A study of the temporal sequence of aftershocks of the 1908 Messina earthquake

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Abstract

The sequence of aftershocks in the great 1908 Messina earthquake has beean analysed by following the Benioff method and applying Bath and Duda's subsequent developments of it as well. The set of aftershocks, 915 on the whole, has a minimum intensity threshold of III MSC and includes the activity in the same area of the great event ($M \simeq 7.2$) beginning on the 28th December 1908 until June 1923. Three phases are identified: the first two are connected with a extensive-type of creep recovery, the last one is of shear-type. Subsequently the sequence-properties are interpreted using the Omori coefficient β and the coefficient b of the Gutenberg and Richter relation. Particularly, a quite distinct phase of activity originating five months after the occurrence of the main shock has been found.

The analysis proposed here is also compatible both with the focal mechanism of events originating in the Strait of Messina and with the regional tectonic framework.

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RIASSUNTO

La sequenza delle repliche del grande terremoto di Messina del 1908 è analizzata secondo la metodologia originaria di Benioff ed i successivi sviluppi di Båth e Duda. Il set di repliche, per complessive 915 scosse, ha intensità minima uguale al 3° MCS e comprende l'attività sismica sviluppatasi nella stessa area del grande evento ($M \simeq 7.2$), dal 28 Dicembre 1908 al Giugno 1923. Sono state individuate tre fasi: le prime due sono connesse a recupero di creep di tipo distensivo, la terza al tipo distorsionale. Successivamente le proprietà della sequenza sono interpretate tramite lo studio del coefficiente β di Omori e del coefficiente b della relazione di Gutenberg e Richter. In particolare rilievo è una fase ben distinta che origina cinque mesi dopo il verificarsi della scossa principale.

L'analisi qui proposta è anche compatibile con i meccanismi focali di terremoti originanti nello Stretto di Messina e con il quadro tettonico regionale.

INTRODUCTION

The great Messina earthquake of 28th December 1908, better known in seismological literature as the *Messina earthquake*, has been and is still now studied. Some of the aspects of greater interest are: the catastrophic effects in the mesoseismic area (~ 400 Km^2, with the destruction of the most part of buildings and more than 80,000 people killed, *Baratta*, 1910); the highest value of magnitude ($M \simeq 7.2$) ever recorded for italian earthquakes and the characteristics of the geodynamic processes affecting the Calabro-Peloritan region.

The aim of this paper is to enlarge the knowledge of a scantily investigated sector: particularly, the stress pattern and the degree of fracturing of the focal zone are investigated. More generally, from the analysis of the sequence it appears the possibility of new interpretative elements of the geo-structural frame of the seismic event, referring also to the results obtained by other Authors for the mechanism of the shock. For this purpose, the Benioff *elastic rebound* models are considered and the characteristics of the various detectable phases in the aftershock sequence are analysed.

GEOLOGICAL OUTLINE

The late Miocene and Quaternary tectonic activity in Messina Strait area is characterized by associations of distension-type faults (Selli, 1974, 1978; Atzori et al., 1978; Selli et al., 1978; Ghisetti, 1979; Ghisetti and Vezzani, 1979); running along five main trends (Selli, 1974, 1978; Selli et al., 1978).

Selli distinguishes two phases in the tectonic evolution of the Strait: the first at the end of Pliocene (1.8-2.0 m.y.) with NNE-SSW and WNW-ESE faulting; the second, from post-siciliano (0.8 m.y.) to the present having produced faults and lineaments E-W and NW-SE.

Among the most ancient faults (Fig. 1), those of Portella Arena (in Sicily) and Gallico (in Calabria) being produced at the end of Pliocene by a distension WNW-ESE and with disjunction but between themselves convergent planes (45° and 60°) caused

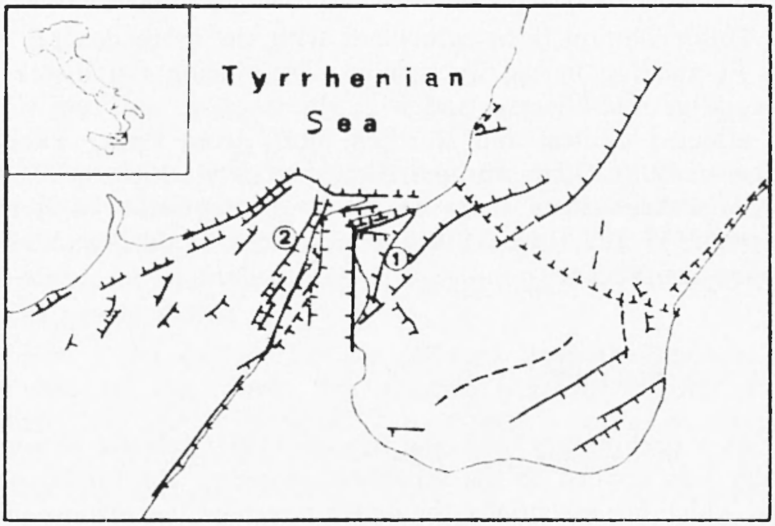

Fig. 1 - A map of the Strait of Messina showing the main faults reported in the literature. In particular, 1 marks the fault of Gallico and 2 marks the fault of Portella Arena.

a primitive graben which is part of the dislocation system known in the literature as the Comiso-S. Eufemia line (Riuscetti and Schick, 1975).

At the beginning of the post-siciliano the faults of the second tectonic phase, which cause the subsidence of the primitive rift valley, gave the Straits its present-day features: access to the north in ENE-WSW direction and access to the south cut by faults running N-S. With this phase Calabria and Sicily were completely separated, as is shown by the differentiated upthrow of the two walls of the graben and by the reciprocal rotation (tilting) of the two shores of the Straits. This is characterized in Calabria by a greater uplift of the Ionian part compared with the Tyrrhenian part and vice versa in Sicily (Selli, 1978).

The faults recognized as active are: the faults running E-W and, in particular, those marking the boundary of the Peloro horst and the valley of Scilla; the N-S faults and, in particular, the one marking the edge of the Calabrian shore from P. Pezzo to Reggio Calabria; and the fault NNE-SSW marking the edge of the Sicilian shore from Fiumara Grotte to Capo Scaletta.

This evolution is in agreement with the more general process of shifting in the Tyrrhenian area during the distension phase after mid-Pliocene and with the isostatic uplifting which has affected Central and Northen Sicily from Upper Pliocene (Ghisetti, 1979). Other Authors (Bousquet et al., 1980) have identified on the eastern shore of the Straits episodes of normal faulting E-W and ENE-WSW due to distension during mid-Quaternary and Recent.

Data and analysis

As a preliminary step, the Benioff (1951) "elastic rebound" theory was applied to the aftershock pattern. The fundamental data, which are essentially the origin time and the seismic intensity of the earthquakes, are those given in the E.N.E.L. Catalogue of Italian Earthquakes (E.N.E.L., 1978).

A first selection of the events was made on the basis of the epicentral coordinates there reported, and all the shocks originating from 28th December 1908 to 3rd June 1923 were considered.

The main shock had an intensity of 11 MCS and it has been noted that in the set of aftershocks there were none of more than 8½ MCS. As will be later pointed out we consider the fact as due to the "uniformity" of the structures giving rise to seismic activity.

The epicentral intensity values I_0 have been utilized for calculating the energy released and, more precisely the quantity $\Sigma E^{1/2}$; the Benioff graph (Fig. 2) has bee draw by means of Marcelli and Montecchi (1962) relations

$$\begin{aligned} &\text{a)}\quad M = 0.481\, I_0 + 1.407 && (M \leqslant 5) \\ &\text{b)}\quad M = 0.024\, I_0^2 + 0.205\, I_0 + 2.15 && (M > 5) \end{aligned} \qquad [1]$$

and of Gutenberg and Richter (1956)

$$\log E = 11.8 + 1.5\, M \quad .$$

Three phases can be identified in the diagram: the first two associated with compressional or extensional mechanism, the third one with a shearing mechanism (Benioff, 1951). The second-third phase transition is evident by applying the Båth and Duda (1964) model also.

The stress pattern can be deduced from the temporal distribution of the shocks. The analysis has been carried out by utilizing the events for which $I \geq 4°$ MCS in order to limit the number of information errors which are much more probable in the low intensity events.

The various attempts at fitting, applying the maximum likelihood method for different unity of time values allowed us to identify in the aftershock sequence in question two sequences of the type $n(t) = At^{-p}$ connected with the decreasing stress

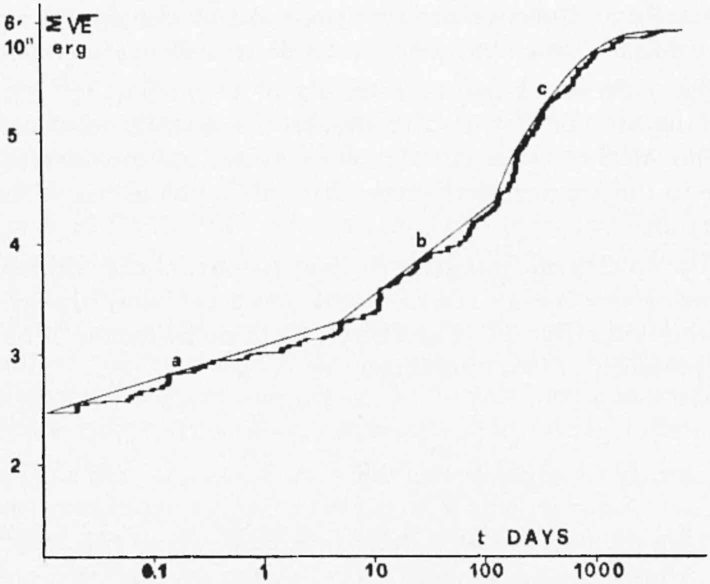

Fig. 2 - Benioff's diagram for the sequence of aftershocks of the great Messina earthquake (December 28th, 1908). Three distinct phases can be identified that are well approximated by the equations:

a) $\Sigma E^{1/2} = (3.085 + 0.310 \log t)\ 10^{11}\ \mathrm{erg}^{1/2}$,
valid for the first five days,

b) $\Sigma E^{1/2} = (2.771 + 0.768 \log t)\ 10^{11}\ \mathrm{erg},^{1/2}$
from day 5 to day 125, and

c) $\Sigma E^{1/2} = [4.39 + 1.54\ (1 - e^{-1.82\ 10^{-2}(t-128.83)^{0.697}})]$
$10^{11}\ \mathrm{erg}^{1/2}$ from day 125 on.

(Omori, 1894; Mogi, 1966): the first of these includes the first ten weeks (Fig. 2a) and the second goes from the 7th to the 14th month approximately (Fig. 2b), with values of β of 0.80 and 1.33, respectively. These β values are comparable with those obtained by other Authors for seismic crises of tectonic origin (Page, 1968; Ranalli, 1968; Harsh and Rastogi, 1976; Del Pezzo and Martini, 1979). The better fit $n(t) = At^{-\beta}$ in the period 7th - 14th months is probably to relate with the arising of a secondary sequence (Fig. 3b, 6th - 7th month). That led to the thought that, in this period a new "strain release" mechanism began which at first produced a renewal of activity and then a decrease in stress (Fig. 3b). This mechanism could be the same detected in the strain release curve of figure 2, where a third phase is clearly distinguished from the previous pattern. The lesser value of β in the secondary sequence may be connected with the higher degree of fracturing of the materials (Mogi, 1965).

Subsequently the Gutenberg and Richter relation (1956):

$$\log N = a - b\,M \qquad [2]$$

was applied to the various phases of the sequence. A significant increase of the parameter b can be noted during the course of the phenomenon (Table 1).

These variations may indicate both a decrease in the stress pattern and that the aftershock foci are migrating towards the surface; these factors can be attributed to an increase in the degree of fracturing (Page, 1968; Gibowicz, 1974; Harsh and Rastogi, 1976). That is in agreement with the lesser value of β determined by Omori method for the sequence beginning in July 1909.

TABLE 1

Maximum likelihood estimates of b and approximate 95-per cent confidence limits (Utsu, 1965) for the phases identified in the Benioff's diagram. Note - In brackets the number of shocks.

Phase		b
1st	(78)	0.51 ± 0.11
1st + 2nd	(341)	0.83 ± 0.09
2nd	(263)	1.07 ± 0.13
3rd	(354)	1.76 ± 0.14
1st + 2nd + 3rd	(916)	1.24 ± 0.08

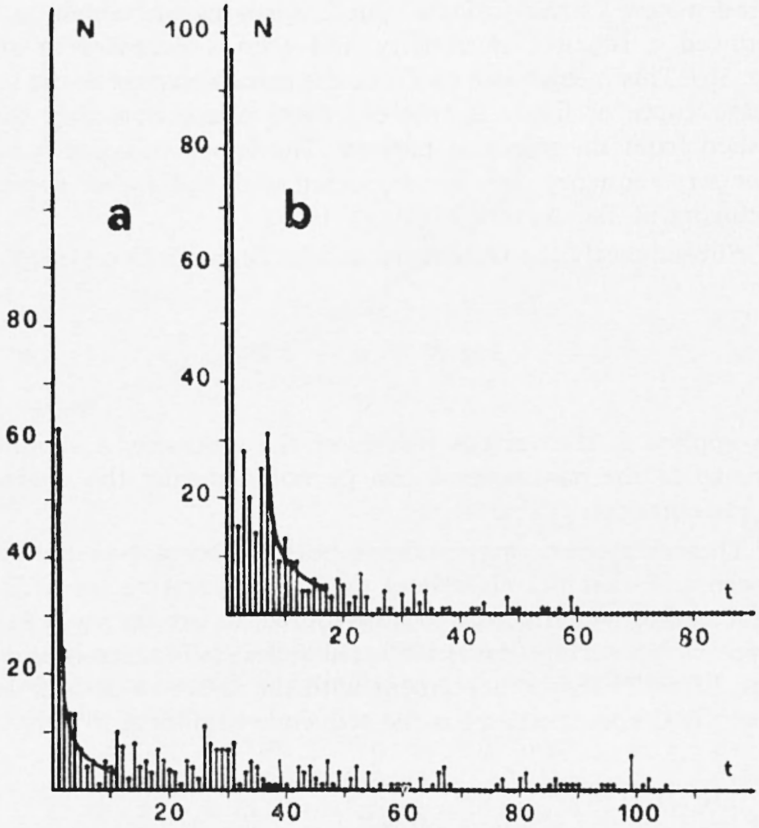

Fig. 3 - In the diagrams "a" and "b" the number of shocks/week and the number of shocks/month are reported, respectively, beginning from the main shock. In both cases, the Omori fit is also shown carried out using the maximum likelihood method.

RESULTS AND DISCUSSION

The presence of one foreshock only and the complete absence of 9° and 10° MCS shocks could shown an interesting level of uniformity in the structures in which the phenomenon was originated.

As has already been emphasized, the study of the strain release shows the existence of three distinct phases. The first two are characterized by an $S = A + B \log t$ type-pattern and exclude the possibility of the phenomenon having originated from shear mechanism; the third phase can be approximate by a relation of the types $S = C + D\,[1 - \exp\,(t - t_0)^{r}]$ and may be connected with gradual decrease of stress.

For the first 10 weeks the temporal distribution of the shocks is of the type $n(t) = At^{-\beta}$, where $\beta = 1.33$. That indicates a gradual reduction of stress.

Subsequently nearly the 6-7th month, when the third phase was beginning, an increase in activity is observed. In association with a strong intensity shock ($I_0 = 8$) one may suppose the beginning of a new sequence. The last is formally analogous to the previous one but characterized by a lower values of β (0.80). These factors make it possible to hypothesize that in June 1909 there was the beginning of a new mechanism, presumably of a shear type. Furthermore, the lesser value of β, together with the considerable increase of the b parameter, characteristic of the Gutenberg and Richter relation, indicates the higher degree of fracturing in the structures giving origin to the seismic events; it also indicates a relative reduction in the stress pattern.

The results presented in this work fit into the framework proposed by other Authors in support of the hypothesis that the phenomenon was generated by extension-type mechanism prevailing in the Messina Straits area. In particular, the results of the strain release analyses (Fig. 2, diagrams a, b. c) support the starting of fracturing initially in the southern part of the Straits from where is spread northwards (Schick, 1977, 1979) and, more in general, support also the "scissor-like" movement of the Calabrian coast compared to the Sicilian, as has been geologically evidenced (Selli, 1978).

The characteristics of the various phases on the energy release diagram are compatible with the hypotesis so far made on the existence of distension-type mechanism in the Messina Strait area (Atzori et al., 1978; Ghisetti and Vezzani, 1979). Moreover, the results of the focal mechanism study of the recent Reggio

Calabria earthquake of 1975 ($M = 4.7$) can be fitted into this framework. The focal mechanism of this last event is to reduce to a model of a double couple with a dislocation plane N 22° E E and dip 75° W (Bottari et al., 1975).

In conclusion, from these considerations on the strain release mechanism and on the tectonic settlement of the Strait area, the focal mechanism of the 1908 Messina earthquake and the course of the aftershock sequence are particularly significant on account of its more immediate seismogenetic implications.

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