



## TECTONO-SEDIMENTARY BURIAL EVOLUTION OF THE MODENA-BOLOGNA APENNINES: CONSTRAINTS FROM COMBINED ORGANIC MATTER, CLAY MINERAL AND STRATIGRAPHIC-STRUCTURAL DATA OF THRUST-TOP BASINS

### EVOLUZIONE DEI CARICHI TETTONICO/SEDIMENTARI DELL'APPENNINO MODENESE-BOLOGNESE: VINCOLI DALLO STUDIO DELLA MATERIA ORGANICA, DELLA MINERALOGIA DELLE AGILLE E DI DATI STRATIGRAFICO-STRUTTURALI DI BACINI DI THRUST-TOP

F. BOTTI <sup>(1)</sup>, L. ALDEGA <sup>(2)</sup> & S. CORRADO <sup>(2)</sup>

KEY-WORDS: TECTONIC/SEDIMENTARY BURIAL, VITRINITE REFLECTANCE, ILLITE/SMECTITE MIXED LAYERS, THERMAL MODELLING, MODENA-BOLOGNA APENNINES.

PAROLE CHIAVE: CARICHI TETTONICO/SEDIMENTARI, RIFLETTANZA DELLA VITRINITE, STRATI MISTI ILLITE/SMECTITE, MODELLAZIONE TERMICA, APPENNINO MODENESE-BOLOGNESE.

#### 1. BACKGROUND

Two different turbiditic successions, known as Mt. Cervarola Sandstones (Burdigalian) and Granaglione Sandstones (Langhian) outcrop between the Scoltenna R. and Silla R. valleys (Northern Apennines). They represent the core of the Modena-Bologna segment of the Northern Apennines fold and thrust belt, which is made up of different structural Units (Fig.1). From the upper to the lower Unit, they are:

- the undifferentiated Ligurian Units (Val Baganza Ophiolitic Unit and Monghidoro Unit);
- the Modino Unit, namely the Ventasso sub-Unit (cfr. Sestola-Vidiciatico Unit of BETTELLI *et al.*, 1989);
- a series of thrust sheets that segmented a pre-constituted tectonic stack formed by the Mt. Cervarola and Granaglione Sandstones, at the bottom, and the Ventasso sub-Unit, at the top.

The geometrical relationship between the Cervarola and Granaglione successions is shown in Fig.2. This scheme proposes two representative cross-sections localized between Mt. Cimone and Roncoscaglia (A) and between Lake Pratignano and Rocca Corneta (B). The timing of deformation, proposed by BOTTI (2002), can be summarized as follows:

- an early deformative event in which the Ventasso sub-Unit was thrust onto the Cervarola and Granaglione Sandstones (MARTINI & PLESI, 1988; CHICCHI & PLESI, 1995). Thrusting of Ventasso sub-Unit onto the Cervarola Sandstones occurred in post-Burdigalian times (Biozones MNN3a-

MNN3b), while the emplacement of the Ventasso sub-Unit onto the Granaglione Sandstones took place in post-Langhian times (Biozone MNN4b);

- a late deformative event in which Cervarola Sandstones were thrust over the Granaglione Sandstones which were subsequently deformed together with the Ventasso sub-Unit. Moving from hinterland to foreland, five thrust sheets crop out: Corno alle Scale thrust sheet, Mt. La Nuda-Rocca Corneta thrust sheet, Mt. Grande thrust sheet, Mt. Pizzo thrust sheet and Pennola thrust sheet.

The youngest deformation is constrained by the age of the Marnoso-Arenacea Fm. (cfr. Castiglione dei Pepoli Sandstones - MNN5a) which is overthrust by Pennola thrust sheet.

The time constraints described above define a piggy-back sequence of deformation.

#### 2. AIMS AND METHODS

The main goal of this contribution is to provide new thermal constraints (vitrinite reflectance and percentage of illitic layers in illite/smectite mixed layers) for the reconstruction of the Neogene-Quaternary evolution of this sector and to define the evolution through time of sedimentary/tectonic loadings.

The methodologies adopted are: (i) field geology, stratigraphic and structural analyses, (ii) optical analysis of the organic matter dispersed in the sediments (iii) clay mineralogy determined by X-ray diffractometry and (iv) thermal modelling.

##### 2.1. ORGANIC MATTER AND CLAY MINERAL DATA

A suite of 31 samples for vitrinite reflectance (Rm%) analysis were mainly collected in stratigraphic sequence in the Cervarola Sandstones from the upper thrust sheet (18 samples for a ~2,000 m thick succession) and in the Granaglione Sandstones (13 samples for a ~500 m thick succession) from the lower thrust sheets. One sample comes from the small tectonic window of Marnoso-Arenacea Fm. to the North of the village of Lizzano in Belvedere which is

(1) Dipartimento di Scienze della Terra, Università degli Studi di Pisa, Via S. Maria, 53

(2) Dipartimento di Scienze Geologiche, Università degli Studi "Roma Tre", L. S. Leonardo Murialdo, 1 - 00146 Roma corresponding author: aldega@uniroma3.it

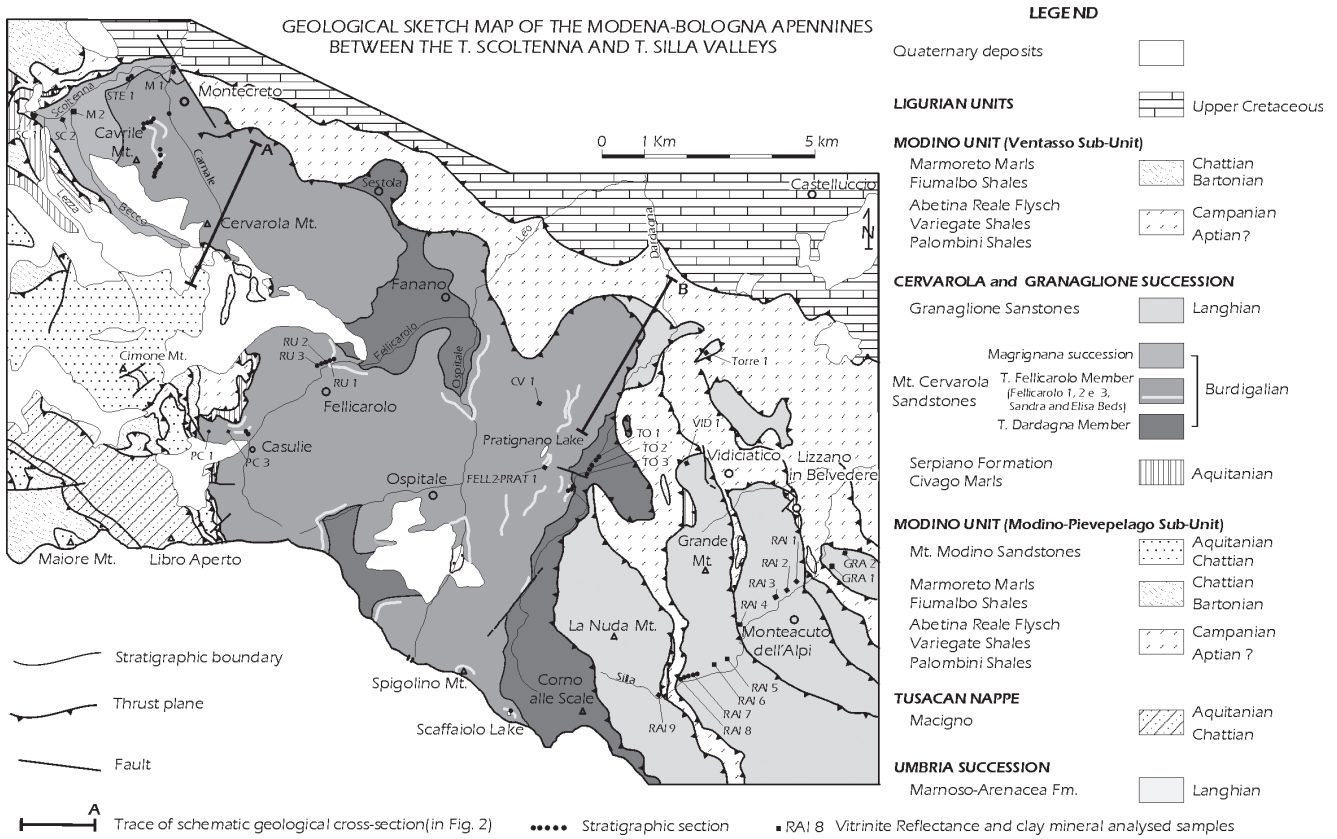


Fig. 1 – Geological sketch map of Northern Apennines comprised between Scoltenna R. and Silla R. valleys with vitrinite reflectance and clay minerals samples location.

Schema geologico dell'Appennino settentrionale compreso tra le valli del T. Scoltenna e del T. Silla con ubicazione dei siti di campionamento relativi alle analisi di riflettanza della vitrinite e mineralogia delle argille.

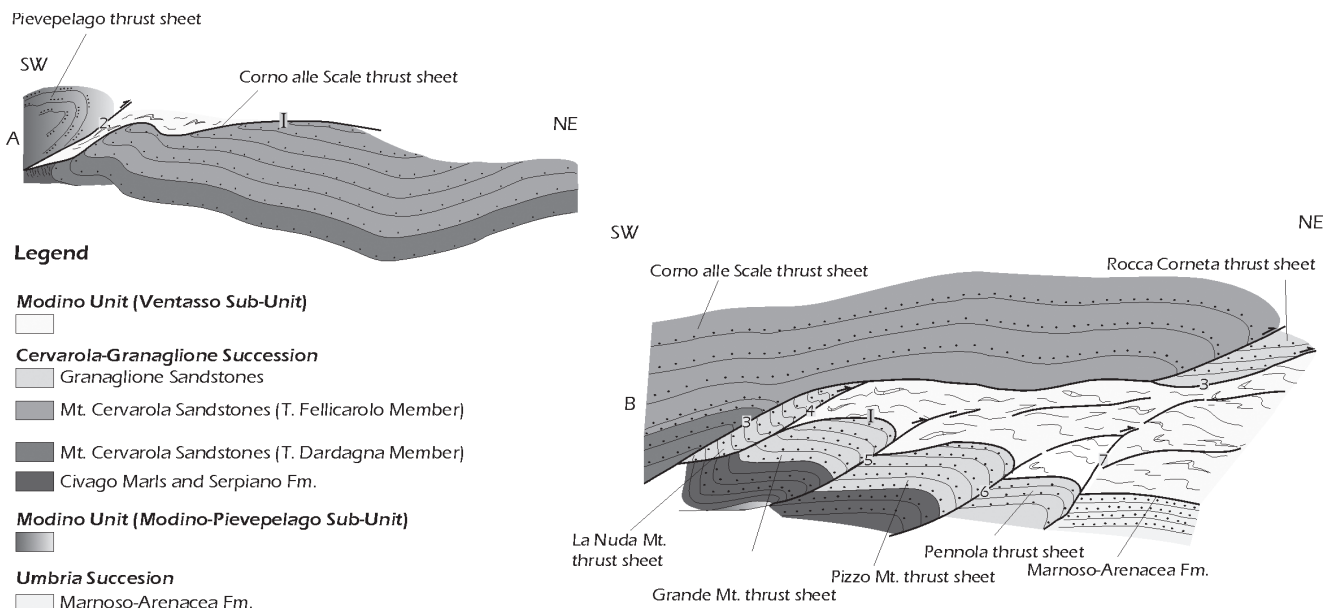


Fig. 2 – Schematic geological cross-sections through Corno alle Scale and Granaglione areas (not in scale). (A) Mt. Cimone-Roncoscaglia and (B) Lake Pratignano - Rocca Corneta. The numbers indicate thrust sequence referred to tectonic Units (Roman number) and thrust sheets (Arabic numbers). Traces are shown in Fig. 1.

Sezioni geologiche schematiche attraverso i settori di Corno alle Scale e Granaglione (non in scala). (A) M. Cimone-Roncoscaglia e (B) Lago di Pratignano - Rocca Corneta. I numeri indicano la sequenza dei thrust riferita alle Unità tettoniche (numero romano) e ai thrust sheets (numeri arabi). Le tracce delle sezioni geologiche sono rappresentate in Fig. 1.

overthrust by the lower thrust sheets. The samples were mainly collected from the Ta-Tc intervals of the Bouma sequence of thin-fine turbiditic beds, thick arenaceous-pelitic beds, arenaceous-pelitic megaturbidites, and arenitic F6 facies (*sensu* MUTTI, 1992) of thick arenaceous-pelitic beds. The 24 samples for X-ray semiquantitative analysis (on bulk samples and <2 mm and 2-16 mm grain-size fractions) were collected in the same sites favouring the Tc and Td intervals of the Bouma sequence of thin-fine turbiditic beds and black shales.

In the Cervarola Sandstones of the Corno alle Scale thrust sheet, Rm% data of autochthonous fragments slightly decrease from the bottom to the top of the succession with mean values between 1.20% and 1.01% that show only local exceptions. The illitic content in I/S mixed layers, measured in the <2 mm grain-size fraction, increases from 80% to 85% from the top to the bottom of the succession, showing good correlation with Rm% data according to POLLASTRO (1993).

In the lower thrust sheets, a slight decrease in organic maturity is recorded from hinterland to foreland. The highest mean Rm value (1.54%) is recorded in the innermost thrust sheet (Mt. La Nuda). Decreasing Rm% values between 1.38% and 1.48% were measured in the two intermediate thrust sheets (respectively Mt. Grande e Mt. Pizzo). A slightly lower value derives from the most external horse, made up of Granaglione Sandstone (Pennola thrust sheet with Rm=1.35%). A slight increase with depth of the illitic layers in I/S mixed layers is also testified in the lower thrust sheets (80%-85%). Furthermore it is possible to recognise a decrease of the illitic content (from 90% to 80%) from the inner to the outer thrust sheet.

The Marnoso-Arenacea Fm., cropping out in the tectonic window in the footwall of the Granaglione Sandstones, shows an even lower value (Rm=1.22%).

### 3. THERMAL MODELLING

Thermo-structural modelling was performed using BASIN MOD-1D SOFTWARE FOR WINDOWS (1996). This software allows the reconstruction of the burial and thermal evolution of sedimentary sequences both in undeformed and deformed conditions from geological data (e.g., age of sedimentary sequences and tectonic/erosional events, pure and mixed lithologies, thicknesses, porosity, permeability and thermal conductivity of sedimentary sequences). These data derive from the integration between the database of physical features provided by the modelling software and the geological information coming from the regional literature and the new stratigraphic and structural data described in the geological background.

Burial curves were corrected for decompaction according to SCLATER & CHRISTIE'S method (1980) and were calibrated with Rm% and I% in I/S according to the geothermometre's correlation proposed by POLLASTRO (1993).

Thermo-structural modelling allowed the

reconstruction of:

- the tectonic loading experienced by the Cervarola succession and caused by the emplacement of the Modino (Ventasso sub-Unit) and Ligurian Units, today partially eroded;
- the tectonic loading experienced by the Granaglione succession and caused by the emplacement of the Ventasso sub-Unit, the Corno alle Scale thrust sheet, and the overlying allochthonous Units;
- Corno alle Scale thrust geometry and its past extension in the southeast sector of the study area where erosion has exposed the Granaglione Sandstones.

The Cervarola and Granaglione successions experienced different thermal histories. The Cervarola succession experienced a tectonic loading of 3,500 m (with a geothermal gradient of 30°C/Km and a surface temperature of 10°C - VENTURA *et al.*, 2001). The emplacement of allochthonous Units (namely Ligurian and Modino Unit) took place in post-Burdigalian times and overlaid the Cervarola succession for ~10 My (VENTURA *et al.*, 2001). According to this modelling, the Cervarola Sandstones experienced maximum palaeo-temperatures that never exceeded 170°C during the tectonic loading. This formation reached a temperature of ~110°C at ~3.6 My, in agreement with apatite fission track data from two samples collected close to Mt. Cervarola (VENTURA *et al.*, 2001).

The Granaglione succession underwent the emplacement of both Corno alle Scale Thrust Sheet and the allochthonous Units that caused its instantaneous deep burial (with a geothermal gradient of 30°C/Km and a surface temperature of 10°C - VENTURA *et al.*, 2001). It exerted a progressively decreasing loading from hinterland to foreland comprised between 5,200 m (nowadays recorded in the Mt. La Nuda thrust sheet) and 4,800 m (nowadays recorded in the Mt. Grande and Mt. Pizzo thrust sheets). This decrease could be due to the progressive tectonic thinning of the Corno alle Scale thrust sheet related to the ramp-and-flat geometry of its basal thrust (Fig.3). No influence on tectonic loading seems to be exerted by the progressive development of the lower thrust system.

In the end, even if a precise comparison with maximum

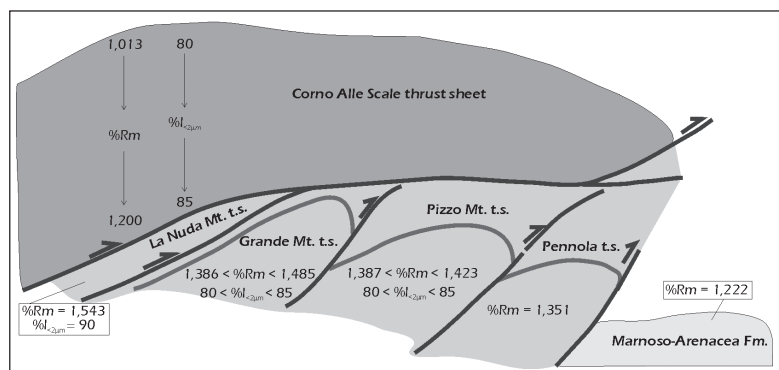


Fig. 3 - Structural sketch of the study area and relative palaeogeothermal data: vitrinite reflectance (%Rm) and %I in I/S mixed layers. This sketch describes a situation before the beginning of exhumation.

Schema strutturale del settore investigato con relativi dati paleogeotermici: riflettanza della vitrinite (%Rm) e %I negli strati misti illite/smectite. Lo schema descrive una situazione precedente all'inizio dell'esumazione.

burial values provided by VENTURA *et al.* (2001) is not possible, their values estimated in the study area are slightly higher (~5-6 km) than ours (~3.5-5 km). This difference could be due both to an underestimate in modelling of the role of the parameter time as a main cause of vitrinite maturation and to timing of deformation (onset of maximum burial Burdigalian-Langhian age in our study and Seravallian age in VENTURA *et al.*, 2001). Nevertheless a cross-check of the exact stratigraphic position of FT samples in the Cervarola succession could allow to slightly reduce this gap.

## REFERENCES

- BASIN MOD® 1-D FOR WINDOWS™, VERSION 5.4 SOFTWARE (1996) - *A Basin Analysis Modelling System*. Platte River Associates, Denver, CO.
- BETTELLI G., BONAZZI U., FAZZINI P., GASPERI G., GELMINI R. & PANINI F. (1989) - *Nota illustrativa alla Carta geologica schematica dell'Appennino modenese e delle aree limitrofe*. Mem. Soc. Geol. It., **39** (1987), 487-498.
- BOTTI (2002) - *Studio stratigrafico, petrografico e strutturale della successione delle Arenarie del M. Cervarola e rapporti con le successioni e unita' limitrofe (Appennino modenese-bolognese)*. PhD thesis, Università degli Studi di Pisa.
- CHICCHI S. & PLESI G. (1995) - *La struttura della finestra di Gazzano (Val Dolo, Appennino reggiano-modenese)*. Acc. Naz. Sci. detta dei XL, Atti del convegno "Rapporti Alpi-Appennino", **14**, 195-227.
- MARTINI G. & PLESI G. (1988) - *Scaglie tettoniche divelte dal Complesso di Monte Modino e trascinate alla base delle Unità subligure e liguri: gli esempi del M. Ventasso e del M. Cisa (Appennino reggiano)*. Boll. Soc. Geol. It., **107**, 171-191.
- MUTTI E. (1992) - *Turbidite sandstones*. Agip S.p.A., San Donato Milanese, 165 pp.
- POLLASTRO R.M. (1993) - *Consideration and applications of the illite/smectite geothermometer in hydrocarbon-bearing rocks of Miocene to Mississippian age*. Clays and Clay Minerals, **41**, 119-133.
- SCLATER J.G. & CHRISTIE P.A.F. (1980) - *Continental stretching: an explanation of the post-mid-cretaceous subsidence of the central north sea basin*. J. Geoph. Research, **85**, 3711-3739.
- VENTURA B., PINI G.A. & ZUFFA G.G. (2001) - *Thermal history and exhumation of the Northern Apennines (Italy): evidence from combined apatite fission track and vitrinite reflectance data from foreland basin sediments*. Basin Research, **13**, 435-448.

**Manoscritto definitivo consegnato il 14 aprile 2003**

**Finito di stampare il 23 maggio 2003**

