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# DEEP SOILS ON STABLE OR SLOWLY AGGRADING SURFACES: TIME VERSUS CLIMATE AS SOIL-FORMING FACTORS.

## The Ferretto-type Paleosol, a case study: the Crocetta profile (Gazzola, Piacenza, Northern Italy).

ABSTRACT: CREMASCHI M. & BUSACCA A., *Deep soils on stable or slowly aggrading surfaces time versus climate as soil-forming factors. The Ferretto-type Paleosol, a case study: the Crocetta profile (Gazzola, Piacenza, Northern Italy).* (IT ISSN 0391-9838, 1994).

The Crocetta soil profile, which is typical of the Ferretto paleosols, is studied in details on the ground of the field characteristics, heavy minerals composition and micromorphological features.

The profile, 12.5 m thick, is located on the upper terrace of the Trebbia river dating to the Early Pleistocene. The parent material is gravel overlied by loess sheets. Three functional zones have been distinguished in the profile.

— Slowly aggrading zone, composed by superposed soil horizons developed in loess sheets that were deposited since Middle to Lower Pleistocene.

— Relict zone including relict features originated in a wetter and warmer pedoclimate during oldest phases of the soil development.

— Gravitative zone, still active which begun to develope since the Middle Pleistocene through decalcification, argilluviation and rubifaction.

The Crocetta profile is the result of a complex set of soil forming processes which acted for a long while, without any important break: in this sense it can be regarded as a Vetusol. However the oldest part of the profile still includes relict features, originated in a different pedoclimate, which are being dissolved by present soil forming processes.

KEY WORDS: Paleosols, Ferretto, Vetusols, Paleoclimate, Soil-forming processes, Northern Italy

RIASSUNTO: CREMASCHI M. & BUSACCA A., *Suoli profondi su superfici stabili o in lenta aggradazione: tempo e clima come fattori pedogenetici. Il paleosuolo tipo Ferretto di Crocetta (Gazzola, Piacenza).* (IT ISSN, 0391-9838, 1994).

Il significato paleopedologico dei paleosuoli denominati Ferretto, assai diffusi al margine alpino e padano, è interpretato in modi contrastanti: vi sono Autori che li considerano il prodotto della pedogenesi interglaciale, mentre altri pongono l'accento su di una evoluzione prolungata nel tempo e propongono per essi il termine di Vetusuolo. Il presente lavoro presenta lo studio di dettaglio del profilo di Crocetta, un «Ferretto» ubicato sull'ordine più antico dei terrazzi pleistocenici del margine appenninico della valle del Trebbia (PC). L'intero profilo del suolo spesso circa m 12,5, è descritto in dettaglio ed analizzato dal punto di vista della articolazione micromorfologica e dell'analisi dei minerali pesanti. Nel profilo, il cui substrato pedogenetico è costituito da ghiaie ricoperte da loess, si distinguono, dall'alto, tre diverse zone funzionali: zona di lenta aggradazione, zona relitta, zona gravitativa. La prima consiste di coltri di loess che si depositarono nelle fasi «glaciali» del Pleistocene Medio e Superiore e si alterarono poi in alfisuoli. La seconda conserva figure non in equilibrio con gli attuali processi pedologici. Tali figure vennero originate in una fase iniziale della pedogenesi in ambiente più caldo e più umido dell'attuale. La zona gravitativa è ancor oggi attiva, benché abbia cominciato a svilupparsi a partire dal Pleistocene Medio ad opera dei processi di decalcificazione, argilluviazione e rubefazione. Il profilo di Crocetta è il prodotto di processi pedogenetici attivi per gran parte del Pleistocene, che le oscillazioni climatiche fredde, responsabili della deposizione del loess non riuscirono ad interrompere; per tali ragioni il profilo di Crocetta può definirsi un Vetusuolo. Nella zona relitta del profilo permangono tuttavia figure che testimoniano condizioni iniziali della pedogenesi più calde ed umide delle attuali; esse sono in fase di attivo smantellamento da parte dei più recenti processi pedogenetici.

TERMINI CHIAVE: Paleosuoli, Ferretto, Vetusuoli, Paleoclima, Pedogenesi, Italia settentrionale

## FOREWARD

The term Ferretto has been used for many years in scientific literature concerning the Quaternary and the Paleopedology to indicate deep rubified soils developed on piedmont gravel terraces at both sides of Alps (CREMASCHI & OROMBELLI, 1982). PENCK & BRUKNER (1909) in their classical work on the Quatemary stratigraphy of the glacial age in the Alps used the Ferretto «paleosol» as a paleoclimatic and chronostratigrafical marker. The pedogenetic characteristics of those paleosols, red colour, thickness, disgregation of the stone fraction, were regarded as relict features typical of the Mindel-Riss interglacial period. These characteristics suggested to PENCK & BRUKNER that the Mindel-Riss was lengthy and had a climate warmer than that of the present.

The concept of Ferretto has become deeply rooted in the European Quaternary studies. Several types of Ferretto have been reported from Europe, and they generally are considered to be typical products of interglacial pedogene-

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sis. A correlation even has proposed with the S5 rubified paleosol of the Loess plateau in China (BILLARD, 1974, 1985, 1993). In this view, Ferretto soils should be regarded as relict soils, whose formation is due to a climate of the past that was warmer and wetter than the present one.

Other authors have taken a contrasting view, that is that time has been the main state factor responsible for the development of the Ferretto soils in Alpine region (ICOLE, 1971; BORNAND, 1978; CREMASCHI, 1987). For example, in the central Po plain of Italy, the Ferretto-type soils were regarded as (CREMASCHI, 1987) the oldest of four member of a local postincisive soil chronosequences whose ages range from 0,01 Myr to 1 Myr.

CREMASCHI (1987) conied the term Vetusols (vetus = old), for the oldest member soils of the chronosequence and asserted that, during the period 0.01 to 1 Myr, these soils on stable surfaces developed under the influence of the same set of major processes, decalcification and disgregation of gravel, argilluviation and rubification, and reacted only slightly to Pleistocene environmental changes (CATT ed., 1990). The major processes are decalcification and disaggregation of gravel, argilluviation and rubification. The assertion inherent in the Vetusol concept is that soil development that began in fluvial gravel has continued to deepen and strengthen the solum even as several loess sheets were added to the top of the terrace during the Middle and the Late Pleistocene. The Vetusol name was conied because the term Ferretto is very ambiguous, both from a lithostratigraphic and paleopedological point of view (CREMASCHI & OROMBELLI, 1982): that is, it has been used as a designation for both coarse deposits of different origins (fluvial and fluvioglacial gravel and diamicton) and the fine deposits that cover them, and as well to designate paleopedological phenomena of different ages.

This paper is focused on the detailed interpretation, by means of heavy mineral analysis, micromorphology, field morphology and routine analises of a Vetusol profile typical of Ferreto-type soils from the Apennine fringe of the Po valley in Northern Italy. We present this in the belief that the Ferretto can best be understood by examining the processes responsible of the development of the soil, their variation or constancy through time, and interpretation of the causative state factors. The question therefore is: are the Ferretto soils (Vetusols) the product of an *évolution prolongée* or of *évolutions successives* (DUCHAUFOUR, 1983). The problem is crucial if we are to understand the significance of Ferretto-type soils and to interpret them correctly in Quaternary studies. Buried soils testify only to the pedoclimatic characteristics of the period during which they evolved at the land surface. There is disagreement whether thick relict soils such as the Ferretto are mainly the product of one distinct pedogenetic phase that lasted for only one interglacial period or are the product of several cumulated phases. It is even possible under some conditions that they might evolve autonomosly with respect to external climatic oscillations. Each of these possibilities implies a different paleoenvironmental and stratigraphic significance and calls into question the role of the state factor climate in the evolution of soils over long time cycles.

## THE CROCETTA PROFILE: GENERAL INFORMATION

The huge thickness of Ferretto soils, generally over 10 metres, makes good exposures rare. It has thus been difficult to give a detailed description of the whole pedological body and adequately sample all horizons. Intensive quarrying of the Pleistocene terraces in the Trebbia river (Piacenza, Northern Italy), however, allowed us to locate and sample a complete profile that has the typical characteristics of a Ferretto soil.

The profile has been described on the walls of two neighbouring quarries, the horizons (Ap — VII B22) close to the Crocetta locality and the lower one horizons (VII B22 — VII CCa) 1 km north from the previous one in a quarry deeply cut into the terrace scarp; the two sections were correlated on the ground of the field characteristics and proved to be part of the same soil.

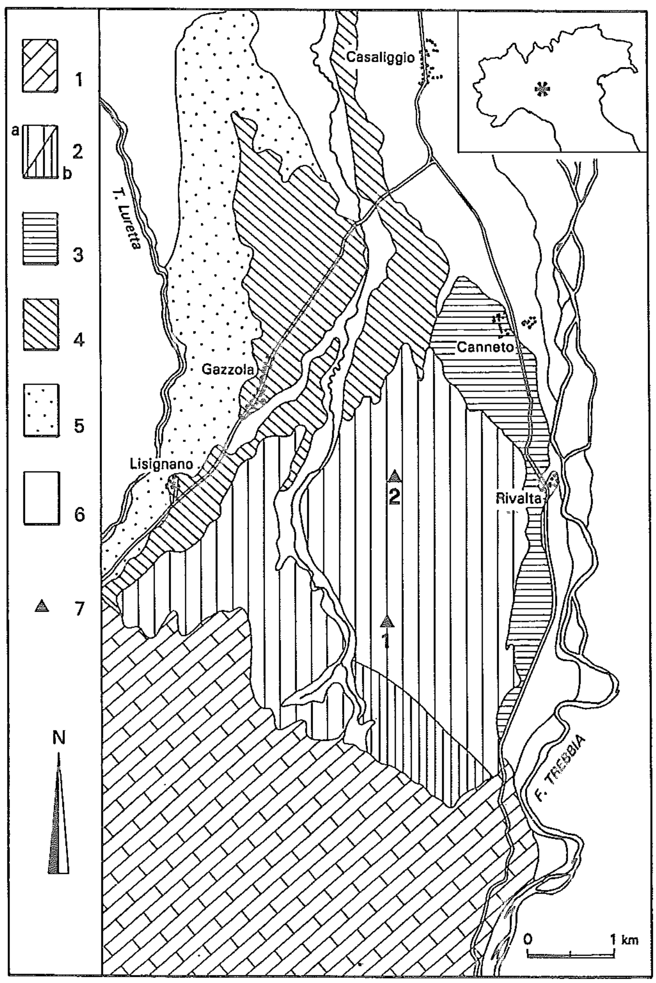


FIG. 1 - Schematic geomorphological map of the area of the Crocetta profile (from BARONI & *alii*, 1990). 1) Bedrock: Val Luretta Flysch; 2) Agazzano unit, erosional glacis (b) and gravel (a); Early Pleistocene, 3) Rivalta unit, gravel; Middle Pleistocene; 4) Gazzola-Costa unit, gravel, Late Middle Pleistocene; 5) Gravelly alluvial fan, Late Pleistocene; 6) Gravelly alluvial fan, Early Holocene; 7) location of the Crocetta profile: (1) upper part, (2) lower part.

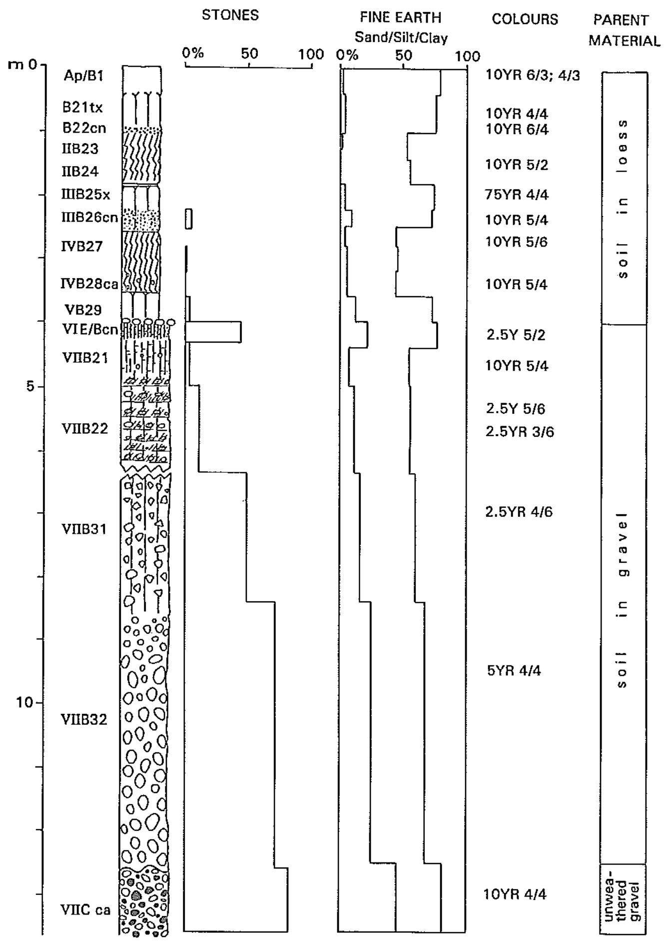


FIG. 2 - Schematic diagram of the morphology of the Crocetta soil profile, showing lithostratigraphy percent of stones, fine earth texture, colour and parent material.

The Crocetta profile lies, at the elevation of 155 m s.l.m., on the highest terrace order (Agazzano gemorphological unit, see fig. 1) and is a part of the oldest member of the soils chronosequence described for the Trebbia valley (BARONI & *alii* 1990). The parent material is loess overlying gravel. The gravel is comprised of marly limestone, sandstone and small amount of mafic rocks and is thought to have been deposited from the Late Pliocene to the Early Pleistocene (MARCHETTI, 1974; MARCHETTI & *alii*. 1979). To day the area has a submediterranean climate, with a MAT of 12.3°C and an MAP of 805 mm.

## FIELD CHARACTERISTICS

The weathering profile is about m 12.5 thick (fig. 2, App. I). We used Roman numerals in our field description to show our interpretation of the sequa that were transforming in this aggrading profile.

The upper part (m 0-4) is the result of the superposition of several sequa (horizons Ap/BI to VB29 ) (fig. 2, fig. 3a). Each of them is composed of a loess sheet that has been formed into an Alfisol or Vertisol. The horizons display hydromorphic features, gleying, mottling and glossic tonguing. The horizons that are composed predominantely of ferromanganese concretions (B22 cn, III B26 cn ) and the stone line at the base of the VB29 overlie old land surfaces that were buried by new additions of loess (CREMASCHI & CHRISTOPHER, 1984). In fact, Mousterian artifacts (Appendix 1) were collected from the B22 cn horizon. Their fresh state of preservation indicates that they were not reworked by fluvial or colluvial processes before burial.

The intermediate part (m 4-12.5) is comprised by soil horizons mainly developed in gravel (VI E/Bcn, VII B21, VII B22, VII B31, VII B32). The horizon VI E/Bcn is interpreted as a former albic horizon with hydromorphic features due to the persistence of a water table Iying on the slightly permeable VII B21 horizon. The parent material of the VI E/Bcn is colluvial gravel and pedorelicts. The VII B21 e VII B22 horizons display strong prismatic aggregation and are mottled; the VII B22 display strongly rubified areas; stones are represented by fragments of quartz and chert and gradually increase in abumdance with depth. From the VII B31 downward (fig. 3b), the decalcified gravel is progressively less weathered, the rubification markely decreases with increasing depth.

The lowest part of the profile is composed of unweathered gravel that is slightly cemented by CaC03 (VII Cca). The boundary between the VII B32 and the VII Cca horizons is abrupt and irregularly undulated, when directly observed it is generally wet and decalcification seems to be an active process, in this part of the profile.

## TEXTURE

The textural diagram (fig. 2) puts in evidence large changes of the clay contents with depth. This, along with associated cutanic features (see below), indicates the occurrence of superposed argillic horizons. The sand content displays a clear peak in correspondence with the colluvial horizon VI E/Bcn, it gradually increases with depth in the lower part of the profile, in the soil in gravel and it correspond to a parallel decrease of clay content.

## THE HEAVY MINERAL COMPOSITION

The heavy minerals were separated and determined according with standard method (CREMASCHI & RODOLFI, *a cura di* 1991; MANGE & MAUER, 1992). The heavy mineral composition of the VII C ca horizon (fig. 4) can be regarded as the composition of the unweathered parent material of the soil in gravel: poor in mica and in opaques, it has a significant content of picotite (group 3, fig. 4), which is derived from the basic rocks that crop out in the catchment area of the Trebbia river. It is also rich in the unstable

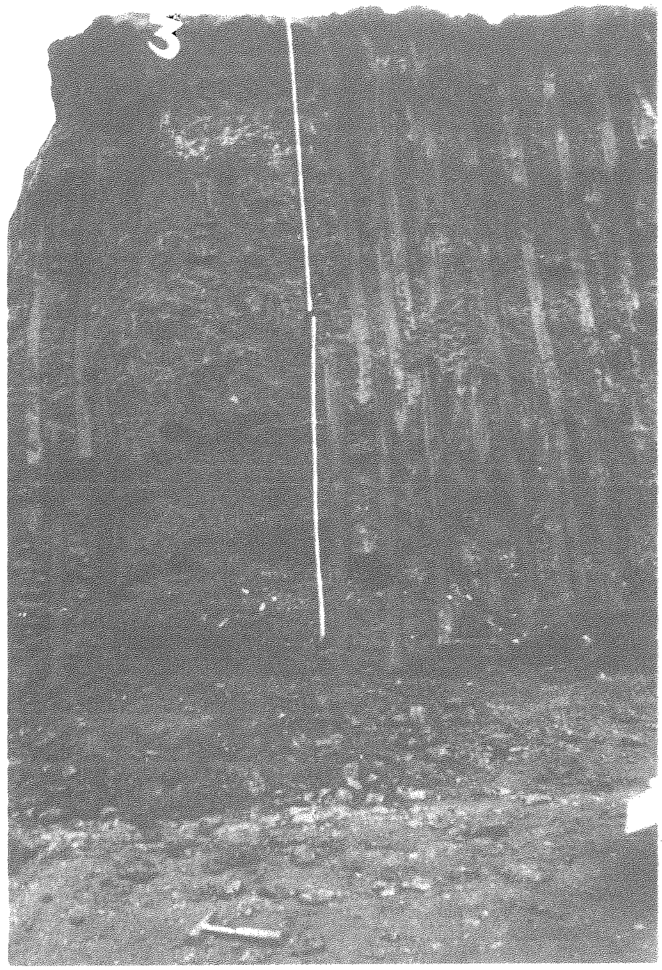

FIG. 3a - The loess sequence on the top of the Agazzano gemorphological unit, showing several superimposed argillic and Fe-Mn nodules rich horizons: note at the base the red upper horizon in gravel.

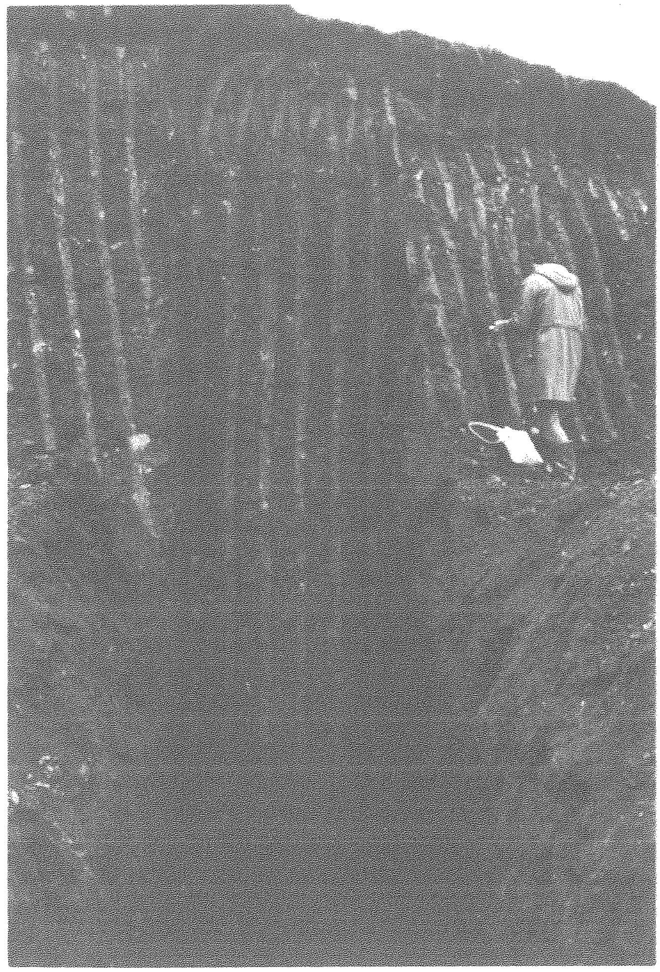

FIG. 3b - The lower horizons of the vetusol in the Agazzano unit: the difference in colour corresponds to the transition between the VII B31 and the VII B32 horizons.

minerals amphibole and epidote (groups 5, 6). The composition of the loess-derived horizons is rather different (horizons Ap/B I through VB29, fig. 4) as it was originated from a wider basin, the alluvial plain of the Trebbia and Po rivers, and therefore its heavy mineral suite contains only a small amount of picotite with a large number of mineral species (CREMASCHI, 1978); notice that it is particularly rich in epidotes (group 6).

A high percentage of mica near the top of the sequence (fig. 4) appears to be typical for slightly weathered loess (CREMASCHI, 1992). It gradually decreases with depth indicating a reduction of this mineral as a consequence of weathering. A measurable fraction of mica occurs in the strongly weathered horinzons at the top of the soil in gravel (horizons VI E/Bcn and VII B21, fig. 4). We interpret this as indicating that loess was admixed into these horizons.

The changes in abundance with depth of stable transparent heavy minerals such as zircon and titanium oxides (groups 1 and 2, fig. 4) confirm the occurrence of minor discontinuities in the loess cover that we observed in the field. The upper loess (Ap/BI and B21tx horizons) appears to becomposed of two slightly different loess sheets. The weathering rate (groups 1, 2, 3) becomes gradually more important with depth. Minor changes in picotite content in loess-derived horizons could be related to colluvial materials from the gravel being added to the lower parts of individual loess layers. The amounts of picotite in sequa IV and V are so large as to indicate that these units formed from loess that had a very significant co-mixture of colluvial material coming from reworking of the top of the soil in gravel, or at the least, that the loess was strongly derived from a Trebbia river source rather than a mixed Trebbia-Po source.

The opaques minerals and the picotite display parallel trends. That is, both groups increase in abundance from the surface down to the about the VII B21 horizon and then decrease with additional depth to the VII Cca. The opaque heavy minerals and picotite are both indicative of strong weathering because they resist weathering and therefore are selectively concentrated in the most strongly altered horizons. In the Crocetta profile, these are the upper horizons of the sequum in gravel (VII B21, VII B22, VII B31). Below these horizons, these minerals gradually decrease with depth, which we interpret to be due to progressively weaker weathering in that direction.

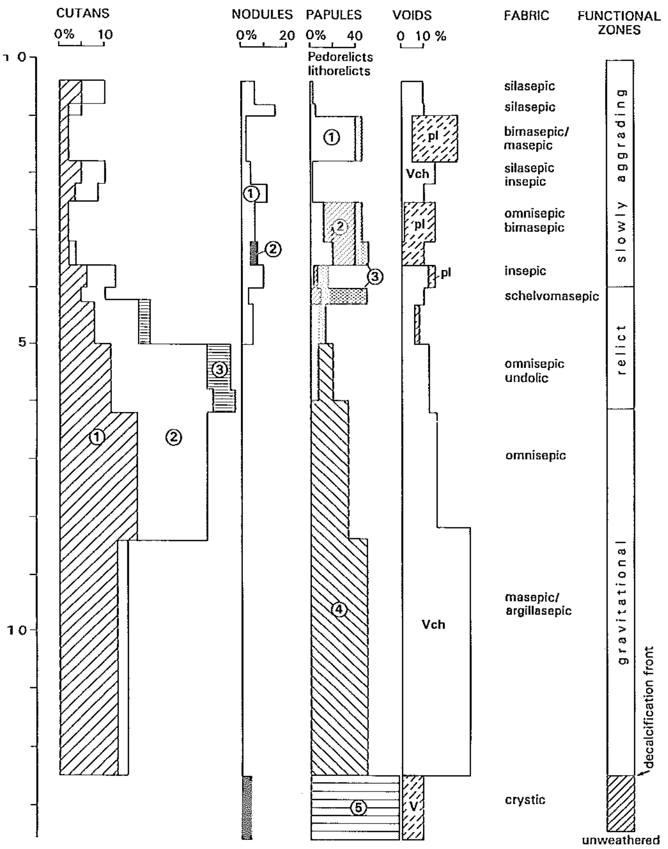


FIG. 4 - Quantitative mineral counts of opaque and transparent heavy minerals and micas in the sand fraction, as well as mineral species counts of the transparent heavy minerals. 1 = zircon plus tourmaline; 2 = anatase, rutile, and titanite; 3 = picotite and spinel; 4 = garnet, sphene and chloritoid; 5 = amphiboles; 6 = epidotes plus zoisite.

This overall pattern is consistent with the Vetusol concept in which the most strongly altered horizons would be expected to be the oldest land surface, the original surface of the terrace in gravel. Each loess sheet that was added after the initial period of soil development in the gravel would be less altered than the one beneath it, if soil-development processes had been relatively continuous and unidirectional. Other phenomena, such as progressive change in parent material composition throughout the time of loess deposition, might also in part explain these trends, so the micromorphology of this Vetusol may be one of the better tools for deciding between these constrasting models to explain the heavy mineral depth trends.

## MICROMORPHOLOGY

Fig. 5 compares the change with depth of relevant micromorphological features and plasmic fabric, indicated according with BREWER, 1977, and BULLOCK & *alii* 1985. We have distinguished the following features:

*Cutans*: three different classes of cutans were observed.

1 - yellow laminated complex (i.e. interlayered with siltans and skeletans) ferriargillans related to voids (fig. 6a). They appear at the very top of the sequence where they are relatively thin and clearly laminated, but they gradually become much thicker from the VI B21 horizon downward (fig. 6e).

2 - yellow complex ferriargillans not related to voids (fig. 6b, e, f). Lamination is occasionally preserved; these cutans are on their way to being integrated in the S matrix.

3 - red laminated ferriargillans that generally are related to voids (fig. 6c). They are strongly birefringent and the lamination is perfectly preserved. This type has been observed only in the VII B21 and VII B22 horizons, and into the pedorelicts of the B type (see below).

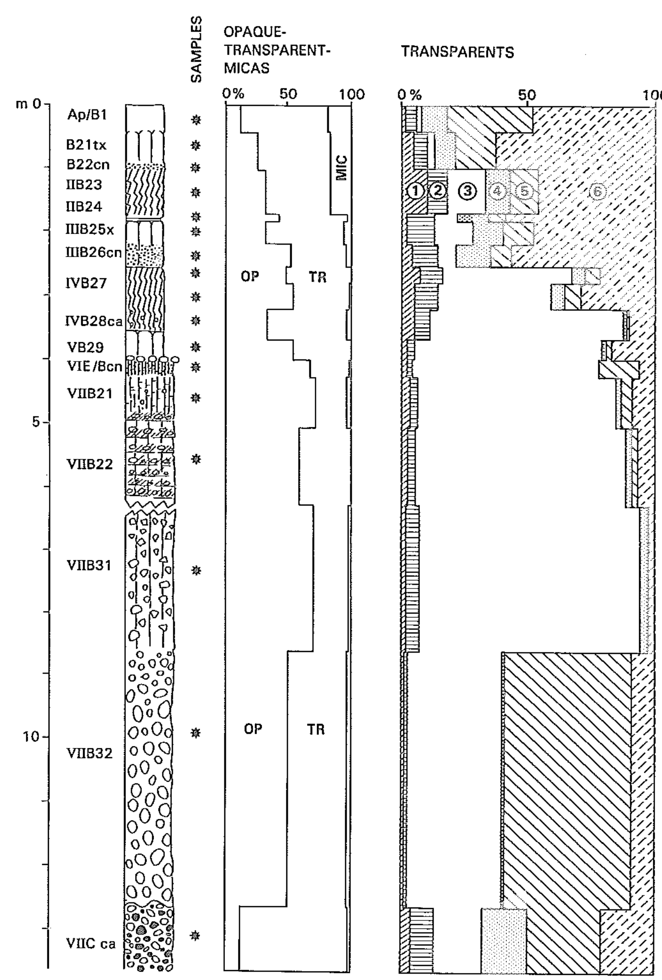


FIG. 5 - Microscopic features of the Crocetta profile. Complex cutans: 1 = yellow, laminated, complex ferriargillans related to voids; 2 = yellow complex ferriargillans not related to voids; 3 = red laminated ferriargillans generally related to voids. Nodules: 1 = Fe-Mn nodules and concretions; 2 = CaC03 glabules. Papules: 1 = papules; 2 = pedorelicts; 3 = lithorelicts (quartz and chert); 4 = lithorelicts (weathered gravel fragments); 5 = lithorelicts (unweathered gravel). Voids: Vch = Vughs and channels; pl = planes; v = vughs.

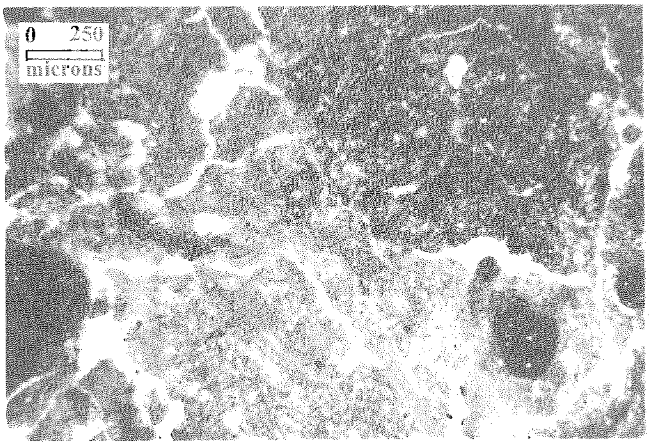


FIG. 6a

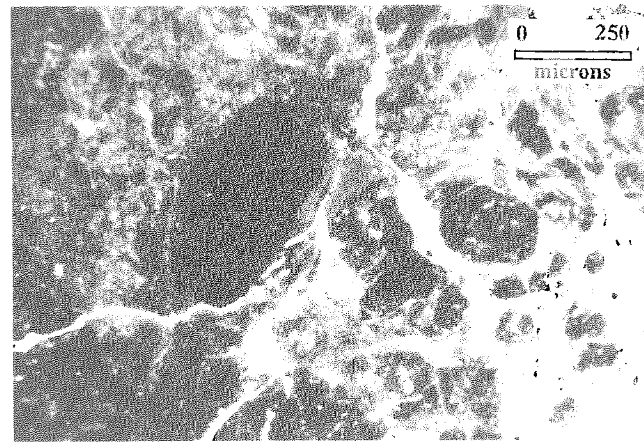


FIG. 6b

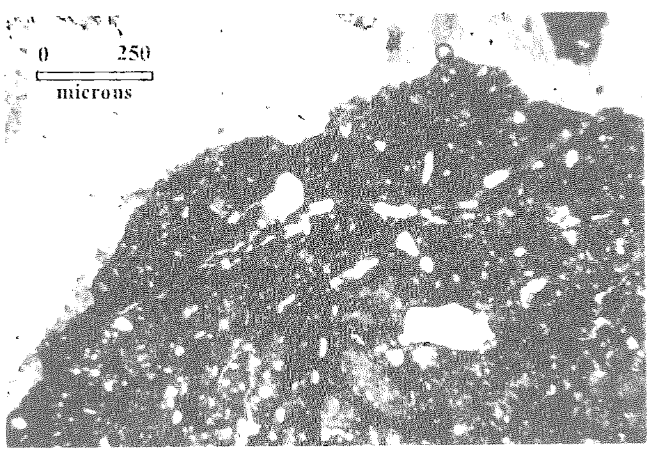


FIG. 6c

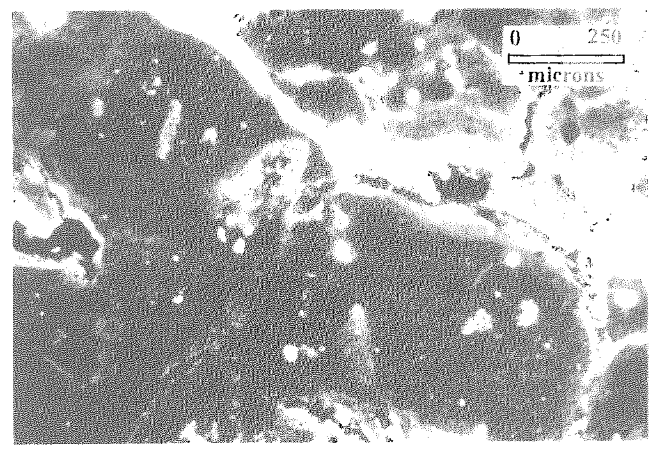


FIG. 6d

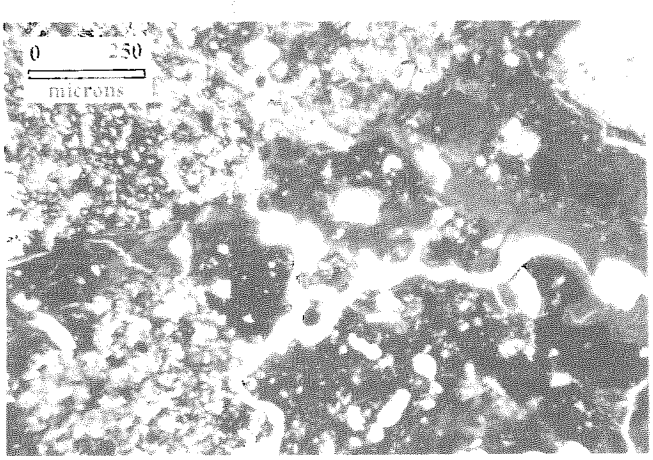


FIG. 6e

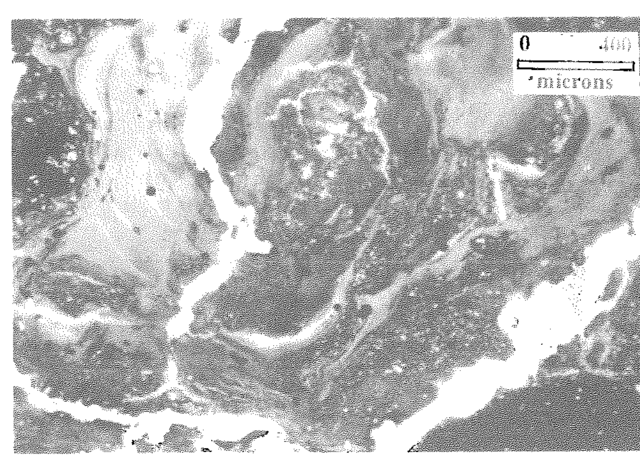


FIG. 6f

FIG. 6 - Micromorphological features of the Crocetta profile. a: B21 tx, P.L., several generations of yellow laminated cutans related to voids; b: IV B27, P.L. yellow laminated cutans, not related to voids, and dislocated by planes, note the pedorelicts of the A type and the Fe Mn nodules; c: VII B21, P.L. a large oxidised area has red laminated cutans, the soil fabric has low birefringence; d: VII B21, X.P.L: fragment of haematite rich soil fabric is disrupted in small peds and surrounded by yellow highly birefringent clay and yellow laminated cutans; e: VII B22, P.L. complex and thick yellow laminated clay cutans embedding lithorelicts; f: VII B22, P.L. detail of the complex yellow laminated cutans.

*Papules, pedorelicts, lithorelicts*: papules are concentrated in the second and fourth sequa and are associated with the vertic properties of those zones. These are interpreted as the result of strong accumulation of dynamic illuvial clay in loess derived horizons that were permeable at the beginning of their episodes of soil development.

The papules at 3.5 to 4.5 m in the IV B27 and IV B28 horizons are associated with the A type pedorelicts, (fig. 6b). They consist of fragments of silasepic plasma that were derived from loess, slightly impregnated by Fe Mn hydroxides, disrupted by vertic movements and locally transported.

A second, or type B pedorelicts consists of haematite-rich and isotic — undulic soil matrix (Fig. 6d). They are found in the V E/B an VI A/Bcn horizons and are composed of rounded fragments originated by the erosion and short transport of soil material having the characteristics similar the VII B21 and VII B22 horizons.

Lithorelicts in the horizons B21 tx through VII B21 are derived from the gravelly terrace alluvial parent material as they are composed of small fragments of chert and quartz. In the loess horizon they are interpreted as due to colluvial input. From the VII B22 horizon downward they become progressively larger and include also fragments of decarbonatated marl and sandstone; in the VII B32 horizon they are decarbonatated gravel that still preserve their original shape, but have been broken in several fragments, which have been only slightly displaced by vertic movements of the soil. The trend of the litho-relicts with depth is, not surprisingly, quite similar to that of the stone fraction in the textural diagrams (fig. 2).

*Voids*: two groups are distinguished, vughs-chambers and planes. The voids decrease with depth down up to the VII B21 horizon, in which they reach the minimum value. At deeper level they again increase in number to the base of the VII B32 horizon. Planes are principally associated with the vertic characteristics of the II B23-II B24 and IV B27-IV B28 ca horizons.

*Glaebules*: the Fe-Mn nodules occur mainly in the upper sequa in loess. High concentrations of iron-mangan glaebules are indicative of buried topographic surfaces (CREMASCHI, 1987): therefore at least three of them appear to be included in upper part of the profile and separate the I to IV sequa. CaC03 nodules have been observed both in field and in thin section in the IV B28 ca horizon. They were originated by the decarbonatation of the loess deposits that overlie the top of the clayey buried soil in gravel. These CaC03 nodules have sharp boundary and seem to be inactive. CaC03 concretions in the form of pendants occur also in the VII Cca horizon; there they display a diffuse lower boundary and apparently are still developing.

*Plasmic fabric*: the plasmic fabric ranges from insepic-silasepic for the higher loess cover to omnisepic in the horizons displaying vertic properties. In the VII B21 and VII B22 horizons, there are red haematite-rich patches which are undulic to isotic. They are surrounded by large cutanic features which have an highly birefringent fabric. The red patches, which originated the B-type pedorelicts, are relicts features that are in the way to being adsorbed by a subsequent generation of plasma.

No evidence of textural features produced by frost have been recorded in this profile, while they were observed in a profile close to the one described here (CREMASCHI & VAN VLIET LANOE, 1990), they were constituted by faint evidence of ice lensing, indicanting just deep seasonal frost.

The micromorphology confirms the field observations and the heavy mineral analyses: the pedological profile apparently composed by gravel covered by loess is indeed constituted by a complex polisequum of soil horizons.

All the loess sheets and the underlying gravel include a large accumulation of cutanic features. A clear hierarchy of the yellow cutans (group 1 and 2) throughout the 12 -m profile cannot be assessed. They progressively increase in number and complexity with depth, indicating superposition of several phases of clay illuviation and of coarse illuviation from the youngest sequum in loess down to the VII B31 horizon. Below this depth they slightly decrease with depth in number and complexity. According to this fact, the difference in loess characteristics with depth (increasing of fine textural fraction and stable minerals) seems related more to soil forming processes than to differences in the source material of the loess.

The red cutans of the group 3 are included in pedorelicts found at 4 m in the VI A/Bcn. These pedorelicts, in their turn, are embedded in the femargillans of the group 2. From this hierarchy, we can conclude that the group 3 cutans already existed when the top of the VII B21 horizon was eroded and subsequently buried by loess deposition.

Furthermore their undulic fabric point to a different mineralogical composition of the plasma that is richer in iron oxides and in 1:1 clay than the surrounding birefringent plama. The VII B21 horizon seems therefore to include features that originated during the first phases of the pedogenesis on the top of the gravel. These features are relict as their have been in part reworked by subsequent erosional and soil-forming processes.

## DISCUSSION

The profile appears to be the sum of several pedogenetical and sedimentary cycles whose effects are superposed upon one another. Its genesis cannot be explained by a simple model because it is necessary to take into account at the same time both the sedimentation and the pedogenetic events.

Stratigraphic evidence indicates that loess began to be deposited on a surface that had already been affected by soil development. This is proved by the fact that the VI E/Bcn horizon includes, in the form of pedorelicts, fragments of deeply weathered B horizons, which still exist in place in the VII B21 and VII B22 horizons. The features that form the pedorelicts, the areas with isotic plasmic fabric, and red laminated ferriargillans, are relict features as they are embedded into subsequent generations of yellow large complex cutans and clay with highly sepic fabric, which form the largest part of the plasma in this part of the profile. They are on the way to being dissolved by hydromorphism.

From this relict core, this complex soil profile developed both downward and onward.

The horizons in gravel developed in a gravitational sense through the process called «*soutirage*» by BORNAND (1978), i.e. dissolution of the carbonates and lowering of the decarbonatation front, consequent argilluviation and pedoplasmation in upper horizons in which the content of dynamic clay increased, as evidenced by the superposition of several generations of clay illuvial coatings. As the whole profile, included the deepest horizons, has been never isolated from the surface, the processes can be regarded as still active.

After deposition of the colluvial material of the VI E/Bcn horizon, the profile continued to develop through the superposition of thin loess sheets. The deposition of the loess has been discontinuous: it clearly has been interrupted several times by the onset of pedological processes, which turned the loess into a succession of hydromorphic Alfisols. Loess sheets always have been too thin to isolate deeper soils from subsequent soil development.

The occurrence of Mousterian artifacts in the B22 cn horizon indicates that the upper loess layer was deposited during late Upper Pleistocene, and therefore the Alfisol developed in it, is the effect of the post glacial-Holocene weathering alike many other Alfisols in loess of the Alpine fringe (CREMASCHI & *alii*, 1990).

Comparing the pedogenetic characteristics of the upper sequum with the underlying ones, the degree of complexity of the illuvial features together with the stability of the heavy minerals (degree of reduction in unstable species) increase with depth. This fact indicates that the loess layers and the individual soils on them developed never acted as a sealed system but experienced several subsequent cycles of weathering.

The upper part of the Crocetta profile acted as a part of a slowly aggrading geomorphic surface (MCDONALD & BUSACCA, 1990) in which soil forming processes were dominant on the rate of sedimentation.

The Alfisols in loess developed under the influence of nearly the same set of soil forming processes that were active in the gravel: i.e. decalcification and argilluviation, while the hydromorfic features are more strongly developed in the loess, derived soils, because of the poor permeability of the parent material. In the vertic horizons, the accumulation of illuvial clay has been so great that the former illuvial features were trasformed into vertic ones. Frost activity have not been strong enough to impart permanent features in the soils in loess.

Three zones displaying different functional behaviours are still working in the profile (fig. 4):

— A relict zone ( horizons VI E/Bcn, VII B21, VII B22) which includes relict features originated in a fossil pedogenetic environment: these features are on the way to being dissolved.

— A slowly aggrading zone (horizons Ap/B1 to V B29), which is constituted by the sheets of weathered loess and was originated by alternating periods of development of Alfisols in wet temperate climate and loess deposition in dry and cold climates. These cycles were repeated at least 5 times. The whole sequence is still developing through argilluviation and hydromorphism.

— A gravitational active zone (horizons VII B31 to VII C ca) which is located in the lower part of the profile and that has been originated by the progressive lowering of the decalcification front with subsequent argilluviation starting from the lower limit of the relict zone. The effects of the weathering processes are progressively weaker with depth, because the lower limit of the profile is still moving downward.

The relict features of the Crocetta profile, isotic, haematite rich matrix and red cutans, should be interpreted as recording the effects of a pedoclimate that existed only at the beginning of the soil development on the terrace of the Trebbia River, i.e Early Pleistocene.

Similar characteristics have been described in relict and buried paleosols of the Northern and Central Italy dated to the Late Tertiary or at the beginning of Early Quaternary (REMMELZWAAL, 1979; BARTOLINI & *alii*, 1984 CREMASCHI & SEVINK, 1987).

These soils are reputed to be representative of the warmer and wetter environment which existed in the area during the pre-Glacial Early Pleistocene, before isotopic stage 12 (CITA & RYAN, 1973; CREMASCHI, 1987).

The common cutanic and other features of the gravitational, relict and aggrading zones required, from the beginning, the processes, decarbonatation argilluviation, which, still active in the area, have started to act from the Middle Pleistocene onward (CREMASCHI, 1987). These processes are responsible for the main features of the profile, both in gravel and in loess.

In the Po plain the loess was deposited during the glacial periods in a cold and dry steppe environment (CATTANI, 1990; CREMASCHI, 1992).

At least five periods of loess sedimentation are recorded in the Crocetta profile. Each of them should have the rank of a glacial cycle, making the Crocetta sequence one of the more continuous loess sequence for Northern Italy. As the last loess sheet dates back to the Upper Pleistocene, the deepest loess could be Early-Middle Pleistocene in age and could be correlated with the onset of the Glacial Pleistocene in the area.

The environmental conditions of each phase of loess sedimentation, because dry, did not allow the argilluviation process to develop. Therefore each period of loess deposition resulted in an interruption or slowing down of the main soil-forming processes, which started again as soon as water supply was again available in the environment. Loess sedimentation did not cover the entire glacial period, but only a part of it (CREMASCHI, 1992).

As frost affected only marginally the soil, water availability, more than temperature, appears to be the critical factor of the system: but it is not a factor exclusive for the interglacial periods, as water could be present in the soil also in the wet stages of the glacial periods (BOWEN, 1978). The soil fomming processes which affected the loess covers and the gravel have not to be related specifically to any interglacial, but to wider periods in which environmental conditions were, in a broad sense, non glacial.

## CONCLUSION

The Crocetta profile is the product of weathering processes which have been active probably for up to one million years. The soil profile is still thickening today, by deepening of the decalcification front and the relict features in it are on the way to being dissolved and integrated into the present plasma. In this sense the soil does not appear to have reached a steady state as indicated in YAALON (1971).

Soil-forming processes reacted with several environmental changes which affected the foreland of the Alps and the Apennine over the whole Pleistocene, but the evidence for these reactions were overprinted by the effects of long-lived soil-forming processes. The relict features are indicative of a subtropical paleoclimate during the initial phases of soil development dating back to Early Pleistocene.

Since the beginning of the Middle Pleistocene, there is evidence of continuous weathering through decarbonatation and argilluviation, which was briefly interrupted or slowed down by the dry periods conducive of loess sedimentation. During the glacial periods, the soil forming processes have never been completely interrupted, and therefore the loess-soil record of the Crocetta profile apparently corresponds to a limited portion of the whole glacial period.

A paleoclimatic signal can still be perceived in the Crocetta profile. Climatic changes of the rank of glacial - interglacial cycles are observable in the soils in the loess cover but are not sharply separated. A stronger signal, that of the main change in pedoclimate that occured since the Early Pleistocene has been documented: the change from ferralitic pedogenesis (relict zone) to fersialltic pedogenesis, and the onset of discontinuous loess sedimentazion starting from the early Middle Pleistocene.

The Crocetta profile, is a Ferretto type soil and can be regarded as a Vetusol as described in CREMASCHI (1987). As a matter of definition (BRONGER & CATT, 1989) it is a pedogenetic body which is not a paleosol because it is related to the present surface and still active. It could be described as a relict soil because it includes relict features, but these features are not stable, i.e. they are in the way to being dissolved by present processes and they consists of a very minor volume in comparison with the whole soil. The profile is indeed polygenetic, but polygenesis concerns only a small part of the processes involved. Furthermore polygenetic term is not informative enough as it has been used also for very young soils (DUCHAUFOUR, 1983).

The term of vetusol seems to be appropriate to indicate that these soils are the product of a long duration of the soil forming processes. This does not exclude the possibility that relict features or fossil evidence of pedogenetic and aggradational processes could be still preserved in their profiles.

## APPENDIX 1: DESCRIPTION OF THE PROFILE

*Crocetta profile.*

location: IGM 72 IV NO Agazzano; lat. 44 58' 47"; long. 2 57' 07"; elevation: m a.s.l. 155.

Geomorphology: flat top surface of the Agazzano terrace and its scarp (for the horizons below the VII B22).

Ap, O-20 cm; 10 YR 6/3, pale brown, dry; 10 YR 4/3, brown, moist; silt loam; subangular blocky poorly developed, weak, fine to medium common voids; clear linear boundaly.

B1, 20-45 cm; 10 YR 4/3, brown, moist; silty clay loam; fine angular blocky; common small mottles; moderately firm; common fine Fe-Mn nodules; common fine and medium voids; few clay cutans on peds; gradual boundary.

B21 tx, 45-90 cm; 10 YR 4/4, dark yellowish brown, moist, very strong — tendency to fragipan — coarse prismatic; thin glossae weakly developed; very thin yellowish clay cutans on peds; common voids; few fine Fe Mn nodules; gradual boundary.

B22 cn; 90-100 cm; 10 YR 6/4, light yellowish brown, moist, silty clay loam; moist, fine blocky poorly developed, moderately weak; 40-60% Fe Mn black nodules; common voids; common clay cutans into the voids; clear linear boundary. Some flint artifacts, with sharp edges, (2 flakes; 1 lateral scraper; 1 discoidal core) have been collected at the base of the horizon; on the ground of theit typological characteristics, they are attributed to the Mousterian cultural assemblage (Baroni & *alii*, 1990).

II B23; 100-125 cm; 7.5 YR 4/4, dark brown, moist, silty clay; strong coarse prismatic structure that parts further to strong coarse angular blocky; firm; few voids; thick continuous yellowish brown clay cutans on ped faces and in voids; clear smooth boundary.

II B24; 125-160 cm; 10 YR 512, grayish brown, moist, silty clay; common small yellowish brown mottles, very coarse low angle slickenside planes, at the base of the horizon, platy structure weakly developed, very firm when dry, gradual smooth boundary.

III B25 x; 160-195 cm; 7.5 YR 4/4 and 5/4 dark brown to brown, moist, silty clay loam; brown 7.5 YR 4/4 cutans; extremely coarse prismatic structure that parts to strong coarse angular blocks; extremely hard and brittle when dry; very firm when moist; vertical glossae are about 1 cm thick, including 10 YR 7/2 silty loam, and are spaced 10-20 cm apart, becoming more intense to the base of the horizon; common to many, moderately thick clay cutans, on ped faces, common Fe Mn cutans and soft nodules; gradual smooth boundary.

III B26 cn; 195-235 cm; 10 YR 5/4, yellowish brown, moist, silt loam, massive to fine angular blocky poorly developed; moderately firm; scarse to commn voids; 30-50% soft black Fe Mn nodules averaging 0.5 cm diameter; irregular, non vertical gray glossae spaced through the horizon; few (5%) 2.5 YR 4/4 red lithorelicts 1-5 mm in diameter; gradual smooth boundary.

IV B27; 235-295 cm; 10 YR 5/6, yellowish brown, moist; silty clay loam; strong very fine angular blocky, determinated by intersecting sliken sides; moderatly firm, common to many voids in the lower part; common reddish mottles (Hue 7.5 YR), many sliken sides, common Fe Mn coatings on the sliken side surface, clear smooth boundary.

IV B28 ca; 295-345; 10 YR 5/4, yellowish brown, moist, silty clay; strong very coarse prismatic and coarse angular blocky turning, toward the base, to platy; hard, scarse voids, many sliken sides; 20-30% of the horizon volume consists of 2.5 Y 5/2, pale olive gray mottles; few faint Fe Mn coatings; few large soft white Ca C03 concretions, 2 cm in diameter, on the ped faces; gradual wavy boundary.

V B29; 345-385; 10 YR 7/4, pale brown, moist, silt loam; weak coarse prismatic, moderately firm, common voids; common moderately thick clay cutans and common Fe Mn coatings on ped faces and into voids; few 7.5 YR 5/6 reddish mottles appear near the base; at the base a stone line inclunding large rounded blocks of chert and deeply weathered sandstone; Ca C03 nodules in the lower part of the stones; clear linear boundary.

VI E/ Bcn; cm 385-410; 2.5 Y 5/2 grayish brown silt loam, moist, massive, hard; common voids; 60 % weackly cemented Fe Mn nodules averaging 1 cm diameter, common fragments of strongly weathered stones; gradual smooth boundary.

VII B21; cm 410-485; 10 YR 5/4, yellowish brown, moist gravelly clay; few fragments of weathered stones; strong coarse angular blocky; weak; common voids; coarse sliken sides; many large Fe Mn coatings on slickensides; continuous thick clay cutans on gravel and ped faces; gradual boundary.

VII B22; cm 485-655; 2.5 Y 5/6 light olive brown, moist, gravelly sand clay; common fragment of weathered stones; coarse platy poorly developed; common large 2.5 YR 3/6 dark red mottles; weak; common voids; gradual ondulated boundary to reddish gravel.

VII B31; cm 655-855; 2.5 YR 4/6 red, moist, gravelly sandy clay; 30-60% fragments of decalcified gravel; fine angular blocky poorly developed; moderately weak, common voids; many thick clay cutans on peds gravel surfaces and gravel dissolution cracks and into voids; gradual boundary.

VII B32; cm 855-1250; 5 YR 4/4, reddish brown, moist, gravelly sandy loam; 60-80%, decalcified and slightly weathered gravel; massive; many voids; many thick clay cutans on peds, gravel surfaces and voids; clear to abrupt gentely wavy boundary.

VII C ca 1250 - ?; 10 YR 5/4, yellowish brown, moist, unweathered sandy gravel, rich in calcareous rocks, slightly cemented by CaC03 coatings.

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