Mineralogica et Petrographica Acta, 1993, v.35, pp. 51-65

Joints in clays of the neogenic basin of Siena

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RIASSUNTO — È stato condotto uno studio fisiografico e strutturale di dettaglio sulle fratture nelle argille del bacino neogenico di Siena, avvalendosi anche di analisi fotogeologiche.
I trends principali dei sistemi di fratturazione rivelano una chiara relazione con la tettonica dell'area.
La genesi delle fratture è coerente con la situazione del campo di stress che si realizza in un regime distensivo associato con un sollevamento, come si è verificato per il graben di Siena a partire dal Pliocene medio-superiore.

Termini chiave: Argille plioceniche-Sistemi di fratturazione - Tettonica recente

ABSTRACT — A detailed physiographic and structural study of joints in clays of neogenic basin of Siena has been performed both in the field and through photogeological analyses.
Main trends of joint systems reveal clear relation with tectonics.
Joint formation is consistent with the stress field existing in the tensional regime linked to the recent and present uplifting of the area.

Key Words: Pliocenic clays-Joints-Recent tectonics.

Introduction

The present study of the joints in clays of the neogenic basin of Siena was performed in the framework of an agreement between ENEA and the University of Siena.

Joints are evident and widespread in superficial levels of recent clay formations and made evident by their borders usually interested by oxidation phenomena. The aim of the study was to understand the causes and mechanisms of formation and spatial distribution of these joints by evaluating the influence of tectonic, geomorphological, biostratigraphic, geochemical and physicomechanical factors.

Here are summarized results made known in previous internal reports (Brondi et al., 1989, 1990, 1992) to which the readers are referred as regards biostratigraphic, geochemical and physicomechanical researches; no relation was observed between these factors and the genesis of the joints.

The areas of the Pliocene basin of

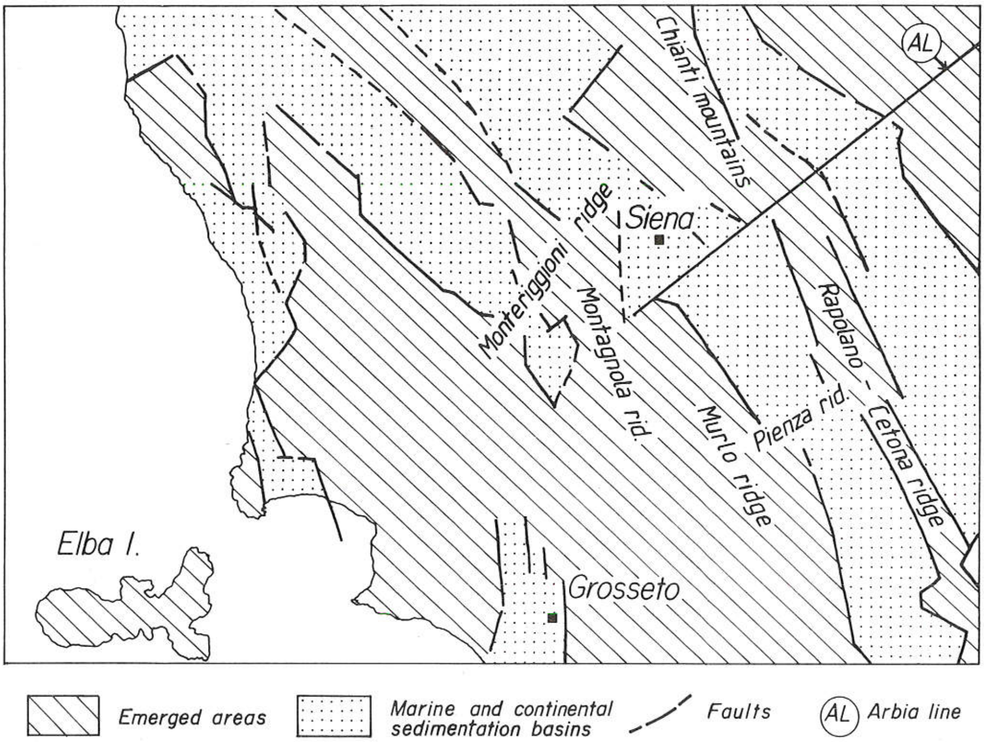


Fig. 1 - Distribution of the main neogenic sedimentation basins in Southern Tuscany.

Siena in which exposure conditions permit study of the joints are relatively scarce; they are generally restricted to quarries, artificial scarps and areas in which erosion has exposed the clay substrate. In all these areas, the vertical and horizontal dimensions of the outcrops suitable for study are extremely variable.

Geological-structural framework of the Siena basin

Apennine orogeny, in Tuscany, ended in the Upper Tortonian when the compressional regime was followed by a tensional regime with relaxation of the upper crust and creation of tectonic depressions orientated NW-SE and NNW-SEE (Fig. 1) (Bartolini et al., 1982; Costantini et al., 1982; Boccaletti e Coli, 1983; Barazzuoli et al., 1987).

One of these depressions is about 300 km long. Crossing the whole of Tuscany from the Serchio Valley (eastern side of the Apuan Alps), it runs southeast along the Elsa, Arbia, upper Orcia and upper Paglia Valleys to the valleys of the Chiana and Tiber. It is divided into segments by raised transverse structures (ridges). Each segment constituted a separate basin, badly connected to adiacent basins, each of independent tectonic-paleogeographic evolution. The Siena basin lies about half way along this long tectonic depression, between the Monteriggioni ridge, in the NNW, and

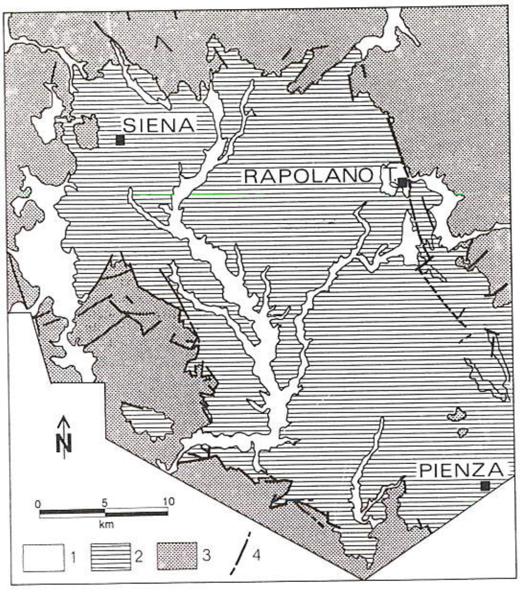


Fig. 2 - Geological sketch map of the Siena basin (from Costantini et al. 1982). 1. Quaternary deposits; 2. Sandy and argillaceous neogenic deposits; 3. Miocene and older; 4. Faults.

the Pienza ridge, to the SSE. It is cut by a tectonic line of regional importance, the Arbia line, a NW-SE oriented strike-slip fault with a complicate sense of movement along it (Liotta, 1991).

The Siena basin (Fig. 2) is filled with more than 1000 m of Pliocene sediments, they are mostly marine clay deposits, with subordinate sands and conglomerates in variable stratigraphic position. The maximum thickness of these sediments lies along a line running slightly east of the central axis of the basin; at the same time middle Pliocene deposits are distributed exclusively along the eastern side of the basin, while, along the western side, lower Pliocene deposits prevail. This asymmetry could be related to the different movements occurring along the bordering normal faults. The main fault runs along the eastern edge of the graben, it has a throw varying from about 2000 m near Rapolano Terme, to 600-700 m 12 km SSE. In the western edge of the basin a complicated net of differently oriented normal faults develops, with throw normally less than 100 m.

Physiography and attitude of joints

Physicomechanical data have revealed that clayey terrains under discussion are mainly constituted by overconsolidated silty-clays of low to medium plasticity and elevated consistency.

In order to study in detail the physiographic and attitudinal characters of the joints, 29 stations, nearly all in the Siena basin, were initially selected (Fig. 3). From each outcrop the measured fracture planes were plotted in statistical stereograms (pole to plane, Schmidt net, lower hemisphere). The joints show very different scattering figures but a clear point maximum is always present; it represents the preferred orientation of the joints in the field.

A general feature of the fractures is their near verticality and absence of movement. Especially near the surface, all joints show typical brown-yellowish oxidation salbdans of variable thickness (average about 5 cm) (Photo 1). Chalk filling, often in large crystals, was sometimes observed in the fractures (Photo 2 and 3). Usually the thickness of the salbands gradually decreases with depth. In fact, below the upper horizon of soil, with pervasive oxidation, the joints acquire clear-cut individuality just because of their yellowish salbands which stand out from the grayish background of the clay sediment (Photo 4). The salbands further below gradually

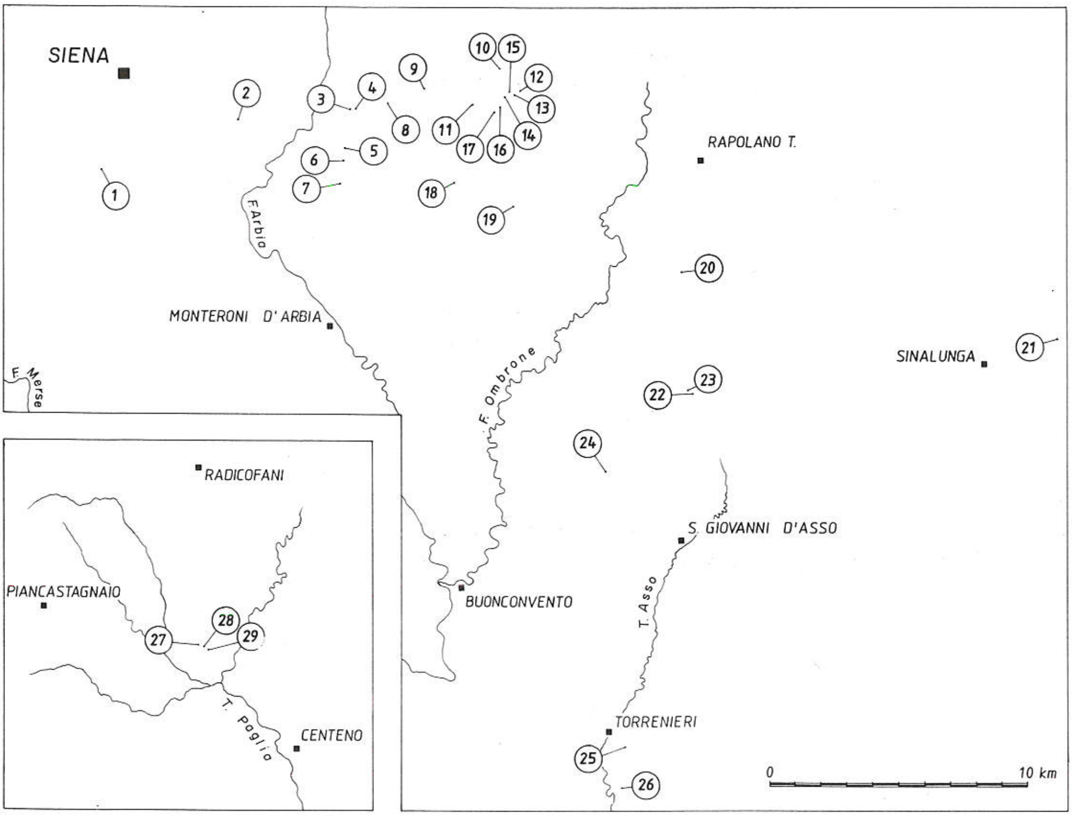


Fig. 3 - Location of the stations considered for the detailed study of physiography and statistical evaluation of joints attitude.

diminish their thickness and practically disappear around 7-8 m from the field level where the joints themselves actually close. The joints, nevertheless, can extend further into the substrate as a consequence of pressure release due to erosion or quarring. In quarries, infact, they can be seen to extend downward as open fractures without oxidation phenomena (Photo 5). Accordingly, where there are thick sand covers, i.e. conditions of considerable load, the underlying clays do not show joints (Photo 6), except sporadically; in these last cases they are without oxidation salbands.

Near the surface, clay fracturing assumes a very complex geometry: many sets of joint cross each other, often following curved lines. This is likely due to the overlapping effects of surface physical phenomena such as volumetric variations and gravitational effects, e.g. creep. At greater depth, however, the geometry is more regular, with a set of parallel and essentially rectilinear joints spaced about one metre (Photo 7) apart first predominating and then becoming exclusive. Figure 4 (a, b, c, d) shows the fracture patterns at different depth and Figure 5 shows Schmidt stereogrammes of typical situations which can be retained as representative of the observed cases; they come from two

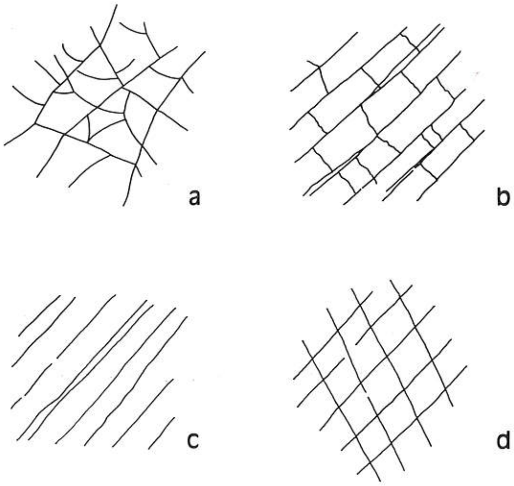


Fig. 4 - Scheme showing the main types of fracturing patterns at different depths (depth increases from *a* to *c*). The type *d* can be alternative to *b* or *c*.

stations in the north of the Siena basin. Marked dispersion of directions is evident near the surface (Fig. 5 - station 11a) but the direction N90 prevails and becomes exclusive deeper down (fig. 5 - station 11b). In station 10, about 2 km NW of the stations just mentioned, the same N90 direction predominates at depth but is accompanied by a secondary system running N-S (Photo 8).

In conclusion, as a general rule, it is always possible to single out, under the superficial pervasive oxidation horizon, a main set of joints even when it is accompanied by a secondary set as in station 10. It is just and exclusively to the direction of this main set of joints that we will refer in our measurements.

From stereogrammes 10 and 11b it is evident that the direction of a single joint set varies to a maximum of 20°, and this can also be observed in the horizontal extension of single joint. Dip can vary up to 10-15° from the vertical.

Photogeological study

In a second phase of this research, the number of stations was increased to a total of 63, 53 of which concentrating on the northern part of the basin from just south of Siena to about 10 km further south. A detailed photogeological study of the area was performed in scales of 1:13,000 and 1:33,000. Satellite images at 1:250,000 (Landsat 5, October 1984; Landsat 2, Novembre 1978) were also analysed.

All the linears identified were plotted on a map (Table 1) along with the main joint trends. More than 3,000 linears were observed in 1:13,000 photos and grouped in four rose diagrams. The first is a cumulative diagram of all the linears found, and reveals a marked dispersion of directions. However it is possible to observe a predominance of Apennine, anti-Apennine and E-W directions in line with the dominant regional tectonic trends (Gelmini 1974, Costantini et al. 1980).

The other three diagrams refer to limited areas (A, B, C) containing groups of stations with the same trend of joints and are given by way of example. In all three diagrams, a clear correlation can be seen between joint trends and the dominant directions of the linears. Although it is not always as clear as in the cases illustrated, a similar correlation may be observed in nearly all stations; in the more or less immediate vicinity, linears parallel of nearly parallel to the mesoscopically detectable directions of the joints are almost always evident.

It is noteworthy that the other groups of linears, present around stations, gen-

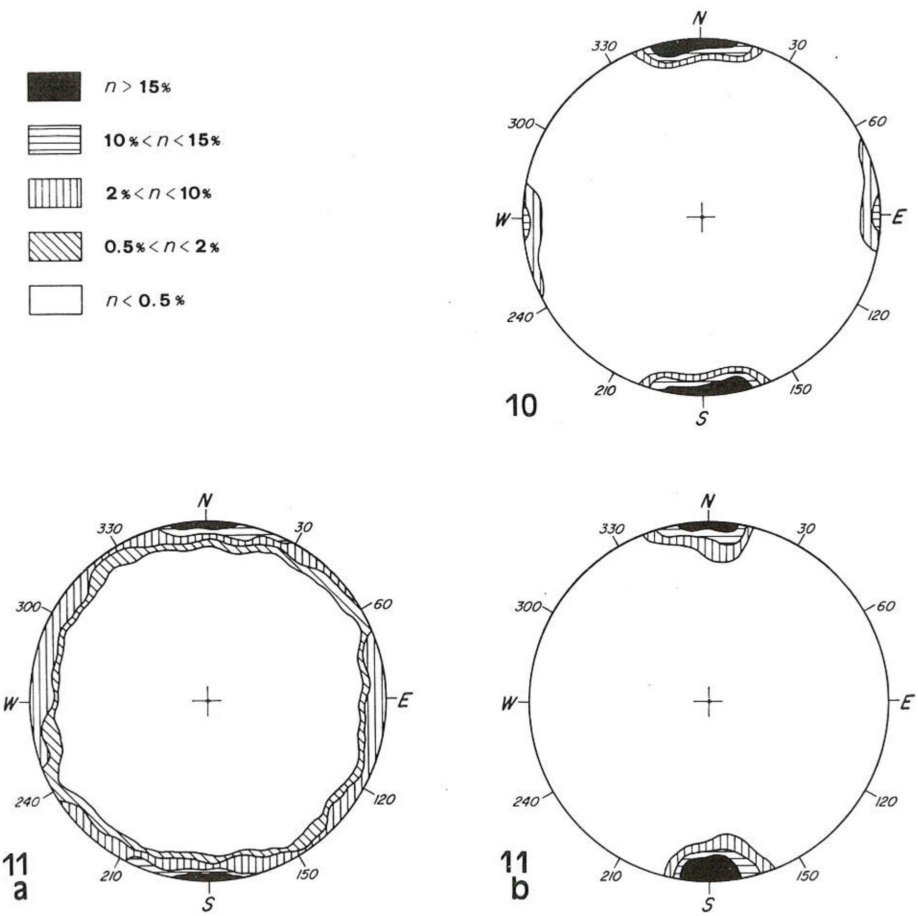


Fig. 5 - Rose diagrams for real situations representative of the fracturing patterns of fig. 4.

erally correspond to the trend of secondary sets of joint, which, as previously described, sometimes accompany the main set trend.

In the course of the study, clear relations often emerged between the direction of joints and of the main morphological lineaments. Another peculiar relation was observed between linears pattern and distribution of small dome-shaped argillaceous reliefs named «biancane» (Colica & Guasparri 1990) (Fig. 6).

Concluding remarks

The main trends observed in the joint systems of the Pliocene clays, in the various stations, are not randomly oriented but follow preferred directions, as shown in table 1. Stations distant many kilometres from each other often show

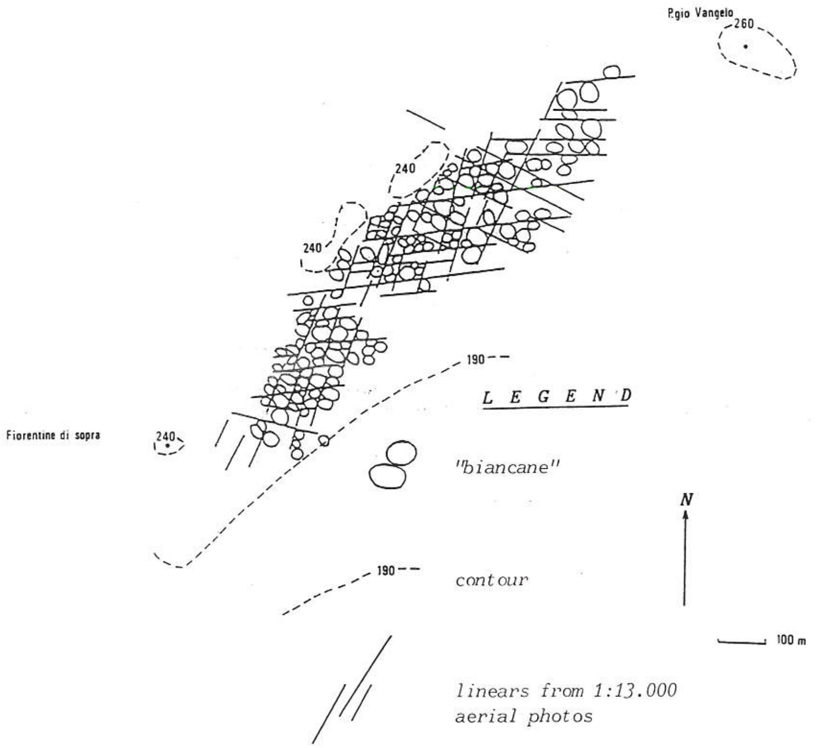


Fig. 6 - Example of relation between linears corresponding to joint trends in the field and distribution of biancane (from Colica and Guasparri, 1990).

perfectly aligned trends. In table 1 it may be seen that there is a clear relationship between direction of the joints and direction of the linear features, which, as already said, trace the pattern of the regional tectonic trends.

If the size of the study area and the uniformity of the findings over the various situations are considered, it seems reasonable to conclude that there is a well defined relationship between tectonics and fracture systems in the clays. The correlation between direction of the joints and local (direction of slopes) and regional (hydrographic pattern and ridges) morphological elements does not reflect a casual relationship but seems more likely to be the effect of the dependence of both upon tectonics, which is one of the fundamental factors determining morphology. This is not to say that locally, morphology cannot play a determinant role, especially in as far as it is the expression of events connected with a release of pressure due to erosion. Nevertheless, that the joints are first of all linked to tectonics is witnessed by the fact that certain trends often actually lie orthogonally to the morphological lineaments; in the study area this is almost always true for trends having Apennine orientation.

A model like that of Wilson (1961) (Fig. 7) for solid rocks can be suggested for the formation of the studied joints in pliocenic clays. The model is consis-

Photo 1 - Example of typical subvertical attitude of joints Castelnuovo Berardenga quarry). In this case, as frequently happens, the fracture plane is grayish.

Photo 2 - Chalk large crystals filled fracture (Costalpino quarry).

Photo 3 - Two parallel joints from a quarry plane with «varved» salbands. The one of the left shows discontinuous chalk filling; the joint opening is due to pressure release caused by quarring.

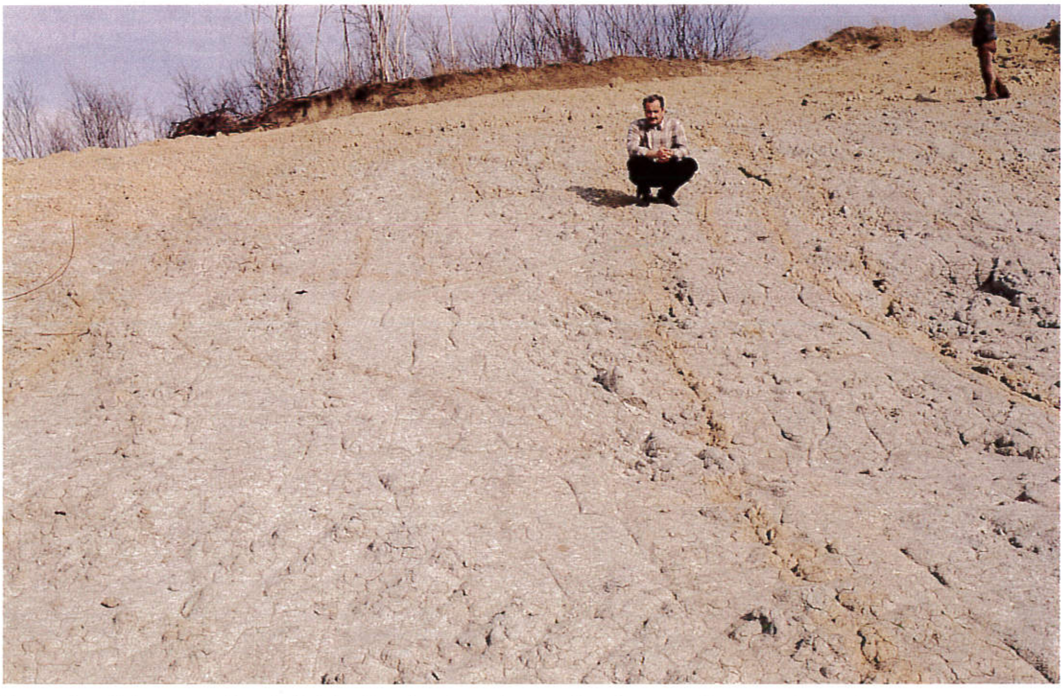


Photo 4 - Joints acquire individuality leaving the oxidized upper horizon (Castelnuovo Berardenga quarry).

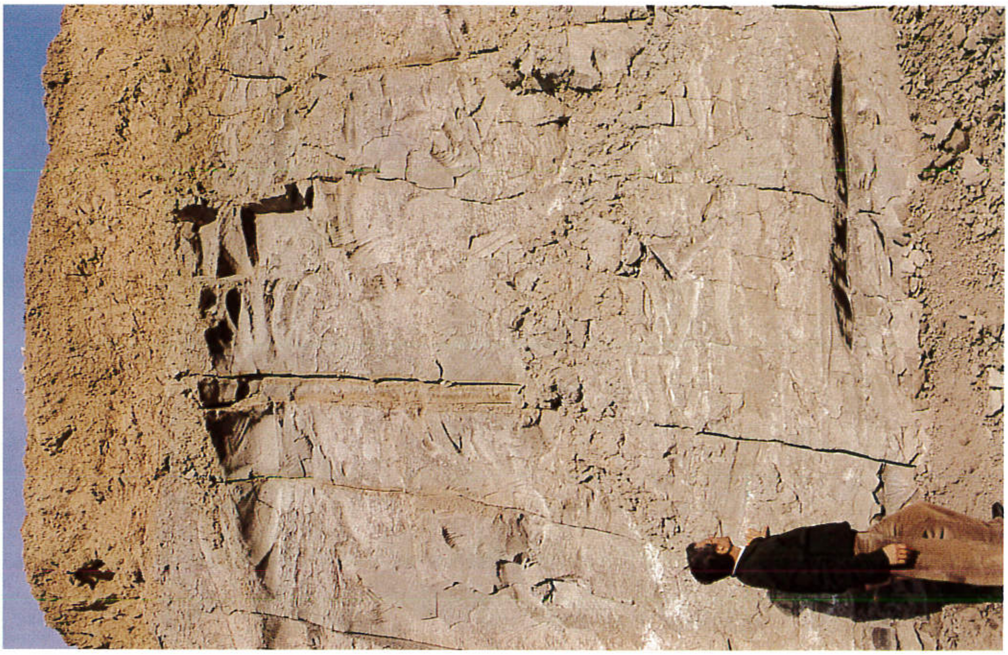


Photo 5 - Prosecution of joints as open inoxidized fracture for pressure release due to quarring.

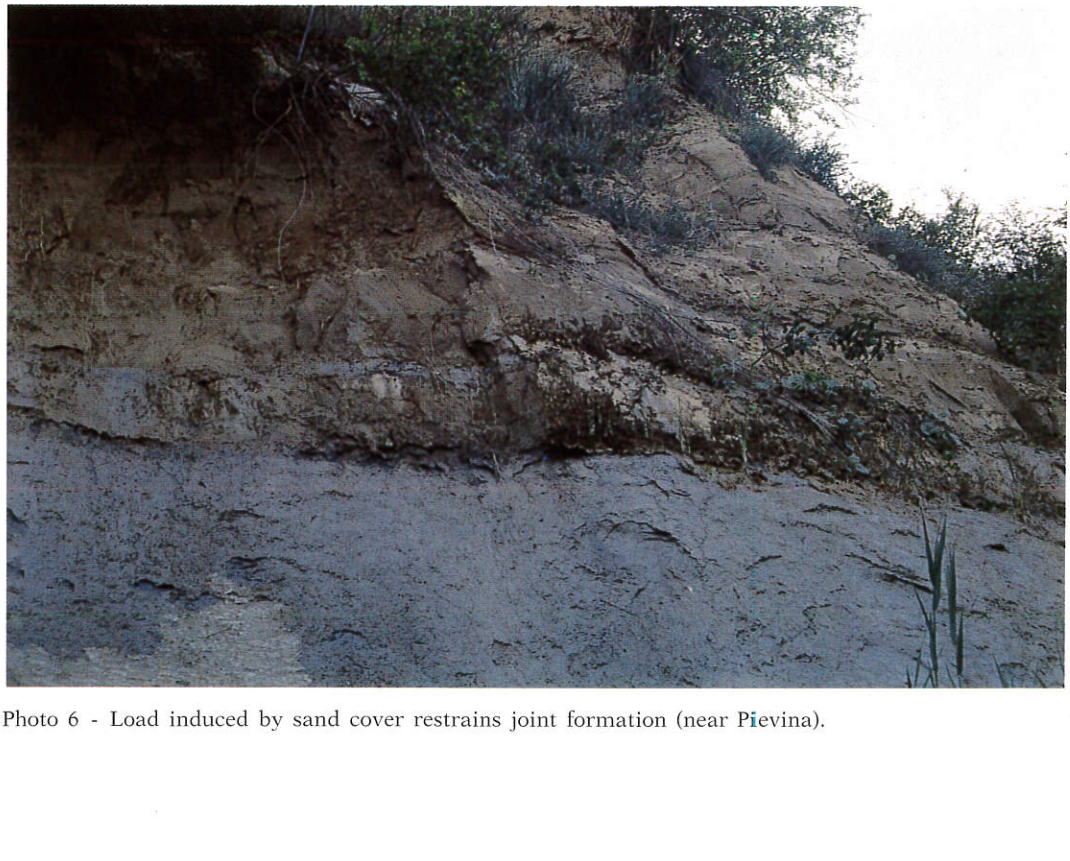


Photo 6 - Load induced by sand cover restrains joint formation (near Pievina).

Photo 7 - Regularly spaced joints in Castelnuovo quarry.

Photo 8 - A main set of joints crossed by a secondary system in a natural erosion surface (station 10).

Photo 9 - Small throw normal fault in the quarry at Costalpino, with N140 strike in agreement with the fractures in the quarry. Note that the oxidation phenomena, which pervade the sandy layers, involve the fault plane.

Photo 10 - Another small normal fault in the Costalpino quarry, with N140 strike as above. Note that the oxidation along the plane of the fault rapidly fades with depth.

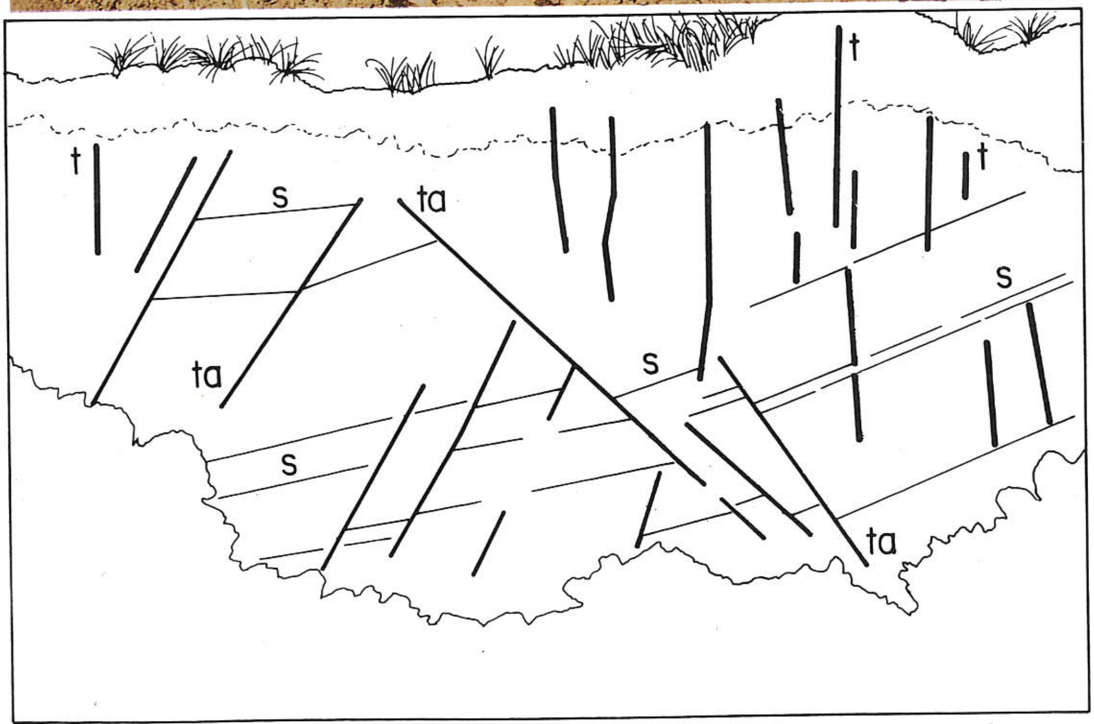
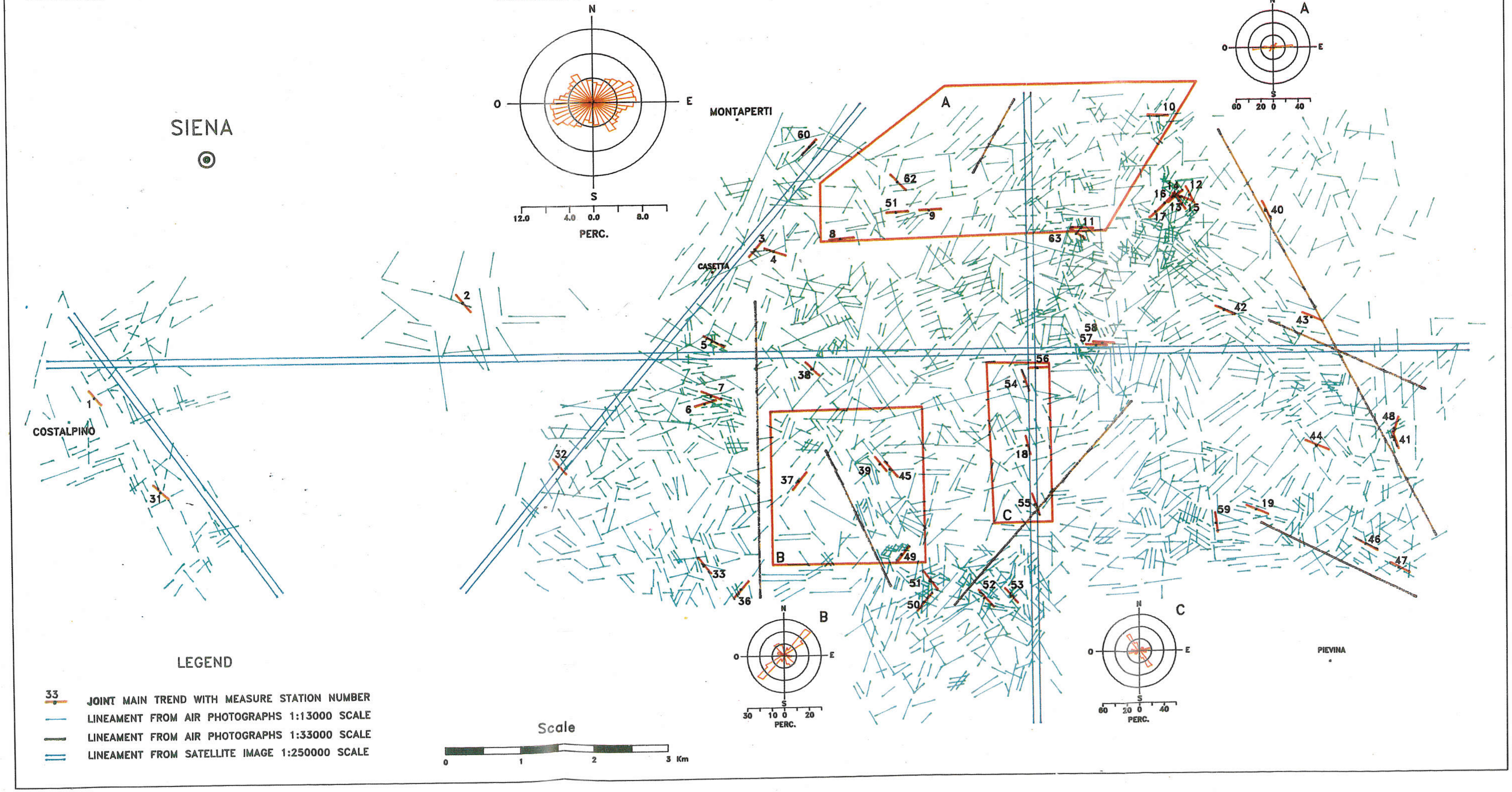


Photo 11 - The angular relationships between the structural elements visible in this photo of an outcrop at S. Miniato (Siena) and shown in the sketch, are the same as those in Figure 7 (*s* = stratification; *ta* and *t* as in fig. 7).

TABLE 1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PERC.
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A
B
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LEGEND
33 JOINT MAIN TREND WITH MEASURE STATION NUMBER
LINEAMENT FROM AIR PHOTOGRAPHS 1:13000 SCALE
LINEAMENT FROM AIR PHOTOGRAPHS 1:33000 SCALE
LINEAMENT FROM SATELLITE IMAGE 1:250000 SCALE
Scale
0
1
2
3 Km