*by Mustapha Meghraoui and the IGCP-601 Working Group**

The Seismotectonic Map of Africa

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Database address: http://sageoscience.maps.arcgis.com/

We present the Seismotectonic Map of Africa based on a geological, geophysical and geodetic database including instrumental seismicity and re-appraisal of large historical events, and harmonization and homogenization of earthquake parameters in the catalogues. Although establishing the seismotectonic framework of the African continent is a difficult task, several previous and ongoing projects provide a wealth of data and outstanding results. The database of large and moderate earthquakes in different geological domains includes the coseismic and Quaternary faulting that reveals the complex nature of the active tectonics in Africa. The map benefits from previous works on local and regional seismotectonic maps that needed to be integrated with the lithospheric and upper mantle structures, seismic anisotropy tomography and gravity anomaly, into a continental framework.

The synthesis of earthquake and volcanic studies obtained from the analysis of late Quaternary faulting and geodetic data will serve as a basis for hazard calculations and the reduction of seismic risks. The map will be useful for the seismic hazard assessment and earthquake risk mitigation for significant infrastructures and their socio-economic implications in Africa. The constant population increase and infrastructure growth in the continent that exacerbate earthquake risk justify the necessity of continuously updating this map.

The database and related map are prepared in the framework of the IGC Project-601 "Seismotectonics and Seismic Hazards in Africa" of UNESCO-IUGS, funded by the Swedish International Development Agency and UNESCO-Nairobi for a period of 4 years (2011 – 2014, now extended to 2016).

Introduction

The African plate has been the site of numerous large and destructive earthquakes, the most recent events being the 2009 Karonga earthquake (M 6.2) in Malawi, the 2008 Bukavu earthquake (M 6.0) in D.R.Congo, the 2006 Machaze earthquake (M 7.0) in Mozambique, the 2003 Zemmouri-Boumerdes earthquake (M 6.8) in Algeria, and the 1990 Juba earthquake (M 7.1) in South Soudan. Seismically active regions are primarily located along rift zones and related volcanic activity, thrust and fold mountain belts, and along mainly offshore transform faults. Several seismotectonic structures may generate large earthquakes in densely populated regions causing severe damage and significant economic losses in Africa.

Seismotectonic regions in Africa are poorly known in terms of the current faulting activity, crustal deformation, and their geodynamic causes. The North Africa thrust and fold belt and the East African Rift system are the most obvious areas of ongoing tectonic deformation experiencing large earthquakes (Yang and Chen, 2010; Meghraoui and Pondrelli, 2012). However, other regions like the Cameroon Volcanic Line and the Congo Basin in Central Africa, the West Africa and Southern African plateau are also seismically active. The presence of major active faults that generate destructive earthquakes is among the most important geological and geophysical hazards in the continent.

The development of a thematic map with the identification and characterization of seismically active zones constitutes the framework for seismic hazard assessment and mitigation of catastrophes. This subject was discussed in a session during the 23rd Colloquium of African Geology in Johannesburg (CAG 23, 8 – 14 January 2011) and was a concern expressed during the Algiers meeting of the Organisation of African Geological Surveys (OAGS, May 2010) which requested the preparation of the Seismotectonic Map of the African continent and assessment of the seismic hazard and risk implications. A Working Group* addressed these issues in the framework of the IGC Project-601 "Seismotectonics and seismic hazards in Africa". The seismotectonic map was prepared by geoscientists (mostly from African academic and research institutions) who conducted several scientific projects in earthquake geology, seismology, seismotectonics, geodesy and geophysics in Africa. This contribution reports the scientific programme, procedure and activities of the Working Group, and the framework for building-up the local, regional and continental studies of crustal deformation and related hazards in Africa.

This paper presents the work done from 2011 to 2015 in the framework of the IGCP-601 project. It is a compilation of the available geological and geophysical data gathered from previous published works and reports. No such map was available before carrying out this project. This is the first and unique map representing the whole seismological, tectonic, geodetic and other geophysical information for the African continent.

The six seismotectonic provinces

The African continent is made up of various geological structures that include zones of active deformation. Seismically active regions are primarily located along rift zones, thrust and fold mountain belts, transform faults and volcanic fields. Using the geological and geophysical characteristics, the Working Group defined six seismotectonic provinces (Figure 1) in collaboration with academics and members of geological surveys who deal with multidisciplinary tasks. The provinces are primarily determined from the tectonic regime and seismicity background (see also Figure 2) as well as the geographical situation.

1. The **Western-Central Africa** “stable” tectonic zones and related islands
2. The **Northwest African** fold-and-thrust belt (Atlas Mountains to Sahara Platform)
3. The **Northeast African** tectonic zones of Libya, Egypt and North Sudan
4. The **Central African** fault systems of Angola, RD Congo, Cameroon to Chad
5. The **East African** Rift (from Malawi to Ethiopia including Madagascar)
6. The **Southern African** shield includes Mozambique, Namibia and southern parts of Angola, and the Cape fold belt.

Province 1 covers West Africa from Nigeria to Senegal and is generally considered to be a stable part of Africa, although several major historical and recent earthquakes have struck the region. The Guinea earthquake of 22nd December 1983 (Mw 6.4) is a good example as an event of intraplate seismicity which occurred on a stable West African craton (2.2-1.8 Ga). The seismicity in this province is infrequent according to the geological context.Province 2 includes Northwest Africa from Tunisia to Mauritania, and is well known for its recent large thrust and strike-slip earthquakes along the plate boundary between Africa and Eurasia. Province 3 encompasses Libya and Egypt is characterized by infrequentlarge and moderate normal faulting earthquakes;this area is also prone to two distinct tectonic regimes, collision of Africa-Eurasia plates and the rifting of the Red Sea. Province 4 covers Central Africa that includes the Cameroun Volcanic and Seismic Line (CVL), Angola, Chad the Congo basin and its seismically active East African Rift(EAR) margin. Province 5 includes the most active part of the EAR and related volcanic and normal faulting system that extends from the Afar triple junction through the Rukwa-Tanzania Rift Valley down to the Zambezi Valley;the province includes Madagascar Island where the seismicity is also associated with the rifting process and the breakup of the African lithosphere. Province 6 covers the southern regions of Africa, which has also been struck by large and moderate intraplate earthquakes and includes Mozambique, Namibia and South Africa. Other major islands such as La Réunion, Mauritius, and Comoros in the Indian Ocean, and Cape Verde, Canary, Madeira and Azores Islands in the Atlantic Ocean, are also included in the seismotectonic analyses and the study of crustal deformation.

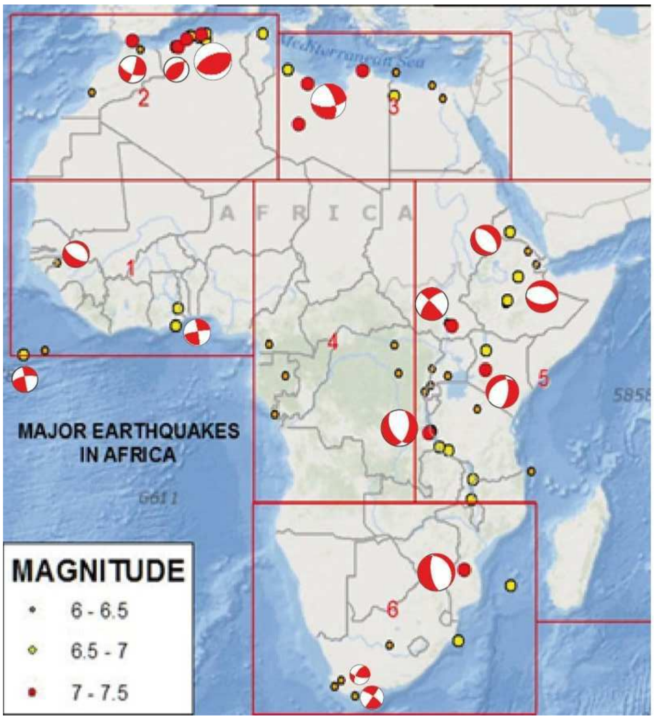

Figure 1: Seismotectonic provinces and major earthquakes of the African continent (see text for the subdivision).Focal mechanisms are from Harvard-CMT solutions. **(http://www.globalcmt.org/)**

Several major earthquakes of the continent (Table 1) were the subjects of detailed field investigations using geological and geophysical data analysis, including space-based geodesy (GNSS and InSAR). Previous studies of major earthquakes emphasized the study of seismic strain release using mainshock and aftershocks with focal mechanisms including field studies of earthquake faulting, GNSS measurements and SAR interferometry.

The seismotectonic database

A major objective linked to the seismotectonic map is the compilation of a database that includes the following items: historical and instrumental seismicity, active tectonics, stress tensor distribution, earthquake geology, paleoseismology, earthquake geodesy and present-day velocity fields (GNSS), crustal structure and seismic tomography, gravity, magnetic and structural segmentation, volcanic fields, rifting processes, geodynamic evolution and heat flow. Guidelines for the seismotectonic map preparation and related data analysis were used in order to obtain homogeneous data and results across the continent. An important step is database harmonization (e.g., earthquake intensities, magnitudes, fault parameters, etc.) at local, regional and continental level. The guideline for the seismotectonic map preparation in order to build a homogeneous database is accessible in the map explanatory notice and in the GIS web site.

Based on the local and regional studies, the seismotectonic map is constructed addressing the following issues: (1) Building a homogeneous database of seismic parameters, making distinction between historical and instrumental data. Location and source parameters were revisited according to new information and procedures especially for past earthquakes. (2) Prepare a database of neotectonic structures with Quaternary faulting. We emphasized in this map only active faults which are the source of significant seismicity (3) Improving the seismotectonic database in regional gaps, (4) Building a GIS interface for the geologic and geophysical database. This map synthetized the main geological background extracted from the Tectonic Map of Africa (CGMW, 2010) and geophysical data such gravity, stress field, heat flow, geodynamic movements derived from GPS survey, (5) Finally the seismotectonic map will aim to serve as a background for the seismic hazard assessment with scenarios and models. African countries need to have such document to better assess the seismic hazard and risk that they are prone to. The dense urbanization, existing and future development may be heavily affected by destructive seismic events. The seismotectonic map (Figure 2) consists of a synthesis of the 1/1 000 000 to 1/5 000 000 scale regional maps which will ultimately constitute the 1/10 000 000 scale map. The Commission of Geological Map of the World (CGMW), the North African Group for Earthquake and Tsunami studies (NAGET), the Global Earthquake Model (GEM Foundation), the International Union of Geological Sciences (IUGS) and the Geological Society of Africa have a direct interest in the IGCP-601 project.

Historical and instrumental seismicity

A significant effort was necessary in order to combine regional catalogues such as those of Benouar, 1994; Amponsah et al., 2012; Midzi et al., 2013; Ayadi and Bezzeghoud, 2015, and Harbi et al., 2015 into a single homogeneous seismicity catalogue across Africa. The search for historical earthquakes at national level and from local old publications represents a major effort throughout the project from

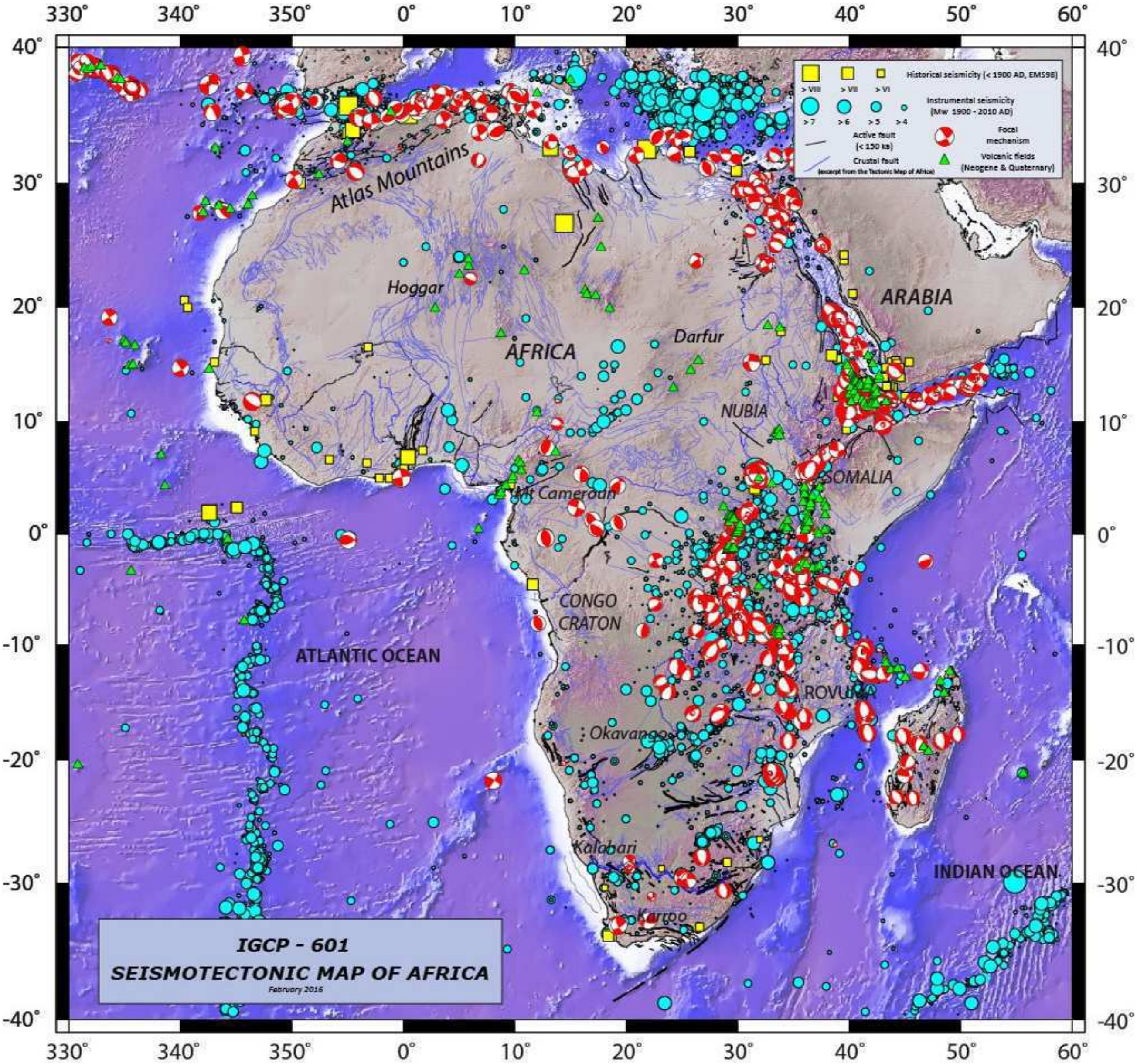

Figure 2 : Seismotectonic map of Africa. The background topography and bathymetry is reproduced from the GEBCO Digital Atlas published by the British Oceanographic Data Centre on behalf of IOC and IHO, 2003. See text for the geological and geophysical data.

Table 1. List of major earthquakes in Africa that were the subject of detailed studies

Earthquakes	Dates	Latitude	Longitude	Mw
Lac Tanganyika	1910 Dec.13	-6.5	29.5	7.4
El-Asnam, Algeria	1980 Oct.10	36.23	1.32	7.2
Nuweiba, Egypt	1995 Nov.22	28.81	34.80	7.2
Juba, South Sudan	1990 Mar.20	5.11	32.18	7.1
Subukia	1928 Jan.06	0.4	36.11	7.0
Al-Qadahia, Libye	1935 Apr.19	31.38	15.4	7.0
Machaze, Mozambique	2006 Feb.22	-21.32	33.58	7.0
Kalemie, Congo-Tanzania	2005 Dec.05	-6.25	29.79	6.8
Zemmouri, Algeria	2003 May21	36.83	3.65	6.8
Orleansville, Algeria	1954 Sep.9	36.28	1.47	6.7
Salima, Malawi	1989 Mar.10	-13.71	34.49	6.6
Accra, Ghana	1939 Jun.22	5.18	0.13	6.5
El-Hoceima, Morocco	2004 Feb.24	35.14	-4	6.4
Dobi, Ethiopia	1989 Aug.20	11.75	41.96	6.4
Ceres, West Cape, S. Africa	1969 Sept.29	-33.36	19.31	6.3
Kivu, DR Congo	2002 Oct.24	-1.905	29.013	6.2
Karonga, Malawi	2009 Dec.19	10.108	33.81	6.2
Gaoual, Guinea	1983 Dec.22	11.95	-13.6	6.2
Mascara, Algeria	1994 Aug.18	35.45	0.08	6.0
Bukavu, DR Congo	2008 Feb.02	28.74	-2.45	6.0
Rukwa, Tanzania	1994 Aug.18	6.5	29.5	6.0
Agadir, Morocco	1960 Feb.28	30.41	-9.6	6.0
Cairo, Egypt	1992 Oct.12	29.78	31.14	5.8

2011 to 2014. The use of the EMS98 or MSK scale instead of the MMI or any other intensity scale (larger than Io = VIII) was preferred in order to harmonize the historical seismicity database up to 1900. The instrumental catalogue covers the period from 1 January 1900, up to the present-day, and a threshold moment magnitude Mw ≥ 4.0 is defined as the minimum size earthquake that illustrates a significant crustal deformation.

As most earthquakes are determined using Ms, mb or Ml, we use recent approaches with standard relations for magnitude conversions into a homogeneous moment magnitude Mw. Locally defined empirical relations are preferred but if no local studies are available the following relations from Scordilis (2006) are applied.

Conversion Ms-Mw (Surface wave magnitude into Moment magnitude):

$$Mw = 0.67\ (\pm 0.05)\ Ms + 2.07\ (\pm 0.03)\ \text{for}\ 3.0 \leq Ms \leq 6.1$$
$$Mw = 0.99\ (\pm 0.02)\ Ms + 0.08\ (\pm 0.13)\ \text{for}\ 6.2 \leq Ms \leq 8.2$$

Conversion Mb-Mw (Body wave magnitudes into Moment magnitude):

$$Mw = 0.85\ (\pm 0.04)\ Mb + 1.03\ (\pm 0.23)\ \text{for}\ 3.5 \leq Ms \leq 6.2$$

A catalogue of more than 13750 seismic events covering all provinces has been compiled showing all parameters and related characteristics of each major event (see GIS web site).

Earthquake ruptures, neotectonic faulting and fault kinematics

Large earthquakes with surface faulting were described in local reports and publications in different regions and throughout all seismotectonic provinces. The digitization of already mapped active faulting and folding is an important step for the seismotectonic map preparation. The map displays geo-referenced active faults where we consider: (1) Quaternary faults with lower and middle Pleistocene tectonic movement (1,8 Ma to 130 Ka), (2) Quaternary faults with upper Pleistocene (130 Ka to 11 Ka) tectonic movement, (3) Quaternary faults with Holocene (11 Ka to present-day) tectonic movement, and (4) Quaternary faults with historical or recent coseismic surface ruptures. These faults are considered as the rupture sources associated with seismic activity in the different provinces considered in the seismotectonic map of Africa. In regions where no specific mapping or studies on late Quaternary and/or active faults are present, we use the background mapping of the recently published Tectonic Map of Africa (CGMW, 2010). We also use Google Earth, ArcGIS and the SRTM DEM as a basis for digitizing and referencing the mapped faults.

Fault kinematics and building the stress field: It is important to remember that stress field governs the fracturing process along a fault. Slips on active faults have been extensively studied following large and moderate earthquakes (Mw ≥ 6.0). Paloseismological studies such that of Meghraoui (1988) following the El Asnam earthquake (October 10th, 1980, Ms 7.3) enable to determine coseismic and cumulative slip on faults. Slip on faults may also be determined by moment tensor summation (Kostrov, 1974) using seismic waveform inversion or focal mechanism parameters (Meghraoui and Pondrelli, 2012). Focal parameters may also be used to retrieve stress field in a seismogenic zone by moment tensor inversion procedure (Ousadou et al., 2014, Soumaya et al., 2015). The kinematics of faulting and related stress distribution have been the subject of specific studies in the frame of projects throughout the African continent (e.g., Delvaux and Barth, 2010, Ousadou et al., 2014; see also Figure 3). For areas with homogeneous stress field, a formal stress inversion is applied to retrieve the stress tensors. This work will be reported in a scientific paper that will update the existing published work. Focal mechanisms

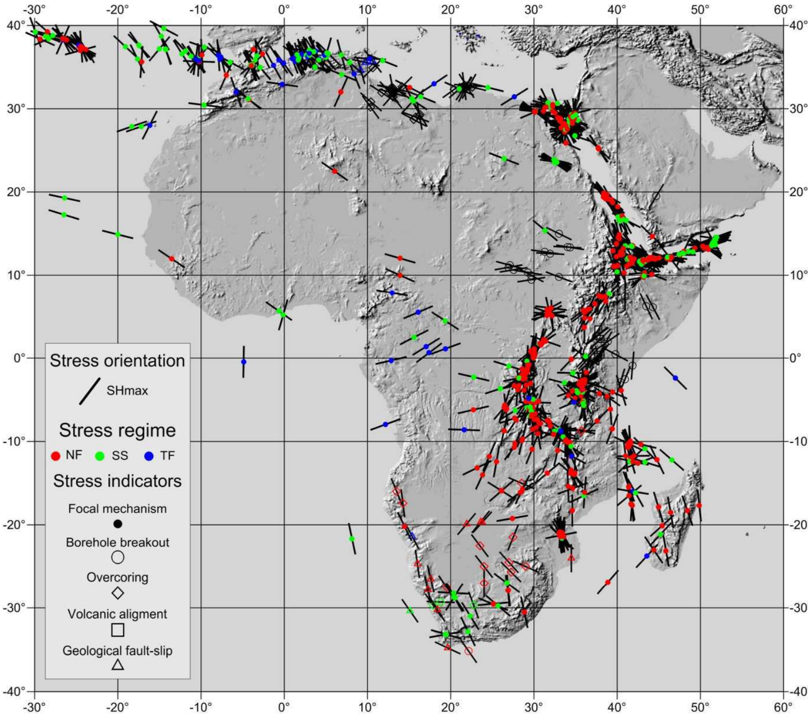

Figure 3: Stress field of the African Plate.

and stress field are presented as follows: (1) Use the Harvard CMT format convention, (2) compile the different CMT catalogues and published data, (3) plot the stress indicators (P and T kinematic axes) as in the World Stress Map.

Strain field and geodetic network

The African continent is tectonically divided into two main plates, Nubia and Somalia, separated by the two rift branches of the East African Rift with 2-3 smaller tectonic blocks in between (Hartnady, 1990; Fernandes et al., 2013). The major parts of the external plate boundaries of Africa are well defined by spreading ridge systems with the exception of the Africa-Eurasia complex convergence system (Figure 4).

More uncertainty exists concerning the number and distribution of the tectonic blocks along the East African Rift region. Nevertheless, this complex sub-plate distribution is being better constrained with the increasing number of permanent GNSS stations in Africa.

The seismotectonic map presents the current status of the strain distribution using the present-day GNSS velocity field of Africa, with respect to the latest global reference frame ITRF2008. The existing number of sites (~100 permanent GNSS stations) and a threshold value of 2.5 years data already permit the computation of a velocity field that can be used to obtain the general pattern of the current strain field for Africa. For the majority of the plate pairs, we present the most recent estimation of their relative velocity using a dedicated processing. The velocity solutions are computed using HECTOR software that takes into account the existing temporal correlations between the daily solutions of the stations in order to properly estimate the velocity uncertainties and to detect any artifacts in the time-series (Bos et al., 2013). For some of the plate pairs, we compare our solutions of the angular velocities with other geodetic and geophysical models. This constraint of active deformation provides us with an assessment of the main seismotectonic characteristics of Africa.

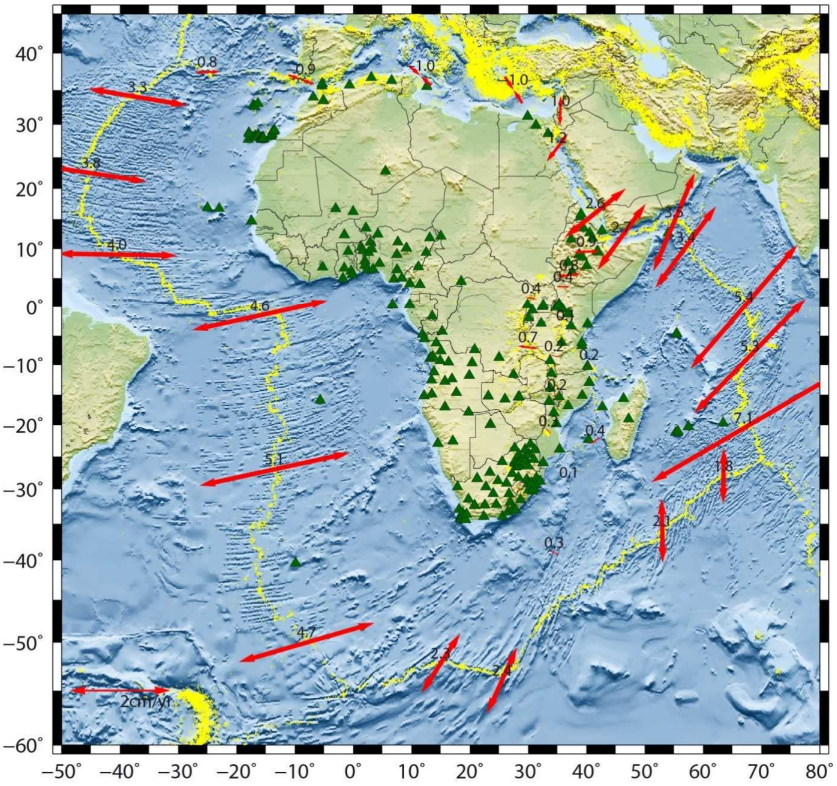

Figure 4: Spreading ridge systems of the African plate and the Nubia-Eurasia complex convergence system.Triangles are GPS stations. Red arrows show extension and convergence direction and rate (reference rate 2cm/yr is for one side)

Geophysical analysis of crustal structure and mantle dynamics

A large number of projects have been conducted in the last decade to study the crustal thickness and lithosphere-mantle structure of the African continent (Figure 5; Pasyanos and Nyblade, 2007; Bonvalot et al., 2010; Fishwick and Bastow, 2011). Therefore, the seismotectonic map of Africa includes: (1) A database of the thickness of the seismogenic layer for each province, (2) a review of main results of tomography and gravity studies on the lithosphere thickness and upper mantle dynamics, (3) a database of mapped volcanoes with a description ofthe most recent eruptions, and coordinates of craters with the age of volcanic fields (Simkin et al. 1981, see also http://www.volcano.si.edu), and (4) heat flow data determined by numerous studies throughout the continent. The heat flow data are obtained through boreholes. A large heat flow anomaly is observed along the African Sahel starting from Mauretania to Red Sea, with the largest values around Sahara basin (Algeria), Sirt Basin (Libya), Red Sea (Egypt) and Afar region are associated with the rifting process. The heat flow anomalies are related to the lithosphere thickness and the presence of rifting and swells both associated with volcanism, melting processes and the presence of mantle plumes in the continent. These crustal structures may also be accompanied by a significant active deformation and seismic activity.

Based on the seismic wave tomography and gravity anomaly studies, the structure and evolution of the lithosphere and upper mantle provide the continental wide structural background for the seismotectonic map. The lithospheric and crustal structure is addressed through the P and S waves anisotropy tomography and the results of receiver functions. The tomography resolution depends on the area of study, the number of stations used and the seismic events available for the tomographic experiment. However, the sparse distribution of the 3-component seismic stations available on the African continent makes it difficult the determination with good resolution of the crustal/lithosphere thickness of the continent from seismic tomography imaging. The role of deep-seated geological heritage in the present-day seismic and volcanic active domains is an important element for the understanding of localized deformation zones. The African continental structure is mainly made of cratons, volcanic fields and sedimentary basins. The thickness of Archean, Proterozoic and Paleozoic crust exhibits strong variation from the thinnest at rift zone to thickest at craton zones (Figures 5a and b) with average thicknesses of 29 km and 41 km, respectively. The East African Rift and related plume extending from Malawi to the Red Sea illustrate the geodynamics of the mantle below Africa and the underlying mantle convection (Figures 5a and b). In comparison with the cratons,

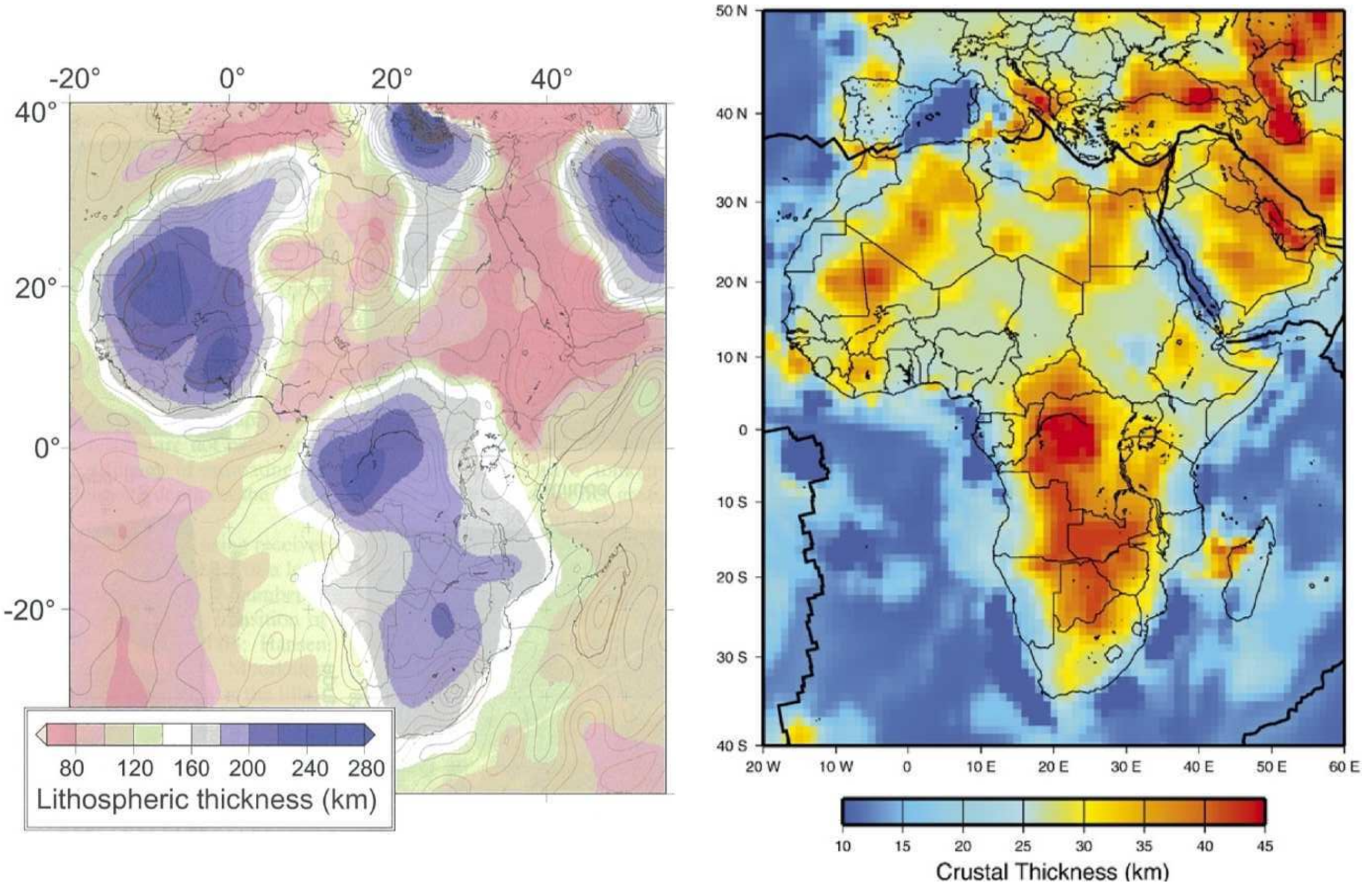

Figure 5: (a) Estimated lithospheric thickness from tomography and gravity anomalies (Bonvalot et al., 2010; Fishwick and Bastow, 2011; (b) Crustal thickness from tomographic data (Pasyanos and Nyblade, 2007).

the plume corresponds to the signature of hot materials and testifies for the volcanic activity with continental deformation in agreement with the seismicity distribution visible in the map. Smaller hotspots are often co-located with seismically active zones and display volcanic centers as in Mt Cameroon and the Tibesti, Aïr, Eghei, Darfur and Hoggar shields.These later form a system of dome uplift with similar scale, morphology and volcanic activity. For instance, under the Hoggar swell (central Sahara, Algeria) the tomographic imagery (Ayadi et al., 2000) shows an anomalous low-density-low-velocity mantle as the consequence of a Cenozoic hotspot volcanic activity, which cooled-off during the NW migration of the African plate.

Database and GIS

The database is a well-structured seamless collection of seismicity data (instrumental and historical), tectonics, geodesy, remote sensing and geophysical data. The collection of the data in one database has also allowed us to overcome possible challenges such as, different projections and datum, different mapping resolutions and different interpretations of existing data. The ArcGIS Suite is used in preparing, managing, analyzing and mapping of the data. This GIS system was selected for this work for the following reasons:

- It allows users to capture, validate, store, manage, query and disseminate digitized spatial and quantitative data,
- There is controlled access through user interfaces,
- It allows users to select and export data sets to other media,
- Importantly, it allows users to produce maps by combining spatial and descriptive data,
- It allows interface with web applications to disseminate data.

Although the database access is for the moment restricted to the project team, the database is already interfaced with internet applications, mainly to keep the team updated on its status (Figure 6).

Implications for the seismic hazard assessment

Many countries in Africa have experienced the severe damage of moderate to large earthquakes and launched a regional evaluation of the seismic hazard assessment (Mourabit et al., 2013, Midzi et al., 2014). Reliable assessment and mitigation of seismic hazards on the continent face challenging problems with clear economic and societal implications. However, one of the main issues encountered in the seismic hazard studies relates to the identification of seismic sources. Understanding the location and evolution of the main seismic sources and related fault ruptures is necessary. In previous regional and/or continental studies (e.g. Ayele et al., 2007; Mavonga and Durrheim, 2009; Midzi et al., 1999; Hlatywayo, 1997) it became clear that very limited information on the long-term earthquake activity and recurrence of seismic ruptures was available for effectively assessing the seismic hazard. Hence, previous studies focused on probabilistic seismic hazard assessments that considered large seismic source areas.

Layer List

Layer Visibility

- ☑ **Seismotectonic Map of Africa**
  - ☐ Focal_Mechanism
  - ☑ Faults
  - ☑ SEISMICITY
  - ☐ Major_Earthquakes
  - ☐ Heat_flow
  - ☐ Stress_Distribution
  - ☐ Volcanoes
  - ☑ TECTONIC MAP

Figure 6: Example of Arc-GIS Internet interface showing the status of the project database on several layers (http://sageoscience.maps.arcgis.com/). (modified for publication)

To carry out reliable studies, it was necessary to improve the seismotectonic characterization of potential sources. In fact, a deterministic approach, as well as a reliable probabilistic approach, requires knowledge about the location, geometry and rupture mechanisms of seismogenic faults in any region. A minimum requirement is the identification of geologically active structures, the activity of which can or cannot be evidenced in the usually reduced historic and/or instrumental record. This task is quite difficult due to the following factors:

1 Lack of instrumentally recorded large earthquakes in most of the continent,

2 Lack of surface faulting evidence together with the poor knowledge of late Quaternary - Holocene tectonics,

3 Lack of comprehensive seismotectonic interpretation of regional tectonic, geodynamical and kinematic framework,

4 Poor resolution of seismic anisotropy studies of the crustal and lithospheric structure and its relationships to the seismogenic structures.

In this project, an effort was made to reduce the uncertainty associated with these factors by collecting and presenting data that can be extracted for the determination of seismic sources in view of seismic hazard assessment. Despite the limited availability of direct evidence across the continent (limited paleoseismic data and coseismic surface rupture information), the association of earthquake epicenters and focal mechanisms with known earthquake ruptures and mapped Quaternary fault ruptures provides valuable evidence of seismogenic faults (Figures 7A, B, C and D). An assumption can be made that the occurrence of earthquakes on or near a fault implies late Quaternary activity of that fault. This assumption is very useful mainly in the western and southern part of the continent where large surface rupturing earthquakes are rare. An exception is the 2006 Machaze Mw 7.1 earthquake where a prominent coseismic rupture was observed at the surface (Fenton and Bommer, 2006; see also location of the green focal mechanism for South Africa in Figure 7C). For all regions in Figure 7, earthquakes seem to be distributed along major faults which have played a role in the recent geodynamic evolution. Where possible, the thickness of the seismogenic zone will be obtained from the hypocentral locations of earthquakes surrounding the faults. For faults with limited historical seismicity, the depths can simply be an average of all earthquake depths located in the vicinity of the fault. The precise location of seismic events and related focal mechanisms can be very useful to improve knowledge on the style of faulting and seismic activity on potentially active structures. Faults identified as active, with information on their kinematic, will be used directly as seismic sources in the seismic hazard assessments.

In addition to the information obtained from the study of active faults in different regions (e.g. Hill, 1988; Goedhart, 2006;

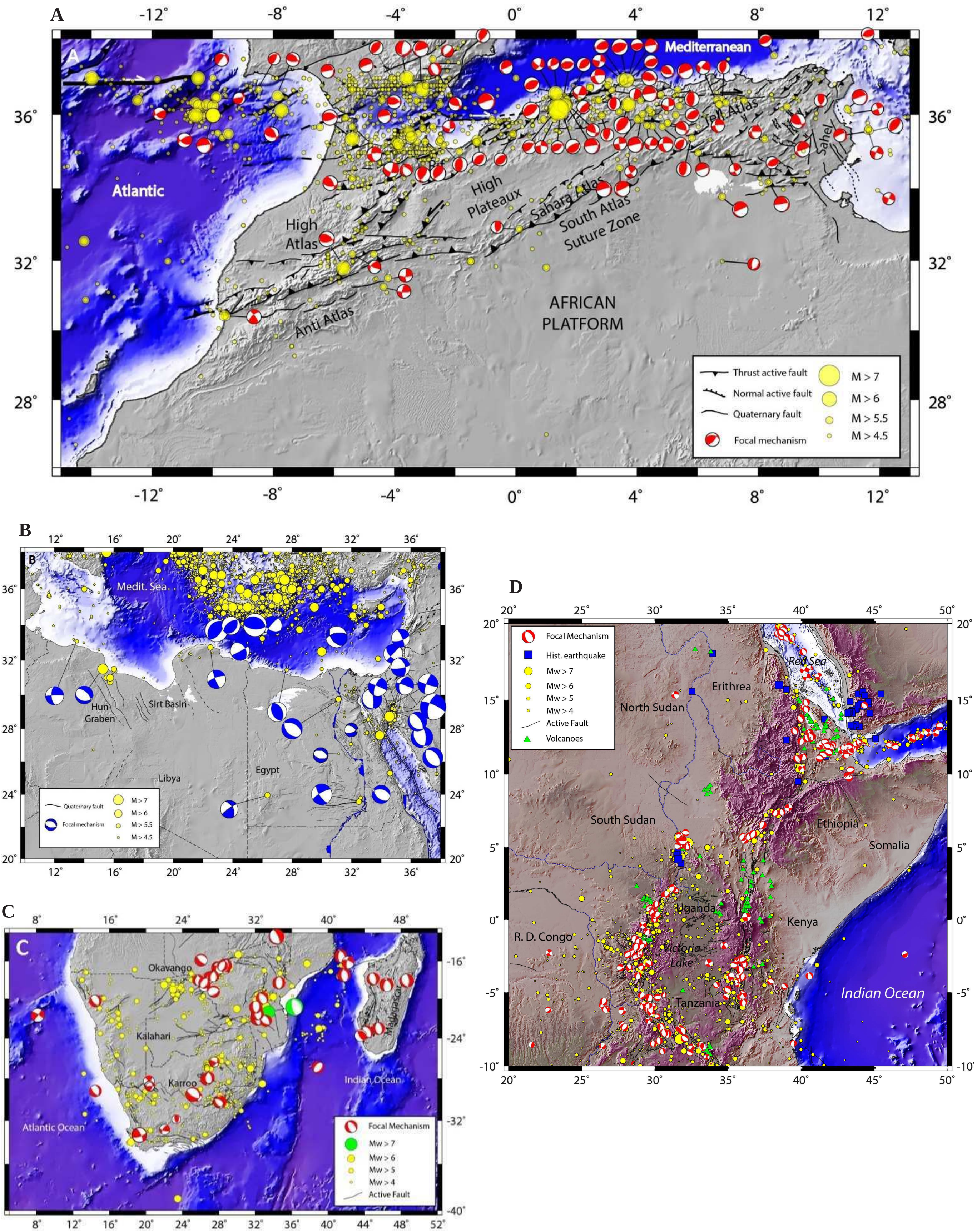

Figure 7: The association of earthquake epicentres with faults and focal mechanisms (CMT) for seismotectonic provinces 2, 3, 5 and 6 (see also Figure 1): (A) northwest Africa, (B) northeast Africa, (C) southern Africa and (D) along the East Africa Rift regions.

Hussein et al., 2006), geodetic, focal mechanism and geophysical data provide insights constraining the stress and strain rates. The strain measurements are not incorporated explicitly in this hazard model because of lack of uniform spatial coverage and availability. The data are included in the map explanatory notice and can provide constraints on the slip rate information independent of geological data and in some cases it is the only source of information on the slip rates.

Where geodetic and geological data are limited, slip rate information can be obtained by considering the annual number of earthquakes of various sizes assigned to each fault using a combination of two statistical distributions: (1) the characteristic earthquake model that implies that a typical size of earthquake ruptures repeatedly along a particular segment of the fault (Schwartz and Coppersmith, 1984), and (2) the exponential model that implies that earthquakes on a given fault follow the Gutenberg-Richter (Richter, 1958) relationship: $N(m) = 10^{a-bm}$ where N is the incremental number of earthquakes, a is the incremental number of earthquakes of $m>0$, b is the slope of the earthquake distribution, and m is magnitude. The data required to carry out such assessments are available as part of the created database, seismotectonic map and accompanying leaflet. However, in characterizing the faults using the above mentioned methods (geological and statistical methods), it is observed that they differ in reliability and weights needed to be assigned for the different fault activity in the seismic source model. It is proposed that those faults with slip rates obtained directly from paleoseismic investigations should have full weight whilst fault activity with slip rates obtained from statistical methods should have a weight of 50%.

Maximum magnitudes are an important variable in calculating the seismic hazard because they determine how much strain is released in larger earthquakes. Information on fault length, rupture area or displacement can be used to estimate a maximum magnitude for each fault using the Wells and Coppersmith (1994) equations. More reliable values of maximum magnitude are obtained where information on displacements per event is available. However, most of the faults identified as active or likely to be active have poorly constrained or unknown slip rates with multiple fault strands distributed over a wide area. These faults will be modeled as aerial source zones. The orientation of faults can then be used to model linear sources.

Conclusion

Although the grasping of the seismotectonic framework and mapping at the level of the African continent is a difficult task, several previous and ongoing regional projects provide wealth of data and outstanding results. The map is based on a completed re-appraisal of the historical and instrumental seismicity catalogue with harmonization and homogenization of earthquake parameters. The database of large and moderate earthquakes in different geological domains, includes the coseismic and Quaternary faulting that reveal the complex nature of the active tectonics in Africa. Although not visible on the map but present in the database, the tsunami hazard on the African coasts also needs to be taken into account. Indeed, the tsunami hazard is directly linked to offshore seismic activity of eastern, western, southern and northern coast of the African continent. Because the seismotectonic map (and related database) is an important document that may serve for the seismic hazard and risk assessment, we consider the inclusion of tsunami events in the database as necessary. The map also benefits from previous works on local and regional seismotectonic maps that needed to be integrated with the lithospheric and upper mantle structures from tomographic anisotropy and gravity anomaly into a continental framework.

The synthesis of earthquake studies with the analysis of long-term (late Quaternary) and short-term (last decades and centuries) active deformation presented along with the seismotectonic map serves as a basis for hazard calculations and the reduction of seismic risks. Any significant infrastructure project needs a seismic hazard and risk assessment due to its implications for the socio-economic impact. The Global Earthquake Model has launched regional programs for sub-Sahara Africa and provides supports for implementing seismic zoning and probabilistic applications for large ground motions. The NAGET for North Africa is also contributing with the necessary scientific knowledge and expertise to achieve the tasks that will complement the use of the seismotectonic map.

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