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Extensional tectonics and seismicity in the axial zone of the Southern Apennines

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ABSTRACT

This paper presents the interpretation of a set of seismic reflection profiles, crossing the Auletta, Diano and Agri basins, in the axial zone of the Southern Apennines. Seismic data reveal that the genesis and evolution of the investigated basins have been controlled possibly since Late Pliocene by a system of NW-SE trending, normal faults, bordering the basins, and related to SW-NE extension, still active in this region, as indicated by seismological (earthquake focal mechanisms), geological (stress indicators, active fault patterns) and geodetic data.

KEY WORDS: *Southern Apennines, Intermountain basins, seismotectonics, seismic reflection profiles.*

RIASSUNTO

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I dati di sismicità storica e strumentale mostrano che i maggiori terremoti dell'Appennino meridionale si concentrano in una fascia, larga circa 50 km, orientata parallelamente alla catena; lungo la stessa fascia, si allinea una serie di bacini intramontani, bordati da faglie dirette, con direzione variabile da NNW-SSE a WNW-ESE.

Lo scopo di questo lavoro è di contribuire alla conoscenza di questi bacini, nella convinzione che essi rappresentino un'importante chiave di lettura per comprendere la tettonica attiva nella regione. I bacini di Auletta (parte della valle del Tanagro), del Vallo di Diano e dell'Alta Val d'Agri sono stati studiati attraverso l'interpretazione di profili sismici a riflessione, messi a disposizione da ENI-Agip. Pur non essendo stati acquisiti e processati per esplorare strutture relativamente superficiali, i profili sismici si sono rivelati uno strumento prezioso per investigare la geometria dei sedimenti che riempiono i bacini intermontani e delle faglie che li delimitano. Sei di questi profili, due per ciascun bacino, ritenuti rappresentativi delle linee sismiche utilizzate per questo studio, sono pubblicati nel presente articolo.

La genesi e l'evoluzione del bacino di Auletta appaiono legate ad una faglia diretta immergente verso NE, con un rigetto di circa 2000 m, che corre lungo il suo bordo SW. Questa faglia sarebbe stata attiva almeno tra il Pliocene superiore e il Pleistocene medio, intervallo di tempo corrispondente all'età dei sedimenti di riempimento, il cui spessore è di 600-800 m. Altre faglie, con andamento analogo, possono essere individuate sia ad W del bacino (Struttura dei M. Alburni) che verso E (Faglia dell'Irpinia, cui è legato il terremoto del 1980).

Il bacino del Vallo di Diano è stato generato e controllato da un set di faglie dirette principali, immergenti verso SW. L'attività di queste faglie a nostro avviso è iniziata almeno nel Pliocene superiore, ed è continuata anche dopo il Pleistocene medio, e lo spessore della sequenza sedimentaria di riempimento può raggiungere i 1000 m; i dati noti non consentono di escludere che tale struttura sia ancora attiva.

Il bacino dell'alta Val d'Agri mostra chiari caratteri di semi-graben, controllato da faglie dirette principali immergenti sia verso SW che verso NE, attive a partire dal Pleistocene inferiore e comunemente considerate responsabili della sismicità attuale.

In conclusione, al di là delle differenti immersioni del piano di faglia principale, la genesi e l'intera storia evolutiva di tutti e tre i bacini studiati appare guidata da tettonica estensionale, con una direzione di massima estensione SW-NE, attiva a partire dal Pliocene superiore. Un campo di sforzi con la stessa orientazione è ancora attivo nella regione, come documentano i dati dei meccanismi focali e le deformazioni misurate nei pozzi profondi.

Questa storia deformativa semplice e coerente contrasta con la notevole complessità della storia tettonica quaternaria, articolata in numerosi eventi, diversi per significato ed orientazione del campo di sforzi, ricostruita da altri autori sulla base dei dati di analisi strutturale. Le complesse deformazioni osservate in superficie ed in particolare le faglie di tipo trascorrente, che dislocano in alcune aree i depositi recenti, non costituiscono necessariamente indizi di fasi deformative indipendenti, ma potrebbero essere spiegate, almeno in parte, come effetti di strutture di trasferimento tra segmenti diversi della zona in distensione, caratterizzati da diversa geometria ed articolazione dei piani di faglia principali.

TERMINI CHIAVE: *Appennino Meridionale, Bacini intermontani, sismotettonica, profili sismici a riflessione.*

INTRODUCTION

Seismological data from both historical and recent earthquakes in the southern Apennines suggest that most of the seismic deformation takes place in a relatively narrow belt, approximately 50 km wide (see AMATO *et alii*, 1997; SELVAGGI, 1998; GALADINI *et alii*, 2000a; VALENSISE & PANTOSTI, 2001). Available data show a consistent pattern of, SW-NE oriented, present-day crustal extension, as well evidenced by earthquake focal mechanisms (AMATO & MONTONE, 1997; PONDRELLI *et alii*, 2002), stress indicators (MONTONE *et alii*, 1999), mapped fault patterns (CINQUE *et alii*, 2000; GALADINI *et alii*, 2000b; VALENSISE & PANTOSTI, 2001) and geodetic data (ANZIDEI *et alii*, 2001; D'AGOSTINO *et alii*, 2001; HUNSTAD *et alii*, 2002).

In this region, the historical seismicity occured in the same areas where intermountain, continental and shallow-marine basins are located, bordered by normal faults, with a pattern following the axial trend of the Apennines. This evidence suggests that the faults bordering these basins represent the main seismogenic faults of the region, i.e. those responsible for the present day seismic extension. The occurrence of the extensional basins and their likely association with the seismicity is not a peculiar feature of the Southern Apennines, but can be observed all along the mountain belt, from Northern Tuscany (Mugello, Pontremoli), through Umbria and Abruzzo (e.g. Gubbio, Colfiorito, Norcia, Fucino), to the southern portion of the Apennines in Campania and Basilicata (Benevento-Mercure).

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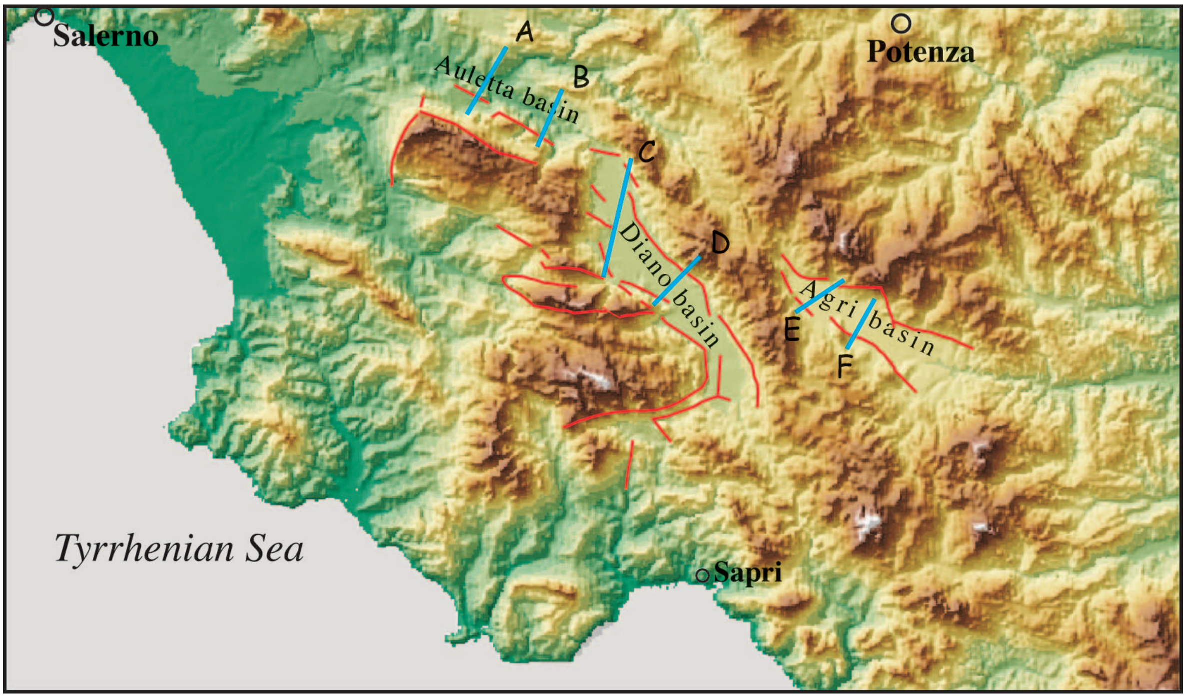


Fig. 1 - Location map of the area. In the fig. is reported the trace of six seismic lines (A to F) crossing the Auletta (see figs. 3 a-b), Diano (see figs. 4 a-b) and Agri (see figs. 5 a-b) basin and the main fault systems.
– Ubicazione dell'area di studio. Nella fig. sono rappresentate le tracce delle 6 linee sismiche analizzate (da A a F) passanti per il bacino di Auletta, Diano e la Val d'Agri; sono inoltre riportati i principali sistemi di faglie dei bacini.

Conversely, some of the studies on recent large earthquakes have proposed that the active normal faults are very young, as they slightly affect the topography and are not related to well developed sedimentary basins (e.g. VALENSISE & PANTOSTI, 2001). According to these Authors the regional seismicity in Southern Apennines is associated to a set of NE-dipping faults, mainly basing on the Irpinia (1980) fault scarp (PANTOSTI & VALENSISE, 1990), which is not related to significant basins and/or morphological evidence.

The goal of this work is to contribute to understand the active tectonics of the region by looking at the deep images of the intermountain basins obtained from commercial seismic reflection lines shot by ENI-AGIP in the past 20 years. Seismic reflection data are compared and integrated with available seismological and tectonic (surface geology) data, in order to highlight the geometry and timing of the ongoing deformation in this highly hazardous area.

In particular, three intermountain basins (fig. 1) have been considered in this paper: the Auletta basin (corresponding to a segment of the present-day Tanagro river valley), the Diano basin (Vallo di Diano) and the Agri basin (corresponding to the high Agri river valley). The shape and orientation of these basins are slightly different, spanning from WNW (e.g. Val d'Agri) to NNW (e.g. Vallo di Diano). However, they depict a general, NW-SE alignment, parallel to the Apennines mountain range.

Different interpretations have been proposed for the genesis and evolution of these basins namely:

a) pull-apart basins, related to an important sinistral fault zone (TURCO & MALITO, 1988; KNOTT & TURCO, 1991; MONACO *et alii*, 1998; CELLO *et alii*, 2000);

b) extensional basins (MENARDI NOGUERA & REA, 2000);

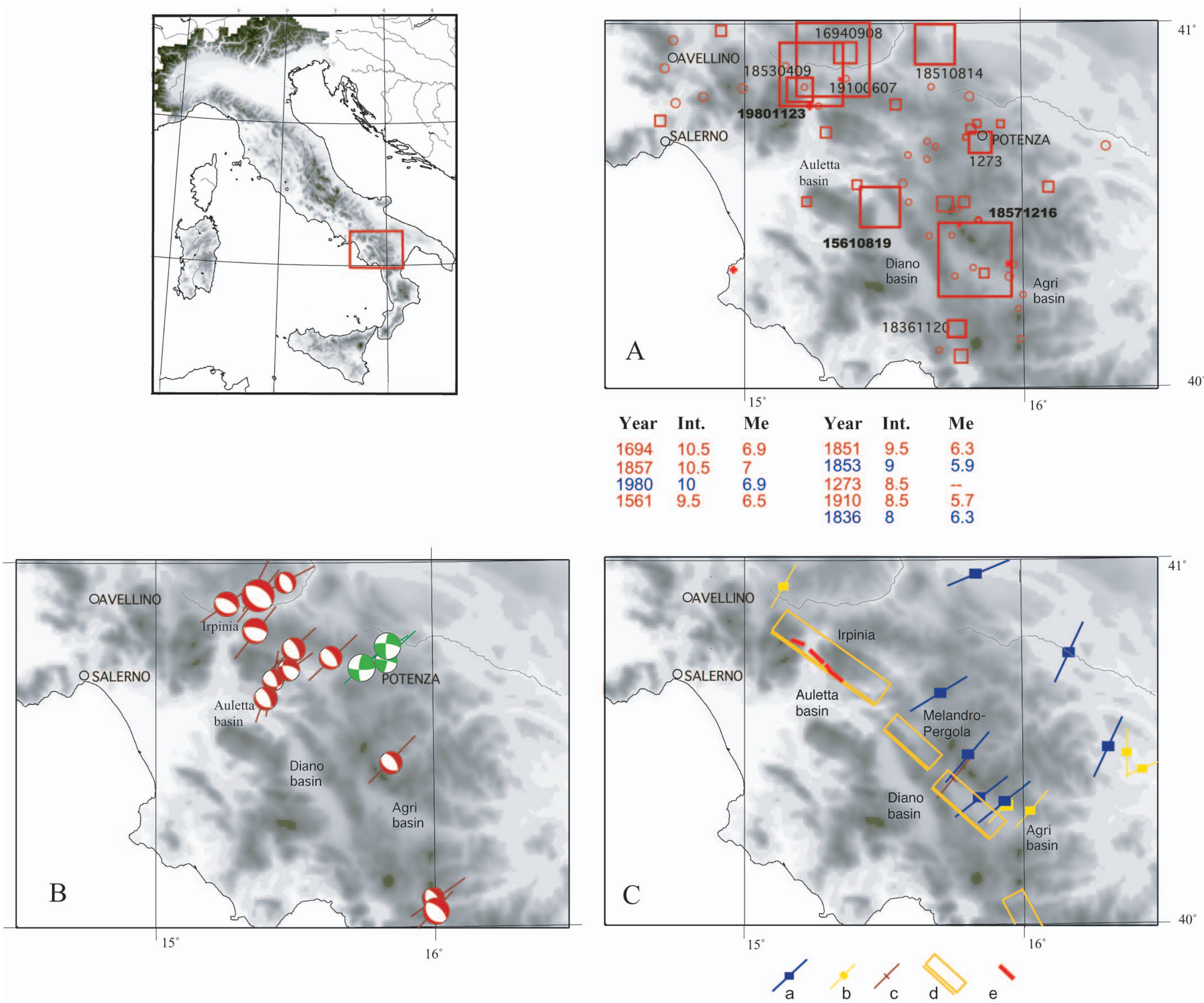
c) basins originated as pull-apart depressions, and recently evolved as extensional basins (ORTOLANI *et alii*, 1992; SCHIATTARELLA *et alii*, 1997; GIANO *et alii*, 2000).

In the following sections, we first present a summary of available seismological data; then we describe and interpret six unpublished seismic reflection profiles, which are relevant to the geometry and kinematics of Auletta, Diano and Agri Basins.

SEISMICITY

The region crossed by the seismic lines described in this work is one of the most hazardous areas in Italy. Several large earthquakes are documented in the historical catalogues (BOSCHI *et alii*, 1997), as shown in fig. 2a. In the north, adjacent to the area of the three basins described here, two M~7 earthquakes occurred in 1694 and in 1980. To the south, the Agri basin was struck by a M~7 earthquake in 1857. In between, a smaller (M~6-6.5) earthquake occurred in 1561. Only for the 1980 Irpinia earthquake there is a clear evidence of the fault geometry and kinematics, determined by both seismological and geological data (WESTAWAY & JACKSON, 1987; PANTOSTI & VALENSISE, 1990). These have shown a NE-dipping normal fault extending for about 40 km along the strike of the Apennines. This fault, that was studied carefully in the field and then trenched for paleoseismology (PANTOSTI *et alii*, 1993), was not clearly linked to a tectonically controlled extensional basin. This was interpreted as an evidence of a «young» fault, whose activity is too recent to give rise to a tectonic depression.

For the 1857 earthquake there is not a general consensus on the fault geometry, although the location is



Year	Int.	Me	Year	Int.	Me
1694	10.5	6.9	1851	9.5	6.3
1857	10.5	7	1853	9	5.9
1980	10	6.9	1273	8.5	--
1561	9.5	6.5	1910	8.5	5.7
			1836	8	6.3

Fig. 2 - A) Main historical earthquakes: in the table below, for the strongest events, is reported Year, Intensity and Equivalent Magnitude (Boschi *et alii*, 1997); B) focal mechanisms from Centroid Moment Solutions (Pondrelli *et alii*, 2002 and references therein, GNDT project) and relative minimum horizontal stress axis: period from 1980 to 2001; Magnitude >4.5, hypocentral depth between 8 and 25 km; C) S_{hmin} directions (*a* and *b* represent best and worst quality for breakouts; *c*) indicates S_{hmin} for fault data), inferred seismogenic sources (*d*) and Irpinia fault scarp trace (Montone *et alii*, 1999; Valensise & Pantosti, 2001).
– A) *Principali terremoti storici: nella tabella sottostante sono riportati Data, Intensità e Magnitudo Equivalente per i principali eventi (Boschi* et alii, *1997). B) meccanismi focali da dati CMT (Pondrelli* et alii, *2002 e referenze all'interno, GNDT project «A. Amato»): periodo 1980-2001; Magnitudo >4.5, profondità ipocentrale tra 8 e 25 km; sono rappresentati anche gli assi di minimo sforzo orizzontale. C) direzione di* S_{hmin} (a e b *rappresentano le qualità migliori e peggiori per i dati di breakout;* c) *indica* S_{hmin} *per i dati di faglia), probabili sorgenti sismogenetiche* (d) *e traccia in superficie della faglia irpina (Montone* et alii, *1999; Valensise & Pantosti, 2001).*

well constrained by intensity data around the high Agri basin (fig. 2a). Two alternative hypotheses were proposed, with a SW- or NE-dipping normal fault by Benedetti *et alii* (1998) & Valensise & Pantosti (2001), respectively. Even more uncertain is the geometry and kinematics of the 1561 event: according to the DPS (Database of Potential sources, Valensise & Pantosti, 2001) it could be related either to a normal fault located between the 1980 and the 1857 faults, or to a transverse structure, separating normal fault segments. It is worth to note that in the same Database, the Melandro-Pergola seismogenic source is not associated with any historical or instrumental earthquake.

In general, all the data on fault plane solutions of recent earthquakes (fig. 2b), as well as those on in-situ stress measurements in deep wells (fig. 2c) are indicative of a normal fault regime, with s_3 trending ~NE-SW (Amato & Montone, 1997). A key point for the seismotectonics and seismic hazard evaluation of the region is whether the strong earthquakes of the region are restricted to the few faults inferred from the most recent earthquakes, or if there are other potentially active faults. In this study, we investigate if the normal faults inferred from the seismic lines are consistent with the past earthquakes and discuss the evidence of recent activity.

SEISMIC REFLECTION DATA

The oil companies have acquired several seismic reflection profiles in this region during various exploration campaigns, using different acquisition and processing techniques, and resulting in different quality and signature.

In this study, we focused our observation onto the segments of the profiles crossing the Quaternary basins, to get information about the internal geometry, the asymmetry and thickness of the sediments infilling the basins and about the major faults bordering them.

Many profiles have been analysed and interpreted during this study. Here we present six seismic profiles, two for each of the studied basins, representative of their tectonic setting. The traces of the profiles, reported in fig. 1, are oriented almost perpendicular to the basins and to the related master faults.

Considering these data, it is important to keep in mind that:

– The seismic profiles were aimed at oil exploration: therefore, they were not acquired and processed with the aim of defining in detail the shallow structures; on the contrary, the processing sequence has been focused to the resolution of the deeper reflections as, for example, the top of the carbonatic platform at the footwall of the regional thrusts; consequently, the shallow reflections quality is often hardly acceptable;

– the quaternary continental overburden often produces a seismic data impoverishment;

– the lithological homogeneity of the carbonatic rocks, which the main tectonic units of the region consist of, results in the lack of good, easily traceable reflectors within the bedrock.

Moreover, it is important to point out that seismic reflection data are not able to positively discriminate active faults. Little amount of deformation and/or small offset of the recentmost outcropping strata could not be registered by seismic reflection profiles, being beyond the power of resolution of the method: for the profiles presented in this paper, this limit can be assumed equal to about 50 m. In general, the sedimentation within these basins is not continuous until the present time: the sedimentary sequences infilling the basins stop to Middle Pleistocene (Auletta and Diano basins) or to Upper Pleistocene (Agri basin), consequently there is no sedimentary record of very recent deformation.

Beyond these limitations, the interpretation of seismic reflection profiles, integrated with surface geology data, is useful for constraining the recent tectonic evolution of the region and its seismotectonic setting, since seismic data highlight the geometry at depth, and suggest the kinematics of the structures responsible for the sedimentary evolution of the recent basins, and consequently constrain the long-term deformation throughout the Quaternary.

The following paragraphs are dedicated to the three basins considered in this study. First, the stratigraphic and structural setting of each basin is summarised, as depicted in the literature. Then, seismic reflection data are illustrated in detail and commented.

THE AULETTA BASIN

The Auletta basin is a tectonic depression, trending about N120°, and presently hosting part of the valley of the Tanagro River. It extends for about 20 km in length and 5 km in width (fig. 1).

The axial zone of the basin is infilled by the Late Pliocene-Early Pleistocene continental «Auletta sequence» (LIPPMAN-PROVANSAL, 1987; ASCIONE *et alii*, 1992a), which overlies the Upper Pliocene marine deposits (AMATO *et alii*, 1992). The continental sequence consists of a 60 m thick clayey sequence (Argille di Auletta), followed by fluvial conglomerates (Conglomerati di Auletta). Lower-Middle Pleistocene conglomerates and travertines (Travertini di Tufariello-Tempa Truiana) unconformably overlie the Auletta sequence.

The structural setting of the Auletta basin, as depicted by AMATO *et alii* (1992) & ASCIONE *et alii* (1992a), is asymmetric: the SW margin is characterized by sharp fault scarps, bordering the Alburni Mts. ridge, trending about NW-SE, whilst the NE flank shows a less marked contact to the M. Marzano structure, trending about E-W. The main fault on the SW margin (Tanagro fault) is N120°-130° trending and is active after the deposition of the Conglomerati di Auletta. Other tectonic elements, mainly extensional faults and fractures, are interpreted as transfer faults between main NW-SE normal faults. The Middle Pleistocene deposits are slightly tilted towards SW and displaced by normal faults.

Two seismic profiles 'A' and 'B' (fig. 3) are presented here, crossing the Auletta basin in a SW-NE trend, almost perpendicular to the strike direction of the basin and of the faults bordering it.

The northermost 'A' profile (fig. 3a) shows the strong, westward asymmetry of the basin: the sedimentary strata infilling the basin are tilted towards SW and dragged along a major, NE-dipping normal fault, bordering it. The reflectors within the underlying carbonatic rocks, at the fault hangingwall, are also tilted towards SW, possibly as a consequence of the fault activity. A second, NE-dipping normal faults, located few km to the W of the main fault, could correspond to the eastern margin of the Alburni Mts. The reflectors within the carbonates at the fault footwall are dragged into the fault. A set of SW-dipping, antithetic normal faults displaces the bottom of the sedimentary sequence, at the eastern flank of the basin. The thickness of the basin infilling is about 600-700 m: this sequence can be referred to the outcropping Upper Pliocene-Lower Pleistocene sequence (Auletta shales and conglomerates), followed by the Pleistocene continental sequence, even if the deeper reflections could correspond to older Pliocene marine sediments.

The southern 'B' profile (fig. 3b) confirms the asymmetrical shape of the basin, as well as the average tilting of the basinal sequence towards the NE-dipping, normal, master fault; a slight growth of the strata towards SW can be also observed. The thickness of the syntectonic sequence is in the order of 800 m. The profile beautifully shows the internal deformation of the basinal sequence, consisting of both synthetical (NE-dipping) and antithetical (SW-dipping), minor normal faults.

These two profiles indicate that the genesis and evolution of the Auletta basin is driven by a NE-dipping normal fault, bordering its SW margin. The time interval of activity of the fault is not well constrained by available data. In fact, according to ASCIONE *et alii* (1992a), the deposition of the Auletta sequence is not related to the basin evolution: it was deposited in a wider area and subsequently downthrown into the basinal subsiding area by

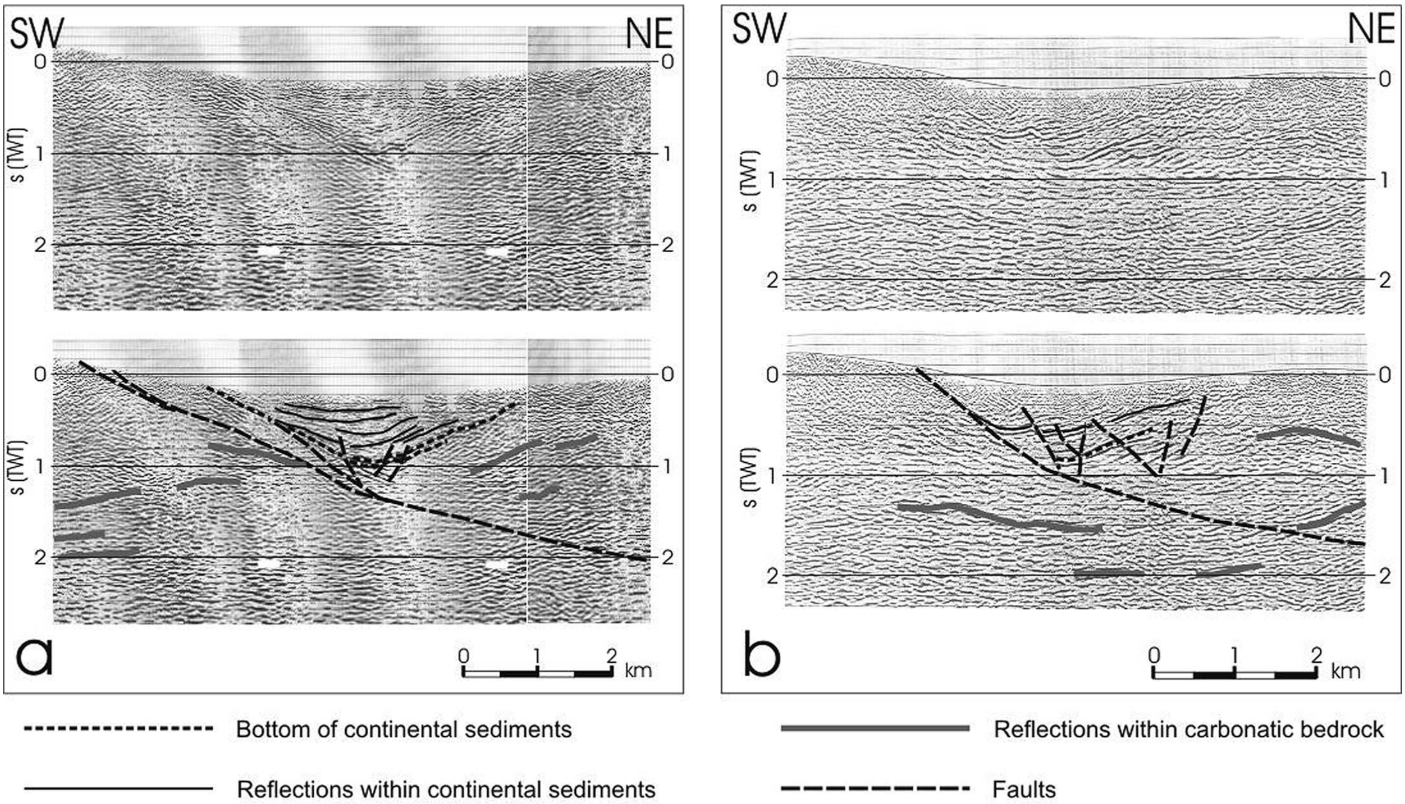


Fig. 3 - Seismic reflection profiles through the Auletta basin: *a*) profile 'A'; *b*) profile 'B' of fig. 1.
– *Profili sismici attraverso il bacino di Auletta (Valle del Tanagro)*: a) *profilo 'A';* b) *profilo 'B'. Localizzazione in fig. 1.*

N120° trending normal faults. However, seismic profile of fig. 3b images the Auletta sequence as slightly growing towards SW suggesting that the deposition of these sediments could be directly related to the activity of NE-dipping normal fault. In this hypothesis the time interval of activity of the master fault could be extended from Upper Pliocene to Middle Pleistocene, while more recent activity cannot be established by these data.

The thickness of the syntectonic sequence and the attitude of the reflections within the underlying carbonates suggest a remarkable displacement, in the order of 2000 m (fig. 3). At the surface, the master fault bordering the basin can be identified as the fault bounding towards NE the M. Forloso carbonate structure, that represents a faulted block, downthrown toward NE, from the Alburni Mts. Ridge: the fault bordering this ridge is also visible in the 'A' profile.

DIANO BASIN

The Diano Valley (Vallo di Diano) is a typical apenninic intermontane basin, placed at 450 m a.s.l., elongated for about 35 km in a N140° direction and 7-8 km wide (fig. 1).

The sedimentary sequence infilling the basin has been defined as a Pleistocene mainly lacustrine deposit since 1898 by De Lorenzo and successively by Lippman-Provansal (1987). The lacustrine facies are accomplished along the flanks of the basin by debris and alluvial fans. Ascione *et alii* (1992b) describe the lacustrine sequence as consisting of two cycles: the older cycle crops out at the flanks of the basin, presently terraced at 500 m a.s.l., and it ends at the early-middle Pleistocene boundary (0.7 +- 0.2 Ma, Santangelo, 1991). The recentmost sequence, entrenched in the first cycle deposits, extends until historical time, when the last remnant of the lake was dried. Well data show that the overall thickness of the lacustrine sediments exceeds 150 m in the central part of the basin.

The structural setting of the basin has been described in different ways. Some Authors (Turco & Malito, 1988; Knott & Turco, 1991) consider the Diano valley as generated by an important strike-slip zone with a sinistral movement, oriented NNW-SSE to NW-SE, involving a large sector of Southern Apennines. Secondary normal faults with N-S and NE-SW trending are also present in this context.

According to Ascione *et alii* (1992b), the opposite flanks of the basin are characterised by different fault patterns: the western flank is affected by N120° trending, left lateral strike slip faults; the eastern flank is controlled by a set of NNW-SSE trending faults (i.e. parallel to the basin), initiated as strike-slip faults, and successively reactivated as normal faults. The tectonic evolution of the basin is characterised by two major strike-slip phases, occurred respectively before the Late Pliocene, and after the Lower-Middle Pleistocene boundary, and separated by an extensional phase.

According to Menardi Noguera & Rea (2000) the master fault, generating the Diano Valley is represented by a NW-SE trending, SW dipping normal fault, which can be recognised not only in at surface, but also in the seismic profiles.

The profile 'C' (fig. 4a) crosses the northern termination of the basin (Polla zone), with a SSW-NNE trend.

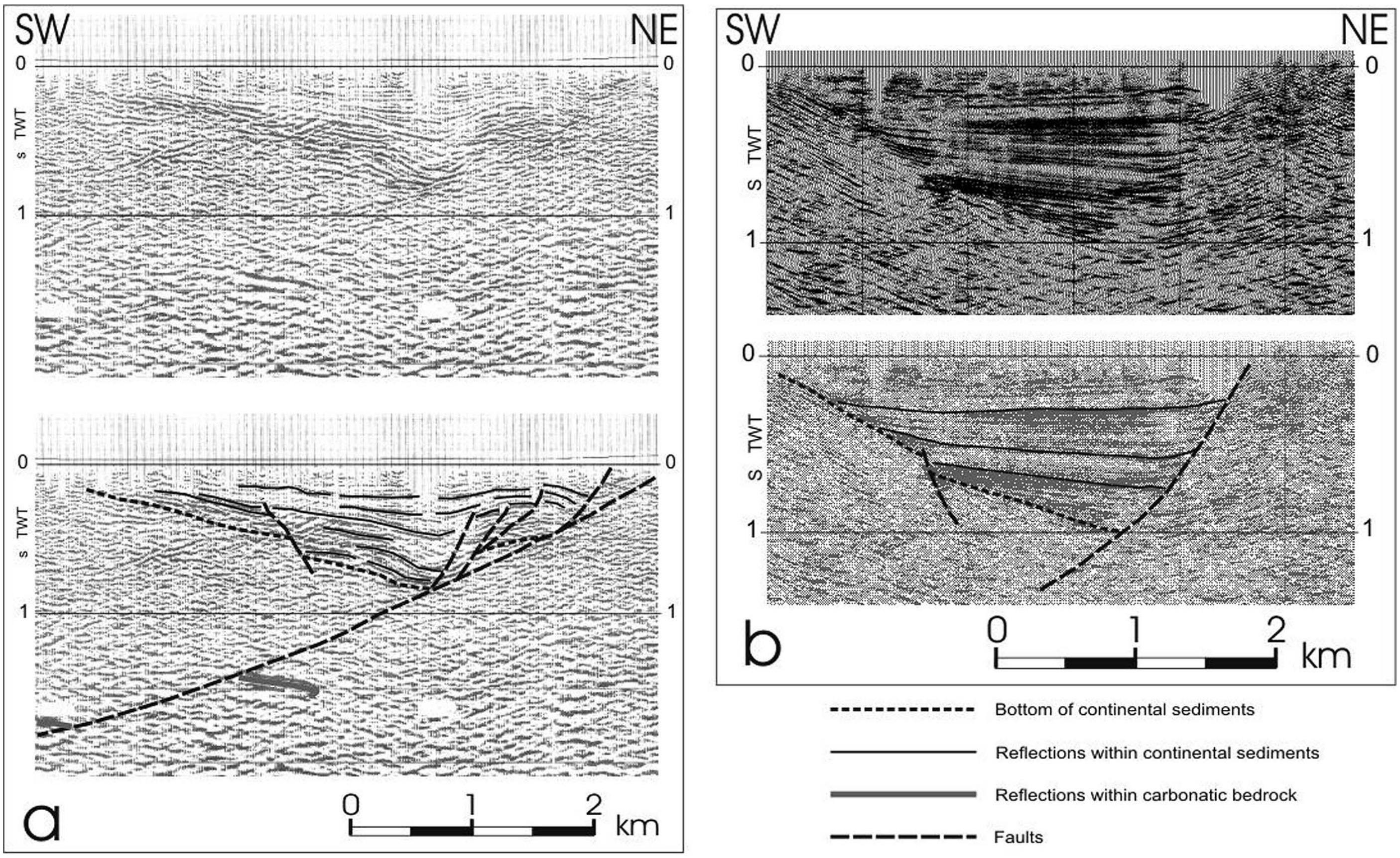


Fig. 4 - Seismic reflection profiles through the Diano basin: *a*) profile ‘C’; *b*) profile ‘D’ of fig. 1.
– *Profili sismici attraverso il bacino di Diano (Vallo di Diano)*: a) *profilo ‘C’;* b) *profilo ‘D’. Localizzazione in fig. 1.*

The SW-dipping, normal master fault, bordering the eastern side of the basin, is quite evident in this profile. The slip along the master fault produces the tilting and growth of sedimentary strata towards the fault itself. The roll-over geometry of the hangingwall and the asymmetrical shape of the basin suggests its syntectonic character. The master fault is accomplished by a set of synthetic, SW-dipping, splays, whose activity is largely synchronous. The westernmost, major splay fault singles out an intermediate, fault-bounded block, about 1 km large, corresponding to the area of greater extensional deformation, whose strata are faulted and folded by dragging towards the bounding faults. A significant, antithetic fault can be observed in the opposite flank of the basin. The thickness of the syntectonic sediments exceeds 750 m, much greater than the values reported in the literature (Ascione *et alii*, 1992b), where the maximum thickness of the Pleistocene sediments is reported to be 150-200 m thick. This observation suggests the presence of an older (Upper Pliocene?) syntectonic sequence, which would not crop out at surface, implying an older onset of the extensional tectonics in this area. In this view, the older sequence could be equivalent to the Upper Pliocene, continental succession, cropping out in the northernmost Auletta basin.

The southernmost, ‘D’ profile (fig. 4b), crosses the central part of the Diano basin, near Sala Consilina (see location in fig. 1). This profile also shows the presence of a W-dipping normal fault, which drives the genesis and evolution of the basin, and the asymmetrical shape of the continental sequence, which appears very thick, exceeding 1 s TWT (about 1000 m). The good seismic data quality highlights the wedge geometry of the sedimentary bodies, constituting the basinal sequence (more evident in the deepest section), and the presence of significant angular unconformities, marking different extensional stages during the trough generation and development. An antithetic, E-dipping normal fault, displacing about 200 m the bottom of the continental sequence, is recognisable on the western flank of the basin. The profile also shows the different attitude of the strata within the carbonatic bedrock, W-dipping in the fault footwall, E-dipping in the fault hangingwall.

In conclusion, profiles ‘C’ and ‘D’ effectively demonstrate that the genesis and evolution of the Diano basin is related to the activity of a SW-dipping normal fault. The onset of the activity of the extensional master fault possibly pre-dates lower Pleistocene, covers the entire time interval of the older sedimentary cycle (lower to middle Pleistocene), and apparently continues after that time, since even the shallower reflectors seem to be deformed. The seismic profiles also show interesting details of the synthetic and antithetic splays of the master fault, even if the overall tectonic setting is much simpler in the southernmost ‘D’ profile than in the ‘C’ profile. The sedimentary sequence infilling the basin is much thicker than reported in the literature (almost 1000 m versus about 200 m).

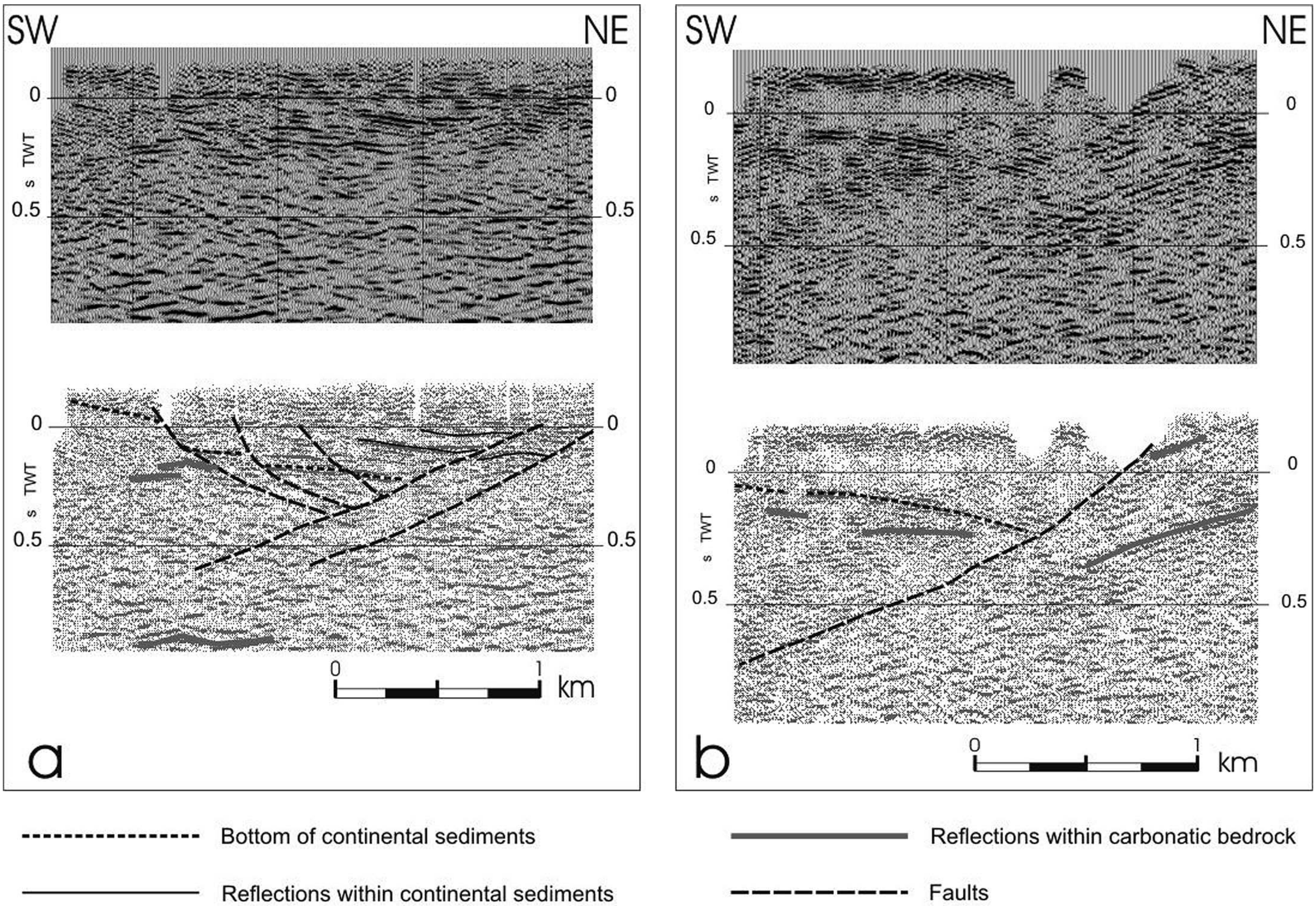


Fig. 5 - Seismic reflection profiles through the Agri basin: *a*) profile 'E'; *b*) profile 'F' of fig. 1.
– *Profili sismici attraverso il bacino della Alta Val d'Agri*: a) *profilo 'E';* b) *profilo 'F'. Localizzazione in fig. 1.*

THE AGRI BASIN

The Agri basin, corresponding to the high Agri river valley, is elongated about N120°; it is approximately 30 km long and 5 km wide (fig. 1).

The Quaternary sediments of the basin are entirely constituted of continental clastics, represented by lower to upper Pleistocene slope coarse-grained deposits, which form coalescent fans along the flanks of the basin, and by middle Pleistocene alluvial deposits in the plain (GIANO *et alii*, 2000). Due to recent fluvial erosion, it is possible to observe more than 100 m of the alluvial sequence, which reaches a thickness of about 250m in the depocenter, as documented by unpublished well data (PIERDOMINICI *et alii*, 2002).

Some Authors (e.g. TURCO & MALITO, 1988; MONACO *et alii*, 1998; CELLO *et alii*, 2000) refer the genesis of Agri basin to prevalent strike-slip tectonics. CELLO *et alii* (2000) recognize a fault system namely «Val d'Agri fault system» (VAFS) that crosses pre-existing, NW-SE trending, tectonic structures, and would be the seismogenic structure responsible of major seismicity of the area. The VAFS is composed by N120° left lateral faults, with associate, transtensional and/or transpressional, minor faults, oriented N20°-30° (right lateral) and N90°-110° (left lateral).

Other Authors (e.g. ASCIONE *et alii*, 1992b; ORTOLANI *et alii*, 1992; SCHIATTARELLA *et alii*, 1997; GIANO *et alii*, 2000) on the contrary refer the recent evolution of Agri basin to an extensional phase, reactivated since middle Pleistocene times. Two different Quaternary tectonic stages are recognized: the first – lower Pleistocene – is characterized by strike-slip along N120° trending master faults; the second – since middle Pleistocene – by NW-SE trending, normal master faults, related to a regional, extensional regime on a regional scale, with NE-SW tensional axis. The Quaternary, brittle faults cut the previous, N-S trending, structures of the Southern Apennines fold-and-thrust belt.

Active tectonics in the Agri basin area is documented by both geological and seismological data. The continental deposits, lower to middle Pleistocene in age, are frequently displaced; recent activity of tectonics is documented also by ^{14}C dating on faulted paleosoils, dated 40-20 ka (GIANO *et alii*, 2000). Finally, the 1857 earthquake is localized in the central part of the basin (BOSCHI *et alii*, 1997).

Two segments of seismic reflection profiles are here presented, crossing the central part of the Agri basin with a SSW-NNE direction (see location in fig. 1). The westernmost profile (Section 'E', fig. 5a) shows the asymmetrical shape of the sediments infilling the basin, suggesting

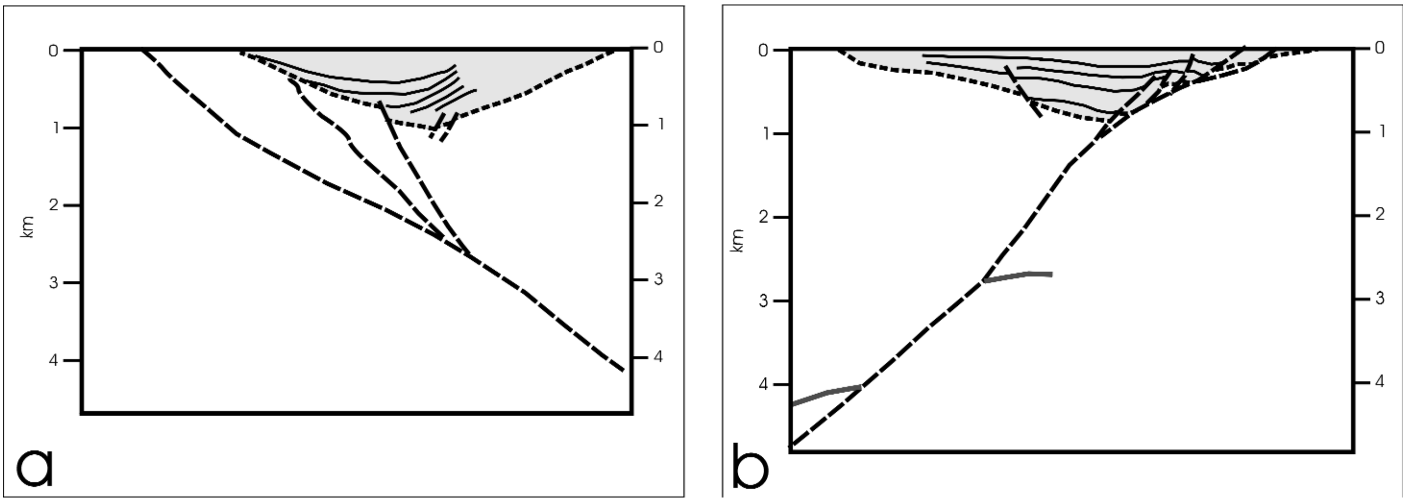


Fig. 6 - Schematic geological sections, based on the depth conversion of the seismic profiles 'A' (*a*) and 'C' (*b*). The depth conversion has been performed using Vp values of 2000 m/s for the basin infilling and 5000 m/s for the bedrock.
– *Sezioni geologiche schematiche, basate sulla conversione in profondità dei profili 'A'* (a) *e 'C'* (b). *La conversione in profondità è stata effettuata utilizzando valori di Vp di 2000 m/s per i sedimenti di riempimento dei bacini e di 5000 m/s per il substrato litoide.*

the synsedimentary activity of a W-dipping normal fault. The maximum thickness of the continental sediments, at the trough depocenter, is about 0.35 s TWT, roughly corresponding to 300-400 m, comparable with surface geology observations, showing a maximum depth of about 250 m (PIERDOMINICI *et alii*, 2002).

In the easternmost profile (Section 'F', fig. 5b), the internal shape of the sediments is not recognisable, but we can trace a well defined reflector, likely to correspond to the bottom of the sediments, bent toward the W-dipping master fault with a distinct roll-over geometry: the maximum thickness of the sediments is about 0.35 s TWT. The different attitude of the carbonatic bedrock, steeply W-dipping in the fault footwall, flat or gently E-dipping in the fault hangingwall, is also evident.

In both profiles (fig. 5), the half-graben geometry of the continental basin suggests that the onset and evolution of the Agri basin is related to the activity of a SW-dipping normal fault. The master fault borders the eastern flank of the basin, and can be traced at depth till about 0.6 s TWT, where it tends to become slightly flatter. Some ~NE-dipping antithetic faults have been recognized, but their throw is negligible.

DEPTH CONVERSION OF THE PROFILES

The profile 'A', crossing the Auletta basin, and the profile 'C', crossing the Diano valley, have been depth converted (figs. 6 a-b), in order to illustrate the real geometry of the basins and of the extensional faults in particular.

For this preliminary study, a very simple, two layers velocity model has been adopted for the depth conversion: V_p values of 2000 m/s and 5000 m/s were assigned to the Pliocene-Quaternary sediments, and to the mainly carbonatic bedrock, respectively. This model is certainly oversimplified and not completely realistic: in fact the lithology of the recent sediments is quite variable, and their compaction and velocity are a function of depth; the bedrock is also heterogeneous, consisting of many different, lithological/tectonic units. Nonetheless, the resulting geological sections, presented in fig. 6, are useful to get an idea of the spatial relationships between the basins, the sedimentary bodies infilling them and the faults generating them.

In particular, the depth converted sections reveal that the faults bordering the basins are almost planar, with a mean dip of 45°-50°, whilst in the time sections the faults seem to flatten at depth: the latter is mainly a velocity effect.

DISCUSSION

In the presented seismic profiles, the Diano and Agri basins show a similar, half graben geometry, driven by SW-dipping, normal faults, even if the overburden thickness is quite different (about 350 and 1000 m, respectively). The control operated by the normal faults on the geometry of the sedimentary bodies is quite evident, for the Diano basin in particular. The Auletta basin case-history is partially different, because its onset and evolution is driven by a NE-dipping, normal fault.

Beyond the different dip direction of the master faults, seismic data show that all the analysed basins are mainly related to extensional deformation. Since the seismic profiles are 2-D images, the presence along the considered faults of minor, horizontal component of displacement, cannot be detected. In particular, transtensional displacements could be related to the different orientations of the faults (ranging from N120° to N150°), moving under the same SW-NE trending, extensional stress field.

The extensional phase seems to be continuous and geometrically coherent throughout the entire tectonic history of the basins, probably extending from Late Pliocene to Middle Pleistocene. More recent activity cannot be documented by seismic profiles: however, it can be noted that the present-day stress field is oriented in the same way of that responsible for the basin emplacement and evolution. In particular, the faults bordering the Agri basin are widely recognised as presently active (BENEDETTI *et alii*, 1998; CELLO *et alii*, 2000; VALENSISE & PANTOSTI, 2001). The constant orientation of the extensional stress field in this sector of the Southern Apennines is in strong contrast with the very complex tectonic history, proposed by different Authors, mainly based on structural analysis of striated fault planes, invoking numerous, different tectonic events during the Quaternary.

A possible explanation of the kinematic complexities evidenced by the structural analysis data is that they could be referred to the presence of transfer zones, linking different normal fault segments. For example, seismic data show that the Auletta Basin is related to a NE-dipping fault, whilst the northern part of the Diano basin, few km farther to the South, is generated by a SW-dipping fault. The stratigraphy of the syntectonic sediments indicate that the activity of these two, opposite dipping faults must be synchronous, at least for the Early-Middle Pleistocene time interval. Seismic data suggest that synchronous activity could have been longer, extending back till the Late Pliocene. The synchronous activity implies the presence of a complex transfer zone between the two master faults, consisting of strike-slip and/or transtensional faults, possibly accomplished by differently oriented normal fault. Another significant example is given by the seismic profiles crossing the Diano basin, which show two distinct tectonic settings, even if both of them are dominated by a SW-dipping normal fault. The other seismic profiles crossing the Diano Valley, not published in this study, confirm the presence of strong, along strike variations of the fault pattern: these observations also claim for the presence of transfer faults, linking the different normal fault segments.

The interpretation of the seismic profiles is also useful to integrate information about the stratigraphy of the sediments within the Pliocene-Quaternary basins. For example, the thickness of clastic sedimentary infilling the Diano basin is much greater than that observed in the Agri river valley trough. The shallower thickness of the sediments in the Agri basin suggests a more recent onset of extensional tectonics, as also indicated by stratigraphy and surface geology data. Along the same trend of the Agri basin, two other structures are present, namely Pergola basin and Irpinia fault, both showing good evidence of present day activity (seismicity and palaeoseismological data) and characterised by very shallow, recent sediments.

From the data analyzed in this study at the moment, it is not clear whether the normal faults recognized in the seismic lines are still active, and can generate earthquakes.

However, the existence of a suite of parallel contemporaneously active normal faults in the region, rather than one single «characteristic» fault, is more consistent with the extension rate measured by historical earthquakes. These estimates range between ~2 and ~5 mm/yr (WESTAWAY, 1992; SELVAGGI, 1998; ANZIDEI *et alii*, 2001; HUNSTAD *et alii*, 2002) for the past centuries, whereas the extension rates measured from paleoseismology on individual faults are significantly lower (VALENSISE & PANTOSTI, 2001). It is therefore extremely important to constrain the age of the most recent activity of the faults and their rate of activity, also in order to determine the seismic hazard of the region.

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