MESSINIAN EVENTS IN A RAPIDLY SUBSIDING AND TECTONICALLY CONTROLLED FORELAND BASIN: THE SOUTHERN LAGA BASIN (CENTRAL APENNINES, ITALY).

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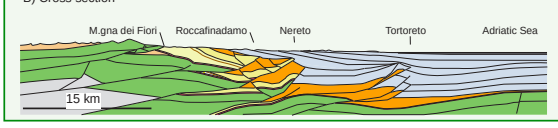
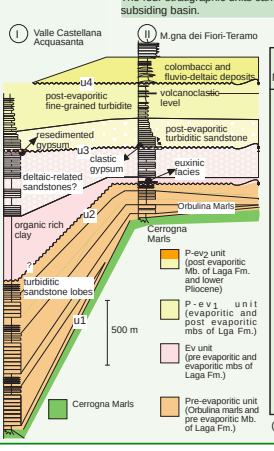
A) Location and geological sketch map

The Laga basin is located in the Marche and Abruzzo regions (Central Italy). The most subsiding portion of this basin is the Southern Laga Basin (SLB) the boundary of which are (A): to the north, the Fiastrone-Fiastrella and Chienti lines, that mark the boundary with the less subsiding Northern Laga Basin (NLB) (Cantalamessa et al., 1986b; Calamita et al., 1996; Bassetti, 2000); to the west, the Sibillini Mountains; to the E, the early Pliocene-Pleistocene deposits that form a homocline dipping toward the Adriatic sea; to the south, the Gran Sasso Range and Maiella. South of the Gran Sasso range, remnants of late Miocene foredeep and wedge-top deposits are preserved (Cipollari et al., 1995).

The SLB is characterised by two positive N-S oriented structures, the Acquasanta and M. dei Fiori-Montagnone anticlines. East of these structures, subsurface thrust systems occur (Crescenti et al., 1980; Calamita et al., 1991; Centamore et al., 1991; Artoni, 1993; Calamita et al., 1994; Casnedi & Serafini, 1994; Artoni & Casero, 1997; Bigi et al., 1999) (A, B).

B) Cross section





The Southern Laga Basin (SLB) of Northern Abruzzo is believed to be the largest and most subsiding turbiditic depocenter of the Apenninic foredeep during the Messinian and early Pliocene. Two stratigraphic sections, to the west (I) and to the east (II) of the M. dei Fiori anticline, suggest average subsidence rates of 1.5 mm/y and 1.8 mm/y respectively (C). Integrating previous works (Artoni, 1993; Casero et al., 1994), a new physical stratigraphic study and the re-interpretation of published data (Adamoli, 1980; Cantalamessa et al., 1982; Centamore et al., 1990; Centamore et al., 1991; Ghisetti et al., 1994) a new stratigraphic scheme is proposed for this portion of the Laga basin. The main Messinian depositional events of Southern Laga Basin (SLB) are recognized and correlated to those documented in the Apennines foreland (Ori et al., 1991; Vai, 1997; Krijgsman e t al., 1999; Roveri et al., 200 1; Ricci Lucchi et al., 2002; Rossi et al., 2002; Bassetti et al., 1994; Roveri et al., 19).

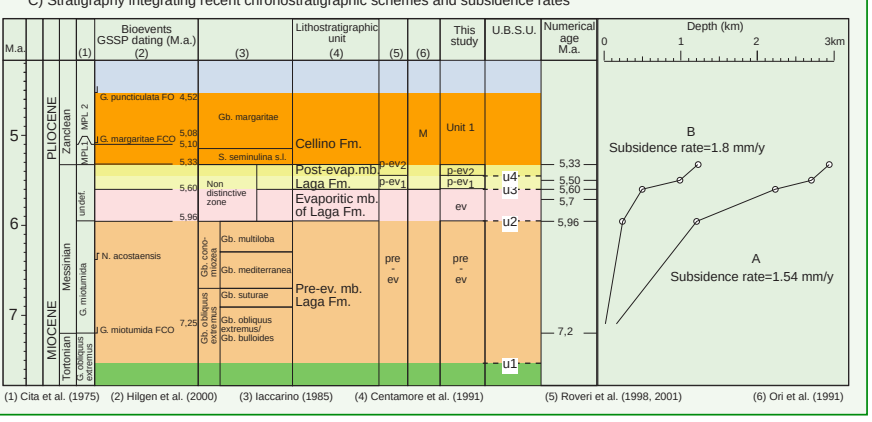
MESSINIAN STRATIGRAPHY OF THE APENNINE FOREDEEP AND SOUTHERN LAGA BASIN

The oldest Messinian units of SLB are the Laga Formation (Servizio Geologico d'Italia, 1969; Crescenti, 1975; Cantalamessa et al., 1986b) and the partially coeval "Marne a Orbulina" (late Tortonian-Early Messinian) (Ghisetti & Vezzani, 1988; Centamore et al., 1991). In lithostratigraphic terms, the Laga Formation, a siliciclastic unit deposited in a deep-sea fan turbiditic system (Mutti et al., 1978), was subdivided in three members, reflecting the classic Messinian "trilogy" (Cantalamessa et al., 1982; Cantalamessa et al., 1986; Centamore et al., 1991): the pre-evaporitic, evaporitic and post-evaporitic members of the Laga Formation (C).

A fall of sea-level, during the Messinian salinity crisis of Mediterranean Sea (Hsü et al., 1977; Ori et al. 1991), is testified by deposition of primary evaporites that are recorded by the lower evaporites in the Mediterranean area. Afterward, the evaporative deposits were eroded and redeposited in a gypsum-arenite horizon. Previous works grouped together the primary gypsum and the gypsum-arenite horizon in the "Gessoso-solfifera Formation". In the recent integrated stratigraphic studies, the Gessoso-solfifera Formation is crossed by an erosional unconformity, named Im unconformity or intra-Messinian unconformity (Iaccarino & Papani, 1979; Ricci Lucchi et al., 1982). Above the intra-Messinian unconformity, siliciclastic units were deposited in a wide lake with ipohaline waters. This is the Lagomare succession which, in Romagna and Marche regions, can be splitted in two units by an unconformity (Roveri et al., 1998; Roveri et al., 2001; Ricci Lucchi et al., 2002). The p-ev$_1$, below the unconformity, is composed by a thick succession of clay and sandstone deposited on a shelf with a regressive trend. The clay-dominated unit contains a vulcanoclastic layer, dated at 5.5 Ma (Odin et al., 1997) (II). The p-ev$_2$ unit, above the unconformity, is composed by coarse-grained sandstones and conglomerates originated by mouth-bars and shelfal lobes dominated by hyper-picnal flows and related to small- medium- sized fluvio-deltaic systems and clay-rich lacustrine deposits with the caracteristic micritic limestone, the "colombacci". The former are believed to correspond to an upper evaporative event or upper evaporites of the Mediterranean area. The above late Messinian cycles punctuate an overall transgressive trend, preceding and heralding the early Pliocene drowning of the whole Mediterranean sea that slightly predate the deposition of the deep-sea fan turbiditic sandstone lobes of the Cellino Formation in the SLB (Casnedi, 1983).

The four stratigraphic units can be also recognized in the SLB; their depositional characters are described below but uncertainties still exist in the location of the intra-Messinian unconformity in this rapidly subsiding basin.

C) Stratigraphy integrating recent chronostratigraphic schemes and subsidence rates



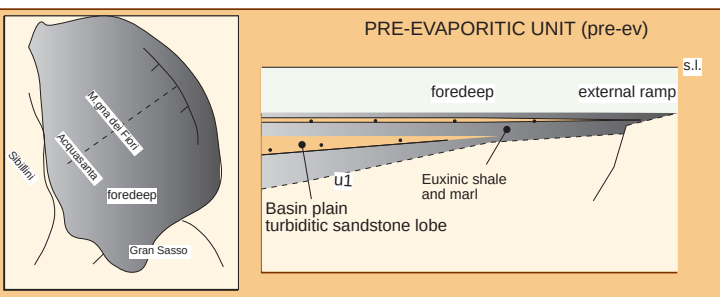
(1) Cita et al. (1975) (2) Hilgen et al. (2000) (3) Iaccarino (1985) (4) Centamore et al. (1991) (5) Roveri et al. (1998, 2001) (6) Ori et al. (1991)

shallowing of depositional environments

increasing shortening and uplift

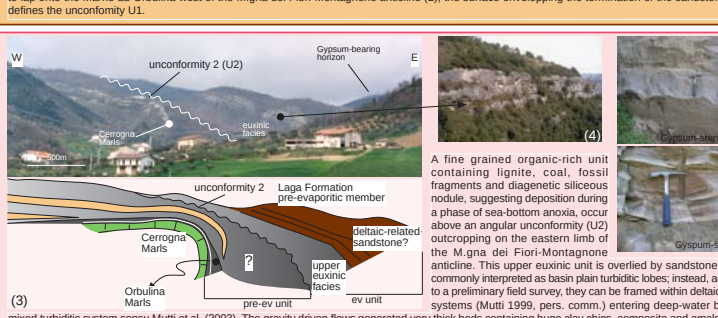
u1

The pre-ev unit consists of banded claystone, made of the rhythmic repetition of organic-rich clay and marl layers (1a) (Orbulina Marl); the organic matter is made of decomposed plant fragments while the marl contain abundant Foraminifera. These euxinic deposits also contain siliciclastic horizons that interfinger with the euxinic facies (1b) (lower portion of pre-evaporitic member of Laga Fm.). On a large scale, the siliciclastic and turbiditic sandstone seems to lap onto the Marne ad Orbulina west of the M.gna dei Fiori-Montagnone anticline (2); the surface enveloping the termination of the sandstone lobes defines the unconformity U1.



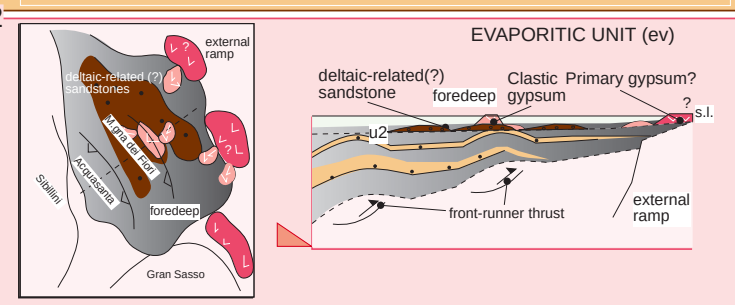
Unconformity 1, envelopping the pinch-out of sandstone bodies toward east, can be followed from the eastern limb of the Acquasanta anticline to the western limb of the Montagna dei Fiori-Montagnone anticline with a constant gentle angle of few degrees. Thus, the pre-ev allounit is lapping against a homocline dipping to the west that is related to a Tortonian tectonic pulse (Patacca et al., 1990). The large-scale onlap geometry is typical of deposition on a foreland external ramp, where basin plain turbidites progressively thin-out laterally, and interfinger with euxinic deposits.

u2



A fine grained organic-rich unit containing lignite, coal, fossil fragments and diagenetic siliceous nodule, suggesting deposition during a phase of sea-bottom anoxia, occur above an angular unconformity (U2) outcropping on the eastern limb of the M.gna dei Fiori-Montagnone anticline. This upper euxinic unit is overlied by sandstone bodies, commonly interpreted as basin plain turbiditic lobes; instead, according to a preliminary field survey, they can be framed within deltaic-related systems (Mutti 1999, pers. comm.) entering deep-water basin, or mixed turbiditic system sensu Mutti et al. (2003). The gravity driven flows generated very thick beds containing huge clay chips, composite and amalgamated beds related to flood events (4). On top of the deltaic-related sandstones, the gypsum-bearing horizon appears. This horizon is mainly made up of sandstones with more than 50% gypsum clasts (gypsum-arenite) (5). Locally, it shows laminated gypsum-siltite made of millimetric/centimetric thick cycles of thin veneer of limestones, at the base, rare ripples and varicoloured fine-grained gypsum with organic content generally increasing toward the top (dark laminae in 6).

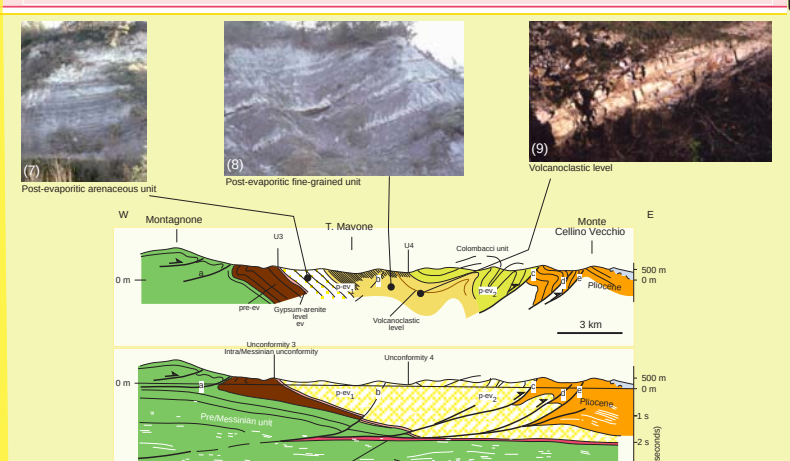
The above gypsum-siltite facies are still controversial. A first and recurrent question is their depth of deposition. If they are considered to be deposited in shallow water environment, they are chemical precipitates reworked by waves and coastal currents. The deltaic-related sandstone laterally associated to this gypsum facies would support a shallow depositional environment. However, the gypsum-bearing deposits of SLB were considered resedimented gypsum in a deep basin. In this case, the laminated gypsum is the fine-grained tail of turbulent flows. A second question arises from the consideration that evaporative events occur throughout the entire Messinian salinity crisis (lower and upper evaporite); the actual stratigraphic position of these gypsum-siltite in the SLB is not yet defined. Sedimentological and stratigraphic analysis, aimed to solve the above questions are in progress. Both questions are critical in constraining the stratigraphic position of the intra-Messinian unconformity in the SLB (see figure caption on the right side).



The angular unconformity 2 (u2 in 3) does not correspond to sharp depositional changes as it occurs within the euxinic unit and records a further confinement and oxygen depletion of the basin. This unconformity marks the base of the local ev unit, related to an early Messinian movement of the Montagna dei Fiori-Montagnone anticline. This pulse created the topographic relief suitable for deposition of probable deltaic-related sandstone and local precipitation of laminated gypsum-siltite. Thus, we interpret the unconformity 2 as generated by a front-runner thrust reaching the external ramp of Apennine foreland.

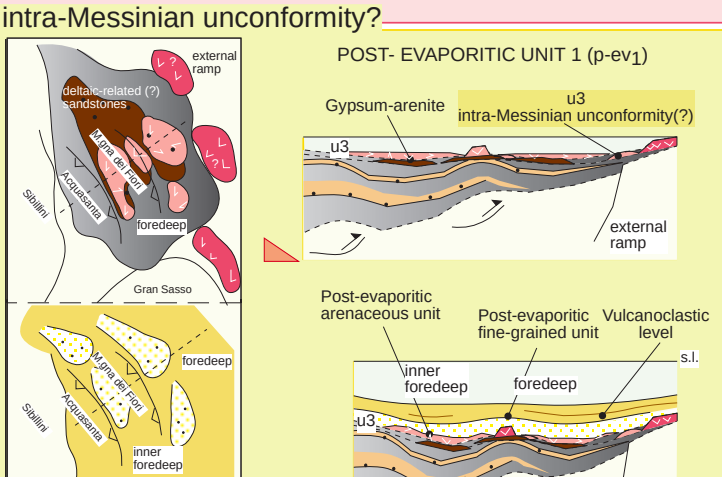
As said before, the laminated gypsum-siltite facies might correspond either to the lower or upper evaporites of the Messinian salinity crisis. Here, we interpred them coeval to lower evaporites. On the contrary, if they will be demonstrated to be coeval to the upper evaporites, the intra-Messinian unconformity should correspond to the U2 unconformity and not the u3 unconformity, as here proposed.

u3 = intra-Messinian unconformity?



The gypsum-arenite horizon (5) marks the base of the p-ev$_1$ unit, composed of the "post-evaporitic arenaceous unit" (7) and "post-evaporitic fine-grained unit" (8); the former contains the volcanoclastic level (9). The "post-evaporitic arenaceous unit" is made up of medium to thick, frequently amalgamated beds of medium to coarse-grained sandstones with erosive bases; it can be ascribed to a turbiditic system characterized by high-density flows (Mutti et al., 1992; Mutti et al., 1999). The cross-section (10) shows that, few kilometers east of the Montagnone anticline, the unit above the gypsum-arenite have maximum thickness while the units below are thinning-out very rapidly. Thus, the base of the p-ev$_1$ unit is a physical boundary that records important structural changes in the basin. This unit represents a step in the eastward migration of the Messinian foredeep and its lower boundary is the unconformity 3. (U3)

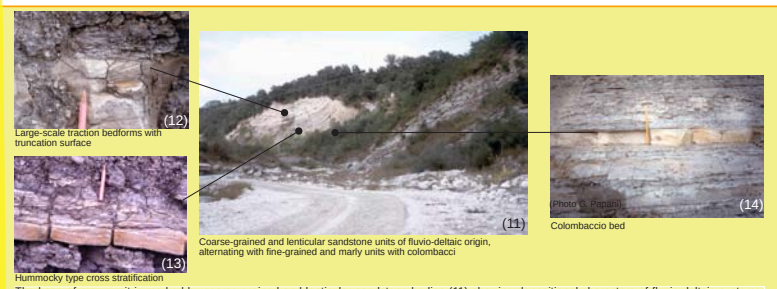
In the upper portion of p-ev$_1$ unit, fine-grained sediments dominated and few sands reached the basin, spreading over a smooth surface and forming lenticular lobes (8) generated by diluted and more evolved turbulent flows (Mutti & Ricci Lucchi, 1975; Mutti et al., 1992; Mutti et al., 1999).



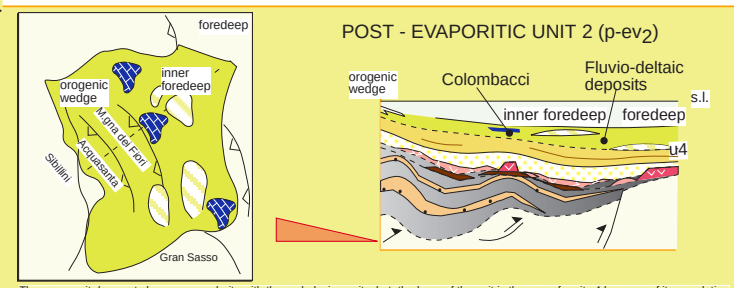
The gypsum-arenite horizon, that marks the important changes in the depositional characters and in the locus of deposition, is here suggested to concide with the intra-Messinian unconformity of the Apenninic foredeep. Evaporitic deposits and euxinic marls were resedimented; coarse-grained turbidites appear. In the SLB, no sharp angular unconformity marks this important regional unconformity; the structures are preferentially sealed because of the high sediment supply and the high subsidence rates. An inner foredeep (Artoni et al., 2001) was developing north and west of the M.gna dei Fiori anticline.

The importance and the widespread occurrence of the intra-Messinian unconformity in the Apenninic foreland is associated to a significant uplift and relief rejuvenation of the Apennines that favoured coarse-grained sediment production and transfer to the deepest and more subsiding portion of sedimentary basins, such as the SLB.

u4



The base of p-ev$_2$ unit is marked by coarse-grained and lenticular sandstone bodies (11) showing depositional characters of fluvio-deltaic systems. Individual beds have a variable lateral continuity and form packages up to ten meters thick with large-scale traction bed-forms and mud drapes (12). The packages are mutually erosive and are interlayered or gradually turn into dark grey clays with thin to very thin beds of fine-grained rippled sandstones that, very often, show hummocky type cross stratification (13). These sandstone bodies generally form three fining and thinning upward cycles, with an overall transgressive trend. They pass upward and laterally to clays and marls, massive or laminated, containing thin limestone beds (Artoni, 1993), the "colombacci" (14). Usually interpreted as carbonate precipitates in lacustrine environments, internal laminations suggest the resedimented characters of the colombacci beds.



The p-ev$_2$ unit does not show any angularity with the underlaying units; but, the base of the unit is the unconformity 4 because of its correlation to similar event in the adjacent area. In fact, sediment feeding systems were localized to the south, close to the Gran Sasso Range (Ghisetti & Vezzani, 1988; Centamore et al., 1991) and Montagna della Maiella (Crescenti et al., 2002), where lacustrine and alluvial fan deposits unconformably cover the thrusted lower Messinian turbidites (Accordi et al., 1969; Cipollari et al., 1999). A similar unconformity is also detected in the Apennine foredeep to the north (Roveri et al., 1998, 2001). The ongoing thrusts motion and the progressive anticline growth caused a generalized uplift of the foredeep basin creating smaller, confined basins. The p-ev$_2$ unit represents this final stage of Messinian foreland evolution. The Montagna dei Fiori-Montagnone anticline became part of the Apennine orogenic wedge.

CONCLUSIONS

1- The Southern Laga Basin (SLB) contains four Messinian stratigraphic units that show close similarities with the Messinian succession of the Northern Apenninic foreland. Even in a radiply subsiding basin, such as the SLB, the Messinian shows four physical stratigraphic units bounded by angular unconformities or sharp changes in depositional characters.

2- The Messinian SLB was not a persistent deep-water turbiditic basin; once accreted to the orogenic wedge, its bathymetry decreased. This is the phase represented by p-ev$_2$ unit. Probably, a first shallowing of the basin occurred during the evaporative event, ev, when probable deltaic-related turbiditic deposits (Mutti, 1999 pers. comm.) predate the deposition of gypsum-bearing deposits. Laminated gypsum-siltite beds occur within these deposits. They are commonly interpreted to be deposited in shallow-water environment; however, the clastic texture of this laminated gypsum poses doubts on the precise depositional environment (shallow or deep water) and stratigraphic position (lower or upper evaporites).

3- The four unconformity bounded units represent depositional events that testify a progressive restriction of the basin caused by Messinian tectonic pulses. Elsewhere in the Apennninic foredeep, it is well documented the presence of the intra-Messinian unconformity sealed by fluvio-deltaic deposits of p-ev$_1$ and p-ev$_2$ units. In the SLB, this unconformity might be represented by the appearance of gypsum-bearing horizon (unconformity u3). However, if future sedimentological and isotopical studies will reveal that the laminated gypsum-siltite facies have fresh water influx, thus they likely belong to the upper evaporites, the intra-Messinian unconformity should coincide with the unconfonity 2 (u2).

4- The four Messinian units record the tectonic and depositional evolution of the SLB. The evolution is mainly related to the growth of the Montagna dei Fiori-Montagnone anticline, representing a good outcrop example of an external foreland ramp evolving through time into a foredeep basin and, finally, a wedge-top basin. This basin evolution occurs during important phases of deformation of the whole Apenninic foreland basin. This suggests a synchronous tectonic activity in all the sectors of the Apenninic foreland, from wedge-top basin to the external ramp, and, probably, in the whole Mediterranean regeion.

MAIN REFERENCES

Artoni A. (1993). Ph. D. thesis. Universita' di Parma.
Bassetti M.A. (2000). Mem. Scl. Geol. Padova, 52.
Bigi S., Calamita F., Cello G., Centamore E., Deiana G., Paltrinieri W., Pierantoni P.P. & Ridolfi M. (1999) . J. Petroleum Geol, 22, 1.
Calamita F., Cello G., Centamore E., Deiana G., Micarelli A., Paltrinieri W. & Ridolfi M. (1991) . Studi Geol. Camerti, Vol. Spec., 1991/1.
Cantalamessa G., Centamore E., Chiocchini U., Micarelli A. & Potetti M. (1982) . Mem. Soc. Geol. It., 24.
Cantalamessa G., Centamore E., Chiocchini U., Micarelli A., Potetti M. & Di Lorito L. (1986). In: Centamore E. & Deiana G. (Eds.) - "La Geologia delle Marche". Studi Geologici Camerti. Vol. Spec.
Casero P., Artoni A. & Rossato A. (1996) In: Boccaletti M., Gelati R. & Papani G. (eds.): Neogene basin evolution and tectonics of Mediterranean area. RCMNS - Basin evolution an tectonics Work Group. Interim Coll.; Rabat, April 7-8.
Centamore E., Cantalamessa G., Micarelli A., Potetti M., Berti D., Bigi S., Morelli C. & Ridolfi M. (1991). St. Geol. Cam., Vol. Spec., 1991/1.
Cipollari P., Cosentino D., Esu D., Girotti O., Gliozzi E. & Praturlon A. (1999). Palaeogeo. Paleoclim. Paleoeco., 151, 149-166.
Crescenti U., Biondi R., Raffi I. & Rusciadelli G. (2002). Boll. Soc. Geol. It., Vol. Spec. 1.
Krijgsman W., Fortuin A.R., Hilgen F.J. & Sierro F.J. (2001). Geol., 140.
Mutti E., Nielsen T.H. & Ricci Lucchi F. (1978). In Stanley D.J. & Kelling G. (eds.); Sedimentation in submarine canyons, fans and trenches. Hutchins & Ross, Dowden.
Mutti E., Tinterri R., Benevelli G., di Biase D. & Cavanna G. (2003) . Marine and Petroleum Geology, 20, 733-755.
Ori G.G., Serafini G., Visentin C., Ricci Lucchi F., Casnedi R., Colalongo M.L. & Mosna S. (1991) In: Agip-EAPG (eds.) - 3rd EAPG Conference, Florence May 26-30.
Ricci Lucchi F., Bassetti M.A., Manzi V. & Roveri M. (2002). St. Geol. Camerti, 1.
Rossi M., Rogledi S., Barbacini G., Casadei D., Iaccarino S. & Papani G. (2002). Boll. Soc. Geol. It., Vol. spec. 1.
Roveri M., Bassetti M. & Ricci Lucchi F. (2001). Sed. Geol., 140.
Roveri M., Manzi V., Bassetti M.A., Merini M. & Ricci Lucchi F. (1998). Gior. Geol., 60.

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