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NEOGENE TECTONICS DURING GRANITE EMPLACEMENT IN NORTHERN APENNINES: THE CASE OF THE GAVORRANO MONZOGRANITE (SOUTHERN TUSCANY, ITALY)

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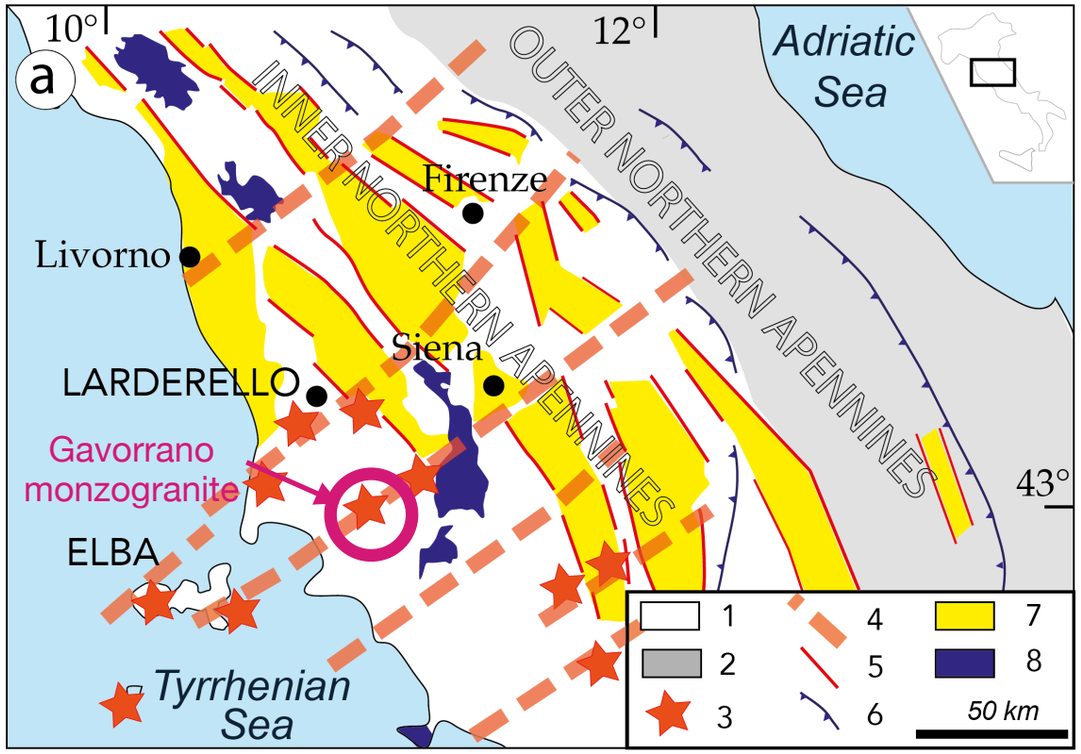
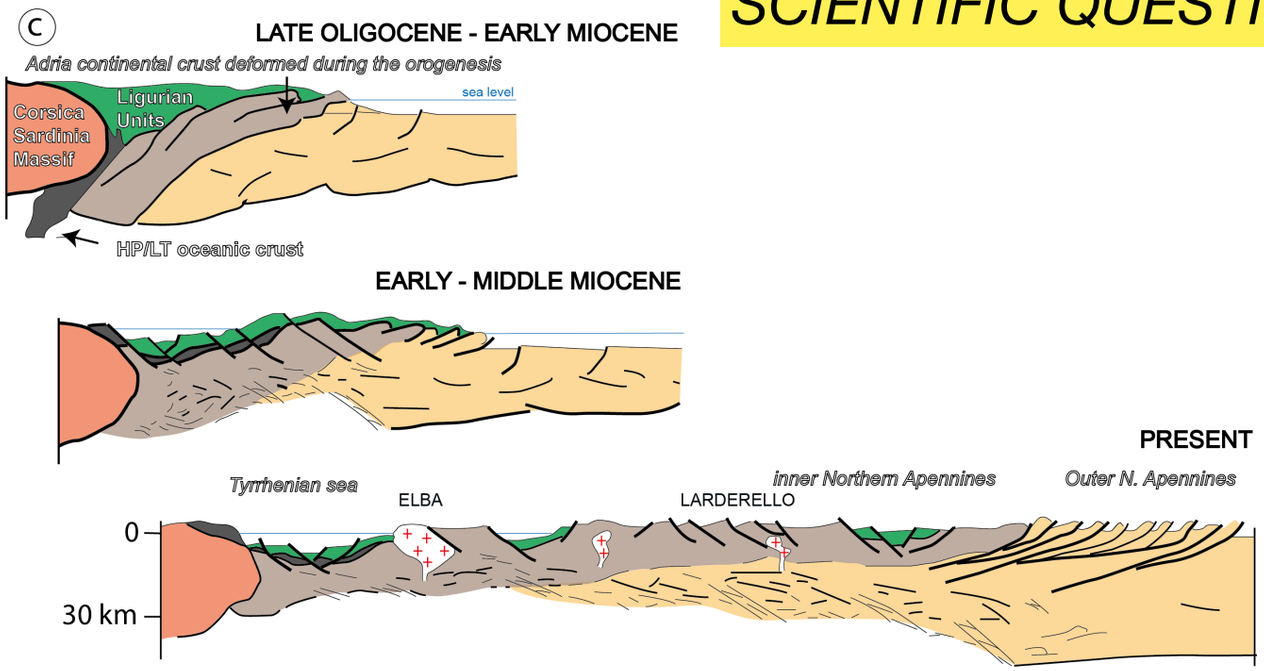
ABSTRACT

The tectonic setting of Neogene is under debate, being interpreted as a contractional, pulsing or extensional framework. On the key-areas to unravel this issue is the Gavorrano monzogranite, located nearby the Tyrrhenian seacoast, in the inner zone of the Northern Apennines (southern Tuscany), where a Neogene monzogranite body (estimated in about 3 km long, 1.5 km wide, and 0.7 km thick) emplaced during early Pliocene. This magmatic intrusion is partially exposed in a ridge bounded by regional faults delimiting broad structural depressions. A widespread circulation of geothermal fluids accompanied the cooling of the magmatic body and gave rise to an extensive Fe-ore deposit (mainly pyrite) exploited during the past century. Data from a new fieldwork dataset, integrated with information from the mining activity, have been integrated to refine the geological setting of the whole crustal sector where the Gavorrano monzogranite was emplaced and exhumed. Our review, implemented by new palynological, petrological and structural data pointed out that: i) the age of the Palaeozoic phyllite (hosting rocks) is middle-late Permian, thus resulting younger than previously described (i.e. pre-Carboniferous); ii) the P-T conditions at which the metamorphic aureole developed are estimated at about 660 °C and at a maximum depth of c. 5 km; iii) the tectonic evolution which determined the emplacement and exhumation of the monzogranite is constrained in a transfer zone, in the frame of the extensional tectonics affecting the area continuously since Miocene.

SCIENTIFIC QUESTIONS



1 - extensional domain; 2 - compressional domain;
3 - magmatic bodies; 4 - transfer zones; 5 - normal faluts; 6 - thrusts;
7 - Pliocene-Pleistocene extensional basin; 8 - metamorphic rocks



Extension has been progressively affected Northern Apennines eastwards since Miocene. The clearest evidence is the opening of the Tyrrhenian Basin. Since late Miocene, extension is accompanied by coeval magmatism.

THE MAIN MAGMATIC BODIES ARE LOCATED ALONG THE MIOCENE-PLIOCENE TRANSFER ZONES

…….NEVERTHELESS…….

Emplacement of the Pliocene Gavorrano monzogranite (4.9 Ma, Borsi et al., 1967) was explained in different tectonic contexts:

EXTENSION → Marinelli, 1961; Arisi Rota et al., 1971

TRANSTENSION → Rossetti et al., 2001

COMPRESSION → Musumeci et al., 2005; 2008; Sani et al. 2009; Montanari et al. 2010;

…….FURTHERMORE…….

AGE OF PALEOZOIC HOSTING ROCKS: Permian (Cocozza et al., 1974) or pre-Carboniferous (Bagnoli et al., 1978)

We addressed to the study of the hosting rocks and the tectonic context in which the Pliocene monzogranite emplaced, by adopting the following methods:

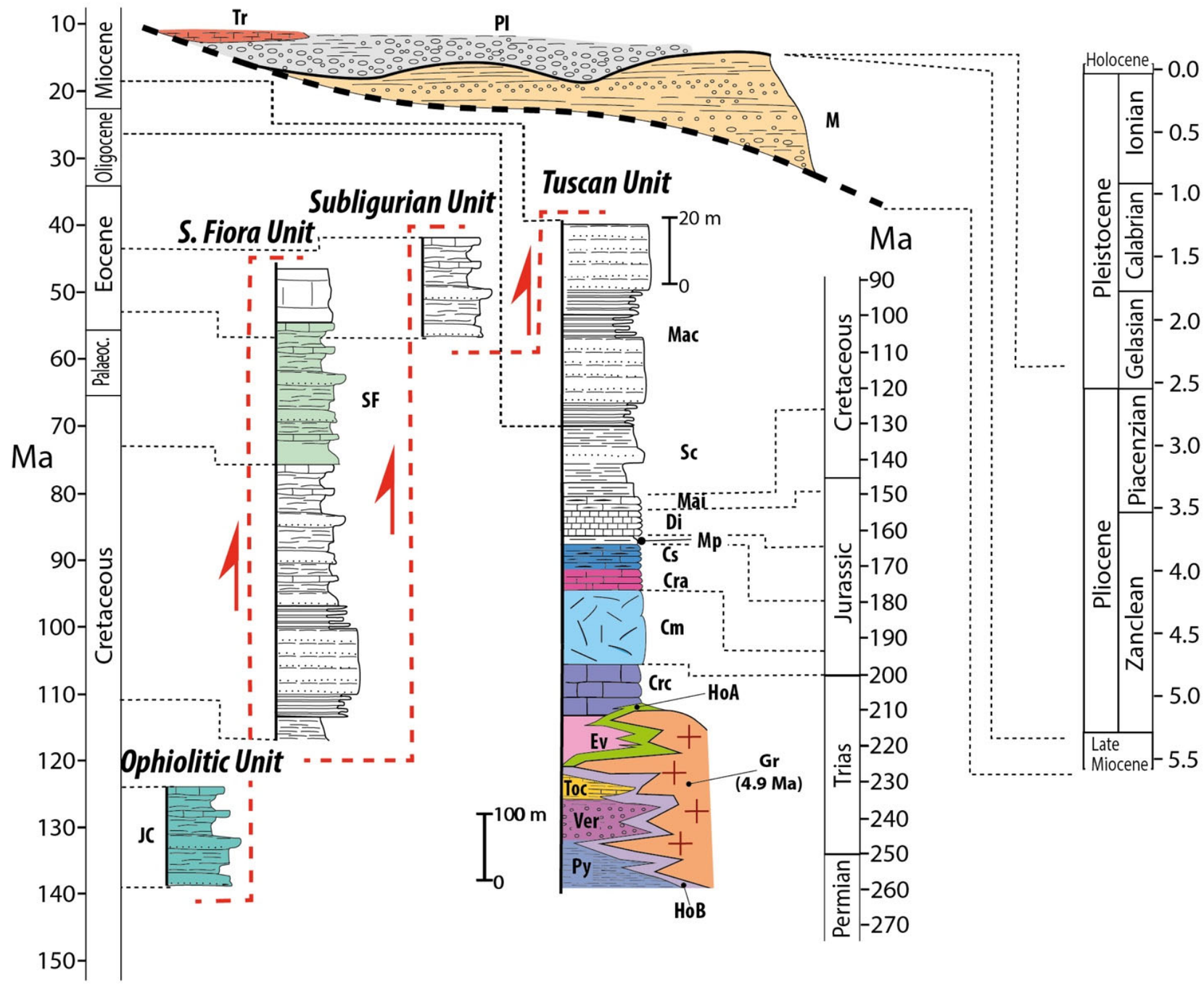
FIELD MAPPING AND INTEGRATION WITH MINING DATA

P-T CONDITIONS IN THE PALAEOZOIC HOSTING ROCKS

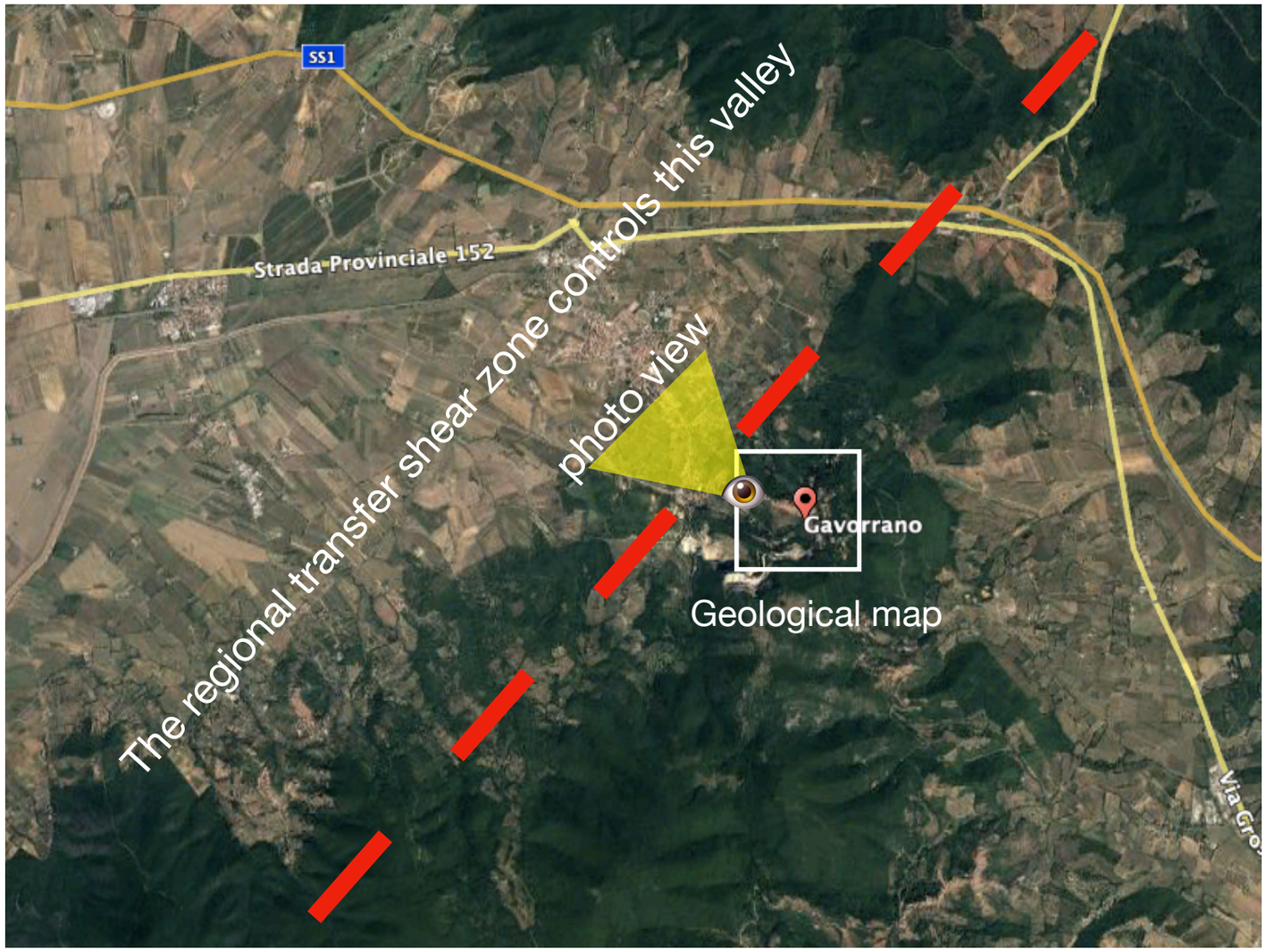
ANALYSIS OF THE PALEOZOIC MICROFLORA IN THE HOSTING ROCKS

STRUCTURAL AND KINEMATIC DATA COLLECTION ON FAULTS

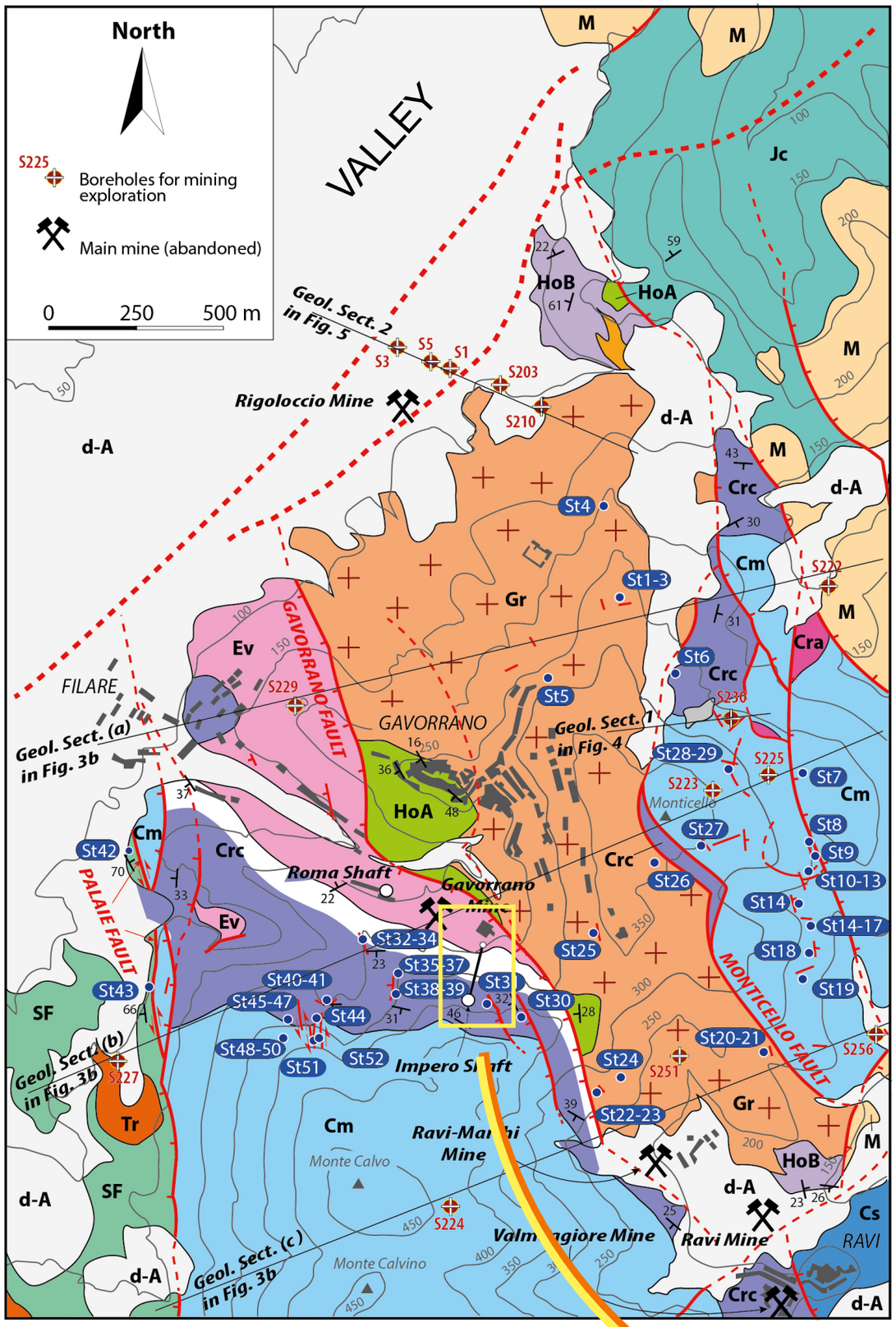
Stratigraphic logs of the tectonic units exposed in the study areas. The successions that are exposed are indicated by colours. **Symbols**: **Tr**—continental carbonate consisting of travertine and lacustrine limestone; **Ple**—fluvio–lacustrine sediments consisting of pebbly sand and sandy clay with interbedded pebble layers; **M**—Late Messinian polygenic reddish sandy–conglomerate and clay level (Montebamboli conglomerate Auctt.); **JC**—Argille a Palombini Fm: siliceous calcilutite, calcarenite, shale and marl; **SF**—Santa Fiora Fm: limestone, sandstone and shale passing to marl and silty–marl at the top; **Mac**—Macigno Fm: quartz–feldspar sandstone and shale; **Sc**—Scaglia Toscana Group: shale, limestone, marl, calcarenite and biocalcirudite; **Mai**—Maiolica Fm: cherty limestone, calcilutite; **Di**—Diaspri Fm: radiolarite and shale; **Mp**—Marne a Posidonia Fm: marl and marly limestone; **Cs**—Calcare Selcifero Fm: cherty limestone, marl and shale; **Cra**—Rosso Ammonitico Fm: reddish nodular limestone and shale; **Cm**—Calcare Massiccio Fm: massive limestone; **Crc**—Calcari a *Rhaetavicula contorta* Fm: bedded limestone and marl. **Ev**—Burano Fm: dolostone and gypsum/anhidryte layers; **Toc**— Tocchi Fm: metacarbonate and phyllite; **Ver**—Verrucano Group: quartz–metaconglomerate, metasandstone and phyllite. **Py**—Palaeozoic phyllite–quarzite Group: organic–matter bearing phyllite and metasandstone. **HoA**: carbonate hornfels; **Hob**: pelitic hornfels; **Gr**: Gavorrano magmatic complex.



FIELD MAPPING



FIELD MAPPING



Quaternary deposits

- **d-A** — Debris and alluvial sediments *Holocene*
- **Tr** — Travertine deposits: slope and palustrine depositional systems *Pleistocene-Holocene*

Magmatic Complex

- **Gr** — Monzogranite with K-feldpspar phenocrysts, tourmaline-rich microgranite and aplitic dykes *Zanclean*

Thermo-metamorphic aureole

- **HoA** — Marble, calc-silicate hornfelses and shale *Zanclean*
- **HoB** — Andalusite-bearing hornefelses, quartzite *Zanclean*

Neogene deposits

- **M** — Contiental reddish gravel, sandy-gravel, sand with hematite patinas *Late Messinian*

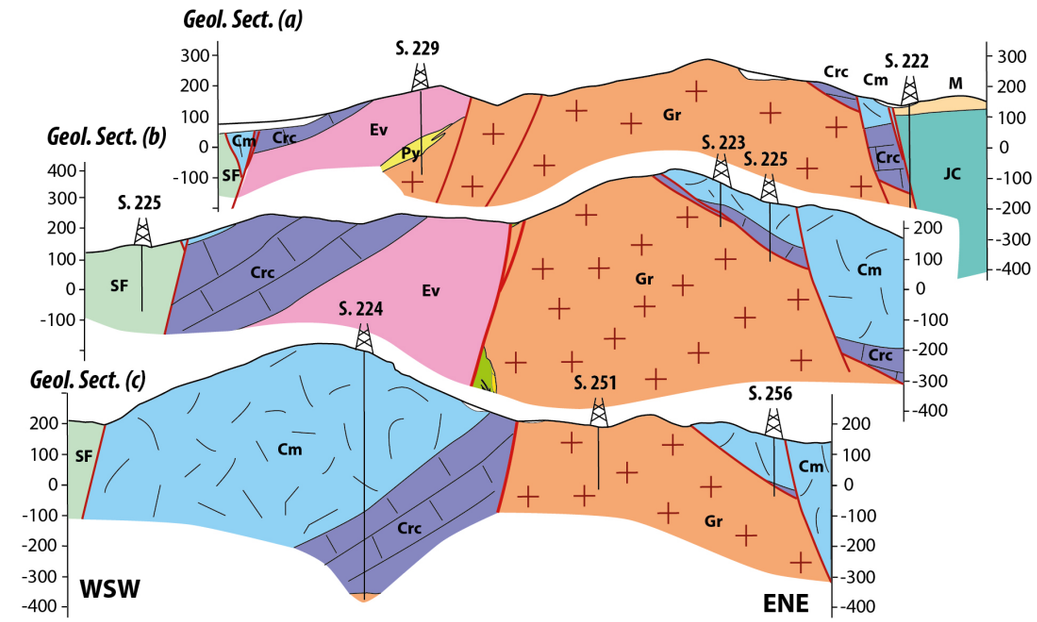
Ligurian Units

- **JC** — Ophiolitic Unit (Argille a palombini Fm): shale, siliceous limestone, marl and quartz-sandstone *Early Cretaceous*
- **SF** — Santa Fiora Unit: marl, shale, limestone, and sandstone *Late Cretaceous*

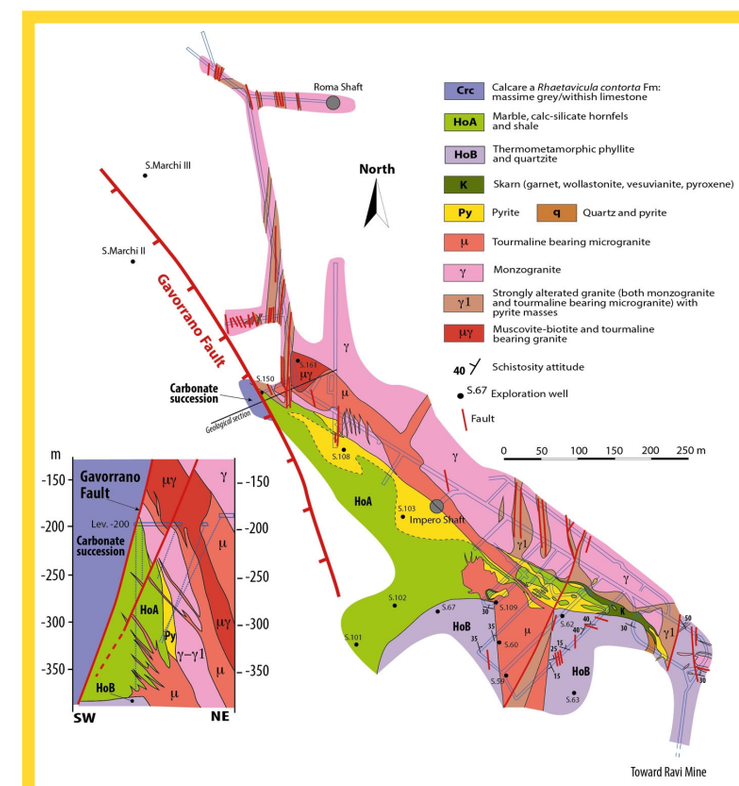
Tuscan Unit

- **Cs** — Calcare Selcifero Fm: grey cherty limestone, yellowish marl *Late Lias*
- **Cra** — Calcare Rosso ammonitico Fm: Reddish nodular limestone, cherty-limestone and marly-shale *Middle Lias*
- **Cm** — Calcare Massiccio Fm: massime grey/withish limestone *Early Lias*
- **Crc** — Calcare a *Rhaetavicula contorta* Fm: massime grey/withish limestone *Rhaetian*
- **Ev** — Burano Fm - Calc. Cavernoso Fm: Dolostone and black shale, vacuolar limestone; carbonate breccia *Norian-Rhaetian*

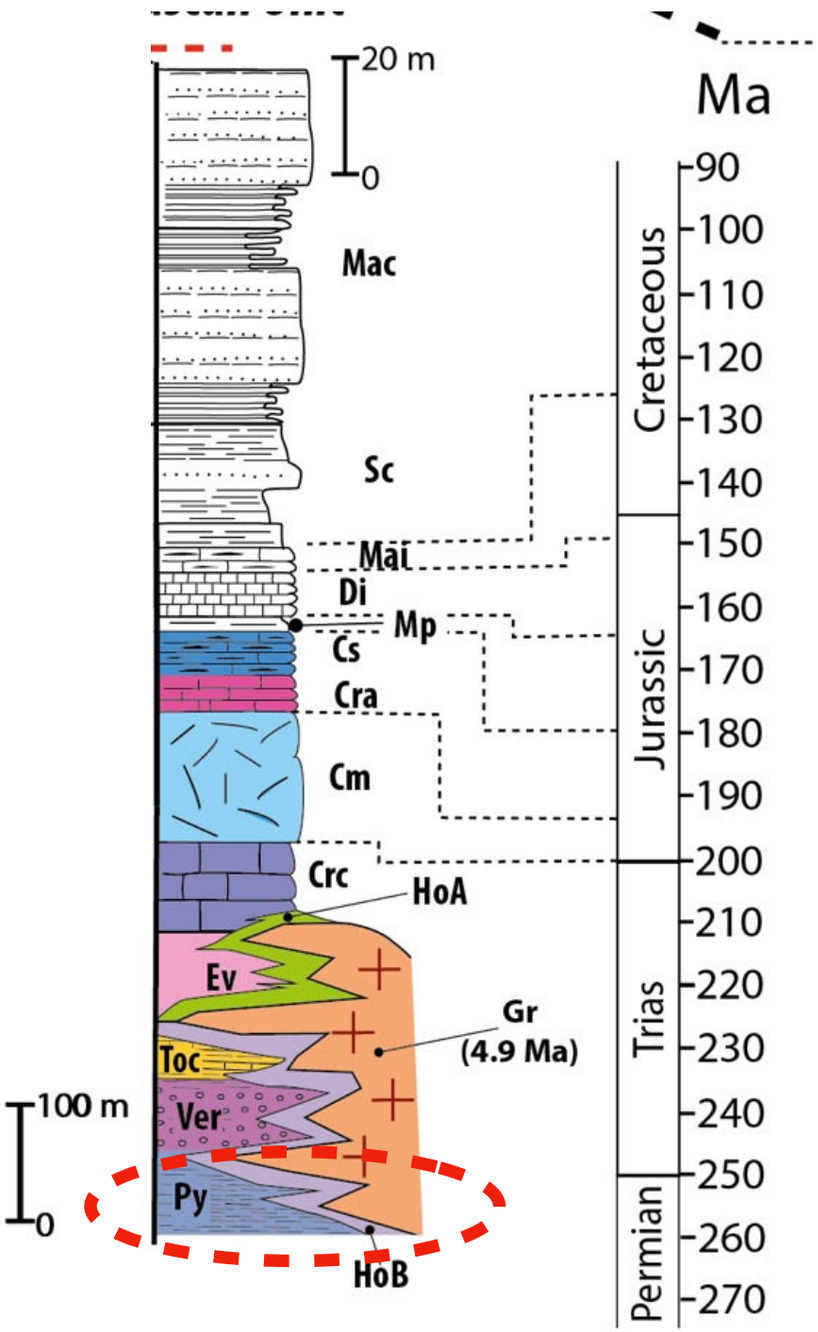
- Low- to middle-angle normal fault
- Strike/oblique-slip fault
- Normal/oblique-slip fault
- St24 — Station for structural analysis

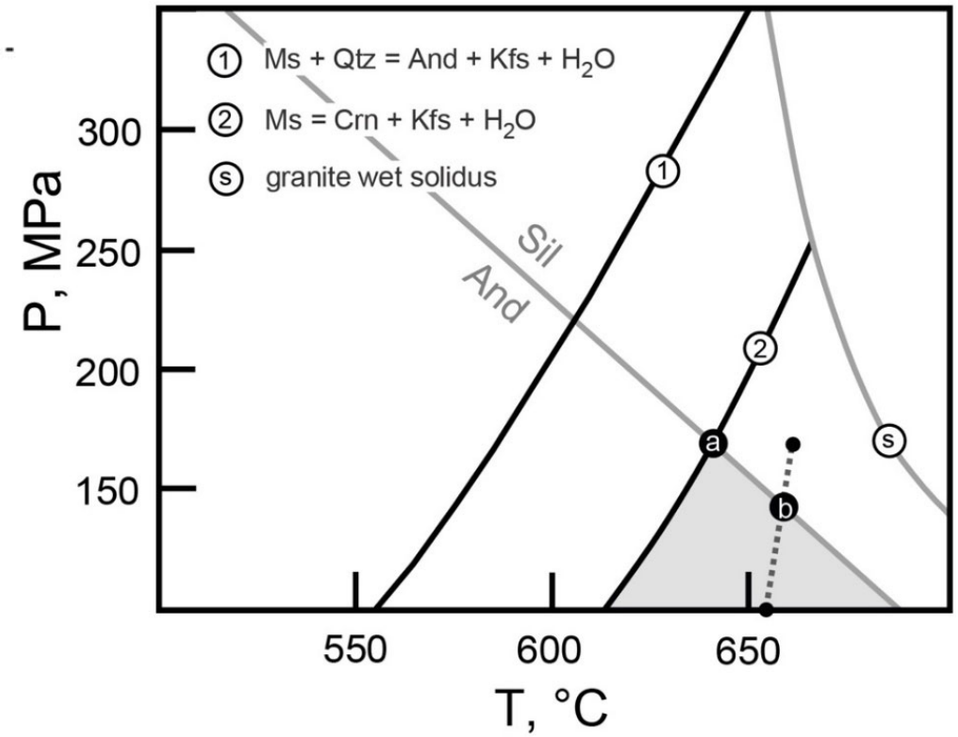


MINING DATA



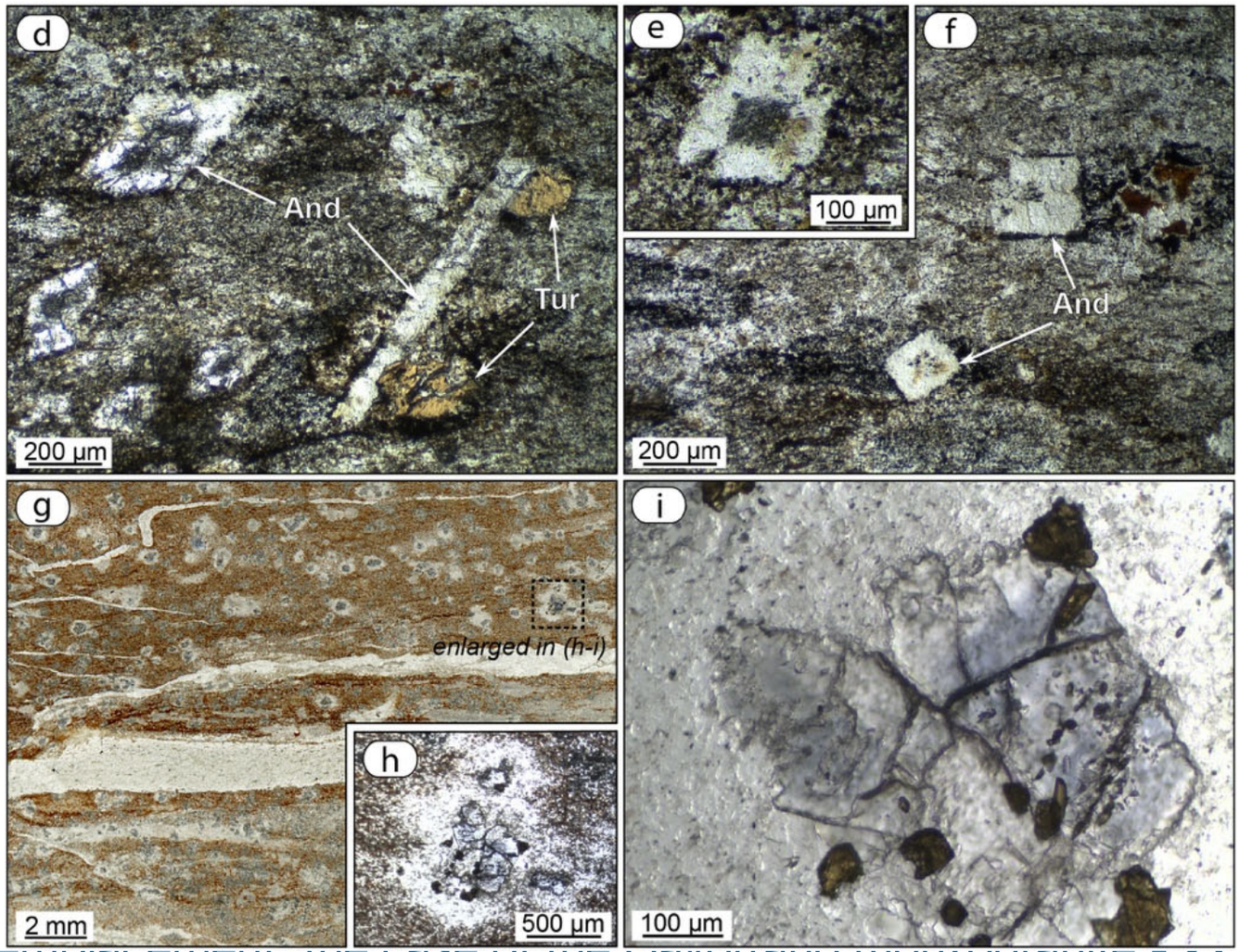
Geological map of the –200 m a.s.l. level of the Gavorrano mine and related geological section, redrawn from original documents stored in the archive of the Tuscan Mining Geopark.





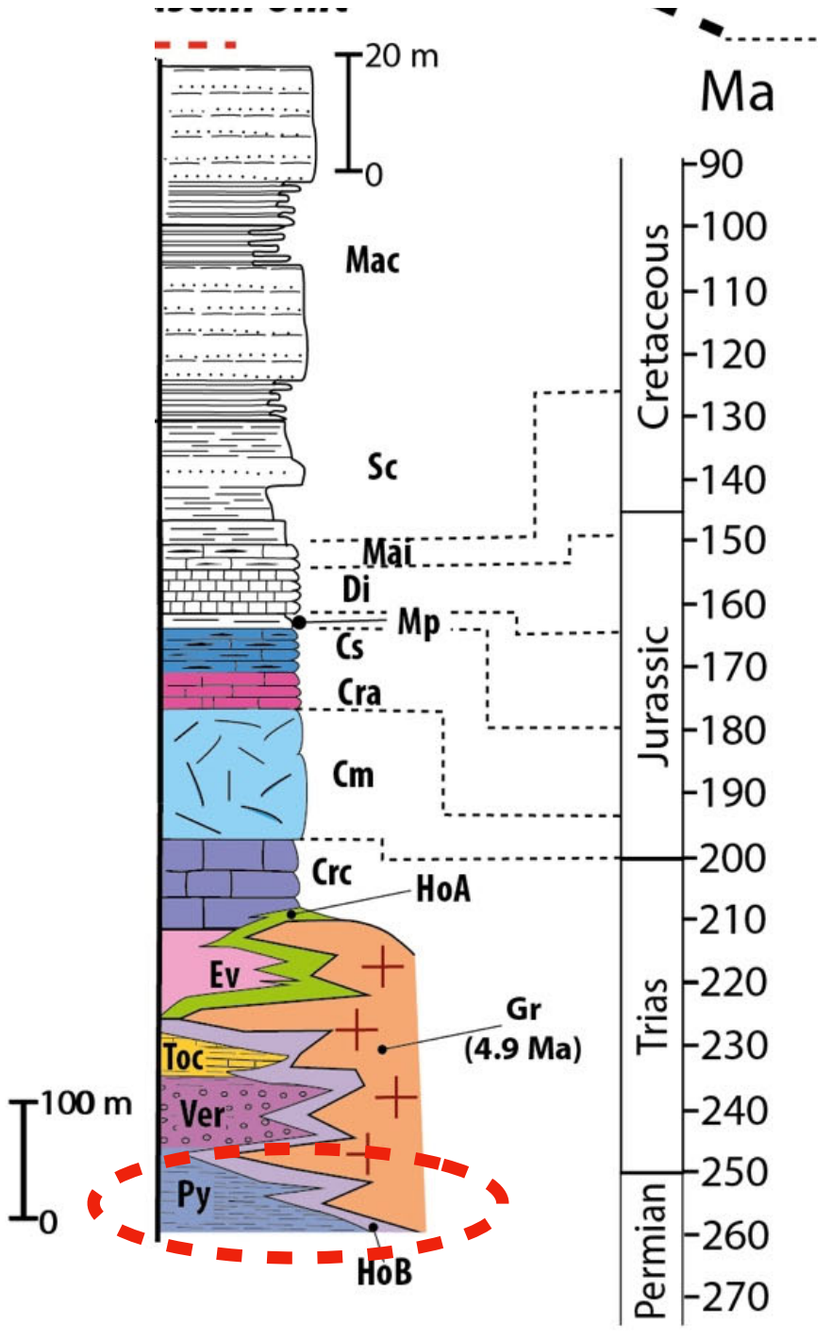
peak contact metamorphism conditions at:
T=660°C; P=150 MPa

Andalusite and Corundum are part of the mineralogical association in the phyllite

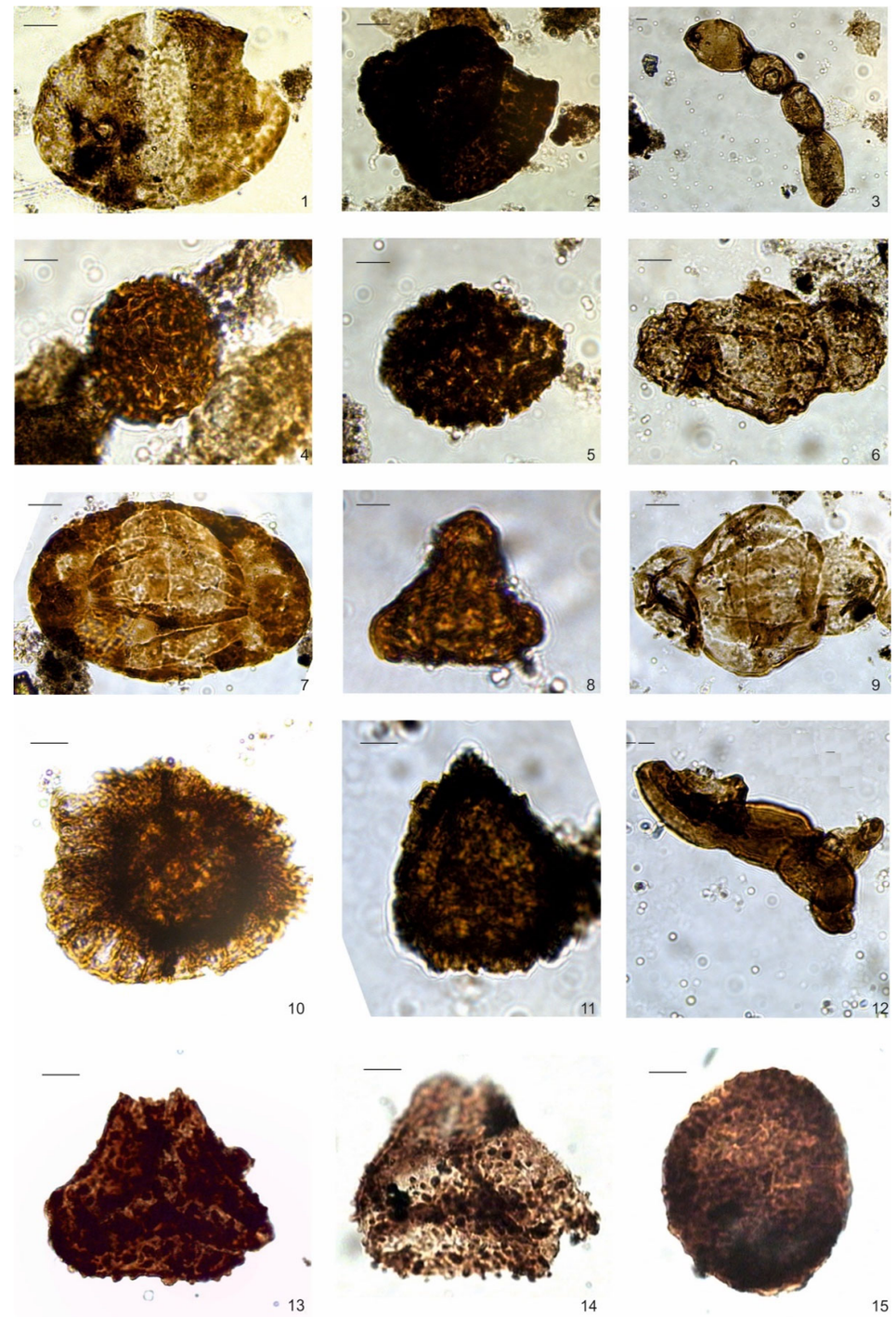


Focus on the Palaeozoic phyllite hosting rocks

AGE OF THE HOSTING ROCKS



Focus on the Palaeozoic phyllite hosting rocks

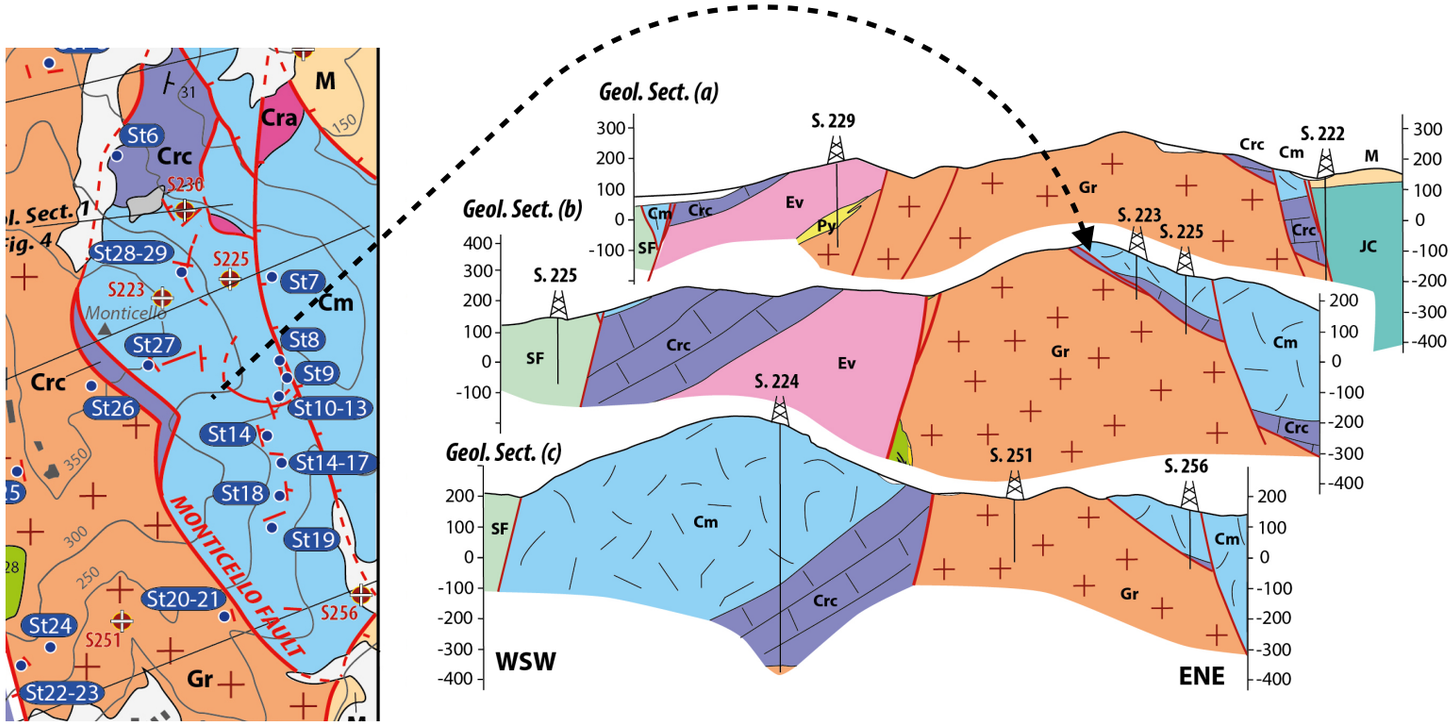


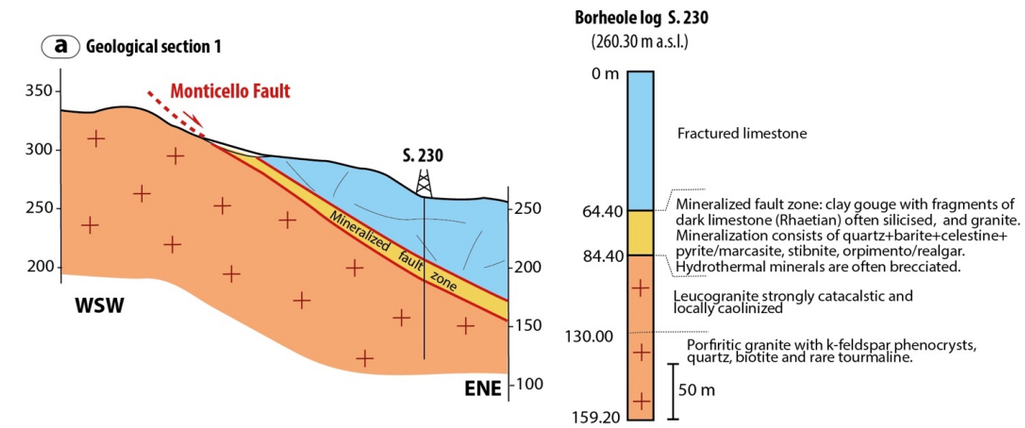
middle–late Permian

Sporomorphs from samples collected in the Gavorrano area (scale bar indicates 10 μm): (1) *Alisporites* sp. cf. *splendens* (Leschik) Foster 1979 (slide: RAV−1); (2) Indeterminate ornamented spore tetrad (slide: RAV−1); (3;12) *Reduviasporonites chalastus* (Foster) Elsik 1999 (slide RAV−1); (4–5) *Thymospora opaqua* Singh 1964 (slide RAV−2); (6,9) *Hamiapollenites* spp. (slide RAV−2); (7) *Distriatites insolitus* Bharadwaj and Salujha 1964 (slide RAV−1), (9) Indeterminate trilete spore (slide RAV−1); *Vallatisporites* sp. cf. *arcuatus* (Marques–Toigo) Archangelsky and Gamerro 1979 (slide RAV−2); (11) *Kraeuselisporites* sp. (slide RAV−1); (13,14) *Horriditriletes ramosus* (Balme and Hennelly) Bharadwaj and Salujah 1964 (slide RAV−1); (15) *Densoisporites* sp.

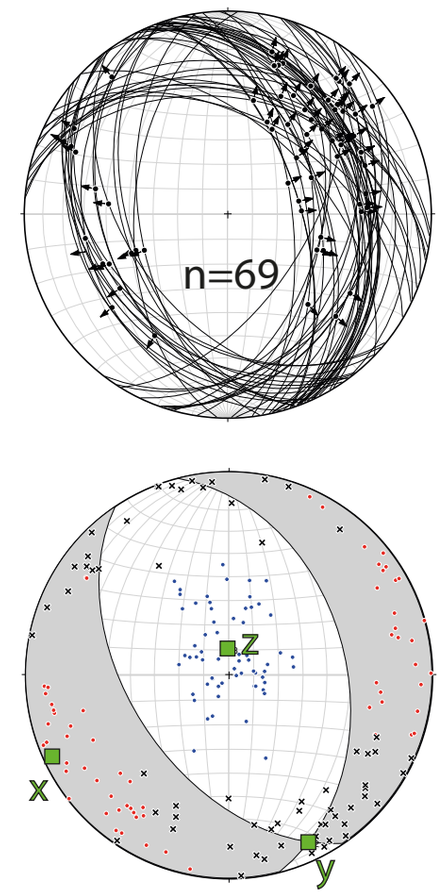
GEOMETRIC AND KINEMATIC DATA

MIOCENE LOW ANGLE NORMAL FAULTS





Miocene Low angle fault zone affecting triassic carbonate rock



Cumulative stereonet. The intermediate kinematic axis in SW-NE trending

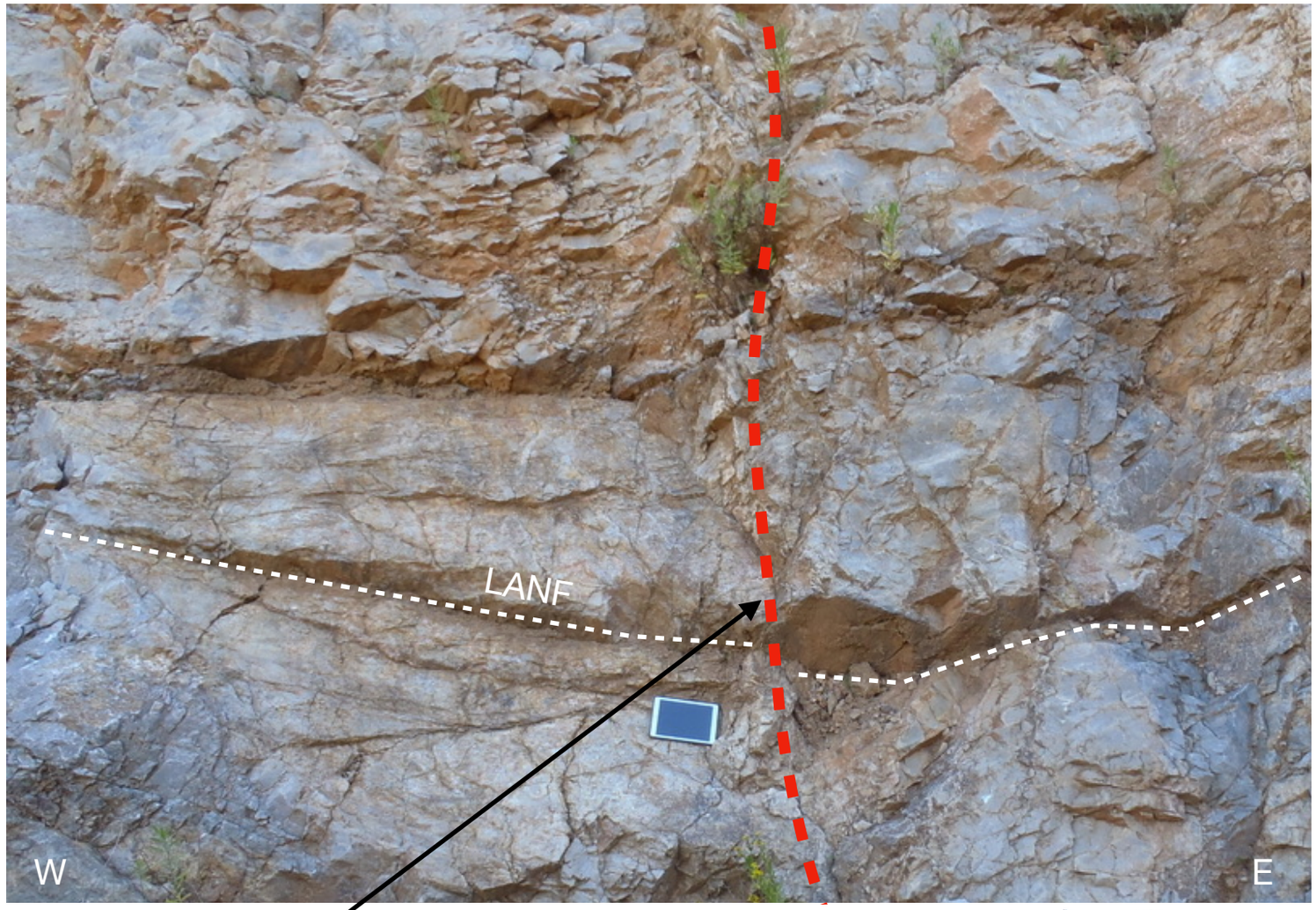
EXAMPLES:

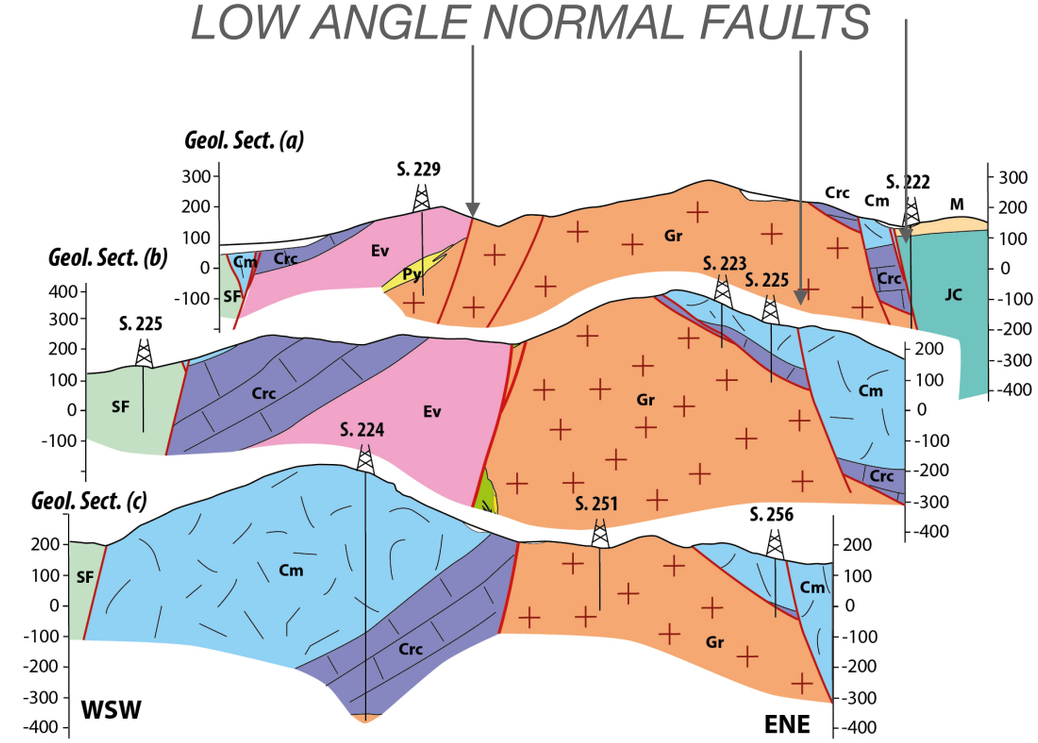
GEOMETRIC AND KINEMATIC DATA

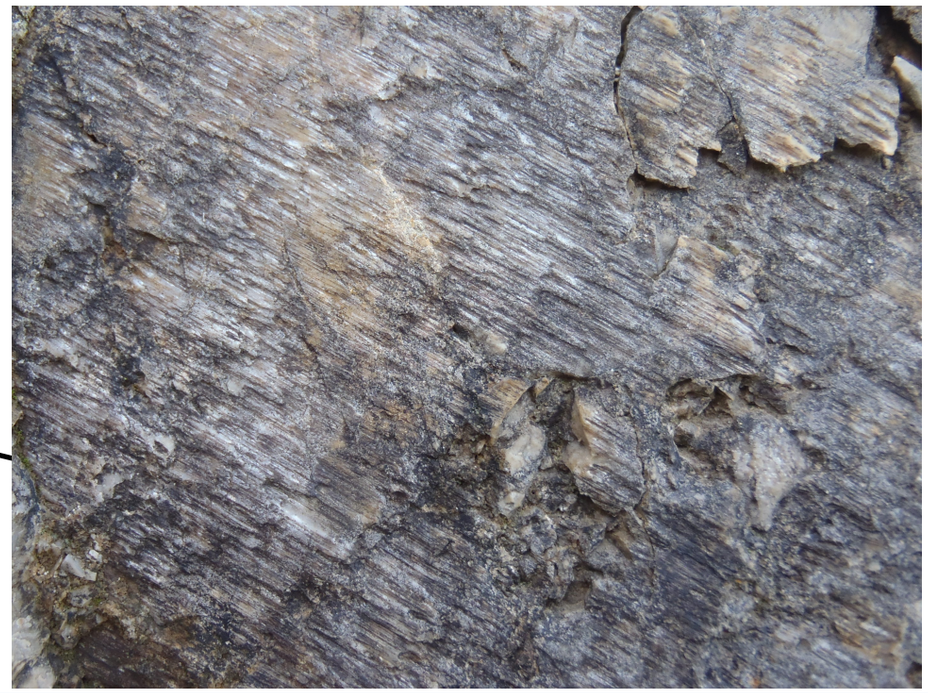
LOW ANGLE NORMAL FAULTS

GEOMETRIC AND KINEMATIC DATA

HIGH ANGLE NORMAL TO OBLIQUE-SLIP FAULTS CROSSCUT LOW ANGLE NORMAL FAULTS

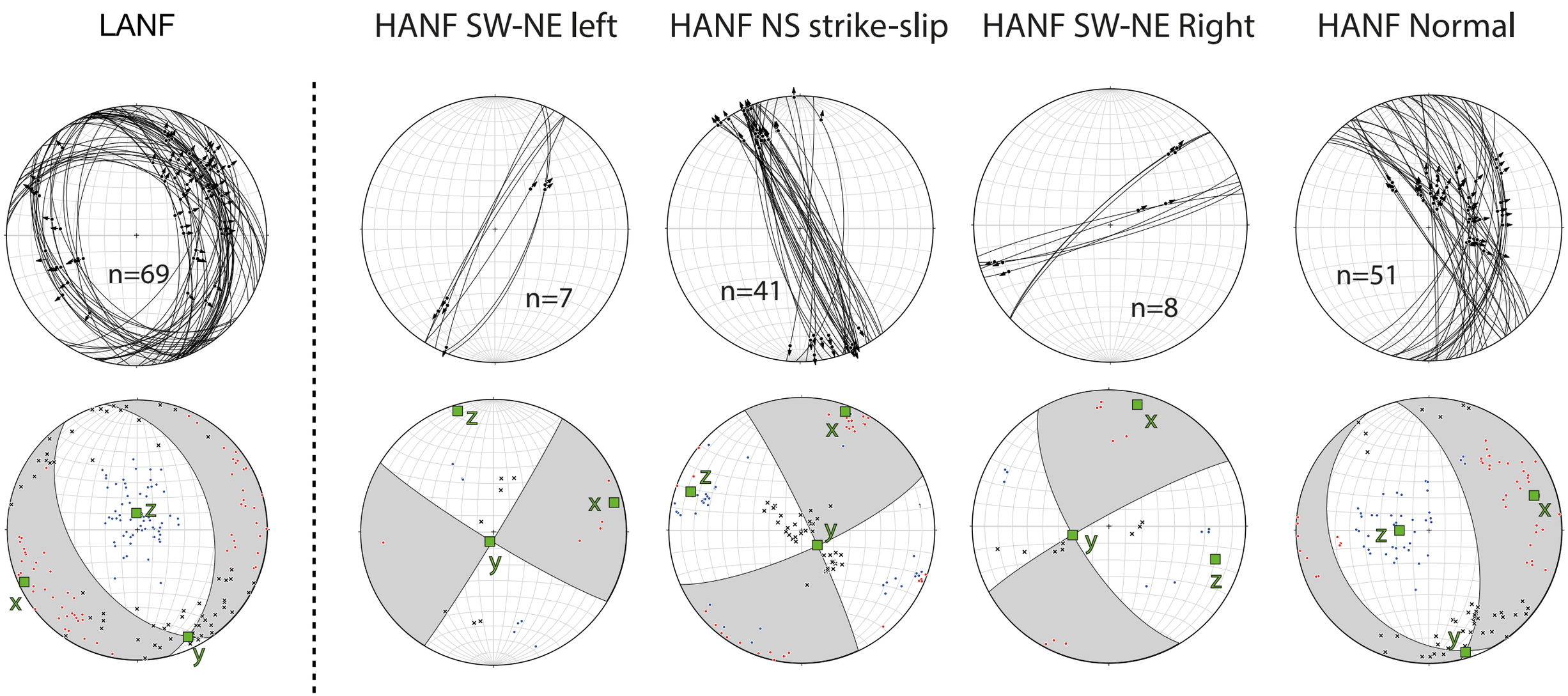






GEOMETRIC AND KINEMATIC DATA

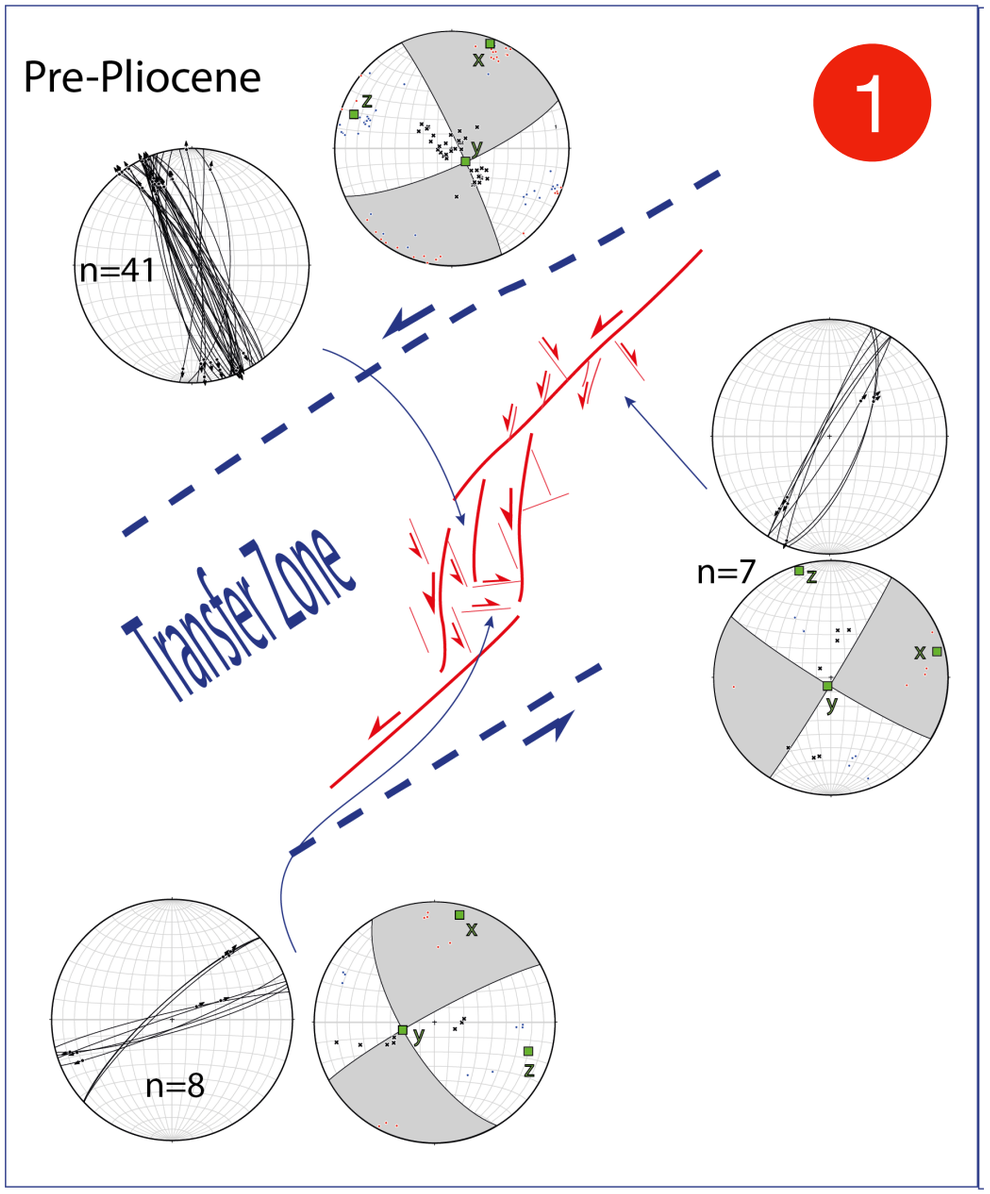
HIGH ANGLE NORMAL TO OBLIQUE-SLIP FAULTS

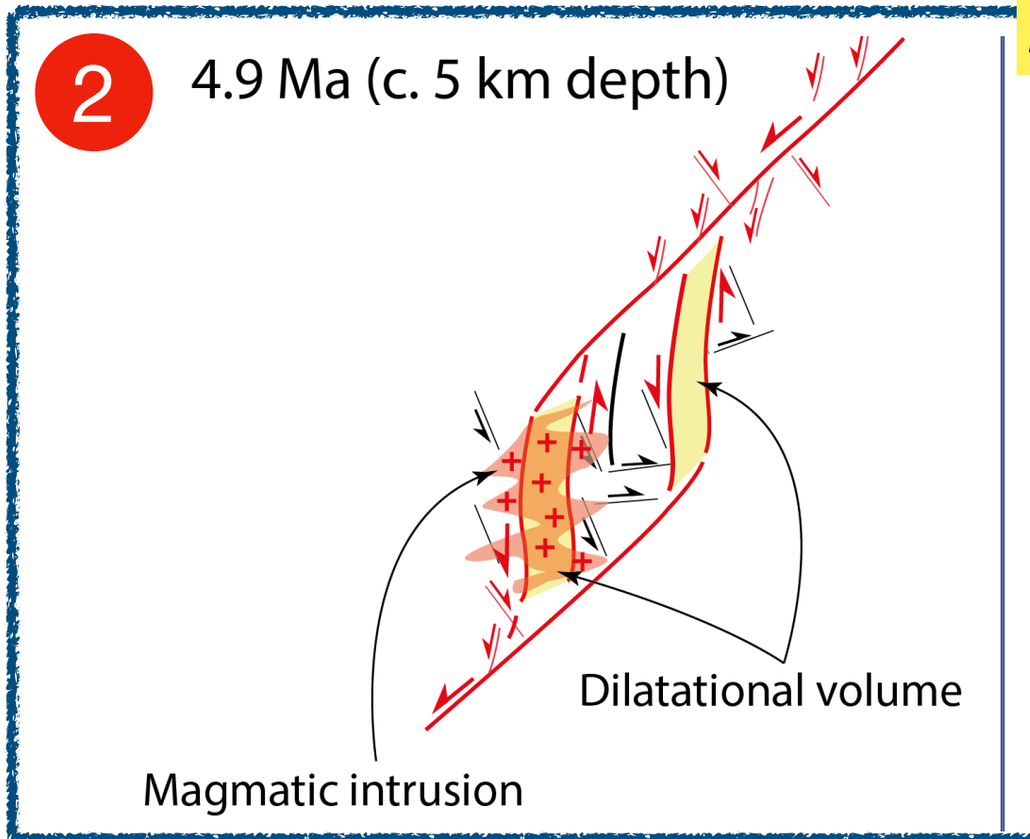


Consistency of the intermediate kinematic axis orientation ——> SW-NE trending

FROM MIOCENE TO POST-PLIOCENE

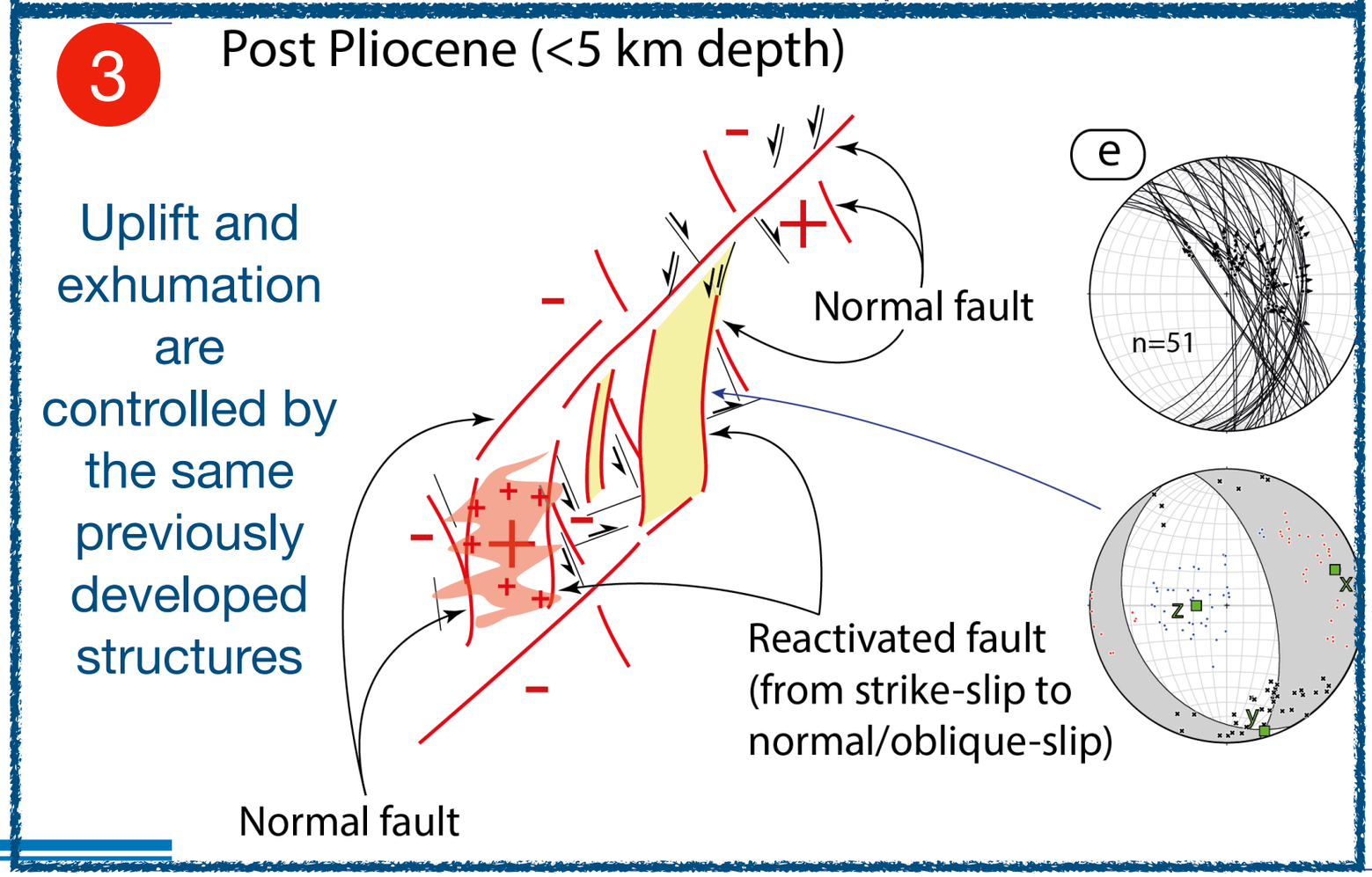
The deformation can be explained as resulting by a realising step-over zone within the transfer shear zone, active since Miocene





INTERPRETATION

The magmatic intrusion was channeled in this context



Uplift and exhumation are controlled by the same previously developed structures

CONCLUSIONS

Clarification of hosting rock age

Definition of the P-T conditions during contact metamorphism

Magma emplacement in the framework of the transfer zone deformation

More details in:

Brogi et al. 2021 - The Gavorrano Monzogranite (Northern Apennines): An Updated Review of Host Rock Protoliths, Thermal Metamorphism and Tectonic Setting. Geosciences, *11*, 124

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