J. Geophys. 42, 225 – 236, 1976

Journal of Geophysics

Provisional Seismicity Map of the Republic of Zambia and Its Preliminary Interpretation *

K.D. Töpfer**

University of Zambia, School of Natural Sciences, P.O. Box 2379, Lusaka, Republic of Zambia

Abstract. The provisional seismicity map of the Republic of Zambia has been compiled from data made available by Goetz Observatory, Rhodesia, for the period from 1966 to 1972.

Seismicity anomalies have been compared with the Provisional Gravity Map and the Geological Map of Zambia. Seismicity highs are closely associated with negative Bouguer anomalies and the distribution of zones of zero to moderate seismic activity seems to be related to the regional geology of Zambia. It appears that seismicity is not directly related to the geochronological history of Zambia.

Key words: Seismicity – Gravity – Geology.

1. Introduction

Little attention has been paid to seismic events occuring in Southern Africa (Africa south of the Equator) until recently, when the Pan-African Rift system was intensively studied geophysically, (Henning, 1937; Porstendorfer and Kuhn, 1966; Girdler, 1968; Fairhead and Girdler, 1969; Girdler and Sowerbutts, 1970; Chapman and Pollack, in preparation; de Beer et al., in preparation), and when large man- made laes (i.e. Lake Karika) increased seismic activity in a limited area (Gough and Gough, 1970).

This present paper aims to present seismological data of the Republic of Zambia for the period 1966 and 1972. The Provisional Seismicity Map is compared with the regional geology and the Gravity Map of Zambia.

Possible rifting within Zambia is out of the scope of this present paper, but will be discussed on a more Pan-African scale in a separate paper (Töpfer, in preparation).

---

* To Prof. Dr. M. Toperczer on the occasion of his 75th birthday

** Address for offprint requests: Lehrkanzel für Geophysik der Universität, Hohe Warte 38, A-1190 Wien, Austria

2. Seismic Network in Southern Africa and Data Collection

Seismological research in Southern Africa has been limited mainly by the inadequate network of observatories, see Figure 1.

A reasonable distribution of seismic observatories exists only in the Republic of South Africa and in Rhodesia (Zimbabwe). Observatories in many other countries have operated only sporadically. The absence of a Southern African Data Center is also regrettable.

Two seismic observatories exist within the Republic of Zambia. LUS is operated by the University of Zambia and BHA is incorporated in the Rhodesian network of observatories.

All data for this present study were taken from available Seismological Bulletins of Goetz Observatory, Bulawayo, Rhodesia, (Archer, 1966–1972) and from Seismological Bulletins of the LUS Observatory, Lusaka, Zambia (Chander, 1971–1974).

Locations of observatories from which data were obtained, are given in Table 1.

The number of listed earthquakes occuring within Zambia apparently decreased from 1966 to 1972, see Figure 2. It is believed that this may be due to administrative changes at Goetz Observatory. Epicenters of earthquakes of magnitudes $mb \geqq 2.5$ only were listed from 1971 onwards, whereas all visible events were interpretated in previous years.

Fig. 1. Network of seismic observatories in Southern Africa

Table 1. Locations of seismic observatories

Symb	Location	Country	Lat (S)	Long (E)	Altitude (m)
BHA	Kabwe	Zambia	14 26.8′	28 28.1′	1,206
LUS	Lusaka	Zambia	15 22.8′	28 19.8′	1,259
CLK	Chileka	Malawi	15 40.8′	34 58.6′	781
MTD	Mount Darwin	Rhodesia	16 46.8′	31 35.0′	967
KRR	Karoi	Rhodesia	16 51.1′	29 37.1′	1,380
BUL	Bulawayo	Rhodesia	20 08.6′	28 36.8′	1,341
CIR	Chiredzi	Rhodesia	21 00.8′	31 34.8′	430

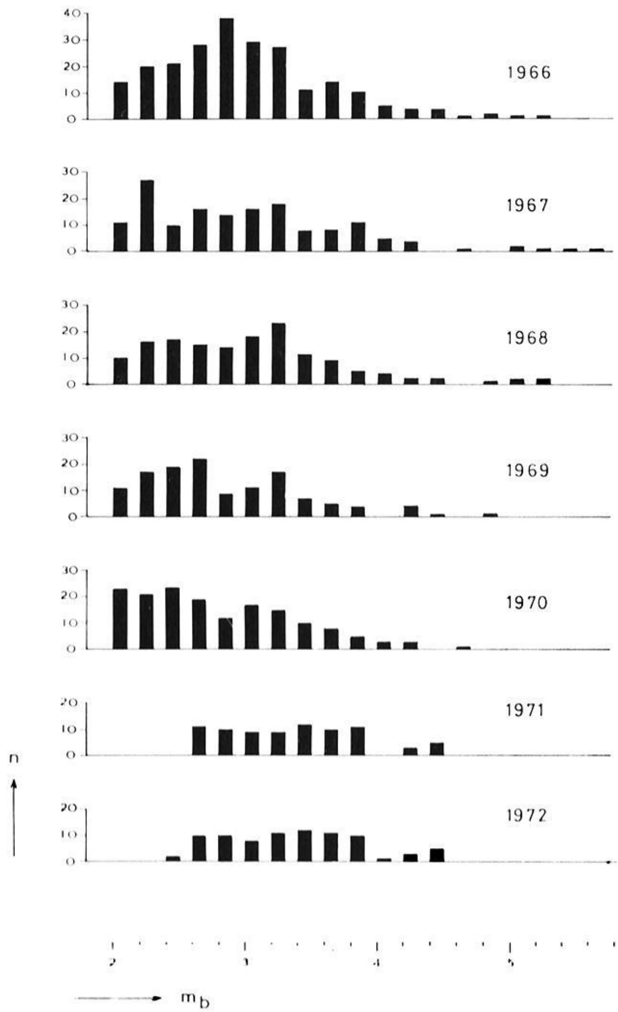

Fig. 2. Yearly distribution of earthquakes with epicenters within Zambia during the period 1966–1972

3. Statistical Analysis of Data

The yearly distribution of the number of events as function of magnitude *mb* is represented in Figure 2.

Magnitude estimates given in the Seismological Bulletins of Goetz Observatory are thought to be comparible with Gutenberg and Richter's *mb*, although they are based on crustal rather than body waves (Archer, 1969).

Only a few medium intense tremors of magnitudes $mb \geqq 5$ were recorded during the years 1966–1972. The majority of recorded earthquakes have magnitudes between $2 \leqq mb \leqq 4$. Many of the reported earthquakes with magnitudes $2 \leqq mb \leqq 3.5$ were located around the man-made Lake Kariba, along the mid-Zambesi Valley.

The distribution of earthquakes in magnitude is shown in Figure 3. The distribution appears to be linear for the range $3 \leqq mb \leqq 5{,}7$ and the least-squares fitted line gives

$$\log N = 3.87 - 0.71\, m_b \qquad (1)$$

obeying the relationship introduced by Gutenberg and Richter (1954)

$$\log N = a - b\, m_b \qquad (2)$$

which has proved to be valid elsewhere on the globe.

The constant *b* for Zambia is within the range of 0.6–1.2 which is found worldwide, (Schick and Schneider, 1973). Bath and Anderson (1968) used the earthquake catalougue published by Gutenberg and Richter (1954) for earthquakes

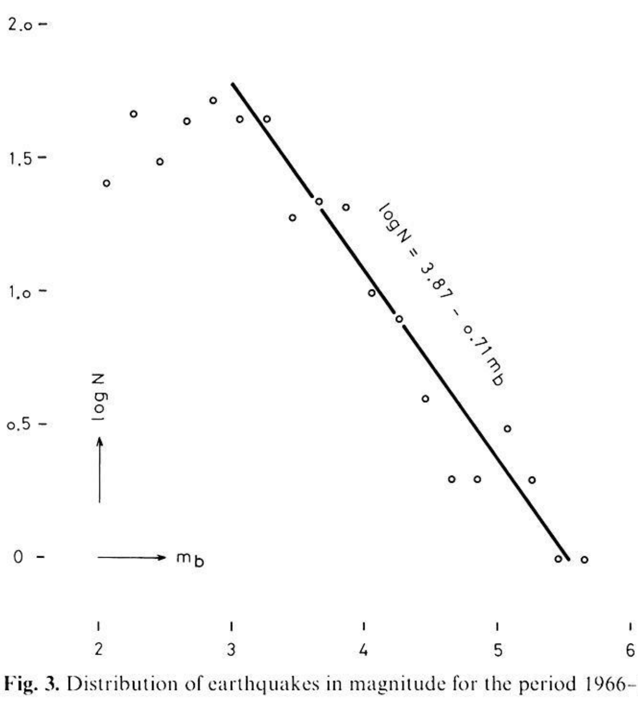

Fig. 3. Distribution of earthquakes in magnitude for the period 1966–1972

of $mb > 5$ during the period 1904–1952 and derived the relationship

$$\log N = 5.25 - 0.71\, mb .$$

An analysis of earthquakes of magnitude $mb > 5$ compiled by Sykes and Landisman (1964) for the period 1955–1964 resulted in the relationship $\log N = 4.98 - 0.71\, mb$ (Bath and Anderson, 1968).

The constant "b" is remarkable constant whereas the intercept "a" apparently decreases from 1904 to 1972.

4. Provisional Seismicity Map of the Republic of Zambia [1]

The number of earthquakes which occured within Zambia during the period 1966 to 1972 is contoured in arbitrary intervals of 0, 1, 2–3, 4, 5–9, 10–20 and >20, regardless of the magnitude of these tremors, see Figure 4.

Epicenters of earthquakes are related to the center of a $0.5° \times 0.5°$ grid pattern laid over the territory of the Republic of Zambia, applying a moving average technique. This procedure is somewhat unusual in seismological research but is in wide use in the representation of gravity and magnetic data in exploration geophysics.

It results in relative smooth iso-lines and seismicity "highs" and "lows" are readily shown. This applied technique may certainly result in errors of approximately ± 60 km in the location of iso-lines. This estimated error is not considered to be too serious since epicenters of earthquakes as listed by Goetz Observatory are thought to be located to an accuracy in the order of 50 km (Reeves, 1972).

Iso-seismicity lines, representing areas of relatively low or zero seismicity during the period 1966 to 1972, follow approximately a north-easterly trend, see Figure 4. This trend is also observed on the Geological Map (Reeve, 1961) and the Provisional Gravity Map (Masac and Töpfer, 1974), of the Republic of Zambia (see also Chapter 5).

Zones of relatively high seismicity show a north-south trend from latitude 12° S to 18° S and anorth north-easterly trend from latitude 12° S to 8° S. This trend is not apparent in the geological map and may therefore be related to the Pan-African rift system.

Five major zones of relatively high seismic activity are recognized on the presented seismicity map, see Figure 4. The seismicity high in the area along Lake Kariba in the South of Zambia is related to positive Bouguer anomalies, whereas the remaining zones of relatively high seismic activity are related to large negative Bouguer anomalies.

---

[1] Seismicity has been defined in this paper as

$$S = \frac{n}{\Delta F \cdot \Delta t}$$

(number of earthquakes per year and unit area of $0.5° \times 0.5°$)

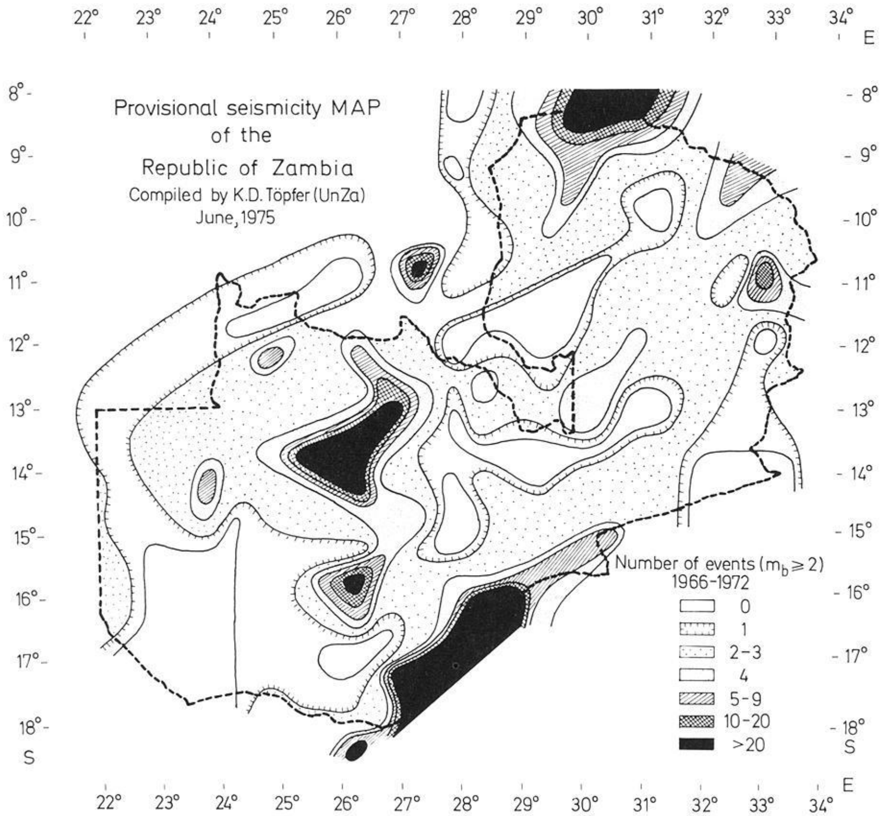

Fig. 4. Provisional seismicity map of Zambia

4.1. Lake Kariba High

All epicenters of this zone of high seismic activity lie in or near the down-faulted rift valley of the mid-Zambezi. A large number of earthquakes were recorded since man-made Lake Kariba was filled in 1963 and it is believed that the lake has re-activated the existing faults formed since late Precambrian times.

Earthquakes of magnitudes $M \geqq 5$ and epicenters in Southern Africa were listed for the period 1904 to 1952 by Gutenberg and Richter (1954) and for the period 1955 to 1964 by Sykes and Landisman (1964). No earthquake was reported from the mid-Zambezi Valley until August 1963 when Lake Kariba reached almost its full capacity. Although it seems to be evident that no intensive earthquakes occured prior to the completion of Lake Kariba, it remains unknown whether this area was inactive or shaken by tremors of relatively small magnitudes.

Gough and Gough (1970) estimated that the elastic strain energy of 5.5×10^{24} ergs is stored in the lithosphere as a result of release of gravitational energy during depression of the rock in a limited volume.

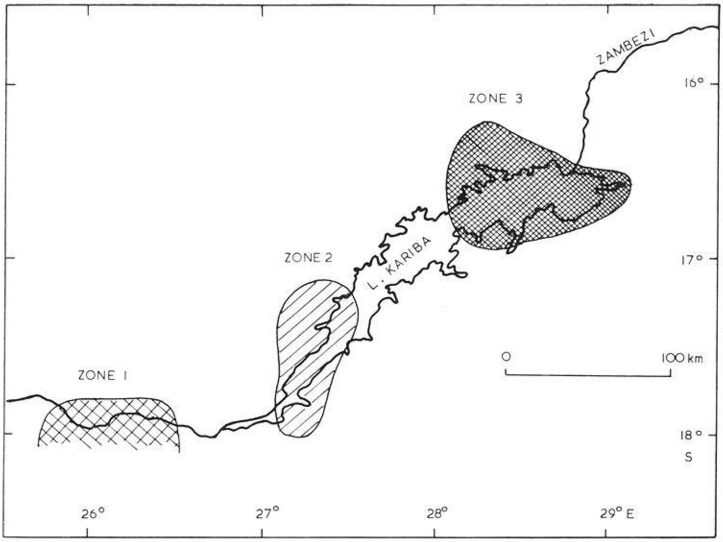

Fig. 5. Seismic energy radiation at Lake Kariba

The elongated seismicity high, which extends from longitude 26° E to 30.5° E, see Figure 4, is resolved into three relatively small zones of high seismic energy radiation, see Figure 5: Zone 1 has an approximate center at 26.3° E/18.2° S, Zone 2 at 27.5° E/17.3° S and Zone 3 at 28.3° E/16.8° S.

Zone 1 occurs approximately 80 km west of the shore line of Lake Kariba and is believed not to be affected by the triggering effect of increasing load. It is more likely that this zone is related to the Pan-African system of rifting.

Zone 2 is associated with the Binga Fault at the south-western shore of Lake Kariba. This zone is believed to have been active before the lake filled (Gough and Gough, 1970).

Zone 3 is located in and near the Sanyti Basin of Lake Kariba, where the water level is highest, and represents the main seismic activity within the lake.

4.2. Namwala and Kasempa Highs

Two seismic active zones occur at Namwala and south of Kasempa, both approximately at longitude 26° E and with centers at latitudes 15.75° S and 14° S, respectively. Both seismicity highs are associated with relatively large negative Bouguer anomalies, see Figure 6.

The gravity low and the seismicity high at the Namwala Anomaly correspond exactly, whereas a displacement of approximately 60 km may be apparent at the Kasempa Anomaly. This displacement may be however fictitious because of the estimated inherent error of ± 60 km in the seismicity map.

The estimated regional gradient of the gravity profile along longitude 26° E is -67 mgal per 1000 km south-north and gradients of -700 mgal and -1500 mgal per 1000 km are evident at Namwala and Kasempa Highs, respectively.

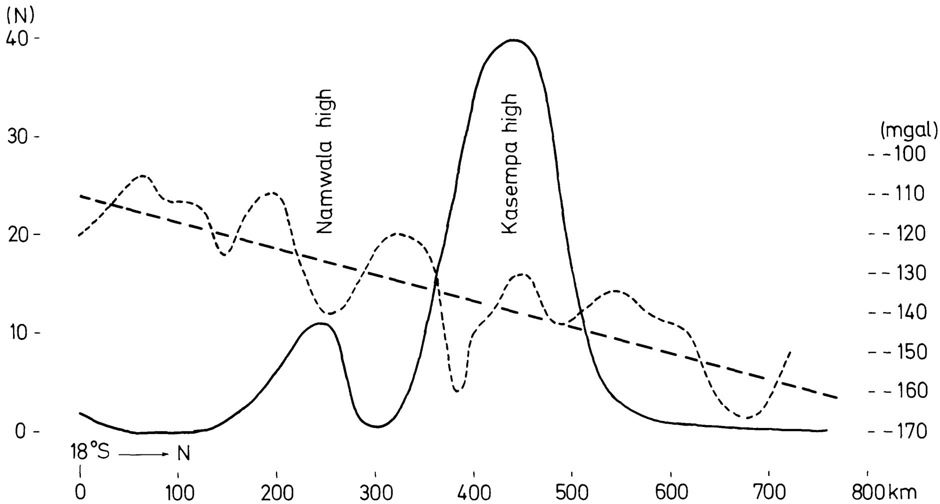

Fig. 6. Seismicity and Bouguer anomaly profiles along longitude 26° E

Although no modelling has yet been attempted to date to interprete the negative anomalies at Namwala and Kasempa, the half-width rule suggests that both gravity anomalies are caused by anomalous mass distributions within the crust.

4.3. Lake Retenue High

Seismic activity at man-made Lake Retenue, some 30 km east of Likasi, Zaire, at approximately 11° S and 27.3° E, is thought to follow the Pan-African system of rifting. No gravity data are available for this region.

4.4. Seismicity Highs in the North-East of Zambia

Three seismicity highs occur in the north and north-east of Zambia and are associated with large negative Bouguer anomalies. They are thought to be related to rifting in Southern Africa (Töpfer, in preparation). It is worth noting that the anomaly at approximately 33° E and 10.8° S is located at the north-eastern edge of the Luangwa Valley, whereas the valley itself shows only moderate seismic activity.

4.5. Seismicity Highs in the North-West of Zambia

The seismicity high at approximate latitude 12° S and longitude 25° E corresponds well with a gravity low (−180 mgals) whereas the seismicity high at 14.25° S and 23.75° E cannot be related to gravity because only few gravity data are available from this region.

5. Comparison of the Seismicity Map with the Geological Map of the Republic of Zambia

Two general trends are visible on the seismicity map of Zambia which may be related to pre-Katangan orogenic episodes which terminated periods of geosynclinal sedimentation: the N to NE Tumbide trend (1,600 m.y.) and the younger NE to ENE Irumide trend (1,000 m.y.) (Vail et al., 1968; Snelling et al., 1972).

The first intense folding of the Katanga System, characterized by the Lufilian Arc (500 m.y.), which is thought to be an extension of the Damara Belt in South-West Africa (Namibia) (van Eden and Binda, 1972), does not find its expression in the seismicity map of Zambia.

Vail (1968) notes that the post-Karroo (Mesozoic) and post-Tertiary Rift Valley fractures tend to follow the ancient orogenic belts, regardless of the age of the belts.

Zones of low and moderate seismic activity apparently resemble geological structures in shape, see Figure 7. This present paper does not attempt to explain this apparent resemblance nor does it go into much detail which would certainly involve the study of the tectonic fault pattern of Zambia. Many large fault systems in Zambia seem to be inactive at present (i.e. Luangwa Valley) so that a tectonic interpretation of the seismicity map becomes difficult.

The western part of Zambia is mainly underlain by rocks of Cretaceous Age (70 – 130 m.y.) in the far east, of Karroo Age (200–270 m.y.) in the south-west and of Katanga Age (600–950 m.y.) in the north. The boundary between Cretaceous and Karroo, stretching from approximately 14° S along 23° E to 17.5° E (Money, 1972), is comparible to the isoseismicity line of Figure 7 which separates the moderate active zone in the east from th non-active zone in the west.

The large area with no apparent seismic activity, extending approximately from 15° S to 18° S and from 22.5° E to 26° E can be compared to the large area in Western Providence which has been mapped to be underlain by Karroo rocks ($\pm 1°$ to the north). The narrow arm of Karroo rocks, which strikes north-westerly into Angola, is also indicated on the seismicity map.

The ENE-striking area of no recorded seismicity, with its center at 17.2° S and 26° E, is underlain mainly by acid igenous rocks believed to be Kibaran in age (1,300 m.y.).

The Namwala High, as discussed in Chapter 4.2, is associated with the Hook Granite Massif of Kibaran Age, whereas the Kasempa High cannot be interpreted on the basis of surface geology.

Areas underlain by rocks of Katanga Age in the Western and North-Western Provinces of Zambia are shown to be zones of moderate seismic activity (2–3 tremors per square grid during the period 1966–1972).

The large seismicity low which strikes NS in the west, from 12.7° S to 15.5° S and ENE from 27.3° E to 31.6° E, cannot be explained on the basis of a single geological unit. The NS-striking western part of the anomaly is underlain by metasediments of Katanga Age, whereas the ENE-striking eastern part follows the Irumide Fold Belt of the Kibaran Orogeny. The small seismicity low with its center at 11° S and 32.3° E also lies in this Fold Belt and may therefore be regarded as an extension of the large seismicity low in the south-east.

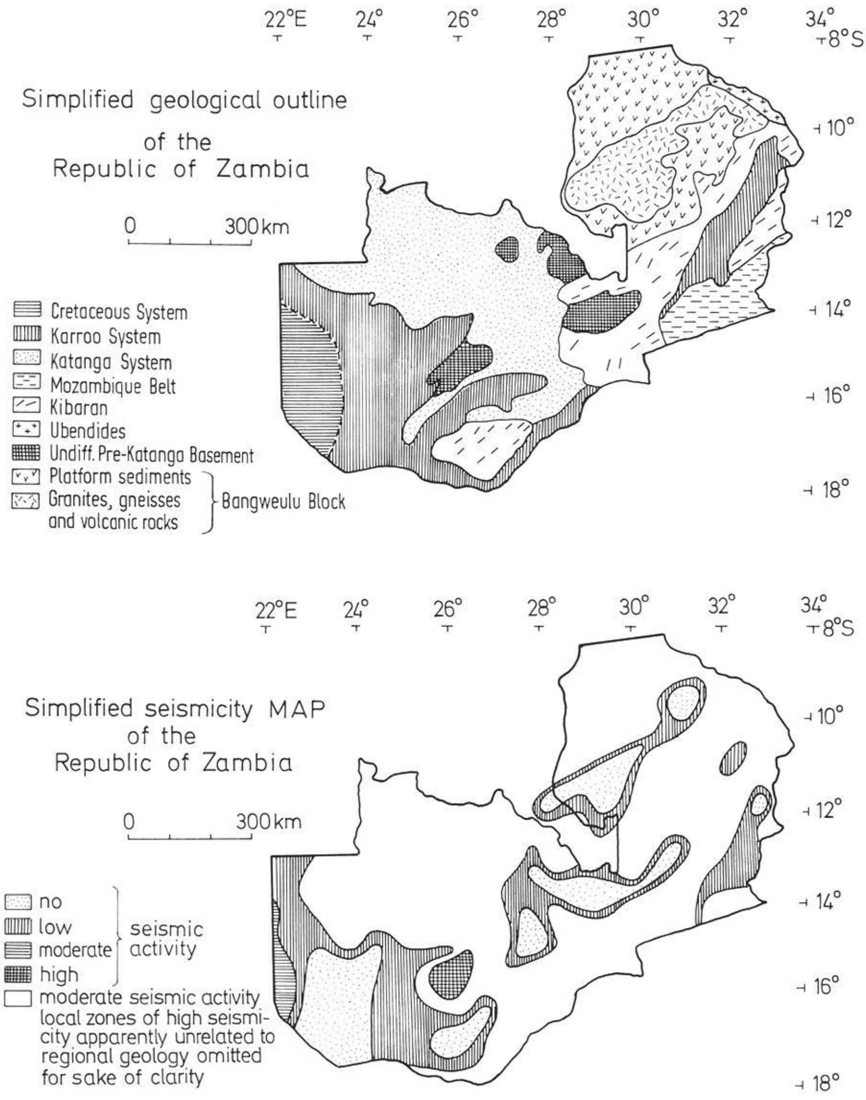

Fig. 7. Simplified seismicity map and geological outline of the Republic of Zambia

The large seismicity low striking approximately NS from 11.5° S to 14.5° S follows the Kibaran Belt in the north and the Mozambique Belt (380–470 m.y.) in the south.

The Luangwa Valley, an errosional valley (Johnson, 1975), which is often mistaken to represent an active rift valley, strikes north-east and is bound by the Irumide Fold Belt in the north and by the same belt and the Mozambique Belt in the south. The large system of faults in the upper Luangwa Valley is seismically inactive and might have been initiated in pre-Karroo times.

The elongated seismicity low, striking NE from 27.5° E and 12° S to 31.6° E and 9.3° S corresponds approximately with granites and gneisses of the Bangweulu Block, whereas the Plateau Series of the Bangweulu Block to the north-west and to the sout-east appear to be characterised by moderate seismic activity.

The NS-striking seismicity low along 28° E cannot be explained with available geological data. This low appears to correspond with a large positive Bouguer anomaly.

6. Conclusions

It appears that the general pattern of the presented seismicity map can be partly related to the simplified geological map of Zambia. In general, areas of low to moderate seismicity follow more strictly the geological pattern, whereas areas of high seismicity are more difficult to interprete in terms of the known regional geology. The Kasempa High seems to be unrelated to the known geology of Zambia.

It is also of interest to note that seismicity in Zambia seems to be neither related to the age of orogenic events nor to major cycles of sedimentation.

Seismicity highs may be rather related to the Pan-African system of rifting, stretching from Ethiopia in the north, and probably to Mozambique in the south-east and Namibia in the south-west (Töpfer, in preparation).

References

Archer, C.B.: A catalogue of earthquakes in the Lake Kariba Area, 1959–1968. Goetz Observatory, Bulawayo, Rhodesia, 1969

Archer, C.B.: Seismological Bulletin. Goetz Observatory, Bulawayo, Rhodesia, 1966–1972

Bath, M., Anderson, A.J.: Seismicity of Zambia and surrounding areas with Plans for the Development of a Seismograph Station Network in Zambia. unpublished 1968

Chander, R.: Seismological Bulletin. University of Zambia, Lusaka, Zambia, 1971–1974

Chapman, D.S., Pollack, H.N.: Heat flow and incipient rifting in the Central African Plateau. In Preparation

de Beer, J.H., van Zijl, J.S.V., Huyssen, R.M.J., Hugo, P.L.V., Joubert, S.J., Meyer, R.: A magnetometer array in South-West Africa, Botswana and Rhodesia. In Preparation

Fairhead, J.D., Girdler, R.W.: How far does the rift system extend through Africa. Nature **221**, 1018, 1969

Girdler, R.W.: Drifting and rifting in Africa. Nature **217**, 1102, 1968

Girdler, R.W., Sowerbutts, W.T.C.: Some recent geophysical studies of the rift system in East Africa. J. Geomagne. Geoelectr. **22**, 153, 1970

Gough, D.I., Gough, W.I.: Load-induced earthquakes at Lake Kariba. University of Alberta, Edmonton, Canada, 1970

Gutenberg, B., Richter, C.F.: Seismicity of the Earth and associated phenomena. Princeton: Princeton University Press 1954

Henning, E.: Die Ostafrikanische Bruchtreppe. Geol. Rundschau 2921, 1937

Johnson, R.L.: Personal communication, 1975

Masac, O., Töpfer, K.D.: Provisional gravity map of the Republic of Zambia. Geological Survey Department, Lusaka: Govern. Printer 1974

Money, N.J.: An outline of the geology of Western Zambia. Records of the Geological Survey, Lusaka **12**, 103, 1972

Porstendorfer, G., Kuhn, P.: Geophysikalische Arbeiten auf Sansibar/Tansania. Publikation des Nationalkomitee für Geodäsie und Geophysik der DDR, Berlin, 1966

Reeve, W. H.: Geological map of Northern Rhodesia. Geological Survey Department, Lusaka, 1961

Reeves, C. V.: Rifting in the Kalahari. Nature **237**, 95, 1972

Schick, R., Schneider, G.: Physik des Erdkörpers. Stuttgart: Enke 1973

Snelling, N. J., Johnson, R. L., Drysdall, A. R.: The geochronology of Zambia. Records of the Geological Survey, Lusaka **12**, 19, 1972

Sykes, L. R., Landisman, M.: The seismicity of East Africa, the Gulf of Aden, and the Arabian and Read Seas. Bull. Seism. Soc. Am. **54**, 1964

Töpfer, K. D.: Rifting in Zambia. In preparation

Vail, J. R.: The souther extension of the East African rift system and related igneous activity. Geol. Rundschau **57**(2), 601, 1968

Vail, J. R., Snelling, N. J., Rex, D. C.: Pre-Katangan geochronology of Zambia and adjacent parts of Central Africa. Can. J. Earth Sci. **5**, 621, 1968

van Eden, J. G., Binda, P. L.: Scope of stratigraphic and sedimentologic analysis of the Katanga sequence, Zambia. Geologie en Mijnbouw **51**(3), 32, 1972

Received December 12, 1975