confidential

SEISMOTECTONICS OF THE GUINEAN EARTHQUAKE ON DECEMBER 22, 1983.

C. DORBATH[1-2], L. DORBATH[1-2], R. GAULON[1], T. GEORGE[1], P. MOURGUE[2], M. RAMDANI[3], B. ROBINEAU[4], B. TADILI[3]

1- Laboratoire de sismologie LA195 CNRS- Institut de Physique du Globe
4 Place Jussieu 75230 Paris cedex 05 FRANCE

2- ORSTOM 24 rue Bayard 75008 Paris FRANCE

3- CNCPRST, Rabat MAROC

4- Faculté des Sciences Université de Dakar SENEGAL

Contribution IPGP Nº 772

LEGSP n: 5430

ABSTRACT.

Field geological and seismological investigations conducted after the Guinean earthquake on december 22, 1983 show a shallow normal fault with a large dextral lateral displacement. The state of 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. One of our conclusions is that it is inadequate to identify potentially hazardous regions only on the basis of the historic seismicity for intraplate shocks.

Introduction

The Guinean earthquake of December 22 1983 occurred in a region considered up to now as aseismic. Table 1 gives the location and the magnitude calculated by NEIS and CSEM. About 300 people were killed during this event, several hundred people injured and most of the dwellings were destroyed or severely damaged. A maximum intensity of VIII (MKS) has been estimated by J.Despeyroux (oral communication). Because of its significance for intraplate seismicity a team of French and Moroccan seismologists and geologists operated a seismological survey and mapped the surface breaks.

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 unmetamorphized unperturbed structures (Fig.1). The metamorphic basement shows a wide range of features with some outcropping inliers and it is covered by sedimentary series, mainly made up of argileous sandstones dated from Precambrian to Devonian times[1]. This region has been affected by several episodes of deformation since the pan-african orogeny (500-600 my) up to Hercynian time (about 300 my), mainly in the Mauritanides belt. The opening of the Atlantic ocean (200my) is associated with local extensions and dolerite intrusions. Sykes[2] (1978) has shown that the seismicity due to the largest intraplate shocks seems to be preferentially located along old zones of weakness near the ends of major oceanic transform faults active in the early opening of adjacent oceans. 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. Only a sandstone cliff has an elevation of some 30 meters, striking north-south. This region is at the foot of a large uplift, the Fouta-Djalon,

.../...

whose 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 (Fig.2) near Kamourapa (KA) and Kounsibamba (KO) progressively decrease at both ends. The detailed map will be published elsewhere.

At these extremities some lineaments about 200-300 meters wide and 1 km long, striking N100-N120, are observed. 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, the alluvial sandy fillings as well as the 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. There we may see:

- Open fissures:

they present 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, but often dip to the north.

- 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 of compressional deformation 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 features of a fault striking about N100. The directions of the principal axes of strain about N150 and N070, 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 may be observed breaking through the laterites. These fissures are cemented by conglomerates of ferrugineous gangue and show decimetric vertical offsets. These accidents are generally parallel to the structures of the last event, some of them having been reactivated by it. Bushes and trees, absent on the laterites elsewhere, have been able to grow along these fissures. These features appear to be related to old tectonic movements and are exceptionally important to evaluate the seismic risk and to estimate the return period of earthquakes in this region.

SEISMICITY.

Although the seismicity of the West Africa is low in comparison to that of the East african rift system, several large and damaging earthquakes have nevertheless occurred in the Accra area of Ghana and to the north of the Cape Verde islands. Morever, several earthquakes have been reported in Guinea during this century, mainly in the coastal area (maximum intensity VI/VII), but the locations may be biased by the location of the colonial administration mainly in the coastal cities. The seismological station at Kedougou (Senegal) close to the Guinean border, recorded a precursor to 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. The b-value of 0.8 of the Gutenberg-Richter relation is low. 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 Hypo71 program we chose a model consisting of a half space with a P velocity of 5.6 $km.s^{-1}$. The value 1.68 of the VP/VS ratio was determined using the Wadati diagram technique. Tests were performed to check the influence of this choice, but the results do not significantly differ from the first ones; for instance a P velocity of 6.0 $km.s^{-1}$ does not change the depth by more than 1 km. The low value of VP/VS may be explained by a sedimentary layer that could produce converted phases and missidentification of S waves. 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.

The aftershock distribution (Fig.3) clearly shows two linear E-W segments with a N-S offset about to 5 kms. The total length of these lines is roughly 15 km, in agreement with the expected length for an event of magnitude 6.3[3]. This value confirms that the disappearance of the seismicity to the West is not due to the absence of stations. Difficulties to extend the network were related to local conditions. The same general pattern is also observed when considering only the largest events. The seismicity is distributed 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 (Fig.4) 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 aftershocks activity will be in the southern block.

The area of the aftershock zone increased by a factor of 1.2 from the begining to the end of the field operation. The eastern segment developped towards the East while the western aftershock area extended towards the North.

FOCAL MECHANISM

Our readings of the first motion of P-waves from the long period stations of the global network are shown in figure 5. We have added observations 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. A shear component should be considered since the modeling of the first part of the waveform of the P wave recorded at these long period stations is incompatible with a pure normal fault.

As it was said above the distribution of the aftershocks of both segments

.../...

pre-existing fault-plane oriented E-W as a dextral lateral and normal dip-slip motion, we can conclude that this motion results of strike-slip motion according to the classification by Armijo et al (1982)[4]. 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. If eastern and southern Africa are two regions where the state of stress in the lithosphere has been well studied, it is not the case in the western part of Africa. Two oceanic intraplate earthquakes and an in-situ strain relief measurement indicate a NW-SE trend for the maximum compressive stress[5-6-7]. This direction is in good agreement with that deduced from our focal solution. Therefore there seems to exist a uniform regional stress field that indicates that such seismic zones are localized weakness area in the crust. That would indicate that there exists some favorably oriented pre-existing crustal faults. A preliminary inspection of satellite pictures does not indicate any significant deformations or accidents striking E-W. Further analysis is required to confirm this point that erosion is acting here more quickly than tectonics.

An uplifted area exists to the south East, the Fouta-Djalon, at the northern edge of the major high topography block in West-Africa. This cenozoïc structure could have affected the tectonics of the region, but this relation has been not yet established.

Return period of earthquakes may be modeled by a reasonably clear scheme in an interplate seismic environment. This concept needs to be enlarged in a 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 normal dip-slip event presenting a significant dextral 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 data was not available from instrumental seismology.

.../...

strikes E-W. It dips South at the eastern part and it is subvertical towards the West. Another important constraint is provided by surface break data: openings and dextral shear. Taking into account all of these informations, we obtained the best fitting of the waveform for the focal mechanism solution presented on figure 5. A depth of 13 km also is the most consistent with this modeling. Therefore our solution consists in a normal dip-slip E-W fault with a large component of dextral lateral motion and a depth varying from 10 to 15 km.

The body wave seismic moment is about 3.5 10^{25} dyne-cm. However two U.S. stations differ significantly from this value by a factor of 0.5. The values of ten other stations fluctuate between 3 and 4 10^{25} dyne-cm. If we assume that the length and the width of the active fault were less than 15 km each, we calculated lower bounds of the slip and of the stress-drop using a uniform circular crack model. We obtained 50 cm and 24 bars respectively. The latter value is low when compared to other intraplate earthquakes[4].

DISCUSSION.

The map of the seimicity showing a clear segmentation illustrates the complexity of the fracture zone. This distribution could be due to the largest aftershock that occured the day after the main event with a magnitude of about 5.

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 events with the most accurate depth and RMS are considered. This absence of seismicity 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 south 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. Then 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 explained by compression striking NNW. Now if we come back to the focal mechanism solution and consider the movement on a

Bibliography.

1. Villeneuve,M.C.R.Somm.Soc.Geol.Fr.2,54-57(1980).

2. Sykes,L.R.Rev.Geophys.Space.Phys.16,621-688(1978).

3. Kanamori,H.and Anderson,D.L.Bull.Seism.Soc.Am.65,1073-1096(1975).

4. Armijo,R.,Carey,E. and Cisternas,A.Tectonophysics,82,145-160(1982).

5. Richardson,R.M.and Solomon,S.C.Pure Appl.Geophys.Res.,81,1847-1856(1976).

6. Sykes,L.R.and Sbar,M.L.Geodynamics of Iceland and the North Atlantic Area,edited by Kristjansson,207-224,D. Reidel,Hingham,Mass(1974).

7. Hast,N.Tectonophysics,8,169-211(1969).

.../...

Table I

	CSEM	USGS
location	11.91N 13.52W	11.950N 13.605W
time	4H 11M 31.13S	4H 11M 29.32S
depth(fixed)	10 km	10 km
magnitude:		
$-m_b$	6.4	6.4
$-M_S$		6.2

.../...

Figure caption.

Fig.1 Regional geological map (after Villeneuve, 1980).

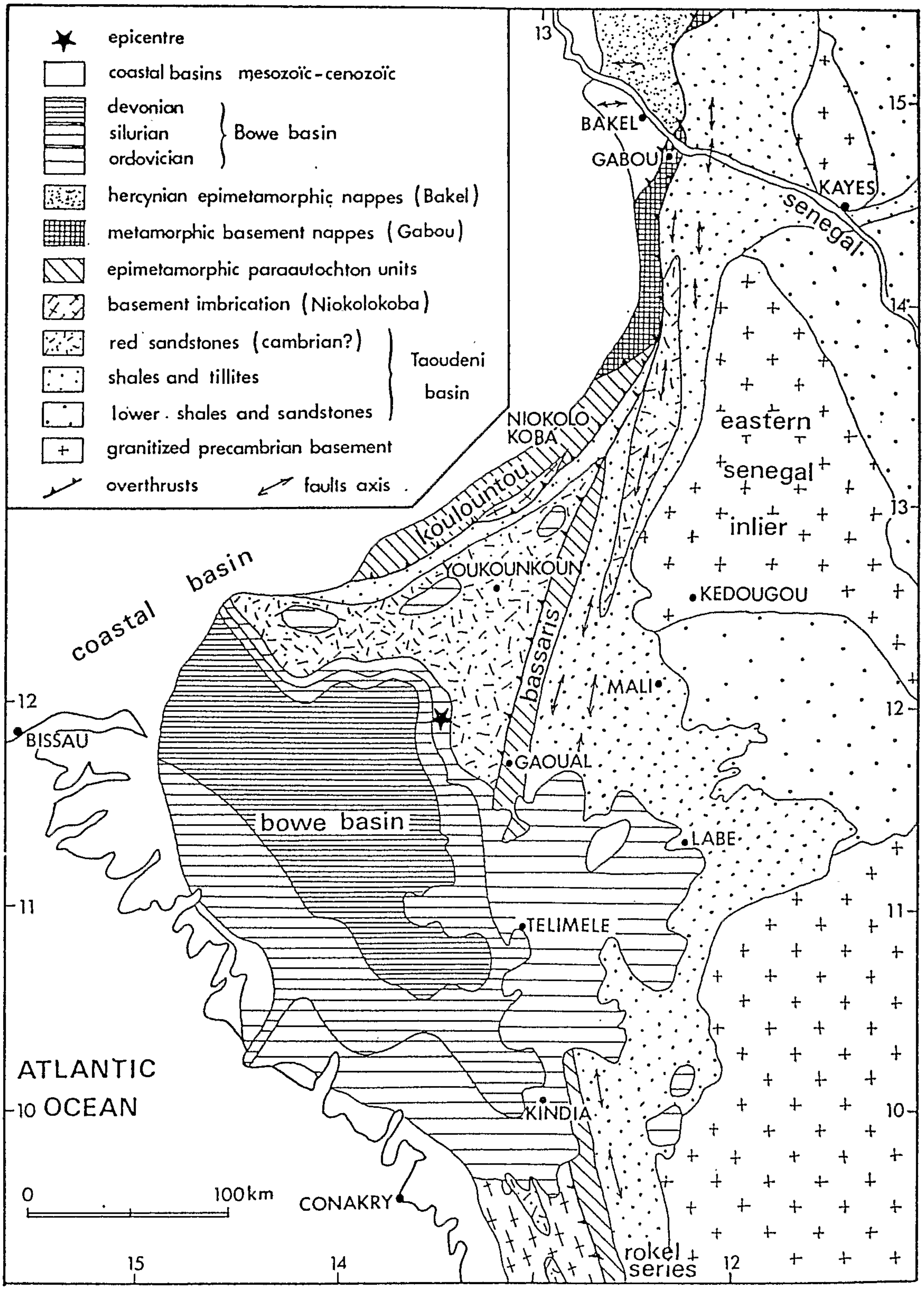
Fig.2 Observed surface cracks superimposed on the local geological map (after a Soviet-Guinean survey, 1976).

Fig.3 The aftershock distribution for the 770 best locations. The straight E-W line indicates the location of the surface cracks. Filled triangles : seismological stations. A and B indicate the ends of the cross section presented in figure 4.

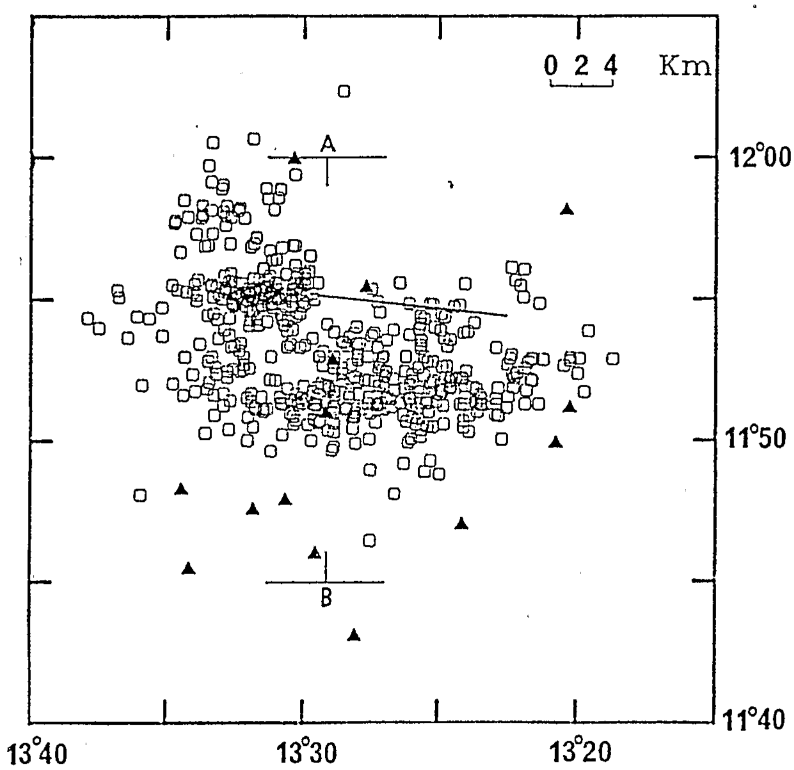
Fig.4 Vertical cross section of the events plotted in figure 3 and located along the line AB in a stripe 8 km wide. The arrow shows the position of the observed surface cracks. Two groups of events are clealy defined in the aftershock distribution. The sloping dashed line indicates the fault plane deduced from the final focal mechanism solution (figure 5). The vertical dashed line corresponds to the hypocentres of the western segment.

Fig.5 Fault plane solution and waveform modeling for the 22 Decembre 1983 main shock. The lower focal hemisphere is represented with open circles indicating dilatational and crosses doubtfull arrivals. 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.

.../...


epicentre
coastal basins mesozoïc-cenozoïc
devonian
silurian
ordovician
Bowe basin
hercynian epimetamorphic nappes (Bakel)
metamorphic basement nappes (Gabou)
epimetamorphic paraautochton units
basement imbrication (Niokolokoba)
red sandstones (cambrian?)
shales and tillites
lower shales and sandstones
Taoudeni basin
granitized precambrian basement
overthrusts
faults axis
BAKEL
GABOU
KAYES
senegal
NIOKOLO KOBA
kouloutou
eastern senegal inlier
coastal basin
YOUKOUNKOUN
KEDOUGOU
bassaris
MALI
BISSAU
GAOUAL
bowe basin
LABE
TELIMELE
ATLANTIC OCEAN
KINDIA
CONAKRY
rokel series
0
100km
15
14
13
12
11
10

F I



F I G . 3

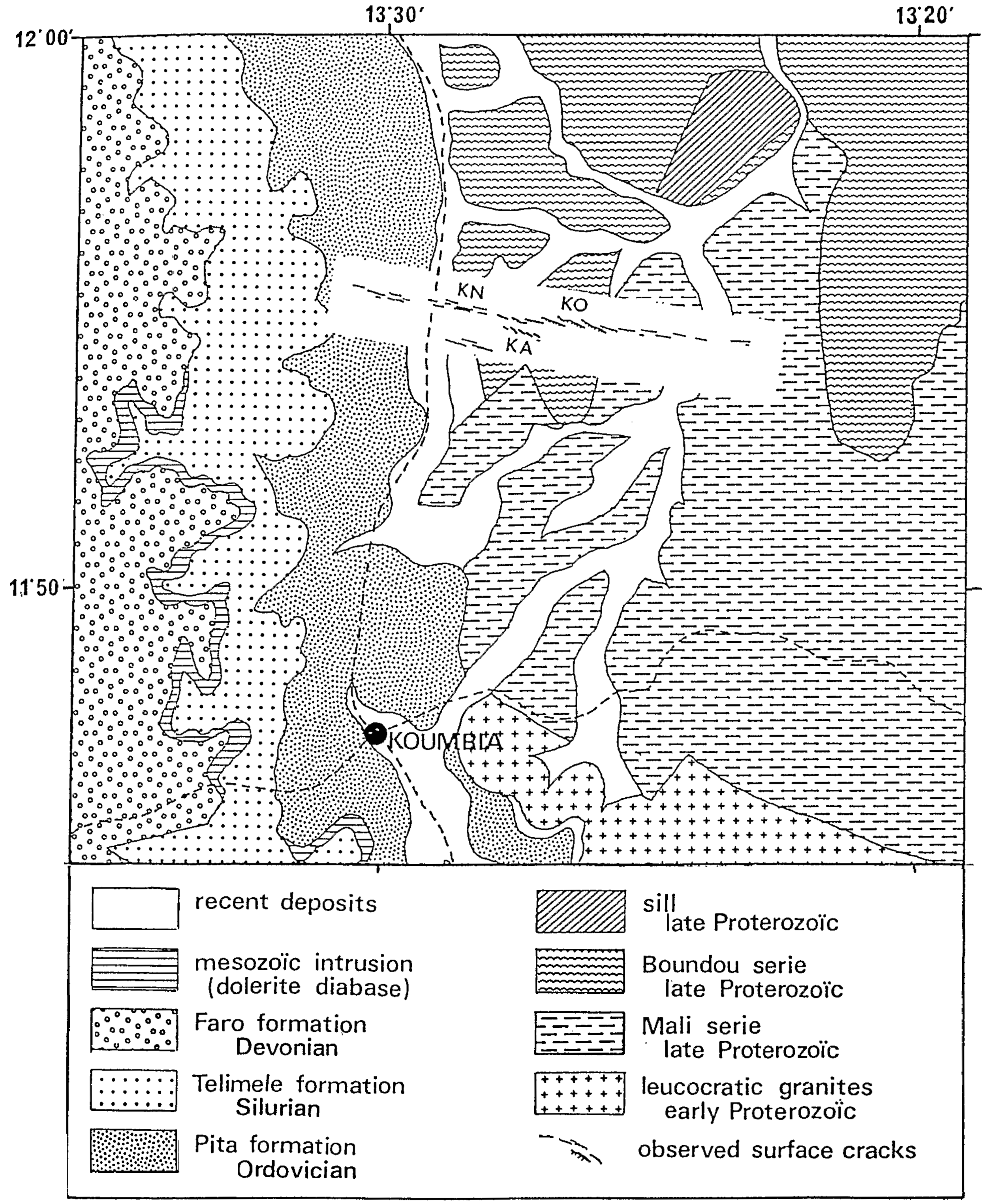

13°30'
13°20'
12°00'
11°50'
KN
KO
KA
KOUMBIA
recent deposits
mesozoïc intrusion (dolerite diabase)
Faro formation Devonian
Telimele formation Silurian
Pita formation Ordovician
sill late Proterozoïc
Boundou serie late Proterozoïc
Mali serie late Proterozoïc
leucocratic granites early Proterozoïc
observed surface cracks

FIG. 2

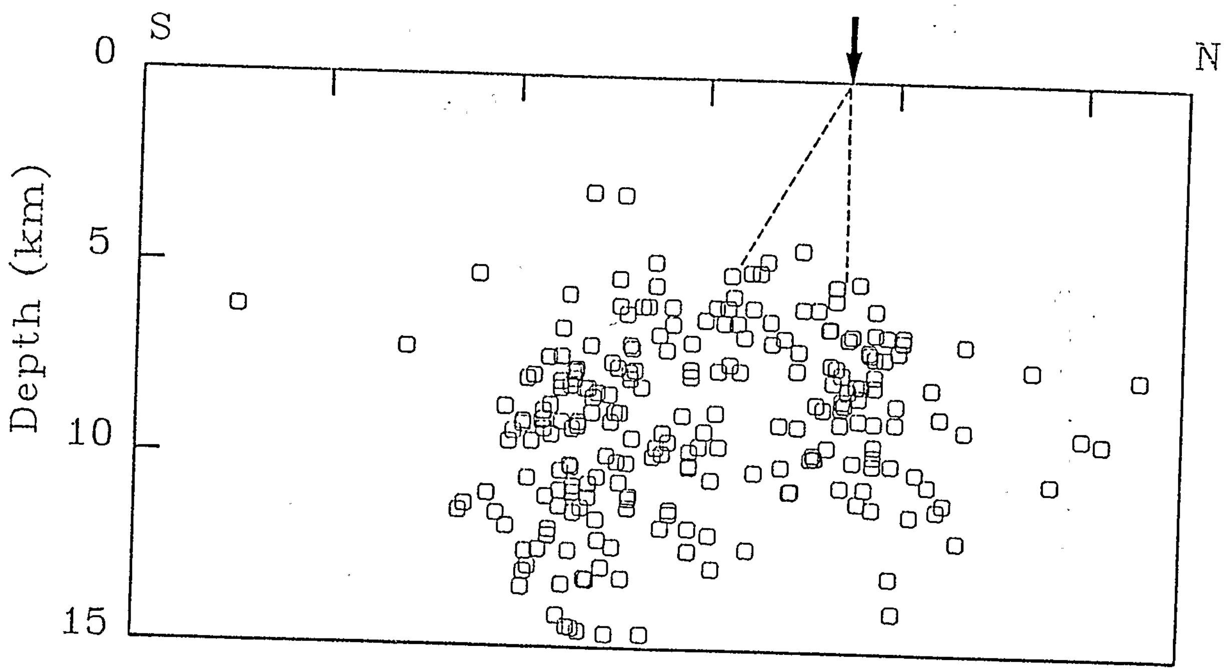


FIG. 4

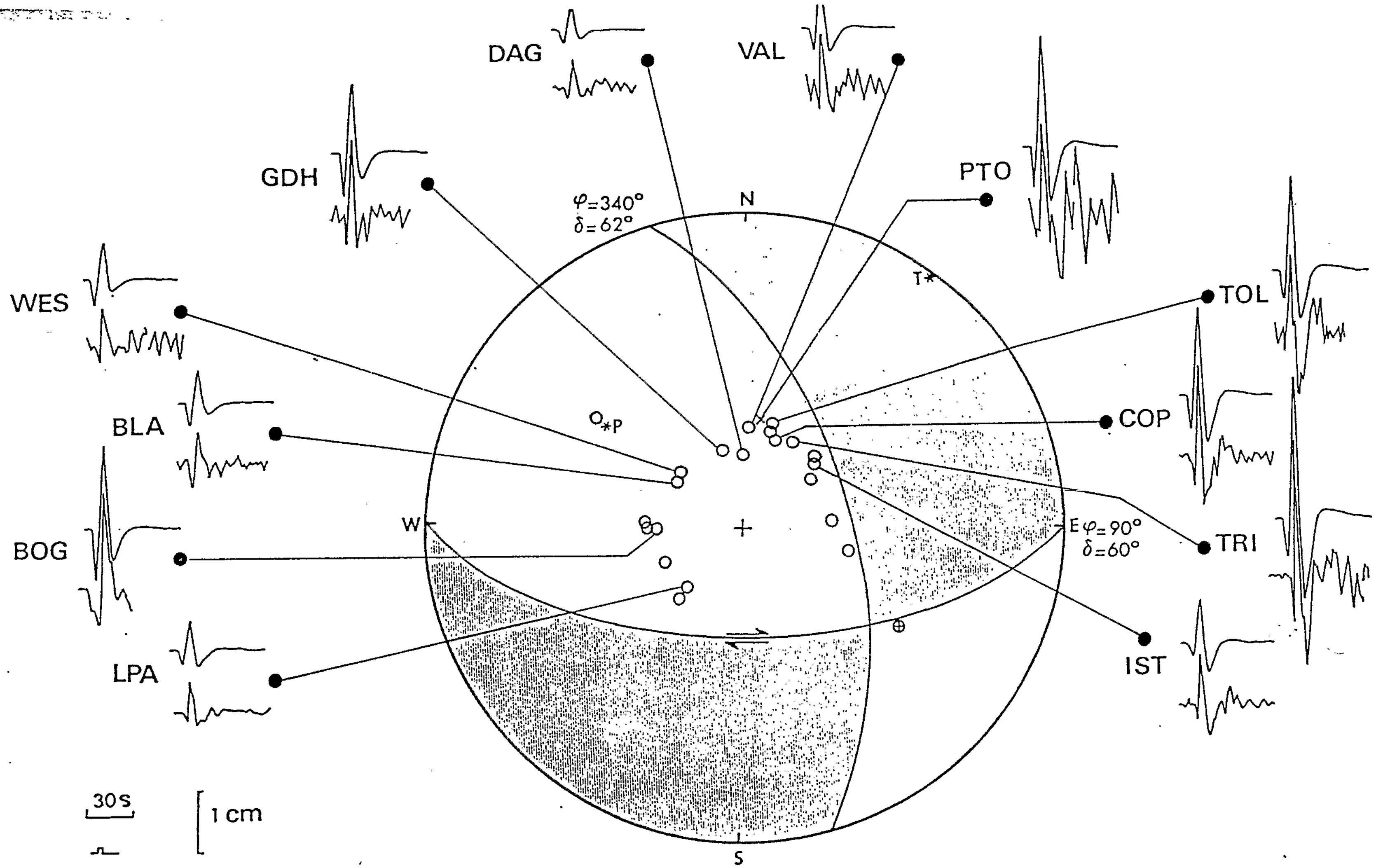

DAG
VAL
GDH
PTO
WES
TOL
BLA
COP
BOG
TRI
LPA
IST
N
S
W
E
φ=340°
δ=62°
φ=90°
δ=60°
T*
P
30 s
1 cm

FIG. 5