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Parameters Related to the Identification of Paleosols in the Geologic Record

by

Robert A. Miller and Wayne R. Sigleo

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Introduction

Paleosols or fossil soils occur in most geologic environments, and where consistent recognition is possible, they can provide important evidence to interpret and correlate local and regional stratigraphic successions (North American Code of Stratigraphic Nomenclature, 1983). A paleosol, whether buried, exhumed, or relict, may indicate a hiatus in deposition, and may be the only record of a certain time interval. Studies of paleosols, especially in conjunction with paleobotanical and geochemical research, are particularly useful in deciphering paleoenvironments, climates, and landscape evolution.

The study of modern soils or pedology provides the basic framework to understand and interpret fossil soils (Fitzpatrick, 1971; Ollier, 1969). Although there is no simple definition for a modeorn soil; most soils include all of the material which differs from underlying rock or parent material through weathering, and is capable of supporting vegetation. The primary designation of a soil profile and horizon names are shown in Figure 1.

		O HORIZON	ORGANIC DEBRIS on the SOIL
SOIL SOLUM	SOIL PROFILE	A HORIZON	ORGANIC-MINERAL HORIZON
SOIL SOLUM	SOIL PROFILE	B HORIZON	HORIZON of ILLUVIAL ACCUMULATION and(or) RESIDUAL CONCENTRATION
	SOIL PROFILE	C HORIZON (with indefinite lower boundary).	WEATHERED GEOLOGIC MATERIALS
		R HORIZON or BEDROCK	UNWEATHERED GEOLOGIC MATERIALS

Figure 1. Pedologic profile of a soil (after Ruhe, 1965)

Soil horizons are relatively uniform layers of laterally persistent material that is usually parallel to the ground-surface. The soil profile constitutes the aggregrate of vertically stacked horizons, organic surface material, and all of the inorganic parent material that influences the genesis and properties of the soil.

Fossil soils are recognized by the same criteria that are used to identify modern soils, principally evidence of physical and pedochemical horizon zonation (Morrison, 1967; Hunt, 1972). Soil or weathering horizons are commonly differentiated by color, biogenic properties, soil structure and texture, clay mineral and oxide distribution, and concretions. Geochemical, micromorphological, and geomorphic criteria (Loughnan, 1969; Brewer, 1964; Daniels and others, 1971) are useful in the recognition and interpretation of fossil soils, but discussion of these parameters is beyond the scope of this essay.

Color

Color helps to differentiate soil horizons and is generally a useful criterion in the recognition of paleosols. The boundaries between the lower horizons of a paleosol commonly exhibit gradational color changes while the upper most horizon contact is usually relatively sharp. Interbedded sequences of paleosols sometimes display spectacular color banding similar to variegated redbeds (Retallack, 1983).

Leaching of organic material and clay minerals from the A horizon, and illuviation or deposition of these constituents in the B horizon is generally an active process in soils. The most commonly leached cations are sesquioxides of iron and aluminium. The color of the B horizon depends primarily on whether or not the iron has been oxidized during the process of illuviation. Oxidized iron in the form of yellowish-brown ferric oxides or goethite, or red hematite usually forms in well-drained soils in both humid and semi-arid environments.

Alternatively, saturation of the soil by water results in the reduction of iron, a process that imparts a bluish-greenish-gray color to the soil. The presence of carbonaceous material will also help to darken soil color. Mottled zones occur principally in the lower horizons of soil profiles where the iron is alternatively oxidized and reduced under conditions of a fluctuating water table, local waterlogging, or some other phenomena which causes the process of reduction (e.g. decaying organic matter).

Biogenic Properties

Biogenic features provide some of the best evidence for the identification of a paleosol. For example, root traces are virtually unequivocal evidence of a fossil soil. Root traces are tapered, downward branching, and often irregular in width and direction. Roots are often surrounded by haloes that exhibit a concertina-like outline if the soil is compacted. A gray or greenish-gray halo is indicative of an anoxic environment caused by waterlogging or anaerobic root decay. Similarly, a halo particularly enriched in iron or manganese probably results from local waterlogging.

The density and size of root casts or traces preserved in paleosols gives some idea of the type, distribution, and approximate size of plants which lived on the soil surface prior to burial. The shape of root traces differentiates them from other types of biogenic soil features, such as pedotubles which are tubular voids of constant width filled with soil matrix. Krotovina, or infilled burrows, are pedotubules which form elongate nodules and are found in bioturbated soils (Kubiena, 1953). Fecal pellets or coprolites can be preserved in soil as pedotubules or single pellets; these generally have a smooth outline, a cylindrical, spheroidal, or elliptical shape, and are denser and darker than the surrounding soil matrix.

In an oxidizing environment, organic material including pollen, spores, leaves, and wood are generally not preserved. Oxidization can eliminate any trace of the A horizon, and under such conditions, biogenic features are not particularly good criteria for the identification of fossil soil. Similarly, soils developed on slopes generally display few biogenic properties due to continued mass movement of thin, stony A horizons.

<u>Soil Structure</u>

The primary structural units composing soils are called peds, which are aggregates of grains separated from each other by zones of weakness (Soil Survey Staff, 1975). The shape and orientation of peds defines the soil structure and they can also be useful in denoting soil horizons. For example, the zone of maximum ped development in most soils is found in the B horizon. Figure 2 shows the classification of peds. Blocky or prismatic structure

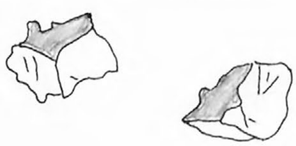
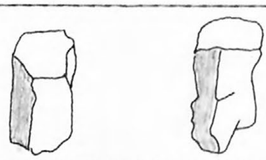
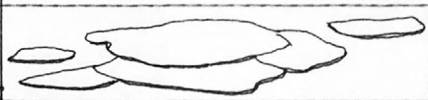
STRUCTURE	APPEARANCE OF PEDS	DESCRIPTION
Granular Crumb		Spheroidal shapes; faces of peds not flush, crumb structure is porous
Angular blocky Subangular blocky		Blocks with planar faces which are accomodating to adjoining ped faces; Angular blocky structure has sharp ped borders, subangular blocky has rounded borders.
Prismatic Columnar		Vertical ped faces are adjacent; prismatic has a flat top while columnar has relatively rounded tops.
Platy		Grains oriented on horizontal surface

Figure 2. General description of soil structure

usually indicates that clay is present and is bonding the grains together. A more massive appearance to the soil is generally indicative of bonding by organic colloids in conjunction with relatively little clay. Platy structure commonly reflects original grain orientation and bedding in fine-grained sedimentary rocks such as shale or siltstone.

Clay Minerals and Sesquioxides

The B horizon of the soil profile should be the most closely observed when identifying a paleosol because it is usually well preserved and contains many diagnostic criteria (Birkeland, 1974). This horizon contains the highest concentrations of clay minerals and sesquioxides due to leaching of these constituents from the A horizon of the profile. Clay minerals tend to be more crystalline in the upper parts of the B horizon. In particular, smectite shows a marked variance in crystallinity due to its common interlaying with illite at greater depths in the profile. Soils which form further downslope generally receive more moisture and have a greater percentage of clay in their B horizons than do soils that form further upslope.

As stated above, sesquioxides are largely responsible for the color of the B horizon. Illuviation in this horizon can result in argillans which consist of thin mineral layers coating ped faces or lining pores in the soil. Argillans can also form in situ (Oertal, 1968), but regardless of their genesis, they are indicative of pedologic processes, and an argillic zone is a very diagnostic feature of both modern and fossil soils.

Clay mineralogy can be an indicator of paleoenvironment to some extent (Grim, 1951; Keller, 1956). For example, smectite is an indicator of alkaline soil conditions with a moderate to high base saturation and cation exchange capacity. Alternatively, kaolinite forms in an acid, leaching soil environment where basic cations and iron have been depleted. Like kaolinite, illite formation also occurs in the absence of basic cations; however, illite genesis is favored by alkaline conditions. Montmorillinite tends to form when basic cations are concentrated, pH is high, and leaching is relatively slight (e.g. in poorly drained conditions) or where precipitation is low. Clay mineral variations are imperfectly understood, but seem to be largely dependent on temperature and precipitation. However, parent material, duration of weathering, and topography can also play an important role in determining what clay minerals are formed in a soil.

Concretions

Besides argillic layers, calcic or other salt layers are extremely important diagnostic features of ancient soils. Layers of calcite or other salts usually form in an environment where evapotranspiration exceeds precipitation, at least seasonally. Caliche or calcrete is a particularly interesting type of calcic horizon (Reeves, 1970). Caliche in some types of fossil soils is recognized by the following succession of zones (from the stratigraphically lowest to the highest):

1. Irregularly shaped calcite nodules composed of small calcite crystals in a microspar fabric. The nodules make up as much as 10% of the soil mass;

2. Larger nodules, commonly vertical and elongate cylinders making up 10% to 50% of the soil mass;

3. Nodules, veins, and diffuse calcite patches composing as much as 95% of the soil mass, and;

4. A continuous layer with a complex fabric of nodules, veins, clasts, laminae, and cement.

(After Hubert, 1977)

The entire calcic horizon is usually between one to three meters thick and is commonly composed of low-magnesium calcite.

In addition to calcic horizons, iron or silica-rich crusts or concretions are also indicative of fossil soils, particularly when these constituents are out of phase with present environmental conditions (Stephens, 1971). Other types of nodules can be useful in the interpretation of paleoenvironments. For example, droughts are usually represented by chalcedony pseudomorphs of barite and gypsum as well as by other types of petrocalcic horizons. Reduced minerals such as siderite and pyrite are indicative of local waterlogging, and very alkaline soils (pH 9-10) often contain zeolite and/or gypsum concretions.

Summary

Despite the fundamental approach of this essay, very little is actually known about the origin and genesis of paleosols. Like modern soils, ancient soils formed as a function of parent material, time, topography, organisms, and climate (Jenny, 1941). Complications regarding the interpretation of paleoenvironment from paleosols arise from the fact that time is the only independent variable of the five. It must be emphasized that paleosol characteristics can be the result of polygenetic formation; that is, a fossil soil may form during successive stages of soil development in different climates. In this case the original features of the soil may be masked. In addition, different processes acting on a soil may produce the same result and interpretations must be flexible and by necessity open-ended. For example, while some of the causes of color have been described, an additional complication is presented when the surface area of the peds is taken into account. A given amount of pigment will not color a soil composed of small peds as deeply as it will color one made of large peds. In fact, the use of color as an indicator of paleoenvironment could lead to gross errors if post-depositional diagenetic redox reactions have changed the original color of the soil (Birkeland, 1974). Therefore, any paleoenvironmental interpretation of a fossil soil should be based on more than one type of observation (Retallack, 1981). Similarly, while the identification of a paleosol can be surmised in the field, it is best to examine several other lines of evidence to ensure the correct identification.

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