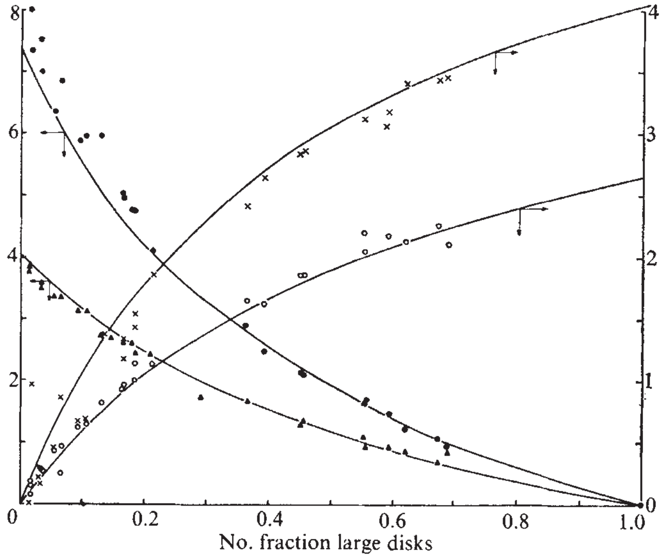

Fig. 2 Comparison of coordination points from the model with the computer simulation. Diameter ratio 2.5. Values of ij from the model multiplied by the compaction factor are shown as curves, and computer simulation results are shown as points: ▲, p_{11}; ○, p_{12}; ●, p_{21}; ×, p_{22}.

for an adhesional probability of 0%. Here the model is concerned only with geometrical factors and relates to an idealised compact gapless packing, with an average total coordination number of 6. The computer simulation includes mechanical factors to a certain extent and gives values for a more realistic packing with a constant average total coordination number of 4.02 ± 0.04 for all mixtures considered here. This geometrical invariant may be used to define a 'compaction factor' which represents the degree to which mechanical factors allow real packings (here computer simulated) to approach the geometry of the idealised packing. In this case the factor is $4.02/6.00 = 0.67$. Multiplying by this factor allows the different coordination numbers obtained from the model to be compared with the computer simulation. The figures show this comparison. Figure 1 (analogous to Fig. 3 in ref. 1) shows values of t_{ij} from the model as smooth curves and results from the computer simulation as points; the agreement is excellent. Figure 2 (analogous to Fig. 6 in ref. 2) gives values of p_{ij} from the model multiplied by the compaction factor as smooth curves and the results from the computer simulation as points. The agreement is excellent which indicates the concept of the compaction factor.

The comparison between the coordination numbers for two-dimensional binary random disk packings as calculated by computer simulation and a theoretical model shows a good agreement between the two methods. Notably the invariability of the average total coordination number with size ratios and mixture proportions is confirmed. This allows the definition of a 'compaction factor' which allows the results of the theoretical model for an idealised gapless packing to be used to calculate coordination numbers for real packings.

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Gravity in Zambia

A RECONNAISSANCE gravity survey of the Republic of Zambia was carried out from 1971 to 1975 by the Geological Survey of Zambia in collaboration with the University of Zambia and The University of Michigan[1]. We present here a Bouguer anomaly map and preliminary analysis of the gravity data, in the context of the principal tectonic elements and structural characteristics of eastern and southern Africa.

Zambia is situated on the Central African Plateau which slopes gently from an elevation of 1,000 m in the south and west of Zambia to a maximum elevation of >2,000 m in the north-east. The characteristic gently sloping terrain is broken in the extreme north by the Tanganyika and Mweru rifts and in the east and south, respectively, by the Luangwa and mid-Zambezi rifts, which contain Karroo (Permo-Triassic) sediments and volcanic rocks. The plateau comprises principally Pan-African (450–750 Myr) and older igneous and metamorphic basement rocks. In the west, the basement is in places broken by fault block basins, but the distribution of these is obscured by a blanket of Quaternary Kalahari sands.

Over 2,700 gravity stations were established along the primary and secondary road network of Zambia, at approximately 10–15-km intervals, with a characteristic density of one station per 400 km^2. All stations were referenced to the previously established East African primary net[2]. Free-air and simple Bouguer anomalies were calculated using the 1930 International Gravity Formula and a density of 2.67 g cm^{-3}. Elevations for about one-third of the stations were taken from topographic map contours; at the remaining stations, elevations were determined with aneroid barometers. A mean uncertainty of ± 2 mgal, arising principally from uncertainties in elevation, is typical.

Our Bouguer anomaly map of Zambia (Fig. 1) shows Bouguer anomalies ranging between −200 and −75 mgal, with a mean near −140 mgal. The regions in the north and northwest marked by the −160-mgal contour lie along the axis of the so-called Great Negative Bouguer Gravity Anomaly[3] of Africa; the long and continuous −120-mgal contour in the south marks its approximate southern boundary. The overall grain of the map is dominantly northeast–southwest, a tectonic trend which is prominently displayed by the Upemba graben in southern Zaire, the Mweru and Luangwa rifts, the middle Zambezi valley, and which continues to the south-west into northern Botswana[4].

Some of the individual features of the map can be clearly identified with structural elements, the best example being the elongated gravity trough in eastern Zambia which coincides closely with the Luangwa rift. The southern terminus of the Tanganyika rift, and the northern margin of the Zambezi rift along Lake Kariba also show gravity depressions. The arcuate trend of the −140-mgal contour in the northern part of central and western Zambia follows closely the curvature of the Lufilian arc, a Pan-African age structural element that hosts the rich copper mineralisation of Zambia and southern Zaire. The moderate gravity depression in central western Zambia is associated with a zone of persistent seismic activity[5]; the large nearly circular depression in northern Zambia lies within a region of Pre-cambrian platform sediments, and could represent a small sedimentary basin.

Three regions show prominent gravity highs: the eastern border with Malawi, the region south of Lake Mweru, and the region north of Lake Kariba. In each of these areas the anomalies reach −80 mgal with gravity relief of at least 40 mgal. These highs are not associated with any obvious structural elements or topographic settings; they are in areas with elevations of 900–1,800 m.

Residual anomalies were obtained by subtracting a smooth regional anomaly field from the observed Bouguer anomaly field. The regional pattern was estimated by a number of techniques, including free-hand smoothing, Fourier and polynomial surface-fitting methods, and a mean anomaly against elevation parameterisation. Each representation of the regional field yielded different residuals, but some anomalous regions were common to all of the residual fields. Those regions, each with residual anomalies > 20 mgal (inset map of Fig. 1) display a north-east–south-west grain, as does the anomaly map. The most prominent feature is the chain of positive residuals extending from south-western Zambia north-eastward along the southern margin of the country. This remarkable feature merely traverses Zambia; it can be traced south-westward through Botswana to the Namibia border[4], and continues north-eastward into the Malawi highlands[6], approaching 2,000 km in length. This prominent positive residual buttresses the southern margin of the Great Negative Anomaly throughout central Africa.

The negative residual over the Luangwa rift arises from the low-density Karroo sedimentary fill. A similar residual probably exists in the mid-Zambezi valley beneath Lake Kariba, but it has not been confirmed due to a lack of data from the valley and beyond in Rhodesia. The negative residual which extends from the north across the Zaire pedicle into the Zambian Copperbelt possibly reflects relatively thick sedimentary accumulations in the north, but is associated with the Copperbelt granites at its south-western terminus.

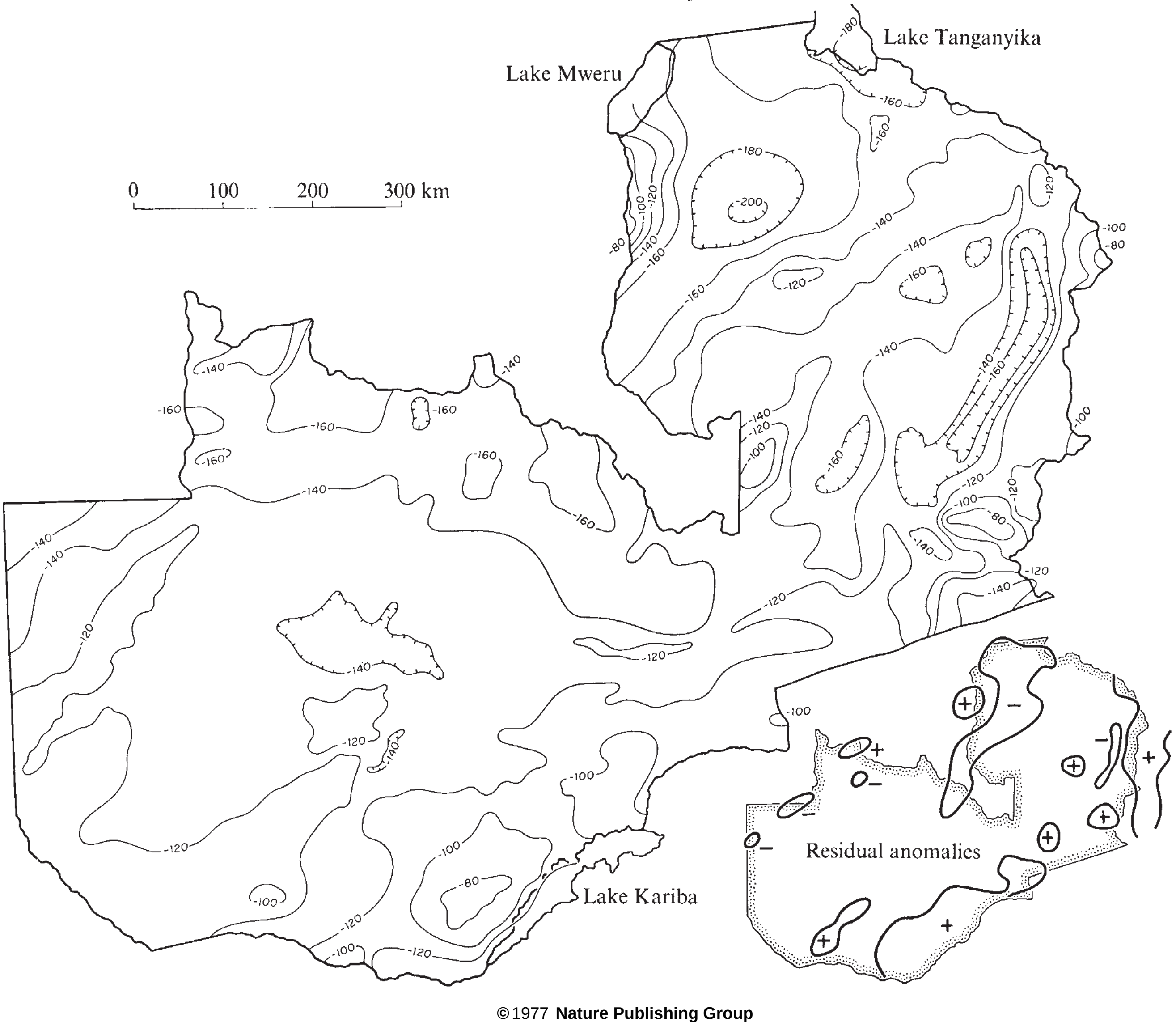
A scatter plot of Bouguer anomalies against elevation is shown in Fig. 2*a*. Stations at < 800-m elevation lie exclusively within the Luangwa, Zambezi and Tanganyika troughs, and thus afford an opportunity to compare gravity variations in rift and non-rift settings. Regression lines were fitted to mean Bouguer anomalies and mean elevations in each 100-m elevation interval; these lines are shown in Fig. 2 and their parameters in Table 1, with similar, earlier analyses from east Africa[7,8].

The Zambia and Kenya regression lines have similar slopes in their respective rift and non-rift settings, but the Zambian intercepts in both settings are substantially more negative. The Zambian line for non-rift stations is almost the same as that determined by Woollard for 3°×3° mean anomalies in east Africa.

The different slopes in rift and non-rift areas implies different densities in the two settings, and suggests contrasting crustal and upper mantle structures. The significance of the different intercepts is unclear, but the differences may stem from the fact that in Woollard's[8] and our analyses, the lines were fitted to mean anomalies, while Khan and Mansfield[7] presented a subset of their individual station data, which may be biased away from the regional mean.

Free-air anomalies are also of interest because they can give to a first order an estimate of how closely a region approaches isostatic equilibrium. When isostasy prevails, free-air anomalies are usually less than a few tens of mgal, distributed randomly about zero, and show very little dependence on elevation. Woollard[8] gives an empirical relationship between free-air anomalies and elevation in isostatic regions as $FA = 0.0075h–6$, where FA is the free-air anomaly in mgal and h is the elevation in m.

Fig. 1 Bouguer gravity anomaly map of Zambia. Contour interval 20 mgal. Reduction density 2.67 g cm^{-3}. Inset map shows residual anomalies > 20 mgal.



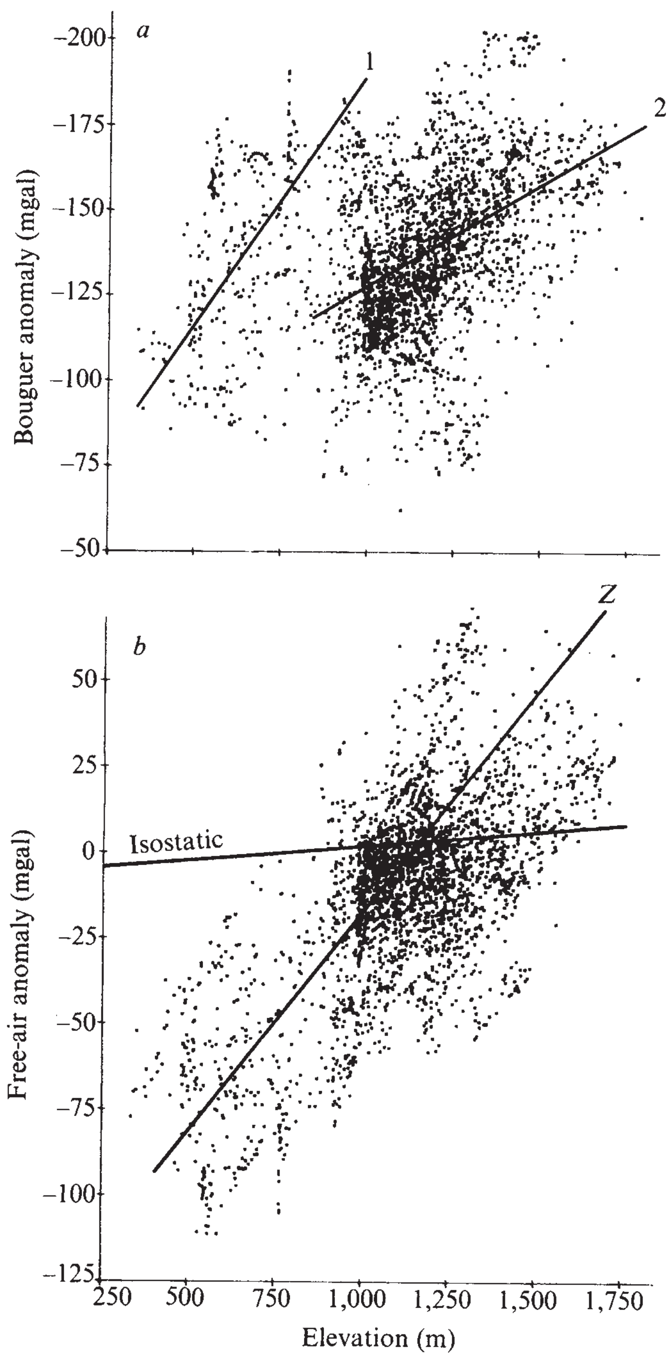


Fig. 2 *a*, Scatter plot of Bouguer anomalies against elevation, with regression lines for rift (1) and non-rift (2) stations. *b*, Scatter plot of free air anomalies against elevation. Line labelled Z represents Zambian data; line labelled 'Isostatic' represents empirical relationship of Woollard[8]. Both lines are fitted to mean anomalies and elevations within 100-m intervals.

Figure 2*b* is a scatter plot of free-air anomalies against elevation for Zambia, and shows a clear departure from the isostatic relationship and an obvious dependence of anomalies on elevation. Such a dependence of free-air anomalies on elevation is not uncommon in regions of considerable relief, but in Zambia, apart from the escarpments adjacent to the rifts, the terrain is very gentle.

It is, therefore, possible that the Central African Plateau may not be in isostatic equilibrium. Woollard[8] notes that a plateau undergoing uplift can exhibit a regional departure from isostasy. Considerable evidence is accumulating that suggests that this part of central Africa is dynamic and responding to tectonic stress. Widely distributed earthquake epicentres[5], tensional focal mechanisms[9,10], anomalous heat flow[11] and disrupted drainage as shown on satellite photography together make an interesting if not compelling case for contemporary tectonism (incipient rifting) in the Central African Plateau. In such a context, it seems possible that isostasy is yet to be fully established in this current phase of tectonism. If tensional block faulting continues, however, and becomes more widespread in the Central African Plateau, a restoration of isostatic equilibrium will probably follow.

Table 1 Regressions of Bouguer anomalies (mgal) on elevation (*h*, m)

	Zambia	Kenya[7]	East Africa[8] (3°×3° mean anomalies)
Rift	−0.15*h* −41	−0.137*h* −4.31	
Non-rift	−0.06*h* −67	−0.082*h* −5.85	−0.063*h* −57

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Electrical conductivity and tectonics of Scotland

A REGION of anomalously high electrical conductivity in southern Scotland, known as the Eskdalemuir anomaly, has been discovered and mapped, in terms of related anomalies in time-varying geomagnetic disturbance fields[1,2]. Magnetotelluric soundings[3] have indicated the depth of the conductor as 12 km, at which depth Jacob[4] has reported an anomaly in seismic wave velocities. Bamford and Prodehl[5] have also found anomalous seismic wave velocities in this region. In 1973 the University of Edinburgh operated two magnetometer arrays which together covered nearly all of Scotland. In each array 20 three-component recording magnetometers of Gough–Reitzel type[6] were operated for 6–8 weeks. These arrays, together with extended magnetotelluric study of the Eskdalemuir anomaly[7], now make possible a fuller description and interpretation of conductive structures. Data from stations north of the Midland Valley, where only limited geomagnetic variation studies [8,9] had preceded ours, indicate further regions of anomalously high conductivity in Scotland. Full discussion and analysis of these data will be presented elsewhere. This note gives some preliminary indications of these conductivity anomalies and suggests possible tectonic implications.

Time-varying magnetic fields associated with induced currents in the solid earth, which may delineate conductive structures, are superposed on the source field due to currents in the magnetosphere and ionosphere. At the geomagnetic latitude of Scotland,