposed on Figure 3 is a simplified version of the provisional Free-Air anomaly map of Zambia (Töpfer, in prep.). Narrow, elongated negative FA-anomalies are apparent along the Luangwa- and mid-Zambezi Valleys, the Luapula Province, part of the Copperbelt and the Northwestern Province. Positive FA-anomalies are aligned mainly to the "Luangwa and Zambezi Lows". There is no correlation apparent between free-air anomalies and intercepts.

Figure 4 depicts slopes as derived from linear regression analysis of Bouguer anomalies versus elevation for unit areas of $1° \times 1°$. Slopes for *FA-H* relations may be calculated from Equation (3). Slopes for *BA-H* relations vary considerably, from −0.996 mgals/m to +0.820 mgals/m, the average being −0.022 mgals/m. It is interesting to note that small slopes seem to occur in areas with relatively large topographic variations (Luangwa- and mid-Zambezi

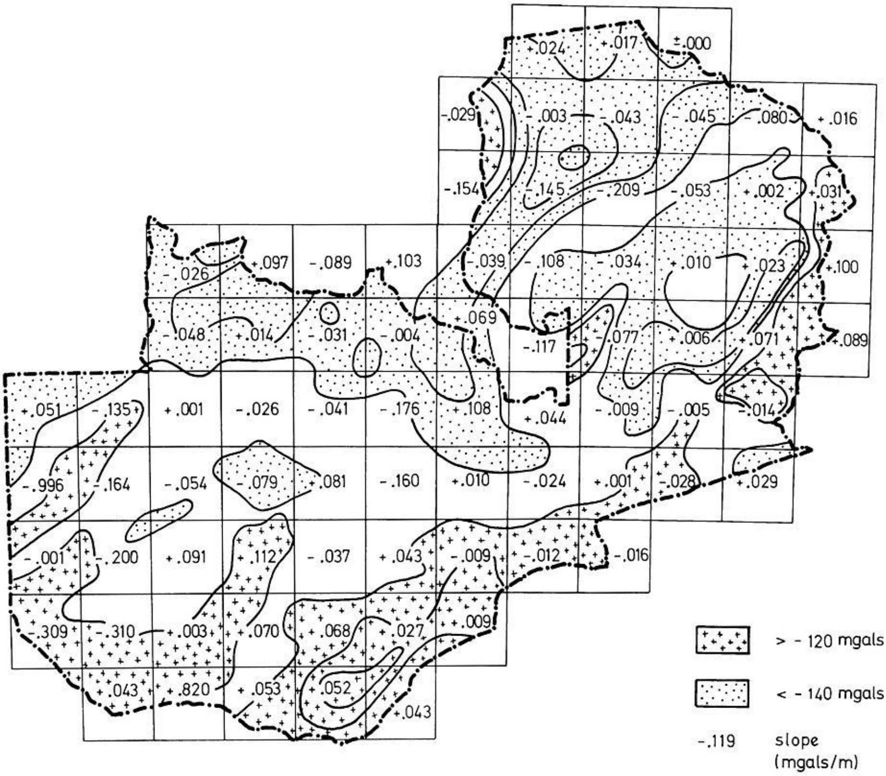

Fig. 4. Simplified Bouguer anomaly map and slopes as derived from *BA-H* relations within 1° × 1° unit areas of Zambia

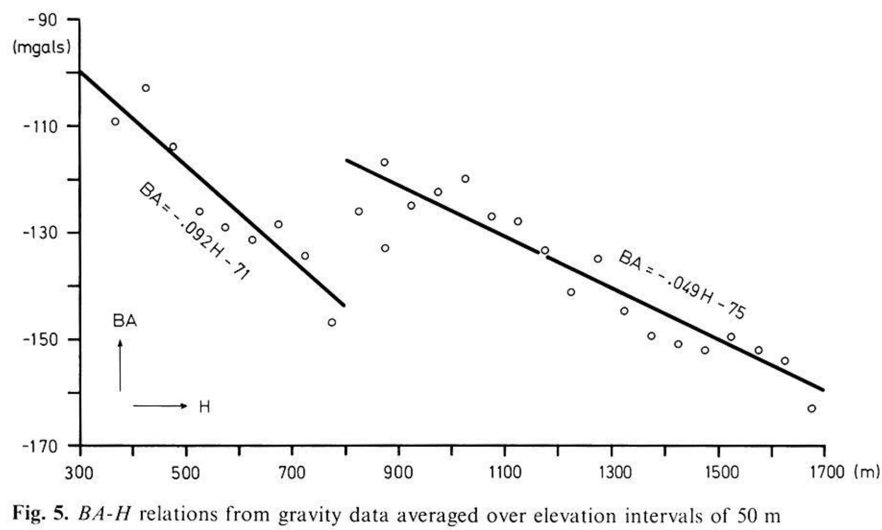

Fig. 5. *BA-H* relations from gravity data averaged over elevation intervals of 50 m

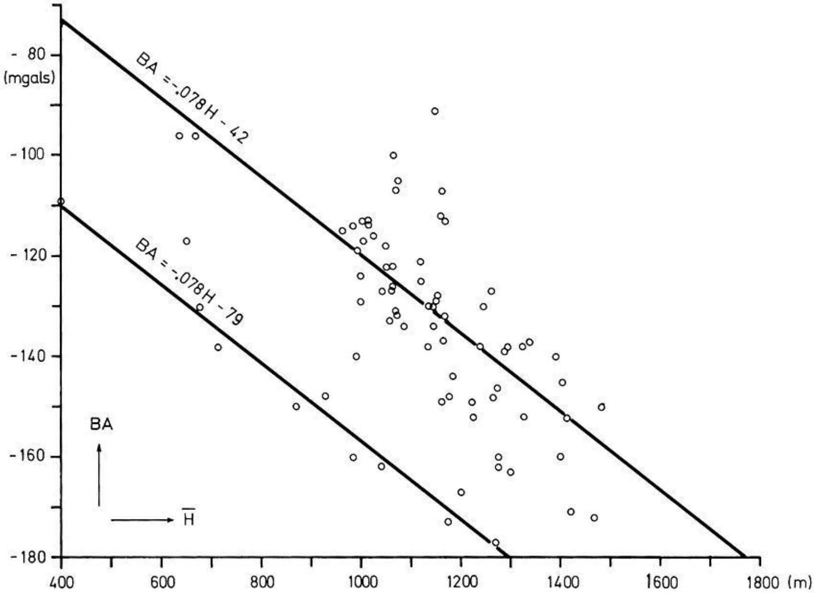

Fig. 6. *BA-H* relations from 1° × 1° mean values

Valleys, Lake Tanganyika) whereas large slopes occur in areas of extremely smooth topography (Western Province). Superimposed on Figure 4 is a simplified version of the provisional Bouguer anomaly map of Zambia (Mazac and Töpfer, 1974). Large anomaly "lows" are observed towards the northern border of Zambia and part of the Luangwa Valley, and gravity "highs" occur at the southern and eastern borders of Zambia. In general, Bouguer anomalies seem to increase from NE to SE. There is no correlation apparent between Bouguer anomalies and slopes as derived from *BA-H* regression analysis.

3.2. Correlation of Mean Pairs of FA-H and BA-H Values Using Different Averaging Techniques

Correlation of mean gravity anomalies to elevation, as averaged over elevation intervals of 50 m, apparently result in two regression lines, see Figure 5. Relations between the elevation interval of 300 to 800 m indicate relatively small gradients of +0.019 mgals/m for the *FA-H* correlation and relatively large gradients of −0.092 mgals/m for the *BA-H* correlation, see Table 1. This elevation interval corresponds with the Luangwa- and mid-Zambezi Valleys and the extreme north of Zambia (Lake Tanganyika). Intermediate gradients of +0.062 mgals/m and −0.049 mgals/m are observed for the elevation interval of 800–1700 m, see Table 1.

The linear regression analysis of 1° × 1° mean gravity anomalies versus 1° × 1° mean elevation results in two, approximately parallel lines, with gradients of +0.034 mgals/m for FA-H relations and −0.078 mgals/m, for BA-H relations,

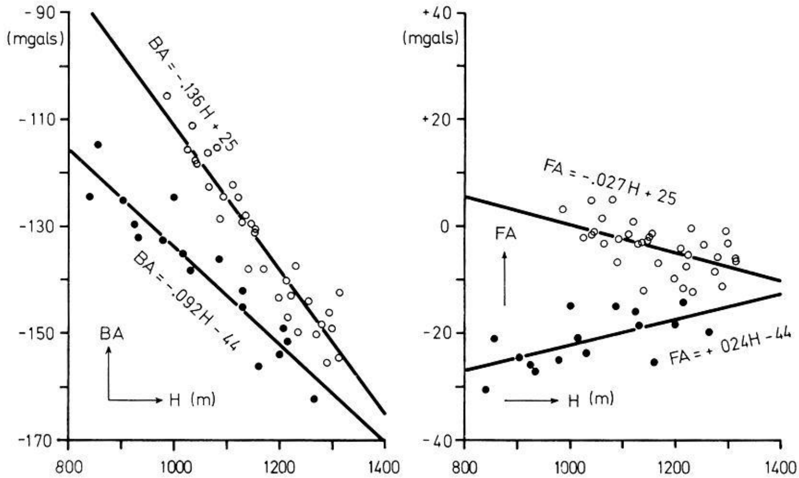

Fig. 7. *BA-H-* and *FA-H*-relations from 3° × 3° mean values

see Table 1 and Figure 6. Both lines are offset by about 40 mgals. The lower intercept of −79 mgls corresponds with 1° × 1° unit areas which include the Luangwa- and mid-Zambezi Valleys and Lake Tanganyika. It is also worth nothing the relatively high correlation coefficient of +0.97 and −0.98 for this latter regressions, respectively, see Table 1.

Correlation analysis between 3° × 3° mean gravity anomalies and 3° × 3° mean elevation results in two lines, repectively, which apparently intersect, see Figure 7. Points of intersection are 1450 m and −12 mgals for the FA-H relations, and 1525 m and −182 mgals for the BA-H relations. The positive intercepts of +25 mgals and the negative slope of −0.027 mgals/m for the *FA-H* relation is of interest, see Table 1. The negative intercept of −44 mgals is observed for 3° × 3° unit areas which include the Luangwa- and mid-Zambezi Valleys and the extreme north of Zambia.

4. Discussion of Results

Individual data deviate considerably in part from the evaluated linear regression fits, see Figures 5–7, although correlation coefficients may be as high as 0.98, see Table 1. It is suggested that local near-surface geological effects are the main cause of this observed scatter of data. This interpretation may be supported by the complex geology of Zambia, which dates from quaternary and tertiary sediments and sediments of the Karroo System (250 m.y.) to metasediments of the Katanga System (600–1300 m.y.) and basements rocks of the Bangweulu Block (1100–2500 m.y.) (Drysdall et al., 1972). In fact, mean gravity anomalies averaged over 1° × 1° unit areas show standard deviations between ±5 mgals and ±30 mgals, a range which may well be explained by near-surface geological effects. It is therefore concluded that neither FA-H nor BA-H relations can be used as gravity predictors in Zambia.

Regression parameters for BA-H relations whereby gravity anomalies are averaged over 50 m elevation intervals, indicate a gradient of −0.092 mgals/m

Table 2. Relations of Bouguer anomalies to elevation in Africa (Woollard, 1969)

Region or country	1° × 1° mean values			3° × 3° mean values		
	Elevation (m) from – to	Intercept (mgals)	Slope (mgals/m)	Elevation (m) from – to	Intercept (mgals)	Slope (mgals/m)
Central and North Africa	0–350 350+	+20 −20	−0.172 −0.050	0–200 200+	+24 + 4	−0.184 −0.072
Equatorial	350+	−57	−0.063	350+	−57	−0.063
Zambia[a]	400–1500	−73	−0.055	800–1400	−42	−0.083
South Africa	0–350 350+	+20 −37	−0.231 −0.061	700+	−20	−0.073

[a] Average regression parameters from present study

for lowlands of Zambia, whereas highlands are characterized by a gradient of −0.049 mgals/m, the transition being at an elevation of about 800 m. The split into a "lowland-correlation" and a "highland correlation" apparently is a world-wide phenomena, although magnitudes of slope and intercept as well as the "transitional elevation" vary considerably (Woollard, 1969; Qureshy, 1971).

In Central and North Africa, the 1° × 1° mean correlations show a transitional elevation of 350 m, whereas 3° × 3° mean correlations indicate transitional elevations between 200 m and 700 m above sea-level, see Table 2 (Woollard, 1969). 1° × 1° and 3° × 3° mean regression analysis for Zambian data do not indicate a transitional elevation but rather show two separate regression lines which are representative for the whole range of elevations, see Table 1.

It is also apparent from Table 1 that regression parameters are not the same for different correlation techniques applied to Zambian data. In general it appears that absolute intercepts decrease and absolute slopes for *BA-H* relations increase (slopes for *FA-H* relations consequently decrease) with increasing mode of smoothing, see Table 1. It is suggested that smoothed gravity anomalies (i.e. 1° × 1° and/or 3° × 3° mean values) represent mainly the regional gravity field since short wavelength gravity effects are filtered out during the averaging process. It becomes therefore obvious that regression parameters as derived from data of different mode of smoothing are of different geophysical significance and must thus be interpreted separately.

Wollard (1969) derived a theoretical BA-H relation (from 3° × 3° mean values) based on the hypothetical model of isostatic equilibrium as proposed by Airy (1855): $BA = \overline{FA} - 0.1119\ H$, where $\overline{FA}$ is the mean free-air anomaly of the region. Garland (1971) interpretes Woollard's results and states that "different values of intercept indicate abnormal crustal density and different gradients are thought to show departure from perfect compensation of the topography". The average intercept for the 3° × 3° mean regression analysis is −42 mgals, see Table 1, whereas the mean free-air anomaly for the whole of Zambia is found to be −9 mgals. Also, the gradient of −0.083 mgals/m for the 3° × 3° BA-H relation differs significantly from Woollard's theoretical gradient, see Table 1. According to Garland (1971) this would infer that the crust in Zambia is not in isostatic equilibrium. However, this interpretation of regression results for Zambia seems to be unlikely, since the last orogenic episode, the Lufilian Arc (Damara-Katanga Belt), occurred in late Precambrian times (Drysdall, Johnson, Moore and Thieme, 1972). An alternative model may be "thinning of the lithosphere" with associated rifting in Zambia (Searle, 1970; Fairhead and Girdler, 1972; Chapman and Pollack, 1975; Girdler, 1975).

5. Conclusions

Relations of *FA*- and *BA*-anomalies to elevation, as derived for Zambia, cannot be used for the interpolation and/or extrapolation of gravity data. Large scatter of individual data is thought to reflect the gravity effect of the near-surface geology. The "US standard relation" which is based on the "US normal crust" (Woollard, 1969), apparently does not hold for Zambia. All discussed relations of gravity to elevation indicate different regression parameters for areas including the Luangwa- and mid-Zambezi Valleys and the extreme north of Zambia (Lake Tanganyika) as compared to the rest of the country.

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