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Active faults in Africa: a review

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Abstract

The active fault database and Map of active faults in Africa, in scale of 1:5,000,000, were compiled according to the ILP Project II-2 "World Map of Major Active Faults". The data were collected in the Royal Museum of Central Africa, Tervuren, Belgium, and in the Geological Institute, Moscow, where the final edition was carried out. Active faults of Africa form three groups. The first group is represented by thrusts and reverse faults associated with compressed folds in the northwest Africa. They belong to the western part of the Alpine–Central Asian collision belt. The faults disturb only the Earth's crust and some of them do not penetrate deeper than the sedimentary cover. The second group comprises the faults of the Great African rift system. The faults form the known Western and Eastern branches, which are rifts with abnormal mantle below. The deep-seated mantle "hot" anomaly probably relates to the eastern volcanic branch. In the north, it joins with the Aden–Red Sea rift zone. Active faults in Egypt, Libya and Tunis may represent a link between the East African rift system and Pantellerian rift zone in the Mediterranean. The third group included rare faults in the west of Equatorial Africa. The data were scarce, so that most of the faults of this group were identified solely by interpretation of space imageries and seismicity. Some longer faults of the group may continue the transverse faults of the Atlantic and thus can penetrate into the mantle. This seems evident for the Cameron fault line.

Keywords: Active faults; Neotectonics; Rift; Lineament

1. Introduction

"Map of Active Faults in Africa" in scale of 1:5,000,000 (Fig. 1) was compiled in the course of the ILP Project II-2 "World Map of Major Active Faults" fulfillment. The Map brings together what has been published by numerous researches of Africa as well as results of field investigations carried out by V.G. Kazmin and a team from the Royal Museum of Central Africa headed by J. Klerkx. The Map is accompanied with the database, which delivers what is known about the age, rate and sense of fault movements in the region.

The database and the Map are not equally informative for the entire continent. It has come out historically that over the last century researchers concentrated their efforts mainly on the Great African

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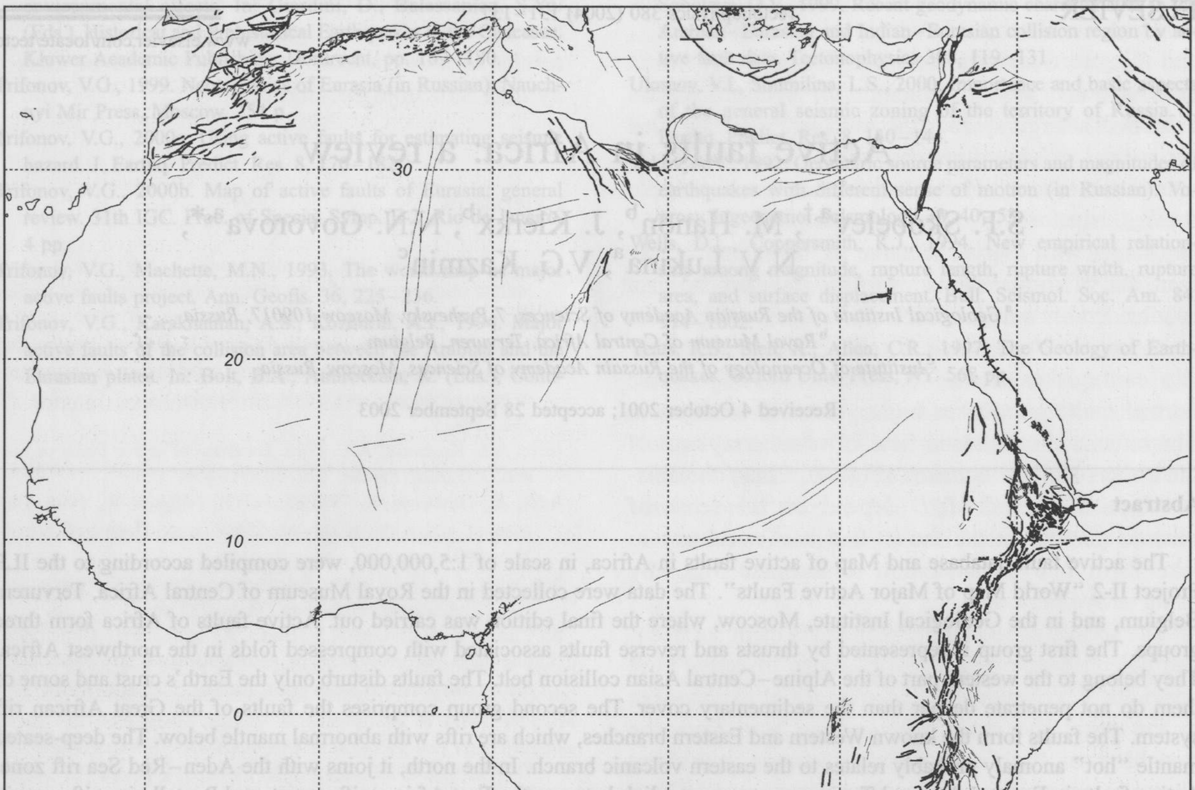

Fig. 1. Simplified map of active faults (thicker lines) and inferred active faults and lineaments (thinner lines) in Africa.

Fault System, so the data on the latter constitute the largest portion of the database. Several last decades yielded significant amount of knowledge about young rift zones of the Red Sea and the Aden Bay, the northwest and east branches of the Great African Faults System continue with. Northwest and northeast trending rift zones, rifts of Sudan, Anza, Kavirondo among them, and some of other transverse zones such as the Nyasa–Tanganyika (Kazmin, 1987) were studied too. Some, again quite important, data was gathered on young movements in Atlas, Anti-Atlas and the south branch of the Alpine–Mediterranean orogenic belt of North Africa. Unfortunately, publications on that part of Africa rather generalize on faulting in the light of plate tectonic models already elaborated than give detailed information on young fault morphology and sense of fault movements.

Data on young faulting in the western Africa have remained scarce. Lack of special neotectonic and seismotectonic investigations as well as regional geologic and climatic-geographical conditions were the factors that hampered in gaining data on young tectonic movements in the region. Many of the faults the Map shows there are only hypothetical.

The process of the Map compilation based, firstly, on integration of many (as in case with the Great African Fault System and the Mediterranean) data from different sources, and, secondly, on extrapolation of the regularities derived from general geological materials, topographic charts and satellite images of Africa (such as the DEM image of Africa from "The Continent Series—by WorldSat" (1996)). As a result of interpretation of the topographic charts and satellite images, the map of lineaments in Africa was compiled (Fig. 1). It was also used for the present interpretation of active faulting in the continent.

Highly uneven distribution of active faults, as shown in the Map, makes the continent of Africa look as if composed of a number of microplates and lithosphere blocks. Zones of active faults, either known or inferred, tend to coincide spatially with rift zones of Paleozoic, Mesozoic and Early Cenozoic age, and reflect thus the ongoing (since accumulation of the Karru formation) process of fracturing of the continent and the influence of preexisting structural heterogeneity on the distribution of younger tectonism. For example, a part of the young Tibesti lineament with signs of dextral slip inherits the Late Paleozoic Anzu rift, which was formed as a pull-apart basin in en echelon system of strike-slip faults (Guiraud et al., 2000). Many Late Cenozoic faults inherit the older tectonic scarps between uplands and basins with intensive sedimentation (Dixey, 1956). Perhaps, the hydrostatic stress caused by erosion of uplands and sedimentation in basins also contributed on the younger faulting.

The data acquired later mostly confirmed hypotheses formulated much earlier (Cloos, 1937; Du Toit, 1939; King, 1967), though other accents were put at first place. Recent studies with seismic profiling, seismic tomography and geothermal measurements revealed some correlation between movements in Africa and neighboring oceanic domains—some transmission of movements from Atlantic transform faults into the body of African continent. At the same time, it was found that Cenozoic tectonic movements within some of the Mesozoic rifts in Central Africa occurred as predominantly vertical or sometimes even causing transverse shortening of those at one time extending structures (the Benin and Congo depressions, Central African rift, Matabele–Schwartsrand zone, the Tibesti lineament). These later movements as well as thrusting of the southernmost mountainous part of Africa onto the Kalahari depression and counter, with a right-lateral component, movements of the northern and southern halves of the continent across the Equatorial Africa tectonic zones caused sort of consolidation of the continent. Still the movements just described remain hypothetical as basing principally on geomorphologic (Machatschek, 1955) and seismological (Ambraseys and Adams, 1986) information. Mid – Late Pleistocene and Holocene fault activity, magnitudes and rates of fault movements within the abovementioned parts of Africa are unstudied yet, even for the faults easily recognizable by topographically high scarps.

2. West and Central Africa

There is a rather good correlation between cellular structure of the African lithosphere distribution of young faulting reveals, from one side, and geoid surface undulation and magnetic field measured from satellites (Bowin, 1991), from the other. It is seen first in spatial coincidence between the ends of oceanic transform faults and faulted boundaries of African continental blocks. Such are the San-Paulu –Romanch transform zone and the Central Strike-Slip Zone of Africa, a segment of which is the Cameron fault zone. Movements are supposed to occur on the boundary of the West African craton (the Cameron Lineament) and on the Sanago fault zone (Bosworth and Morley, 1994), which is the northern limit of the Congo craton. It should be noticed though that some seismicity and well-proved strike-slip character of Mesozoic fault motions cannot suggest alone that the same lateral movements occurred in the Quaternary. These pre-Quaternary faults can be considered as lineaments with fragmental manifestations of the young activity.

The similar young linear zone may go just north of the Schwarzrand mountains, and further to the north-east towards the northern edge of the Matabele highland or the Zambezi River valley. It crosses, with its central segment, the Victoria waterfall and it is seen there as well-expressed cleavage of old rock complexes (Machatschek, 1955). Regarding West and Central Africa as a whole, we may conclude that young faulting there is principally confined to Paleozoic and Mesozoic rifts, and is by essence a process of remobilization of the latter.

3. East Africa

Young faulting in East Africa mainly occurs in two branches of the East African Rift System (Kazmin, 1987). The east branch, especially its Kenyan rift, is studied better. Some faults show Late Pleistocene and Holocene normal offsets, and many of them were active at least in the Middle Pleistocene time. All this as well as current seismicity attests to ongoing extension within the rift zone, its rates reaching values of 5 – 10 mm per year. Moreover, signs of longitudinal lateral movements were found too, left-lateral in the Ethiopian rift (Boccaletti et al., 1998) and right-lateral in the junction of the Rukwa and Malawi rifts (Delvaux et al., 1992). This grounds an idea of the rifts as pull-apart basins. It is significant that left-lateral strike-slip movement seems more characteristic for the northeast-trending faults, while right-lateral movements occur mainly along the northwest-trending faults. This may evidence geodynamic coordination between extension in the rifts and strike-slip fault movements. Fault movements were found to occur by impulses likely governing intermittent character of limnogenic complexes accumulation and final most important stage of graben formation (Machatschek, 1955).

Rift zones are characterized by thinner (20–30 km) crust (Berckhemer et al., 1975; Braile et al., 1994; Keller et al., 1994), reduction of elastic horizon in the lithosphere (Ebinger et al., 1989), and alternation of high- and low-velocity layers (Ritter and Achauer, 1994). Thus, the central part of the Kenyan rift has a 6.6 km/s layer at the depth of 10 km. Uneven distribution of high and low velocity layers, which is probably caused by spot-like heating of the Earth's crust, predetermines nonuniformity of young movements within rift zones.

High (up to 10 mm per year) rates of the Late Quaternary movements were found in the southern part of the East African rift system, in the fault system, which joins the rifts of Rukwa and Malawi (Nyasa) and continues by the Umbe graben. Strike-slip movement along the northeastern limit of the Malawi rift occurs simultaneously with relative underthrusting of the rift bottom beneath its flanks (Delvaux et al., 1992). Junction between the East and West rift systems with the southern extension of the West system (the Malawi rift and coastal scarps of the Lembo monocline (the Urema graben) (Dixey, 1956) with about 0.05 mm/year of vertical component of the Late Cenozoic motion (Machatschek, 1955)) looks like a southern counterpart of the Afar triple junction zone (Kazmin, 1980, 1987).

There is a positive correlation between young movements and crustal seismicity. Both phenomena follow boundaries of microplates, relative motions of which constitute modern geodynamics of the region. According to Kazmin (1987), the Late Cenozoic movements along the faults of the West Branch of the Great African Rift System reflect north-directed advance and counterclockwise rotation of the Victoria block. Some rotation of the Rhodesian and Mozambican blocks may be expected too.

4. The rifts of the Red Sea and Aden Bay

The rifts, in which new oceanic crust is forming, stretch as en echelon extension of the rifts of East Africa. They undergo spreading at the rates of 1 – 1.7

cm/year, on an average, and episodically up to 10 and more cm/year (Kazmin, 1987). Late Quaternary vertical movements in the Read Sea rift take place not only in its central rift valley, but also in its flanks, as deformation of Late Pleistocene marine terraces of the Red Sea western coast testifies to. In contrast to simple rifting in the Read Sea, extension in the Aden Bay may have resulted from strike-slip movements along the faults of the Aden zone, and individual rifts originated as pull-apart basins bordered with transform faults (Manighetti et al., 1997). Rates of strike-slip fault movements in the Aden zone range from 2 to 5 mm/year. Similar combination of extension and lateral fault movements may occur along the Yemeni–Omani coastal area of Arabia.

5. North Africa

Young deformation and fault zones are distributed irregularly in the North Africa. They are concentrated mainly in the northwestern part of the continent, which belongs to the Alpine–Himalayan belt, and particularly in the Atlas orogenic system (the High Atlas, the Tell–Atlas, the Anti-Atlas, and the Sahara Atlas). Their number decreases to the east of the Sidra (Great Sirt) Bay, where the faults are represented in the Jebel El-Ahdar Mts. and somewhere to the east of them. The faults are accompanied by young folds in the sedimentary cover. This structural paragenesis can correspond or not correspond (be detached relative) to the adequate structures in the basement that is typical for the continental collisional belts (Skobelev et al., 1988; Trifonov, 1999). The folds deform the Mesozoic and Cenozoic sedimentary cover in the Tell–Atlas and Er Rif, but southerly young deformation affects older folded zones. Reverse faults, their planes dipping north and northwest, have developed in the Late Pleistocene and Holocene along the fold flanks. Parallel to them active normal faults and thrusts with sinistral component of motion have formed in the southern front of the orogenic belt (Meghraoui, 1995). Rates of young fold uplift is essentially higher than those of the fault displacements, which vary from 0.2 up to 0.9 mm/year. They are the highest on strike-slip faults. Offsets during strong earthquakes can reach several meters. Multiple pulse displacements on some faults correspond to strong crustal seismicity in the region (Meghraoui, 1995). Structural pattern of young thrusts, reverse faults and folds suggests subhorizontal northwest-directed compression. Dextral slip on the Azore–Gibraltar fault zone and sinistral motion on the northeast-trending oblique (normal and strike-slip) faults in Morocco and Mauritania (Carte Neotectonique du Maroc, 1993) and in the Atlas correspond to this stress field.

Faults and folds just described join in Tunisia with transverse normal faults, which represent southern extension of the western branch of the Pantellerian rift system of the Mediterranean. Dominant strike of normal faults matches the stress field described above (Meghraoui, 1995). Easterly the very style of active tectonics changes. Young folds practically disappear, and the most prominent structure is the system of Libyan grabens of southeastern trend, with manifestation of Late Quaternary movements in the east of the Sidra (Great Sirt) Bay. As the normal faults in Tunisia, they die away southeasterly to be replaced more southerly with two long strike-slip (?) lineament zones with known geothermal anomalies. The Ahaggar block between the zones has likely rotated counterclockwise in the Late Cenozoic. Till at least the mid of Pleistocene the block together with the western flank of the Tibesti massif have, however, remained by zones of crustal extension and volcanism. Whatever the sense of movements along these lineament zones has been, they stretch between the East and West cratons of Africa and thus originated most likely from relative movements of those cratons in the Late Cenozoic time. This system of young faults and lineaments has been controlled by the 6000-km-long Tibesti lineament, which perhaps represents the deep-seated (reaching the mantle) dextral strike-slip fault zone and has controlled also the Late Cenozoic volcanism from the Canary Islands up to Kenyan rift. The Tibesti lineament and the N–S-trending lineament system form a kind of triple junction (Guiraud et al., 2000).

It may be supposed that the Pantellerian rift system together with the grabens of Libya as its southern extension, and the Red Sea rift make altogether a single en echelon row with about north-trending Quaternary normal faults in Egypt linking them. About east-trending right-lateral strike-slip faults (Kalabsha, Seniyal) with some reverse component of motion were mapped between some of the normal faults west of Aswan (Trifonov et al., 1996). The faults are currently active, as geodetic measurements show (Vyskocil et al., 1991).

6. Conclusion

The data on young fault movements in Africa show more significant role of strike-slip fault movements than it was considered before. The strike-slip motion can be combined with either normal (East Africa fault system) or reverse (the northwestern Africa) component. Different active fault zones penetrate into different depths of the lithosphere, and some of them correspond to the particular structures in the upper mantle. According to seismic tomography, the highest depths (penetration into the mantle part of the lithosphere and correlation with anomalies of the seismic wave velocities that can correspond to the thermal anomalies in the underlying mantle) is characteristic to the East African rift system and the Red Sea and Aden rift zones. The faults of the western and central Africa, which bound cratons, microplates and lithosphere blocks, may also penetrate into the mantle part of the lithosphere. This conclusion is supported by continuation of some of the faults by the transform faults in the Atlantic. Similarly, the hypothetical fault manifested by the scarp along the Somali coast can be by a continuation of a branch of the Owen oceanic fault. The faults in the Northwest Africa (which is a part of the Alpine–Himalayan collision belt) rupture the upper crust and only some of them may reach the Moho discontinuity.

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