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SEISMOTECTONICS OF THE GUINEAN EARTHQUAKE OF DECEMBER 22, 1983

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Abstract. Field geological and seismological investigations conducted after the Guinean earthquake on December 22, 1983 show a shallow dextral strike-slip fault with a large normal component. The NW-SE horizontal compressive stress deduced from this event is consistent with measurements made at other places in this region. Old fissures, some of them reactivated during this earthquake, show that this intraplate area constitutes a localized weakness zone in the crust.

Introduction

The Guinean earthquake of December 22, 1983 (M_S=6.2) occurred in a region considered up to now as aseismic (USGS location: 11.95N and 13.60W). Because of its significance for intraplate seismicity and plate driving mechanism French and Moroccan seismologists and geologists operated a seismological survey and mapped the surface breaks several days after the event.

Geology

The epicentre of the earthquake is located in a region bordering the West-African Craton at the southern end of the Mauritanides fold belt and at the edge of the Bowe Basin characterized by horizontal non metamorphic sedimentary layers (Figure 1). A wide range of geological features outcrops in the area: Lower Proterozoïc metamorphic and granitic basement, Upper Proterozoïc to Devonian clayed sandstones and Mesozoïc volcanics. Large scale tectonics result from the superposition of the pan-african orogeny (500-600My), Hercynian folding and combined stretching and shearing induced by the opening of the Atlantic ocean.

No evident oceanic fracture seems to be related to this epicentral region, although the shelf extends abnormally off the Guinean coast. The topography of this area is also rather smooth, except a sandstone scarp about 30 meters high striking North-South. The region is at the foot of a large uplift, the Fouta-Djalon: its origin is not well studied, although it is generally considered as recent [Trompette, oral communication].

Surface breaks

Field observations show a continuous linear system of 10 km long breaks, with cracks and en-échelon faults that strike roughly N100. Large deformations in the central part (Figure 2) near Kamourapa (KA) and Kounsibamba (KO) progressively decrease at both ends.

Extremities of the main structure are characterized by strips of cracks, 200-300 meters wide and about 1 km long, striking N100-N120. The density of cracks varies along them. Cracks are more widely opened in the N120 direction than in the N100 one; they affect all formations, alluvial sandy fillings as well as laterites. The vertical offsets, when they exist, are small and form series of horsts and grabens (Kantakourou, KN).

In the central part deformations are important and numerous. Two parallel zones can be seen (KA 1km and KO 3 km long) with similar patterns characterized by en-échelon fissures connected by compressed zones. The vertical and horizontal offsets have amplitudes of the same order of magnitude. We can see here:

- Open fissures that show large variations in strike, length and opening, but their arrangement is well-ordered:

. maximum openings, up to 40 cm, are always observed along cracks in the direction N150.

. the N100-N110 segments are weakly opened and display dextral lateral motion of up to 10 cm.

. the southern block is always pull down, the vertical offset reaching 15 cm.

. cracks are subvertical and often dip to the north. But sligthly overturned dips often occur in unconsolidated sediments [Mercier et al., 1983].

- Compressed zones: the zones connecting the open fissures that display the most important horizontal offsets are under compression, as indicated by uplifted clods, small thrusts and exposed bent and broken roots. These zones strike N060-N080 and are always bounded by the extremities of two open fissures.

The extension of these observations and their consistence all along the deformed zone allow us to claim that it corresponds to the surface breaks of a fault striking about N100. The orientations of the strain axes about N150 and N060 can be deduced respectively from the opening of the cracks and from the compressive deformations.

Many breaks, some of them rather long, can be observed in the entire epicentral area outside the main fault trace without any clear ordering.

In the region of the largest deformations (KO) old cracks breaking through the laterites show decimetric offsets. These fissures, reactivated or not, are cemented by conglomerates of ferrugineous gangue and run parallel to the onesof the last event. Bushes and trees, absent on the laterites elsewhere, have been able to grow along these fissures. These features appear to be related to ancient tectonic movements and they could be exceptionally important to evaluate the seismic risk and to estimate the return period of earthquakes in this region.

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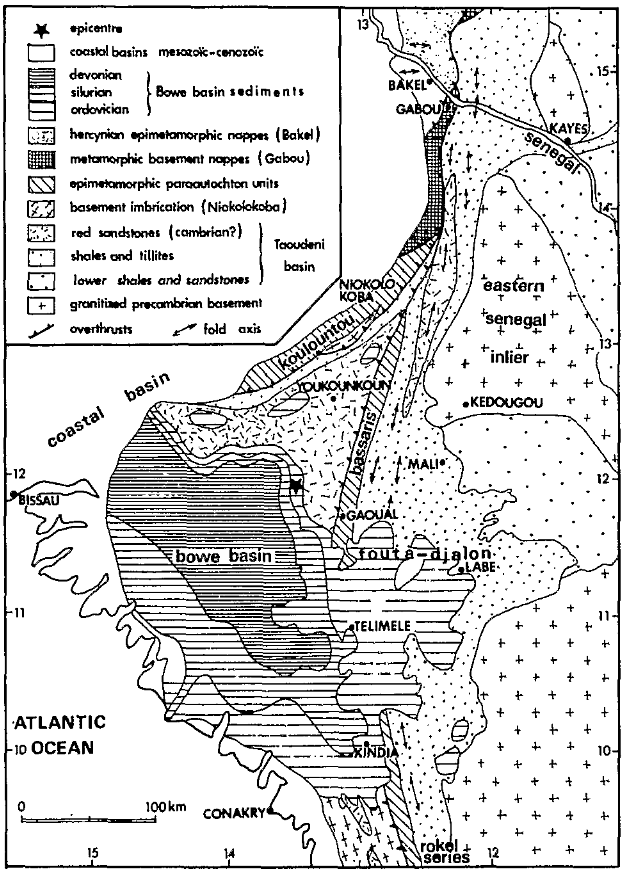

Fig.1 Regional geological map [after Villeneuve, 1980].

Seismicity

The seismicity of West Africa is low; several large and damaging earthquakes have nevertheless occurred in the region of Accra (Ghana) and to the North in the Cape Verde islands. Earthquakes have been reported in Guinea during this century, mainly in the coastal area (maximum intensity VI/VII). A seismological station at Kedougou (Senegal) close to the Guinean border recorded a foreshock of the December 22 event on the day before at 10:30 AM with a local magnitude 3.0. This station allows us to estimate the seismic activity before the installation of a network of 12 MEQ 800 instruments that operated since December 30 1983 until January 06 1984. Unfortunately during this operation, there was no earthquake large enough to be recorded in other nearby stations (Senegal and Ivory Coast) and hence useful to relocate the main shock.

No information about the local seismic velocity is available. In order to calculate the hypocentres of more than 1000 aftershocks using the Hypo 71 program we chose a half space model with a P velocity of 5.6 km.s^{-1}. The value 1.68 of the V_P/V_S ratio was determined using the Wadati diagram technique. The locations do not significantly depend on the model; for instance a P velocity of 6.0 km.s^{-1} does not change the depth by more than 1 km. Only events with more than four P and one S arrival times have been kept and a total amount of 770 shocks satisfy the following conditions: standard deviation in epicentral coordinates 2 km, in depth 3 km and RMS of arrival time residuals 0.30 s. In fact in most cases the data of 7 stations were used and time residuals are generally smaller than 0.15s.

The aftershock distribution (Fig.2) clearly shows two linear E-W segments with a N-S offset about 5 km. The total length of these lines is roughly 15 km, in agreement with the expected length for an event of magnitude 6.3. The same general pattern is also observed when considering only the largest events. The seismicity is confined between depths of 5 km and 15 km and mainly between 7 km and 11 km. It is noteworthy that there are only very few events located above 5 km. The epicentres of the western segment are aligned along the western continuation of the observed fault trace. All the seismicity of the eastern segment is located at the South of this trace. A vertical N-S cross-section (Figure 3) of this segment shows that the distribution of the aftershocks dips roughly to the South. This slope is steeper and actually subvertical for the western aftershock area where the seismicity is more clustered at a depth of 8-10 km. If we adopt a dip angle of 60° for the fault plane as indicated by the focal mechanism solution discussed in the next section, then the seismicity is uniformly distributed at each side of this plane, but if the dip is 70° then all the aftershock activity will be within the hanging wall.

Focal mechanism

Our readings of the first motion of P-waves from the long period stations of the global network are shown in figure 4. We have added obser-

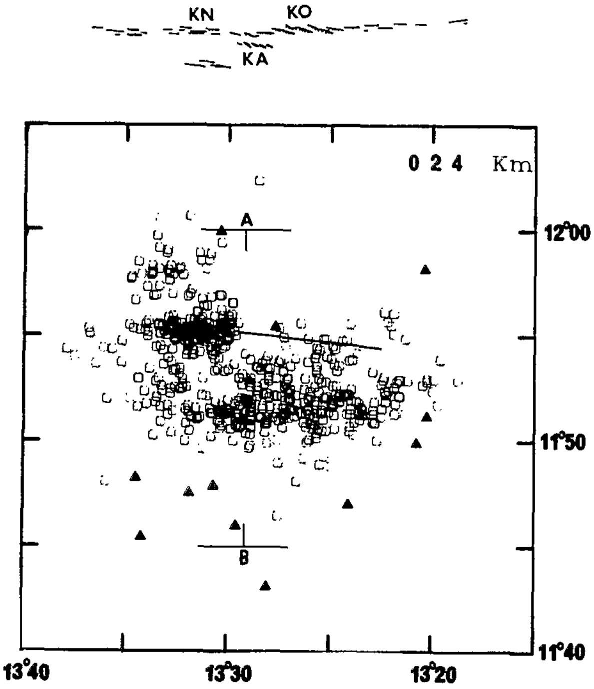

Fig.2 Observed surface cracks and aftershock distribution. The E-W straight line among the epicentres indicates the location of the surface cracks shown above the map. Filled triangles: seismological stations. A and B indicate the ends of the cross section presented in figure 3.

vations from a short period array in Ivory Coast and from a station in Senegal (MBO at a distance of about 500km). All of them correspond clearly to dilatation, except for doubtful observations at PTO and VAL where the seismic signal is rather noisy. With these data it is impossible to determine accurately the nodal planes, nevertheless a normal dip-slip motion must be introduced in the final solution. Morever the synthetic P-wave seismograms calculated for a pure normal fault are incompatible with the observations at these stations and a shear component should be introduced.

As said above the distribution of the aftershocks of both segments strikes E-W. It dips to the South at the eastern part and it is subvertical to the West. Another important constraint is provided by surface breaks: openings and dextral shear. Taking into account all of this information, we obtain the best fitting of the waveform for the focal mechanism solution presented on figure 5. The most consistent depth is 13km. Therefore our final solution is a right-lateral strike-slip E-W fault with a large normal component and a depth varying from 10 to 15 km.

The body wave seismic moment is about 3.5 10^{25} dyne-cm. If we assume that the length and the width of the active fault were less than 15 km each, we can calculate lower bounds of the slip and of the stress-drop using a uniform circular crack model. We obtain 50 cm and 24 bars respectively.

Discussion

The map of the seimicity showing a clear segmentation illustrates the complexity of the fracture zone. A large aftershock occurred the day after the main event with a magnitude of about 5 and could explain this double fracture.

Another important characteristic of the seismicity is the absence of activity between the surface and a depth of about 5 km. This pattern is also observed when only the accurately located events are considered. This absence of activity could be explained either by a low strength of the material or by a complete stress release at shallow depths during the main shock. Besides the subsidence of the southern block relatively to the northern one, surface breaks as described above show extension in the direction N060, compression in N150 and finally shear along N100. These features are quite compatible with the response of a weak medium lying over a more competent substratum which is subjected to shear faulting along the direction N100. Morever the surface displacements are roughly 10-40 cm while the average dislocation deduced from the seismic moment is about 60 cm. Therefore it is possible to suggest that a layer about 5 km thick exists where no seismic activity takes place after the main event and that cracks are the consequences at the surface of deep movements: dextral lateral motion and subsidence of the block to the South of the surface trace. On the other hand if stress release had been complete during the main event, the surface observations could be also explained by compression striking NNW. Now if we come back to the focal mechanism solution and consider the movement on a pre-existing fault-plane oriented E-W as a dextral lateral and normal dip-slip motion, we can conclude that this motion results from strike-slip motion according to the classification by Armijo et al [1982]. Hence σ_1 is in the direction NW and σ_2 vertical. The parameter $R=(\sigma_2-\sigma_3)/(\sigma_1-\sigma_3)$ has a value between 0 and 1.

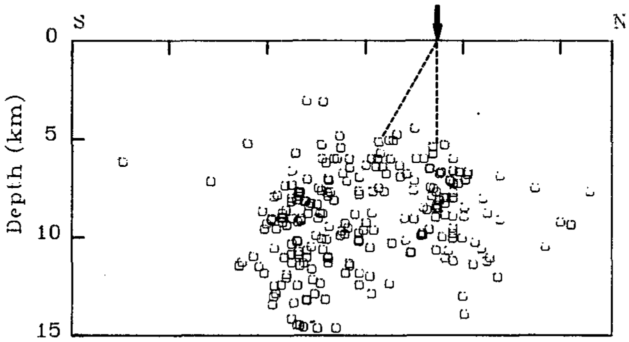

Fig.3 Vertical cross section of the events plotted in figure 2 and located along the line AB in a stripe 8 km wide. No vertical exaggeration. The arrow shows the position of the observed surface cracks. Two groups of events are clearly defined in the aftershock distribution. The sloping dashed line indicates the fault plane deduced from the final focal mechanism solution (figure 4). The vertical dashed line corresponds to the hypocentres of the western segment.

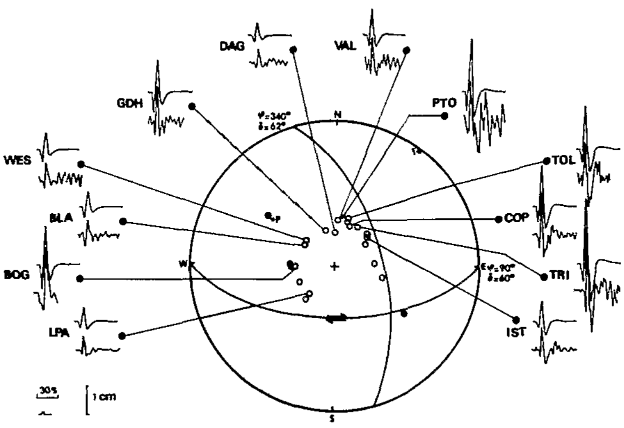

Fig.4 Fault plane solution and waveform modeling for the 22 Decembre 1983 main shock. The lower focal hemisphere is represented with open circles indicating dilatational, crosses doubtful arrivals and crossed circles short period readings. The synthetic waveforms are calculated for a point source double couple with the 1-3-1 time function shown at the bottom left of the figure. The vertical bar represents 1 cm on a 1500 amplification WWSSN station.

There is a general agreement [see for instance Okal, 1980 and 1983, Richardson et al, 1979] that earthquakes share common compressional stress direction over large areas indicating relations with large scale plate dynamics. Two earthquakes within the Africa plate in the Atlantic ocean have allowed for the determination of principal stress axis [Sykes and Sbar, 1974, Richardson and Solomon, 1977 and Liu and Kanamori, 1980]. The compressional axis azimuth varies from NW-SE to N-S. An in-situ strain relief measurement in

Sierra Leone [Hast, 1969] indicates a NW-SE trend for the maximum compressive stress. This direction is in good agreement with that deduced from our focal solution. Therefore there seems to exist a uniform regional stress field indicating that such seismic zones are localized on weakness areas of the crust with favorably oriented preexisting faults. Preliminary study of satellite views does not reveal prominent fractures striking E-W.

The return period of interplate earthquakes may be modeled by a simple scheme. This concept needs to be enlarged for the case where no plate consumption is taking place. The observed ancient cracks reveal that some recurrence of seismic activity may exist. Further field observations have to be carried out to obtain a fairly representative picture of the seismic history of northern Guinea.

Conclusions

Geological and seismological studies of the main mechanism of the 1983 Guinean earthquake show that it was a dextral strike-slip event presenting a significant normal motion. The rupture mechanism may be relatively complex. The aftershock distribution shows two segments striking E-W and dipping more or less to the South. There is a clear relationship and complementarity between surface observations and the seismic source obtained by seismological means. Breaks in the laterites show the importance of the ancient seismic activity in connection to seismic risk. This information was not available from instrumental seismology.

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