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THE OCCURRENCE OF PALEOSOLS IN THE LOWER VISEAN OF THE WALHORN SECTION (VESDER BASIN,E-BELGIUM)[1]

by

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(3 figures, 1 table and 1 plate)

RESUME.- Une étude sédimento-pétrographique nous a permis de distinguer quatre paléosols différents dans la carrière de Walhorn. Les quatre paléosols se trouvent dans le Calcaire de Terwagne (Viséen inférieur), qui est composé de cinq «shallowing upward cycles». Le sommet de trois cycles se compose d'un paléosol. Il existe deux types de paléosols : un paléosol du type vertic et un rendzina.

ABSTRACT.- Using sediment petrographical methods, four different paleosols have been recognized in the Terwagne Formation (Lower Visean) of the Walhorn section. This formation consists of five shallowing upward carbonate cycles. Three cycles end with paleosol horizons. The different features within the paleosols enabled us to differentiate two types : a vertic calcite-bearing paleosol and a rendzina.

1.- INTRODUCTION

The Walhorn quarry (reference n° Belgian Geological Survey, 123E-224; fig. 1) is situated in the Vesder Basin, southeast of the Brabant Massif. Lower and Middle Visean dolomites and limestones are exposed in the quarry. Swennen *et al.,* (1982) and Swennen (1986) reported on the sediment petrography and lithogeochemistry of the main carbonate units which consist of the Vesder Dolostone Formation, the Belle Roche Breccia and a limestone sequence comprising the Terwagne Formation, the Neffe Formation and the Lives Formation (fig. 2A).

The general stratigraphy is outlined in figure 2A. This study is confined to the dark blue fine-grained limestones of the Terwagne Formation. They are underlain by a limestone breccia/conglomerate. The transition between both units is gradual. Within the breccia/conglomerate the majority of the fragments reflect lagoonal and inter- to supratidal depositional conditions. The Terwagne Formation is overlain by grey massive limestones of the Neffe Formation. These limestones are mainly composed of oolitic to bioclastic packstones/grainstones reflecting subtidal sedimentation conditions. Within the Neffe Formation

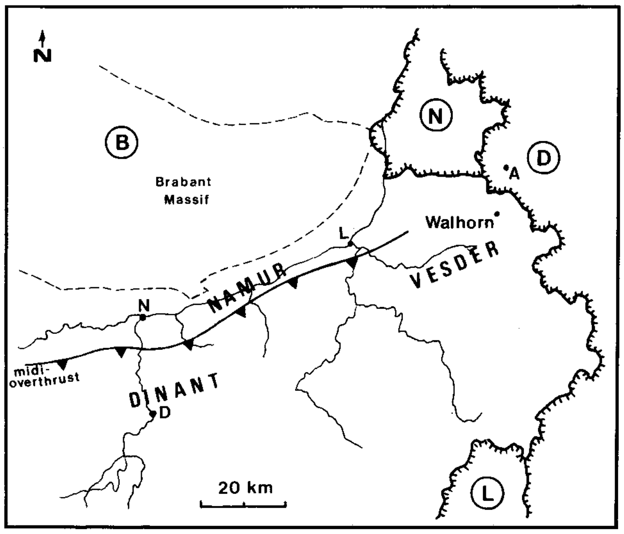

Fig. 1.- Location of the Walhorn quarry
(L: Liège; N: Namur; D: Dinant; A: Aachen)

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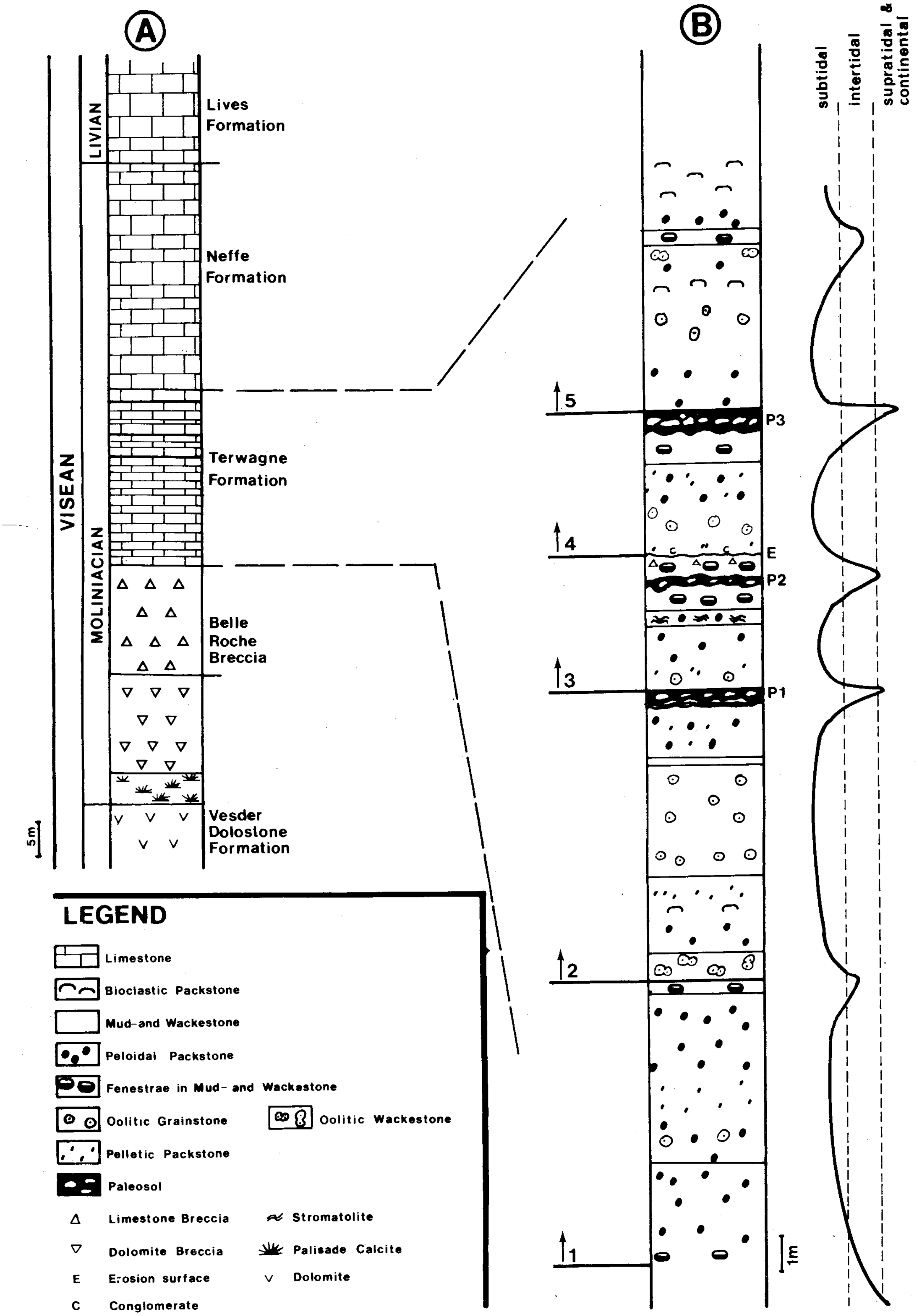


Fig. 2A.- Generalized stratigraphy of the Walhorn section (modified after Swennen, 1986)

Fig. 2B.- Detailed log of the Terwagne Formation. Five shallowing-upward cycles and three paleosol horizons (P) were recognized several transgressive megasequences were recognized (Swennen, 1986).

The purpose of this study is to obtain an insight in the occurrence, the characteristics and the development of the paleosol horizons and of the associated peritidal sediments, of the Terwagne Formation.

The rocks were investigated macroscopically and microscopically. The clay minerals were determined using X-ray diffraction techniques.

2.- MACROSCOPIC AND FIELD OBSERVATIONS

Field observations already allow us to recognize five units corresponding to sedimentary cycles. The main features can be summarized as follows :

- the Terwagne Formation starts with a grey, intraclastic limestone with peloids and ooliths, which grades into a much darker limestone with fenestrae;
- a second cycle consists of a grain-supported limestone with peloids, ooliths and bioclasts. A stromatolitic horizon underlies an undulating, red-green mottled clay-rich horizon (~15 cm thick) containing limestone fragments of 0,5 to 5 cm (Pl. I : 1);
- the third cycle starts with an oolitic grain-supported limestone. These strata pass into a grain-supported limestone with fenestrae; the top is undulating. Above it a clayey horizon with limestone fragments is present. It has an undulating top and is overlain by a limestone with large fenestrae, which grades into a breccia, having an erosive upper contact;
- rounded conglomerate fragments and a packed limestone, form the base of the fourth cycle. At the top, a clayey horizon with nodules (40 cm) occurs immediately above a limestone with fenestrae;
- the fifth cycle starts with a grain-supported limestone containing peloids, ooliths and bioclasts, and evolves into a limestone with fenestrae.

Above this fifth cycle, the layers (Neffe Formation) consist mainly of bioclastic, oolitic grain-supported limestones. Brachiopods and bivalves often occur. At the base of these layers some fenestrae and algal fragments also are present. The transition with the Neffe Formation is characterized by the remarkable thickening of the layers. Most striking in the Terwagne cycles are the red-green mottled clay-rich horizons, containing limestone fragments and nodules of 0,5 to 10 cm. These horizons range in thickness from 15 to 40 cm and have an undulating bottom.

3.- SEDIMENT PETROGRAPHY OF THE TERWAGNE FORMATION

Eight distinctive lithofacies have been recognized. Their main features and interpretation are summarized in table 1. Lithofacies H i.e. the clayey horizons with nodules will be discussed in more detail in the next paragraph.

Lithofacies A : the bioclastic packstones contain some mud and lack crinoids and brachiopods; these features suggest a subtidal, possibly lagoonal, environment. The vermiform gastropods and the algae point to a deposition in a shallow environment (Burchette & Riding, 1977; Wright, 1986).

Lithofacies B : the oolitic grainstones contain type 4 ooliths, described by Strasser (1986). They are typical for a low energy environment. The grainstone texture however, points to a moderate wave or tidal inluence (Bathurst, 1975). The presence of meniscus cements indicates periodic emergence and cementation in the vadose zone.

Lithofacies C and D : the peloidal and pellitic packstones are characterized by peloids of the Bahamite type. They are typical for a very shallow environment (Beales, 1958). The presence of grapestones however, suggests an irregular water turbulence (Winland & Matthews, 1974). The absence of desiccation features and of fenestrae indicates a subtidal setting.

Lithofacies E : the ooliths within the wackestones are similar to the type 2 ooliths of Strasser (1986). They point to a low energy lagoonal environment. Locally this facies contains fenestrae, suggesting low intertidal sedimentation (James, 1984).

Lithofacies F : the mudstones and wackestones with fenestrae are typical for an intertidal environment. They show emergence features such as desiccation cracks and intertidal fenestrae which are laminar, tubular, round or irregular.

Lithofacies G : stromatolites normally indicate intertidal sedimentation conditions. However, they also occur in subtidal and supratidal environments (James, 1984). Because this stromatolite horizon is present between an intertidal wackestone with fenestrae and a paleosol (lithofacies H), it is believed to be deposited in the high intertidal zone.

Table 1.- Different lithofacies in the Terwagne Formation in the Walhorn quarry : description and interpretation.

litho-facies	description	interpretation
A	Bioclastic packstones mollusks, gastropods, foraminifers ostracods, calcispheres	shallow, subtidal environment
B	Oolitic grainstones ooliths have cortical laminae with fine-radial structures and are patchy micritized; meniscus cements and dripstones	type 4 ooliths of Strasser (1986): quiet water environment, subtidal; periodic emergence
C	Peloidal packstones different stages of micritized bioclasts: bryozoas, foraminifers, gastropods, bivalves	Bahamite-type peloids (Beales, 1958), shallow subtidal setting
D	Pelletic packstones calcispheres, ostracods and reworked algae (e.g. girvanella and ortonella)	restricted subtidal
E	Wackestones with ooliths ooliths have irregular shapes, fine micritic laminae and occasional layers of fine-radial crystals; fenestrae	type 2 ooliths of Strasser (1986): lagoonal environment with quiet water, periodic emergence
F	Mudstones and wackestones with fenestrae, calcispheres, ostracods, desiccation cracks	intertidal environment
G	Stromatolite alternation of micritic and pelletic layers with fenestrae	high intertidal deposit
H	Clayey horizon with nodules	paleosol, continental environment

Lithofacies H : the clayey horizons with nodules have been interpreted as paleosols (see next paragaph). They are characteristic for a supratidal to continental environment.

The succession of lithofacies gives the pattern of shallowing upward cycles (fig. 2B) which consist of subtidal units that evolve to intertidal, supratidal and even continental units. The cycles display regressive trends. In the studied section (fig. 2B) three of the five cycles follow the ideal pattern (table 1) from subtidal to continental. The two other cycles reach only the intertidal zone; probably a paleosol was never formed as no erosive contacts were found. Moreover the fenestrae in these intertidal units have no dissolution features in contrast with the units below the paleosols.

4.- SEDIMENT PETROGRAPHY OF THE CLAYEY HORIZONS WITH NODULES : PALEOSOLS

4.1.- DESCRIPTION

Figure 3 gives the detailed logs of the three paleosol horizons and their associated sediments. The general microscopic features of these horizons are :

- **nodules** (Pl. I : 2, 3) : several types of nodules can be distinguished. They have gradational to sharp contacts with the matrix and are called orthic, respectively disorthic nodules (Wright, 1982). The latter show several varieties : nodules with circumgranular cracks, nodules with internal cracks or with small internal nodules and nodules which have been brecciated. They vary in size from 200 μm to several mm.

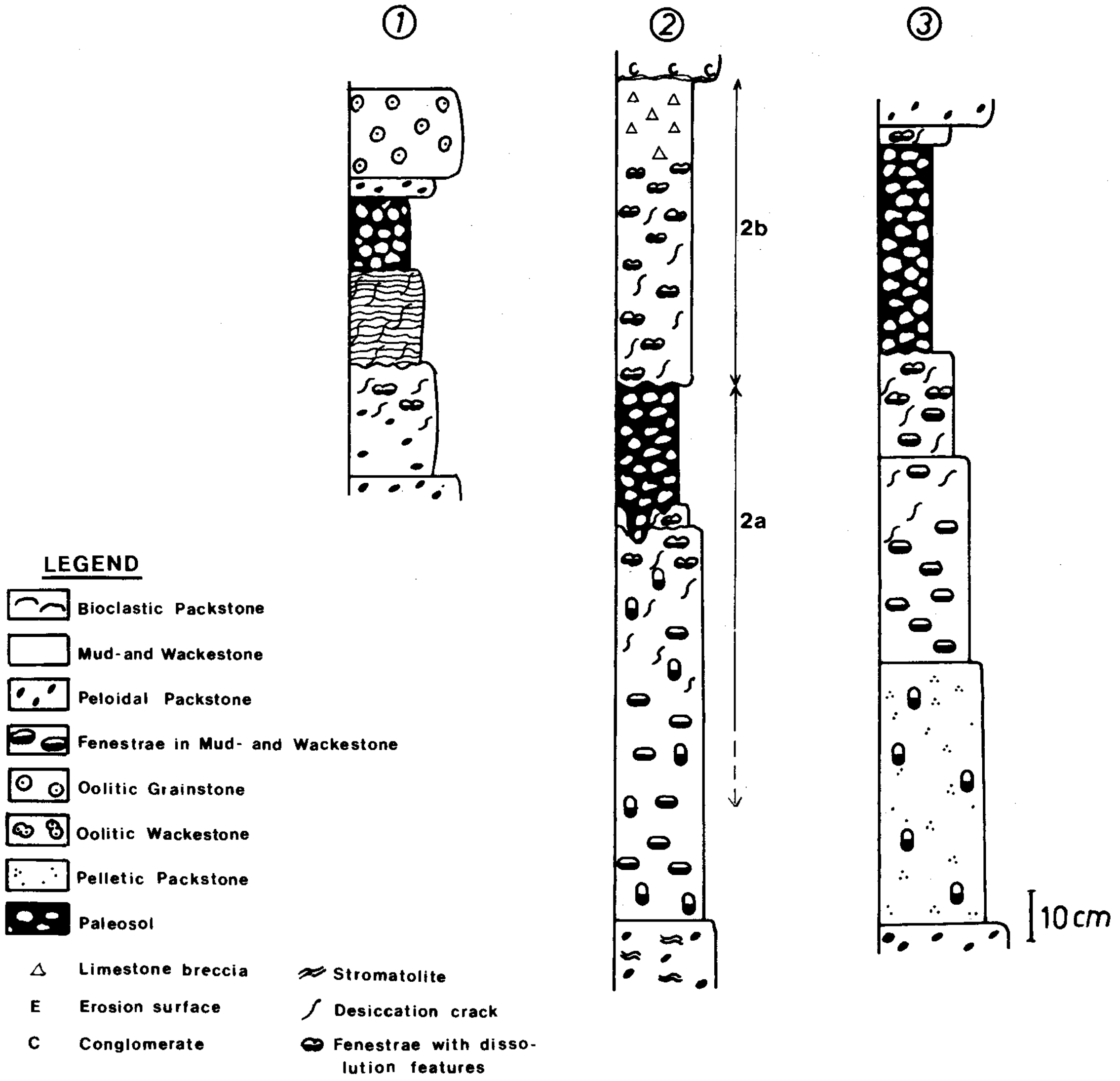


Fig. 3.- Detailed logs of the paleosol sequences
(C: affected parent material; D: unaffected parent material). Numbers 1 to 3 refer to the paleosols in figure 2B.

- **platey calcrete crusts** : they consist of micritic laminae separeted by thin clay seams (Pl.I: 4).

- **root voids** : using the classification of Klappa (1980), root casts, root tubuli and a few rhizocretions were recognized (Pl. I : 4).

- **micritic and microsparitic matrix** : the crystals are of equal size. Rhombohedral calcite crystals can also be distinguished.

- **fragments floating in the matrix** : these fragments are mostly derived from the underlying sediments. They may contain distorted fenestrae.

Details of the different paleosols are the following :

Paleosol 1 (fig. 3.1)

The parent material of the paleosol mainly consists of a stromatolite with desiccation cracks. The stromatolite is affected by the paleosol. Locally the paleosol has also affected the underlying peloidal wackestone with burrows and fenestrae. The allochems in the wackestone show solution features and the fenestrae and burrows have an irregular rim. A few desiccation cracks also were found within the wackestones.

The paleosol consists of nodules which occur in a microsparitic matrix. The nodules are strongly brecciated and most of them were found in the top part of the paleosol. They also show desiccation features.

X-ray diffraction analyses pointed out that the clay matrix consists of the mineral groups illite (1M and 2M), mixed-layer illite-montmorillonite and illite-chlorite, Mg-chlorite and kaolinite.

Paleosols 2a and 2b (fig. 3.2)

Paleosol 2a occurs above an intertidal mudstone, in which fenestrae, burrows and desiccation cracks were found. Closer to the paleosol, fenestrae with dissolution features are present. The mudstone with fenestrae forms the parent material of the paleosol. Between the paleosol and the underlying sediments, a mammillary layer of approximately 4 cm thick was found. It contains very irregular fenestrae with dissolution features. In these fenestrae peloids, pellet coatings and partly dissolved pellets were observed, indicating the importance of a dissolution phase. The fenestrae are linked with each other via desiccation cracks.

In the paleosol three varieties of disorthic nodules occur : nodules with circumgranular cracks, nodules with internal cracks and nodules with small internal nodules. Some of the larger nodules show a first stage of brecciation. Fragments of the underlying mudstone also were found in the paleosol. In this paleosol the clay minerals are illite (1M and 2M) and a mixed layer illite-montmorillonite.

This paleosol (2a) is overlain by a wackestone with fenestrae (fig. 3.2b), showing dissolution features. Fenestrae with a lacy fabric as described by Wright (1983) occur frequently. The distribution of the pellets and peloids in this horizon is different from that found in earlier described wackestones and packstone. The peloids show a granular fabric and the pellets have a welded dropping fabric. Sometimes the pellets show a coated and linked distribution or an agglomeratic fabric when they occur between the peloids (Pl. I : 5, 6). In the fenestrae the pellets occur as pellet arches, pellet bridges or as coatings around the rim of the fenestrae. These distributions are termed tubulic (Pl. I : 7; for the terminology : see Bal, 1970, 1973). The fenestrae have an irregular wall and contain many cement generations. The top of the wackestone unit grades into a breccia, containing wackestone fragments. The matrix consists of mottled micrite and is rich in organic material. It shows alveolar textures (Pl. I : 8), orthic nodules and desiccation cracks, now filled with calcite.

The transition with the overlying conglomerate is erosive. The conglomerate fragments contain orthic and disorthic nodules. It is assumed that they are derived from the underlying, now eroded paleosol.

Paleosol 3 (fig. 3.3)

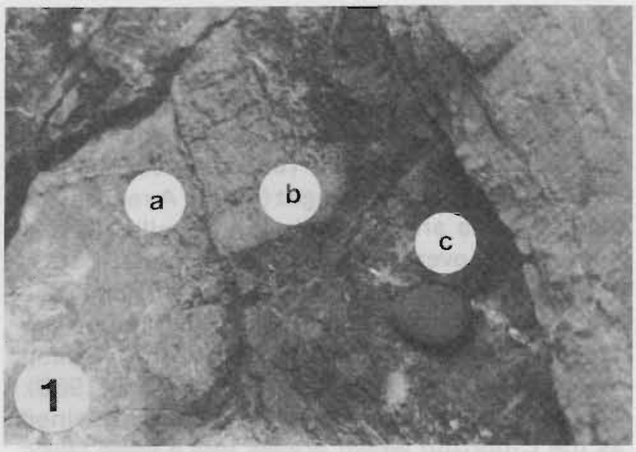
This horizon developed above a mudstone with fenestrae. The mudstone forms the parent material of the paleosol (~ 40 cm, thick). In addition to the general features, the paleosol consists of :

- fragments of an oolitic packstone with weathered contacts, floating in a microsparitic matrix. They have only been found at the base of the paleosol horizon;

- fragments of a brown micrite with root voids, burrows and irregular fenestrae. The fenestrae show many dissolution features such as irregular

PLATE 1

1. General view of the first paleosol.
   a: wackestone with fenestrae; b: stromatolite; c: paleosol.
   Diameter of lens cap : 6 cm.
2. Thin section photomicrograph showing orthic glaebules in a micritic matrix.
3. Thin section photomicrograph showing disorthic glaebules in a micritic matrix.
4. Thin section photomicrograph of a platey calcrete crust (a) above an horizon with root voids (b).
5. Thin section photomicrograph of pellets with an agglomeratic fabric : pellets in intergranular voids.
6. Thin section photomicrograph showing skeleton grains coated by pellets (coated distribution) and linked by pellet bridges (linked distribution). See arrows.
7. Thin section photomicrograph of compacted pellets, forming an arch in the fenestrae (arrow). The matrix consists of compacted pellets.
8. Thin section photomicrograph showing an alveolar fabric in the centre (arrow).


a
b
c
1


2
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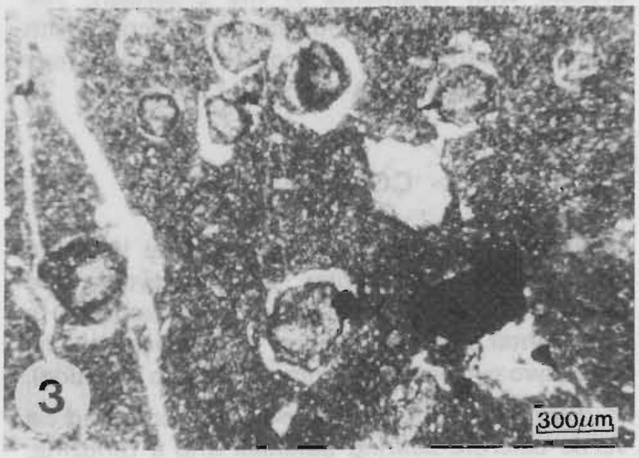
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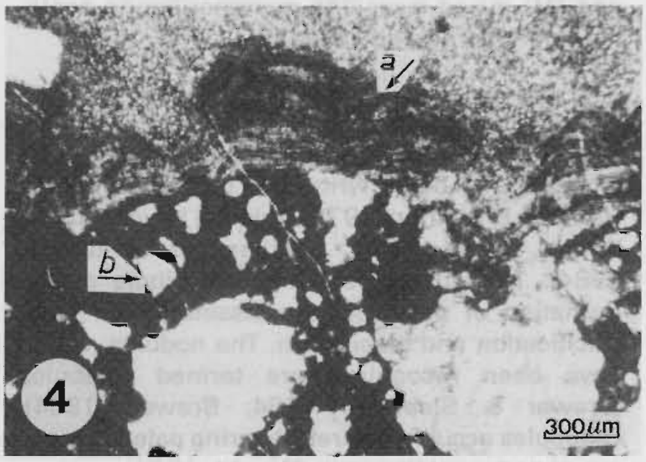
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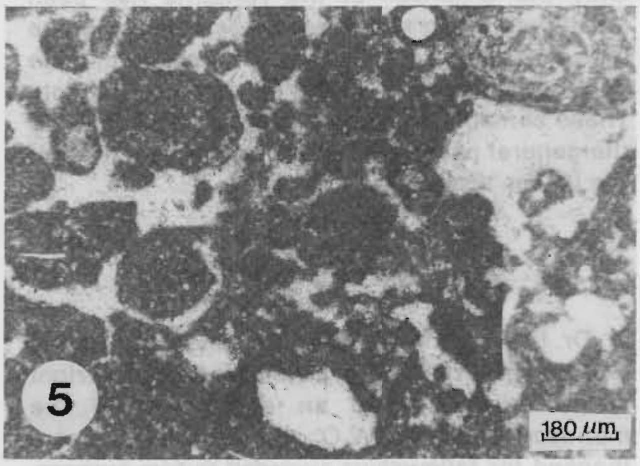
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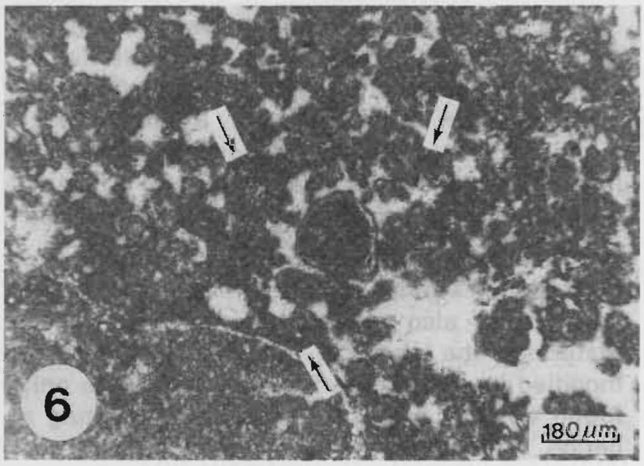
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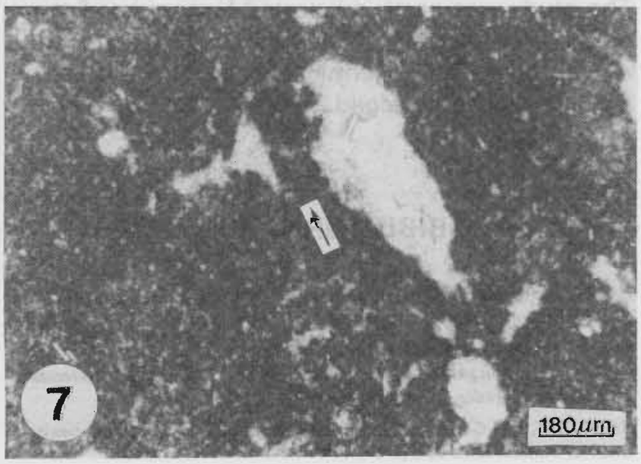
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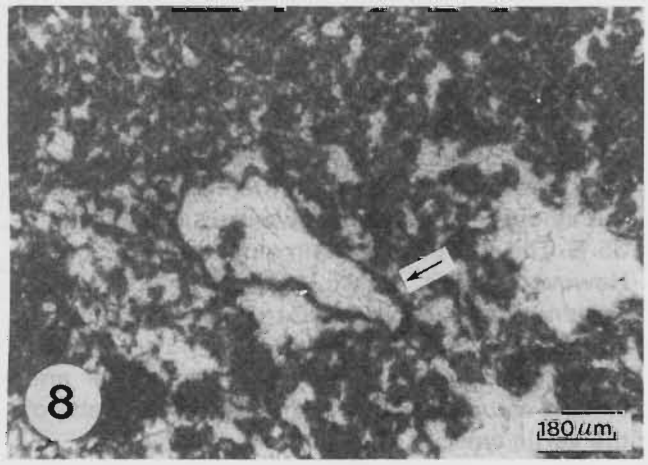
8
180µm

rims, partly dissolved micritic fragments and micritic rims. These brown micrite fragments also are floating in the microsparitic matrix;

- platey calcrete crusts, covering the brown micrite fragments;

- orthic and disorthic nodules. The disorthic nodules show internal and circumgranular cracks.

The top of this paleosol consists of a 4 cm thich layer of brown micrite with fenestrae, root voids and burrows.

In this paleosol the clay minerals are illite (1M and 2M), mixed-layer illite-montmorillonite, sepiolite, Mg-chlorite and kaolinite.

4.2.- INTERPRETATION AND DISCUSSION

Several publications about paleosols in limestones have been written (e.g. James, 1972; Harrison & Steinen, 1978; Riding & Wright, 1981; Wright, 1982, 1983; Goldhammer & Elmore, 1984). The processes which contribute to the formation of paleosols are dissolution of lime, calcification and brecciation. The nodules, which have been recognized are termed glaebules (Brewer & Sleeman, 1964; Brewer, 1964). Glaebules occur in calcrete-bearing paleosols and are of pedogenetic origin (Wright, 1982).

The laminated crusts are similar to the platey calcrete described by Wright (1982) from the Llanelly pedoderm of probable Arundian (Moliniacian) age, in South Wales. Bender (1981) mentioned the formation of secondary carbonates in the form of concretions, layers and crusts as characteristic for soils in arid and semi-arid areas.

The evolution from intertidal to supratital and continental strata, deduced from the facies analysis, is also reflected in the microscopic features of the fenestrae. Intertidal fenestrae are modified by dissolution features which are only found when a paleosol is present, indicating a period of emergence. The root voids are the remains of the flora developing on the soil.

The cracks in the soil and in the glaebules are the results of swell and shrink processes resulting from seasonal rainfall. When these features are found and more than 35 % of the clay minerals are swelling clay minerals, the paleosol is of the vertic type (Fao-Unesco, 1974). In the studied sections, the amount of swelling clay minerals is less than 35 %. The clay does contain more than 50 % illite. However, it is possible that smectite has diagenetically been altered to illite during burial. Therefore paleosols 1, 2a and 3 can be calcretes which have been formed in a semi-arid or arid climate with seasonal rainfall. They are probably of the vertic type.

The textures, described from the horizons above the second paleosol (2a) correspond with the typical features of a rendzina described by Bender (1981) and by Wright (1983). A rendzina is defined as «a shallow soil with a mollic horizon immediately overlying calcareous material ($CaCO_3$ $>$ 40 %)» (Fao-Unesco, 1974). The agglomeratic fabric and the coated and linked distribution are the result of an illuviation process and the washing down of material in suspension (Wright, 1983). The wackestone with fenestrae can be explained as the C-horizon which grades into a fitted fabric breccia with fragments of the C-horizon. The organic matter-rich and mottled micrite with alveolar textures, on top of the breccia, may correspond with the A-horizon of the soil.

5.- CONCLUSIONS

In the Terwagne Formation of the Walhorn section, five shallowing upward cycles are present. Three of them range from subtidal to continental and are capped by a paleosol. The other two cycles range from subtidal to intertidal.

Two paleosol types have been recognized : a vertic calcrete-bearing paleosol and a rendzina. Only the C-horizon of the rendzina has been preserved. Using the paleosols as a paleoclimate indicator, they suggest an arid or semi-arid climate during the deposition of the Terwagne Formation. These climatic conditions are in agreement with the general paleogeographical reconstructions of the Lower Visean (Tarling, 1985).

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