Abstract

Starting from a general tectonic description of the Strait of Messina, where attention is on the positioning of the stations adapted to observing microseismic activity in the area.

The main tectonic and stratigraphic characteristics of the area are highlighted together with the equipment used, and the main problem of the network of microseismic observations set up in the area and in the recent past, and to the microseismic energy threshold.

A number of observations regarding the seismic crisis in the Gulf of Patti (1978) are analyzed, with the aim of suggesting a crustal model compatible with the area of the Messina Straits.

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The travel times observed in the epicentral distance-interval, 0.1 A° ≤ 2.0, are tentatively placed into groups according to their hypocentral depth. From a first evaluation of the hypocentral coordinates (by the I.N.G.) it was possible to divide the data into two groups (for \( h' = 10 \text{ Km} \) and \( h'' = 20 \text{ Km} \), respectively). Using the slopes of the various linear regressions obtained from the data contained in the two groups, it was possible to elaborate a crustal model suitable by employing the differences in the times of the intercepts of the travel-time curves. To prevent the differences in the times from exceeding the experimental errors, the linear times were compared with the proposed model:

\[
\begin{align*}
\Delta t_1 &= 2 \text{ Km}, \quad c_1 = 3 \text{ Km sec}^{-1} \\
\Delta t_2 &= 12 \text{ Km}, \quad c_2 = 4.5 \text{ Km sec}^{-1} \\
\Delta t_3 &= 10 \text{ Km}, \quad c_3 = 4.5 \text{ Km sec}^{-1} \\
\Delta t_4 &= 10 \text{ Km sec}^{-1}
\end{align*}
\]

Such a model is compatible with the crustal sections obtained by similar deep refraction studies in areas along the margins of the Straits as well as with the trend of Bouger's isopachs in the propagation zone of the seismic rays.

**RIASSUNTO**

Muovendo da una descrizione generale della struttura della crosta di Messina, sono esposti i criteri adottati nella scelta dei siti delle stazioni sismiche costituenti la Rete dello Stretto. Le principali caratteristiche litologiche e meccaniche dei terreni di fondazione delle stazioni, unitamente alle dotazioni strumentali, sono riportate e messe in relazione all'ubicazione dei maggiore centri sismici attuali e recenti e al livello di soglia di energia dell'attività microsismica. Un congruo numero di osservazioni relative alla crisi sismica del Golfo di Patti (1978), è poi analizzato al fine di elaborare un modello di crosta compatibile con l'area dello Stretto di Messina. I tempi di tragitto osservati nell'intervalllo di distanze epicentrali 0.1 A° ≤ 2.0, sono preliminarmente discriminati in base alla profondità ipocentrale. Da una prima valutazione delle coordinate ipocentrali (effettuate dall'I.N.G.) è possibile suddividere l'intera popolazione dei dati in due gruppi, rispettivamente di profondità focale 10 e 20 Km. Dalle inclinazioni dei vari
allineamenti ottenuti con i dati dei due gruppi, è possibile elaborare un modello crostale (MSM), correlando progressivamente gli elementi deducibili dai due raggruppamenti relativamente alle velocità delle onde longitudinali ed ai tempi intercetti delle rispettive 
dromocrome. In particolare sono confrontate le differenze dei tempi intercetti delle fasi osservate con quelle corrispondenti, deducibili dal modello proposto.

Un modello di crosta a quattro strati è così caratterizzato:

\[ \begin{align*}
    h_1 &= 2 \text{ Km}, \quad v_1 = 3.0 \text{ Km} \cdot \text{sec}^{-1}; \\
    h_2 &= 4 \text{ Km}, \quad v_2 = 4.5 \text{ Km} \cdot \text{sec}^{-1}; \\
    h_3 &= 16 \text{ Km}, \quad v_3 = 5.8 \text{ Km} \cdot \text{sec}^{-1}; \\
    h_4 &= 13.5 \text{ Km}, \quad v_4 = 6.4 \text{ Km} \cdot \text{sec}^{-1}; \\
    v_5 &= 7.8 \text{ Km} \cdot \text{sec}^{-1}.
\end{align*} \]

Tale modello risulta compatibile sia con le sezioni crostali ottenute mediante sismica a rifrazione profonda in aree ai margini dello Stretto, sia con l'andamento delle isoanomale di Bouguer nella zona di propagazione dei raggi sismici.

**INTRODUCTION**

The area centered on the Straits of Messina has been affected by some of the worst seismic catastrophes that occurred in Italy in the last two centuries. For this reason the necessity of creating a suitable infra-structure for seismological observation has been felt since the last century; but it was only after the disastrous earthquake that destroyed Messina and Reggio Calabria on December 28, 1908 that steps were taken to fill the gap.

In 1976 the C.N.R., granting financial support to the seismic-network of the Straits of Messina, through the Italian Geodynamic Project, made possible the realization of this modern network.

**GEOLOGICAL AND STRUCTURAL FRAMEWORK**

The Straits of Messina are the most important tectonic feature cutting across the southern branch of the Calabro-Peloritan mountain range, along the SE edge of the Tyrrhenian Sea.
This range is mostly made up of the Calabride Complex, which consists of terrigenous clasts of Hercynian metamorphites, as well as by Mesozoic and Tertiary sedimentary rocks.

During the Appennine orogenesis the Calabride Complex, consisting of several nappes, was emplaced by an overthrust moving SE. Later during the Senonian and Middle Miocene the metamorphic and igneous rocks were greatly altered by weathering. For this reason such nappes, especially in Calabria, are intensely cataclastic and superficially arenitic.

Recent studies in marine geology and neotectonics (Selli, 1978; Barbano et al., 1979) confirm the presence in the Straits of an already suspected graben structure. According to the most recent studies the post-orogenic tectonic evolution in the area of Straits can be summarized thus:

— after the phases of subsidence, during the Tortonian, a transgression took place with the formation of coastal environments. This transgression was accompanied by a post-orogenic phase in which the formation of lacustrine and low-lying fan systems took place, e.g., the Fiume Mesima, which also involved the area of the Straits of Messina (Barbano et al., 1978).

— a compressive tectonic phase followed, probably due to the continuing southeastward movement of the range accompanied by transcurrent movements at the edges (Barbano et al., 1978; Selli, 1978).

— between the Upper Senonian and the Pliocene, a compressional Tertiary phase directly involved the genesis of the Straits. In an early stage, the Straits between the faults of Portella Arena and Gallico (Fig. 1, a and b), had the shape of a major graben, created by a major extension a, N31W-35E (Selli, 1978).

— in the Upper Pliocene a transversal tensional tectonic phase began, which seems to be still going on. This phase caused normal faulting and lineaments (NWW-NNW, NNE-SSW) and reacted on earlier faults. According to Selli (1978), this phase was characterized by a NW-SE main extension, which generated a conjugate system EW-NS. This phase has been...
responsible for strong uplift, more noticeable on the Calabrian side, with the formation of various series of terraces. The complete separation of the two shores of the Straits is thought to belong to this phase, which, with the opening of the Graben (ENE-WSW), gave the Straits their northern access, and their present shape.

It is important to note that, according to geophysical research and stratigraphic soundings in the area of the Straits, the greatest thickness of the post-orogenic sedimentary cover on the crystalline formations is generally less than 1 kilometer.

SEISMIC STATION SITE SELECTION

The trend of the recent and current seismic activity in the area conforms to the tectonic picture given above. There are two levels of seismic activity. The first one refers to larger events (e.g. the earthquake of December 28, 1908, M = 7.1) while the second one, very active, refers to microseismic activity. Both types have their origins in the internal structures of the Grabens of the Straits (Baratta, 1910; Bottari, 1971; Bottari and Lo Giudice, 1975; Bottari et al., 1979). In particular, the most energetic activity is located in the northern Graben and along the Calabrian shore of the southern one (Fig. 1), while the microseismic activity is higher along the Sicilian shore (Bottari, 1971) of the southern Graben.

Seismological observations and mechanical considerations regarding the geological and structural patterns of the area lead to the suggestion that seismogenetic structures are most probably found in the crystalline terrains. The sites of the seismic stations were chosen accordingly using the following criteria:

— optimum distribution of the sensors in order to locate hypocenters and to study the focal mechanism of seismic events in the Straits;
— area covered by the network to be commensurate with the spatial distribution of the microseismic activity to be examined;
— possibility of placing the sensors in contact with the 
epicentral formations where the seismic phenomena are claimed 
to occur.

It was not always possible to fulfills these criteria because:

of the marine location of the major epicentral clusters, the

1) Middle Pliocene-Recent Formations:

2) Tortonian - Intrapliocene Sediments:

3) Alloctonous Units:

4) Main Regional Faults.
complex topography of the area and the scattered occurrence of crystalline outcrops along the coast.

The configuration of the network shown in Fig. 2 is, in our opinion, the best solution compatible with the environmental and technical constraints. The network, in fact, has the peripheral stations well sited on the postorogenic formations (GZ, OR, VN), the central ones on the Mesozoic overthrust sheet (MMS), and the peripheral stations on the metamorphic formations (MEN, MIN, SCI, VN). The network is well balanced and suited to the area's characteristics. The peripheral stations are sited on the crystalline complex and on the postorogenic sediments, in close contact with the crystalline complex and with better mechanical characteristics (GZ, OR, VN).

On the Sicilian side of the Straits:
- GZ1 (Ganzirri) 38° 15' 53" N, 15° 36' 31" E, 85 m (a.s.l.)
- MEN (Messina) 38° 11' 54" N, 15° 33' 18" E, 45 m (a.s.l.)

For these two stations, already existing installations were used. The first rests on the Lower Pleistocene marine sandy conglomerates; the second, housed in the Geophysical Institute of the Messina University rests on recent alluvial sands and poorly cemented gravels.

SCI (Scaletta) 38° 03' 08" N, 15° 27' 51" E, 185 m (a.s.l.) is sited on the most coastal tongue of the crystalline basement, consisting of limestone embedded in a large formation of biotite paragneiss.

VN1 (Mt. Veneretta) 37° 52' 10" N, 15° 15' 51" E, 610 m (a.s.l.) is situated at the extreme edge of the Peloritani Range, on Mesozoic limestone covering the crystalline terrains, at the limit of the latter's overthrust. The station rests on top of a sequence of marly limestone, dolomitic limestone, and marly dolomitic layering, with a thickness of 350 meters. The sequence is transgressively resting on the epi-mesozoic formations.

Two other stations are planned to be set up in Sicily, on the upper slopes of the Peloritani Range. The first one near Dinorcaria: DN1 will be sited on biotite paragneiss in which an extensive amphibolite body is embedded; the second one will
be installed at the extreme northern edge of the range, near Mt. Ciccia (CC1), in an area where geophones are interesting. The stations presently operating in Calabria are:

- **OR3 (Orti)** 38° 09' 14" N, 15° 41' 22" E, 490 m (a.s.l.) is sited on Tortonian massive conglomerates with interbedded micaceous sands and sandstone transgressively resting on the metamorphic terrains. They show the best mechanical characteristics among the post-orogenic sediments and they appear to be quite resistant to erosion. A local thickness of 10-15 m, and a dip of 23°-33° is inferred for the Tortonian sediments, directly resting on biotite paragneiss.

- **MT1 (Martino)** 38° 01' 05" N, 15° 42' 08" E, 560 m (a.s.l.) rests on poorly stratified micaceous sands with interbedded clayey silt. These Tortonian units are younger than the sediments described for the station OR3 (Orti). They show a reasonable resistance to erosion and reasonably good mechanical characteristics. At the site of the station, they rest on limestone and sandstone silty clays of Middle to Lower Miocene age. The total thickness of the Miocene sediments, covering the biotite schists of the crystalline basement, is ranging from 20 to 40 m.

The other stations are planned to be set up in Calabria on crystalline terrains. The first one will be installed near Palmi (PL1) in a zone which is mainly characterized by granitic and quartz-dioritic rocks. The second one, in the area of Gambarie, which is characterized by frequent outcrops of phyllite, biotite gneiss, and augengneiss.

**STATION EQUIPMENT**

The network presently consists of six peripheral stations connected by UHF radio to the central station sited in the Geophysical Institute of Messina University. The peculiar configuration of the Straits, together with the conditions imposed by a suitable choice of sites, sometimes created problems for the realization of telemetric communication.
In Fig. 2 and Table 1 some of the basic features of the sites and their equipment have been set out.
In order to evaluate the magnitudes of the less energetic shocks (M < 2.5) the duration-magnitude equation (Fig. 3):

\[ D = 0.65M^{3/752} \]

has been characterized for the station at Orti (OR3), using approximately fifty observations of events of known magnitude ranging between 1.8 and 4.3.

Seismic signals are recorded on a magnetic-tape (Geostore, Racal), and contemporarily monitored on paper ink-recorders, for an early analysis of the local shocks.

Lennartz equipments, in terms of actual shifting of the ground, vary from station to station — from a minimum of 15,000 to a maximum of 40,000 — according to the geological characteristics of the terrain, and distance from the sea and/or urban areas.

Retrieval of the recorded signals is achieved by means of a Store-14 recorder-player manufactured by Racal, whose output, after any necessary filtering, is fed into a Siemens Oscillomink ink-jet recorder.

### Table 1

| Station | Seismometer Type | Component | System |
|---------|------------------|-----------|--------|
| GZ1     | Geotech S13      | Z         | Lennartz, M.F., Multiplex |
|         | Geotech S13      | E-W       |        |
| MES     | MK III A         | Z         | Racal, M.F., single channel |
|         | MK III A         | E-W       | Racal, M.F., single channel |
| VN1     | MK III A         | Z         | Racal, M.F., single channel |
| PL1     | MK III A         | Z         | Racal, M.F., single channel |
| OR3     | MK III A         | Z         | Racal, M.F., single channel |
| MT1     | Geotech S13      | Z         | Lennartz, M.F., Multiplex |
The continuity of the power supply at the central station is guaranteed by a Corel emergency static group which is capable of supplying with electricity even the complex and varied instruments of the Geophysical Institute of Messina's observation station.
The time-signal, generated by a radio-corrected (HBG) M.H.
Type Patek watch, synchronize the recording clock inside the
Geostore and produces the time marks on the ink recorders.
The paper in these recorders runs at the speed of 60 mm/min,
and they have an operating autonomy of ~ 24 hours with a
spring between the lines of 4 mm.

For the low consumption peripheral stations (Racal) sources
have a life of approximately 1000 Ah batteries which
have a life of approximately one year, while the stations with
three components (Lennartz) are run off especially charged
batteries. In this case a suitable changing device
was designed and includes a replacement group.

In the particular orographical position that does not allow sta-
tions SCI and VN1 to transmit directly to the central station
(MES), and it is therefore necessary to send their signals first
to an intermediary station in Calabria (MT1) where an inter-
face allows transmission to the central station (MES) via the
same carrier which the local station (MT1) uses.

TRAVEL TIMES ANALYSIS

The analysis of the data refers to observations made by
the Straits network, integrated by records of other nearby
networks.
The seismic event which took place in the Spring of 1978
in the Gulf of Patti resulted in several hundred readings
including records from neighbouring Aeolian Islands and Etna
networks.

A further modest contribution to the overall picture was
brought by records of several events originating on the
Aeolian - The epicentral distances cover the interval 0.1°
through 2.0° although the highest density of data refers to the interval
0.2° through 1.0° approx.

Lacking orientative seismological elements, analysis was
primarily limited to the first return when identifying the various
phases present on the seismograms. Data can be considered
accurate both because of the interval of epicentral distances
and the recording speed of 60 mm/min.
considered, and because of the characteristics of the instruments in the short period stations. The records usually have very clear "impulse"-type, with only slight (+ 0.2 sec) wavetrains in the readings.

The epicentral travel-time couples (A, T) that can be deduced from the parameters determined by the National Geophysical Institute (I.N.G.) for events of magnitude M < 3.0, based on a 2-layered crustal model, which has better fit on MAA (H = 20 Km, w = 5.3 km/sec; h = 27 Km, w = 6.6 km/sec).

This model, although not compatible with the results of seismic research and deep seismic exploration in the zone under examination (Cassinis et al., 1969; Bottari and Girlanda, 1974; Kiese and Morelli, 1975; al.) does not appreciably alter the attributed epicenters due to favorable distribution of the stations around the focal area.

The data population has been divided into two groups, respectively for focal depths of 10 ± 5 Km (H') and 20 ± 5 Km (H"").

The A, T couples for the two groups allow the identification in both cases of two distinct alignments (Figs. 4, 5). The second branch of these may first can be interpreted as the travel-time of a reflected phase.

The model MAA, although compatible with the studied zone, constrains the origin time and therefore the travel-time of the first phase through the first refracting horizon. It has been accordingly possible to characterize the relations of the longitudinal waves along several refracting horizons. The first travel-time branch of the first group (H') is initially taken as reference for the propagation of P-wave in an environment with a velocity of 5.8 km/sec. The second branch refers to a reflected phase along the horizon with a velocity of 6.49 km/sec. In the second group a reflected phase with a velocity of 6.41 km/sec, is evident. The remarkable clustering of data regarding the first phase (Fig. 5) shows a nearly rectilinear trend-time curve valid for the interval 0.2 < A < 1.0.
Fig. 4 - Reduced travel-time diagram for the hypocentral depth: $/; = 10 \pm 5$ km.

Fig. 5 - Reduced travel-time diagram for the hypocentral depth: $/; = 20 \pm 5$. 
Using the two groups of observed data and the specified limitations, it appears possible to suggest a crustal model (MSM) having at least two seismologically characterized layers and a Moho velocity of 7.8 km/sec, but incomplete as far as the characterization of its superficial part is concerned.

This gap is filled up by introducing into the model two layers (\( h_1 = 2 \) km and \( h_2 = 4 \) km; \( v_1 = 3.0 \) km/sec and \( v_2 = 4.5 \) km/sec), compatible with the results of deep refraction seismic profiles carried out at the edges of the area (Cassinis et al., 1969; Scarascia and Colombi, 1971; Morelli et al., 1975).

The first target of this analysis is to evaluate the hypocentral depth for the group \( \beta \), allowing the model MAA to be replaced by a three-layered model defined thus:

\[
\begin{align*}
  h_1 &= 2 \text{ km}, \\
  h_2 &= 4 \text{ km}; \\
  v_1 &= 3.0 \text{ km/sec}, \\
  v_2 &= 4.5 \text{ km/sec}, \\
  v_3 &= 5.8 \text{ km/sec}.
\end{align*}
\]

The difference between the intercept times of the direct phase (\( T = 1.72 \text{ sec} \)) and the straight line:

\[
T = (1.26 + 0.30) + (19.032 \pm 0.536) A [1]
\]

that most closely agrees with the data observed in the epicentral interval \( 0.13 < A < 0.88 \) has been calculated. This difference (\( A_t = 0.46 \text{ sec} \)) is mostly approached by that obtained (\( A_t = 1.59 - 1.13 = 0.46 \text{ sec} \)), when in the model MSM the focus is placed at a depth of 6.2 km. The second intercept time (\( 1.13 \text{ sec} \)) refers to the interception of the refracted waves

\[
T = 1.13 + 19.171 A, \quad v = 5.8 \text{ km/sec}. [2]
\]

It is therefore assumed 6.2 km as focal depth for the first data group to the model MSM.

It is observed that seismic waves of the studied phase are located in the uppermost portion of the 5.8 km/sec layer, and that the observed travel times are matched by the straight
line of equation [1]. It is consequently assumed a velocity of 5.8 Km/sec for the longitudinal waves along the 6 Km depth wave-refractor.

In the preliminary hypothesis, assuming the existence of layers of uniform velocity, a depth $h_i$ can be evaluated from the difference between the second phase intercept times (group $h'$) according to the equation:

$$T = (2.6 \pm 0.2) \times (17.337 \pm 0.212) \times (6.41 \text{ Km/sec})$$

and the first phase of equation [1]. This difference, $A = 2.6$ sec, is confirmed in the model MSM as the difference between the intercept times of two refracted phases ($v_3 = 5.8$ and $v_4 = 6.49$ Km/sec) described by the equations:

$$T = (2.6 \pm 0.2) \times (17.134)$$

when $h_i = 84.38$ Km, is the thickness of the third layer.

As already shown, the first phase of the second group closely fits a straight line (Fig. 5) according to the equation:

$$T = (3.86 \pm 1.02) + (17.136 \pm 0.584) \times (6.41 \text{ Km/sec})$$

This is in contrast with the typical trend of the travel times of a direct phase originating in a layer either of uniform or normally increasing velocity, at a relevant depth ($h'' = 20 + 5$ Km).

This feature can be related to a mechanism involving the canalization of seismic energy which originate within a layer showing a velocity flexion. This hypothesis is supported by seismological soundings carried out in neighbouring areas to the
Straits of Messina (Cassinis et al., 1969; Scarascia and Colombo, 1973; Morelli et al., 1975) and in the other can be attributed to a medium having its lower limit at a depth of approximately 22 km (ii = 16.25 km, v = 6.49 km/sec) and an upper boundary consisting of that horizon along which the refracted phase, by equation (5), is propagated at a velocity of 6.41 km/sec.

The focal depth of the second group (h') can be evaluated from the model MSM, considering the difference A\[\tau\] = 1.89 sec for the two longitudinal waves which respectively originate at depths of h' = 20 km and h' = 10 km, given A° = 0. This difference is verified in a layer showing a velocity of 5.8 km/sec for a difference in the focal level of 10.94 km. The focal depth for the second group can therefore be located in the model MSM at a depth of 17.14 km (h' + 10.94 km).

The difference between the two intercept times respectively obtained from the straight line of equation (5), where T = 2.51 sec, and from the straight line which most closely fits the second branch of group (ii):

\[ T' = 5.7 + 0.29 A, \quad v = 7.82 \text{ km/sec} \]  

is A\[\tau\] = 3.46 sec. This difference is verified in the model MSM for a focal depth of 17.14 km when \( H_{A} = 13.5 \) km. In this case, the two phases selected by harmonic filtering selection of both, Kecce and \( T_{2} \) Kecce, are respectively fitted by the equations:

\[ T = 273 + 15.64 A, \quad v = 6.41 \text{ km/sec} \]  
\[ T = 463 + 14.22 A, \quad v = 7.41 \text{ km/sec} \]

The analyzed data are in the whole compatible with a four-layered crustal model, as schematically drawn in Fig. 6.
The values attributed to the velocity and thickness of the intermediate crustal layers, as well as to the crustal thickness itself (35-36 km), are mostly integrated within the general framework resulting from deep seismic soundings. In particular, the two crustal sections corresponding to the area around Capo Calava in Sicily, and to the edge of the Aeolian Archipelago (points B and A in Fig. 7) in the Southern Tyrrhenian Sea, seem to suggest a total crustal thickness of 30-35 km for the source area of most of the seismic events considered. The same range of values for the depth of Mohorovicic's discontinuity is reported by Morelli et al. (1975) for the area of the Straits.

It is furthermore to be stressed that a nearly horizontal...
pattern of the Mohorovicic discontinuity can be assumed according to the trend of the Bouguer's iso-anomalous pattern as shown in the area of propagation of seismic rays emerging at the stations of the Striae Network (Fig. 7). Explosions in the Tyrrhenian and Ionian Seas, planned to be carried out on July 1979, are believed to be able to supply an useful quantitative check to the crustal model.
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