Bulletin of the Seismological Society of America, Vol. 81, No. 4, pp. 1403–1407, August 1991

A DEEP EARTHQUAKE UNDER SOUTH SPAIN, 8 MARCH 1990

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The existence of very deep earthquakes under south Spain, with depths about 640 km, was first observed with the earthquake of 29 March 1954 with magnitude 7. This earthquake, with its unusual depth and magnitude for the Mediterranean area, excited the interest of seismologists and has been the subject of several studies (Hodgson and Cock, 1956; Bonelli and Esteban Carrasco, 1957; Chung and Kanamori, 1976; Udías *et al.*., 1976; Grimison and Chen, 1986). Another deep earthquake took place at about the same epicenter on 30 January 1973 with similar depth but lower magnitude 4. Recently, on 8 March 1990, a new deep earthquake has taken place with similar epicentral coordinates and depth and magnitude 4.3. Hypocentral data for the three earthquakes taken from the Instituto Geográfico Nacional, Madrid (IGN) Seismicity Data File, are given in Table 1. The epicenters of the three events are located south of Granada, near the town of Dúrcal, at the center of the seismically active region of south Spain (Fig. 1). Intermediate depth earthquakes, with depths down to 150 km, have been also observed in this region. Upgraded seismological stations networks in the area have made it possible for recent years to determine with sufficient accuracy the depths of these intermediate earthquakes (Buforn *et al.*, 1988). As can be seen from Figure 2, the deep earthquakes are located under the region where there is a greater concentration of intermediate earthquakes. Intermediate shocks are limited to depths above 150 km, and no earthquakes have been observed with depths between that depth and the deep shocks, near 640 km. For the instrumental period (after 1910), none of the intermediate depth shocks had magnitudes above 5. All shocks with magnitudes larger than 6 in south Spain belong to the historical period (previous to 1910), and all of them are believed to be shallow (Muñoz and Udías, 1989). Large deep earthquakes in historical times will be difficult to identify, because they would not be associated with great damage. The repetition of these deep shocks points to an anomalous situation at the depth, with material sufficiently cold and rigid to produce sudden release of strain energy in the form of earthquakes.

The focal mechanism of the 8 March 1990 is given in Table 2, and shown in Figure 3. Although all data correspond to regional stations and come from up going rays they have been projected on the lower hemisphere of the focal sphere. In the same Table 2 and Figure 3, the mechanisms of the other two deep events are given. They have been determined for this study. Polarities for the 1954 event are taken from Hogdson and Cock (1956), and those for the 1973 earthquake have been newly read from the original records. The solution for the 1954 earthquake is similar to those already given by Hogdson and Cock (1956) and Chung and Kanamori (1976). It can be seen that all three shocks have very similar mechanism with one plane nearly vertical and oriented N–S, while the second plane is nearly horizontal and its strike is not well defined. In all three cases, the P axis dips to the east and the T axis to the west. For the shocks of 1973 and 1990, the N-S–striking plane dips to the west 74° and 62°, respectively, while for the 1954 shock the plane is nearly vertical (88°). Due to the low

TABLE 1

HYPOCENTRAL DATA FOR THREE DEEP EARTHQUAKES IN SPAIN

No.	Date (m/d/y)	Time	Latitude	Longitude	Depth	Magnitude
1	03/29/1954	06-17-05.0	37.00°N	3.50°W	640	7.0
2	01/30/1973	02-35-59.8	36.85°N	3.74°W	660	4.0
3	03/08/1990	01-37-12.2	36.99°N	3.55°W	637	4.3

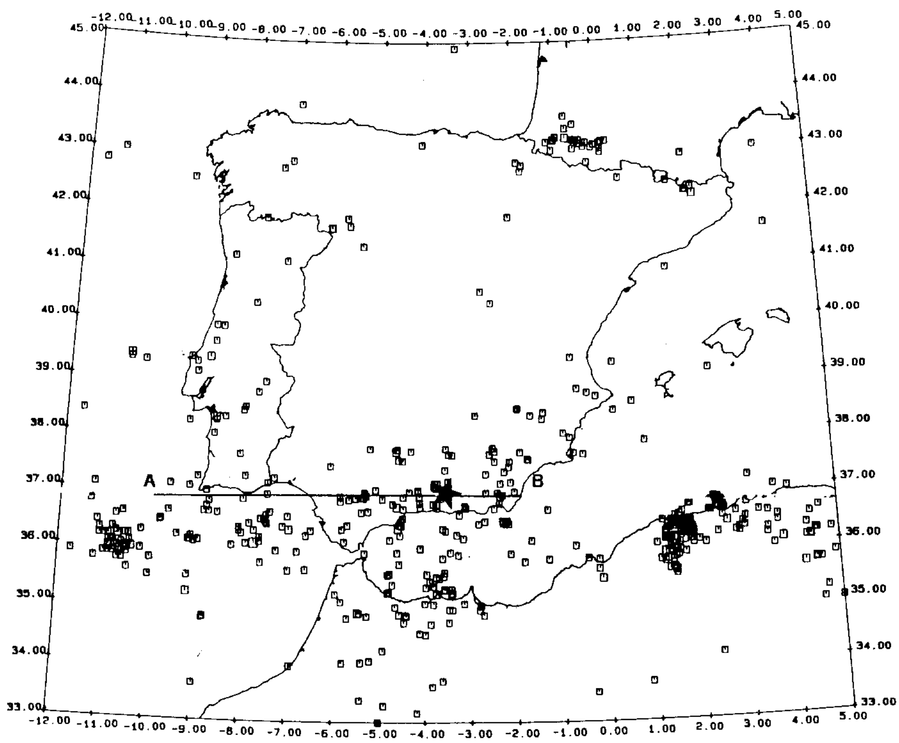

FIG. 1. Epicenter distribution for the period from 1970 to 1990 with magnitude greater than 4 (Instituto Geográfico Nacional, Madrid, Seismicity Data File). Star correspond to the location of the three deep shocks.

magnitude ($M \cong 4$) of the 1973 and 1990 earthquakes, their data come from stations at regional distances and correspond to upgoing rays, while the data of the 1954 earthquake come from teleseismic distances corresponding to downgoing rays. The fault-plane solution for the 1990 earthquake is better defined than that for the 1973 shock, due to the improvement of the seismological networks in Spain, Portugal, Morocco, and Algeria since about 1975. Spectra from 10 short-period digital stations in Spain have been used to calculate the seismic moment which results in $M_0 = 1.7 \pm 0.7 \times 10^{23}$ dyne-cm. This seismic moment is high for the given magnitude, 4.3 (IGN), 4.1 (NEIC) resulting in very low apparent average stress 1 bar. If the average stress is about 50 bars (Kanamori and Anderson, 1975), the corresponding magnitude would be 4.8. This inconsistency between the seismic moment and magnitude may be due to the fact that the adequate attenuation has not been used.

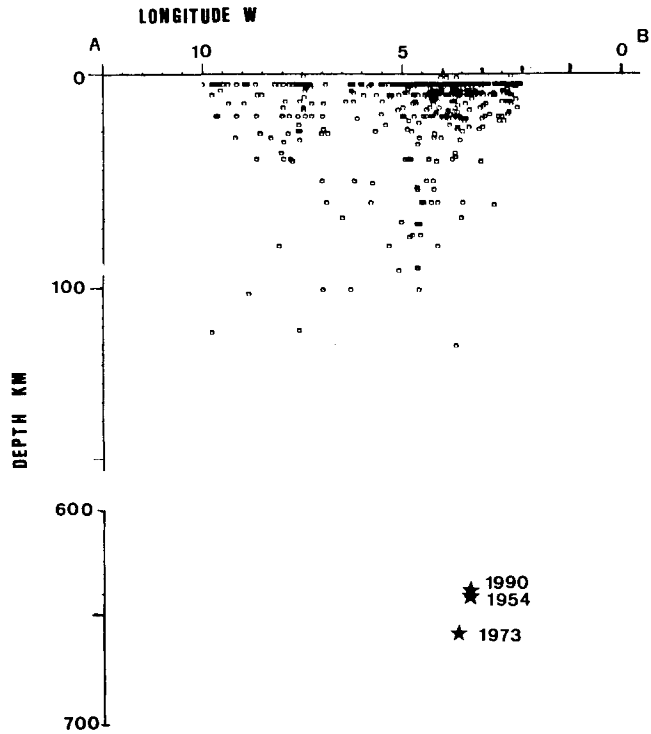

FIG. 2. Cross section of hypocenters of earthquakes in south Spain corresponding to the line in Figure 1 (Instituto Geográfico Nacional, Madrid, Seismicity Data File). Stars correspond to the location of the three deep shocks.

TABLE 2

FAULT-PLANE SOLUTIONS FOR THREE DEEP EARTHQUAKES IN SPAIN

No.		Axes T and P Θ	Φ		Nodal Planes ϕ	δ	λ	Number of Stations	Score
1	T:	55 ± 11	297 ± 13	A:	87 ± 28	32 ± 12	-3 ± 34	89	0.91
	P:	52 ± 8	61 ± 9	B:	179 ± 7	88 ± 18	-122 ± 11		
2	T:	68 ± 15	256 ± 23	A:	303 ± 30	37 ± 48	-153 ± 15	15	0.80
	P:	41 ± 16	139 ± 22	B:	191 ± 3	74 ± 12	-56 ± 49		
3	T:	73 ± 7	268 ± 15	A:	0 ± 41	28 ± 7	-88 ± 40	40	0.95
	P:	17 ± 6	84 ± 58	B:	177 ± 12	62 ± 7	-91 ± 120		

Deepest events in the Mediterranean subduction zones of the Sicily-Calabria and Hellenic arcs do not extend beyond 450 km. Since these subduction zones can be related to the collision of the Eurasian and Africa plates, the deep shocks under south Spain at greater depths must have a different origin. Assuming a converging rate of 1 cm/yr, by simple subduction it will take about 60 Myr for lithospheric material to reach a depth of 600 km, if there have ever existed 600 km of oceanic lithosphere between the two plates at that region (Grimison and Chen, 1986). The discontinuity of the intermediate shocks under south Spain, the Alboran Sea, and Morocco, which do not extend beyond 150 km, and the small hypocentral region of the deep earthquakes points to a detached block of lithospheric material that has sank to its present depth. Assuming that for deep

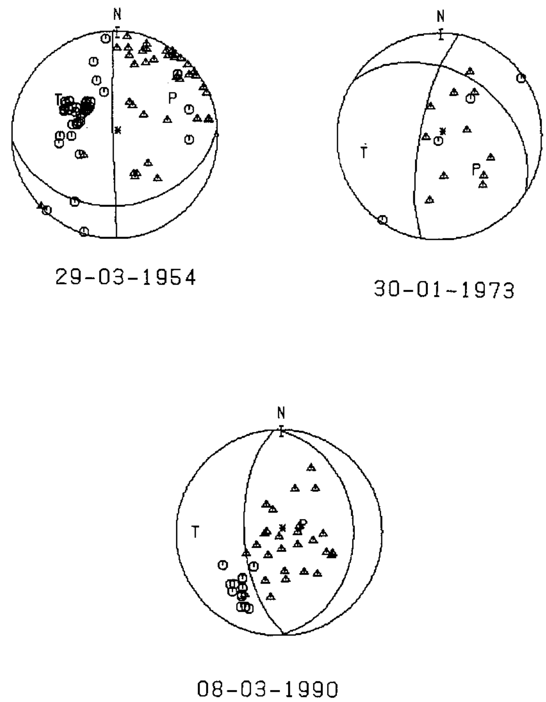

FIG. 3. Fault-plane solutions of the three deep Spanish earthquakes. Projections shown are for the lower hemisphere (triangles represent dilatations and circles compressions).

earthquakes pressure axes point downdip of the subducted slab, the orientation of the pressure axis for these earthquakes (dipping east) makes difficult to relate their orientation to the actual plate collision, which in this region is N–S to NW–SE. Focal mechanism of intermediate earthquakes in this region ($60 < h < 100$ km) have P axes dipping NW (Buforn *et al.*, 1988). The east-dipping orientation of the P axis has puzzled seismologists that have tried to interpret the 1954 earthquake in the light of plate tectonics (Isacks *et al.*, 1968; Isacks and Molnar, 1969; Chung and Kanamori, 1976; Udías *et al.*, 1976; Grimison and Chen, 1986). The occurrence of the 8 March 1990 earthquake, at practically the same depth and location and similar focal mechanism, confirms that there exists at that region a nest of seismic activity that in the last 40 years has repeated at about 20 years intervals and may even generate large earthquakes ($M \cong 7$). Grimison and Chen (1986) proposed for the source of the deep earthquake of 1954 a detached block of lithospheric material of about 100-km radius that has sunk from 100 to 600 km in a few million years. The long distance of 500 km of sinking through mantle material may explain by itself the change in the orientation of the stress axes. The present mechanism of these earthquakes may not be related, then, to the stresses in the subducted lithosphere at the time of its formation near the surface. Recent seismic tomographic studies for the Iberian peninsula show, under its southern part, the presence of a pronounced anomaly with higher velocity in the upper mantle extending to a depth of about 600 km (Blanco and Spakman, 1990). This anomaly in velocity had been detected before in the analysis of surface waves (Panza *et al.*, 1980). These results point to the presence of an anomalous body in the upper mantle at this region, which may explain the presence of the intermediate and deep seismic activity. Remaining unexplained; however, are the concentrated volume of the earthquakes at 640 km depth and the orientation of their focal mechanism.

ACKNOWLEDGMENTS

The authors wish to thank the directors of the Seismological Observatories that have provided copies of seismograms for the 1990 shock. Part of this work has been supported by the Dirección General de Investigación Científica y Tecnológica, project PB-89-0097 and the European Economic Community, project SCI*0176-C (SMA). Publication No. 326 Departamento de Geofísica, Universidad Computlense, Madrid, and contribution 1180, Institut de Physique du Globe, Université Paris VII.

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Manuscript received 2 January 1991