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The Guinea, West Africa, Earthquake of December 22, 1983--Reconnaissance Geologic and Seismologic Field Studies

By

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ABSTRACT

The northwestern Guinea epicentral area in West Africa is a coastal margin, intraplate locale with a very low level of historical seismicity. The magnitude 6.4 (m_b) main shock of December 22, 1983, was accompanied by some 9 km of east-southeast to east-west-trending surface faulting. The fault displacement (f13 cm) was predominantly right-lateral strike slip and an additional small component of vertical movement, southwest side down was observed in several places. Main-shock focal mechanism solutions derived from teleseismic data by other workers show a strong component of normal faulting motion that was not observed in the ground ruptures. The surface faulting occurred on a preexisting fault whose field characteristics suggest a low-slip rate with very infrequent earthquakes. There were extensive rockfalls and minor liquefaction effects at distances less than 10 km from the faulting and main-shock epicenter. A spectacular effect of the earthquake was the subsidence of the roof of a cave in laterite, dropping the ground surface and its cover of trees as much as 4 m over an area some 30-m long by 20-m wide. This is the first instance known to the writers of earthquake-related collapse of such a cavern.

A 15-day period of aftershock monitoring, commencing 22 days after the main shock, was conducted. Eleven portable, analog short-period vertical seismographs were deployed in a network with an aperture of 25 km and an average spacing of 7 km. Over 200 aftershocks, with duration magnitudes of about 1.5 or greater, were recorded. Analysis of a sample of 94 of those events revealed a tabular aftershock volume (27 km long by 14 km wide by 2 km thick) trending east-southeast and dipping steeply (f60°) to the south-southwest. Four composite focal mechanisms for groups of events, distributed throughout the aftershock volume, all exhibited right-lateral, strike-slip motion on a steeply dipping (near-vertical) plane striking east-northeast. Thus, the general agreement between the field geologic and seismologic results is good, but does not support the large component of normal faulting reported for the main shock.

INTRODUCTION

On the morning of December 22, 1983, a region of West Africa previously considered to be virtually aseismic was shaken by a moderate (m_b = 6.4) earthquake. The epicentral locale was in northwestern Guinea, near the border with neighboring Guinea-Bissau (fig. 1). The Guinean communities of Gaoual and Koumbia experienced moderate damage, but several villages extending in a line between about 5 and 15 km due north of Koumbia were damaged extensively. Unconfirmed casualities include at least 275 people killed, 1,000 people injured, and 18,000 people left homeless. The shock was felt in the adjacent countries of Guinea-Bissau, Senegal, the Gambia, Sierra Leone (U.S. Geological Survey, 1984), and over a broad area of Liberia (Ntungwa Maasha, Univ. of Liberia, written commun., 1984).

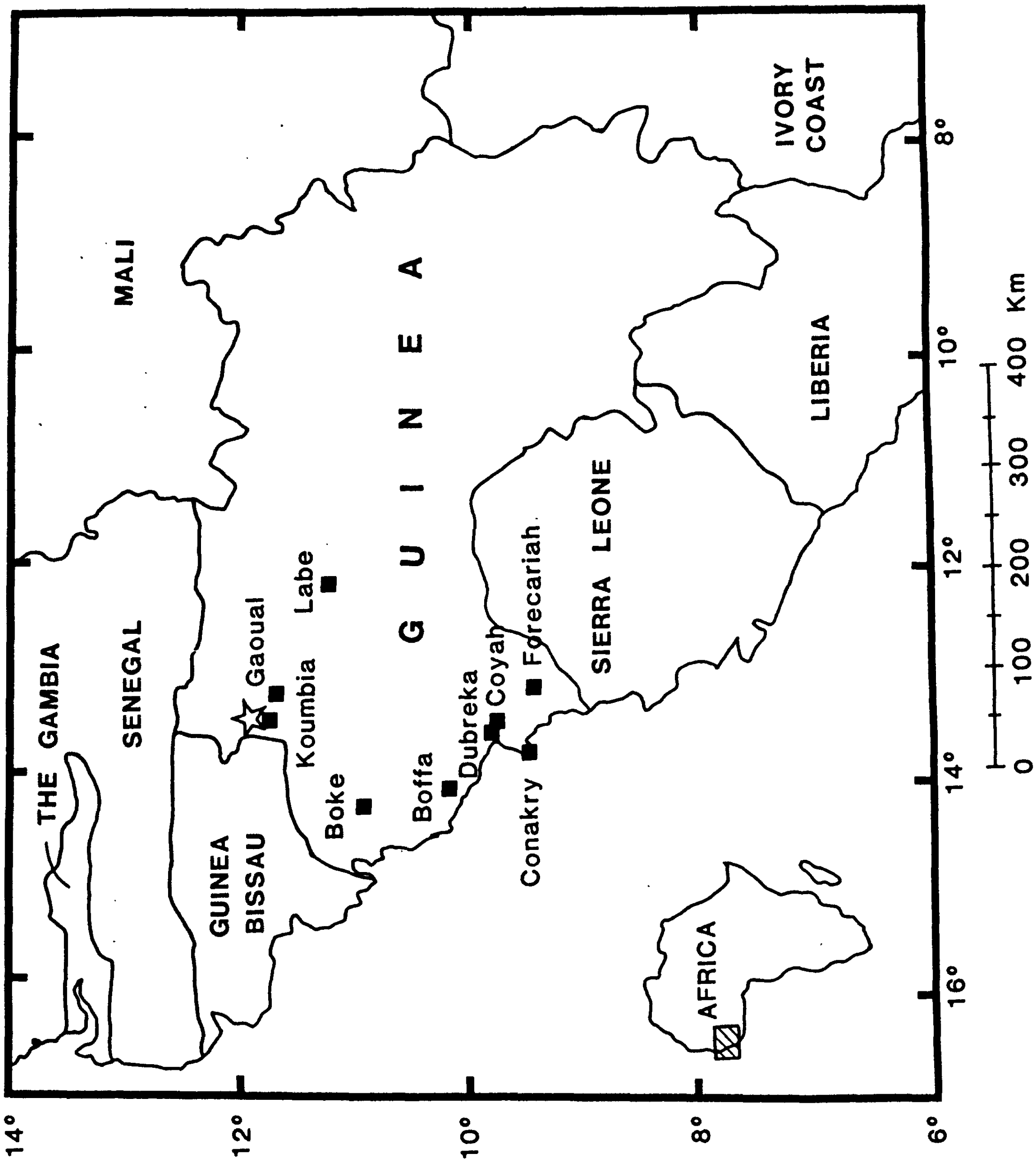

FIGURE 1.--Epicentral locale map for the December 22, 1983, earthquake (star) in northwestern Guinea. Inset map shows location of area (shaded).

Because of the rare occurrences of earthquakes of this size in West Africa, teams of French and Moroccan scientists (Dorbath and others, 1984) as well as U.S. Geological Survey (USGS) investigators converged on the epicentral area. This paper reports on the results obtained by the USGS group.

SEISMOTECTONICS OF THE EPICENTRAL REGION

Guinean West Africa is nearly aseismic and occupies an intraplate, coastal margin location. The regional tectonic setting has been described recently by Neev and others (1982) from their photogeologic analysis of extensive satellite imagery (13 LANDSAT photomosaics covering 4,500 by 1,500 km at a scale of 1:5 million) supported by a limited amount of ground truth (due to geographic and (or) political inacessibility). They postulate a megashear system extending southwestward from Turkey, diagonally across Africa, then into the South Atlantic, that has functioned as a system of en echelon, left-lateral megashears since Precambrian time. Whether the above megashear interpretation of the broad tectonic systems of Africa has any bearing on Guinean seismicity is highly speculative. But, to the west the Vema and Doldrums fracture zones (Heezen and Tharp, 1977) extend easterly from the Atlantic Ridge toward and near to the coast of Guinea and Guinea Bissou. Williams and Williams (1977, fig. 1) have hypothesized an extension of the Vema fracture zone that passes close to the epicenter of the 1983 earthquake. Thus, landward extension of an oceanic fracture may be more closely related to previous and current seismic activity in Guinea than some proposed megashear system.

There have been 19 (27?) historical earthquakes between 1892 and 1941 described in the Guinean State publication HOROYA (1983; see appendix A). It is not known at this time if all of these reported shocks were centered within the borders of Guinea. The maximum estimated intensity is VII (scale unknown) and includes three tremors on August 18 (19), 1928, that were reported to have been accompanied by "smoke emanating from ground breaks."

Therefore, while it is clear that the seismicity of the region is very low, it is certainly not aseismic. Indeed, Krenkel (1923, cited by Sykes, 1978) shows an average annual frequency of up to five earthquakes for the area immediately to the north of the 1983 epicenter, and in the region extending westward offshore to include the Cape Verde Islands. Two earthquakes of magnitude 6 1/4 to 6 3/4 in 1938 and 1941, and two earthquakes of magnitude less than 6 occurred near (northwest of) the Cape Verde Islands and well within the oceanic lithosphere (Sykes, 1978) and about 1,500 km from the 1983 epicenter. On January 4, 1957, an earthquake (magnitude less than 6) took place on the Sierra Leone coastal area near lat 7.4° N., long 12.5° W. (Sykes and Landisman, 1964.) That earthquake was "well located" and is spatially associated with the terminus of the offshore Guinea fracture (Sykes, 1978.) Its location is about 500 km south-southeast of the 1983 Guinea earthquake epicenter and, thus, most probably on a different seismogenic structure from that of the recent event.

Surface ground breakage along a zone nearly 10 km long, roughly the same length as observed for the 1983 Guinea shock, was reported for the Accra earthquake of 22 June 1939, roughly 1,800 km to the southeast. Seventeen residents of the Gold Coast (now Ghana) were killed and 1,000 buildings destroyed by that magnitude 6 1/2, intensity (modified Mercalli) IX event (Sykes, 1978). Junner (1941) writes that the Accra area had previously experienced major earthquakes in 1636, 1862, 1906, and 1939; at least

12 smaller shocks between 1858 and 1935; and during their period of operation from 1914 to 1933, Milne seismographs at Accra instrumentally monitored and recorded very slight tremors almost daily. Burke (1969a, b, 1971, cited in Sykes, 1978) has reported on faults in this area that show evidence of recent movement. He suggests that the oceanic Chain fracture zone extends into this seismic area, but Sykes (1978) favors the extension of the Romanche fracture zone. Regardless of which is correct, the setting of the 1939 Accra earthquake is the continental terminus of a major oceanic fracture, which may also be the setting for the 1983 Guinea earthquake. Sykes (1978) argues that seismic activity tends to concentrate within such intraplate regions by reactivation of preexisting zones of deformation, or along faults of old fold belts (which are present in West Africa) within the thicker lithosphere of the continents.

Some instrumental seismic monitoring has been conducted in the neighboring country of Senegal (Briden and others, 1981, 1982) about 130 km north of the 1983 Guinea epicenter. Two separate eight- or nine-station seismic arrays, each of which covered about 20 km, were connected by a 150-km-long mobile linear array. The study was teleseismic in nature (measurement of traveltime delays) and was designed to study mantle properties to depths of 400 km. Briden and his co-workers (1981) mention that some 100 seismic events of "local origin" were recorded during the one-year period of field recording. Because these events were all small and had emergent first arrivals, no analysis of the data was performed (J. C. Briden, written comm., 1984).

In addition to the background seismicity, tectonic movements in Guinea are indicated by recent subsidence of the coast from Conakry northward. Several kinds of evidence suggest subsidence: laterites, which formed subaerially, are below sea level at several places along the Guinean coast and in Senegal to the north (Chatelat, 1938a, b; Gorodiski, 1952); the coast has many estuaries, low islets, and extensive development of mangrove swamps typical of drowned coasts (Chatelat, 1938a; Francis-Boeff and Romanovsky, 1946); some mangroves and dryland trees have been affected by an apparent rise of sea level (Chatelat, 1938a). In addition to the verifiable evidence just cited, Chatelat was told that palm groves have been inundated and destroyed, and a village was repeatedly moved inland to avoid invasion by the sea. No change in relative sea level in connection with the 1983 earthquake has been detected at Kamsar, a seaport on the northern part of the Guinean coast (John Seck, Directeur Technique, oral commun., January 13, 1983).

Nearly horizontal Ordovician and Silurian sedimentary rocks underlie most of the epicentral area, and Precambrian sandstone with dips as high as 40° underlies the eastern part (Renaud and others, 1959). A laterite of unknown thickness mantles all of the rocks in the area except where the slopes are very steep. The possibility of minor faulting in the region after development of the laterite was mentioned by Chatelat (1938a), but he did not identify any particular young faults, and none are conspicuous on photomosaics or on the ground in the epicentral area. The age of the laterite is unknown but it may be Neogene or younger (Maignien, 1966).

THE MAIN SHOCK

The parameters of the main shock, as reported by the U.S. Geological Survey (1984), are as follows:

Epicenter: lat 11.866° N., long 13.529° W.
Depth: 11 km
Origin time: 04-11-29.2 UTC
Magnitude: 6.4 (m_b), 6.2 (M_s)
Moment: 3.4×10^{25} dyne-cm
Number of stations used: 343
Standard deviation of traveltime residuals: 1.0 s

At least four different focal mechanisms have been obtained from teleseismic data for the main shock (fig. 2). Two solutions using P-wave polarity plus waveform modeling (fig. 2a, b) show a predominately strike-slip mechanism with a significant normal component of movement on east-west and north-northwest nodal planes. The other solutions (fig. 2c, d) exhibit predominately normal faulting on west- to northwest-striking planes.

SURFACE FAULTING

Surface faulting was found in an area that is southeast of Kambala and northeast of Kamele (fig. 3). Evidence of right-lateral displacement, such as left-stepping en echelon fractures, pressure ridges, and small thrusts could be seen at several places in the central reach of the fault (figs. 4 and 5). Much of the faulting is in hard laterite, and the surface expression of the faulting in those areas is influenced by preexisting fractures in the laterite. The maximum right-slip displacement that we measured was 12-13 cm on a single fracture. The maximum displacement across the whole zone is surely greater but could not be accurately measured because no fence, road, or straight path crossed the entire zone. A vertical component of displacement could be seen at several places and is consistently down on the south or southwest side of the fault (fig. 4). The largest vertical displacement observed was about 5-7 cm.

The 0.5-km-long segment of fault that is almost due south of Kambala (fig. 3) consists of discontinuous fractures in a zone as much as 34 m wide. Mapping of the fractures revealed a broad left-stepping, en echelon pattern indicating a component of right slip but the amount of displacement could not be measured. Except for a small graben with a few centimeters of vertical displacement, no vertical component of displacement was detected in this segment. We could not trace the fault westward to the Koumbia-Dombiagui Road on January 16, nor could we find it between the road and the line of cliffs to the west on January 18. Because of a cover of fallen leaves and a shortage of time, we did not try to trace this segment eastward to the Kakossa River, but assume that it joins the western part of the central segment, which has a similar strike. We searched for a southeastward extension of the central segment, mostly in grass and fallen leaves, but only found a short segment of it near the Kondiouol River (fig. 3). The total length of surface faulting, from the vicinity of the Koumbia-Dombiagui Road to the Kondiouol River, is 9.4 km.

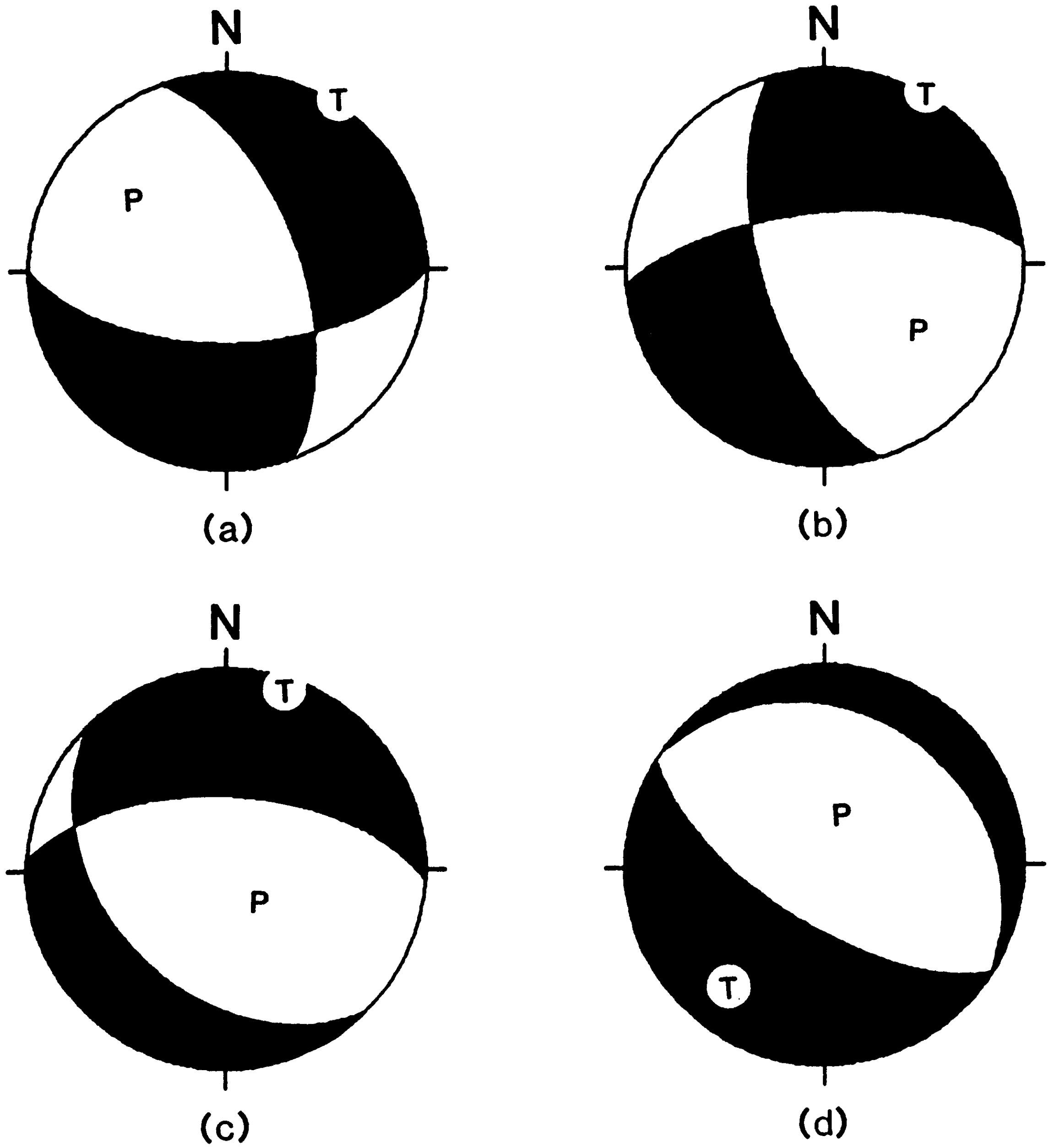

FIGURE 2.--Focal mechanisms (lower hemisphere, equal area projection; compressional quadrants shaded) from teleseismic data for the December 22, 1983, main shock. (a) P-wave polarities and long-period P-waveform modeling by Dorbath and others, 1984; (b) P-wave polarities by USGS (R. Needham, written commun., 1984); (c) body-wave moment tensor inversion (Sipkin, 1982) by USGS; and (d) long-period body and mantle wave moment tensor inversion (Dziewonski and others, 1981) furnished to USGS by Harvard University.

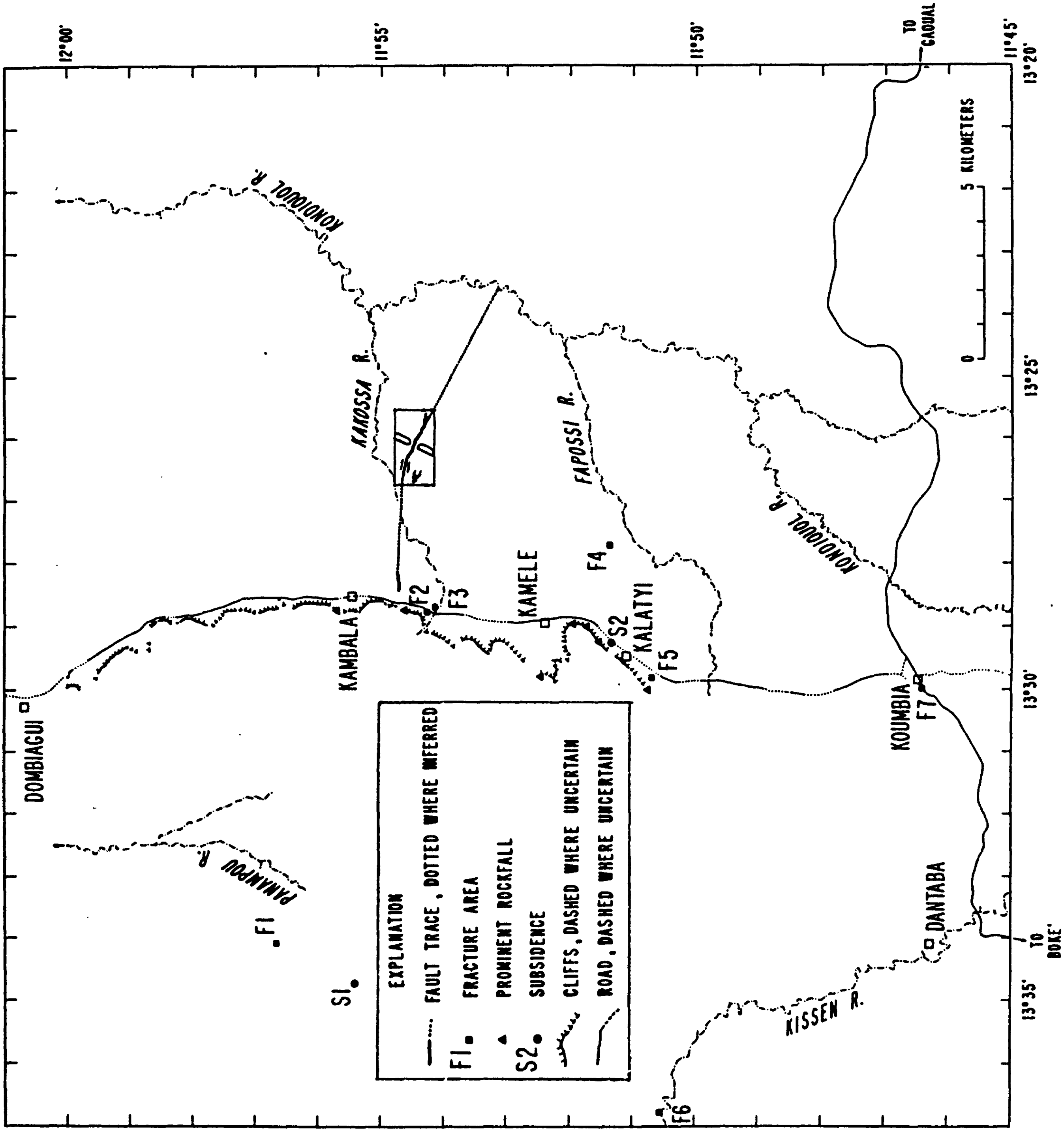

FIGURE 3.--Map showing surface faulting, fracture and subsidence areas, prominent rockfalls, and line of cliffs. Rectangle shows area of figure 4. Mapping by M. G. Bonilla, N. H. Barry, T. S. Diallo, V. Tonguino, and A. P. Koulibaly. Base map prepared from 1/500,000 scale photomosaic, sheets Koumbia 3d and 4c, universal transverse mercator projection.

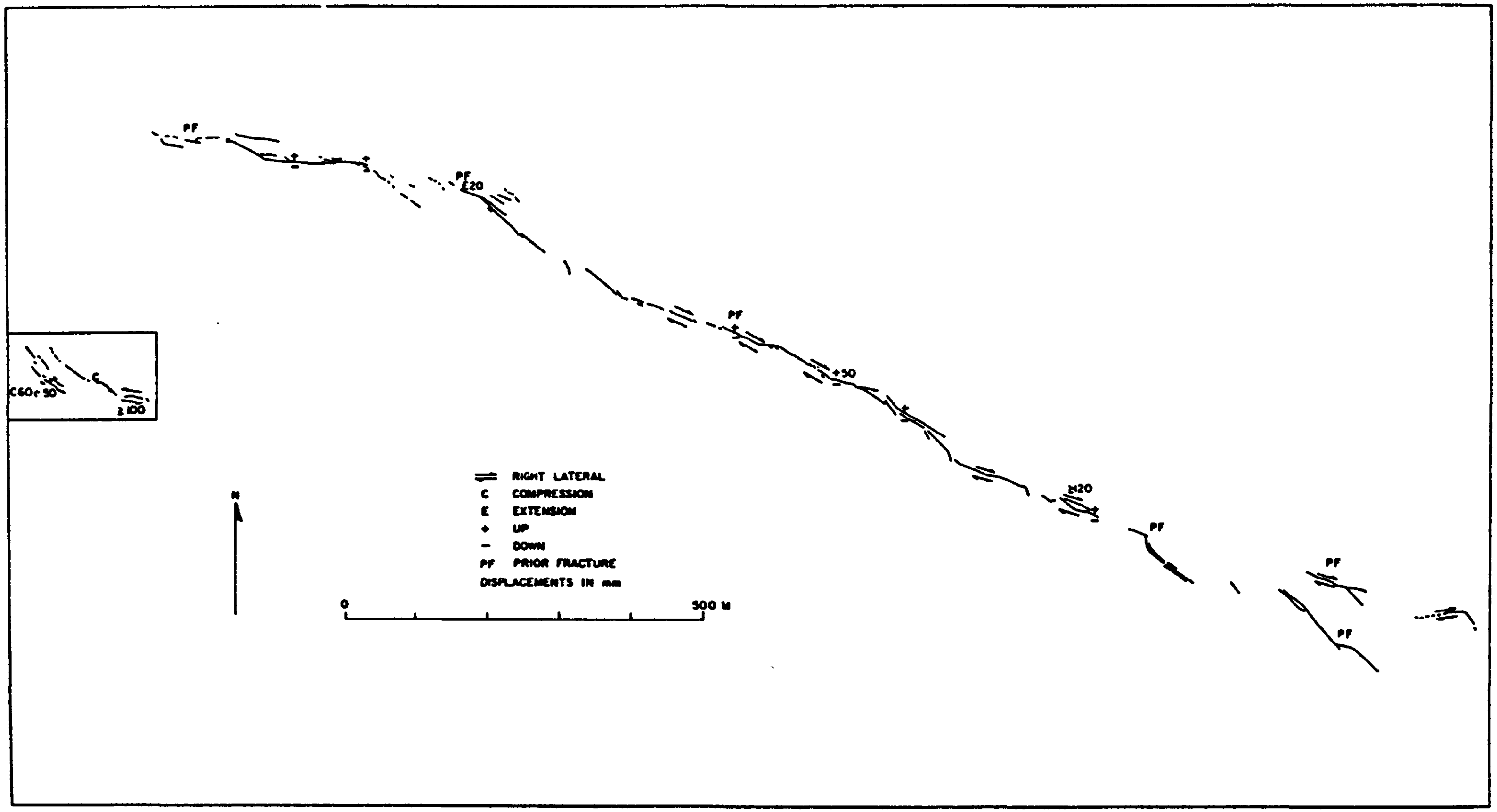

FIGURE 4.--Map of central segment of surface fault rupture. Locations where evidence of pre-1983 fractures was seen are marked "PF." Rectangle shows area of figure 5. Mapping by M. G. Bonilla, N. H. Barry, T. S. Diallo, V. Tonguino, and A. P. Koulibaly.

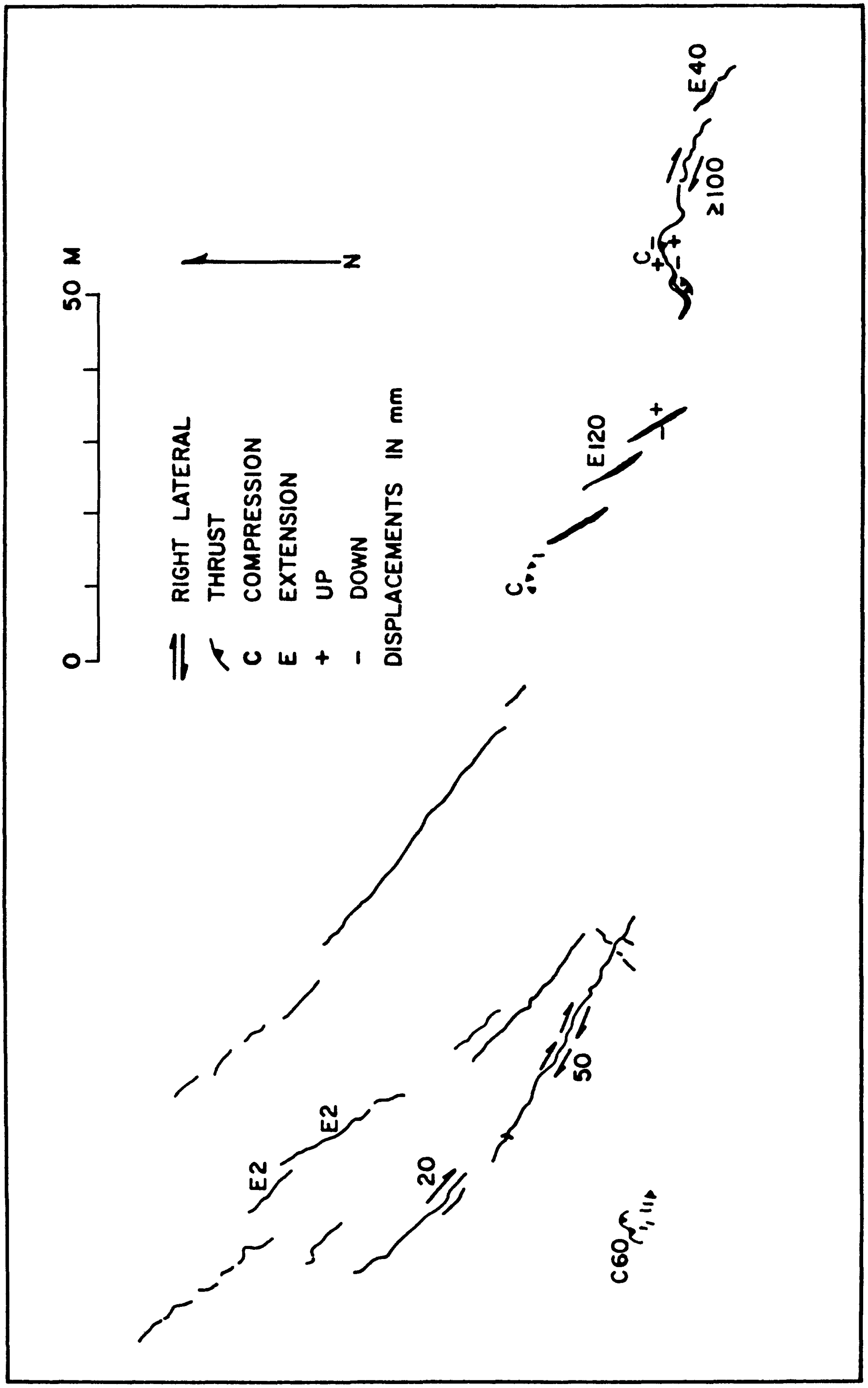

FIGURE 5.--Map showing details of faulting in part of figure 4. Mapping by M. G. Bonilla, N. H. Barry, T. S. Diallo, V. Tonguino, and A. P. Koulibaly.

The observed surface rupture length and surface displacement are comparable to other earthquakes of similar size. Table 1 shows the expected surface rupture dimensions based on empirical data from other surface faulting events in various parts of the world (Bonilla and others, 1984). One can see that the 9.4-km surface rupture length is similar to that for other M_s 6.2 events, but that the 0.13-m maximum measured displacement is more than one standard deviation smaller than expected. This discrepency may be explained by the fact that the measurement of displacement did not span the whole zone of faults. Thus, the surface rupture length is similar, and the surface displacement may be similar, to that which has accompanied shallow earthquakes of the same size in other parts of the world.

TABLE 1.--Surface rupture expected for M_s 6.2 earthquake[1]

Fault type group	Surface length (km)		Maximum surface displacement (m)	
	Expected value	1-S Range[2]	Expected value	1-S Range[2]
Strike slip--------	8	4-17	0.8	0.4-1.4
All types----------	12	6-23	0.7	0.4-1.3

[1]From Bonilla and others (1984, table 3).

[2]S is standard deviation about the regression line.

The surface rupture occurred on a poorly defined pre-1983 fault. In the central segment (fig. 4), the faulting followed preexisting fractures in laterite, rare small scarps (at least one of which is in unconsolidated material), lines of vegetation, and a few small drainageways. The aforementioned evidence indicates that the 1983 faulting occurred on a preexisting fault on which movement had occurred after formation of the laterite, but the age of the laterite is uncertain. Some laterite in western Africa is known to have formed in Tertiary time, and evidence from stone tools of early man in Guinea suggests that laterite formation has continued into the last 10,000-100,000 years (Bronevoy and others, 1971). Thus, the pre-1983 displacement on the fault could have been in late Pleistocene or Holocene time. Judging by the topography along it, and the lack of reported earthquakes in this part of Guinea, the fault probably has quite a low slip rate.

FRACTURES, SUBSIDENCE, AND ROCKFALLS

We investigated many fractures of various kinds that were reported by the local inhabitants. Except for those few fractures that proved to be faults, nearly all were clearly the result of earthquake shaking. Of the fractures that are listed in table 2 and shown in figure 3, only the group at F1 is possibly, but not likely, of tectonic origin. Discharge of sand from fractures at F4 and F5 indicates that liquefaction occurred in those areas, and landsliding was responsible for the fractures at F3 and F6. Other minor shaking-induced fractures were examined but are not shown on figure 3.

TABLE 2.--Earthquake-related fractures and subsidence

Map symbol	Location	Description
F1	11°56.6′ N. 13°34.1′ W.	Discontinuous fractures in northeast-trending zone about 40 m long; up to 2-cm extension but no strike slip or dip slip. Also, two northwest-trending fractures each about 5 m long; one has 1-cm vertical displacement down to northeast, on earlier fracture. Other minor fractures nearby. Developed on hard laterite; surface even, but slopes about 7° northwest. Origin of fractures unknown.
F2	11°54.2′ N. 13°28.8′ W.	Two zones of discontinuous fractures on flat surface show neither strike slip or dip slip. One set is 15 m long, trends N. 75° E. and shows 3-mm extension. Another set 10 m long trends N. 33° E. and has as much as 50 mm of extension. Both sets probably result from shaking.
F3	11°54.1′ N. 13°28.7′ W.	Fractures on flood plain of Kakossa River have a few centimeters of extension and vertical displacement, downdropped toward channel. Produced minor fractures in approach fills of bridge. Similar fractures, parallel to channel, were seen along the several hundred meters of the river that were examined. Caused by lateral spreading toward channel.
F4	11°51.4′ N. 13°27.7′ W.	Fracture trending N. 70° E. Sand was discharged along it, indicating liquefaction at depth.
F5	11°50.7′ N. 13°29.8′ W.	Fractures of various orientations were seen in area extending a few hundred meters west of the road. Discharge of fine white sand along the fractures indicates liquefaction at depth.
F6	11°50.6′ N. 13°36.8′ W.	Fractures in zone trending N. 85° W. about 30 m long on steep north bank of Kissen River. Maximum vertical displacement 15 cm, down on riverside. Fractures result from movement of old landslide blocks.
F7	11°46.4′ N. 13°30.0′ W.	Fractures in several places in western part of Koumbia have various orientations. Some are parallel to small stream channels and others are not. Maximum vertical component is a few centimeters. Fractures probably caused by shaking.
S1	11°55.4′ N. 13°34.7′ W.	Collapse of roof of cavern in laterite dropped the ground surface about 4 m over an area estimated to be 33 m long by 23 m wide. Many trees in subsided area remained vertical. Cavern extends beyond both ends of collapsed area.

TABLE 2.--Earthquake-related fractures and subsidence--Continued

Map symbol	Location	Description
S2	11°51.4′ N. 13°29.2′ W.	Fractures extend about halfway around a circular depression. Displacement is vertical, downdropped toward depression. Initial displacement is said to have increased during aftershocks. Maximum vertical component was 13 cm on January 16, 1984. Fractures caused by shaking, and may reflect subsidence over a cavern in laterite.
S3	11°53′ N. 13°39.8′ W.	Local inhabitants state that section of bed of Kissen River near Vellore subsided during earthquake. The apparently subsided section was vaguely visible under water in gravel on January 17, 1984. Visible part estimated to be 5 m long, 3 m wide, and 0.2 m deep. No corresponding on-strike (about S. 50° E.) fractures visible in riverbank. Origin unknown.

A spectacular effect of the earthquake was the subsidence of the roof of a cavern in laterite, dropping the ground surface and its cover of trees as much as 4 m over an area some 30 m long by 20 m wide (S1, table 2). The development of caverns in the laterite of Guinea is not uncommon (Chatelat, 1938a), but this is the first instance known to the writers of earthquake-related collapse of such a cavern. The subsidence at S2 may also be related to cavern development.

Rockfalls were common along the cliffs west of the Koumbia-Dombiagui Road (fig. 3). The rockfalls occurred in vertically jointed sandstone that has a low westward dip. Because of varying resistance to erosion, overhangs are common along the cliffs and many of the rockfalls resulted from failure of overhangs bounded by the vertical joints. Some of the blocks that fell are extremely large. One block of sandstone in a rockfall west of Kamele measures about 18 x 18 x 9 m; it made a depression in the ground and threw up a rim of earth more than 1 m high where it came to rest.

The minor liquefaction effects and the many rockfalls that we noted all occurred less than 10 km from the faulting and mainshock epicenter. Based upon experience in other earthquakes, that distance from the earthquake source area is well within the limits to which similar liquefaction effects and rockfalls can occur as a result of magnitude 6 earthquakes (Youd and Perkins, 1978; Keefer, 1984).

PORTABLE SEISMIC NETWORK STUDIES--AFTERSHOCK ACTIVITY

Field Survey

Because of the Christmas holiday season and logistical factors, the network of portable seismographs (1 Hz seismometers, smoked-paper recorders operating at 60 mm/min) was not installed until some 22 days after the December 22 main shock. The first three stations were installed on January 13 and the entire network was in place by January 18. Table 3 lists the station location and operational parameters. The stations were installed chronologically according to station number and the maximum number operating at any one time was 11. Monitoring continued for 16 days, that is, until January 28. By that time, the level of aftershock activity had declined noticeably in both number and size of events from a peak level on January 20. The initial level was 10 or more aftershocks per day with durations (onset of P-wave until return to background noise level) of 30 s or longer (duration magnitude (Md) = 2.0; Lee and others, 1972). At the January 20th peak (see fig. 6), the level was roughly half again the initial level.

TABLE 3.--Station parameters

Number	Location Lat N., (degrees)	Location Long E. (degrees)	Elevation (m)	Magnification (X103 @ 10 Hz)	Dates of operation (Jan. 1984)
1	11.874	13.494	180	688	13-27
2	11.998	13.499	180	344	13-27
3	11.777	13.471	180	344	13-28
4	11.774	13.566	175	344	14-23
5	11.848	13.611	230	344	14-21
6	11.807	13.413	142	688	16-28
7	11.882	13.357	160	688	16-28
8	11.960	13.345	155	688	16-28
9	11.801	13.345	140	688	16-28
10	11.986	13.413	140	688	17-27
11	11.927	13.456	180	688	18-27
12	11.915	13.478	210	344	24-28

Network dimensions were approximately 25 km (north-south) by 30 km (east-west) with an average station spacing of about 7 km to assure reliable hypocenter locations (see Lee and Stewart, 1981, p. 17). Timekeeping was based on use of a master clock synchronized to WWV (reception in West Africa was generally quite good late at night). Station locations were determined by electronic reception of global satellite positioning signals and were verified by checking on a 1:50,000 aerial photomosaic.

Data Base and Location of Aftershocks

A total of 94 aftershocks was selected for analysis. The largest and best recorded events comprised about half that number and the remainder were included to give a good spatial and temporal representation from the data set. Magnitudes were computed from a California coda-duration relationship (Lee and others, 1972) and, thus, are internally consistent but not directly comparable with magnitude determined using other networks. Seismic phase arrival times were read using a 10x magnifier and P-wave times were reproducible to within 0.05 s.

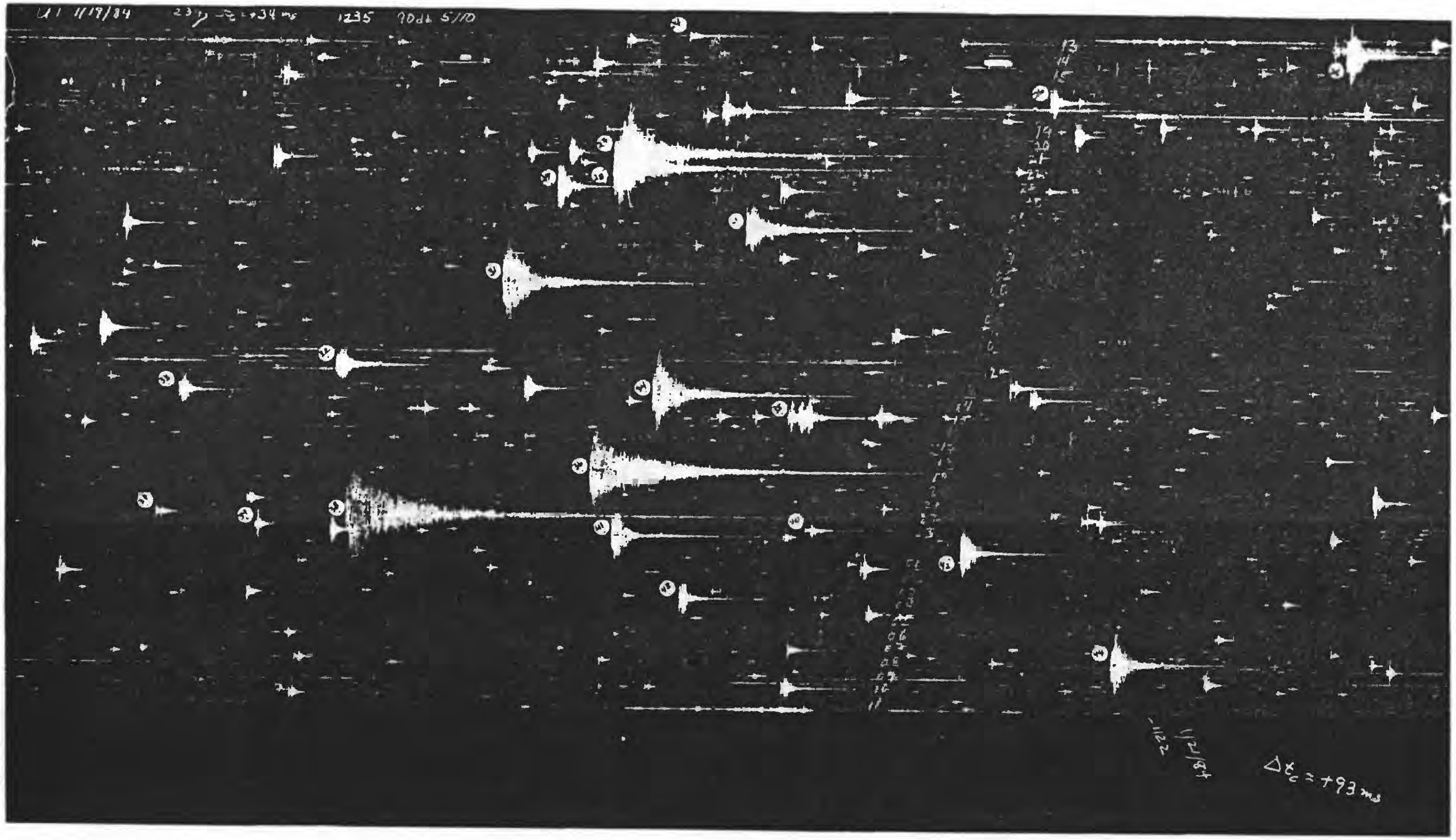

FIGURE 6.--Seismogram recorded at station GU1 west of Kamele during peak level of seismicity. Period of recording is from 1235, Jan. 19, 1984, to 1122, Jan. 21, 1984 (UTC).

Averages and ranges for the size/location and quality/error measure parameters from HYPOELLIPSE calculations (see Lahr, 1979) for the 94 aftershocks are as follows:

	Average	Range
Magnitude (Md)-------------------------------	2.4	0-4.3
Depth--	6.3 km	1.3 -14.6 km
RMS (deviation of traveltime residuals)------	0.087 s	0.04-0.20 s
Number of phase arrival times used in determining the hypocenters (P & S)--------	13	11-17
ERH (horizontal error estimate)--------------	0.78 km	0.3 -3.2 km
ERZ (vertical error estimate)----------------	1.81 km	0.5 -5.6 km
DMIN (epicentral distance to nearest station)------------------------------------	4.6 km	0.4 -10.3 km
GAP (largest sector with no observing stations)-----------------------------------	128°	46°-310°

Appendix B gives a complete listing of all the aftershock parameters.

No velocity structure data for Guinea are known by the authors, or is there information about crustal velocities from the seismic study in Senegal (J. C. Briden, written commun., 1984). The velocity model that we assumed for our analysis was a V_p=5.5 km/s half-space and a V_p/V_s of 1.73. This P-wave velocity derives from a nominal value for sedimentary rocks and the V_p/V_s ratio from testing in the location calculation procedures and a Wadati diagram. Values of 1.78, 1.73, and 1.70 were employed for V_p/V_s in the HYPOELLIPSE program. The 1.73 value gives the minimum residuals and error statistics. A Wadati diagram (fig. 7) shows good agreement with the 1.73 value out to an (S-P) time of about 2.25 s. Beyond that time interval, the agreement is not so good. Thus, we restricted the S-arrival times actually used for hypocenter locations to be within an S-P time frame of 0.5 to 2.0 s.

Dorbath and others (1984) also noted the absence of information on the local seismic velocity. They assumed a half-space with a P-velocity of 5.6 km/s and a V_p/V_s of 1.68 based on Wadati diagrams. They also performed a velocity check by using a velocity 6.0 km/s and noted that the focal depths did not change by more than 1 km.

INTERPRETATION OF AFTERSHOCK DATA

The distribution of the 94 aftershocks, located by data from our portable network of seismographs, occupies a tabular volume (2 km thick by 27 km long by 14 km wide) that dips south-southwest (figs. 8, 9, and 10). The overall trend of the epicenters is east-southeast, in general agreement with the trend of mapped surface ruptures (fig. 8a). Those ruptures were observed to be present for a portion of the eastern half of the aftershock area where they tend to form a northernmost boundary for the aftershock epicenters. The western portion of the aftershock activity (west of station G1) does not have associated surface rupturing. Hypocenters are distributed rather uniformly between about 2 km and 14 km (fig. 9) with approximately 60 percent of the locations occurring above 7 km. Our hypocentral distribution does conflict with the results of Dorbath and others (1984) where they show only a small

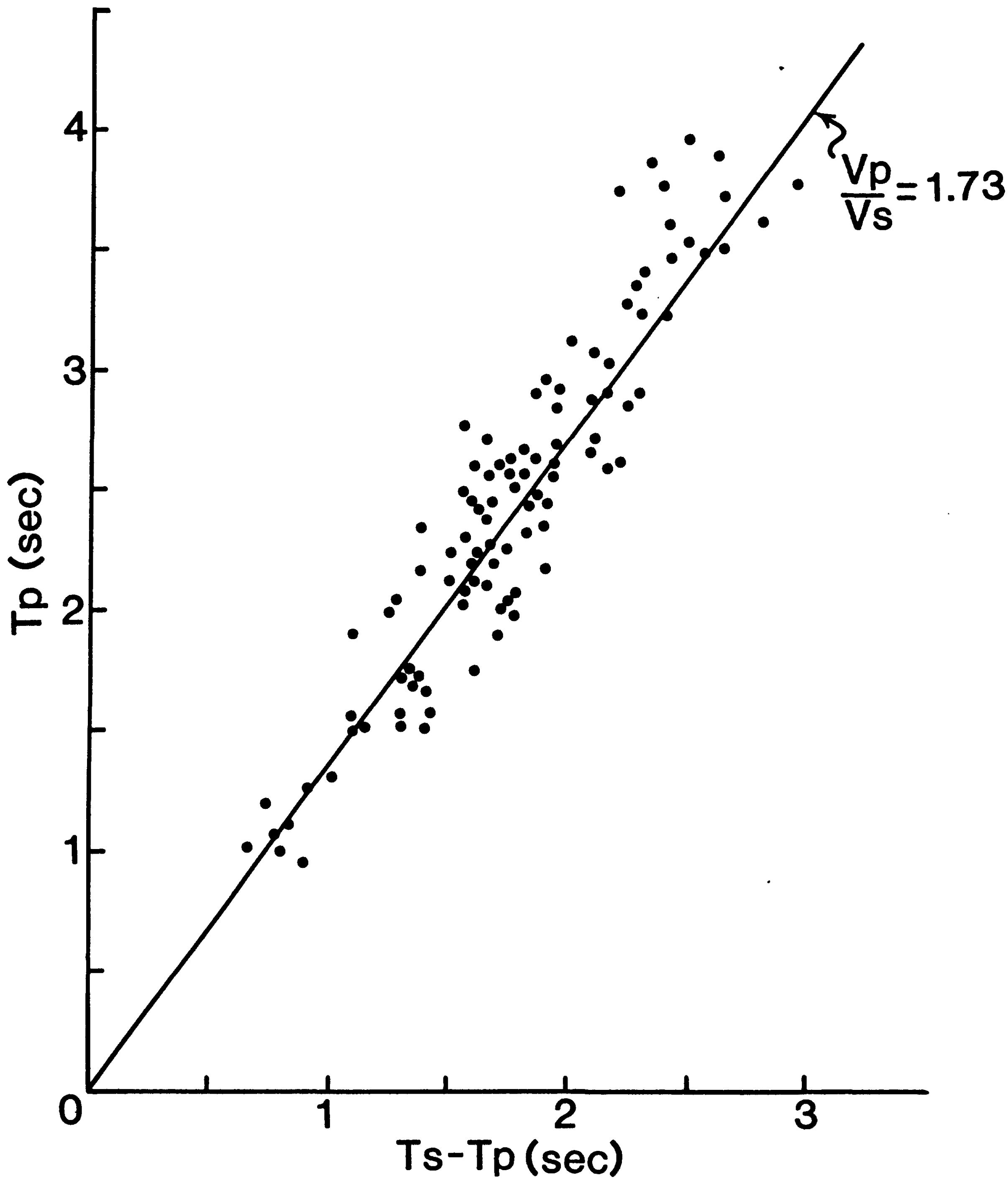

FIGURE 7.--Plot of traveltime of P-wave (Tp, sec) versus traveltime of S-wave minus traveltime of P-wave (Ts-Tp, sec) for 15 aftershocks in the east central groups (see fig. 12). Solid line represents the V_p/V_s ratio of 1.73 employed in this study.

GUINEA AFTERSHOCKS January, 1984

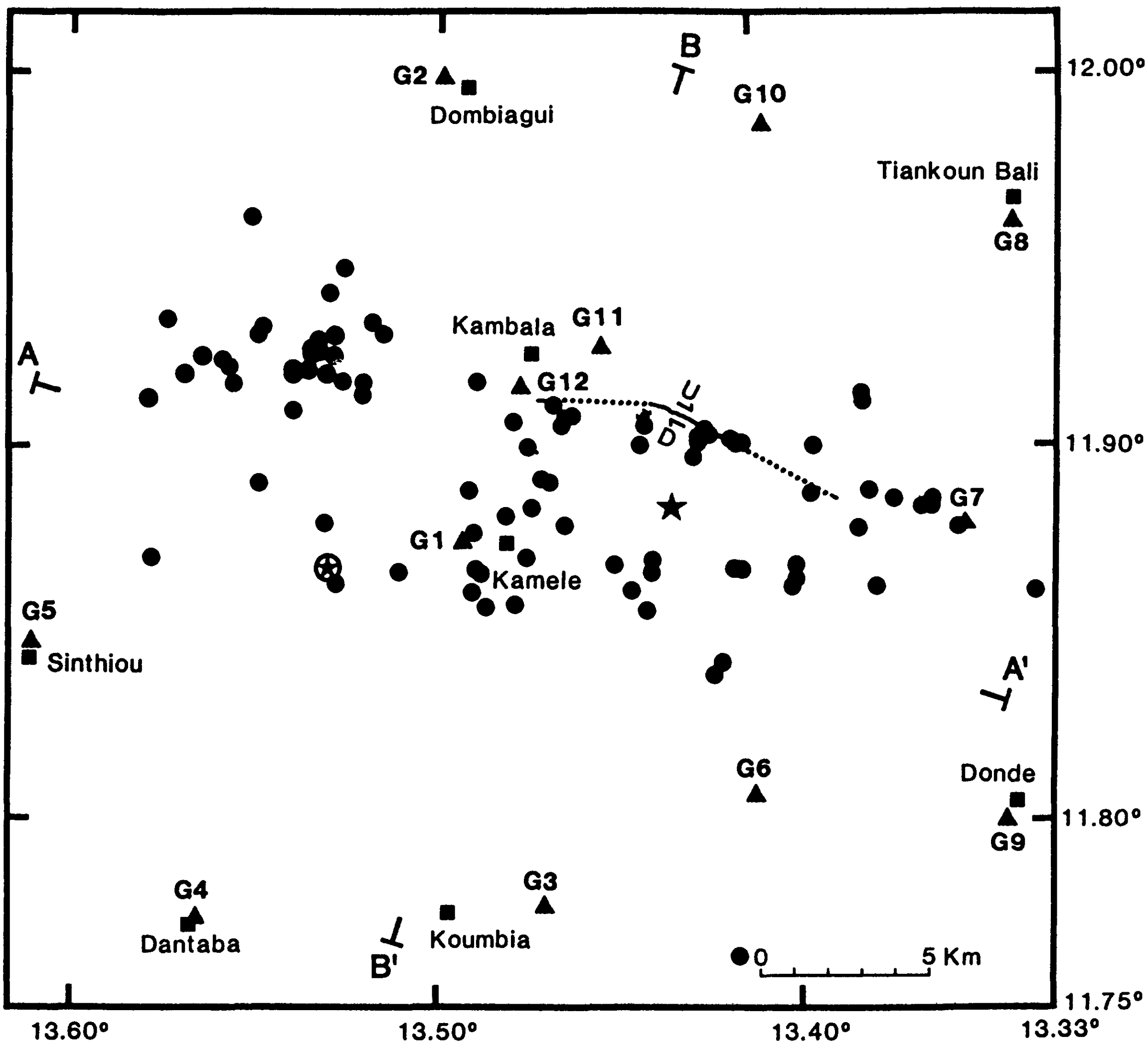

FIGURE 8a.--Aftershock epicenter maps. Dots = aftershock epicenters; triangles with 2 or 3 character code = station locations; squares = towns; solid/dotted line = surface rupture where mapped/inferred, arrows show direction of horizontal movement, U/D = up/down movement; circle and star = USGS epicenter; star = epicenter inferred from the spatial distribution of aftershocks; A-A' and B-B' = locations of projection planes for figures 9 and 10, respectively.

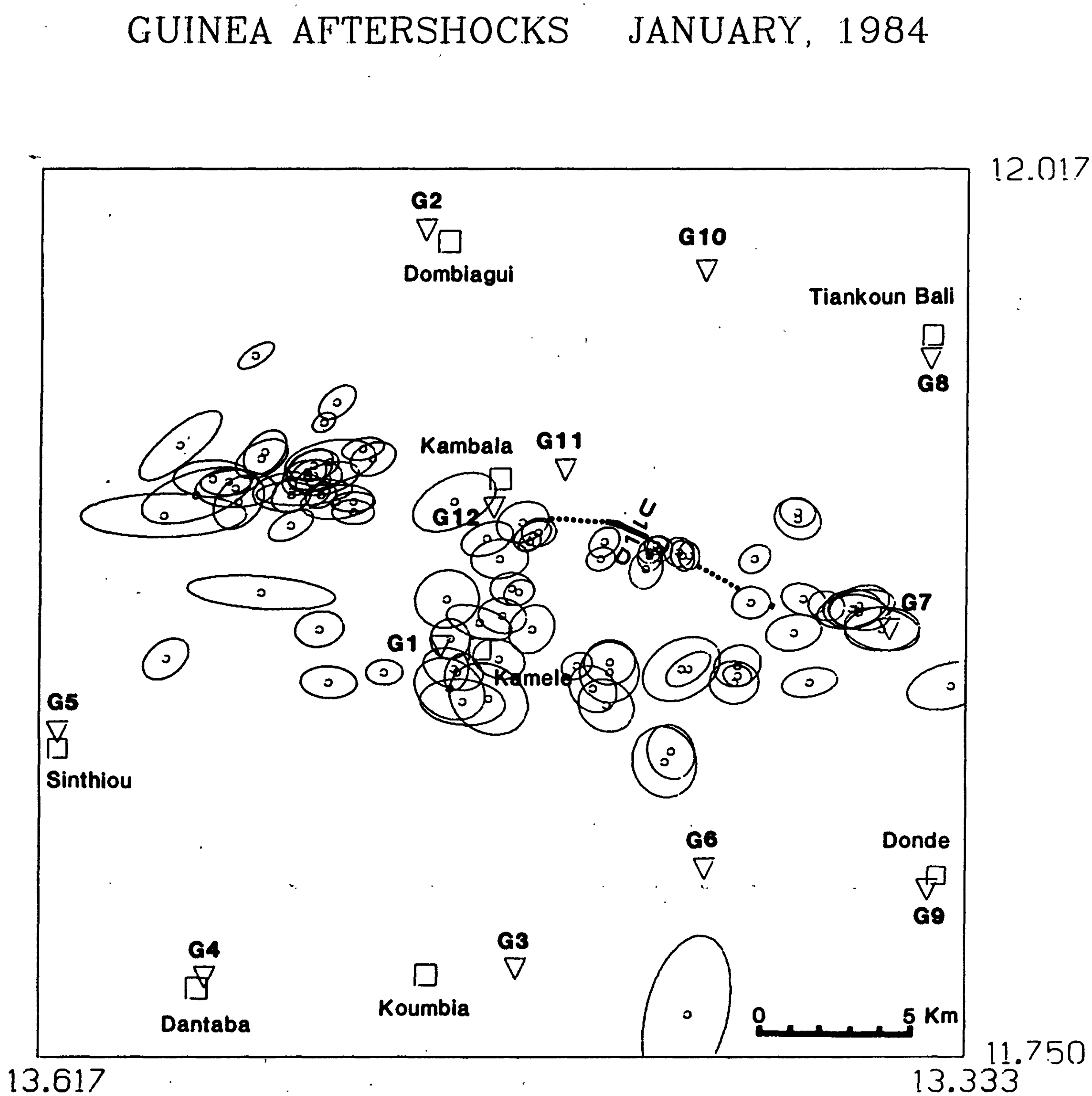

FIGURE 8b.--Small circles (epicenters) with 68 percent confidence ellipses (Lahr, 1979); open inverted triangles with 2/3 character code = station locations; open squares = towns; solid/dotted line = same as for (a) above.

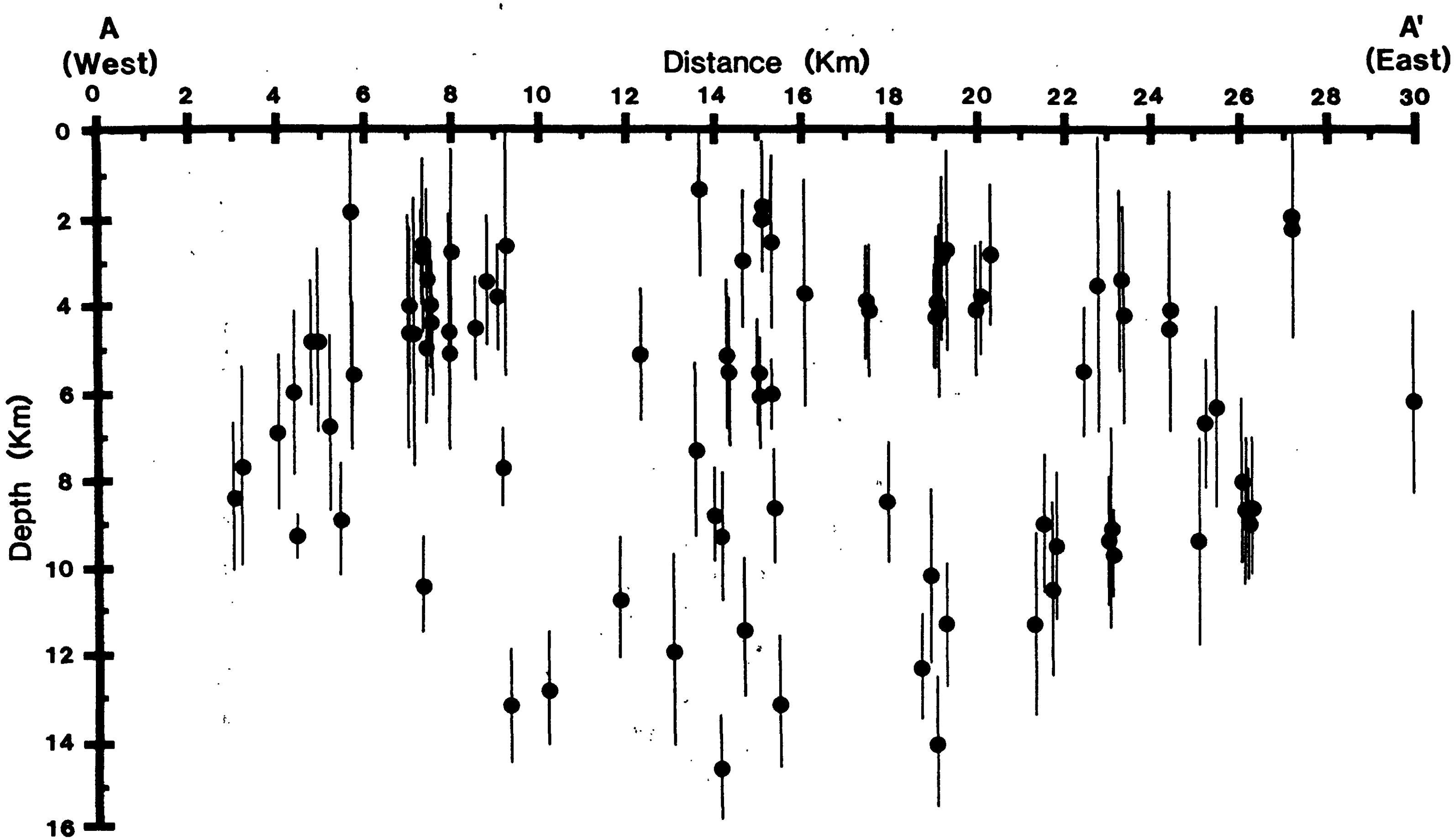

FIGURE 9.--Vertical section plot of hypocenters projected onto a west-east (A-A') plane. Hypocenters (dots) and vertical error (68 percent confidence, Lahr, 1979) bars shown.

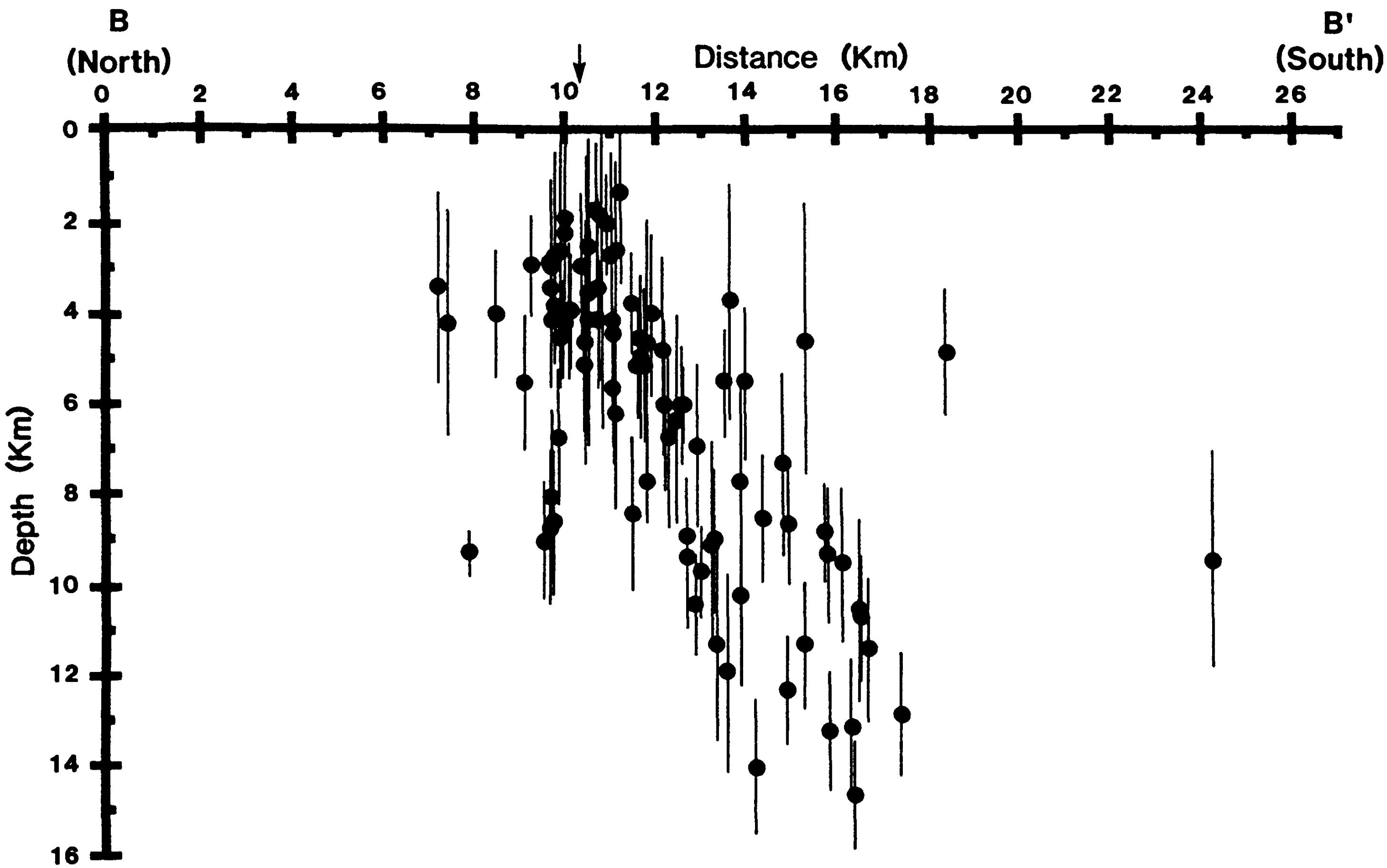

FIGURE 10.--Vertical section plot of hypocenters projected onto a north-south (B-B') plane. Hypocenters (dots) and vertical error (68 percent confidence, Lahr, 1979) bars shown.

number of aftershocks located above 7 km. Dip of the aftershock zone is to the south-southwest at about 60° (fig. 10). If the east-southeast striking surface ruptures (figs. 4, 5, and 8) represent the uppermost expression of the southerly dipping causal fault, which we believe is the case, then the aftershock activity is mostly confined to the footwall of the principal fault.

The main shock epicenter (fig. 8a), as determined from teleseismic data by the National Earthquake Information Service (NEIS), is within the zone of aftershock activity. This epicenter is remarkably well located, particularly when considering the absence of nearby seismograph readings. Following the earthquake, the closest station to report a P-wave arrival to NEIS was M'Bour, Senegal (MBO) which was at an epicentral distance of 4.18°; the next closest station was Averros, Morocco (AVE) at a distance of 22.06°. Although the NEIS epicenter is certainly admissible, we suggest that the location indicated by a solid star in figure 8a may be preferable for the following reasons. It is (1) closer to the mapped surface rupture believed to be of tectonic origin; (2) in an aftershock void or region thought to have been destressed by the main shock; and (3) east of the majority of aftershocks which occur near the central and western part of the zone. In some other earthquakes, the greatest amount of aftershock activity has been recorded at the end farthest from where rupture was initiated (for example, Langer and Bollinger, 1979; Berberian, 1982; Ouyed and others, 1983).

Composite focal mechanism solutions (CFMS) for the aftershocks are shown in figures 11 and 12. They exhibit right-lateral strike slip on steeply dipping nodal planes that strike east-northeast. The CFMS's for the epicenters associated most closely with the surface ruptures (figs. 11b, 11c, and near the bottom of fig. 12) are well constrained with consistent polarity data covering a major portion of the focal sphere. The CFMS for the aftershocks to the east of the ruptures (fig. 11d and right side of fig. 12) agree very well with their aforementioned neighbors. However, the CFMS for the aftershocks to the west of the surface ruptures (fig. 11a and left side of fig. 12) have P-wave polarity data in only three quadrants as the shocks are at the very edge of the temporary network. Those data are also less consistent (compressions and dilatations intermixed) due, probably, to less accurate focal depths and (or) variation in faulting at the rupture terminus. It appears, then, that the mode and direction of faulting described, collectively, by the CFMS's are reasonably consistent with our geologic observations. There is, however, a departure in our results between the angle of dip (60°, SSW) inferred for the causal fault by the hypocentral distribution in figure 10 and the dip of the preferred nodal planes (near vertical) for the CFMS's. The discrepancy noted in the dip angles has not been resolved and is subject for further investigation.

Thus, while there is general agreement between the surface faulting, the spatial distribution of the aftershock hypocenters and their CFMS, there is some disagreement in detail. These rather small differences can, perhaps, be accounted for by the accuracy of our instrumental results and (or) the validity of our velocity model and CFMS assumptions. Also, we recognize that our aftershock data were obtained late in the sequence and so could represent seismicity resulting from a redistribution of stress(es) into zones or planes not expressly associated with the main shock. However, the overall coherence between our geologic and instrumental findings is good, suggesting that our sample of located aftershocks _is_ directly related to the causal fault.

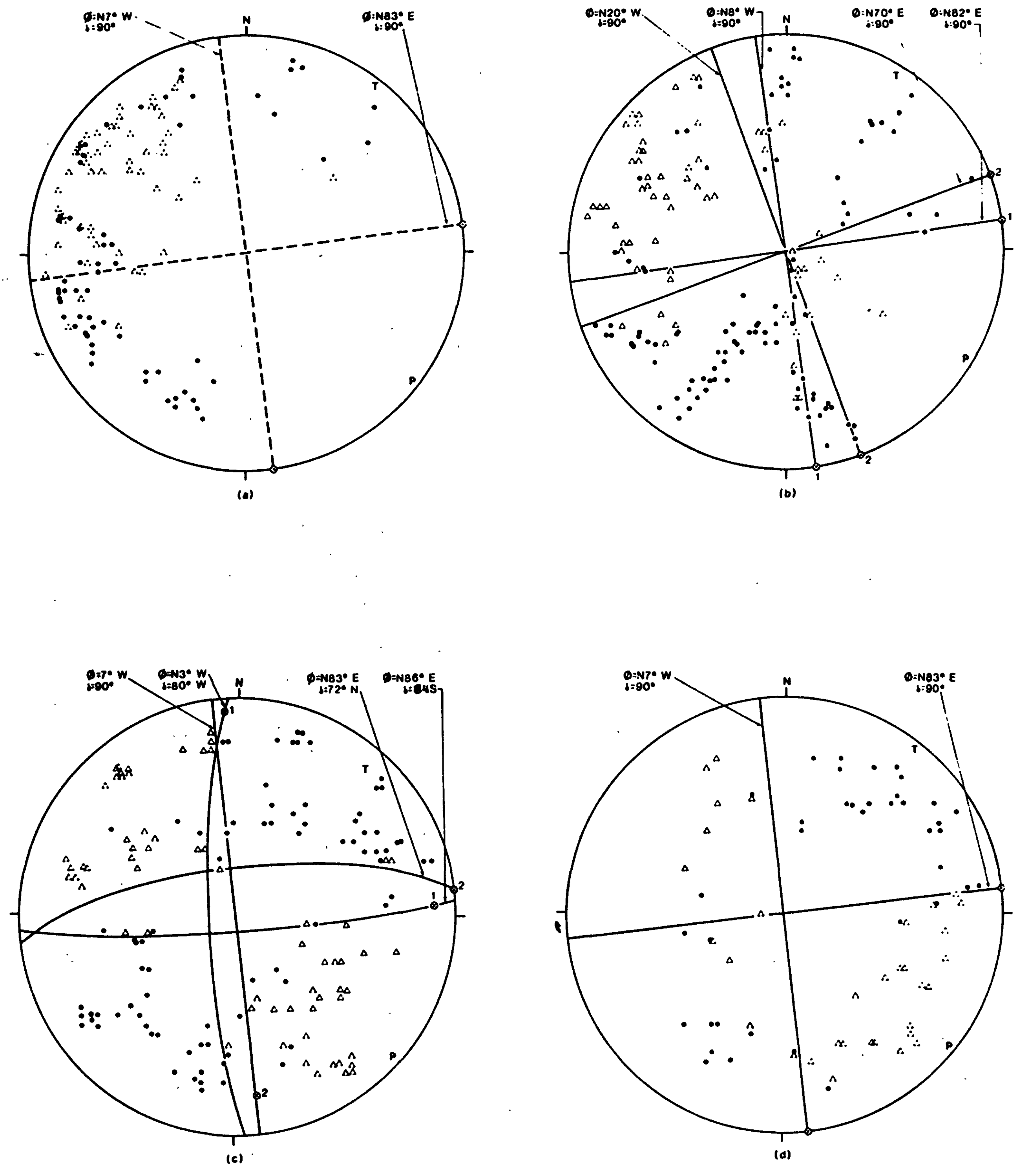

FIGURE 11.--Composite focal mechanism solutions for aftershocks; see figure 12 for epicenters of the events composited. (a) West group, (b) west-central group, (c) east-central group, and (d) east group. Lower hemisphere, equal area projections; dots for P-wave compressional first-motions and open-triangles for dilatations. Range of acceptable solutions shown by double-solutions for (b) and (c).

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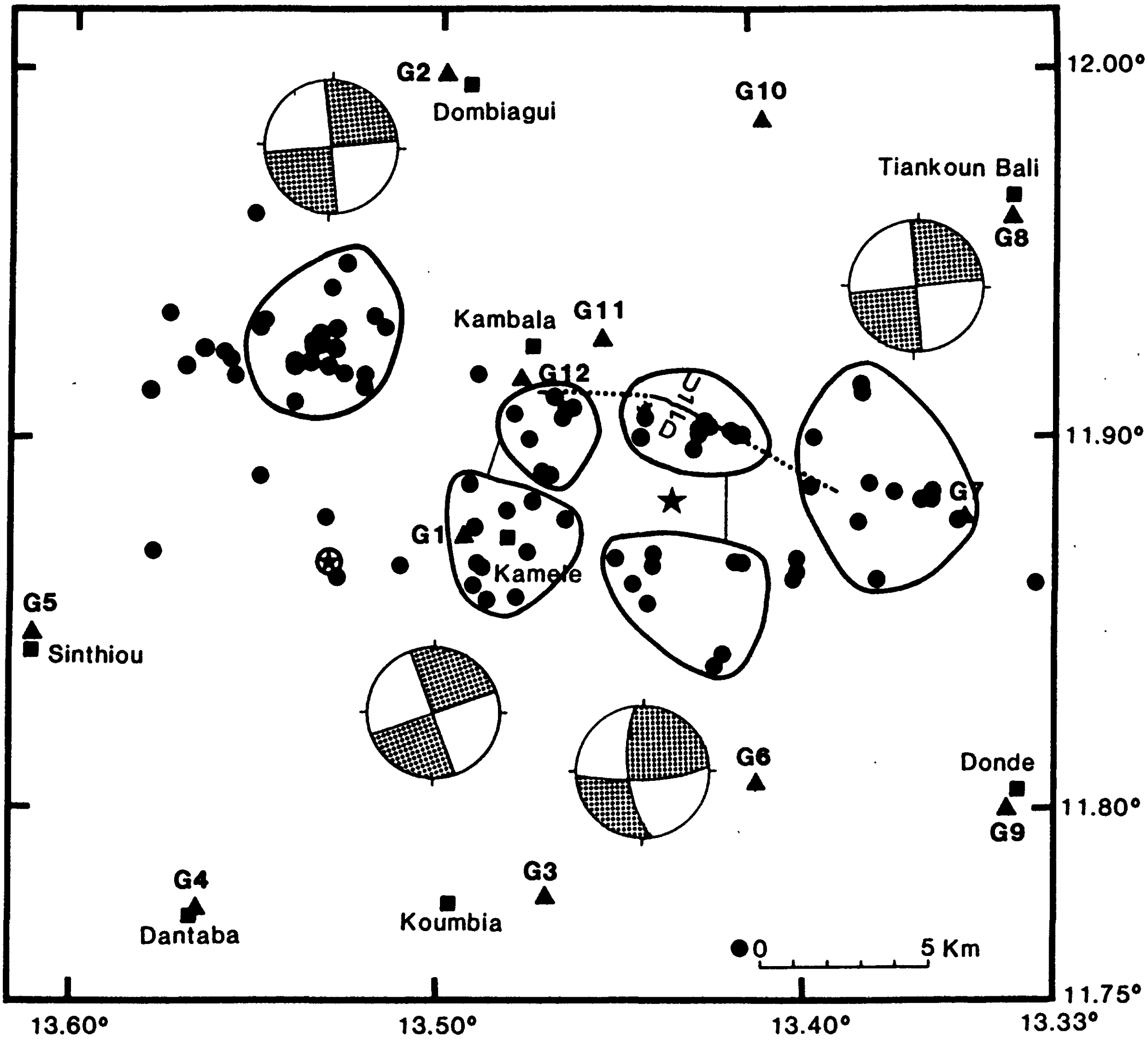

FIGURE 12.--Composite focal mechanism solutions (compressional quadrant shaded) from figure 11 adjacent to groups of epicenters indicating aftershocks used for respective solution. Figure symbols same as figure 10a.

DISCUSSION

The recent Guinean earthquake provides another example of the infrequent occurrence of a moderate to large shock in an intraplate location previously thought to be "aseismic." Similar events in neighboring Sierra Leone (M<5, 1957) and in Ghana (M=6 1/2, 1939) have already been discussed. That latter earthquake was roughly equivalent to the 1983 Guinea shock in size and associated occurrence of surface breakage, but was different in having a much more seismically active history. Presumably, the size of such historic earthquakes is large enough that, had some also occurred in Guinea, they would not have been missed. Across the Atlantic Ocean, at Charleston, South Carolina, a somewhat larger earthquake in 1886 occurred in the same general type of host environment ("aseismic," intraplate, coastal margin, terminus of ocean fracture; Bollinger, 1977; Sykes, 1978), but apparently without the ground rupturing. However, given the swampy nature of that event's meizoseismal area, it is possible that such evidence was missed.

There are undoubtedly other examples of earthquakes analogous to the 1983 Guinea earthquake that could be cited, but certainly they are not numerous enough to shed light on their sporadic, unexpected occurrences. Given the 1983 and historical shocks in Guinea and the reference to "local origin" seismicity (Briden and others, 1981) in neighboring Senegal, it would seem that some type of seismographic monitoring of Guinea and environs would be in order. Only with such instrumental data could we hope to advance our understanding of these "aseismic" region earthquakes. A suitably configured network would help to identify any faults in Guinea that are presently active. Finally, a more complete earthquake history should be sought by a search of any written records as well as the oral history and legends of the Guinean peoples.

Geological investigations can improve our knowledge of the recent seismic and tectonic history of Guinea. Trenching should be done across the Kamele area fractures, as well as any other locations where such trenching might provide stratigraphic evidence of earlier faulting. Many rockfalls occurred on December 22 along the cliffs that extend generally north-south in the Kaladje-Kambala area. It is obvious that other rockfalls have occurred along the cliffs in the past, possibly as the result of earlier earthquakes. Studies should be made to see if lichens, which probably have grown on the old rockfalls, can be dated and inferences made about earlier earthquakes in that area. Known faults in Guinea should be examined for evidence of tectonic displacement on them in the last 10,000 to 500,000 years. Evidence of displacement in that time span will indicate faults that are presently active and may produce earthquakes in the future. Aerial photos of Guinea should be studied for evidence of presently unknown faults that may have had displacements during that recent 10,000- to 500,000-year time frame, and field examinations should be made of them. If young lake deposits (that is, less than perhaps 10,000 years old) exist in Guinea, they should be examined for a stratigraphic record of disturbance of the lake deposits by earlier earthquakes.

CONCLUSIONS

Our reconnaissance field studies support the following conclusions:

(1) Many fractures formed during the earthquake of December 22. Most of these resulted from the shaking and are of little value in understanding the cause of the earthquake.

(2) Fractures northeast of Kamele and southeast of Kambala are of tectonic origin and very probably constitute the faulting that caused the earthquake. The observed and reasonably inferred surface faulting is more than 9 km long and the overall trend is east-southeast. Strike-slip displacement is at least 13 cm in a right-lateral sense, and locally there is a small component of vertical displacement, with the southwest side downdropped.

(3) Faulting occurred on a preexisting fault. Judging by its appearance, the slip rate on the fault is probably low and earthquakes on it are probably quite infrequent.

(4) Extensive rockfalls and minor liquefaction effects were noted within 10 km from the surface faulting and main shock epicenter. An earthquake-related subsidence (as much as 4 m) of the roof (30 x 20 m) of a cavern in laterite is the first such instance known to the writers.

(5) The 15-day aftershock survey that began some 22 days after the main shock defines a tabular aftershock volume (27 km long by 14 km wide by 2 km thick) that trends east-southeast, dips steeply (about 60°) to the south-southwest, and has a fairly uniform distribution from near-surface to about 14 km in depth.

(6) Composite focal mechanisms are very consistent throughout the entire seismic data set and indicate right-lateral, strike-slip movement on a steeply dipping (near-vertical) plane(s) striking east-northeast.

(7) The overall agreement between our field geologic and seismologic data is good and does not support the large component of normal fault motion reported by Dorbath and others (1984) or by the the main shock focal mechanisms shown in figures 1c and 1d.

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APPENDIX A
Historical Seismicity of Guinea
(Translated and modified from HOROYA, 25-31 Dec. 1983)

Date	Time[1]	Location[2]	Intensity[3]	Remarks
3/4 Nov. 1892	p.m.	Conakry	---	9th earthquake to be observed in west Africa. (No explanation or description given about the previous 8 earthquakes.)
2 Jan. 1911	06:45	Tamara Island In one of the Loos group of islands.	---	---
Feb. 1914	--	Boffa	---	---
Feb. 1922	--	Boffa	---	---
11 July 1927	10:30	Kakoulima region ($9^{o}46'$ N.- $13^{o}27'$ W.)	IV-V	Lasted 10 sec., traveled east to west, accompanied by an underground rumbling.
5 Apr. 1928	08:02 09:32	"...with a NNW. and SSE. direction in Conakry."	VI	Both tremors felt in Conakry, Boffa, Dubreka, Boke, Kakoulima, Forecariah, Maneyah, and Coyah.
1928	--	Forecariah ($9^{o}26'$ N.- $13^{o}06'$ W.)	---	"The epicenter of this seismic tremor was situated 12 km NNE. of Forecariah."
18/19 Aug. 1928	night	(Not stated specifically but probably area near Forecariah.)	---	Three close-linked tremors accompanied by underground rumbling and smoke emanating from ground breaks. Felt area about "20 ha with an egg-shaped contour, in the narrow side in the east-west direction and the larger side on the west sector."

APPENDIX A--Continued

Date	Time[1]	Location[2]	Intensity[3]	Remarks
26 Mar. 1930	21:30	Boffa	---	Tremor lasted for several seconds.
15 Nov. 1932	21:05	--	V-VI	Two quakes accompanied by a strong rumbling.
17 July 1935	14:19	Boffa	VI-VII	Within a 60 km radius of the Boffa region, one tremor of 2-3 sec., from the east direction, accompanied by an underground noise.
26 May 1939	19:05	Lower Guinea	III	4 sec. tremor, with rumbling; felt in Dubreka, Forecariah, and Conakry. Traveling from SW. and exhibited vertical motion.
29 May 1939	23:56	--	III	---
30 May 1939	07:21	--	III	---
06 Mar. 1941	12:08	--	V	3-4 sec. tremor, coming from the south, preceded and followed by underground rumbling.
15 Apr. 1941	16:30	--	V	Accompanied by underground noise.

[1]Local time

[2]In Guinea

[3]Scale unknown