MICROMORPHOLOGICAL RECOGNITION OF PALEOSOLIC FEATURES IN SEDIMENTS AND SEDIMENTARY ROCKS

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ABSTRACT

Experience with micromorphological examination of continental rock formations in Argentine indicates that numerous soil fabric features occur in the sedimentary sequences. In the tuffaceous sediments of the 2,000-m thick Chubutian Group (Cretaceous) of central Patagonia, about half of the examined levels showed micromorphological evidence of pedological features and fabrics, whereas in marine sedimentary rocks and other formations studied they were generally absent.

Cutans and certain sepic fabrics were the predominant features observed. Assuming that these features owe their origin to pedological processes only and in view of the fact that they are able to withstand diagenetic changes, they can be used to detect fossil soils and soil material.

Most voids, glaebules and crystallaria can be both pedogenic and sedimentogenic or are unstable under diagenesis; they are thus unsuitable for identifying paleosolic features.

INTRODUCTION

With the exception of some fossil soils related to coal-seams, the problem of recognizing paleosols in pre-Cainozoic deposits has usually been a moot question. The effects of diagenesis and lithification generally tend to obliterate most or all diagnostic features and, as a result, very seldom indeed has a sedimentary rock been identified as an old soil.

Notwithstanding the fact that pedologists and sedimentologists have as a common basis a rock body fashioned on the surface of the earth, a chasm does exist between them. This chasm grows wider as the needs of modern science impose an ever increasing specialization.

Perhaps the most evident example of the lack of communication between sedimentologists and pedologists lies in the field of micromorphology, an important branch of the study of soils initiated by Kubiena in 1931. Through the years, micromorphology has developed into a broad field of research and textbooks on this subject have lately been published (Brewer, 1964; Jongerius, 1964). However, despite this impressive development, few of the abundant observations, contributions and interpretations of soil fabrics made by micromorphologists have been applied to the study of sedimentary rocks.

Our experience with close to 500 thin-section analyses of continental formations of Argentina has shown us that numerous and varied soil fabrics do occur in sedimentary sequences. On the one hand, our findings can be of importance for the better comprehension of sedimentary processes and their products; on the other, they may prove extremely valuable for the recognition of paleosols in those cases—so common in old rocks—where megascopic pedogenic characteristics are totally lacking. Thus, the present contribution aims at narrowing the gap between sedimentology and pedology, while at the same time stressing the possibility of applying micromorphological criteria to the clarification of both rock genesis and paleosol formation.

SOIL FABRICS IN ARGENTINE SEDIMENTARY ROCKS

Although many changes in floral composition have taken place through geological time, one has to accept the fact that, once the continents were colonized by plants, soils began to develop. Therefore, paleosols should be fairly common in stratigraphic sequences, and not the exception as seems to be the case nowadays. Two different reasons may be mentioned to explain the scarsity of paleosols: 1) post-burial destruction of soil features; 2) lack of sufficient information on continental deposits of the past, since, as is well known, geology has for a long time concentrated on marine formations. Admittedly, the marine environment can produce chemical (halmyrolysis) and biochemical (benthonic faunal influences) changes in bottom sediments, but they are entirely different from pedological processes.

In studying sedimentary rock formations of Argentina, a country where continental deposits are widespread and very often of a tuffaceous nature, we were suprised at finding in our thin sections abundant evidence of pedological features and fabrics. We were thus led to conclude that, if they are truly pedogenic remains, then diagenesis and lithification had not been able to destroy them.

In what follows, we shall describe soil features and fabrics found in continental deposits of different geological ages. Our work is still in progress but we have already analyzed several Palaeozoic, Mesozoic and Tertiary formations. In order to make our presentation clear, we here follow Brewer's (1964) classification of structures and fabrics, mentioning in each case whether they are pedogenic, sedimentogenic or both.

Voids

Most classes of voids described in soils are also present in sedimentary rocks. We have observed packing voids, vugs, vesicles, channels, chambers and planes. Of these, packing voids are obviously the result of sedimentation and compaction of the parent material. Vugs and vesicles have been variously ascribed to adhesion and flocculation of clays, to lixiviation, to trapped air bubbles, etc. Channels and chambers are assumed to be of biological origin, i.e., they are attributed to root systems and burrowing animals. Finally, planes are probably due to shrinking and swelling during periods of drought and humidity. Skew planes and craze planes are apparently caused by irregular drying of heterogeneous materials.

The pedogenic significance of voids is doubtful, since they can also be produced by normal sedimentary processes. Channels and chambers are perhaps the only void types that are frequently associated with soils. For these reasons, we have not attached great importance to the presence of voids in sedimentary rocks.

Cutans

Known for a time under the names of "clay skins" and "Tonhäutchen", cutans (coating—derived from Latin) are probably the commonest of all pedological features. They are plasma concentrations or separations connected with surfaces of skeleton grains or voids. They constitute a portion of the soil which is recognized by a special texture, structure or composition.

Cutans are classified on the basis of composition and type of surface affected (argillans, ferrans, calcitans, skeletans, etc., see Brewer, 1964).

Cutans are widely distributed in the Palaeozoic, Mesozoic and Tertiary formations studied by us. Argillans constitute the commonest type (Fig.1), but ferri-argillans are also very abundant (Fig.2). Sesquans, especially ferrans (Fig.3), are fairly widespread and skeletans are rare. The remaining types of cutans are very seldom encountered. All cutans are found either around skeleton grains or connected with voids, particularly planes and channels.

Since cutans have such widespread occurrence in sedimentary rocks, it is appropriate to consider here their possible formation mechanisms. According to Brewer (1964), four major groups can be recognized:

1) Illuviation cutans: formed by movement of plasma in solution or suspension.
2) Diffusion cutans: surface concentration caused by diffusion in the matrix.
3) Stress cutans: produced by differential forces, such as shearing.
4) Complex cutans: the result of a combination of the processes mentioned above.

In our sedimentary rocks, cutans are of the illuviation and diffusion types.

Of greater significance than their mode of formation is the question whether

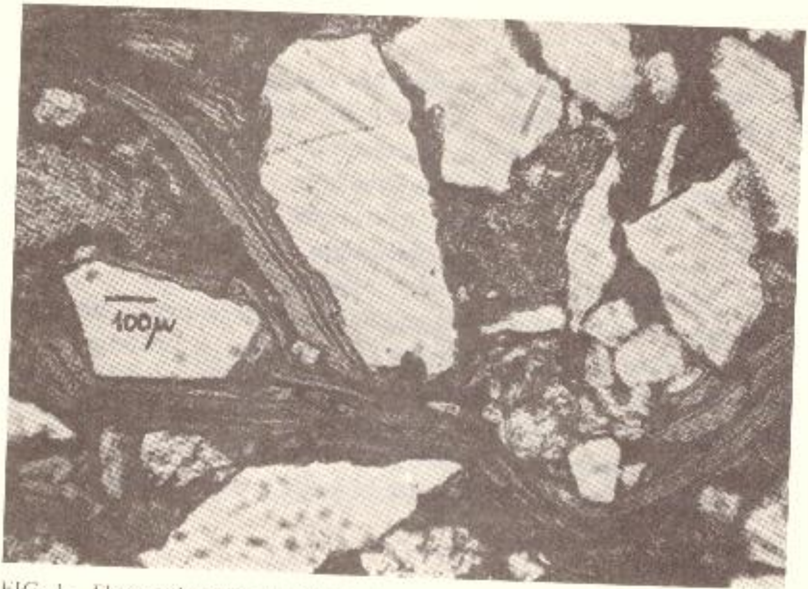

FIG. 1. Elongated argillan (illite) in arkose, connected with a skew plane. Thin section under crossed polarizers. Paganzo Beds (Carboniferous), La Rioja, Argentina

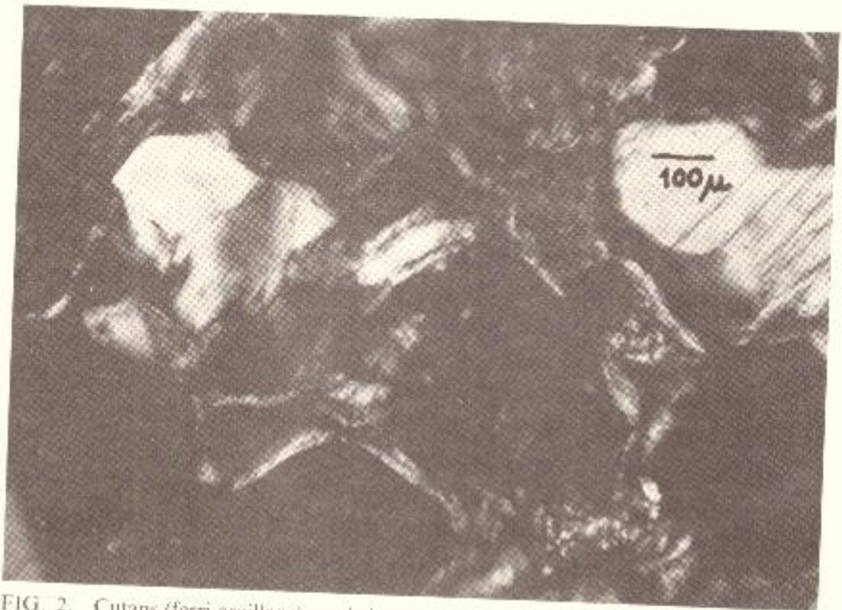

FIG. 2. Cutans (ferri-argillans) on skeleton grains of conglomerate. Thin section under crossed polarizers. Oriented clay mineral is montmorillonite. Bajo Barreal Formation, río Senguerr, Chubut, Argentina

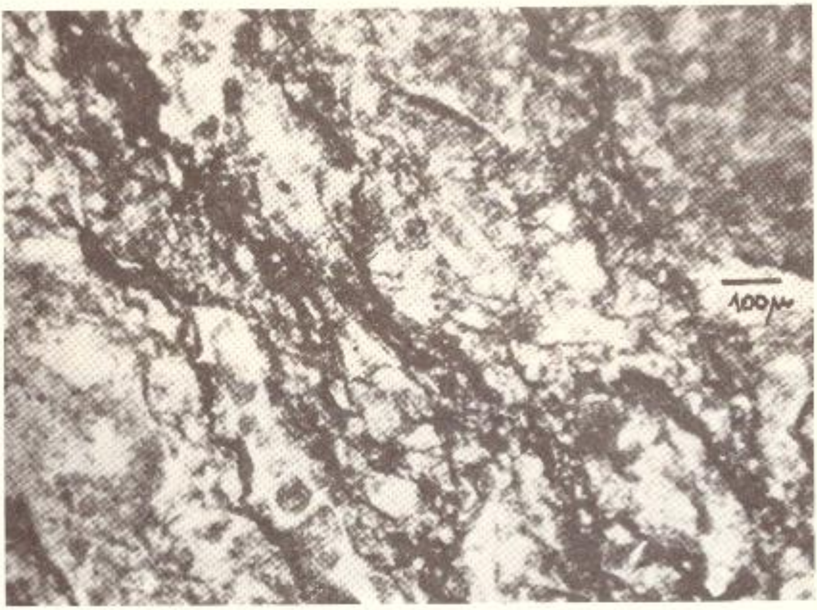

FIG. 3. Skew planes with ferrans in sandy tuff. Thin section in plain light. Castillo Formation, río Deseado, Chubut, Argentina.

cutans are exclusively pedogenic. If this were the case, their presence in any sedimentary rock would be a clear indication of the latter having been, at some time, a real soil. It is impossible at the present moment to answer this question, but we hold that the presence of cutans constitutes evidence that merits very careful consideration. Lafeber (1964), who has analyzed preferred orientation and spatial distribution of soil materials, concludes that oriented clay cutans have no counterpart in the orientation pattern of rock fabrics. On the basis of our experience, we agree with Lafeber's conclusion.

Pedotubules

Pedotubules are roughly cylindrical or irregular holes made by roots or burrowing organisms. They are usually of megascopic size, but microscopic varieties are not unknown.

Pedotubules are occasionally found in sedimentary rocks. However, they are never common features and are very often missing in rocks characterized by abundant other pedological features.

Glaebules

Glaebules, or discrete units characterized by a certain shape and composition, are very common in soils and sedimentary rocks of all kinds. They are known in sedimentology under the name of cretional bodies and a variety of terms (nodules, concretions, septaria, secretions, etc.) has been coined to designate different types.

Glaebules are common both in marine and continental rocks (Fig.4). Obviously, they constitute a feature currently produced by sedimentary processes. Therefore, they are not in themselves good indicators of a possible paleosol.

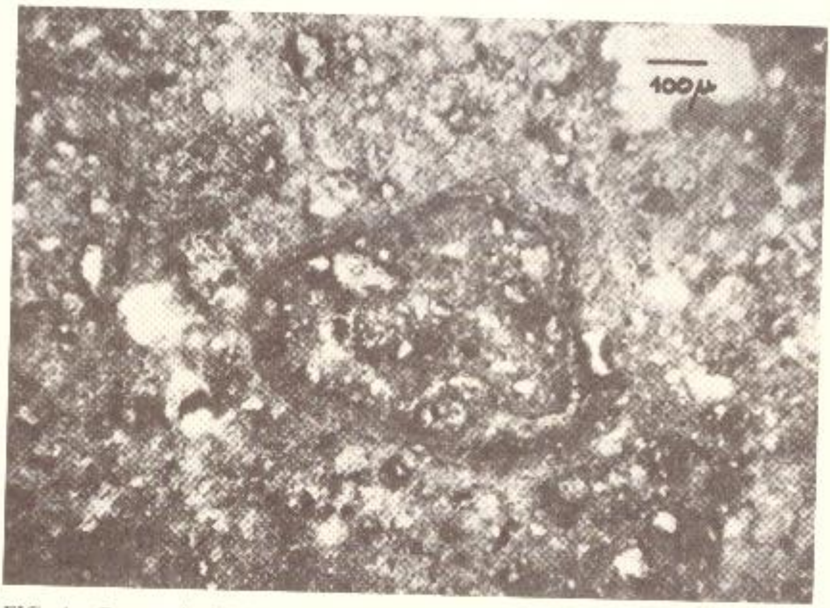

FIG. 4. Concentric fabric (hematite concretion or glaebule) in tuff. Thin section in plain light. Castillo Formation, río Deseado, Chubut, Argentina

Crystallaria

Crystals or aggregates of crystals are extremely common in soils and sedimentary rocks. Their value as indicators of soil formation seems to be small.

S-Matrix

The s-matrix is the soil material that makes up the soil itself, in which pedological features occur. The s-matrix is only roughly equivalent to the sedimentologist's matrix, because the latter is confined to smaller-grained aggregates whilst the former includes all grain sizes.

A complex terminology has been developed by soil micromorphologists to cover all possible types of s-matrix structures. Fundamentally, five types have been characterized:

1) Asepic plasmic fabric: anisotropic material with unoriented constituents.
2) Sepic plasmic fabric: anisotropic fabric with preferred orientation of constituents in certain areas. This is the most important plasmic fabric, with a large number of varieties, each described with a specific name (insepic, mosepic, vosepic, skelsepic, masepic, lattisepic, omnisepic, etc.).
3) Undulic plasmic fabric: isotropic fabric with a certain undulose orientation.
4) Isotic plasmic fabric: isotropic in its totality.
5) Crystic plasmic fabric: made up of recognizable crystals.

S-matrixes are fairly common in sedimentary rocks, as has been shown by Brewer (1964, pp. 326–335) in his brief discussion of rock thin sections. S-matrixes were found by us in many of the formations we studied, being generally associated with other pedological features. The most frequent type is the sepic plasmic fabric, in several of its varieties (Figs. 5 and 6).

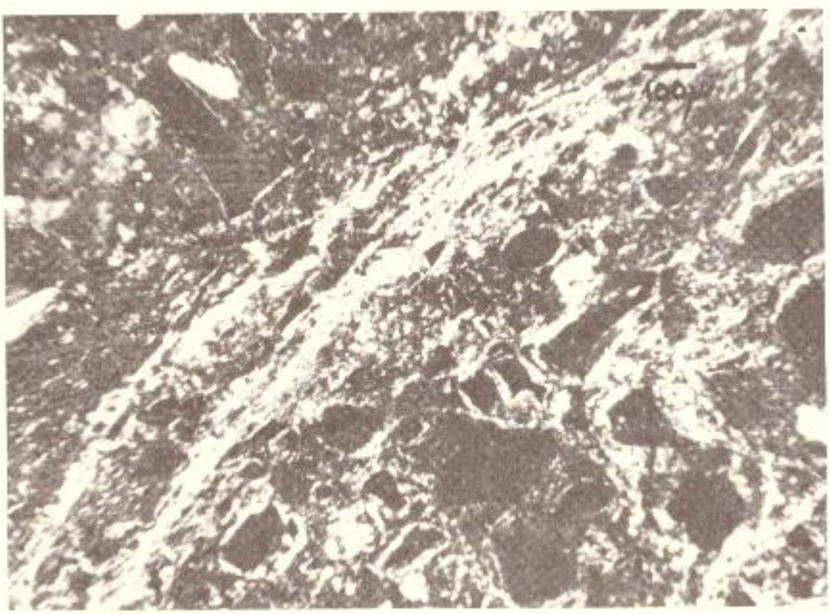

FIG. 5. Sepic plasmic fabric (vo-masepic type) in tuff. Thin section under crossed polarizers. Castillo Formation, rio Deseado, Chubut, Argentina

FIG. 6. Sepic plasmic fabric (bi-masepic type) in tuff. Thin section under crossed polarizers. Castillo Formation, río Deseado, Chubut, Argentina

Some sepic fabrics (vosepic, lattisepic, skelsepic) have been atributed to pressure and tension produced by wetting and drying. On the other hand, inheritance appears to be the likely cause of varieties of the mosepic and insepic types.

Asepic fabrics, which are also found in sedimentary rocks, are generally ascribed to sedimentary processes.

In our experience, most sepic plasmic fabrics seem to be incompatible with sedimentary processes.

Peds

In the realm of sedimentary rocks, pedality is very seldom seen, either in outcrops or in hand specimens. Apparently, this extremely important property of soils is easily obscured or destroyed by diagenetic processes.

THE CHUBUTIAN GROUP

As an illustrative example, we have selected the Chubutian Group, a continental series of Late Cretaceous age. With a total thickness of about 2,000 metres, the

Chubutian Group outcrops in central Patagonia and is made up of tuffaceous sediments which texturally may be classified as psammites, pelites and psephites.

The entire Chubutian section—subdivided into two formations, Bajo Bareal and Castillo—was first studied by Teruggi and Rossetto (1963) and has recently been revised by us with regard to pedological features and fabrics. In the upper, Bajo Barreal Formation, 43 thin sections were examined, 24 of which reveal pedological evidence; in the lower, Castillo Formation, thin sections of 73 samples were examined, 32 of which exhibit pedological features. This means that in the type section 48% of the arenaceous members sampled show micromorphological evidence of soil fabrics. Cutans constitute the predominant feature and are represented by argillans (Fig.8), ferri-argillans (Figs. 2 and 7), ferrans (Fig.3), skeletans and silicans; the first two types are far more abundant than the others. Cutans are found in tuffaceous sandstones, sandy tuffs, tuffs, sandstones and, rarely, conglomerates. Plasmic fabrics, represented by sepic matrixes (Figs. 5 and 6) are also found in association with cutans.

The Chubutian Group represents a case where strata with pedological structures are nearly as abundant as structureless strata. A careful petrological study has shown that, in many cases, both types of strata are absolutely identical in composition, granulometry, degree of alteration, compaction, porosity and other specific features.

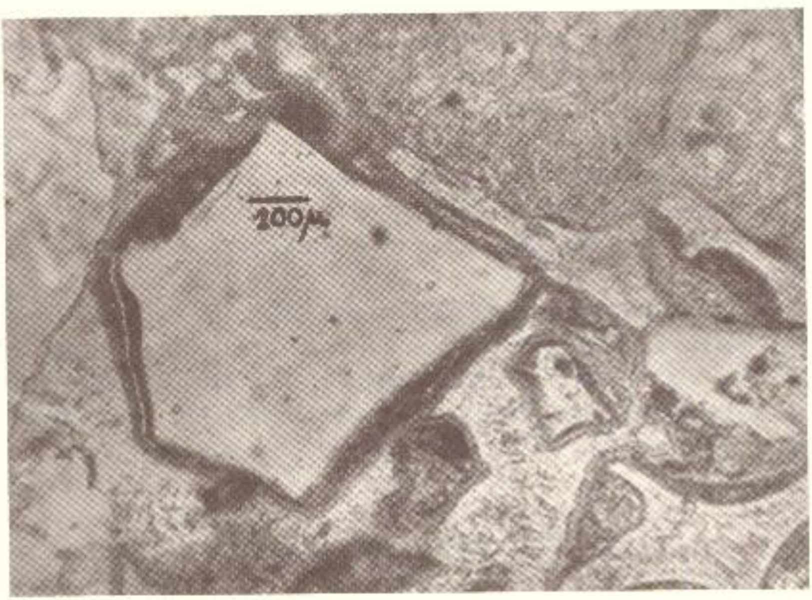

FIG. 7. Cutans (ferri-argillans) on skeleton grains of sandy conglomerate. Thin section in plain light. Castillo Formation, rio Senguerr, Chubut, Argentina

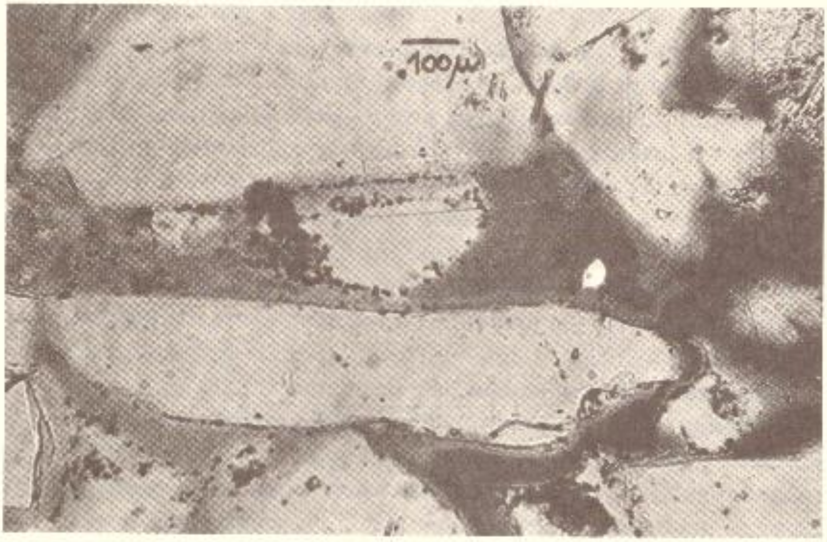

FIG. 8. Argillans around plagioclase skeleton grains of sandy tuff. Thin section in plain light. Castillo Formation, rio Senguerr, Chubut, Argentina

It would seem, then, that the Chubutian Group represents a very special case. Teruggi (1964) has demonstrated that Chubutian sediments were deposited in shallow continental basins which, under semi-arid conditions, were exposed to periods of dessication causing sodium-bearing minerals (analcime) to be precipitated. If pedological features are the result of soil-forming processes, there must have been periods of non-deposition sufficiently long to allow for the development of soils. The inspection of a cross section of the Chubutian Group shows that pedological levels appear either individually or in sets of two or more successive levels. From this it may be inferred that the rhythm of sedimentation is closely related to soil formation.

In other formations, pedological features and fabrics are far rarer. We may cite as an example the Paganzo Beds (Carboniferous-Permian) with an overall thickness of more than 2,000 metress, which contain less than ten levels characterized by pedological evidence. Some Tertiary formations revised by us are also poor in pedological features, although the latter are invariably present.

DISCUSSION AND CONCLUSIONS

We have shown that certain pedological features and fabrics are fairly common in Phanerozoic continental formations, so much so that it is surprising that they have not apparently been noticed in sedimentological research. We are sure that by a careful use of micromorphological criteria it will be possible to gain a better understanding of the post-depositional history of sedimentary rocks and their time relationships.

The importance of cutans and plasmic fabrics, as we have tried to prove, resides in the fact that, once formed, they seem to be able to withstand diagenetic changes and are consequently preserved in indurated rocks. These indurated rocks bear the imprint of soil-forming processes and can be used to detect fossil soils.

The main possible objection to our interpretation stems from the doubt that the so-called pedological features and fabrics might not be exclusively pedogenic, i.e., that they could also be formed by sedimentary processes. Should this be the case, pedological features and fabrics would lose their value as indicators of paleosols.

We repeat that it is our belief that certain pedological features and fabrics, such as cutans and s-matrixes, are produced solely by soil processes. The following facts support our interpretation:

1) Cutans and sepic plasmic fabrics have not been observed in sediments being deposited today; furthermore, their mechanisms of formation do not seem to correspond to normal sedimentary activity.

2) Cutans and sepic plasmic fabrics are not universally distributed in sedimentary rocks. They may be either present or absent in rocks which, otherwise, are entirely similar or identical, as has been shown for the Chubutian Group. This is a strong point in favour of their probable pedogenic nature.

3) None of the numerous marine sedimentary rocks studied by us have revealed pedological features and fabrics. If this observation is found to be a general one, it could serve as a decisive argument supporting our interpretation that some micromorphological features and fabrics are truly pedogenic in origin.

We are well aware that much research is needed before pedological features and fabrics can unequivocally be distinguished from sedimentary features and fabrics. Most voids, glaebules, crystallaria and peds are possibly features with a double origin or are unstable during diagenesis. Cutans, sepic plasmic fabrics and pedotubules are probably truly pedogenic and stable under diagenesis.

It is this double character which opens a vast field of research for sedimentologists and micromorphologists, who must join forces in order to exhaust the possibilities offered by the rocks themselves.

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DISCUSSION

KUBIENA remarked that from his worldwide experience he can join in emphasizing the significance of micromorphological investigations of soil sediments. In most cases, they show surprisingly well the main characteristics of the former soil. Micromorphological investigations in general are of the greatest value for paleopedology, because thin sections provide decisive information on the former and present environmental conditions.

Replying to questions by RUHE, RUELLAN and DOUGLAS, TERUGGI explained that all rocks studied were thoroughly lithified and no macromorphological features indicating soil origin were evident, either in outcrops or in hand specimens. The fluvial Chubutian Group does not appear to have features preserved from soil detritus of older eroded and redeposited soil material. No transported aggregates were observed. Other, gravity-transported formations could contain inherited features from older soils. The cutans observed were uniformly distributed in the rocks, never patchy, and indicated formation *in situ*.