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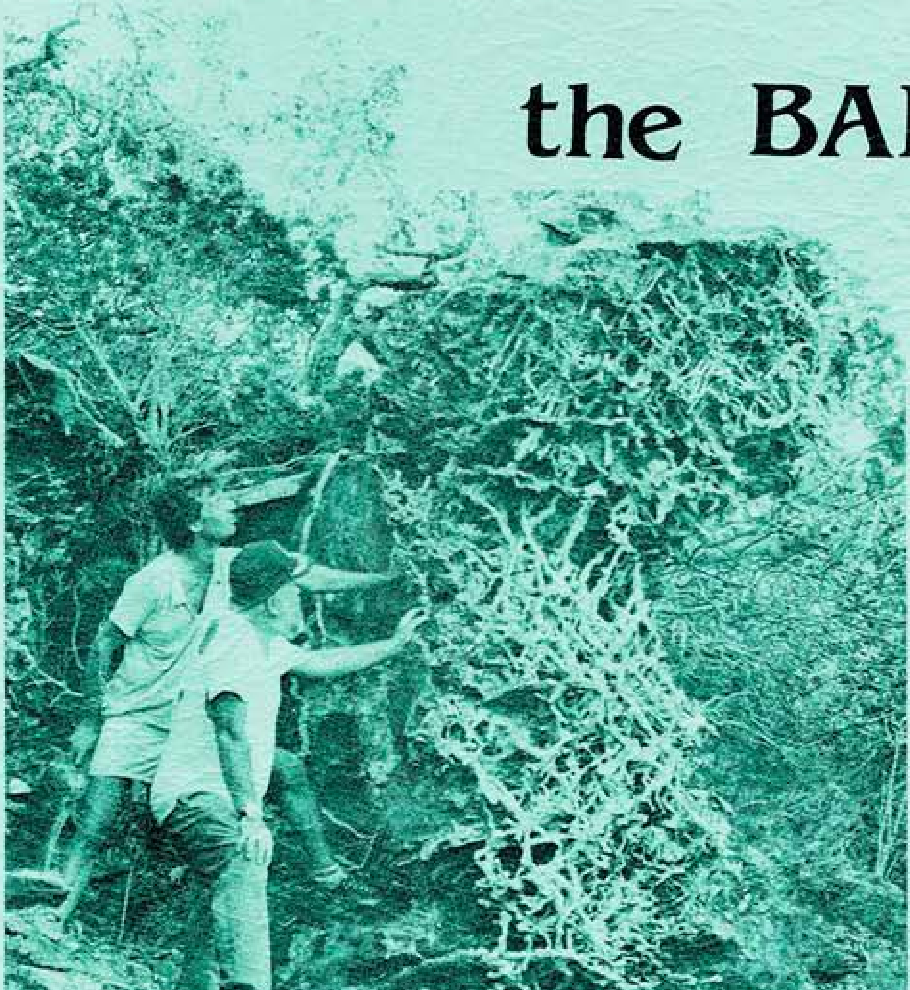

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MICROMORPHOLOGICAL FEATURES OBSERVED IN PEDOGENIC CARBONATES (CALICHE) ON SAN SALVADOR ISLAND, BAHAMAS

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Abstract

Pedogenic accumulations of calcium carbonate (caliche) on San Salvador Island are typified by subaerial exposure features such as dense-to-porous laminated crusts and microcrystalline rinds, solution-hole features, solution-hole breccias, sascab, pisolites, and rhizocretions. Caliche profiles form by pedogenic (soil) processes, and thus generally exhibit features indicative of pedogenesis such as genetic horizons; a thin, incompletely developed organic horizon, a leached horizon, an accumulation horizon, and a partially weathered horizon. Samples of subaerial exposure features collected from San Salvador were studied and described both macroscopically and petrographically in a pedogenic context, rather than a diagenetic, geologic context.

The main emphasis of the study concerns the description and formation of the dense-to-porous laminated crusts and microcrystalline rinds so prevalent on this subtropical carbonate island. Macroscopic evidence such as thickness of crust zones, color, presence of root tubes, and composition of some laminae attest to a pedogenic origin of these crusts. Petrographic descriptions of these subaerial exposure crusts also confirm this origin because of the presence of cutans (soil, channel, and plane), glaebules, voids, and crystallaria.

Introduction

Macroscopic features that indicate subaerial exposure and pedogenesis are common on San Salvador and include dense-to-porous laminated crusts, solution-hole breccias, pisolites, and rhizocretions. Formed on oolitic and/or skeletal calcarenites, these features are grouped collectively as caliche soils, and are therefore studied in a pedogenic or "soils" context. Because the exposed carbonates have been degraded by soil-forming processes (e.g., solution, brecciation, rooting, bacterial activity, etc.), various microscopic soil features seen in thin sections are presented and emphasized as further evidence of pedogenesis on San Salvador. Similar caliche soils have been described from the Pleistocene of Barbados and Florida (Multer and Hoffmeister, 1968, 1971; James, 1972; Harrison, 1977) and from the Mississippian of Kentucky (Ettensohn et al., 1984; Grow, 1982; Harrison and Steinen, 1978).

Soil and Caliche

Basic to the study of subaerial exposure features is the understanding that most of these features are included in the category of caliche soils. In order to study these caliches in a pedogenic context, some fundamental knowledge of soils and related terminology is essential. Familiarity with soil concepts and usage will provide a clearer view and comprehension of the processes involved in the formation of Pleistocene and Recent caliches on San Salvador.

Pedology is the study of soils and incorporates the subdisciplines of pedography and pedogenesis. Pedography is description of soils in profile, hand sample, and thin section, whereas pedogenesis deals with the origin of soils, and all three disciplines are encompassed in geology. Indeed, Brewer (1964) emphasized the fact that soils cannot be thoroughly studied unless one has a thorough knowledge of the rocks from which the soils are derived.

Soils are ultimately derived from the weathering of sedimentary, igneous, and metamorphic rocks and exhibit macroscopic and microscopic variations with increasing depth, as seen in the genetic horizons composing a soil profile. Caliche profiles are a specific type of soil profile, defined by the Lexico-Sedimentologico (Gonzalez-Bonorino and Terrugi, 1952) as

> "a strataform to irregular deposit, formed primarily by calcium carbonate, with earthy, concretional, pisolitic, banded, or massive structure that is formed in the soil of arid or semiarid regions."

Caliche profiles, if complete, exhibit up to 5 horizons, the most important in this study being the B horizon, or the zone of accumulation, located below the A horizon, or the zone of leaching. The zone of accumulation is the horizon in which the subaerial exposure features (crusts, solution-hole breccias, pisolites, and rhizocretions) form on San Salvador.

Therefore, this paper will assume that dense-to-porous laminated crusts, breccias, pisolites, and rhizocretions are parts of caliche accumulations and that caliches are a type of soil. With this in mind, we will now describe some characteristic examples of micromorphological soil features in thin sections taken from these caliches.

Micromorphological Soil Features

In order to describe thin sections of the exposure features from San Salvador in a pedologic context, terms unfamiliar to geologists must be defined. Table 1 lists 6 common pedologic features, their geologic counterparts (if applicable), and figures showing each. Table 1 is adapted from Grow (1982) and all subsequent definitions of pedologic terms are derived from Brewer (1964).

Table 1: Micromorphological Soil Features

PEDOLOGIC	GEOLOGIC	EXAMPLE
Plasma	Soluble $CaCO_3$	Fig. 1a-i
Voids	Voids	Fig. 1b,g,h
Cutans	Micritic Coating	Fig. 1a,b,c
Grain cutan		Fig. 1a
Plane cutan		Fig. 1b
Channel cutan		Fig. 1c
Pedotubule	Root tube, burrow	Fig. 1d,e
Glaebule	Nodule, concretion	Fig. 1f
Crystallaria	Calcite spar	Fig. 1a,g,h,i

Plasma

Most soils are composed of two major consitutents: skeleton grains and plasma. Skeleton grains are those individual grains larger than colloidal particles ($< 2 \mu m$) and mainly consisting of authigenic mineral grains and organic bodies (Brewer, 1964). Skeleton grains are relatively immobile and are capable of weathering to form plasma. The plasma component of a soil is "all the material of colloidal size and relatively soluble material that is not bound up in skeleton grains; it consists of mineral (amorphous and crystalline) and organic material" (Brewer, 1964). Thus, the plasma of a soil can be readily transported, reorganized, and concentrated by pedogenic processes. In the case of San Salvador caliches, the most common plasma component in the soils is soluble $CaCO_3$, which forms the various macro- and microscopic features apparent in the San Salvador caliches (e.g., crusts, cutans, crystallaria). The $CaCO_3$ is dissolved by acidic waters, transported by the percolating waters, and reprecipitate by capillary action related to evapotranspiration. This reorganization of $CaCO_3$ reflects the movement of the plasma in a soil.

Voids

The various arrangements that the constituent minerals (skeleton) grains make with each other together with solution (movement of plasma) result in the formation of voids of various shapes, sizes, and arrangements. Voids in the soil material are very important because it is in them that many micromorphological soil features form, as we will demonstrate subsequently. Indeed, Brewer states that "a number of morphological characteristics are consistently associated with particular groups of voids." Morphologically, voids can be grouped into packing voids (Fig. 1b, arrows), vugs, vesicles, channels, chambers (Fig. 1g), and planes. Genetically, voids are grouped into three categories: (1) those resulting simply from random grain packing, (2) those much larger than those voids resulting from simple packing systems, (3) those resuting from a different process superimposed on simple packing, such as solution.

Cutans

As stated above, the plasma is the soluble, mobile $CaCO_3$ which is reorganized into various soil features. One of the most

Figure 1: Various micromorphological soil features observed in San Salvador caliches. Bar scales = 1 mm.

(a) Thin section from a crust showing crystallaria (crystal tube) developed in an elongate pedotubule. Note the grain cutan formed around a superficial oolith above the crystal tube. (Polarized light, 16x).

(b) Darkened plane cutan (middle of photograph) formed in crust horizon suggesting movement of plasma through skeletal calcarenite (Polarized light, 6x).

(c) Transverse cross-section of a channel cutan formed around a root. Light area on outside of the tube is a calcitan, whereas the dark area in the center is an organic cutan. (Plane light, 6x).

(d) Pedotubule filled with soil material from another horizon or vadose silt. Note crystallaria filling remainder of tube. (Plane light, 6x).

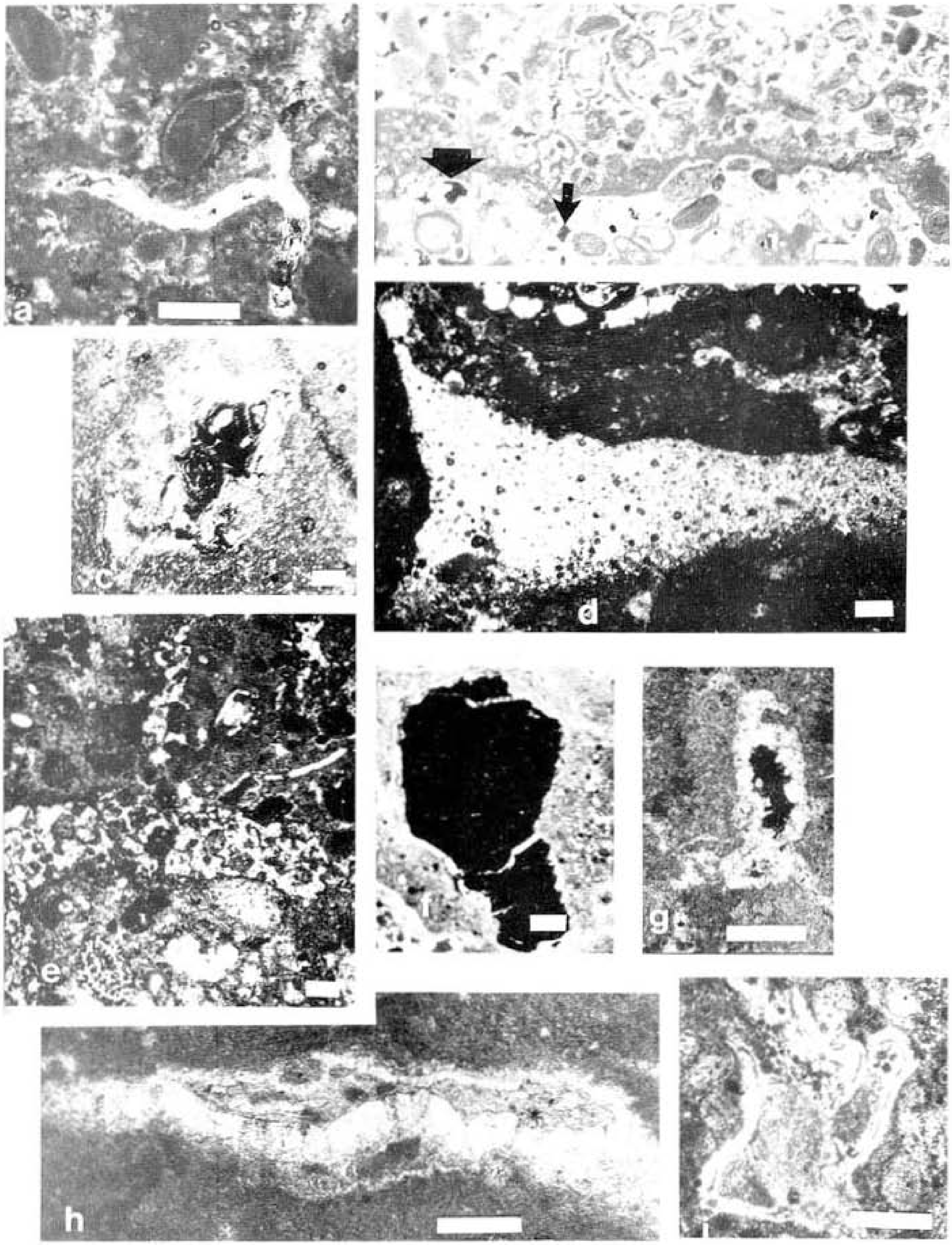
(e) Pedotubule in skeletal calcarenite filled with soil material and crystallaria and showing dark channel cutans along the margins of the tubule. (Plane light, 6x).

(f) A soil glaebule (nodule) formed of structureless iron-rich or organic material. (Polarized light, 6x).

(g) Small crystallaria (crystal chamber) showing extreme development of cutans in a possible solution chamber. Note the presence of central void. (Polarized light, 16x).

(h) Large crystallaria (crysal chamber) developed in an elongate pedotubule within a dense micritic crust. (Polarized light, 16x)

(i) Three small crystal tubes (crystallaria) formed in small root tubes (root hairs still present?) in a micritized skeletal calcarenite. (Plane light, 16x).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common of these features is the cutan, which is essentially a coating on the faces of peds (soil aggregates), skeleton grains, and the walls of voids. The above three surfaces are the areas where the greatest reorganization of plasma occurs.

Cutans are classified morphologically by looking at the type of surface they affect (Brewer, 1964). Cutans formed on the surface of skeleton grains (Fig. 1a) are grain cutans; those formed in channels (Fig. 1c) are channel cutans; and those formed along planes in the soil material (Fig. 1b) are plane cutans. All cutans seen in Figures 1a, 1b, and 1c were observed in surficial crusts and are a type of cutan known as calcitans, based on the mineralogy of the cutanic material. Although the plasma in San Salvador caliches is dominantly soluable CaCO , instances occur where plasma rich in organic material will form cutans, as seen by the channel cutan formed in a root tube in Figure 1c.

Brewer outlines four major processes of cutan formation; two of which are important in San Salvador caliches. Illuviation cutans form by transport and deposition of cutanic material in solution; Figures 1a and 1b are examples of illuviation cutans. Diffusion cutans are formed by surficial concentrations due to plasma diffusion, as observed in the channel cutan formed in a root tube (Fig. 1c).

Pedotubules

Another pedological feature observed in San Salvador crusts are pedotubules (Figs. 1d,e). These pedotubules exhibit an external tubular form that has a relatively uniform cross-sectional size and shape, and they are usually filled with soil material (skeleton grains and plasma). Pedotubules are characterized by their internal fabric, the composition of the plasma, their external form, and their distinctness relative to the enclosing soil material. Figure 1d shows a pedotubule filled with soil material that differs drasticaly from the surrounding soil material; this suggests that the tubule was possibly filled with vadose silt from the surface or with a soil material from another horizon. Pedotubules, although pedological features themselves, can contain within them other pedological features such as cutans (Fig. 1e).

Most pedotubules are attributed to faunal and plant-root activity. Burrowing and rooting probably formed the external tubular form, which was later filled with soil material.

Glaebules

The s-matrix of a soil is all the material (plasma and/or skeleton grains) that does not occur as pedological features (cutans, pedotubules, crystallaria, etc.). The s-matrix is similar to the matrix or ground-mass of a petrologist. Therefore, a glaebule is a three-dimensional unit within the s-matrix that did not form in a single void. Glaebules form because of a greater concentration of some constituent or a difference in fabric as compared with the surrounding soil material.

Glaebules include such things as nodules, concretions, septaria, pedodes, glaebular halos, and papules. The glabule in Figure 1f is a nodule because it exhibits an undifferentiated internal fabric; it is thought to be a concentration of organic or iron-containing material. Nodules that are rich in soluble fractions of the plasma formed by accretion.

Macroscopically, pisolites seen at the Bluff (Adams, 1983) are examples of soil glaebules called concretions, because they show concentric laminations of micrite around a friable carbonate nucleus of some soil unit. Pisolites are also thought to form *in situ* below the crustose zone.

Crystallaria

Crystallization of relatively soluble fractions of the plasma on the walls of voids is commonly observed in thin sections of San Salvador caliches (Figs. 1a,g,h,i). These crystals are found in chambers, tubes, and sheets. Because the crystals are common in subaerially exposed carbonates, they are reorganized as a separate type of pedological feature known as crystallaria. Crystallaria are single crystals or arrangements of crystals of relatively pure fractions of the plasma, which form in voids in the soil material. Crystallaria may be thought of as an extreme development of cutans in voids (Brewer, 1964).

Four principal kinds of crystallaria are known: crystal tubes (Fig. 1a,i), crystal chambers (Fig. 1h,g), crystal sheets and intercalary crystals. Crystal tubes (related to channel cutans) are crystallaria that occur in simple or branching channels, which exhibit crystallization from the wall toward the center of a tube. Crystal chambers form in vugs, vesicles, and chambers, and also demonstrate crystallization from the wall inward by the presence of a central void (Fig. 1g). Crystal sheets are similar to crystal tubes and chambers, but form in planar voids in the soil material; they are related to plane cutans. Intercalary crystals are single large crystals not associated with voids of equivalent size and shape, which show some well developed crystal faces.

It should be pointed out that Figures 1a and 1i provide evidence for biologic degradation of San Salvador caliches. Figure 1a is interpreted to show a burrow, and Figure 1i is interpreted to show tubes formed by three small root hairs. The presence of these structures in the form of crystallaria further attests to processes of soil formation acting on the exposed carbonates of San Salvador.

Conclusions

Various micromorphological soil features observed in thin sections of San Salvador caliches, along with observed profiles and hand samples, provide evidence for pedogenesis of San Salvador. The presence of root tubes and burrows attest to biologic activity in these exposed carbonates, whereas cutans and crystallaria reflect processes of illuviation, dissolution, transport, and precipitation of soluble $CaCO_3$ by percolating meteoric waters. Soil formation has most likely occurred at various times on San Salvador, when the carbonates were exposed by fluctuating sea levels. Indeed, Freytet and Plazait (1982) believe that such rocks are beset by soil-forming bacteria and processes immediately after emergence, and that soils will develop more advanced profiles with time. San Salvador caliches are younger than 120,000 years and have been exposed during most of this time. Hence, complete profiles are rare because of the short time involved and the extent of erosion.

Many areas of pedology need additional work in San Salvador. Soil genesis is very complex in that it incorporates chemistry, biology, microbiology, botany, and mineralogy in trying to delineate the origins of soils. The crusts, pisolites, solution-hole breccias, and rhizocretions themselves need individual attention in light of pedogenesis. This paper has barely "scratched the surface".

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