Deep Structure of the Mediterranean Basin

by

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The model of plate tectonics is by now well known and needs no significant review here. It suffices to state that on this model, the earth is covered with a small number of rigid plates, each in motion relative to the other; plate area is created at oceanic ridges and is destroyed at trenches. The margins of the plates are delineated by earthquakes and the focal characteristics of these earthquakes describe the interactions between the plates.

A contact between two such plates is to be found in the Mediterranean where the African plate abuts the European plate. LE PICHON [1968] drew the contact in the western Mediterranean along a line extending from Sicily to the north of Corsica and thence south to Gibraltar. Recent epicenter maps [BARAZANGI & DORMAN 1969] and analysis of volcanic magmas [MARINELLI G. & MITTEMPERGHER 1966; MARINELLI G. 1967; BARBIERI *et al.* 1967 ; BARBIERI *et al.* 1969 ; CARAPEZZA M. 1960; MARINELLI G. 1969] show this contact to lie along the North African Coast from Gibraltar to Tunisia and thence into Sicily and onward to the east.

LE PICHON showed that the two plates are in relative compression along this contact. In other regions of the earth where there is relative compression between two plates, the contact is characterized by volcanic activity, with magmas typical of island arcs, along a line parallel to the contact and deep focus earthquakes are found well back of the trench.

Volcanic activity is present in the vicinity of Sicily along two apparently intersecting alignments (Fig. 1). The first extends from Etna to Vesuvius and includes the Lipari Island; the second is almost perpendicular to the first and includes volcanoes of the Oran region, Tunisia, Pantelleria and Linosa, submarine activity south-west of Sicily, Etna, and the volcanic region of south Anatolia. The magmas of this last alignment are basic and come from the upper part of the mantle.

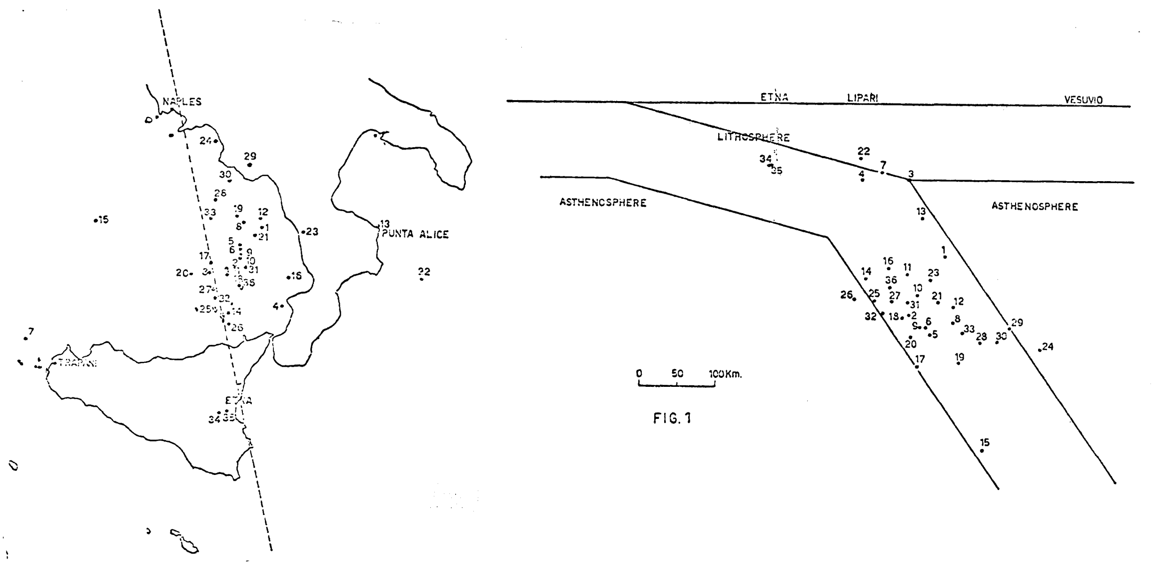

FIG. 1. — Map of South-Italy with locations of considered earthquakes. The number near dots refers to table 1. Vertical sections along the dash lines.

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North of this alignment the magmas have characteristics clearly different, as in the Lipari region and in the Aegean sea where the magmas are typical of the volcanoes of the islands arcs. North of Lipari the magmas come from the crust.

Deep focus earthquakes are to be found in this region as well, extending to 450 km depth beneath the Tyrrhenian Sea. The Tyrrhenian Earthquakes (table I) [IACCARINO E. 1968; ROTHÉ J.P. 1969; USCGS: US Coast and Geodetic Survey] lie in a dipping seismic zone, but one whose orientation is ambiguous. From fig. 1, it can be seen that the earthquake hypocenters, plotted along aNNW line (almost perpendicular to the E-W volcanic lineations) show reasonably good fit to the usual ideas of dipping seismic zones observed in other parts of the world. [BENIOFF 1962; SYKES 1966]. The dip of this zone is about 58° with some uncertainty.

Fault plane solutions for this region show dextral strikeslip solutions along E-W lines from Sicily into North Africa for the shallow shocks [RITSEMA, 1969; DI FILIPPO & PERONACI, 1959 *a,b*]. The intermediate and deep Tyrrhenian shocks show, on the other hand, maximum compressions dipping at about 60° to the WNW. This would suggest that the seismic zone would appear to dip to the WNW, as well as in any other direction (except to the NNE).

We suspect the existence of a plate dipping beneath the Tyrrhenian Sea, along which the principal stresses are in the direction WNW. This plate may be deformed, bowed or even fragmented to account for the two volcanic lineations.

In the Eastern Mediterranean, the case is somewhat more clearcut. A rudimentary trench is to be found to the south of Crete. Volcanic activity is found in the Aegean Sea, including the Islands of Santorin, Nisiros, Methana, Milos, Pathucos and so on. The seismic zone dips to the north at an angle of about 35° with some uncertainty (Fig. 2), using the shocks listed in Table II. One intermediate focus shock on our list n°. 12 has a well developed compression along a line striking about 5° to 10° East of North. [WICKENS & HODGSON, 1966].

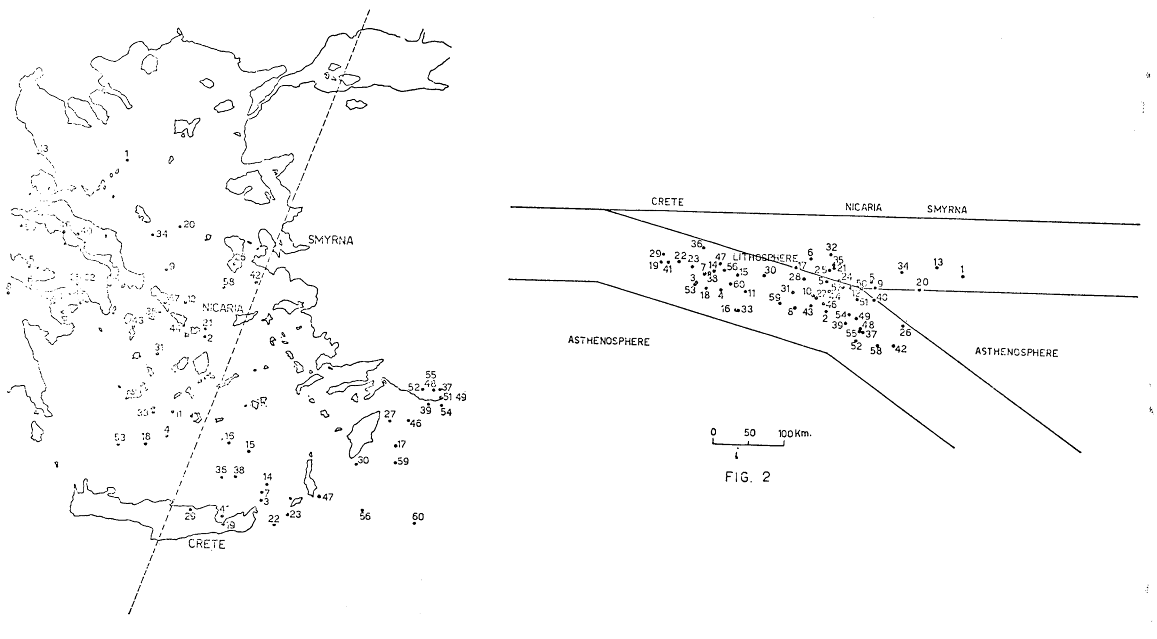

FIG. 2. — Map of Egean Sea with locations of considered earthquakes. The number near dots refers to table 2 Vertical section along the dash line.

As may be expected even this region is not free of complications to the simple model of the African plate thrusting beneath the European plate. Certainly the seismic activity in Turkey, along the anatolian Fault and elsewhere cannot be disregarded and the seat of deep focus earthquakes in Romania must also provide an interaction with this dipping zone as well.

To this general picture we can add the famous earthquake of Spain at a depth of 650 km. The fault plane solution for these earthquake [DI FILIPPO & PERONACI 1959*b*] revealed an angle of inclination of about 80° and an orientation of the dip fault almost parallel to the North African coasts.

The region considered is locally characterized by spatial variations in the magnetic declination due to magma being thrust towards the surface; another testimony is the high seismic activity of the central-south Italian area [BOSCHI *et al.* 1969], which can be explained by considering the motion the African lithosphere as being the cause of vertical and horizontal displacement.

As regards vertical displacement, DI LORENZO [1937] and IPPOLITO [1959] conclude that in southern Calabria there are frequent marine teraces of the quaternary period, at a height of about 1000 meters as compared with the present level of the sea. Other evidence come from restorations carried out on the cathedral of San Nicola in Bari from 1543 to 1892 [SCHETTINI 1967].

If we accept, as is generally accepted, that the average rise of the sea is 0.150 cm/year, the rate of uplift for the soil is 0.034 cm/year. This situation is confirmed also by an investigation regarding archeological finds along the Ionian coasts [ZOCCOLI 1969]. In 1957 SALVIONI comparing the data of the Italian geodetic leveling of 1897-1903 with those of the geodetic survey of 1950-1956, concludes that central-north Italy is involved in a general subsidence, with lines of equal subsidence in the direction NNE to SSW approximately.

An analysis of heat flow data [SCHEFFER 1964a, 1964b], [BIRCH, 1956], [BALDIRSAR, 1963], [LEE & UYEDA, 1965], [LEE & MCDONALD, 1968], [LUBIMOVA, 1966], indicates that the Lipari region is characterized by a value typical of island arcs, connected with volcanic intrusion.

From the analysis of the gravity anomalies in the Mediterranean Basin we note [KAULA 1969, WORZEL 1965] :

1. an alignment of positive anomalies involving the northern coast of Sicily and the western Mediterranean of the coasts of Africa. This alignment is found to be roughly parallel to the E-W volcanic alignement and to the mountain ranges of North Africa and Sicily;

2. negative anomalies in the Ionian Sea to the south of Crete. This is in agreement with the structure that one finds in islands arcs, even if this is not equally well delineated in the region of the Lipari Islands.

MOLNAR & OLIVER [1969] in an investigation of the attenuation of the upper crust show that the propagation of S_n waves through the concave part of many island arcs and through the mid-oceanic ridge is in general inefficient. while it is efficient in the convex part. In the Italian region generally, for southern Italy and for north Africa one can observe an inefficient transmission of S_n waves through the concave part of the arcs. For the region of the Aegean and for the north Turkey the data are more definitive since, besides the inefficient transmission on the concave part of the arc one observes an efficient transmission on the convex side. This evidence is supported by the qualitative analysis of the attenuation at the station surrounding the Lipari's earthquakes.

Abstract

From an analysis of the seismicity of Mediterranean basin we obtain a model of the deep structure of this region which is a further improvement to the plate tectonic theory. Taking into account the data of seismology, the gravity anomalies, volcanims and the few available data on the heat flow in this region, we concluded that the African plate is wedged under the Euroasiatic plate with a slope of approximately 58° in the Lipari region and 35° in the Egean region. This model can explain the high seismicity of Middle-South Italy, the sinking of the Middle-North Italy and the uplift of South-Italy. The last movement is confirmed also by geologic and archeologic data. The archeologic data give an uplift rate of 0.034 cm/year.

References

BARAZANGI (M.) & DORMAN (J.), 1969. — World seismicity maps compiled from ESSA, Coast and Geodetic survey, Epicenter data, 1961-1967. *Bull. seismol. Soc. Amer.*, **59**, 1, pp. 369-380.

BARBIERI (F.), BORSI (S.), FERRARA (G.) & INNOCENTI (F.), 1967. — Contributo alla conoscenza vulcanologica delle isole dell'arcipelago Pontino. *Mem. Soc. geol. ital.*, **6**, pp. 581-606.

BARBIERI (F.), BORSI (S.), FERRARA (G.) & INNOCENTI (F.), 1969. — Strontium isotopic composition of some recent basic volcanites of southern Tyrrhenian sea and Sicily channel. *Contr. Mineral. and Petrol*, **23**, pp. 157-172.

BENIOFF (H.), 1962. — Movements on major trancurrent faults. *Int. Geophysics Series*, **3**, pp. 103-134.

BIRCH (F.), 1966. — Earth heat-flow measurements in the last decade. *Adv. Earth Sc. U.S.A.*, pp. 403-430.

BOLDIZSAR (T.), 1963. — Terrestial heat flow in the natural steam field at Larderello. *Geofis. pur. appl.*, **56**, pp. 115-122.

BOSCHI (E.), CAPUTO (M.) & PANZA (G.F.), 1969. — Stability of seismic activity in Italy, with special reference to Carfagnana, Muggello and Forlivese. *C.N.E.N. RT* (ING), **69**, 24.

CARAPEZZA (M.), 1960. — Caratteri petrochimici e litologici delle lave dell'Etna. *Acta geol. Alpina*, **8**, pp. 1-71.

DI FILIPPO (D.) & PERONACI (F.), 1959 *a*. — Sui terremoti profondi del Mediterraneao. *R.C. Oss. geofis. reggino*, **7**, pp. 1-9.

DI FILIPPO (D.) & PERONACI (F.), 1959 *b*. — Natura fisica della scossa all'ipocentro di alcuni terremoti profondi nel Mediterraneo. *Ann. Geofis.*, **12**, pp. 549-566.

DI LORENZO (G.), 1937. — *Geologia dell'Italia meridionale.* 284, E.P.S.A. Ed., Neaples.

IACCARINO (E.), 1968. — *Attività sismica in Italia.* C.N.E.N. RT/GEO, **68**, 14, .

IPPOLITO (F.), 1959. — Bibliografia geologica d'Italia. **4**. Calabria, C.N.R. Comit. per la Geogr., Geol. e Mineralog.

KAULA (W.M.), 1969. — A tectonic classification of the main features of the Earth's Gravitational Field. *J. geophys. Res.*, **74**, pp. 4807-4826.

LEE (W.H.K.) & UYEDA (S.), 1965. — Review of heat flow data. Terrestrial Heat flow. *Geophys Monogr.*, **8**, pp. 87-190.

LEE (W.H.K.) & MAC DONALD (G.J.F.), 1963. — The global variation of terrestrial heat flow. *J. geophys. Res.*, **68**, pp. 6481-6492.

LE PICHON (X.), 1968. — Sea Floor spreading and continental drift. *J. geophys. res.*, **73**, pp. 3661-3697.

LUBIMOVA (E.A.), 1966. — On construction of temperature profiles for the Earth's crust and reduction of seismic ambiguity. *J. Phys. Earth*, **14**, pp. 27-36.

MARINELLI (G.) & MITTEMPERGHER (M.), 1966. — On the genesis of some magmas of Typical Mediterranean (Potassic) Suite. *Bull. volcan.*, **29**, pp. 113-140.

MARINELLI (G.), 1967. — Genèse des magmas du volcanisme plioquaternaire des Apennins, *Geol. Rdsch.*, **57**, pp. 127-141.

MARINELLI (G.), 1969. — Some geological data on the geothermal areas of Tuscany. *Bull. volcan.*, **33**, pp. 319-334.

MOLNAR (P.) & OLIVER (J.), 1969. — Lateral variations of attenuation in the upper mantle and discontinuities in the lithosphere. *J. geophys. Res.*, **74**, pp. 2648-2682.

MORGAN (J.W.), 1968. — Rises, Trenches, Great Faults and Crustal Block. *J. geophys. Res.*, **73**, pp. 1952-1982.

RITSEMA (A.R.), 1969. — Seismic data of the west Mediterranean and the problem of oceanization. *Verh. K. ned. geol.-mijnb. Genoot*, 26.

ROTHÉ (J.P.), 1969. — The seismicity of the earth, 1953-1965. *Earth Sci.*, UNESCO, 1.

SALVIONI (G.), 1957. — I movimenti del suolo nell'Italia centrosettentrionale. *Boll. Geod.*, 16, pp. 325-366.

SCHEFFER (V.), 1964 *a.* — Il flusso di calore terrestre in Europa. *R.C. Semin. Sci. Cagliari*, 34, pp. 226-238.

SCHEFFER (V.), 1964 *b.* — Geophysical investigation of the geothermal zones of the Earth. *Acta tech. Acad. Sci. hung.*, 47, pp. 409-429.

SCHETTINI (F.), 1967. — *La basilica di San Nicola*, Bari, ed. Laterza.

SYKES (L.R.), 1966. — The seismicity and deep structure of islands arcs. *J. geophys. Res.*, 71, pp. 2981-3006.

WICKENS & HODGSON 1967. — Computer re-evaluation of mechanism solution. *Publ. Dom. Obs. Ottawa*, 33, pp. 1-560.

WORZEL (J.L.), 1965. — Pendulum gravity measurements at sea, 1936-1959. *John Willey & Sons, New York, London, Sydney.*

ZOCCOLI (R.), 1969. — Per la ricerca dei livelli marini nell'antichità. Esame di alcuni manufatti archeologici sulla costa del Mar Jonio. — *Graduation Thesis, Istituto di Archeologia, Univ, Bologna.*

Remarque de M. Louis Glangeaud

L'utilisation du mot « plaque » offre une équivoque fondamentale car on ne peut appliquer le même concept pour la clôture supérieure et le Manteau.

Les concepts de cisaillement qui ont été émis notamment en 1951 (Colloque d'Hersey) en rapport avec les courants de convection étaient plus nuancés. Vouloir appliquer aux courants de convection du du Manteau supérieur les mêmes propriétés qu'à la croûte rigide est une erreur anthropomorphique. Elle s'oppose à ce que l'on connaît des phénomènes à haute pression et à haute température comme ceux du Manteau supérieur.

Cette erreur doit être évitée en employant le mot « *zone* » qui laisse une marge libre à l'interprétation. Nous proposons de nommer « zone de Bénioff-Gutemberg » la zone en question sans préjuger de ses caractéristiques dans les conditions de température et de pression du Manteau supérieur pour des durées d'ordre géologique. La mécanique et les propriétés du Manteau supérieur commencent à peine à être entrevues. Une prudence scientifique élémentaire demande que l'on n'emploie pas des mots analogues pour des phénomènes qui peuvent être aussi différents. Dans la croûte supérieure rigide, le mouvement d'une zone, même avec une faille aussi nette que celle de San Andrea demande un certain temps pour la mise en tension du matériel élastico-rigide, mais la même fracture peut jouer plusieurs fois. Pour un matériel visco-plastique, les phénomènes de rupture s'étalent sur une zone plus ou moins large avec une propagation différente. Telle est, à mon avis, la véritable conception géodynamique, tenant compte de tous les facteurs. La conception du réseau pentagonal rigide d'Elie de Beaumont a fait commettre beaucoup d'erreurs aux géologues. Il ne faudrait pas les renouveler avec le mot « plaque » (plate).

TABLE 1. — List of earthquakes used for the construction of the model of Fig. 1 (*)

Order number of earthquakos	Day	North Latitude	West Longitude	Depth Km	M
1	5. 4.1911	39°30′	15°30′	200	5.7
2	7. 7.1915	39°00′	15°00′	250-300	6.0
3	17. 8.1926	39°00′	14°45′	100	5.7
4	7. 3.1928	38°36′	15°47′	100	6.3
5	17.10.1937	39°18′	15°12′	300	5.8
6	13. 4.1938	39°18′	15°12′	290	6.9
7	16. 3.1941	38°26′	12°07′	90	6.2
8	17. 9.1943	39°30′	15°12′	270-300	5.3
9	31. 7.1947	39°12′	15°12′	290	5.4
10	1. 9.1947	39°12′	15°12′	250	5.2
11	10. 9.1952	39°00′	15°00′	200-250	5.3
12	26.12.1952	39°48′	15°30′	265	5.7
13	30. 7.1953	39°30′	17°00′	100-200	5.0
14	23.11.1954	38°33′	15°00′	230	5.8
15	17. 2.1955	39°36′	13°06′	450	5.3
16	1. 2.1956	39°12′	15°45′	215	6.2
17	25. 3.1962	39°06′	14°42′	343	...
18	1. 6.1963	39°00′	15°00′	280	4.4
19	26. 7.1963	39°36′	15°12′	337	4.2
20	14. 4.1964	39°00′	14°30′	305	4.3
21	4.10.1964	39°24′	15°24′	260	4.2
22	12. 3.1965	38°54′	17°42′	70	4.6
23	19.12.1965	39°24′	16°06′	230	4.1
24	23.12.1965	40°36′	14°54′	320	4.4
25	3. 2.1966	38°36′	14°48′	257	4.2
26	14. 2.1967	38°24′	15°06′	256	4.3
27	2. 6.1967	38°56′	14°48′	259	4.0
28	21. 4.1968	39°48′	14°54′	311	4.3
29	1.10.1968	40°12′	15°24′	291	4.2
30	29. 3.1969	40°01′	15°12′	310	4.6
31	2. 4.1969	39°01′	15°18′	258	4.8
32	13. 4.1969	38°48′	14°48′	274	4.1
33	15. 4.1969	39°36′	14°48′	299	4.1
34	....	Etna		80	...
35	....	Etna		80	...
36		Stromboli		240	...

(*) We used earthquakes 34-36, even if day, and magnitude are unknown, because we had sure informations about the depth (CALOI, personal communication).

TABLE 2. — List of earthquakes used for the construction of the model of Fig. 2

Order N. of earthquakes	Day	North Latitude	West Longitude	Depth Km.	M Body Waves
1	23. 1.1961	39°30′	22°00′	80	...
2	2.10.1961	37°24′	23°12′	135	...
3	3.10.1971	35°24′	24°06′	99	...
4	10. 1.1962	36°12′	22°36′	107	...
5	1. 5.1962	38°12′	20°36′	92	...
6	6. 5.1962	33°00′	20°30′	61	...
7	8. 2.1962	35°30′	24°06′	86	...
8	6. 7.1962	37°54′	20°12′	129	...
9	16. 7.1962	38°12′	22°36′	99	...
10	28. 7.1962	37°48′	21°18′	113	...
11	31. 7.1962	36°30′	22°42′	109	...
12	28. 8.1962	37°48′	22°54′	100	...
13	14. 9.1962	39°36′	28°36′	69	...
14	28.12.1962	35°36′	24°12′	82	...
15	15. 1.1963	36°00′	23°54′	87	...
16	1. 3.1963	36°06′	23°36′	136	...
17	5. 3.1963	36°00′	26°12′	73	...
18	1.10.1963	36°06′	22°18′	106	4.6
19	2.10.1963	35°06′	23°30′	72	4.5
20	6.11.1963	38°42′	22°48′	100	4.0
21	31. 1.1964	37°30′	23°12′	75	4.3
22	8. 4.1964	35°06′	24°18′	71	5.0
23	20. 4.1964	35°12′	24°30′	78	4.5
24	24. 4.1964	38°00′	21°48′	92	4.1
25	25. 5.1964	38°00′	21°12′	77	4.1
26	17. 7.1964	38°12′	23°42′	150	5.4
27	18. 7.1964	36°18′	26°06′	115	4.9
28	4.10.1964	37°48′	20°54′	90	4.0
29	12.12.1964	35°18′	23°00′	60	4.4
30	31.12.1964	35°48′	25°36′	86	5.1
31	15. 1.1965	37°12′	22°30′	108	4.3
32	8. 3.1965	38°00′	21°12′	55	4.2
33	23. 3.1965	36°30′	22°24′	136	4.4
34	31. 3.1965	38°36′	22°24′	78	6.3
35	7. 4.1965	37°42′	22°30′	70	4.9
36	27. 4.1965	35°42′	23°30′	50	5.5
37	7. 5.1965	36°42′	26°43′	162	4.6
38	6. 6.1965	35°36′	23°42′	86	4.1
39	10. 6.1965	35°30′	26°42′	151	4.9
40	14. 7.1965	38°36′	21°12′	117	4.1
41	18. 1.1966	35°12′	23°24′	71	4.8
42	27. 3.1966	38° 9′	24°00′	179	4.2
43	12. 5.1966	37°30′	22°06′	125	...
44	21. 5.1966	37°30′	22°54′	105	...
45	4. 6.1966	36°36′	21°00′	91	5.0
46	18. 8.1966	36°18′	26°24′	122	4.3
47	2. 9.1966	35°24′	25°00′	72	...

Order N. of earthquakes	Day	North Latitude	West Longitude	Depth Km.	M Body Waves
48	6. 9.1966	36°42′	26°36′	157	4.4
49	10. 9.1966	36°36′	26°54′	146	4.2
50	26. 9.1966	26°42′	20°24′	101	...
51	16. 1.1967	36°36′	26°54′	151	...
52	28. 8.1967	36°42′	26°48′	174	4.3
53	14. 9.1967	36°06′	21°54′	102	4.5
54	5.12.1967	36°30′	26°54′	138	4.6
55	7. 2.1968	36°42′	26°48′	161	5.0
56	7. 3.1968	35°12′	25°42′	81	4.4
57	25. 4.1968	37°48′	22°36′	99	4.3
58	18. 6.1968	37°54′	23°24′	179	4.3
59	13.11.1968	35°48′	26°12′	123	...
60	24. 7.1969	35°00′	26°30′	101	4.0