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SEISMIC ACTIVITY IN PALHANO, CE, OCTOBER, 1988 PRELIMINARY RESULTS

MARCELO ASSUMPÇÃO[1,3], JOAQUIM M. FERREIRA[2], JURACI M. CARVALHO[1]
MARCELO L. BLUM[1], EDUARDO A. MENEZES[2], DARLAN FONTENELE[1]
ABDÊNEGO AIRES[2]

Um surto de atividade sísmica em Palhano, CE, foi estudado com cinco estações sismográficas durante dez dias após o primeiro sismo grande, de magnitude 4,2 m_b, ocorrido em 19/10/1988. Os eventos estavam confinados aproximadamente numa faixa de 2,5 a 5 km de profundidade. A distribuição espacial dos hipocentros mostrou que a ruptura ocorreu em um plano de orientação WNW-ESE e grande mergulho para NNE. Um mecanismo focal composto indicou movimento predominantemente transcorrente dextral com uma pequena componente normal. Estas características são muito parecidas às de outros sismos próximos da borda da Bacia Potiguar (Pacajus, CE, 1980, e João Câmara, RN, 1986/89). No entanto, a orientação NW-SE do eixo P em Palhano é bastante diferente da orientação aproximadamente E-W daquele dois outros sismos. Esta diferença pode sugerir que o campo de esforço regional, com σ_1 tendo orientação média WNW-ESE, pode ser modificado localmente pela Bacia Potiguar.

A swarm of activity in Palhano, Ceará, was studied with five portable seismographs during a period of ten days following the first large event of magnitude 4.2 m_b occurred on October 19, 1988. The events are confined to a depth range between about 2.5 and 5 km. The spatial distribution of the hypocenters showed that rupture occurred on a WNW-ESE oriented fault with a steep dip to NNE. A composite focal mechanism indicates a predominantly strike-slip (dextral) motion with a small component of normal faulting. These characteristics are very similar to other earthquake swarms near the border of the Potiguar Sedimentary Basin (Pacajus, CE, 1980, and João Câmara, RN, 1986/89). However, the NW-SE orientation of the P axis in Palhano is somewhat different from the roughly E-W orientation for the other two swarms. This difference may suggest that the regional stress field, with average WNW-ESE orientation for σ_1, could be locally modified by the Potiguar Sedimentary Basin.

INTRODUCTION

The earthquakes in Northeastern Brazil (Fig. 1) seem to be concentrated around the continental border of the Potiguar Sedimentary Basin. Seismic activity in this area quite often occurs in the form of long swarms lasting for several weeks or even months. The best known series are:

- Pereiro, CE, 1968 (epicenter 1 in Fig. 1): the events, with magnitudes up to 4.6 m_b, were felt by the local population for almost eight months (Berrocal et al., 1984, Ferreira & Assumpção, 1983).
- Parazinho, RN, 1973 (epicenter 2 in Fig. 1): events were recorded by the station NAT (at Natal, 70 km away) for over five months. The largest event occurred in July with 4.3 m_b (Ferreira & Assumpção, 1983).
- Pacajus, CE, 1980 (epicenter 3): an event of 5.2 m_b, occurred on November 20, 1980, produced aftershocks recorded by the station ITT (Itataia, 150 km away) for over two years. The largest aftershock, occurred in January 1981 with 3.8 m_b (Berrocal et al., 1984).
- João Câmara, RN, 1986/1989 (epicenter 4): the activity was first felt by the local population on

1. *Observatório Sismológico, Instituto de Geociências, Universidade de Brasília, 70910 Brasília - DF.*
2. *Departamento de Física, Universidade Federal do Rio Grande do Norte, Campus Universitário, 59000 Natal - RN.*
3. *Departamento de Geofísica, Instituto Astronômico e Geofísico da Universidade de São Paulo, Caixa Postal 30627, 01051 São Paulo - SP.*

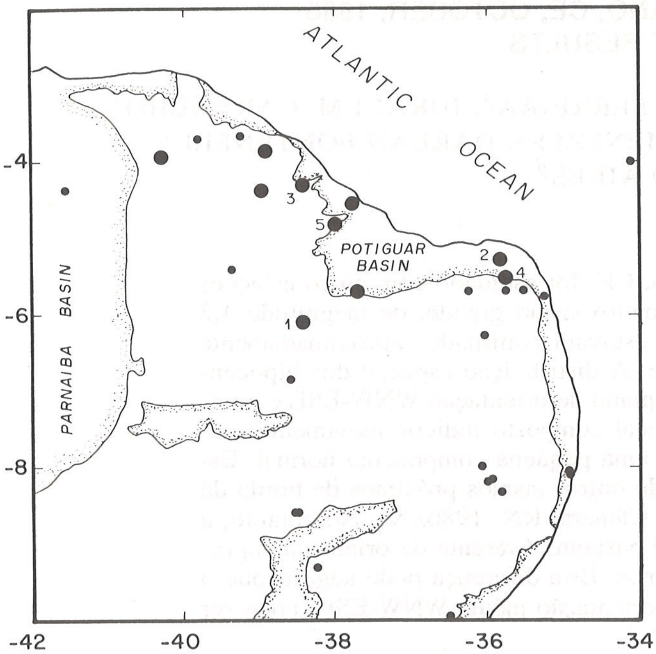

Figure 1. Distribution of earthquakes (magnitudes greater than 3.0) in Northeastern Brazil. Only the main events in each series are shown. Small and large circles refer to magnitudes less and greater than 4 respectively.

August 5, 1986. The events are distributed on a 30 km long fault and the largest earthquake, occurred on November 30, 1986, had a magnitude 5.0 m_b (Ferreira et al., 1987, Takeya et al., 1989). In 1989 the activity is still being recorded with strong reactivations: on March 10, 1989 an event with 4.9 m_b caused additional damage in the area.

The present seismic activity in Palhano seems to be yet another example of a long lasting sequence which started to be recorded by regional stations in December 1987 (Fig. 2a). The activity increased dramatically in early October which prompted the University of Rio Grande do Norte (UFRN) to install one station in Palhano on October 6th. At that time the population had been feeling earth tremors for several weeks and was beginning to get worried. The presence of the UFRN staff in the area explaining to the population the nature of the earth tremors greatly contributed to calm the inhabitants and avoid panic when a large event ($m_b = 4.2$) occurred on October 19th. After this main event four additional stations were installed in the area by the University of Brasília to carry out a local study in a joint project with UFRN during the period October 21 to November 1.

Table 1 lists the largest events of this series. The large event of October 19 caused intensity VI MM (craks and small fissures, fall of plaster and sliding of roof tiles in poorly built houses in the countryside) and was felt up to 150 km away. Another large event occurred on October 29 causing additional fall of plaster and some more cracks near the epicenter. The activity decreased during the following four months. Another reactivation occurred in March 1989 (Fig. 2b).

Five portable smoked-paper seismographs (Willmore and Ranger seismometers with MEQ recorders) were used to study the events for a period of ten days. Four stations were left fixed surrounding the epicentral area, and a fifth seismograph was moved around to cover the focal sphere from various distances and azimuths (Fig. 3). As the number of events recorded is very high and careful reading of smoked-paper seismograms is extremely time consuming, in this paper only the events recorded in the period October 21 to 28 were analysed. A more complete study of the whole series will be published later.

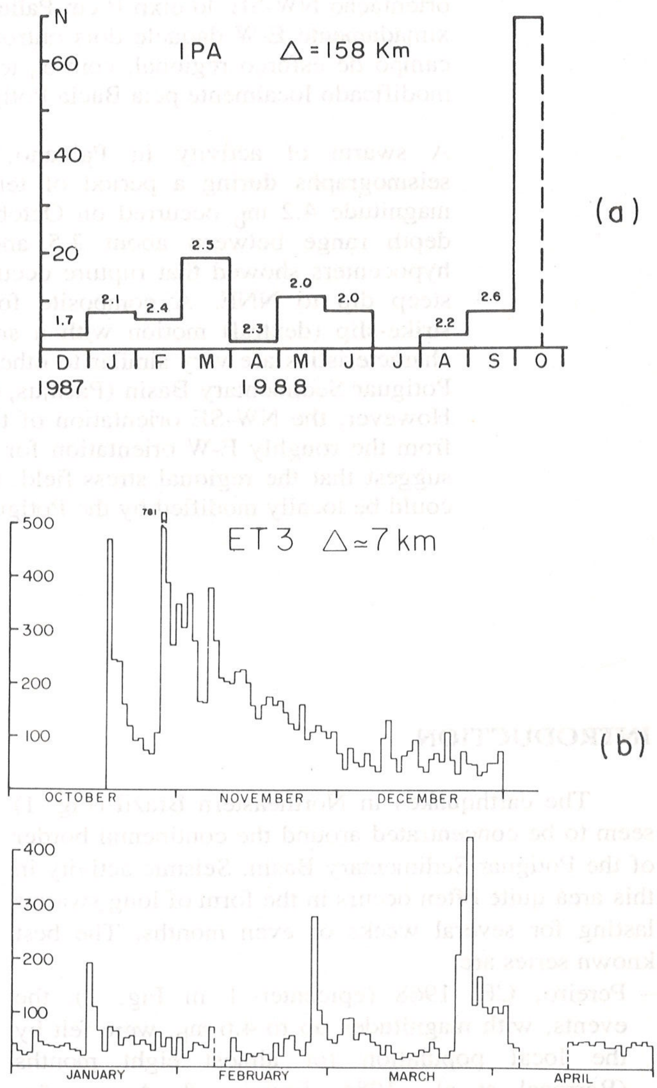

Figure 2. a) Number of Palhano events per month recorded by station IPA (Ipanguaçu, RN). Numbers above the histogram are maximum magnitudes in each month. Note the increase in activity just before October 19th. b) Number of daily events recorded by the local station ET3 from October 1988 to April 1989.

Table 1. Major earthquakes of the Palhano sequence.

Date	Time	Lat.	Long.	m_R*	N+
18 OCT 1988	09:44:37	–4.807	–37.980	3.7	3
18 OCT 1988	21:03:29	–4.807	–37.980	3.9	4
19 OCT 1988	02:15:50	–4.807	–37.980	4.2	4
29 OCT 1988	03:24:28	–4.809	–37.975	4.1	4
30 OCT 1988	07:13:04	–4.809	–37.975	3.2	2
25 MAR 1989	15:29:20	–4.810	–37.970	4.2	2
26 MAR 1989	13:25:30	–4.810	–37.970	4.5	2
26 MAR 1989	18:17:45	–4.810	–37.970	3.7	2

* m_b equivalent magnitude scale using regional stations in Brazil (Assumpção, 1983).

\+ number of stations used in the magnitude.

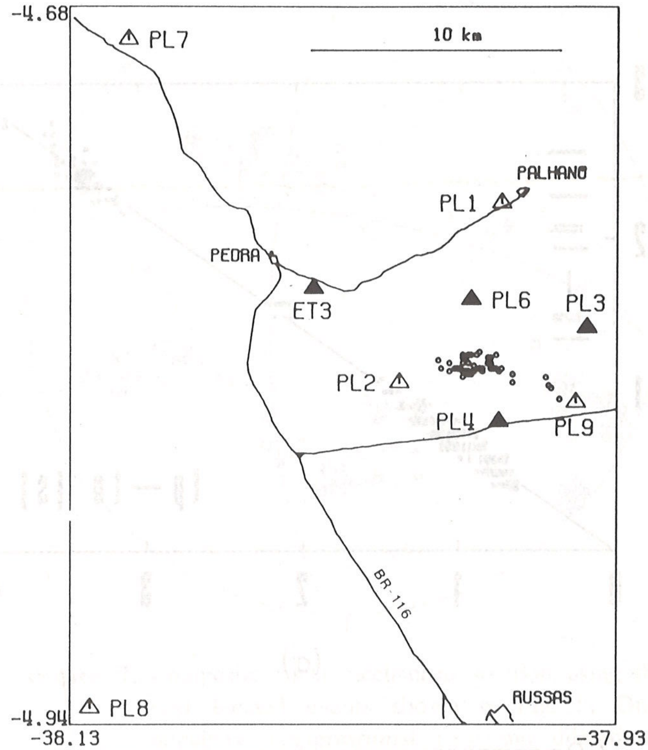

Figure 3. Distribution of fixed stations (solid triangles), moving stations (open triangles) and epicenters (dots). A maximum of five stations were operating at any time.

DETERMINATION OF HYPOCENTERS

The clocks of the seismographs were set using a WWVT (Kinemetrics) receiver. A time signal (Universal Time) was recorded daily in every seismogram to determine the drift of every station. The seismographs were run with a speed of 120 mm/minute with tick marks every second. Readings were made with a magnifying lens with 10 times enlargement and divisions of 1/10 mm. For good quality seismograms and impulsive arrivals the accuracy of the arrival times was estimated to be about ± 0.03 s (taking into account the precision of both the reading and the time correction, which are about 1/3 of a division each).

Velocity model

Initially the best ratio of P to S velocities (assumed constant for all depths) was estimated independently of the P velocity model to be used later. Calling tp_i and ts_i the arrival times of P and S waves, to_i the origin time of the i-th event, the ratio K = Vp/Vs is defined by:

$$ts_i - tp_i = (K - 1) \cdot (tp_i - to_i)$$

Using a set of 111 events (in the magnitude range of 0 to 1) with good P and S readings, the ratio K was determined by least squares (the origin times of all events are also determined in this process). A value of Vp/Vs of 1.707 ± 0.003 was found (Fig. 4a). Using this ratio, hypocenters were determined with the program HYPO71 (Lee & Lahr, 1975), using simple regression, for various 2-layer models to find the best velocity structure. This was done with a selected set of 52 events which had good P and S readings at all five stations. Three different station configurations were included in that set of 52 events. The thickness of the first layer was fixed arbitrarily at 3 km. The velocities V_1 of the first layer and V_2 of the half-space were varied until a minimum in the average of the travel-time residuals was found. Fig. 4b shows the contours of the average of the 52 root-mean-square residuals. Velocities of 5.4 km/s for the first layer and 6.3 km/s for the half space, giving the minimum average residual of 0.025 s, were chosen for the velocity model. Note the the strong trade-off between V_1 and V_2 indicating that the average of these two velocities (5.85 km/s) is better constrained than either V_1 or V_2. Using this 2-velocity model, the average residual for each station was less than 0.02 seconds.

Hypocenter trend

The standard errors of the hypocenters of the selected events, due to reading uncertainties and the use of a simplified velocity model, were about 0.2 km in the epicenter location and about 0.3 km in depth. Actual hypocentral errors can be somewhat larger if we take into account possible deviations from the simple velocity structure used. For example, if a half-space velocity structure with 5.85 km/s is used, epicenters are shifted by 0.1 to 0.4 km (average shift 0.2 km) and the depths are increased on average by 0.4 km (depth shifts range from +0.2 to +1.1 km).

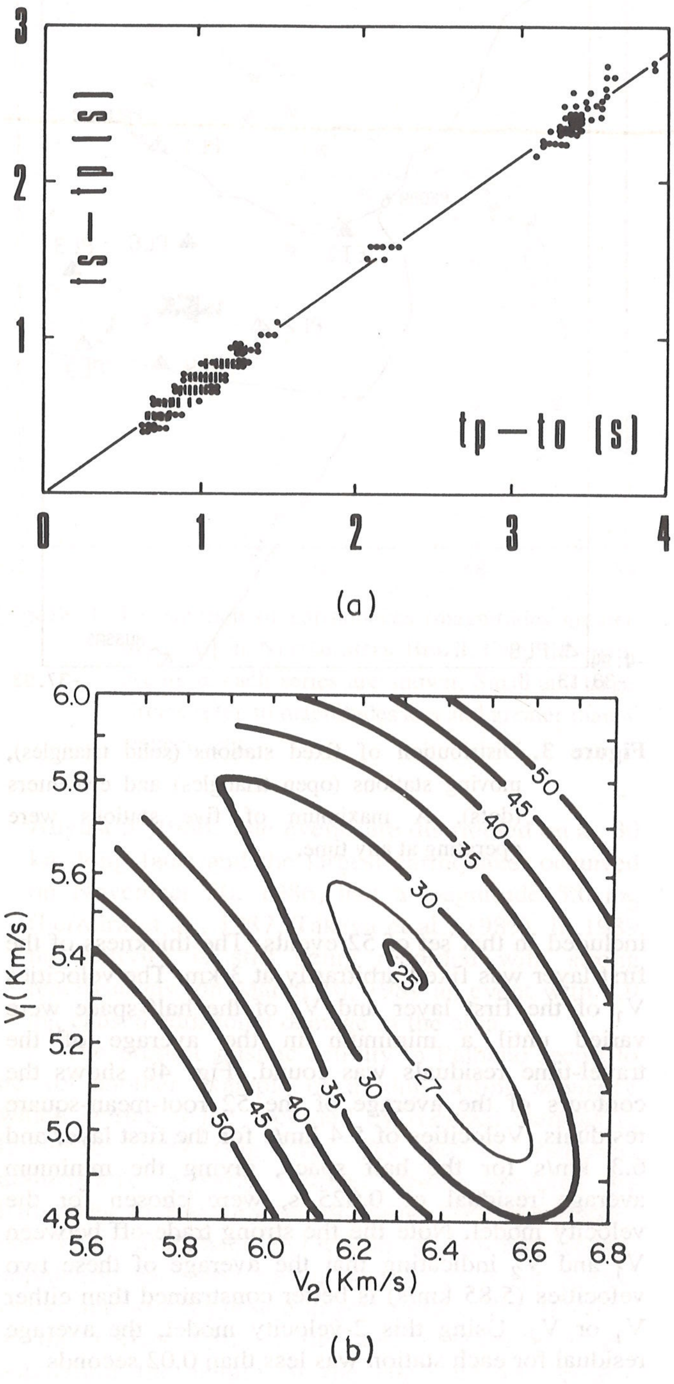

Figure 4. a) Wadati diagram with data from 111 well recorded events. Dot = one data point; small bars = four or more data points. Straight line corresponds to the least squares value of Vp/Vs = 1.707 ± 0.003. Standard deviation is 0.05 s. b) Contour of the average of the r.m.s. residuals (in miliseconds) of 52 events located with P and S waves read on all five stations. V_1 is the velocity of the first layer, V_2 of the half-space. Thickness of the first layer is 3 km. Note the best velocity model (V_1 = 5.4, V_2 = 6.3) produces a minimum average residual of 0.025 s.

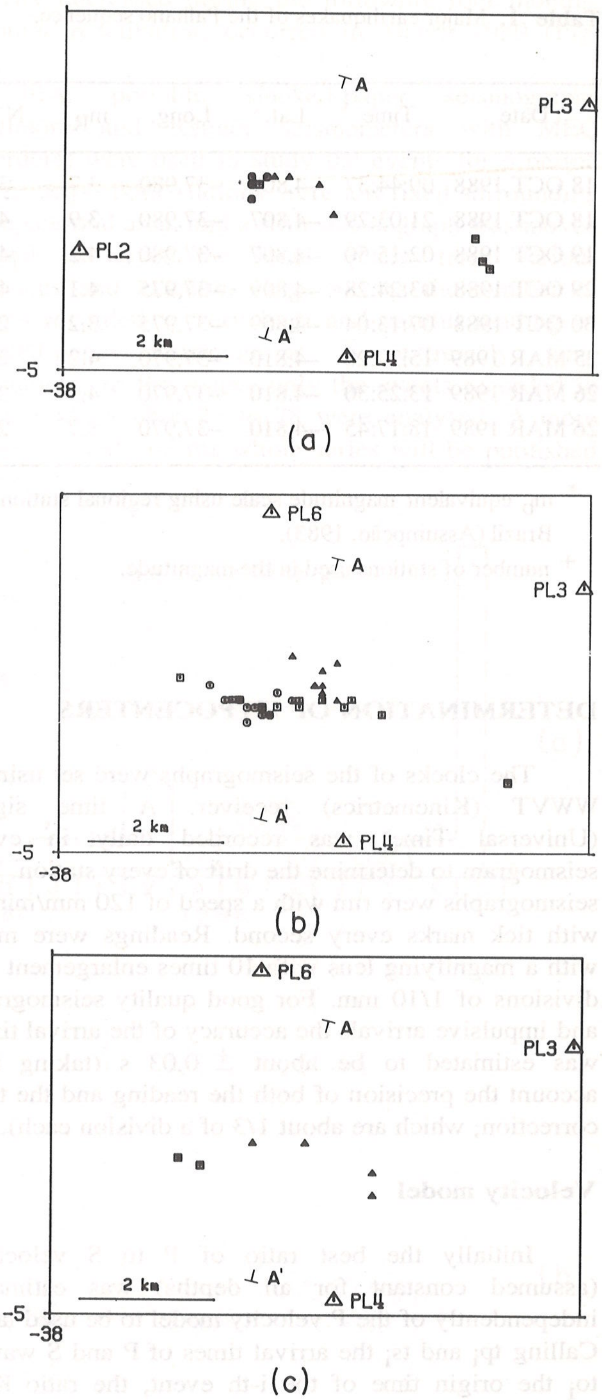

Figure 5. Plots of epicenters determined with three different 5-station configurations. Note that not all stations (large triangles) appear in the figure. All events had P and S arrivals read on all five stations. Hypocentral depth ranges are 2.0-3.2 km (circle), 3.2-4.5 km (square) and 4.5-6.0 km (small triangle). A and A' correspond to the projections of Fig. 6.

(a) Events recorded by stations PL1, PL2, PL3, PL4 and ET3 (October 22).

(b) Events recorded by stations PL3, PL4, PL6, PL7 and ET3 (October 24 to 26).

(c) Events recorded by stations PL3, PL4, PL6, PL8 and ET3 (October 26 to 27).

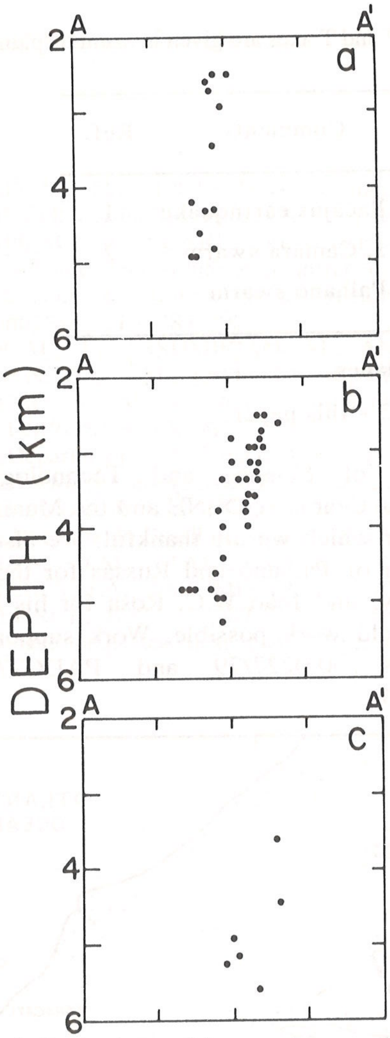

Figure 6. Projections of hypocenters on the vertical plane AA' indicated in Fig. 5. a, b and c correspond to Figs. 5a, b and c respectively. No vertical exageration.

Fig. 5 shows the best located events (r.m.s. residual ≤ 0.04 s with P and S readings from all five stations) recorded by three different station configurations. The distribution of these events reveals a fault oriented WNW-ESE with a steep dip to NNE (Fig. 6). A plane fitted to the hypocenters of Fig. 5 (minimizing by least squares the distance of the points to the plane) gave azimuths for the fault strike of 288° (Fig. 5a), 289° (Fig. 5b) and 286° (Fig. 5c). The depths of the events are confined between 2.5 and 5 km.

FOCAL MECHANISM

A composite focal mechanism with the best located events above is shown in Fig. 7. Only impulsive P-wave first motions were used. The polarity data require one of the nodal planes to be roughly in the E-W direction. Thus, the orientation of the nodal plane striking 280° was chosen as close as possible to that of the fault plane inferred from the hypocentral distribution (strike of 288°, as seen above). In this solution inconsistent polarities are almost always near a nodal plane and could be attributed to small hypocentral errors or to slight deviations (< 10°) of individual fault plane parameters. Stations which are far from the nodal planes (such as ET3, PL3, PL7 and PL8) show consistent polarities. Thus, the composite focal mechanism is fairly consistent with the results of the hypocentral determinations and faithfully represents the type of fault motion common to the majority of the events. These results indicate a dextral strike-slip fault with a small component of normal faulting. The parameters of this solution are in Table 2.

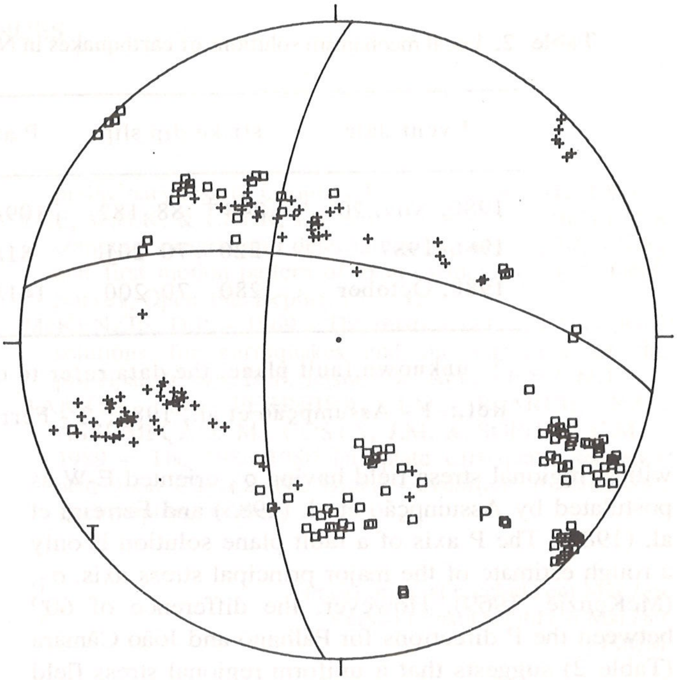

Figure 7. Composite focal mechanism solution using the best located events shown in Fig. 5. Only impulsive compressional (+) and dilatational (square) P-wave first motions were used. 'P' and 'T' are the pressure and tension axes respectively. Lower hemisphere equal-area projection.

DISCUSSION

The epicentral area, characterized by a thin cover of Late Tertiary-Quaternary sediments of the Barreiras Group overlying a Precambrian gneissic basement, lies near the border of the Potiguar Sedimentary Basin (Fig. 8). Although a NE trending Precambrian fault has been mapped close to the epicentral area (Fig. 8), it does not seem to be directly related to the Palhano seismicity because the distribution of hypocenters showed that the rupture occurred on a WNW-ESE striking plane.

The orientation of the P axis (roughly NW-SE) is somewhat different from previous earthquakes in other areas of Northeastern Brazil (Table 2). In fact, the focal mechanism of Palhano (Fig. 7) is inconsistent

Table 2. Focal mechanism solutions of earthquakes in Northeastern Brazil. P and T axes are given in azimuth/plunge.

Event date	strike dip slip	P axis	T axis	Comments	Ref.
1980, Nov. 20	244+ 88 182	109/03	199/00	Pacajus earthquake	1
1986-1987	220 70 201	81/29	171/00	J. Câmara swarm	2
1988, October	280 70 200	141/28	232/01	Palhano swarm	3

+ unknown fault plane; the data refer to one of the nodal planes.

Ref.: 1 - Assumpção et al., 1985; 2 - Ferreira et al., 1987; 3 - this paper.

with a regional stress field having σ_1 oriented E-W as postulated by Assumpção et al. (1985) and Ferreira et al. (1987). The P axis of a fault plane solution is only a rough estimate of the major principal stress axis, σ_1, (McKenzie, 1969). However, the difference of 60^0 between the P directions for Palhano and João Câmara (Table 2) suggests that a uniform regional stress field in Northeastern Brazil is unlikely. It is interesting to note, however, that the strike of the border of the Potiguar basin near Palhano is roughly SW-NE (Fig. 8) whereas the border of the Basin near João Câmara strikes E-W. The P directions of Table 2 may suggest that the average regional stress field in Northeastern Brazil has σ_1 oriented ESE-WNW and σ_3 NNE-SSW. This regional stress field may be locally modified by some process related to the Potiguar Basin. The fact that, in Northeastern Brazil, the regional seismicity seems to be concentrated around that basin (Fig. 1) makes the hypothesis of a relationship between the stress field and the Potiguar Basin worthy of further studies.

CONCLUSIONS

The seismicity occurred in Palhano, CE, was caused by rupture on a WNW-ESE oriented fault with a large component of strike-slip. The events were confined mainly between depths of 2.5 and 5 km. The active part of the fault, indicated by the events from October 21 to 28, was about 4 km long.

The seismic activity in Palhano seems to be part of a "seismic zone" around the continental border of the Potiguar sedimentary basin. This zone is characterized by shallow seismicity (about 5 km in Pacajus, 1 to 7 km in João Câmara, and 2.5 to 5 km in Palhano) and predominantly strike-slip faulting.

It is suggested that the regional stress field, with σ_1 having an average orientation WNW-ESE, is locally modified by some process related to the Potiguar Sedimentary Basin.

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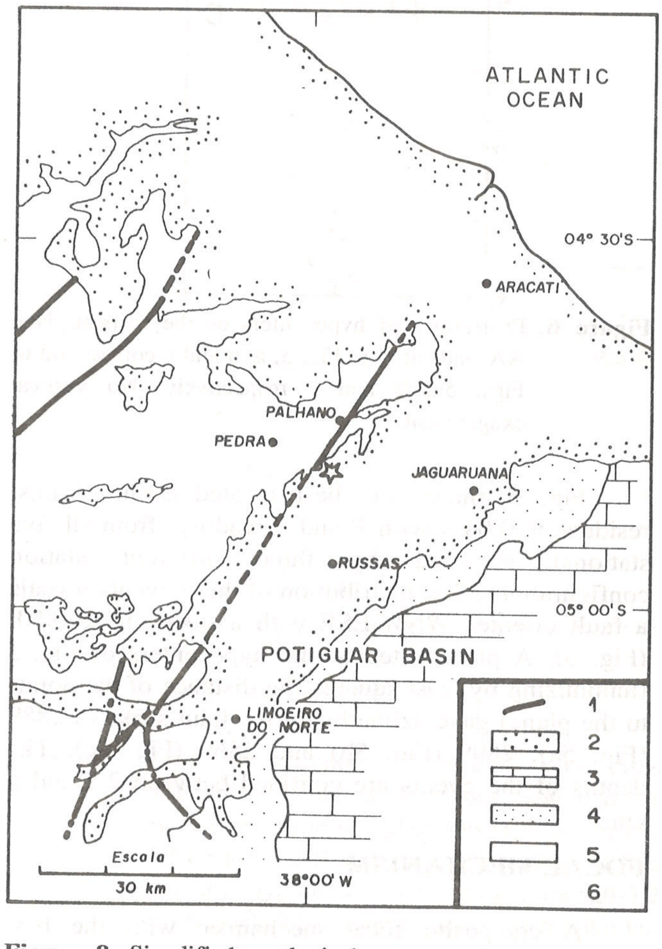

Figure 8. Simplified geological map of the area (after DNPM, 1983). The epicentral area is indicated by the star. 1 = fault (dashed where inferred); 2 = Tertiary/Quaternary clayish sandstones and gravel (Barreiras Group); 3 = Upper Cretaceous limestones (Jandaira Formation); 4 = Cretaceous sandstones (Açu Formation); 5 = Precambrian gneisses and migmatites.

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