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Cover Photo: Outcrop showing Pleistocene soil profile,
caliche crust, and rhizocretions,
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SIMILARITY OF DEVONIAN AND PLEISTOCENE TERRA ROSA PALEOSOLS, SILVER CITY AREA, NEW MEXICO, AND SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

A major Siluro-Devonian unconformity is characterized by a paleokarst with small sinkholes, fissure fillings, networked cavities, and complex fracture zones filled with terra rosa paleosols and/or pedogenic breccias. A direct comparison of this paleokarst and its associated paleosols with Pleistocene paleokarst and terra rosa paleosols on San Salvador Island shows that, in spite of age and compositional differences, there are striking similarities.

Devonian paleosol samples contain a framework of pebble- and sand-size dolomite clasts dispersed in a matrix of iron-oxide-coated dolomicrite, dolosilt, and micrite, with virtually no clay. Pleistocene samples generally have fewer framework grains and a matrix dominated by iron-rich, chlorite-like HIC clay and boehmite, rather than by carbonate. However, both sets of samples exhibit similar thin-section-scale infrastructure: a matrix pedogenically organized into peloids, grain cutans, and glaebules; moderately to highly dispersed by complex anastomosing networks of irregular fractures, cavities, alveolar textures, and root-produced pedotubules; and cemented by nonluminiscent calcispar. Stages of fabric evolution in Devonian samples have their counterparts in Pleistocene samples.

INTRODUCTION

In southwestern New Mexico, terra rosa paleosols occur in a paleokarst that defines a major unconformity between Lower Silurian and Upper Devonian strata (Young and Bingham, 1991). On San Salvador Island, significant Pleistocene paleokarst and terra rosa paleosols occur at two stratigraphic horizons (Carew and Mylroie, 1994b). In spite of such a vast difference in age, there is strong morphologic similarity in the paleokarst of each area, and striking similarity in thin-section infrastructure of the paleosols despite both age and compositional differences. These basic similarities attest to the continuity of karst- and soil-forming processes of the past 400 my.

DEVONIAN PALEOSOLS, NEW MEXICO

The Silurian Fusselman Dolomite at its stratotype locale in the Franklin Mountains of west Texas and southern New Mexico is as much as 185 m thick (LeMone, 1992), includes the entire Llandoverian, Wenlockian, and lower Ludlovian stages, and is disconformably overlain by Middle and Upper Devonian strata (LeMone, 1988). The formation becomes an erosionally truncated wedge to the north and west; in the Silver City area of southwestern New Mexico, where it is disconformably overlain by the Upper Devonian (Frasnian-Famennian) Percha Shale, the formation is as little as 33 m thick (Pratt and Jones, 1961), and only the middle Llandoverian Stage is present (Berry and Boucot, 1970). The profound nature of the unconformity in the Silver City area has long been recognized (Paige, 1916), but only recently have its paleokarst and paleosols been recognized and described (Young and Bingham, 1991). Detailed descriptions of the paleokarst and paleosols appear in Young (1994) and are summarized below. Four locations in the area were used for field observations and sample collections (Fig. 1).

Devonian Paleokarst

Exposures of the upper 5 m of the Fusselman Dolomite and its contact with the Percha Shale exhibit numerous cm-to-dm-to-m size fissures, pits, and networked cavities typical of karren, and filled with red-to-maroon pedogenic breccias and paleosols. Simple linear fissures typically are up to a few dm wide, up to several m long, and as much as 2 m deep (Fig. 2A). Complex fissure zones

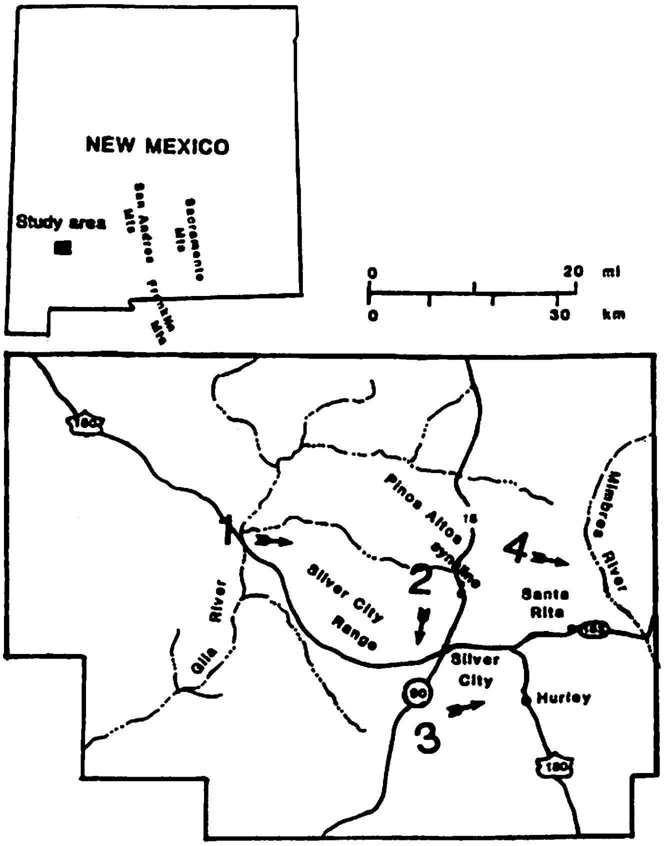

Figure 1. Location of study area and sample locales near Silver City, New Mexico. 1=Bear Mountain; 2=Chloride Flat; 3-Lone Mountain; 4=Georgetown.

form an intricate network of intersecting, brecciated fissures a few cm wide and a few dm long, reaching depths of 1 to 2 m and having the shape of inverted cones. Several generations of fissure/breccia formation and paleosol filling may occur (Fig. 2B). There is a strong correlation between fissure/breccia sites and development of paleokarst and paleosols.

Solution cavities and small sinkholes are semicircular and range from several dm to several m in diameter, with depths up to 1 m. These, too, are filled with breccias and paleosols. Locally, some fillings have proven more resistant than the host rock and occur on the outcrop as relict spheroidal bodies with positive relief (Fig. 3A).

Former caves in the upper 3 to 5 m of the formation, up to 15 m across and 2 m deep, are preserved as silicified fillings either enclosed within the host rock or as unroofed, isolated knobs rising above the outcrop surface (Young, 1992) (Fig. 2C). These fillings consist of quartzose layers several cm thick stacked parallel to cave floors. Relict bedding planes are distinct and locally stylolitic; distorted pisolite-like bodies several cm in diameter occur locally. The cave fillings originally appear to have been carbonate, but they are now almost entirely replaced by a mosaic of anhedral to subhedral sand-size megaquartz. This replacement probably occurred during Laramide mineralization of the region, when the overlying Percha Shale formed a seal and trapped rising mineralizing fluids along the unconformity (Hernon and others, 1965).

Devonian Breccias and Paleosols

Red-to-maroon pedogenic breccias and paleosols fill cavities and fissures in the upper Fusselman; the only distinction between the two is dominant clast size. Breccias contain many pebble-size host-rock clasts up to 10 cm long, whereas paleosols contain mostly granule to coarse sand-size clasts. Some breccias exhibit an immature stage of soil evolution; these have clasts in stages of *in situ* disintegration and rounding dispersed in a dolosilt/dolomicrite matrix. Other breccias show a greater degree of clast dispersal, have a pedogenically derived matrix, and are true paleosols. Paleosols have matrixes of sand/silt-size detrital dolomite, scarce sand-size detrital quartz and feldspar, iron-oxide-coated dolomicrite, micrite, and soil structures resulting from mobilization of soil plasma, disturbance by plants, and cementation.

PLEISTOCENE PALEOSOLS, SAN SALVADOR ISLAND

Two major terra rosa paleosol horizons occur in the Pleistocene of San Salvador Island, at the top of the Owl's Hole and Grotto Beach formations, respectively; both were produced during sea-level lowstands (Carew and Mylroie, 1994b). Samples were collected at the three localities shown in Figure 4. Other paleosol outcrops were observed on Gaulin Cay and at French Bay.

Pleistocene Paleokarst

Much of the Pleistocene karst on San Salvador is karren, produced by dissolutional sculpturing of the carbonate host rock; the

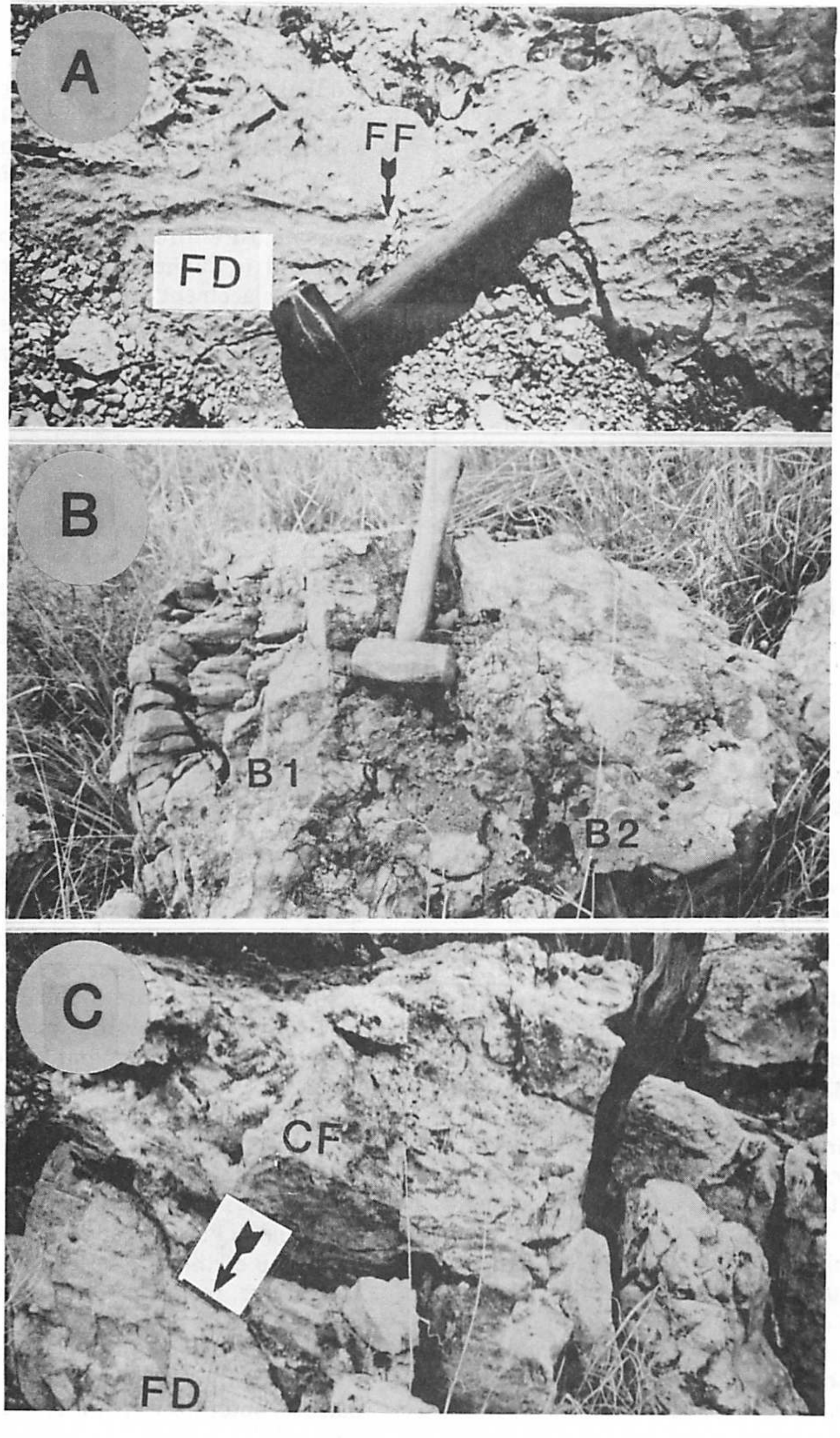

Figure 2. Devonian paleokarst near Silver City. A) Linear fissure (FF) in Fusselman Dolomite (FD) at Chloride Flat filled with terra rosa paleosol. Hammer handle is 22 cm long. B) Complex brecciated karren in Fusselman Dolomite at Chloride Flat. Two generations (1, B2) of paleosol devleopment are present. Hammer handle 22 cm long. C) Silicified cave filling in uppermost Fusselman Dolomite at Lone Mountain. Arrow points to contact between host rock (FD) and cave filling (CF), which is approximately 2 m thick.

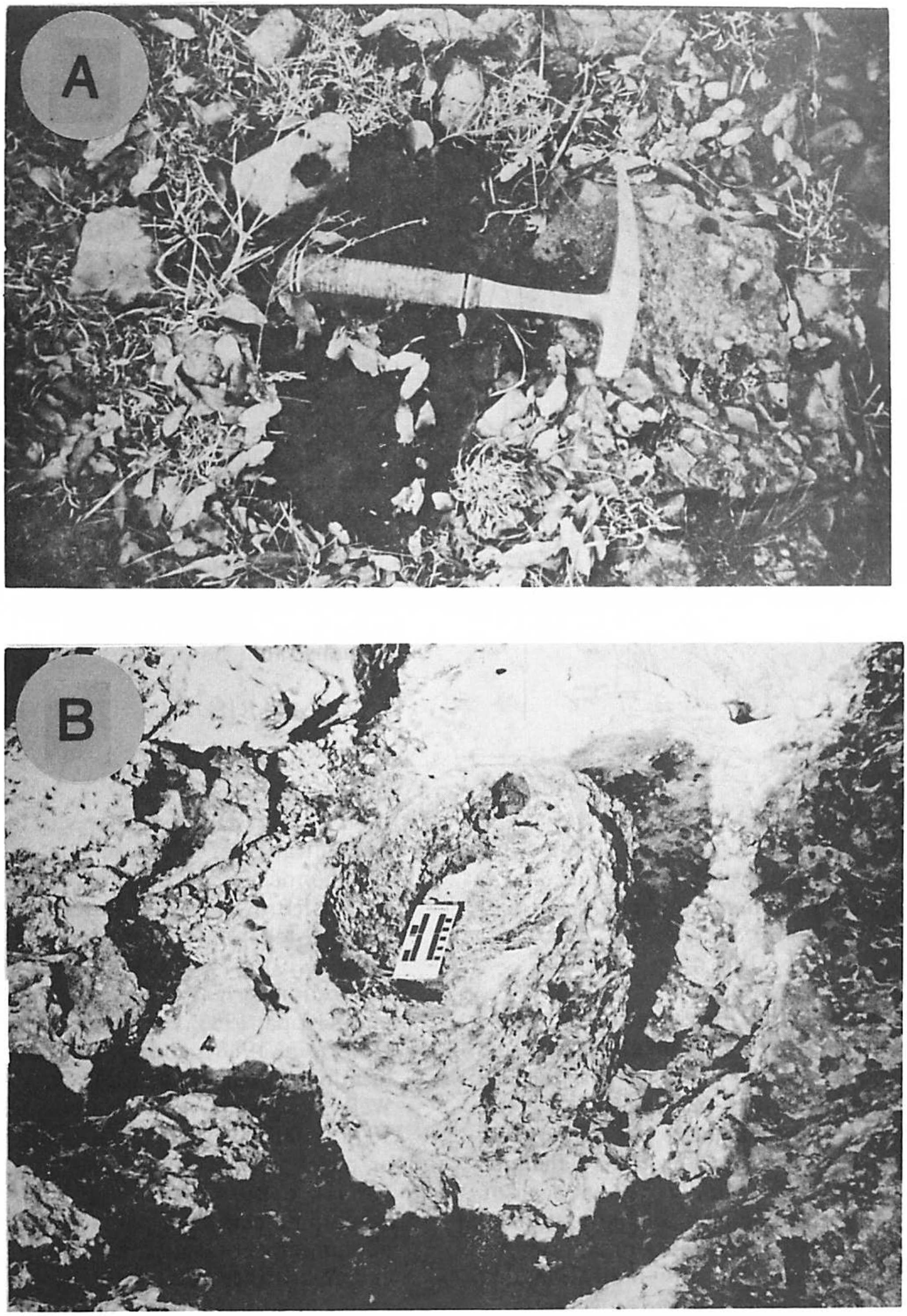

Figure 3. Devonian and Pleistocene solution-cavity fillings. In both cases, paleosol in small sinkholes has proven more resistant than the host rock, resulting in topographic inversion. A) Devonian at Chloride Flat; diameter is 5 dm; relief is 15 cm. B) Pleistocene at French Bay, San Salvador; diameter and relief are several dm.

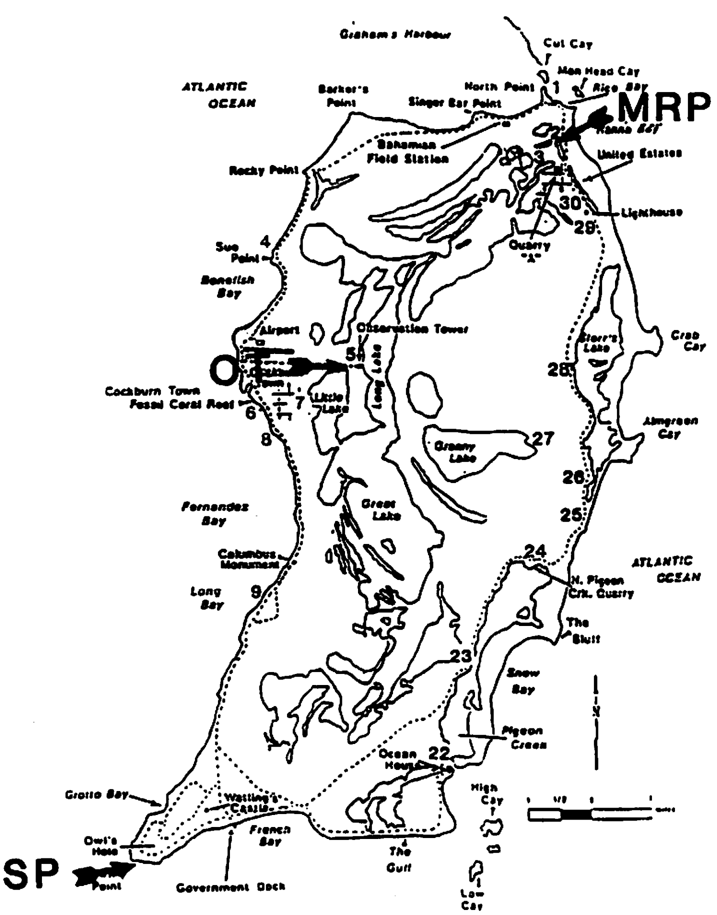

Figure 4. Location of sample locales on San Salvador Island, Bahamas. MRP=Moon Rock Pond; OT=Observation Tower; SP=Sandy Point.

result of etched and fretted surfaces and a subsurface network of small holes and interconnected tubular passageways, all at a cm-to-m scale (Carew and Mylroie, 1994b). In most cases, the openings are filled with terra rosa paleosols (Fig. 5A). This Bahamian karst is, in fact, very similar to that seen on outcrops of the Fusselman Dolomite, except that more cm-scale networking of cavities has occurred. Nor is there any indication that fissuring and brecciation played any major role in determining sites of later karsting, such as occurred in the Fusselman Dolomite. Other karst consists of both open (more recent) and filled solution pits and sinkholes (Fig. 5B). At some locales, as on Gaulin Cay and at French Bay, probable dissolution pit fillings now stand exposed as positive features on the outcrop (Carew and Mylroie, 1994a,b), in a manner similar to that already noted for the Fusselman Dolomite (Figs. 3A,B). Caves are plentiful on San Salvador, but there are no direct analogs of the silicified cave fillings found in the Fusselman.

Pleistocene Paleosols

The basic nature of Bahamian paleosols was described by Foos (1992) and the author concurs with her observations. Paleosols on San Salvador are generally host-rock-clast deficient compared with their Devonian counterparts; breccias are notably absent. Another important difference is that the Devonian paleosols are carbonate-dominated and lack appreciable clay minerals, whereas Pleistocene paleosols contain significant amounts of clays, primarily iron-rich, chlorite-like HIC clays and boehmite (Foos, 1991; 1992). However, these differences are minor, as the following comparison of Devonian and Pleistocene paleosol textures will demonstrate.

COMPARISON OF THE PALEOSOLS

Paleosol matrixes in Devonian and Pleistocene samples show many similarities in their basic structure. Mobilization and concentration of soil plasma has resulted in the common occurrence of sand-to-coarse-silt-size peloids (Brewer, 1964; Harrison and Steinen, 1978; Esteban and Klappa, 1983; Wright and Wilson, 1987), glaebules or nodular, concretionary grains (Brewer, 1964; Esteban and Klappa, 1983; Ettensohn and others, 1988; Goldstein, 1988), and grain and cavity cutans or mineral coatings and linings (Brewer, 1964; Walls and others, 1975; Harrison and Steinen, 1978; Ettensohn and others, 1988). Crystallaria or pore- and cavity-filling cement (Brewer, 1964) occurs both as a pervasive, nonluminescent calcispar cement and as mosaic nonluminescent calcispar filling pedotubules and microfractures. Peloids, glaebules, and grain cutans have been coated with iron oxide, the *rubification* of Buol and others (1980) and Duchafour (1982). Examples of pedogenic structures as well as basic paleosol similarity between Devonian and Pleistocene samples are illustrated by Figures 6 and 7.

Pedotubules (Retallack, 1988) consist of elliptical cavities up to several mm in diameter and irregular tubular cavities several mm or more in length. Many contain micrite

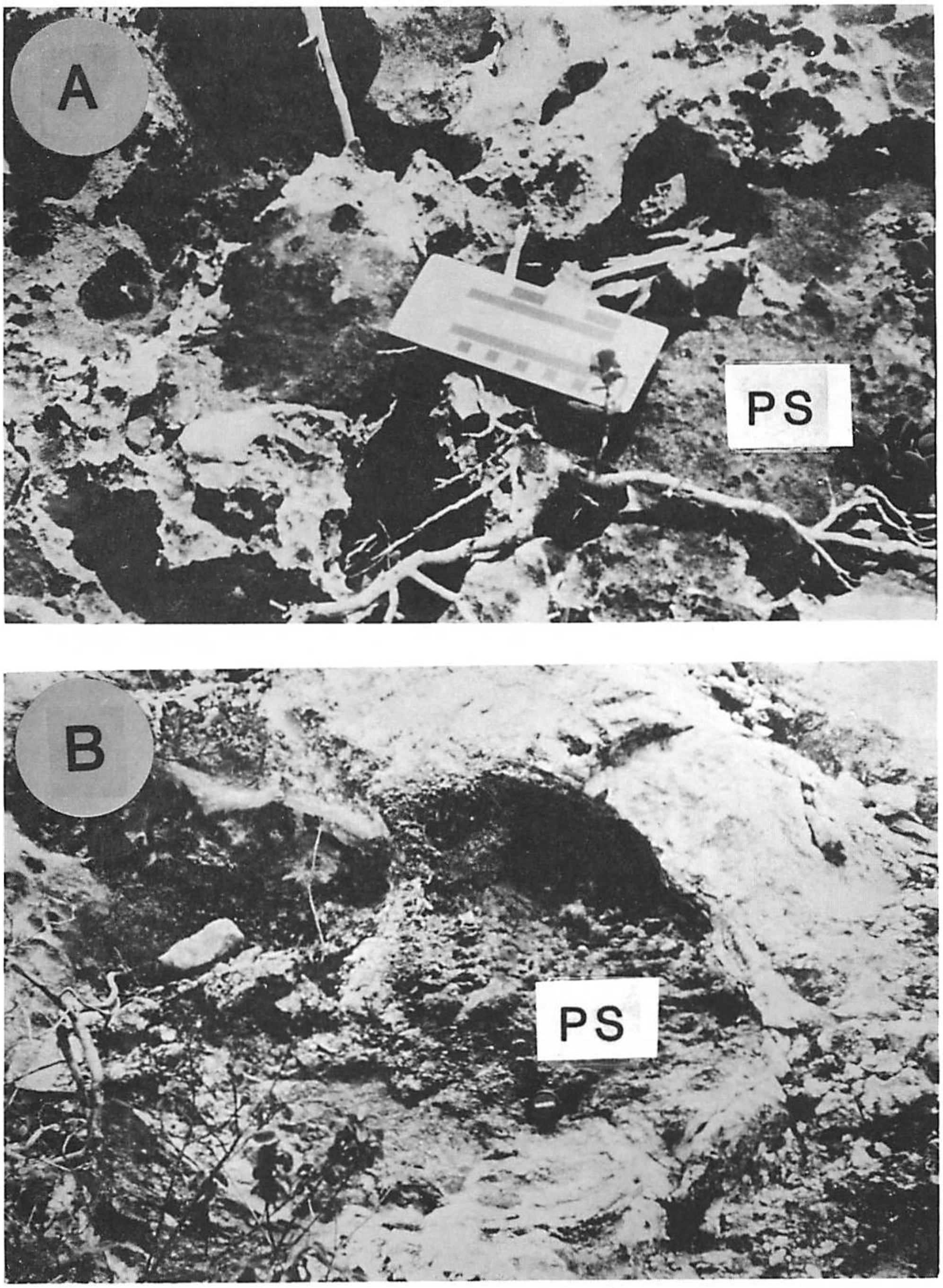

Figure 5. Pleistocene paleokarst, San Salvador Island. A) Closeup of intricate network of paleosol-filled cavities (PS) in karren at Moon Rock Pond. This type of karren is typical of the two major unconformities on San Salvador. B) Solution pit at Sandy Point filled with terra rosa paleosol (PS). Pit or "banana hole" is about 50 cm in diameter.

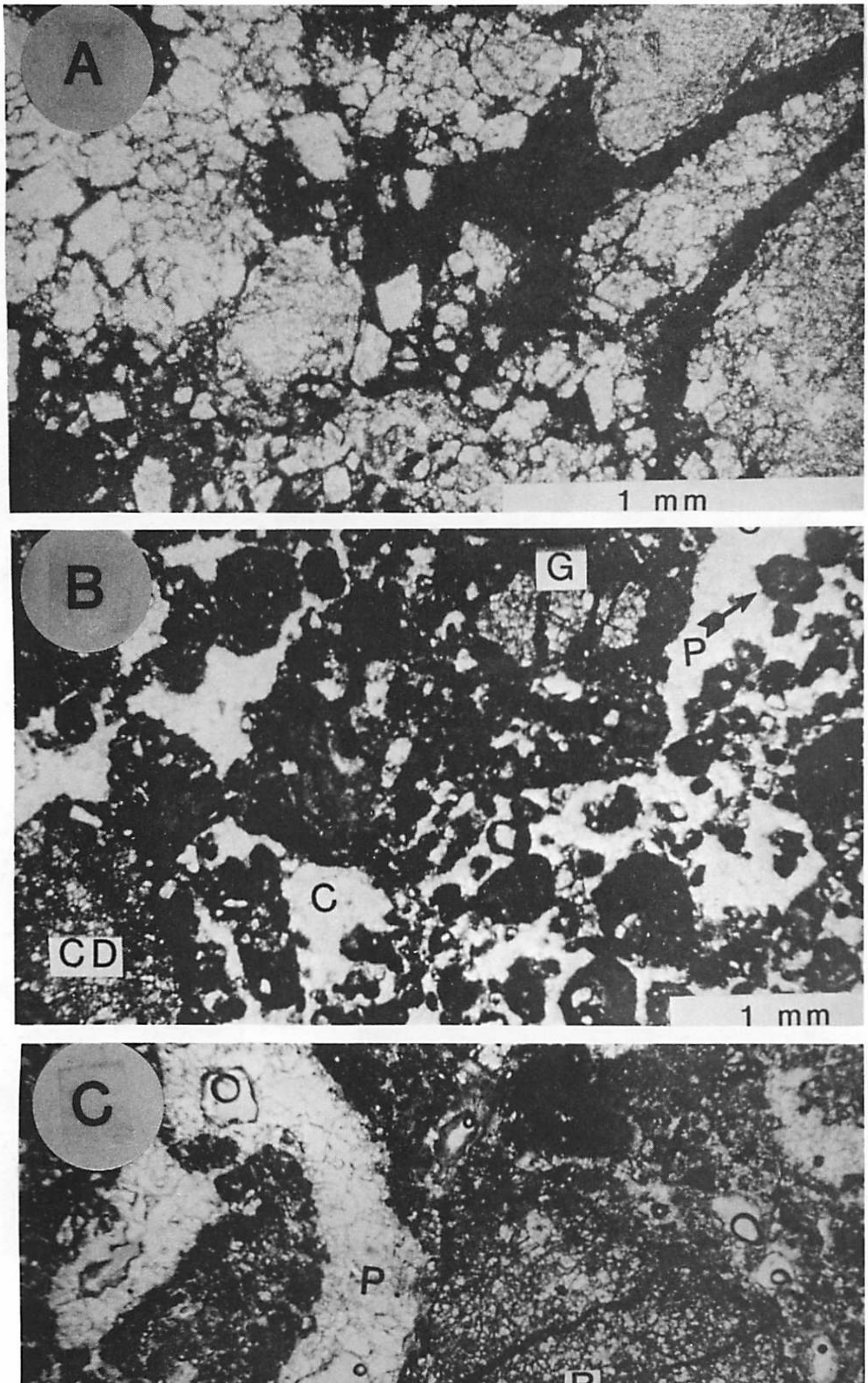

Figure 6. Photomicrographs of Devonian paleosol fabrics under plane light. A) Fusselman host rock shows in situ brecciation, rounding, and disintegration into dolosand and dolosilt. Matrix is iron-stained dolomicrite. B) Typical paleosol fabric with coated host-rock clast or grain cutan (CD), concretionary grain or glaebule (G), peloid (P), and crystallaria or calcispar cement (C). C) Breccia/paleosol with dolomite breccia clast (B) in a matrix penetrated by cement-filled pedotubules (P).

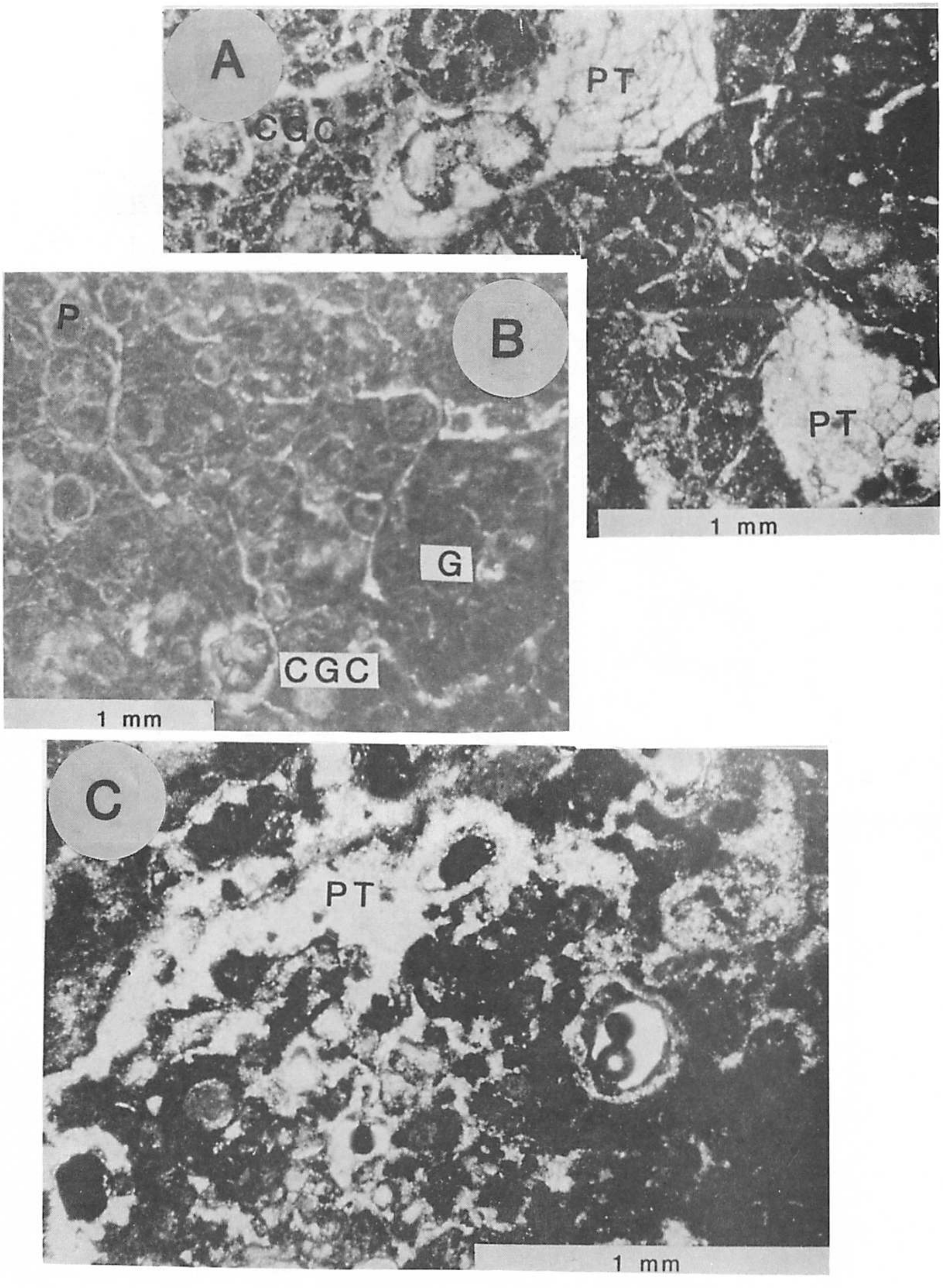

Figure 7. Photomicrographs of Pleistocene paleosols under plane light. A) and B) paleosol fabrics at Sandy Point developed in iron-rich HIC clay showing circumgranular cracks (CGC), glaebules (G), peloids (P), and pedotubule (PT). Cement is calcispar. C) Paleosol fabric typical of Moon Rock Pond and Observation Tower. Peloids and glaebules of iron-rich clay and micrite are dispersed and penetrated by calcispar-cemented pedotubules (PT).

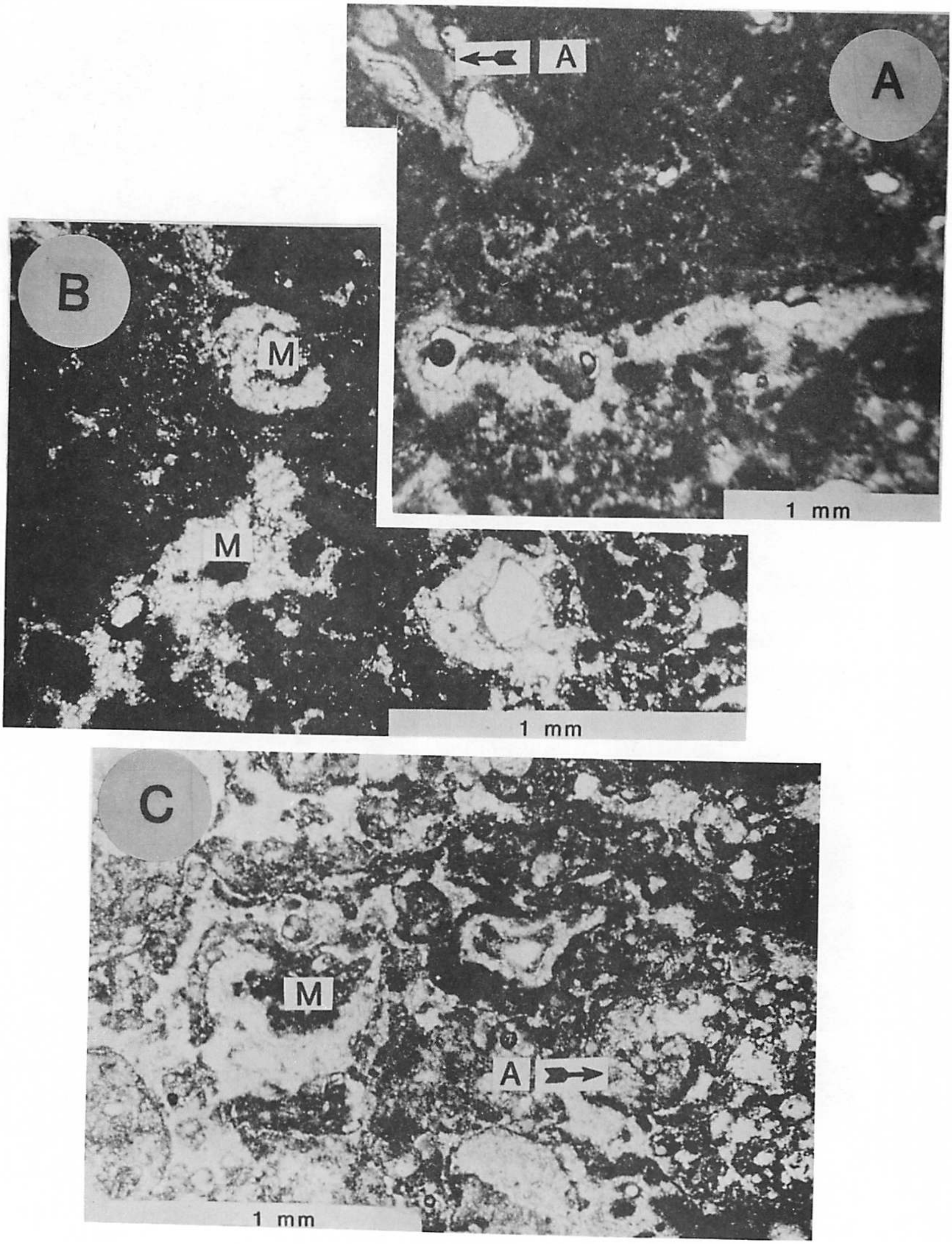

Figure 8. Photomicrographs under plane light showing comparison of Devonian and Pleistocene pedotubules or rhizoliths. Longtitudinal and transverse views show micrite cores of some tubules (M) and root-produced alveolar texture (A). A) and B) Devonian; C) Pleistocene.

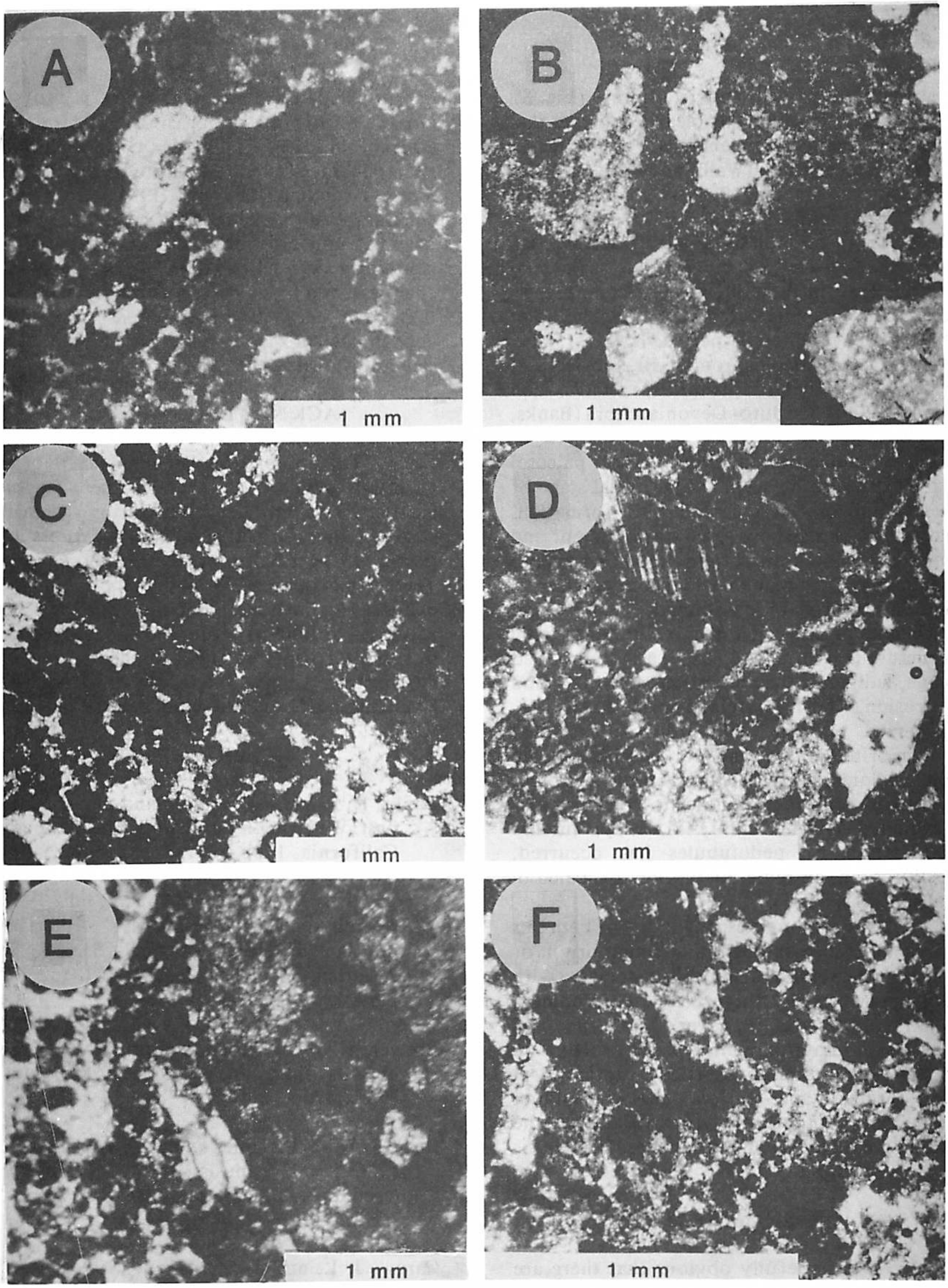

Figure 9. Photomicrographs under plane light showing comparison between stages of evolution seen in Devonian and Pleistocene paleosol fabrics. A) Devonian and B) Pleistocene: Host-rock clasts and soil clasts are tightly packed in micrite matrix; few crystallaria. C) Devonian and D) Pleistocene: Greater degree of clast dispersal by soil fractures and pedotubules; crystallaria more prominent. E) Devonian and F) Pleistocene: Greatest degree of clast dispersal; crystallaria and pedotubules dominant.

cores, and some show micrite linings (Fig. 8). Size, shape, and context clearly indicate that the Pleistocene occurrences are rhizoliths or fossil root cavities (Walls and others, 1975; Harrison and Steinen, 1978; Wright and Wilson, 1987; Ettensohn and others, 1988; Retallack, 1988; Wright and others, 1988). The Devonian occurrences are so similar in scale and morphology to their Pleistocene counterparts that their biogenic origin is certain. Rather than being root fossils per se, however, they may be fossil rhizoids, rootlet-like projections off the rhizomes of primitive vascular land plants typical of Siluro-Devonian flora (Banks, 1970).

Similarities in evolution of paleosol fabric can also be seen. In an initial stage of pedogenic brecciation and soil formation, host-rock clasts show some displacement and *in situ* disintegration and rounding (more common in Devonian than Pleistocene samples) within an iron-oxide-stained, fine-grained carbonate or clay-rich matrix with pedogenic structure (Figs. 6A; 9A,B). In a more evolved stage, full-scale disintegration, rounding, and corrosion of host-rock clasts occur, and a well-dispersed matrix of iron-oxide-stained dolomicrite, micrite, and/or clay, carbonate silt, peloids, grain cutans, and glaebules cemented by nonluminescent calcispar has developed (Figs. 9C,D). Locally, intense penetration by pedotubules has occurred, resulting in extreme disruption of paleosol fabric (Figs. 9E,F).

The nonluminescent nature of both sets of cements may indicate a common origin of meteoric cementation, logically associated with soil diagenesis in a highly oxic environment (Platt, 1989). However, inference of diagenetic environments based solely on cathodoluminescent properties is cautionary at best (Machal and Burton, 1991). Without supporting isotopic data (unavailable to the author), a meteoric origin for these cements is only speculation.

SUMMARY

It is hopefully obvious that there are many similarities between the Devonian paleosols of New Mexico and the Pleistocene paleosols on San Salvador Island and that dissimilarities are quite minor. Both sets of paleosols were derived from weathering carbonate host rock under moist, subtropical/Mediterranean climates (Duchafour, 1982). New Mexico was within a near-equatorial southern latitude during the Siluro-Devonian (Levin, 1991), certainly comparable to that of modern San Salvador Island. Similarities may also be attributed to continuity of a package of mechanical, chemical, and biogenic soil-forming processes that have been in place at least since the appearance of land plants with root-like structures during the Silurian.

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