A 3D geological model of the Fossombrone area (Northern Apennines)

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ABSTRACT

The 3 dimensional representation of the sheet 280 Fossombrone (Geological Map of Italy at the 1:50,000 scale) represents the attempt to reconstruct and visualize geological data for a wide area (600 km^2). The area of the sheet 280 Fossombrone, which was surveyed by the Geological Survey of Italy in collaboration with the University of Urbino, has been selected for the great and direct availability of surface data combined with the availability of subsurface data (wells and seismics) kindly provided from ENI S.p.A. - div. AGIP.
The 3D model was built using the Digital Elevation Model and the outcropping geological data integrated with the subsurface data.
The first step towards the 3D model has been the reconstruction of a 2.5D representation of the outcropping geology; afterwards continuous 3D surfaces representing the same stratigraphic horizons or faults were built, using constraints from subsurface data.
The creation of the 3D geological model allows to better understand the geological structures at depth and to highlight the geological uncertainties both in space and time.

AIMS

The main purpose of the project is to better understand geological structures at depth to reduce geological uncertainties both in space (underground management) and time (natural hazard control), these uncertainties being fundamental issues for the scientific and administrative communities. It is possible to summarize these aims in four points:
- To Construct a three-dimensional geological model;
- To integrate outcropping geological data and subsurface data;
- To reduce geological uncertainties both in space and time;
- To produce a user-friendly visualization for non-geologist specialists.

KEY WORDS

3D visualization, 3D geological model, subsurface geometry, structural modelling, geological map, Umbria-Marche Apennines.

RIASSUNTO

La rappresentazione geologica tridimensionale del Foglio 280 Fossombrone (Carta Geologica d'Italia, scala 1:50.000) costituisce un primo tentativo di ricostruzione e visualizzazione dei dati geologici di una vasta area in un formato diverso dalle classiche rappresentazioni bidimensionali.
La scelta del foglio Fossombrone è strettamente connessa alla diretta disponibilità dei dati derivanti dal rilevamento geologico, eseguito dal Servizio Geologico d'Italia in collaborazione con l'Università di Urbino, e alla presenza, nell'intera area del foglio, di sondaggi profondi e di linee sismiche a riflessione rese disponibili da ENI S.p.A. - div. Agip. La ricostruzione del modello è stata sviluppata a partire dal modello digitale del terreno e dai dati geologici di superficie, opportunamente e necessariamente integrati dai dati di sottosuolo. L'elaborazione ha portato alla produzione, dapprima, di una mappa geologica 2.5D e successivamente, grazie ai vincoli forniti dai dati di sottosuolo, Alla costruzione di superfici 3D rappresentative di superfici tettoniche e di limiti geologici fra unità litostratigrafiche. Il modello geologico 3D così ottenuto fornisce, in modo immediato, una efficace comprensione dell'assetto geologico dell'area studiata.

GEOLOGICAL 3D MODEL OF THE FOSSOMBRONE AREA

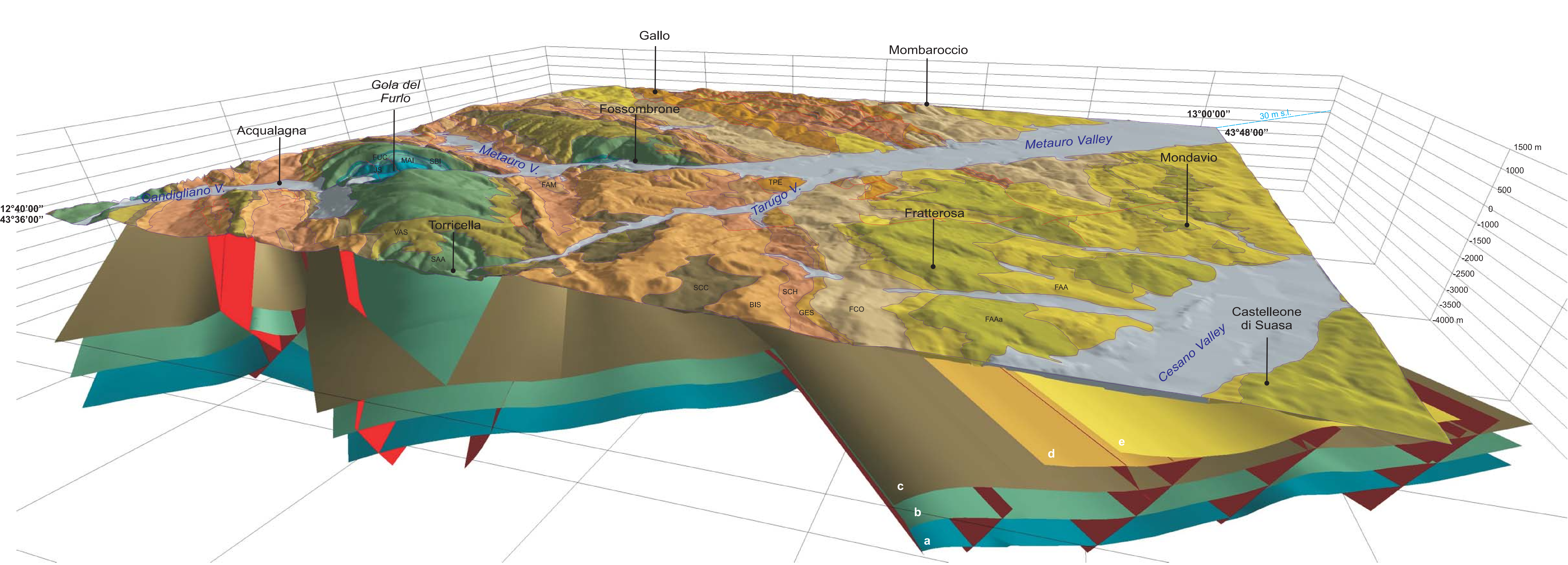
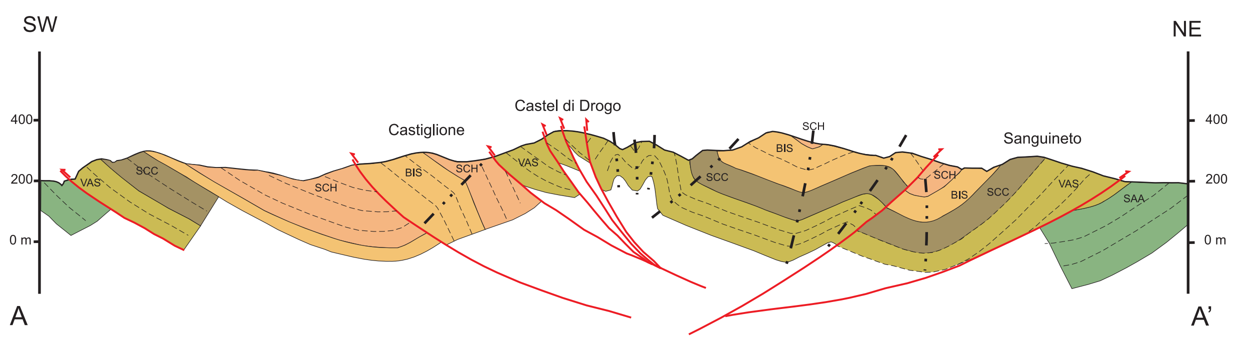
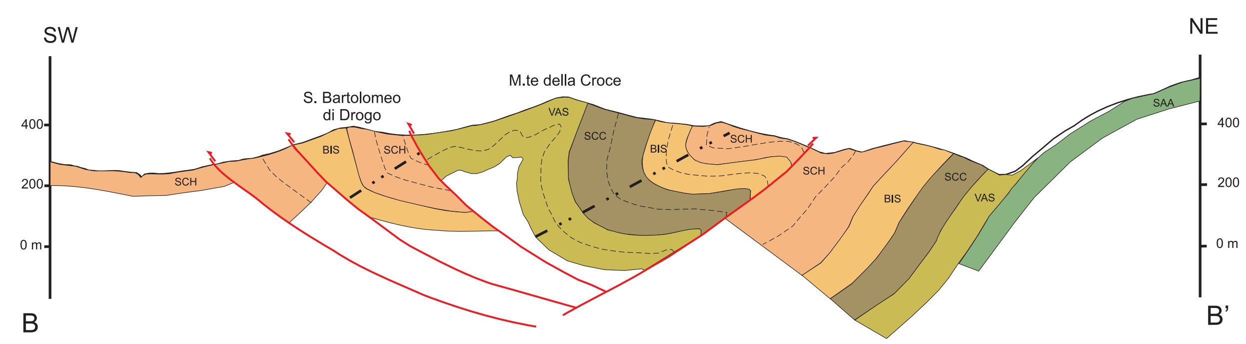
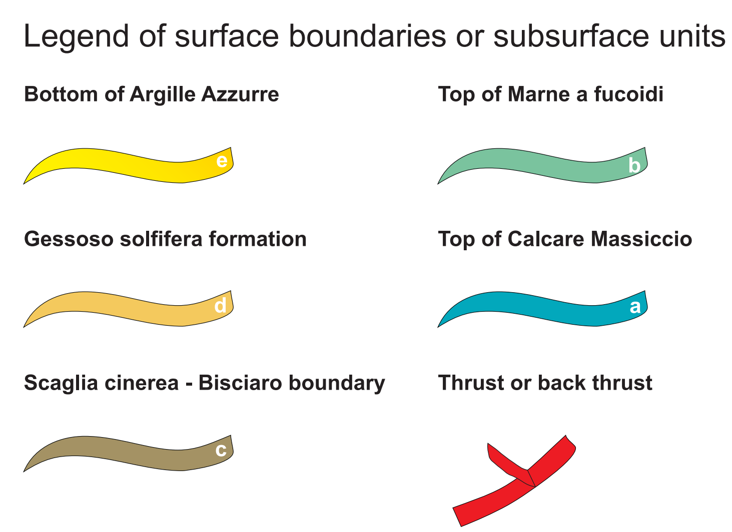
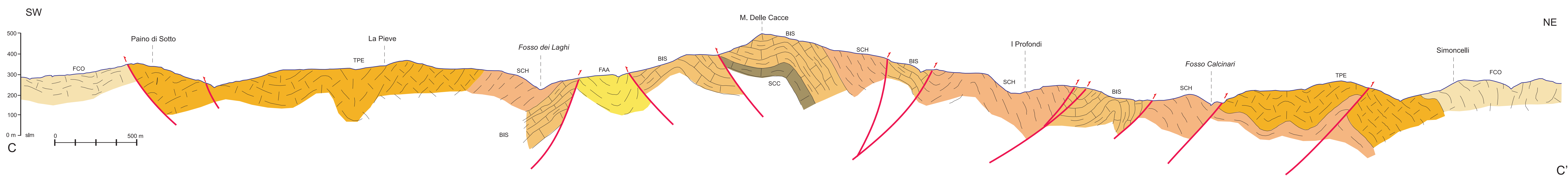


Fig. 1 - *Three dimensional geological model of the Fossombrone area and geological cross-sections (for the ubication see Fig. 2).*









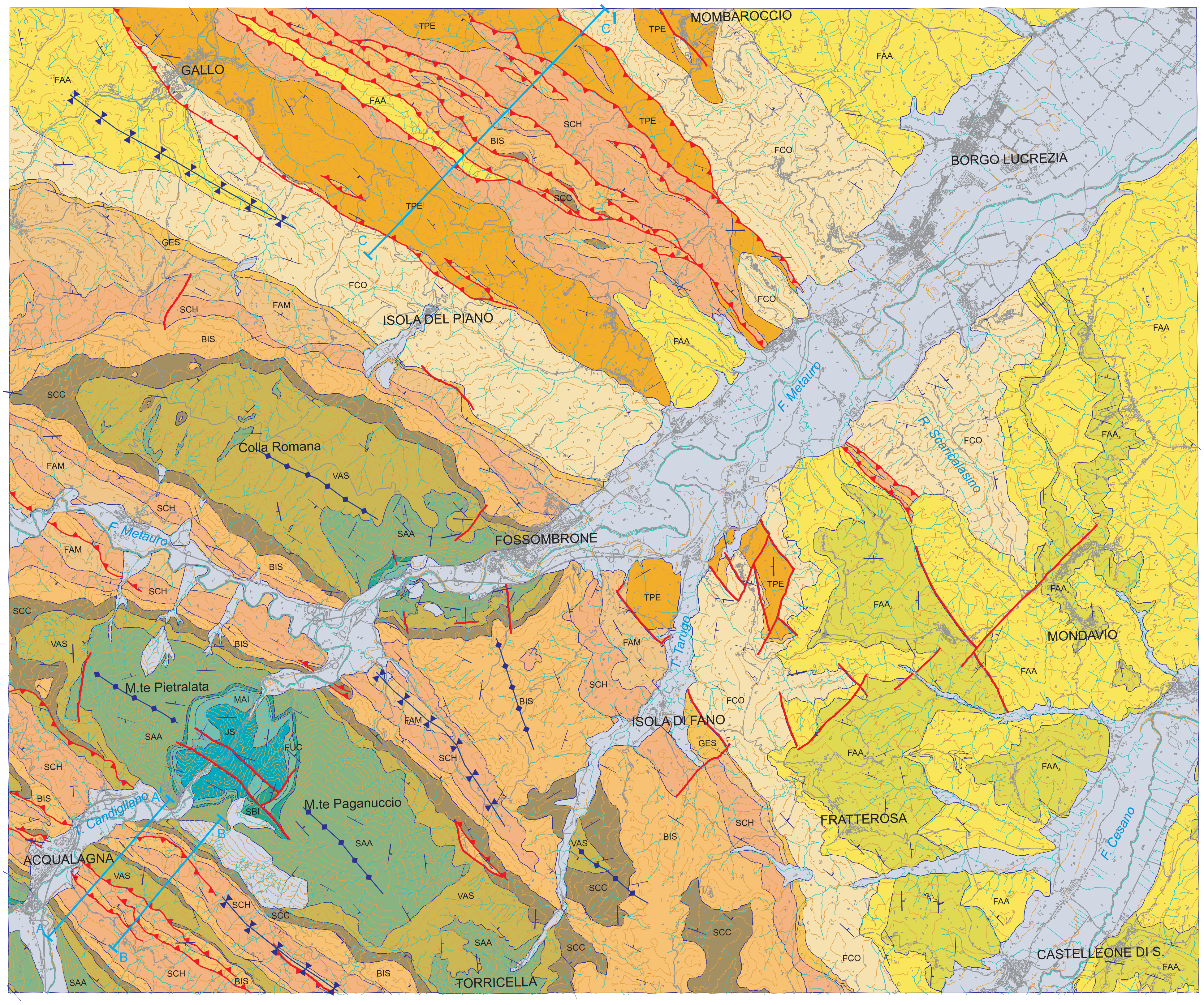


Fig. 2 - *Geological map of Fossombrone area (graphic by F. Pilato).*

Quaternary deposits (Q)
Alluvial plain, alluvial fan, slope waste deposits: gravels, sands and clayey sediments.
MIDDLE PLEISTOCENE-HOLOCENE

Argille azzurre (FAA, a)
Blue-grey clays (FAA) with sandstones (FAAa).
PLIO-PLEISTOCENE

Colombacci fm. (FCO)
Grey-red clays and sands with evaporitic limestones.
UPPER MESSINIAN

Gessoso-solfifera fm. (GES)
Grey silts and laminated marls, gypsum.
MIDDLE MESSINIAN

Tripoli unit (TPE)
Sands with microconglomeratic levels. Euxinic clays.
MESSINIAN

Marnoso-arenacea marchigiana fm. (FAM)
Arenaceous-pelitic turbidites.
TORTONIAN *p.p.*-MESSINIAN

Schlier (SCH)
Grey marls , locally calcareous marls.
UPPER LANGHIAN-TORTONIAN *p.p.*

Bisciaro (BIS)
Limestone and clay marls with chert.
AQUITANIAN *p.p.*-LANGHIAN

Scaglia cinerea (SCC)
Grey calcareous marls.
UPPER EOCENE-LOWER MIOCENE *p.p.*

Scaglia variegata (VAS)
Red-gray to green marly limestones and calcareous marls.
UPPER EOCENE *p.p.*

Scaglia rossa (SAA)
Pink-red micritic limestones with marly limestones and marls.
TURONIAN *p.p.*-EOCENE *p.p.*

Scaglia bianca (SBI)
White micritic limestones with bands and layers of chert.
ALBIAN *p.p.*-CENOMANIAN *p.p.*

Marne a fucoidi (FUC)
Marls, marly limestones and limestones; bituminous shales.
APTIAN *p.p.*- ALBIAN *p.p.*

Maiolica (MAI)
White micritic limestones with thin interbedded dark pelites.
TITHONIAN *p.p.*-APTIAN *p.p.*

Diasprigni limestones, Posidonia marls, Rosso ammonitico, Corniola, Calcare massiccio (JS)
Micritic limestones, marls and nodular limestones, chert lenses, nodules and layers.
HETTANGIAN-TITHONIAN

- Attitude of strata
- Fault
- Thrust
- Axis of anticline
- Axis of syncline
- Geological cross-section

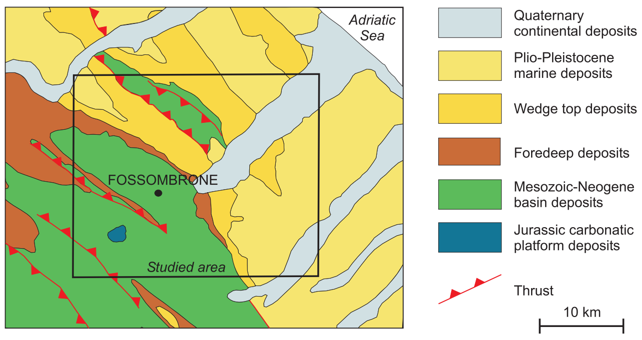


Fig. 3 - *Geological-structural sketch of the Umbria-Marche Apennines.*

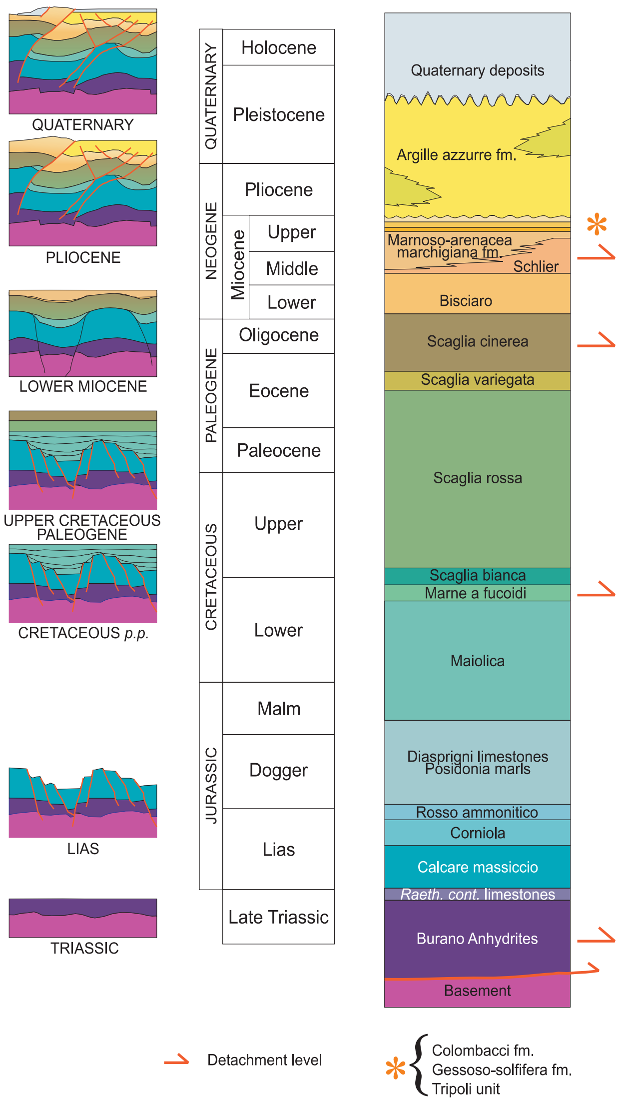


Fig. 4 - *Chronostratigraphic sketch of the Umbria-Marche succession, related to the main structural evolution of the area.*

GEOLOGICAL SETTING

The Umbria-Marche Apennines are an arcuate fold-and-thrust belt, developed during the Neogene as a result of the collision between the European and African continental margins.

Their stratigraphic sequence is mainly composed of a Mesozoic-Neogene silico-carbonate multilayer, typical of a passive margin, detached from the Permo-Triassic basement by the Middle-Upper Triassic anhydrites. This succession is overlain by Miocene foredeep and wedge top deposits, up to Plio-Pleistocene marine sediments. The Quaternary continental deposits consist of fluvial terraced deposits, alluvial fans and stratified debris of peri-glacial environment (Figs. 3 and 4).

The overall structures can be described as anticline-syncline pairs detached from the basement by buckling and cut by a number of thrusts and back-thrusts (NW/SE-trending) related to the orogenic events which produced the Apennine mountain belt (LAVECCHIA, 1981; MENICHETTI *et alii*, 1991; DE DONATIS *et alii*, 1995). These structures are usually situated in the Marne a fucoidi, Scaglia cinerea and Schlier formations, the most incompetent levels of the Umbria-Marche succession.

The structural setting is complicated by transfer and trascurrent anti-Apenninic faults. Plio-Pleistocene extensional tectonic also affected the deformed multilayer.

3D MODEL OF THE FOSSOMBRONE AREA

Surface data and subsurface information, collected for the realization of Sheet 280 - Fossombrone, and organised in accordance with the CARG database (SERVIZIO GEOLOGICO D'ITALIA, 1997) (Fig. 5), were used to build the 3D geological model of the area studied.

Topographic data were imported into the 3DMove software (Midland Valley Expl. Ltd, Glasgow, UK), and a triangulated mesh Digital Elevation Model (DEM) was built honouring topographic contour data (Fig. 6).

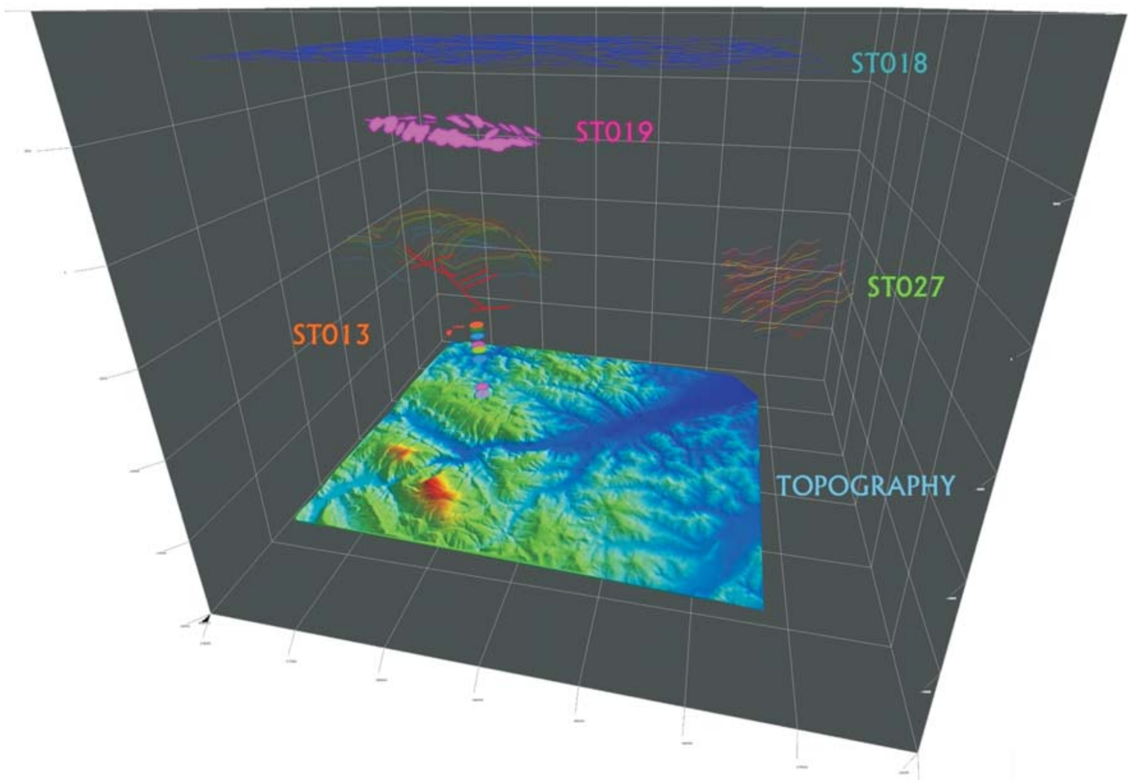


Fig. 5 - *Visualization in 3DMove of geological data collected and stored in the layers of the CARG database. Surface data: ST018 geological boundaries; ST019 dip data (represented as circles with strike and dip); ST027 geological cross-sections; Topography. Subsurface data: ST027 seismic reflection profiles; ST013 position of wells (represented as vertical logs).*

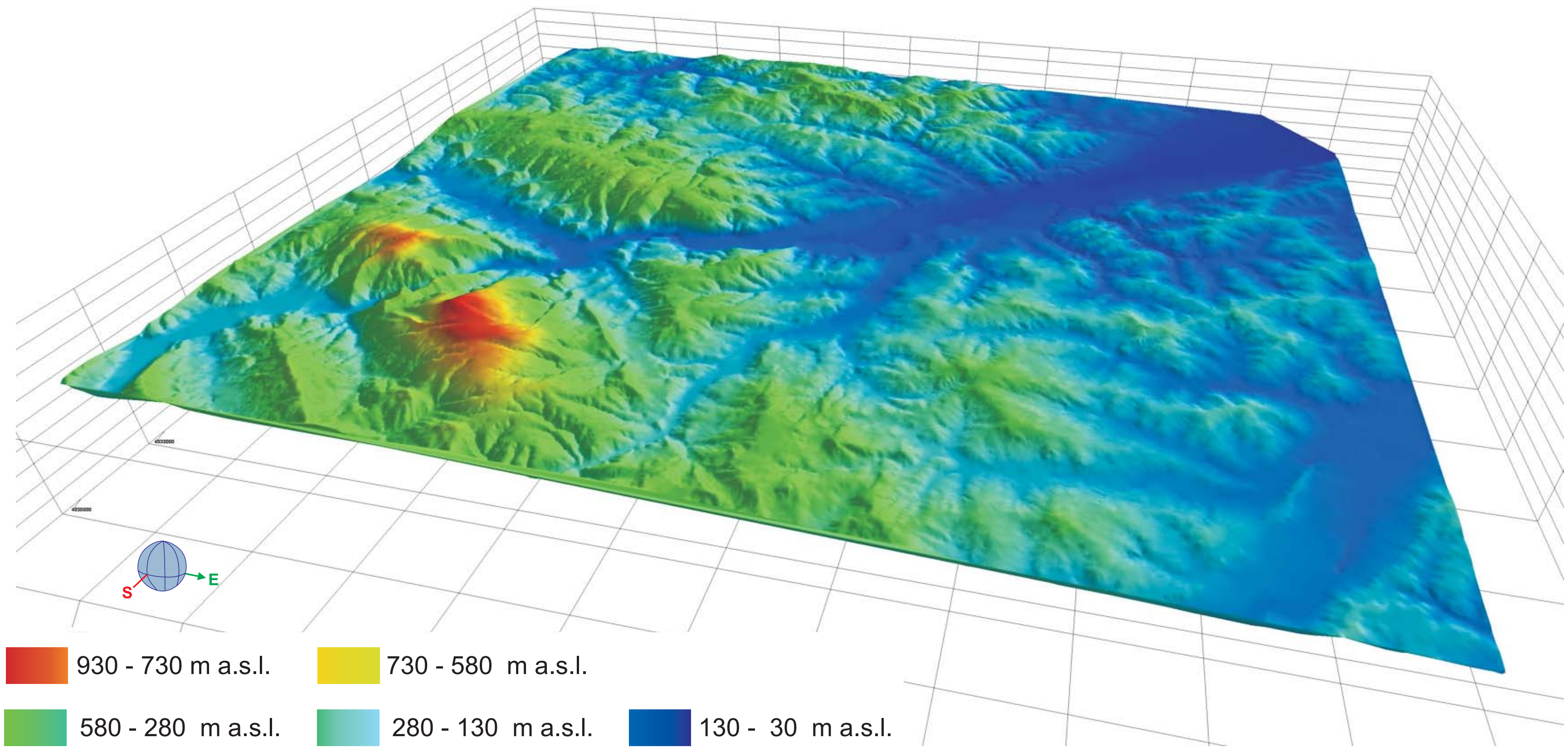


Fig. 6 - *Digital Elevation Model of the Sheet 280 - Fossombrone.*

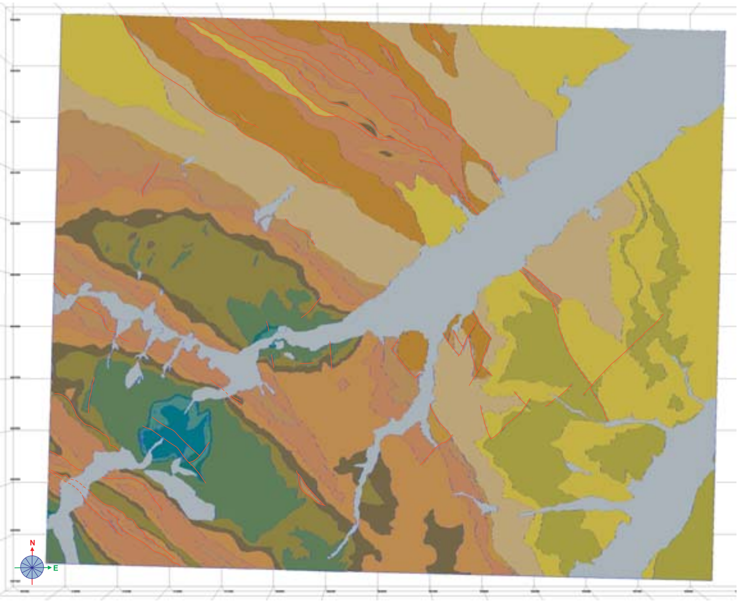


Fig. 7 - *2D geological sketch realized with the geological data organized in layers of the CARG database. This is the first step towards shaping a 3D geological model through the construction of plane surfaces using a specific interpolation algorithm. This algorithm can build surfaces using just geological boundaries (ST018). A particular feature of these surfaces is their elevation value equal to zero.*

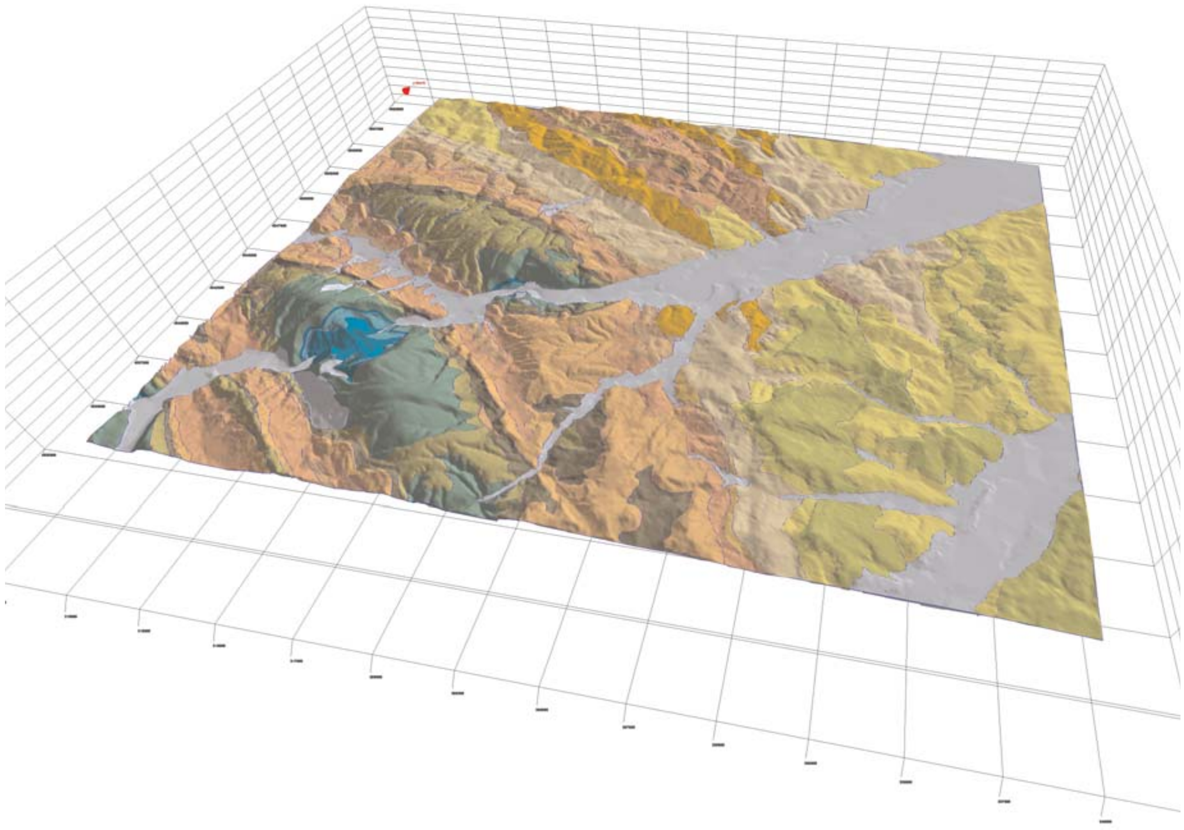


Fig. 8 - *2.5D visualization of outcropping formation units. By restoring the 2D geological sketch to the Digital Elevation Model, every point of the geological map acquires its real elevation value. Consequently, this procedure allows an elevation value to be assigned to every point of the geological boundaries. This feature enables the boundaries to be used for subsequent 3D processing (see Fig. 2 for the legend).*

The geological data (boundaries, azimuth and dip, tectonics) for the area were also imported into 3DMove to create a digital geological representation (Fig. 7) that was integrated onto the DEM by restoring geological 2D surfaces to the topographic surface; the result was a 2.5D representation of the outcropping geology (Fig. 8). Several geological cross-sections, orthogonal to the axis of the main structures, were built starting from outcropping geological data and integrated with the interpretation of seismic reflection profiles (Fig. 9).

These georeferenced cross-sections, together with surface geological boundaries and constraints from strike and dip and from some wells data, were used as the starting point from which to build the structural models at depth.

This technique involved joining together lines representing the same stratigraphic horizons or faults to form continuous 3D surfaces (Fig. 1). The creation of a 3D geological model allowed the validation of the structures both at depth and laterally by the three dimensional correlation of faults and horizons. As a result, the geological uncertainties highlighted by the fieldwork were addressed and investigated at various scales.

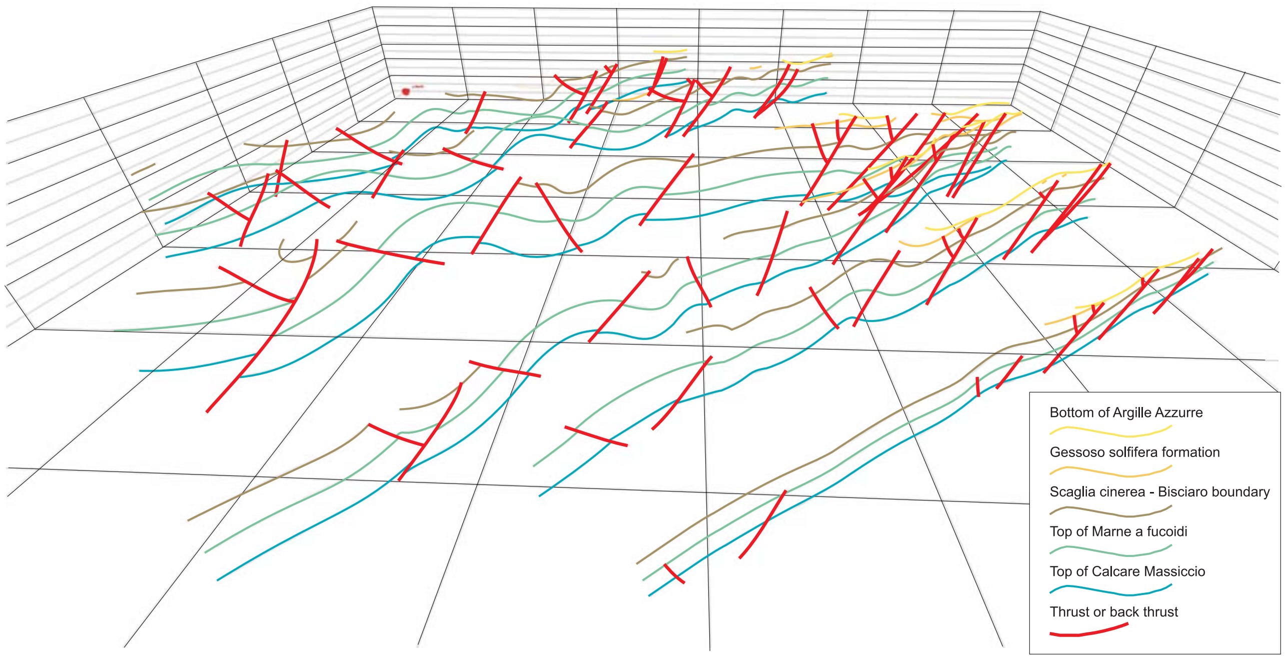
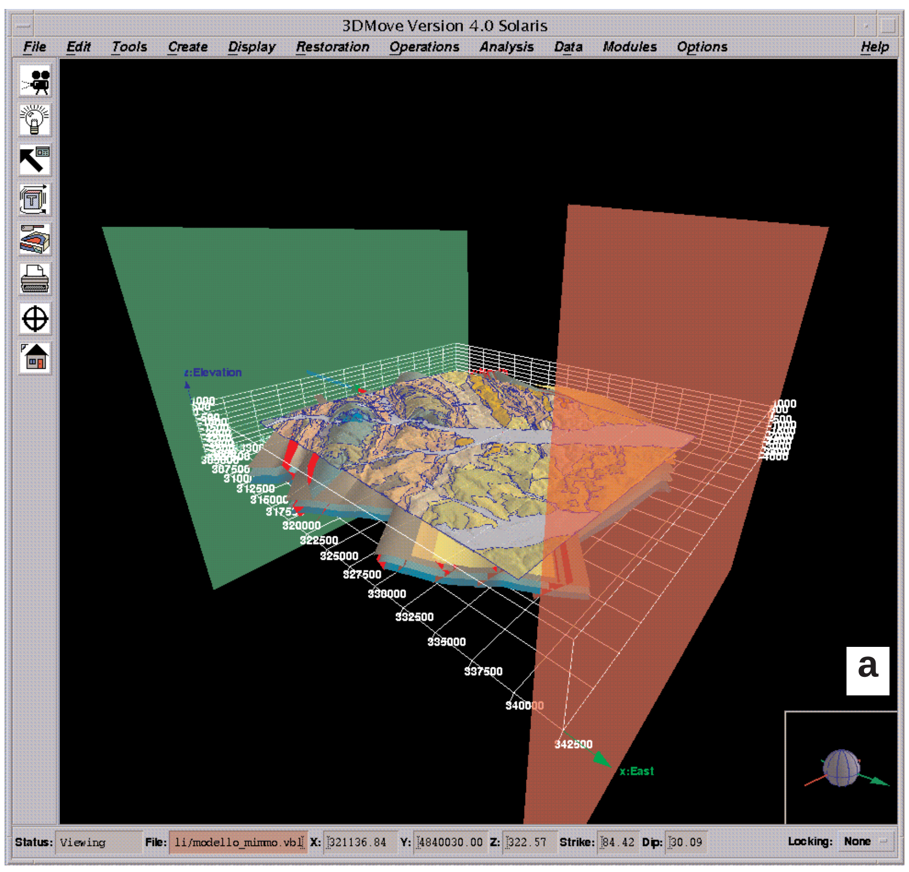


Fig. 9 - *Interpreted and georeferenced seismic cross-sections included in the studied area. The 3D geological model is developed using the main seismic reflectors identified in the seismic lines (see legend). The software allows conversion of travel time to depth using a specific function that considers the velocity at the top of the layer.*



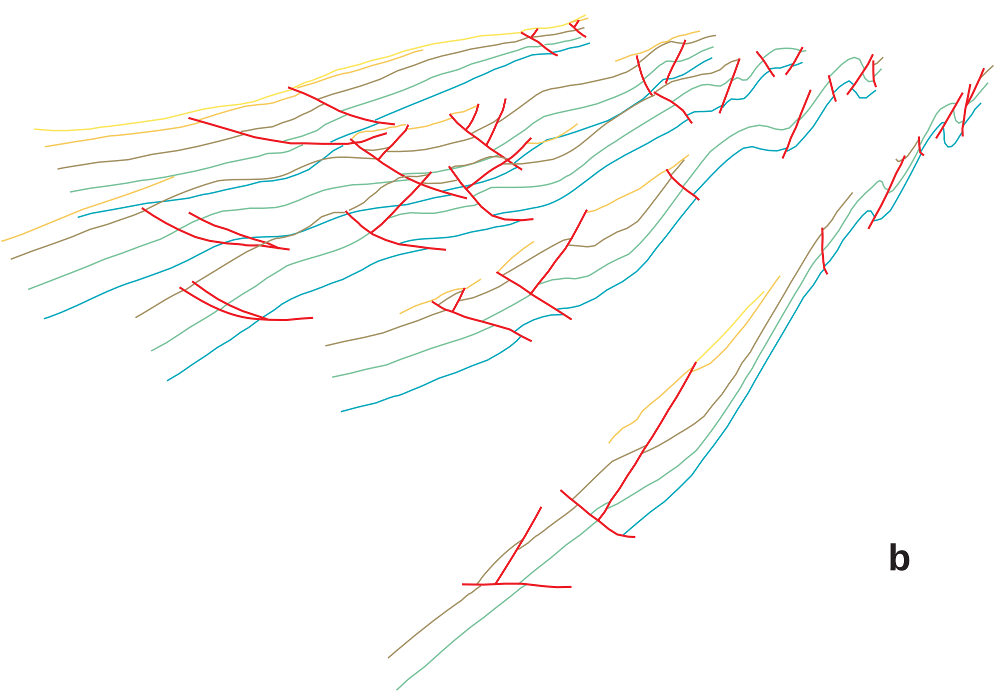


Fig. 10 - a) *Adjustable oriented slicer plane for automatic production of geological profiles from 3D geological model;* b) *geological profiles from contour slicer tool (see Fig. 9 for the legend).*

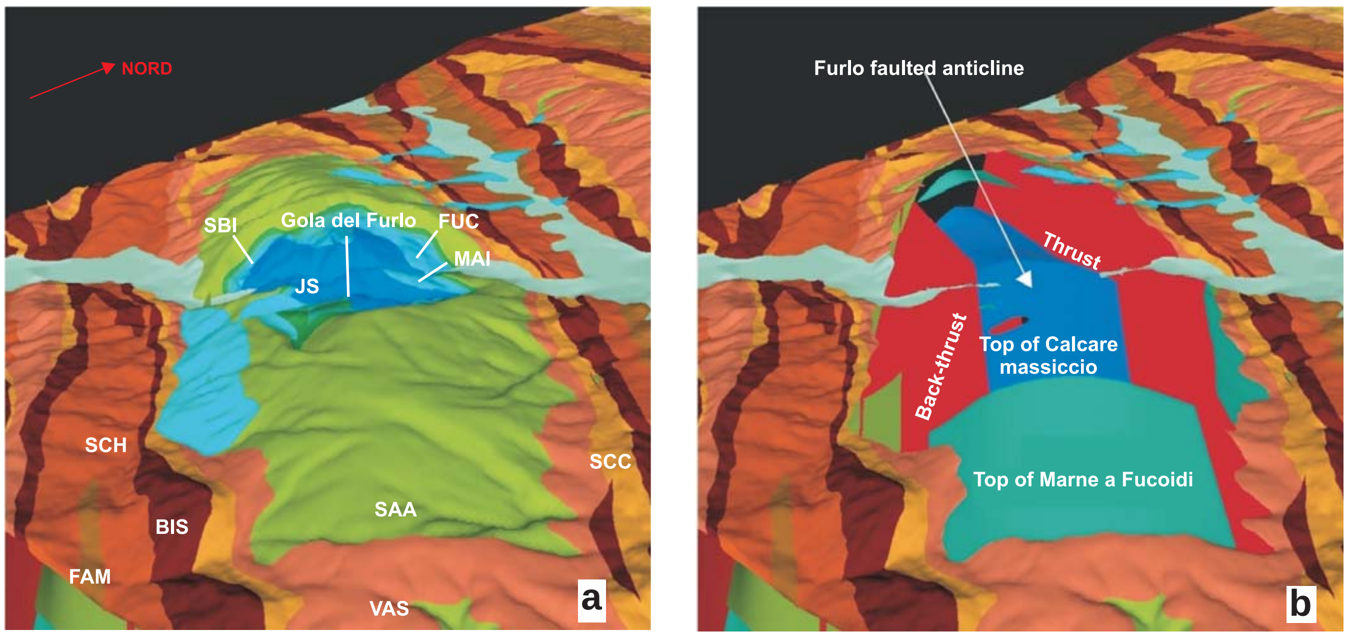


Fig. 11 - *Visualization of the Mt. Paganuccio-Mt. Pietralata anticlinal structure at the Gola del Furlo, on surface* (a) *and at depth* (b). JS: *Jurassic succession;* MAI: *Maiolica;* FUC: *Marne a fucoidi;* SBI: *Scaglia bianca;* SAA: *Scaglia rossa;* VAS: *Scaglia variegata;* SCC: *Scaglia cinerea;* BIS: *Bisciaro;* SCH: *Schlier;* FAM: *Marnoso-arenacea marchigiana formation.*

3D geological and structural modelling software allows the performance of data consistency checks and some "automatic" geological processing.

The Contour slicer functionality extracts cross-sections and constructs structure contour maps from a 3D model, where users can select the most useful orientation of the slicer plane (Fig. 10).

The cross-sections thus automatically produced can be compared with seismic profiles to verify the consistency of the 3D model with the former data.

The possibility of visualizing geological structures in their real dimension is one of the more elementary results of 3D software.

In Fig. 11, the surfaces of outcropping formations of the Mt. Paganuccio-Mt. Pietralata anticlinal structure have been removed to show the main tectonic and stratigraphic elements at depth. Once the geological information is made more accessible and intelligible, even non-geologists users can understand the spatial meaning of thrust, back-thrust and stratigraphic surface boundary.

CONCLUSIONS

3D visualization allows the processing of large quantities of data, the performance of data consistency checks and the promotion of integration between disciplines.

The 3D geological model of the 280 - Fossombrone area reduces the uncertainties of standard geological 2D representations and allows the validation of the structures both at depth and laterally; furthermore, the 3D model produces a user-friendly environment, aimed not only at geologists, but also at managers and technicians working in land use planning.

The construction of geo-realistic models of subsurface structures and their integrated visualization with outcropping geological data allows further analyses to be carried out - such as of fluid migration and potential sediment flow pathway - that are useful towards implementing better solutions and decisions in environmental and risk management.

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