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GEOSTRUCTURAL FEATURES OF THE MIDDLE TIRSO VALLEY FROM SEISMIC REFLECTION DATA

Abstract. The main geostructural features of the central north sector of the middle Tirso valley (Central Sardinia) and the seismic characteristics of the volcanic sedimentary deposits of the area within the upper first 2 km have been determined from reflection seismic data along a 4 km profile. The data were acquired with a Geometrics ES-2420 seismograph and processed on an IBM 3090 computer with an FP array processor using the Halliburton Geophysical Services seismic package. Five seismic units have been distinguished on the basis of configuration, continuity, amplitude and frequency of the reflections. An integrated analysis of the seismic and geological data contributes to our knowledge of the main deep geostructural features of the study sector and to a correlation of the seismic units with the stratigraphic units outcropping in this sector. The dislocation of the Paleozoic basement was found to be greater than expected from the surface observations. From correlation of the seismic units with the stratigraphic units outcropping in this zone, we deduce that the lower ignimbritic series are thicker in depth than at the surface, both within the study area and in other sectors of Sardinia.

INTRODUCTION

The NE-SW striking late Oligocene Middle Tirso valley graben lies between the two Paleozoic horsts of the Marghine-Goceano and Barbagia-Mandrolisai complexes (Fig. 1).

The events determining the origin of this graben are associated with the distensive tectonics which occurred between the Oligocene and the Aquitanian and caused the opening of the Sardinian rift, which, as is well known, represents one of the easternmost branches of the Western Mediterranean rifting system (Cherchi and Montadert, 1982).

The dynamics of the events determining the present order of the middle Tirso valley and its chronological-structural relationship with the Sardinian rift are still not completely clarified. For this reason, a series of seismic reflection profiles has been planned. Moreover, this region is extremely important for understanding the relationship between the Sardinian Rift and the transversal grabens, which, like the Tirso valley, cut the continuity of its edges.

The present study shows the results from a profile in the central-north sector of the middle Tirso valley, where the deepest subsidence of the Paleozoic basement and overlying formations is believed to have occurred.

An extensive geological study by one of the Authors (Porcu, 1983) was used for the interpretation of the seismic data.

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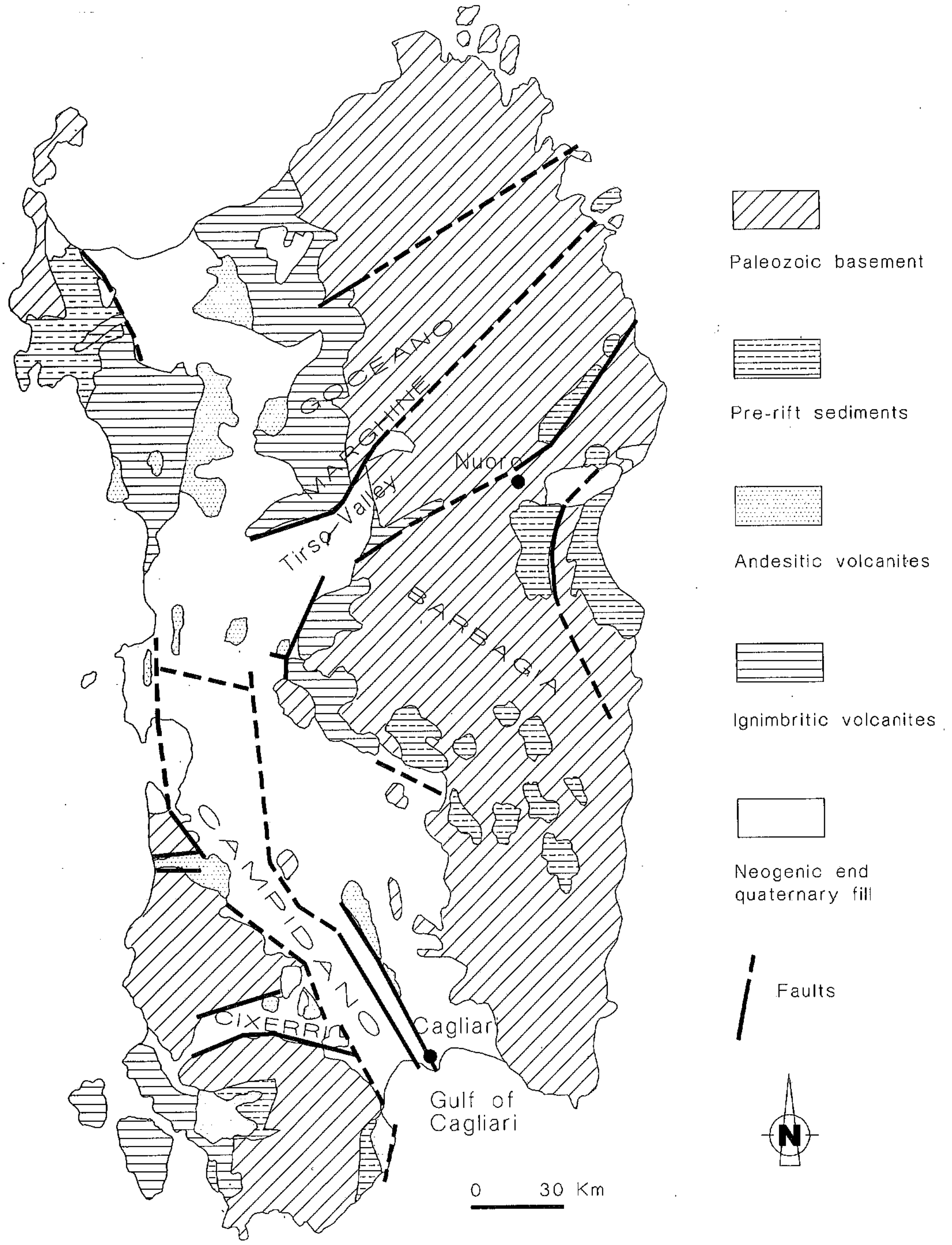


Fig. 1 - Regional geological map.

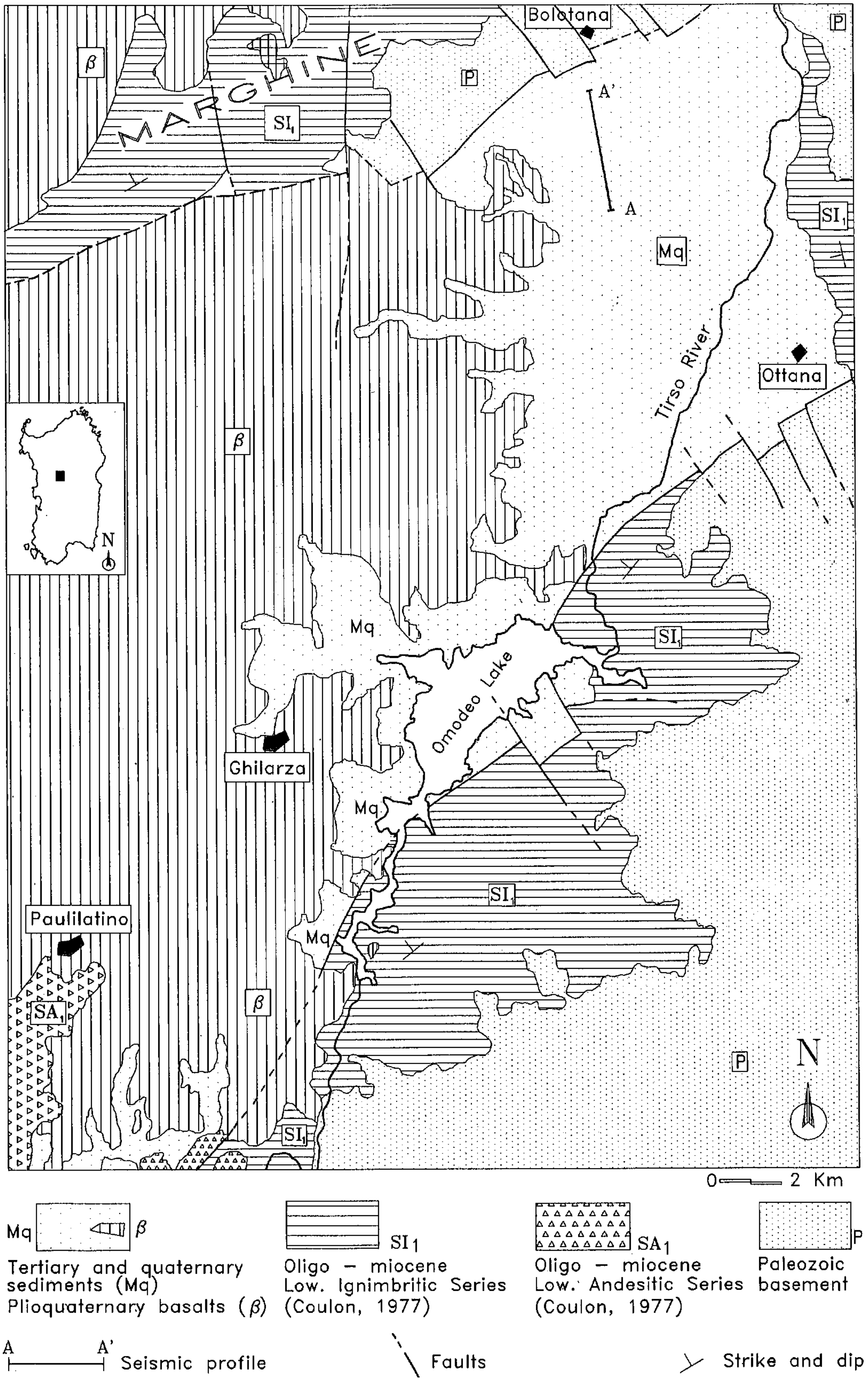


Fig. 2 - Geological map of the study area and location of the seismic reflection profile.

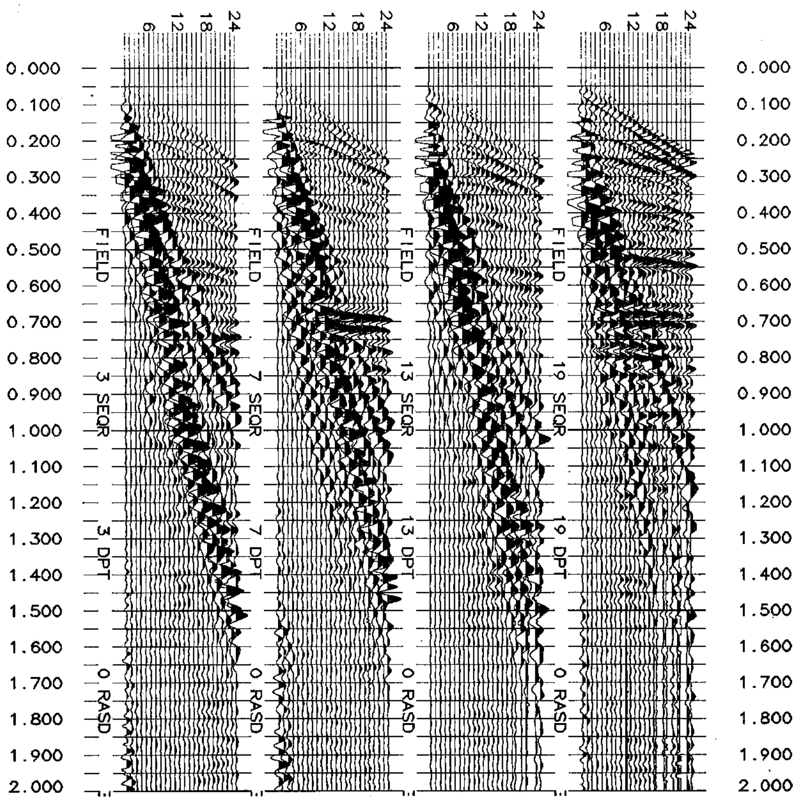


Fig. 3 - Field records.

GEOLOGICAL SETTING

The graben of the middle Tirso valley strikes NE-SW and is marked by two main tectonic structures: the Marghine and Nuoro faults to the N and S, respectively (Fig. 1). The former marks the southern border of the Marghine-Goceano complex, a low-grade metamorphic complex made up essentially of Ordovician acid metavolcanics (”porfiroidi” Auct.) and phyllites, at times carbon- and graphite-bearing, with frequent intercalations of marbles and schistose crystalline limestones of uncertain age (Ordovician? - Devonian?) and with tonalitic-granodioritic intrusions of the Hercynian late-tectonic phase. The Nuoro fault forms the north-western boundary of the Barbagia-Mandrolisai complex, which consists prevalently of monzogranitic and tonalitic intrusions, locally covered by phyllite edges and metasandstones, which are evidence of the Hercynian chain nappes.

The graben is on average 15 km wide, and is bounded by the monzogranitic intrusion of the Serra di Orotelli to the NE, while to the SW the Plio-Quaternary fill covers its graft into the Miocene-Oligocene Sardinian rift.

The Miocene-Oligocene volcanites of the calc-alkaline cycle lie directly on the Paleozoic basement (Fig. 2); there is in fact no trace of the Mesozoic cover in this sector nor has any evidence been found in the clasts contained in the Tertiary deposits.

In this sector of the middle Tirso valley, the Oligo-Miocene volcanics are represented by acid elements made up of ”rhyolitic-rhyodacitic” ignimbrites, while further north in Planargia, and further south in the Paulilatino-Fordongianus sector, they are also represented by basic and intermediate ”andesitic” types. The ignimbrites are continuously visible in cuestas (due to the alternation of tuffaceous and stony levels) all along the northern border, with a visible

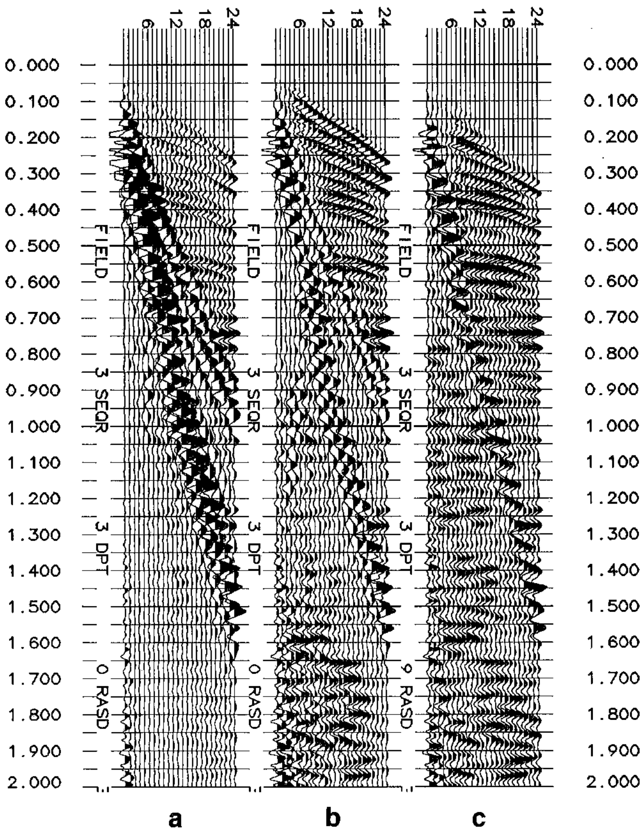


Fig. 4 - Record 3: a) original data, b) with expanded window balance, c) with beam-steering

thickness of about 550 m, and lying directly both on the granites and on the metamorphites. On the north-eastern border of the graben, they lie directly on the monzogranites of the Serra di Orotelli.

A sedimentary continental formation outcropping in the northern sector of Lake Omodeo lies on these ignimbrites. This is made of sandstone conglomerates which change progressively from coarse to fine towards the inner part of the basin. The structural characteristics are typical of a fluvial-delta environment. The maximum visible thickness is about 60 m, but considering that this sediment is easily erodible, it must have been much greater originally.

Pyroclastic sediments follow, largely of lacustrine facies and with a visible thickness of 70-80 m, which could also be greater in the middle of the basin.

Following the pyroclastic levels is an alternation of conglomerates, sandstones and limestones in a fluvial-lacustrine to fluvial delta and therefore littoral facies completely filling the graben. This complex can be dated to the Upper Aquitanian (Porcu, 1983). In the sector under investigation, there is no trace of the Miocenic marine sedimentation that filled the "Sardinian rift", either because it has been eroded or because it was never deposited.

The Plio-Quaternary cover is made up of basaltic lava flows resulting from a distensive tectonic phase, and terraced piedmont deposits accumulated behind the Paleozoic reliefs.

As mentioned above, the origin of the graben of the middle Tirso valley is related to the distensive tectonics which developed between the Oligocene and the Aquitanian, and to which the opening of the Sardinian rift is also due. From field observations and especially from the disposition of the volcanites and the sedimentary formations covering them, an asymmetry of the graben with greater dip towards the north can be inferred: Oligo-Miocene volcanites of the far north-eastern sector can be seen at least 700 m lower than those of the Marghine chain.

Table - Acquisition parameters for the middle Tirso valley seismic reflection profile.

1	Recording instrument	Geometrics ES2420
2	No. of channels	24
3	Sample interval	1 ms
4	Record length	2 s
5	Field low cut	10 Hz
6	Notch filter	50 Hz
7	Spread type	End-on
8	Min. offset	40 m
9	Geophone spacing	20 m
10	Geophone type	10 Hz single
11	Source spacing	40 m
12	Charge type	Explosive of high detonating velocity
13	Charge size	4 kg
14	Charge depth	4 m

The latter emerge to the NW under the basalts and Miocene sediments of Campeda (Fig.2). This dislocation is evident in the landscape and is interrupted by a series of lines, normal to the principal trend, that have divided the Paleozoic basement into a series of blocks horizontally transported in a normal direction to the fault. In the southern and eastern sectors, though evident, the tectonics were probably milder, and the lowering towards the axis of the graben seems progressive, although there are dislocations of the order of a hundred metres. The more sudden and pronounced lowering of the northern sector could have been due to the fact that the Alpine tectonics, which caused the sinking of the graben, here reactivated preexisting Hercynian lineaments.

DATA ACQUISITION

The four kilometre CDP seismic profile was designed taking into account the target of the research, the geological setting of the area, and the capabilities of the equipment.

Field tests were done to help selecting the main field parameters, especially the geophone natural frequency, geophone spacing, source-receiver offset and spread type.

The main characteristics of the survey are given in the Table.

Tests were carried out to ascertain the ideal quantity of charge, which was strongly conditioned by the near-surface geology. The tests indicated that a charge of 4 kg was necessary to obtain deep penetration and thus good data quality from the deepest targets.

In order to check the data quality and frequency content of the test records, field processing with the PAP (post acquisition processor) installed in the ES-2420 seismograph was carried out.

Some of the field records obtained using the parameters in the Table are shown in Fig. 3. A number of reflectors at different depths are clearly visible, though a cone of strong noise is also present. This noise could have been further reduced during the acquisition phase by increasing the depth of the charge. However, in this we were conditioned by economic factors.

PROCESSING

The seismic reflection data were processed at the Data Processing Centre of the Osservatorio Geofisico Sperimentale (Trieste) using an IBM 3090 computer with FP array processor. The processing sequence was as follows:

Demultiplex
Resample to 2 ms
Beam steering
FK filtering
Sort into CMP order
Gain recovery and predictive deconvolution
NMO application and mute
Residual statics
600 % stack
FX deconvolution
2D powering
Equalization

Data quality was found to be quite good, apart from the cone of strong noise frains with velocities between 300 and 750 m/s. The slower wave trains can be related to the airblast, and the others to surface waves (Raleigh) with propagation velocity dispersion.

The high energy content of the ground roll was the first problem to be solved in the processing of these data. Several different tests were carried out to attenuate this noise, including equalization algorithms, such as balancing with fixed temporal windows, balancing with windows which vary by trace distance, and automatic gain control. In order to be effective, all these operations require the use of very narrow windows, which leads to a flattening of the seismic response and loss of control over amplitude variations in the seismic signal. Therefore, an attempt was made at attenuating the noise by using beam steering, that is by simulating a geophone acquisition spread which sums the undesired signals in phase opposition (push-pull). The result of this simulation is good since the signal/noise ratio on the processed records is significantly increased (Fig. 4). Furthermore, this particular operation which mixes adjacent traces highlights the continuous events, thus showing up the main structural elements of the area, which is the primary purpose of this survey.

The post-stack application of a space-frequency domain deconvolution was found to be effective in attenuating random noise.

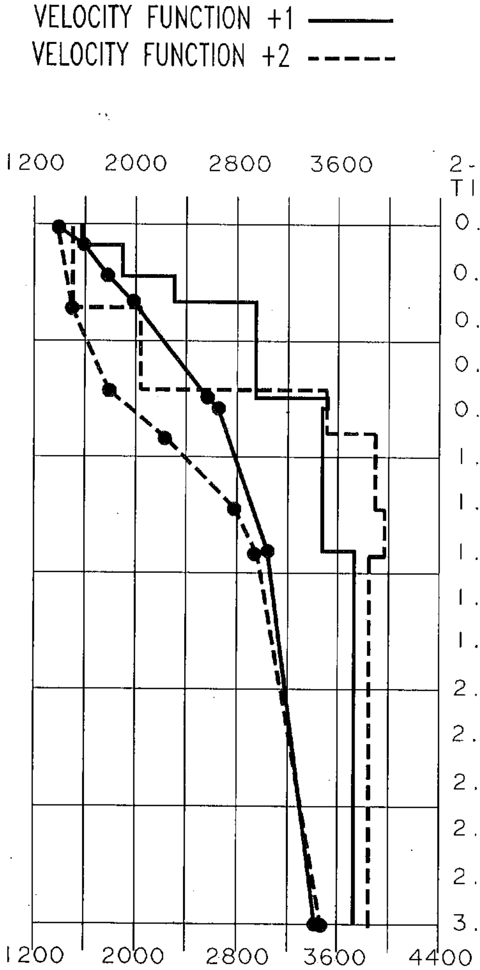
Fig. 5 illustrates the stack velocity functions applied to the data. The spread geometry, together with the muting of far traces, means that the moveout on the useable traces is too small for good velocity discrimination. However, although the interval velocities obtained are not exact, they are still indicative of lithological variations. As can be observed in Fig. 5, in the shallowest part of the section (within the first 0.6-0.7 s), there is a reduction in the velocity value on going from south to north.

Figs. 6 and 7 show the final STACK-TVF version and the display of the corresponding instantaneous phase. This kind of display highlights the geometric configuration, lateral limits and continuity of the seismic horizons independently of their amplitude, and is thus useful for resolving geometric relationships between the different seismic facies.

SEISMIC INTERPRETATION

The final stack is characterized by the presence of various reflectors affected by distensive faults (Fig. 8). Within the first 0.6 s, the reflectors show a subparallel and subhorizontal trend. Below 0.6 s, the reflectors have a slight inclination towards the central part of the section, thus indicating a discordance with the overlying reflectors.

The seismic reflectors beginning respectively at 0.1, 0.5 and 0.7 s at the southern end of the section are at major changes in the acoustic impedance contrasts. The instantaneous



2-WAY TIME	OTTANA V.F.1 AVG VEL-1	OTTANA V.F.1 INTER VEL-1	GRABEN V.F.2 AVG VEL-2	GRABEN V.F.2 INTER VEL-2
0.00	1400	1600	1400	1500
0.20	1785	1912	1459	1500
0.40	2117	2985	1550	2043
0.60	2410	2985	1717	2043
0.80	2700	3580	2050	3530
1.00	2833	3564	2467	3935
1.20	2967	3564	2800	3935
1.40	3100	3564	3000	3994
1.60	3150	3815	3062	3885
1.80	3200	3815	3125	3885
2.00	3250	3815	3187	3885
2.20	3300	3815	3250	3885
2.40	3350	3815	3312	3885
2.60	3400	3815	3375	3885
2.80	3450	3815	3437	3885
3.00	3500	3815	3500	3885

Fig. 5 - Velocity functions used for the final stack of the middle Tirso valley seismic profile.

phase display was extremely helpful during the line-drawing process.

The deepest reflector beginning at 1.2 s at the southern end of the section marks the top of a zone characterized by a complex pattern of reflections. The pattern differs completely from those above this depth.

Between 0.2 and 0.4 s, coherent and relatively high amplitude reflections are present. Nevertheless, it was not possible to trace any reflector continuously, because it was difficult to relate the reflections of the southern sector of the section with those of the northern. This was due to the presence of an important fault zone with consequent strong velocity change (see Fig. 5).

The reflector beginning at 0.5 s at the southern end of the section and reaching about 0.6 s at the centre marks the base of a stratified sequence of subhorizontal, parallel, and sometimes discontinuous reflections of variable frequency and amplitude. The variability could be a consequence of lateral and vertical lithological changes. This sequence of reflections is discordant with the deeper ones. The interval velocity is about 2800 m/s.

The high amplitude reflector that begins at 0.7 s at the southern end of the section and dips to 0.95 s at the centre marks the base of discontinuous, parallel to divergent, oblique reflections of variable frequency and amplitude. The interval velocity is about 3200 m/s.

The reflector that begins at about 1.0 s at the southern end of the section and ends at about 1.2 s at the northern end is not easily traceable but provides the base to a sequence

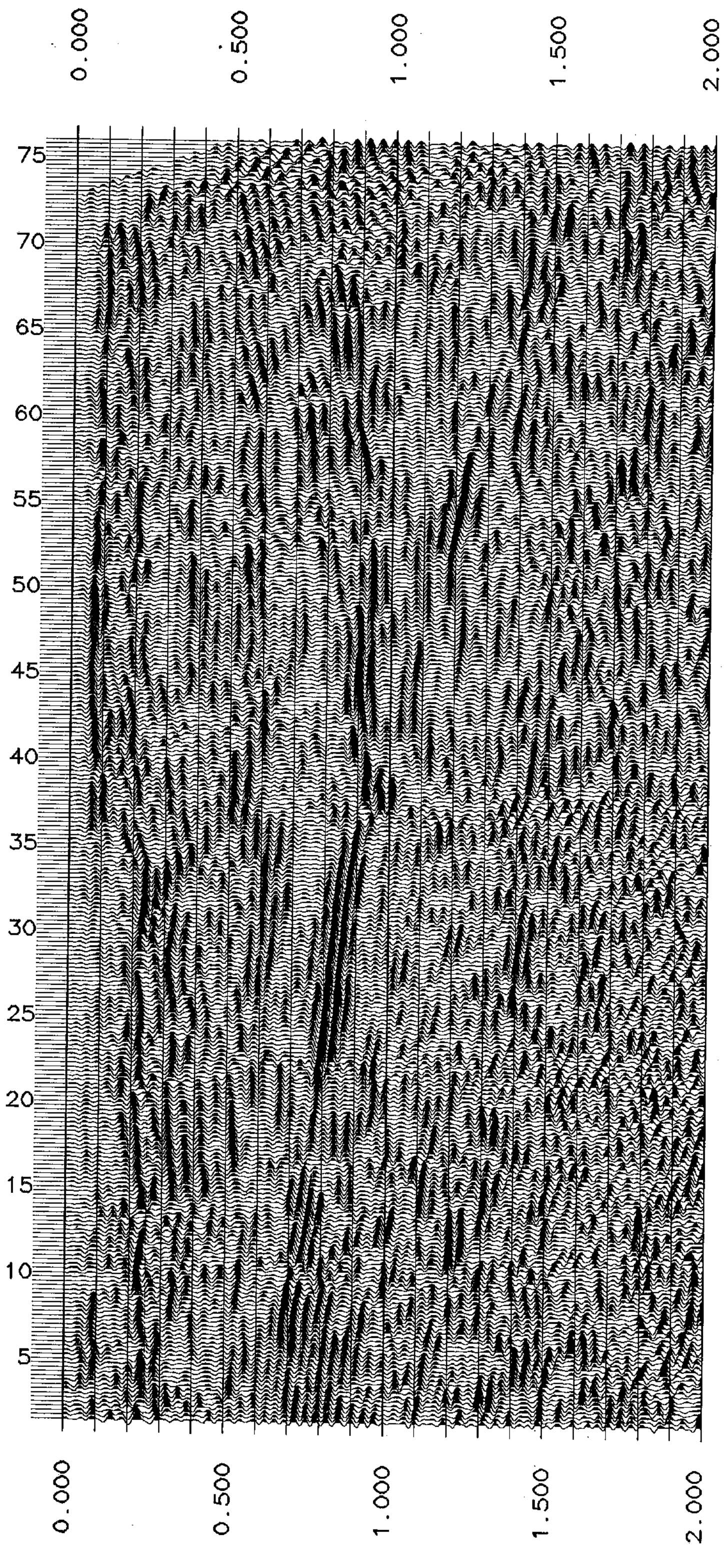


Fig. 6 - Seismic section from the northern sector of the middle Tirso valley (location AA' in Fig. 2).

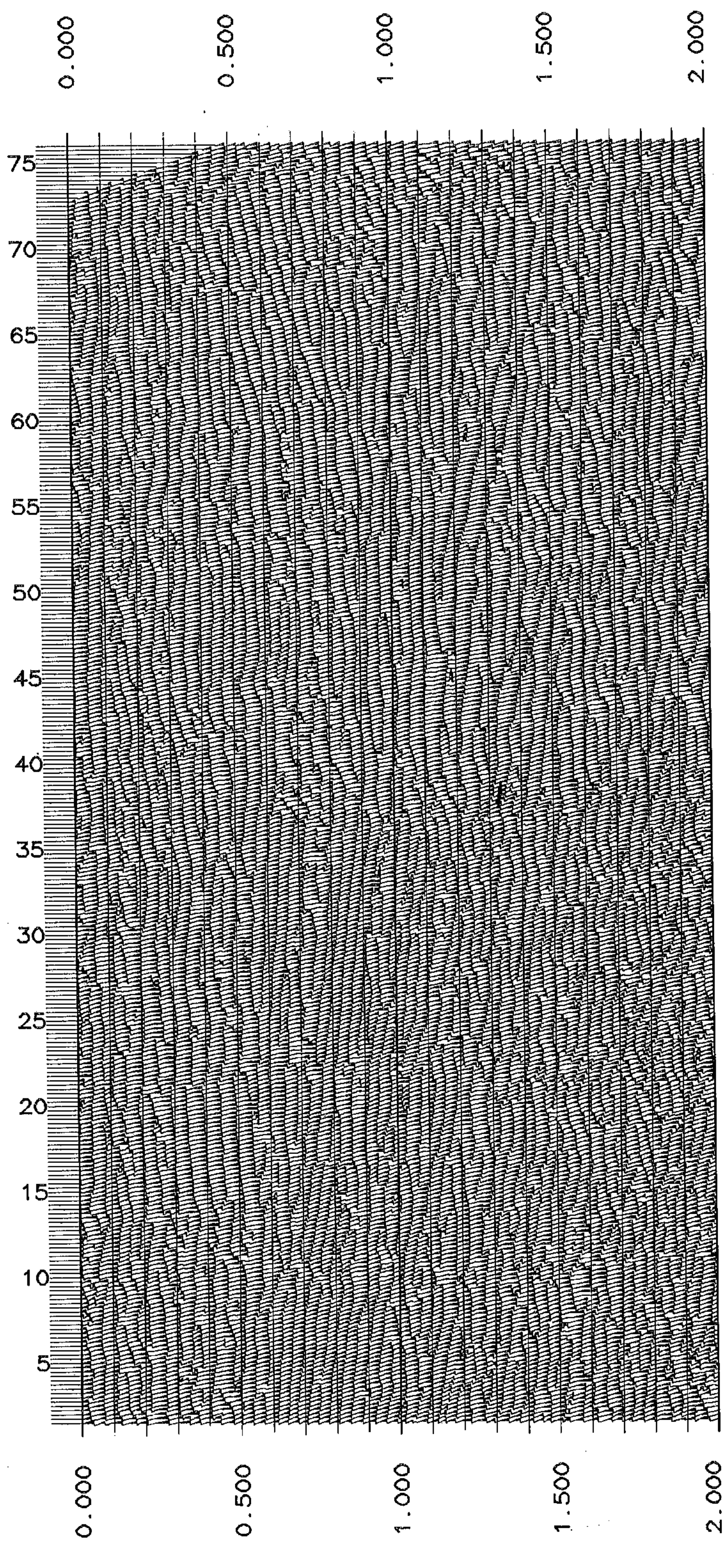


Fig. 7 - Instantaneous phase display corresponding to the section in Fig. 6.

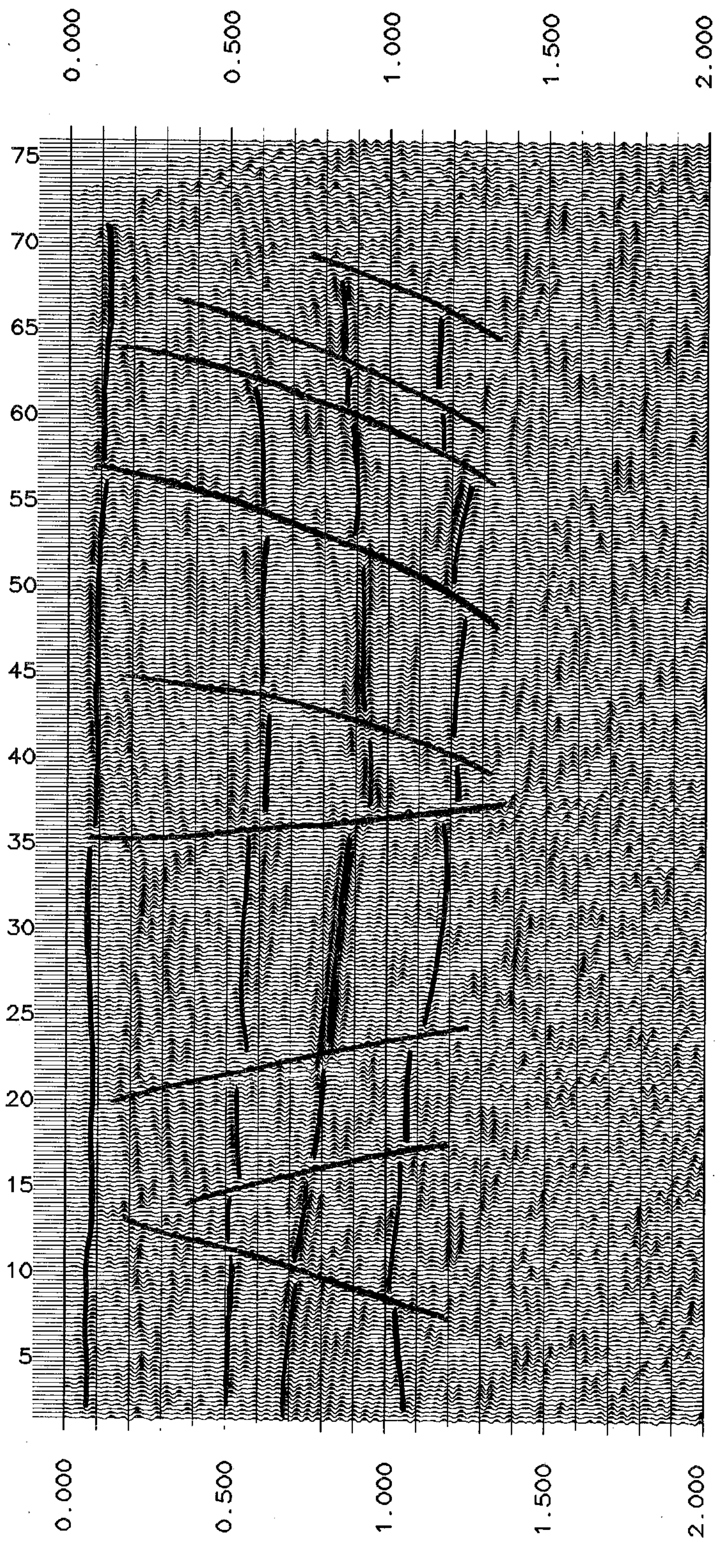


Fig. 8 - Interpreted seismic section.

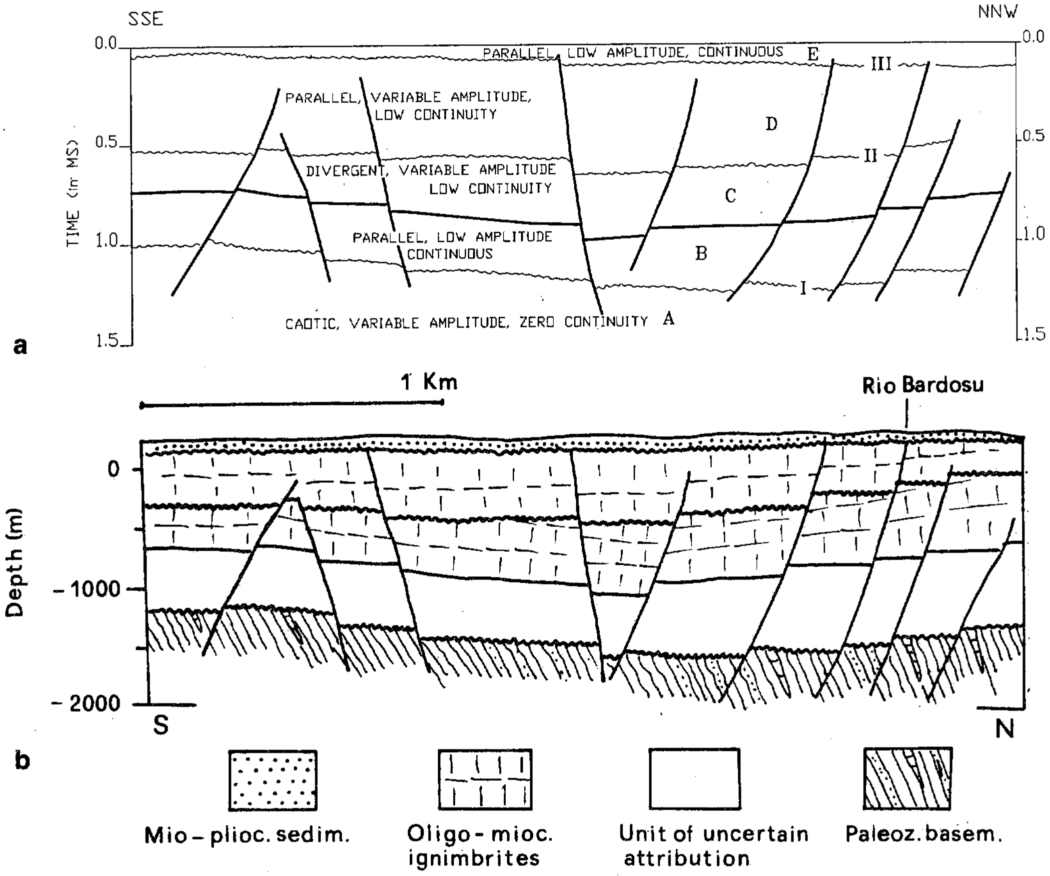


Fig. 9 - The section of Fig. 6: a) division into the seismic units A, B, C, D, E; b) geological interpretation of the seismic section.

of discontinuous, low to moderate amplitude, parallel to divergent reflections. The interval velocity is about 3800 m/s. This sequence overlies a sequence of irregular discontinuous high amplitude reflections. The chaotic character of these latter reflections is indicative of very tectonized rocks.

On the basis of the previous considerations, five seismic units (A to E in Fig. 9a) can be identified in the seismic section with boundaries prevalently coinciding with the unconformities (I to III in Fig. 9a).

GEOLOGICAL INTERPRETATION

Using the seismic interpretation and the interpretation of geological and petrographical data on the area under consideration, an attempt was made to correlate previously defined seismic units with outcropping stratigraphic units (Fig. 9b).

The shallowest seismic units, marked by the letter E in Fig. 9a and delimited below by the first noticeable horizon at a depth of about 150 m, can be correlated with the lacustrine pyroclastic deposits and river delta sediments outcropping throughout the area. This formation is slightly discordant on the second unit D, which has velocity values and characteristics, both of attitude and thickness, consonant with the outcropping ignimbritic complex, which is characterized by large subhorizontal lithoid banks alternating with thinner pyroclastic horizons.

The emplacement of unit D is in angular unconformity on an erosion surface.

The third unit, represented by the letter C in Fig. 9a, presents seismic characteristics quite similar to the previous unit, which leads to the supposition that its lithological nature is analogous to that of the previous unit. The evident angular discordance between the two units may be attributed to a compressive tectonic phase with the subsequent relative quiescence of volcanic activity.

The passage to the fourth unit, indicated by the letter B in Fig. 9a, is extremely clear, since it is distinguished by a reflection of high amplitude, and by a sharp increase in velocity. The attitude is still stratiform, subparallel and concordant with the base of the unit above it. In this case, it is more difficult to correlate between seismic and geological units since the lower ignimbritic series lies directly on the outcropping Paleozoic basement. The characteristics of this seismic unit are compatible with a marine-type sedimentation previous to the Oligo-Miocene volcanic sedimentary series, but in the study area, or in the immediate vicinity of it, there is no trace of marine sediments of that age, either outcropping or in the components of the more recent sedimentary formations. If the presence of marine formations is excluded, and if we take into account the literature (Savelli, 1975; Coulon, 1977), below the lower ignimbritic series (unit C), we should find the lower andesitic series. Where it outcrops, this series is represented by brecciated agglomerates of slag fragments and flattened lava (masses) alternating with thin flows. The brecciated horizons are often cemented by hydrothermal fluids, which confer compactness to the rock. The seismic response of a formation of this kind does not appear to be in very good agreement with the seismic characteristics of unit B. Furthermore, correlation of seismic unit B with other formations outcropping below Tertiary formations in other parts of Sardinia cannot be excluded. However, we are not in a position to assign a reliable geological meaning to seismic unit B because we do not dispose of deep wells in the area.

The deepest horizon, corresponding to the unconformity indicated by the Roman numeral I in Fig. 9a, can be correlated with the top of the Paleozoic basement. Below this, in fact, the configuration of the reflections becomes chaotic and is characterized by the presence of incoherent, discontinuous signals, at times of high amplitude. These characteristics are in good agreement with the geological nature of the outcropping metamorphic basement.

CONCLUSIONS

Though the research is still in progress, an interpretation of the early data gives the following conclusions, at least for the sector under investigation:

- the seismic reflection data confirm that distensive tectonics have affected the sector under investigation: the deeper sinking of the Paleozoic basement and of the Tertiary cover to the north as hypothesized from the geological data at the surface seems also confirmed;
- a dislocation of the Paleozoic basement by about 1800 m with respect to the present outcrops at the edges of the graben has been located;
- the lower ignimbritic series was found to be thicker in depth than at the surface, as can be seen at Logudoro and Bosano (Deriu, 1964; Coulon, 1977); the angular discontinuity found within the lower ignimbritic series suggests two successions within the same lower ignimbritic complex;
- below the ignimbritic series, it was possible to locate a formation whose seismic characteristics were different from the overlying series. At the present state of knowledge, it is difficult to attribute a geological meaning to this formation.

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