KARST POROSITY DEVELOPMENT IN LAYERED AND FRACTURED CARBONATES

FIELD EVIDENCES OF STRUCTURAL CONTROL ON SULFURIC ACID SPELEOGENESIS (MAJELLA MASSIF, ITALY)

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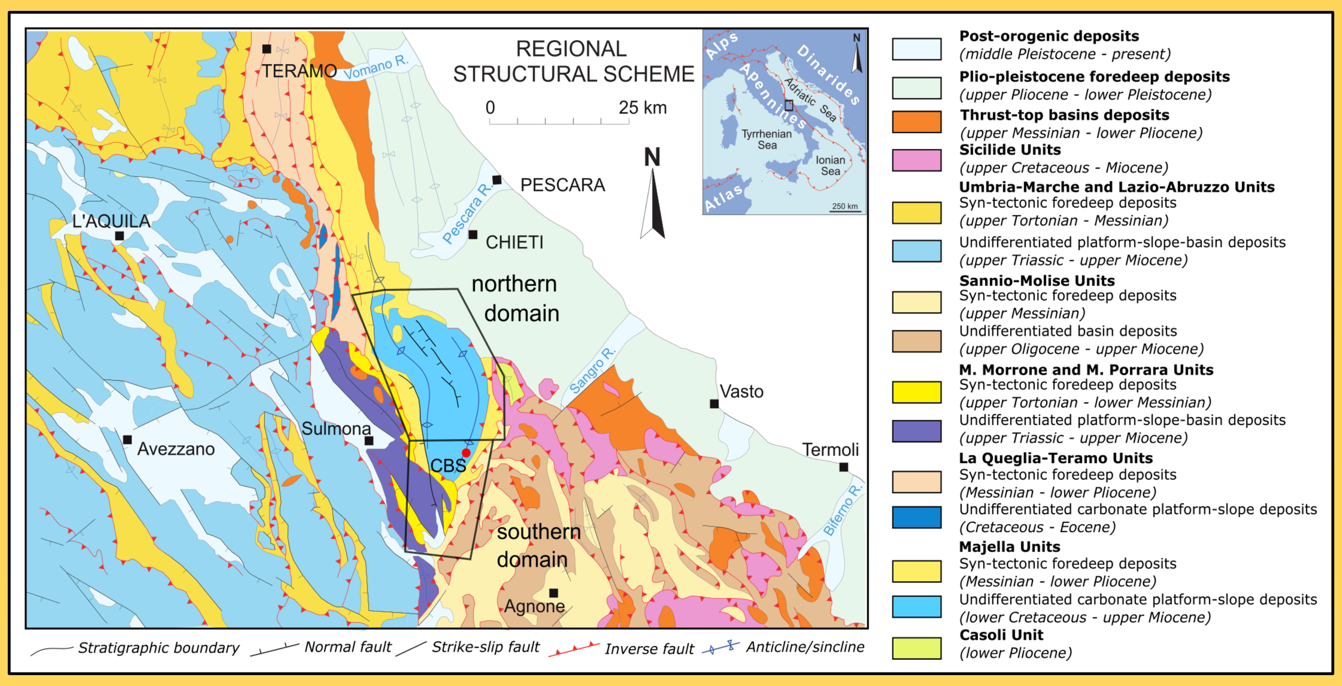
Introduction

Sulfuric acid speleogenesis (SAS) has been widely recognized as one of the most aggressive processes involving carbonate dissolution and rapid formation of karst porosity under hypogenic conditions. The Cavallone-Bove cave system (CBS) is one of the longest natural caves in Abruzzo region (over 1 km of length) and opens along the cliffs of the Taranta Valley, in the southern domain of Majella Unit (Fig.1).

This tectono-stratigraphic unit is the easternmost of the major thrust sheets of Central Apennines chain, with the most prominent structural feature consisting in an elongated, curvilinear anticline with steeply dipping eastern forelimb.

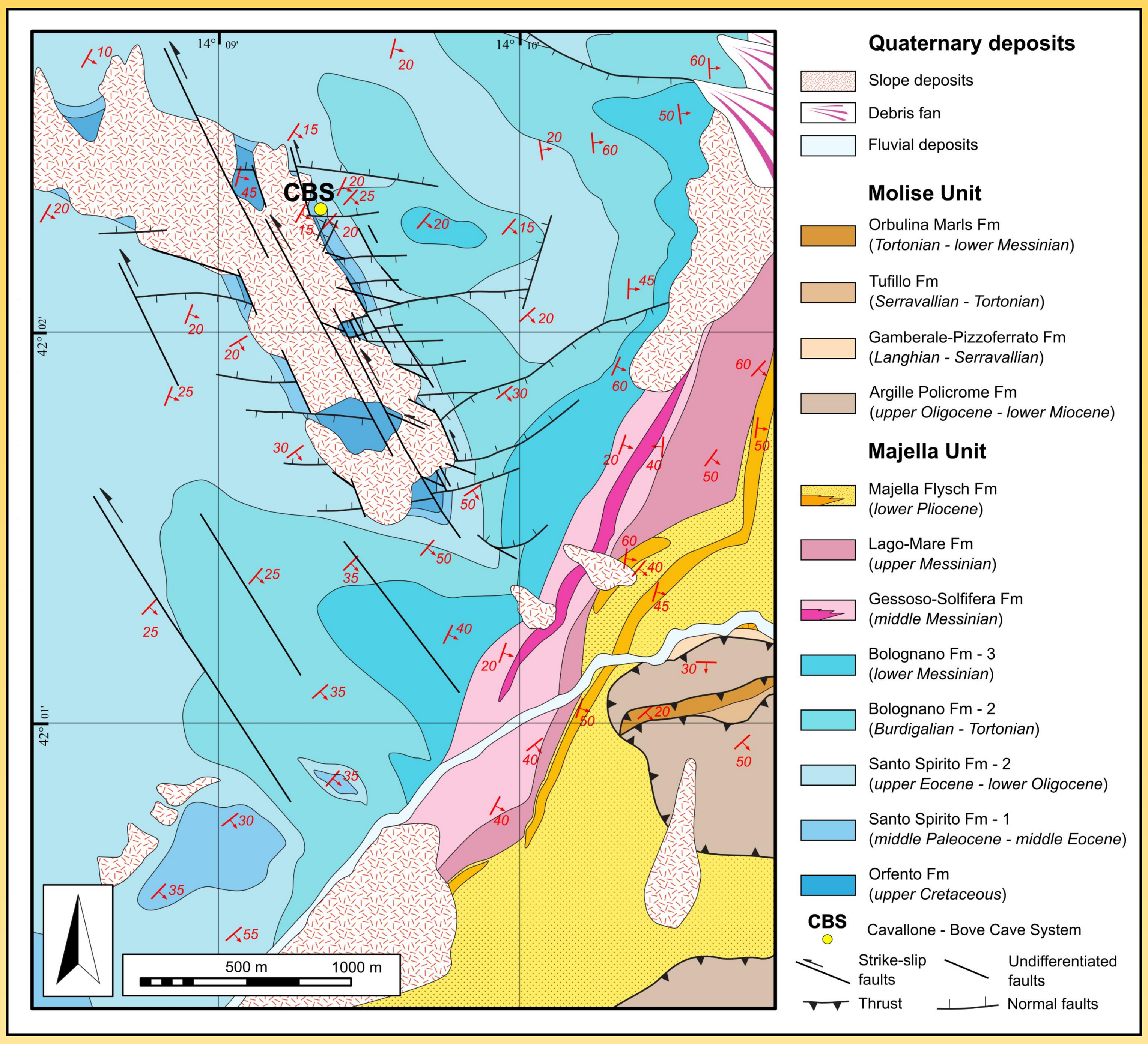
The sulfuric acid origin of this inactive hypogenic system has been previously proven by D'Angeli et al. (2019) using field evidences, secondary minerals and stable isotopes analysis. Both caves are characterized by a main sub-horizontal rounded or trapezoidal passage with only minor secondary branches and sub-vertical rift-conduits, called feeders.

Understanding the structural framework of faults and fractures in a complex thrust front provides essential tools for prediction of fluid flow pathways, especially in low primary permeability rocks such as carbonates (Aydin et al., 2010). We performed detailed geological and geomorphological surveys to characterize the structural evolution of the carbonate sequence hosting the caves, and to explain the relationship with the peculiar spatial and functional organization of CBS.



▲ *Fig. 1 – Schematic structural scheme of central Apennines. Location of CBS is indicated with a red dot (modified from Festa et al., 2014).*

▲ *Fig. 2 – Replacement pockets and solutional cavities (typical SAS morphologies) in Cavallone Cave.*



▲ *Fig. 3 – New geologic map of the Taranta Valley, in Majella Massif, with the main structures observed (modified from Festa et al., 2014).*

Geological mapping and structural analysis

Remote sensing, geological mapping and structural analyses were performed to build an original geologic map of the Taranta Valley (Fig.3) and characterize the type of structures observed in the field and in the caves. We reconstructed different deformative phases which affected the *Cretaceous* to *Miocene* carbonate sequence of the study area constituted by Orfento Fm (ORF), Santo Spirito Fm (SS) and Bolognano Fm (BOL). Structures assemblages (letters *a,b,c,* etc. referred to Fig.4) are conceptually schematized below:

i) EXTENSIONAL – pre orogenic, burial-related

1. formation of NNE-SSW extensional syn-sedimentary shear surfaces (*a*)
2. formation of bedding-parallel pressure solution seams (PSS1)
3. formation of E-W calcite veins (J1)
4. formation of conjugate sets of E-W normal faults (*b*, Fig.7B)

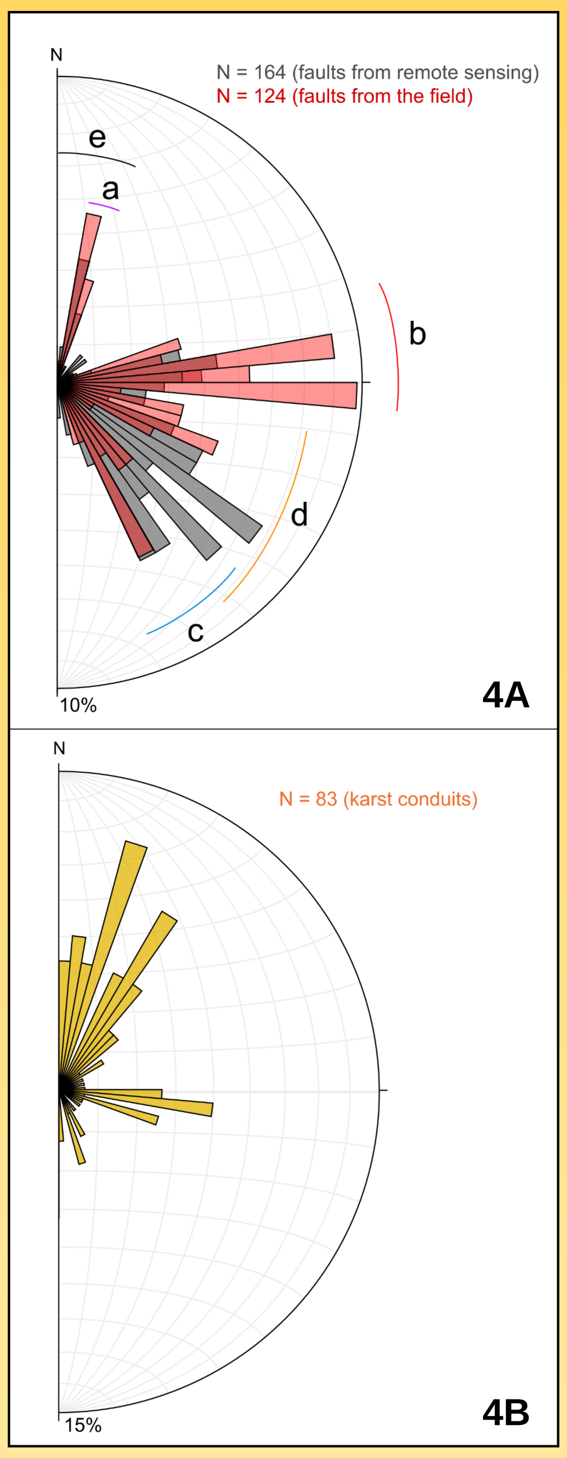
ii) EARLY COMPRESSIVE PHASE – beginning of compression and thrusting

5. formation of bedding-normal pressure solution seams (PSS2)
6. formation of NW-SE joints/veins (J2)
7. formation of NW-SE sub-vertical strike-slip shear fractures. N150-160E sets show left-lateral kinematic and are the predominant sets (*c*)

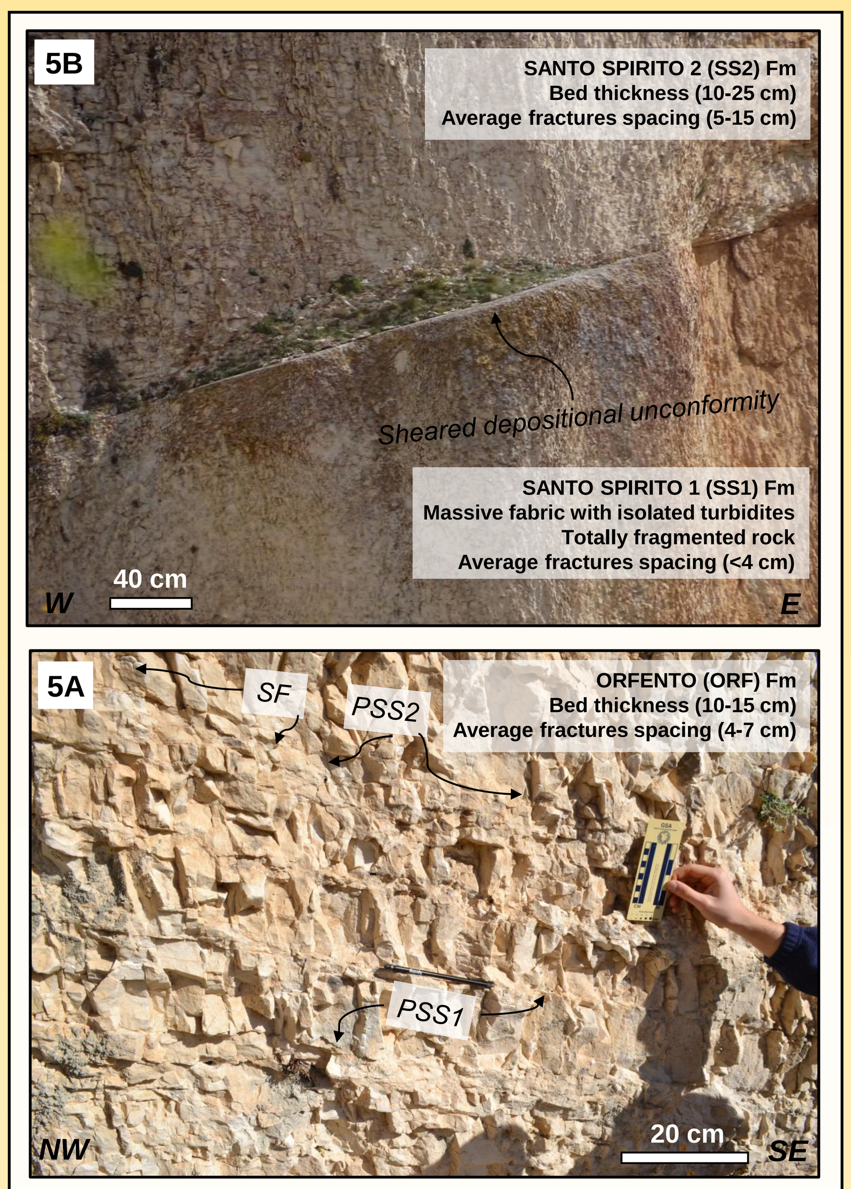
iii) LATE COMPRESSIVE PHASE – growth and structuration of Majella's anticline

8. formation of splay fractures (SF) at oblique-angle on sheared PSS1
9. WNW-ESE (mainly N115E) subsidiary faults of system *c* (*d*, Fig.7A, Fig.7B)
10. tilting of E-W faults (*b*) and possible reactivation as oblique-slip or strike-slip (Fig.6, Fig.7A)
11. growth and linkage of the N150E left-lateral sub-vertical faults (*c*) in strike-slip fault zones segmenting the thrust (tear faults), with associated highly-fragmented damage zones (Fig.7C)
12. formation of through-going N-S and NNE-SSW joints (J3) and fracture-clusters zones (FCZ) in the anticline hinge (*e*, Fig. 6, Fig.10)

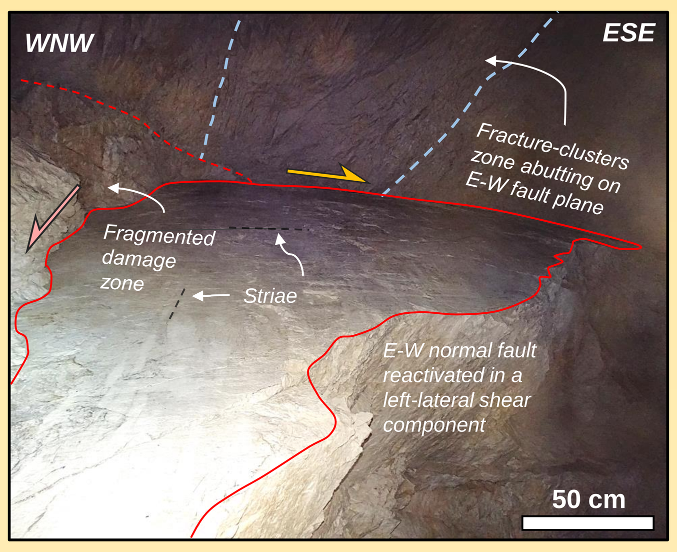
Structural position in the regional context and lithological variations strongly influences background fracture-stratigraphy, both in assemblages and properties (Fig.5). J3 localization occurs during the latest deformative phase. FCZ are mainly aligned parallel to the fold hinge (Fig.9) and associated to NW-SE left-lateral strike-slip fault damage zones, which are more common toward the center of the valley (Fig.7C). Geometric relations between NW-SE strike-slip fault segments produced subsidiary splays faults, extensional/contractional steps and possible reactivation of early E-W normal faults, creating linkage and wide damage zones.



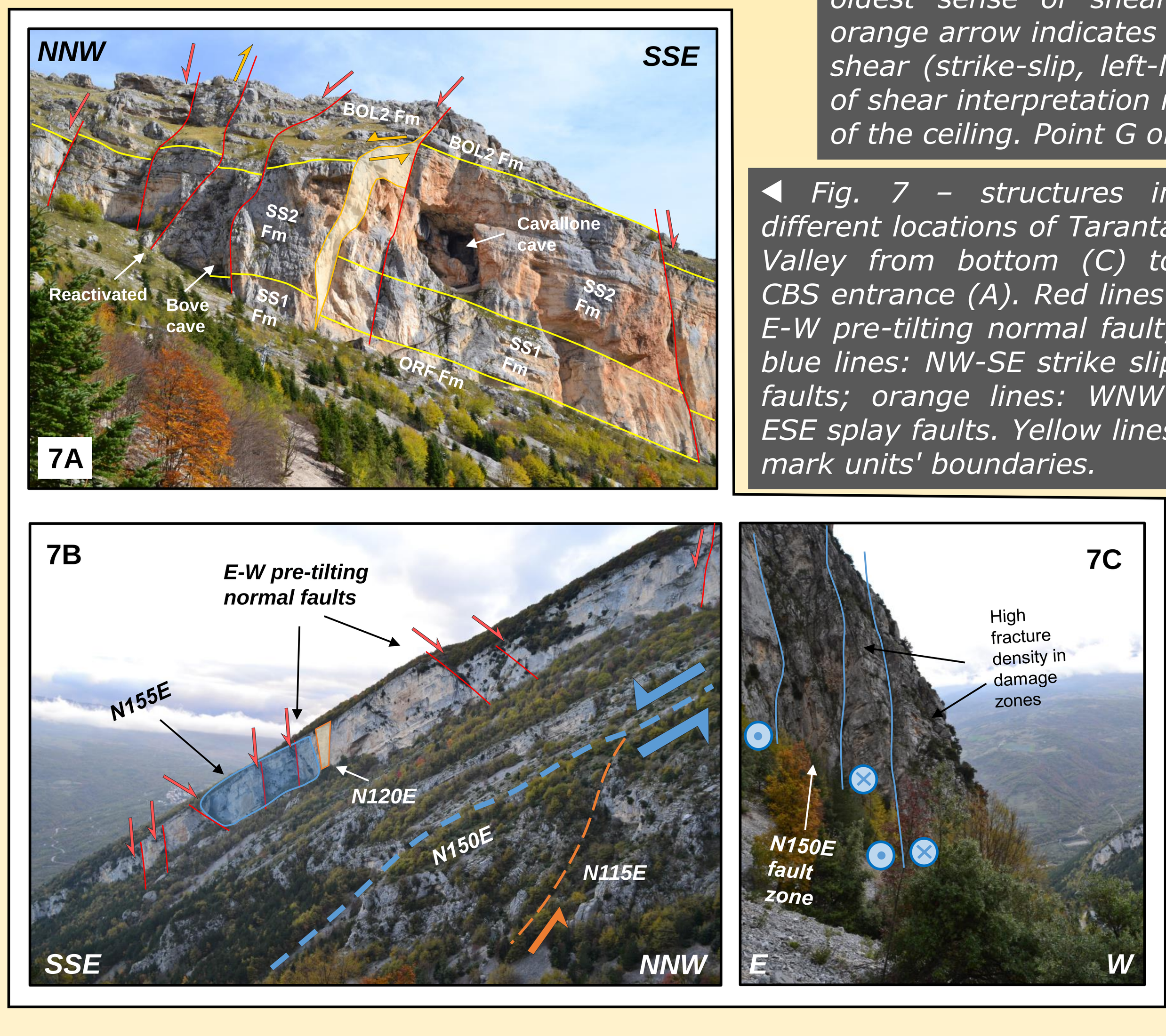
▲ *Fig. 4 – rose diagram of the measured structures (A) and normalized cumulative frequency of karst conduits orientation, extracted by processing of the cave topographic survey (B).*



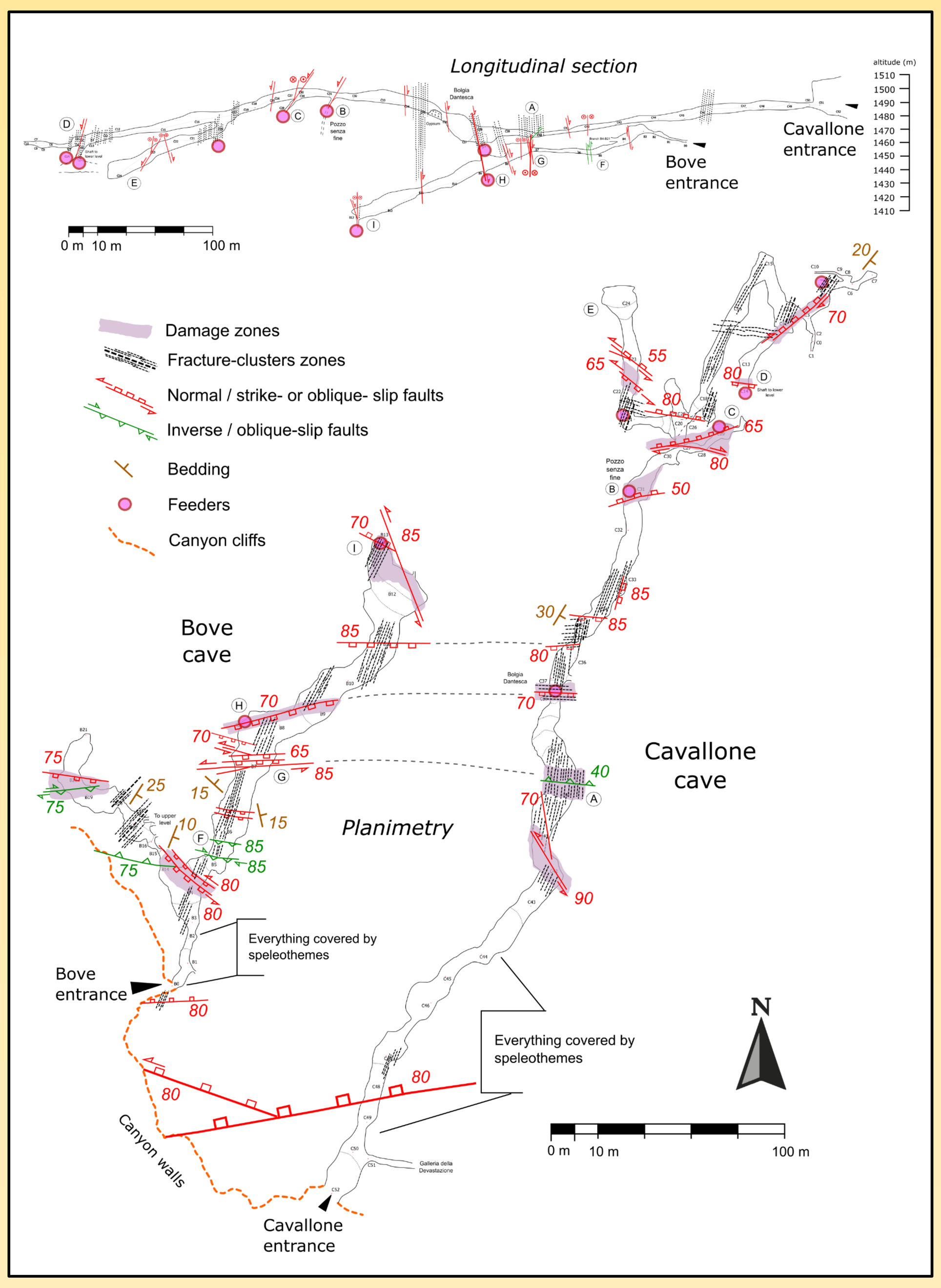
◀ *Fig. 5 – Background structural assemblages in Orfento Fm (A) and Santo Spirito Fm (B). Background deformation structures (J1, J2 and PSS2) are mainly strata bound and just occasionally through-going. Oblique-angle splay fractures (SF) on sheared PSS1 and bedding interfaces are present both in ORF and SS2 Fm. SS1 Fm is observed completely fragmented with fractures spacing generally < 4 cm.*



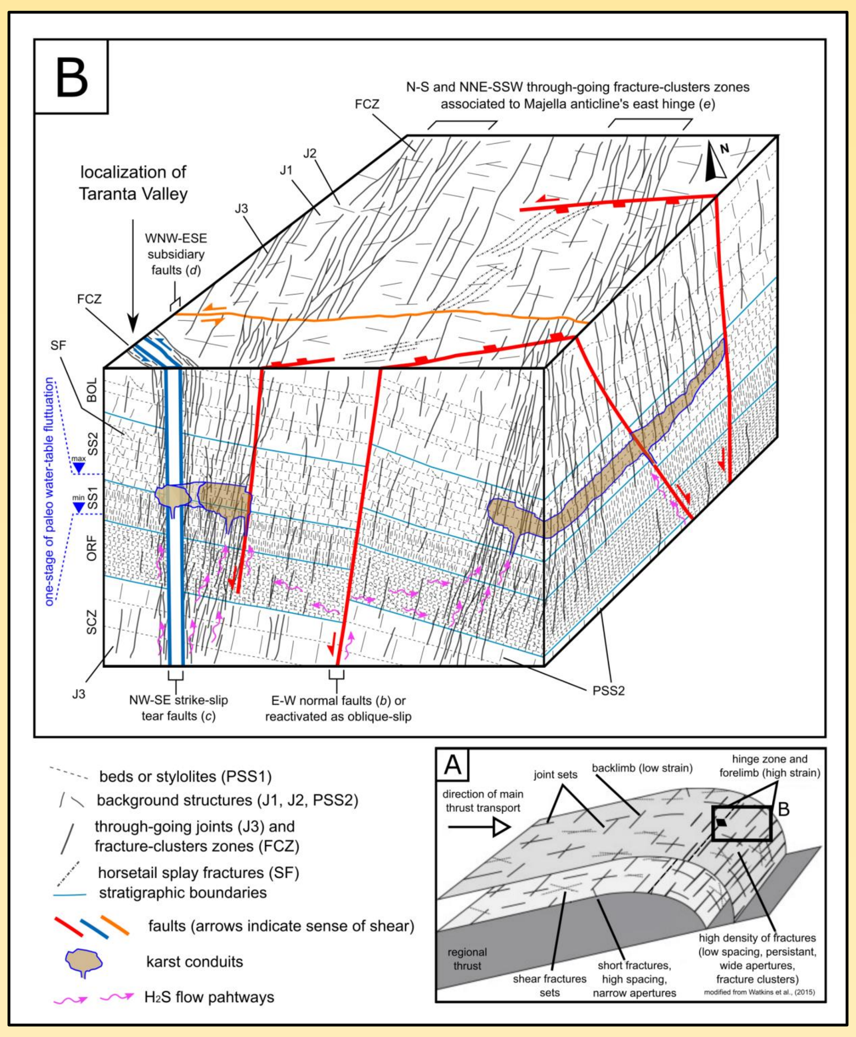
▲ *Fig. 6 – ceiling view of NNE-SSW FCZ abutting on E-W normal fault plane, reactivated in a strike-slip left-lateral sense of shear. Note two generations of fault striae. Light red arrow indicates oldest sense of shear (dip-slip), while orange arrow indicates youngest sense of shear (strike-slip, left-lateral). For sense of shear interpretation note that is a view of the ceiling. Point G on map of Fig.8.*



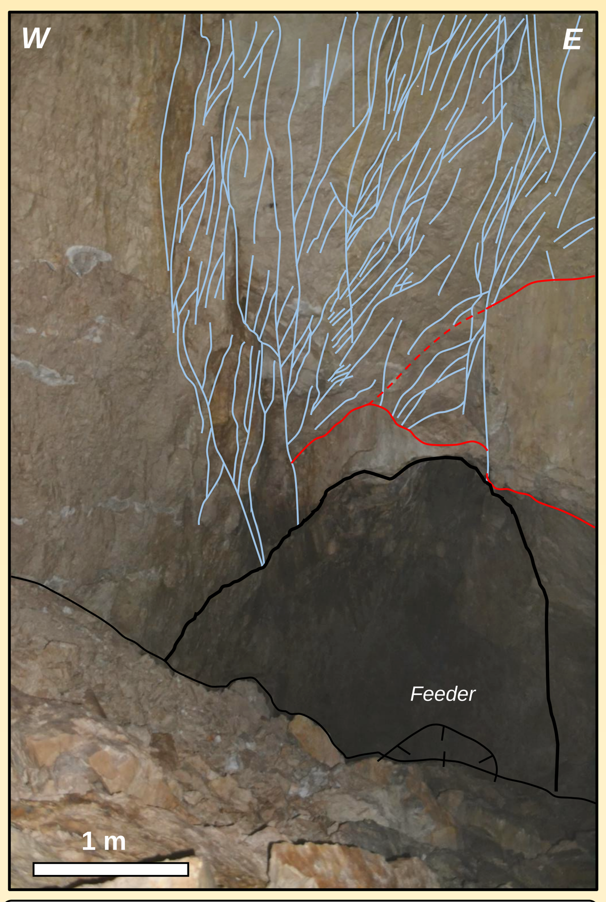
◀ *Fig. 7 – structures in different locations of Taranta Valley from bottom (C) to CBS entrance (A). Red lines: E-W pre-tilting normal fault; blue lines: NW-SE strike slip faults; orange lines: WNW-ESE splay faults. Yellow lines mark units' boundaries.*



▲ *Fig. 8 – New original topographic survey of the CBS main branches with geo-structural map.*



◀ *Fig. 9 – schematic conceptual model for CBS speleo-genesis. A) regional context in the thrust sheet; B) box diagram with surveyed structures in Taranta Valley and spatial distribution of karst conduits. H_2S-bearing fluids came from deep-buried Triassic evaporites at the base of the thrust.*



▶ *Fig. 10 – Feeder imposed on the intersection between a partially collapsed E-W normal fault plane (in red) and NNE-trending FCZ (in blue) at the end of Bove Cave (point I on map of Fig.8).*

Controls on karst development

The cave system is organized in NNE/NE-trending master conduits, with occasional E-W or NW-SE secondary passages, and a multi-level configuration due to water table oscillation and evolution of the thrust front since lower *Pleistocene*. Interaction between well-developed left-lateral strike-slip faults, their splay and pre-orogenic normal faults form combined barrier-conduit structures for vertical fluid flow. Sub-vertical tear faults and their wide damage zones were able to transmit H_2S from depth (*Triassic* evaporites) to oxidizing water table, where aggressive H_2SO_4 was produced. Conductivity provided by a dense network of linked faults and associated subsidiary splays determine multiple deep recharge point (feeders) in the cave system. Structural position in Majella's anticline also determines the localization of through-going joints (J3) and closely-spaced FCZ (Fig.10) related to the hinge deformation, which enhanced fluid flow anisotropy and preferential permeability pathways (Fig.9). For each genetic level of the system, orientation and geometrical relationship between FCZ and fault planes created a tridimensional 'stepping-like' pattern at the intersection with the SE-dipping SS Fm layers. This 'stepping' pattern is clearly visible in the planimetric view and determined an 'up-and-down' pattern in elevation view (Fig.8).

Conclusions

Using detailed structural analysis we created a conceptual model which can be used as a first order tool for prediction of hypogenic karst development in a complex fold-and-thrust front, where deep fractures such as strike-slip tear faults can contribute to fluids migration from depth, providing conditions for SAS processes to act. This contribution can be useful also for prospection and characterization of carbonate reservoirs.

References

Aydin, A., Antonellini, M., Tondi, E., Agosta, F., 2010. Deformation along the leading edge of the Maiella thrust sheet in central Italy. J. Struct. Geol. 32, 1291–1304.

D'Angeli, I.M., Nagostinis, M., Carbone, C., Bernasconi, S.M., Polyak, V.J., Peters, L., McIntosh, W.C., De Waele, J., 2019. Sulfuric acid speleogenesis in the Majella Massif (Abruzzo, Central Apennines, Italy). Geomorphology 333, 167–179.

Di Domenica, A., Pizzi, A., Ciuffi, P., D'Agostino, S., Madonna, R., 2015. Geological-structural control on the formation of the Cavallone Cave (Maiella massif , Central Apennines). Rendiconti online Società Geologica Italiana, 31(1), conference abstract.

Festa, A., Accotto, C., Coscarelli, F., Malerba, E., Palazzin, G., 2014. Geology of the Aventino River Valley (eastern Majella, central Italy). J. Maps 10, 584–599.