GEOLOGIE EN MIJNBOUW VOLUME 51 (5), p. 541–545 1972

DEEP EARTHQUAKES OF THE TYRRHENIAN SEA

A.R. RITSEMA[1]

TYRRHENIAN SEA – A REVIEW

The Tyrrhenian Sea is a small triangular inland sea with a greatest dimension of about 600 km and a maximal depth of 3.600 m. It is surrounded by Mesozoic and Cenozoic mountain structures of the Apennines, Calabria, Sicily, the Tell-Atlas, Sardinia and Corsica. The Calabrian sector for the greater part consists of Paleozoic crystalline rocks.

At the bottom of the basin a number of nearly north-south trending ridges have been found, in some cases rising from the bathyal plain to heights of −700 m. Sediment thicknesses are irregular, from 0-700 m in the bathyal plain to several kilometers in the marginal basins adjoining Calabria and Corsica. The top of the acoustic basement is probably of Lower Miocene age. Most of the sediment blanket has a Pliocene age. Geological structures surrounding the basin indicate that during Upper Mesozoic and part of the Cenozoic a landmass did exist at the place of the present basin.

Magnetic measurements in the basin do not show a regular anomaly pattern as in the mid-oceans. Part of the magnetic anomalies correlate directly with some of the ridges, which in such cases may be assumed to be of volcanic origin. The amplitude of the anomalies increase towards ESE, parallel with the intensity and age of the volcanic activity, the heat flow and the seismicity of the region.

Some of the basin ridges are notably free from magnetic anomalies. On the steep side of one of the non-magnetic ridges in the centre of the basin metamorphic rocks have been dredged. This means that at least part of the basin floor consists of foundered continent. Numerous fault steps in the sea bottom also point to continuing subsidence of the basin.

The Bouguer anomalies of 100-200 mgal with maxima up to +260 mgal, are comparable with those encountered in marginal seas of the western Pacific. The small positive free-air anomaly of the basin implies that regional isostasy has not yet been reached and that the subsidence continues.

Heat flow from the sea bottom is very high with an average of 2.8 HFU for 12 observations, and seems closely related to the positive gravity anomalies. In the southeastern part of the basin the heat flow reaches an average of 3.4 HFU. The 24 data of the Balearic basin show a somewhat lower mean of 2.3 HFU, but also this is about two times higher than normal. The temperature of the upper mantle under the basins thus is relatively high and exceptionally so in the southeastern corner of the Tyrrhenian basin. This is in accordance with the Recent volcanic activity which in the past 7 m.y. migrated from the sea to its present more landward position.

Sub-Moho velocities are relatively low, of the order of 7.7 km/sec for the Pn wave. This velocity is reached at a depth of about 11-12 km, normal for an oceanic Moho. For the Balearic basin there are indications that under the 7.7-discontinuity a velocity of 8.1-8.2 km/sec is reached at a depth of about 30 km. In the upper mantle an ultra-low-velocity layer has been found with its top at a depth of only 50-60 km

1) KNMI, de Bilt

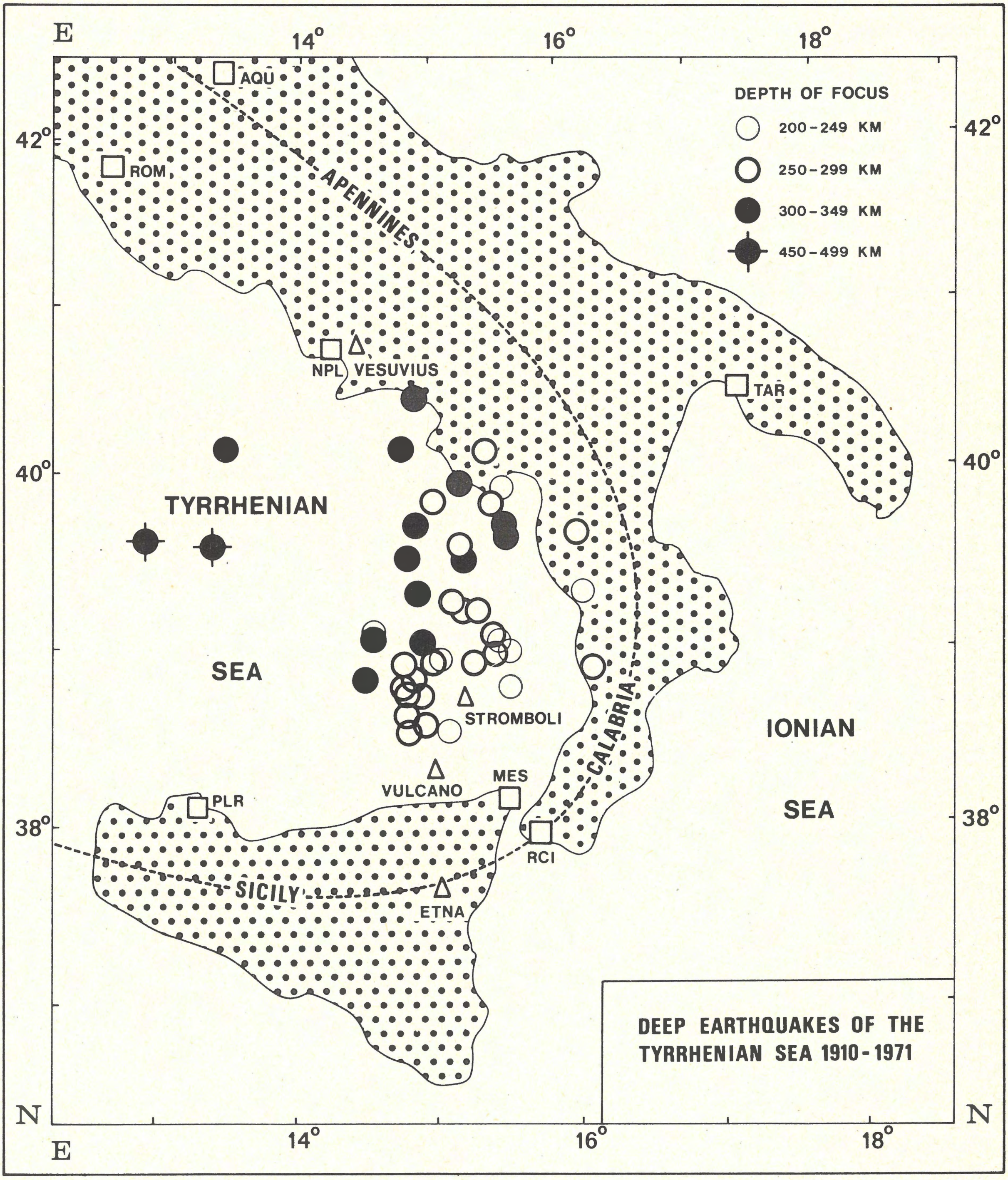

Fig. 1
Epicenter map of the deep earthquakes of the Tyrrhenian Sea 1910 - 1971.

and with a transverse wave velocity of only 4.1 km/sec. These extreme conditions at such shallow depth in the mantle do point to exceptional processes being active at present in the region.

SEISMICITY

Crustal seismicity is rather high all around the NE, SE and S borders of the Tyrrhenian basin and seldom exceeds de depth of 60 km. The western border is notably free from earthquakes.

Under the basin, and especially at its southern corner, deep mantle earthquakes do occur at depths of 200-350 km, some between 450 and 500 km. A computer program for the re-location of earthquakes using available P wave data results in the following picture: In general the focal depth increases with a more westerly location. Lines of equal focal depth strike roughly parallel in an about NNE direction. There is no clear connection of these deep shocks with the more or less continuous smooth arc of shallow seismicity. The deep shocks between 220 and 500 km depth seem to be concentrated in a less than 60 km thick slab with a width of only 200 km dipping about 50° from the ESE to the WNW. In this case therefore it is better to speak of a narrow tongue rather than of a slab.

In accordance with the picture of a lithosphere tongue plunging down in the upper mantle of the basin is the observation of traveltime anomalies of the direct P waves coming up from these deep foci in the immediate surroundings of the region: The stations Messina, Reggio and Taranto, lying more or less in the direction of the supposed tongue show early arrivals of, on the average, −1 to −1½ sec. In the station groups of Napoli and Roma, situated in directions about perpendicular to the supposed tongue late arrivals of about +1 sec are usual. This feature has also been found in the Japan and Tonga-Kermadec regions of the western Pacific where it has been used as an additional argument for the hypothesis of the plunging lithosphere slab.

The mechanisms in the foci of the seven stronger deep Tyrrhenian Sea earthquakes seem to be identical. The motion in the foci is either of the block-faulting type along a nearly vertical plane with a strike in NNE direction and the western block rising with respect to the eastern (or the eastern block subsiding with respect to the western block); òr of the thrust type along a subhorizontal plane in which the upper block overthrusts the lower block in WNW direction (or the lower block underthrusts the upper block in ESE direction). Maximum pressures (P-axes) plunge about 60e WNW, minimum pressures (tension axes) about 30° ESE. The orientation of the P and T axes and of the possible fault planes with respect to the position of the arc is identical with those of the deep earthquake zones of the Pacific. It looks as if the supposed tongue in the deep mantle of the basin stands under an internal pressure directed in the dip-direction of the tongue.

At low-velocity-layer depths of roughly 100-200 km no earthquakes do occur. This should either be attributed to the absence of those internal pressures at these depths, or to a complete interruption of the lithosphere tongue across this depth-interval.

CONCLUSION

The summarized data, relevant to the generation of the Tyrrhenian basin, are suggestive for an originally continental crust extended and fragmented in an about E-W direction by the Calabrian arc actively overriding the Ionian Sea region. Many of the presented features are reminiscent of similar data from the western Pacific marginal basins, for which recently also an extension has been postulated at the concave inner side of the arc. Volcanic outpourings form new oceanic floor in between the crust fragments of continental origin.

An active sub-thrusting of the ocean-side lithosphere of the Ionian Sea under the Calabrian arc and its hinterland of the Tyrrhenian basin, is extremely unlikely. The neighbouring Aegean arc namely, is thrusting over the same Ionian Sea basin in an about ENE-WSW direction. The Ionian block is internally stable (no earthquakes do occur in the basin) and structurally forms part of the African continent block. It is a structural and geometric impossibility for this Ionian Sea sector to play the active sub-thrusting role to the WNW (Tyrrhenian arc) as well as to the ENE (Aegean arc) without any internal disturbance of the Ionian block itself.

The thinning of the earth crust in the Tyrrhenian

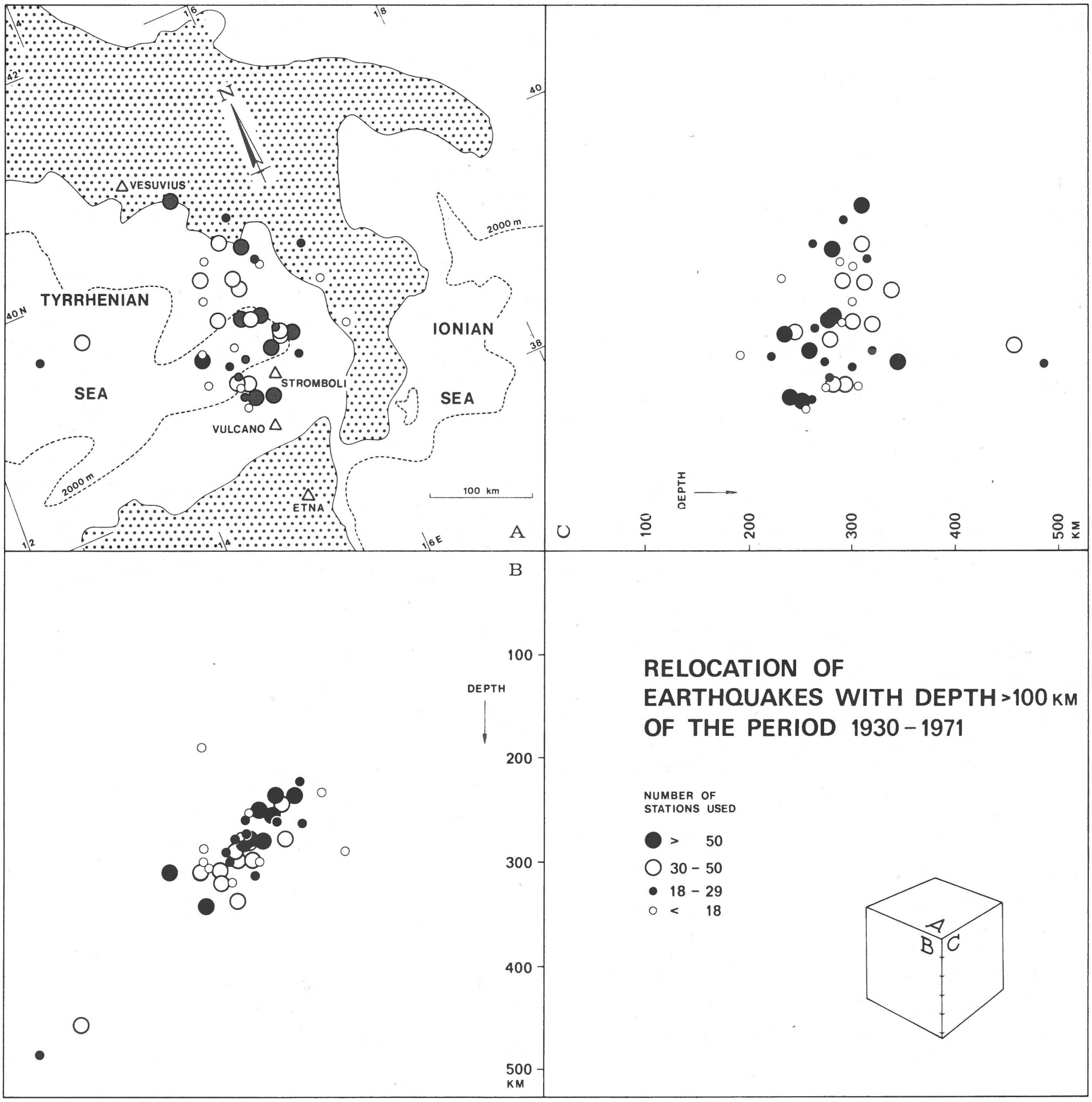

Fig. 2
Blockdiagram of the centre of deep earthquake activity of the Tyrrhenian Sea 1930 - 1971.

basin must be attributed to an earlier upheaval of the block in Upper Mesozoic and Lower Cenozoic times, with subsequent erosion and removal of the upper crustal layers, possibly accompanied by a later sub-crustal erosion and basification of the lower crustal layers.

SELECTION OF CONSULTED LITERATURE

Allan, T.D. and Morelli, C. (1971) – A geophysical study of the Mediterranean Sea, Boll. Geof. Teor. Appl., 13, p. 99-142.

Bemmelen, R.W. van (1969) – Origin of the western Mediterranean Sea. Trans. Roy. Geol. Min. Soc., 26, 13-52. Netherlands.

Berry, M.J. and Knopoff, L. (1967) – Structure of the upper mantle under the western Mediterranean basin, J. Geophys. Res., 72, p. 3613-3626.

Bousquet, J.-C. (1972) – La tectonique récente de l'Apennin Calabro-Lucanien dans son cadre geologique et geophysique. Thèse Univ. Sci. Techn. Languedoc, 13 Janvier 1972, CNRS: A.O. 5316, p. 172.

Booy, T. de (1969) – Repeated disappearance of continental crust during the geological development of the western Mediterranean area. Trans. Roy. Geol. Min. Soc. Netherlands, 26, p. 79-103.

Finetti, I., Morelli, C., Zarudsky, E. (1970) – Reflection seismic study of the Tyrrhenian Sea. Boll. Geof. Teor. Appl., 12, 48, p. 311-346.

Giorgetti, F. and Iaccarino, E. (1971) Seismicity of the Italian region. Boll. Geof. Teor. Appl., 13, 50, p. 143-154.

Heezen, B.C., Gray, C., Segre, A.G., Zarudski, E.F.K. (1971) – Evidence of foundered continental crust beaneath the central Tyrrhenian Sea. Nature, 229, 5283, p. 327-329.

Karig, D.E. (1971) – Origin and development of marginal basins in the western Pacific. J. Geophys. Res., 76, 11, p. 2542-2561.

McKenzie, D.P. (1970) – Plate tectonics of the Mediterranean region. Nature, 226, p. 239-243.

Morelli, C. (1970) – Physiographic gravity and magnetism of the Tyrrhenian Sea. Boll. Geof. Teor. Appl., 12, 48, p. 274-308.

Pannekoek, A.J. (1969) – Uplift and subsidence in and around the western Mediterranean since Oligocene: a review. Trans. Roy. Geol. Min. Soc. Netherlands, 26, p. 53-77.

Ritsema, A.R. (1969) – Seismic data of the western Mediterranean and the problem of oceanization. Trans. Roy. Geol. Min. Soc. Netherlands, 26, p. 105-120.

——— (1969) – Seismo-tectonic implications of a review of European earthquake mechanisms. Geol. Runds., 59, 1, p. 36-56.

——— (1970) – On the origin of the western Mediterranean basins. Tectonophysics 10, 609-623.

——— (1971) – On plate tectonics and arc movements in the Mediterranean region. Proc. Eur. Seism. Comm. Luxemburg 1970 (in print).

Ryan, W.B.F., Stanley, D.J., Hersey, J.B., Fahlquist, D.A., Allan, T.D., (1971) – The tectonics and geology of the Mediterranean Sea. In The Sea, Vol. 4, Edit. A.E. Maxwell, Interscience, New York.

Schuiling, R.D. (1969) – A geothermal model of oceanization. Trans. Roy. Geol. Min. Soc. Netherlands, 26, p. 143-148.