INTRODUCTION

The Northern Apennines foredeep successions are some of the most important syn-orogenic deposits, involved in the Miocene collisional processes related to development of Northern Apennine fold-and-thrust belt. Three different turbiditic successions, knows as Macigno Fm, Montagnaccia Fm and Marnoso-Arenacea Fm, outcrop in the Trasimeno Lake area (Central Italy), where the remnants of the Tuscan, Tuscan and Umbria transition and Umbria-Marche Domains are deformed in a sequence of structural units. In Tuscan-Umbria Appennine the most important units -segmented into top-to-the-NE thrust sheets- are from top to bottom:

- Ligurian Units (Monti Rognosi Ophiolitic Unit) present in limited and confined exposures;
- Tuscan Units, namely Tuscan Nappe and Acquerino Unit, formed by Rupelian-Chattian pelagic deposits (Scaglia toscana Fm) and Chattian-Aquitanian siliciclastic turbidites (Macigno Fm);
- Rentella Unit made up of Rupelian-Aquitanian pelagic and emipelagic deposits (Mt. Rentella Fm) and Aquitanian-Burdigalian siliciclastic turbidites (Montagnaccia Fm);
- Umbria-Romagna Unit represented by the complete foreland/foredeep succession, from Triassic evaporites to Langhian siliciclatic turbidites (Marnoso-Arenacea Fm).

The geometrical relationship between these tectonic units is shown in Fig.1.

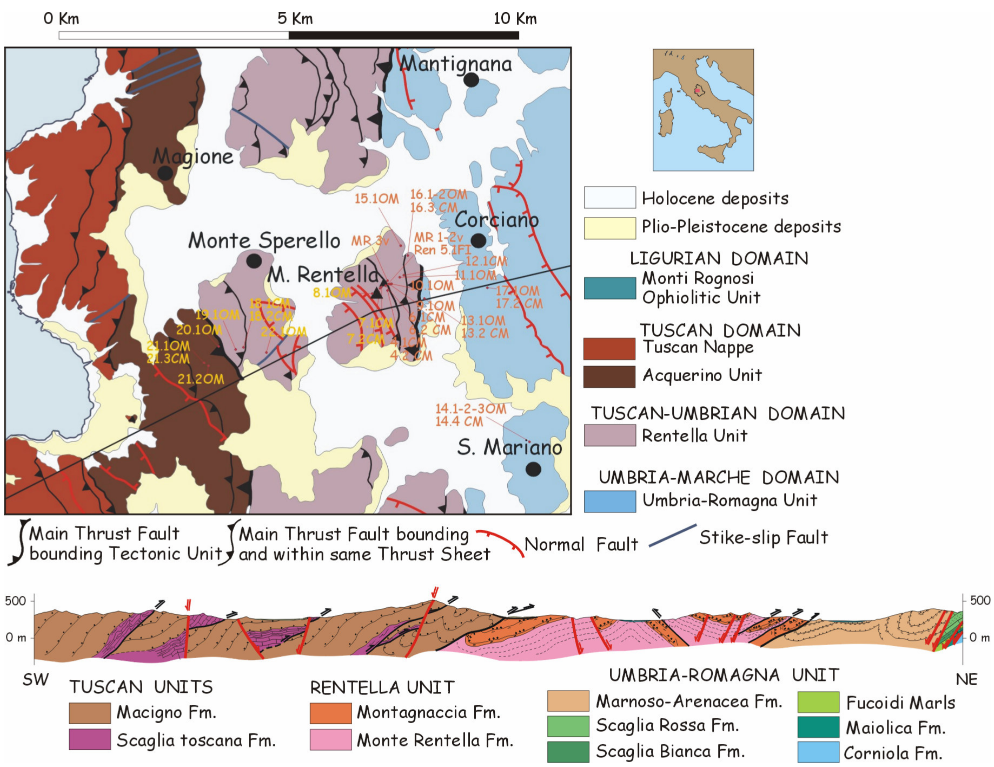

Fig. 1. Schematic structural map and section through the study area. Samples location in the map: OM stands for organic matter and CM for clay mineralogy sampling.

The timing of deformation, can be summarized as follows:

- thrusting of Ligurian Units onto Tuscan Nappe; in this segment of the Northern Apennine the tectonic event occurred in post-Aquitanian times (Biozones MNN1d).
- Tuscan Domain involvement in the Miocene Appennine accretionary/collisional system; in this area the Tuscan Nappe basal thrust climbs up to the Scaglia toscana Fm and the thrusting of the Tuscan Nappe onto Tuscan-Umbria and Umbria-Marche Domains is Burdigalian-Langhian in age (Biozone MNN2b and MNN4 respectively);

- Post-Langhian migration of compressive deformation front in the Tuscan-Umbria and Umbria-Marche Domains;
- Plio-Pleistocene extensional tectonics that segmented the structural stack with the development of the Valtiberina and Val di Chiana intermountain basins.

AIMS AND METHODS

The main goal of this contribution is to provide new structural and paleo-thermal constraints in order to:

1. define the accretionary mechanisms with special respect to the structural and thermal evolution of shear zones of regional relevance;
2. constrain the thermal evolution of regional thrust sheets that might represent outcropping analogous structures of buried traps for hydrocarbons accumulation.

The methodologies adopted are: (i) field geology, stratigraphic and structural analyses, (ii) microstructural study, (iii) optical analysis of the organic matter dispersed in the sediments with special respect to vitrinite reflectance measurements, (iv) XRD analysis on clay minerals to investigate mixed-layer illite-smectite composition.

Concerning the first aim we focussed our attention on the Rentella Unit, where several compressive shear zones developed during shallow level accretion. The most complete and well-exposed brittle shear zone (hereafter reported as **MRSZ**), with ramp geometry, crops out in the east side of Mt. Rentella, where the Mt. Rentella Fm (Rupelian-Aquitanian) thrust onto the Montagnaccia Fm (Aquitanian-Burdigalian).

MRSZ MESOSTRUCTURAL DATA

The MRSZ, striking roughly N160/170° with a dip of 60/70° toward SW, is marked by a ca. 50 m thick disrupted zone, featuring a variably penetrative scaly foliation in the marls (Mt. Rentella Fm). Based on mesoscale fabric, MRSZ can be divided, from bottom to top, into three zones: footwall damage zone (FDZ), about 12 m thick; core zone (COZ), about 3.5 m thick; hangingwall damage zone (HDZ), about 28 m thick.

The **FDZ** develops in the Montagnaccia Fm**.** Deformation is accommodated by a well-developed fractures and dissolution foliation showing a spacing ranging from 2 to 5 cm and web structures. Fractures are arranged in three main coeval sets:

- two sets dip 30° (1) and 75° (2) towards the NE, both striking N150°-N180°.
- the third set (3) strikes N130°-160°, dips 20°/40° towards the SW and it generally bears out a strong striation lineation (strike: N040°-060° and top-to-the-NE sense of shear).

(1), (2) surfaces can be interpreted as R, R' Riedel planes associated with a main shear surface oriented as the (3) set, giving a top-to-the-NE sense of shear.

The **COZ** develops in the upper part of the Mt. Rentella Fm. A continuous to scaly dissolution cleavage (spacing: 1 mm; strike from N160° to 110°), brittle S-C structures top-to-the-E-NE and associated calcite veins are the principal tectonic features. Vein density in the fault core is up to two times higher that observed in the damage zone, suggesting extremely efficient fluid circulation focused in the fault core. Both foliation and veins are strongly folded by sub-isoclinal to open asymmetric folds. A boudinage and the related necking of the veins along their limbs developed. These folds arrangement is typical of shear zones with a prevailing component of simple shear. The cylindrical best fit of the fold axes represents the plane of main shear, i.e. the thrust fault. The obtained shear plane is correlated with good approximation with the C-planes (N162°, 45°SW).

The **HDZ** develops in the central-upper portion of the Mt. Rentella Fm (Chattian: Biozone MNP25b-MNN1). The transition from HDZ to the undeformed Mt. Rentella Fm (Chattian-Aquitanian: Biozone MNP24-MNN1) is sharp and characterized by low-angle reverse faults, as detected by biostratigraphic analyses. The fabric of HDZ is characterized by well-developed S-C brittle structures. The S-planes are represented by anastomozing, dense (2-5 mm) and discontinous dissolution cleavage (N140°-N180°, 50-80° toward SW and W), forming high to low angles with the C-planes. The C-planes (N150°-170°, 40°-50° toward SW) show a texture similar to S-planes, but are generally filled by calcite veins. Walls of the veins feature a well-developed lineation on calcite crystals striking from N060° to N110°.

Along the same C-surface a progressive strike variation of the calcite fibres from N020° to N090° has been observed.

MRSZ MICROSTRUCTURAL DATA

In the fabric of the **FDZ**, up to 2 cm thick extensional veins are characterised by antitaxial infilling of fibrous calcite. Vein walls are sharp and planar. Calcite fibres are free of inclusions and not curved. The median line is highly discontinuous and, when visible, is marked by either small sandstones chips or by the boundary between different calcite crystals. Web structures are characterised by grain-size reduction.

In the **HDZ** most of the veins are arranged along the C-type shear planes that accommodate deformation. Only locally, S-parallel veins occur, being more discontinuous as an effect of extensive, shear-related folding. C-parallel veins show regular, sharp and sub-planar boundaries with the host rock and are characterized by many crack-and-seal episodes.

Most episodes are clearly shear-related, the texture being similar to that described in the dilational jogs of Sibson (1987) or for the striped veins of Koehn and Passchier (2000). MRSZ veins show long and thin stripes of calcite crystals, separated by crack-seal bands parallel to the jog where first opening occurred. Jogs of different veining episodes show frequently a staircase shape that helps defining the shear sense (top-to-the-NE). Generally, S-foliation in the wall rock, marked by discontinuous pressure solution seams, makes very low angles with the C-planes and its deflection towards the C-planes is again consistent with top-to-the-NE sense of shear.

Veins are locally "dirtied" by chips of wall rock marls, trapped between different crack-seal episodes. Generally, these wall fragments accommodate deformation through dilatational jog structures (Sibson 1987), always consistent with the main top-to-the-NE sense of shear. Striped veins in the **COZ** are frequently deformed and disrupted by flexural slip folding. Fold overturning and facing are always consistent with top-to-the-NE sense of shear. Locally, repeated folding and shear-related deformation allow to complete disruption of veins, giving way to brecciated structures. C-surfaces, and associated veins, are arranged in systems that can be frequently and easily associated to specific Riedel shear planes. The R, P and Y reconstructed setting, is always compatible with a top-to-the-NE sense of shear. Later episodes of fracture and mineralization, cutting sharply all striped veins, are characterized by thicker calcite veins with blocky texture. Their thickness can be up to twice as that of a single "striped episode". Infilling is made by up to 1 mm clear calcite blocky crystals. Following Burkhard (1992) classification, calcite twins in MRSZ veins (striped and blocky) can be described as of type II, that, in his model, suggest formation temperatures of 150-200°C for both vein systems.

ORGANIC MATTER AND CLAY MINERALOGY DATA

About thirty samples for vitrinite reflectance and XRD analyses were collected in:

- the siliciclastic turbidites (Macigno Fm) of the Tuscan Units;
- the pelagic and emipelagic deposits (Mt. Rentella Fm) and siliciclastic turbidites (Montagnaccia Fm) of the Rentella Unit;
- the siliciclatic turbidites (Marnoso-Arenacea Fm) of the Umbria-Romagna Unit.

Samples derive both from MRSZ and slightly deformed stratigraphic sections forming the main thrust sheets, far from regional shear zones.

The paleo-temperatures conversion for vitrinite reflectance data was obtained using the equation proposed by Barker and Pawlewicz (1994). Concerning clay mineralogy, I-S data were converted into paleo-temperatures adopting the Basin Maturity Chart of Merriman and Frey (1999).

Analysed kerogene is generally abundant, homogenous and mainly made up of well-preserved macerals, for the most part derived by wooden fragments of continental origin. They belong to humite-vitrinite group, with predominance of collotelinite and telinite fragments, and rarely to the inertinite group. Generally on each sample, one cluster of Ro-values was recognised; it is characterised by a Gaussian distribution with mean values between 0,30 and 0,60% placing in the immature to early mature stages of hydrocarbon generation field and with paleo-

temperature ranging from ca. 40 to 100°C. The highest values are recorded in the Rentella Unit directly at the footwall of the Tuscan Units under the influence of tectonic overburden.
XRD analyses of randomly-oriented whole-rock powder patterns show that sampled shales and sandstones are composed essentially of quartz, Na-plagioclase, calcite and phyllosilicates. Pyrite, and dolomite are also recorded in the Marnoso-Arenacea Fm. The <2 μm grain size fraction contains I-S mixed layers with an illite content between 63 and 76% indicating maximum paleotemperatures in the early diagenetic zone (maximum 100-110°C).

CONCLUSIONS

In the present study, we provided a new data-set of structural and thermal maturity indicators for the tectono-stratigraphic units that make up the backbone of the Northern Apennines in the Trasimeno area.
Concerning the main sedimentary successions, the independent methodologies supplied comparable maximum paleo-temperatures in the early diagenetic zone and in the immature to early-mature stages of hydrocarbon generation. They indicate a satisfactory match of different data sets in the main sedimentary successions that still preserve the thermal signature of the original foreland basin according to Ro% vs. I% in I-S mixed layers correlation proposed by Hillier et al. (1995).
Concerning the structural study of the shear zones, the veins formed during MRSZ evolution are due to episodic injection of fluids into the shear zone according to Koehn and Passchier (2000). The blocky texture of the later mineralization events may be due to a late, static crystallization of calcite, in absence of shear. Alternatively, the observation that blocky texture occur only in thicker veins, suggests that mineralization occurred during fast opening of a large fracture.
Blocky and striped veins both formed at the same temperature conditions, ranging from 150° to 200°C.
This range strongly contrasts with the vitrinite reflectance and mineralogical paleo-thermal parameters, which suggest the development of the MRSZ at shallow depths (ca. less than 3 km). Therefore, a source area for hot fluids located at deeper structural levels in the collisional prism is highly probable.

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