The decreasing $\delta^{18}O$ trend through the middle of PB indicates significantly cooler conditions that correlate with oxygen stage 4. The strong Bt (Btt) in the lower part of PA is within stage 3 at a time when the $\delta^{18}O$ indicates moderately warm conditions. In the upper part of PA, the $\delta^{18}O$ results indicate an overall cooling trend to a near minimum condition that we correlate with stage 2. The $\delta^{18}O$ values begin to rise in what we think is the transition into the Holocene. However, rather than continuing to rise the trend reverses to a minimum value, which is not understood at this time.

The $\delta^{13}C$ values of soil organic carbon indicate that nearly a pure C3 forest existed several times based on modern relationships of vegetation type with the $\delta^{13}C$ content. The highest proportion of C3 forest (greater than 92%) occurred twice after Geosol-1 during the early parts of stage 3 and Substage 5b, while a mixture of C3 trees and C4 grasses (50–80% C3) existed during all other stages. The maximum proportion of C4 grasses (50%) appears to have occurred during a cooling phase of stage 3 and not during the coldest parts of the record.

In summary, the $\delta^{18}O$ values from pedogenic carbonates in the lower part of the Liujiapo Section show a good correlation with the oxygen stage 5 deep sea record, but a complex relation with the pedostratigraphic units of the same age. The key paleosol, S1, the first major paleosol observed at other localities on the Loess Plateau, is older than at least one major paleosol (PA) that occurs in the Malan Loess (L1) at Luijiapo. Pedogenic features and isotope trends indicate that climatic conditions here were measurably different than at other parts of the Loess Plateau during the late Pleistocene. The stable C and O isotopes indicate that the intermediate to warmer climatic conditions appear to coincide with a habitat dominated by trees, and that the cooler conditions are associated with a mixed grass–tree habitat. The large variations in the isotope trends are likely caused by the moisture factor and the effects it had on the paleosols of the Loess Plateau during the last 130,000 years.

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PART IV — SHORT PAPERS

ADAPTING SOIL TAXONOMY FOR USE WITH PALEOSOLS

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Soil classification is a fundamental aspect of soil science, and now is finding application to the study of paleosols (Retallack, 1990). One good reason for attempting to classify paleosols in soil taxonomies is to interpret their significance for paleoenvironments. Applying soil taxonomy to paleosols enables one to identify general cases and specific profiles of modern soils that can be compared in detail with a particular paleosol. If a paleosol is very similar to a modern soil, then perhaps environments similar to those that formed the soil can be inferred for the paleosol (Retallack, 1990). Classification is also a way of navigating the enormous published literature on soils. The classifications of the U.S. Soil Conservation Service (Soil Survey Staff, 1975), of U.N.E.S.C.O. (F.A.O., 1971–1981) and of the Australian C.S.I.R.O. (Stace *et al*., 1968) are supported by a vast bank of soil profile descriptions, often with chemical and petrographic data.

Unfortunately, the differentiating criteria of most soil classifications are not directly applicable to buried soils, and new criteria for delimitation of paleosols are needed. Bulk chemical and petrographic criteria are especially promising, because they can be shown to differentiate effectively between surface soils (Fig. 1) and have been increasingly reported from paleosols (Retallack, 1991). In recent work (Retallack, unpublished) with molecular weathering ratios from chemical analyses of 126 modern North American soils reported by Marbut (1935), a value higher than 2 for the ratio of alumina/bases distinguishes Ultisols from Alfisols in most cases. From another study (Retallack, 1993) on the relationship between depth to calcic horizons and mean annual rainfall, an uncompacted depth of 1 m or less to the calcic horizon may be a useful criterion for defining Aridisols (Fig. 2). Even though the organic matter of Mollisols is seldom preserved at anywhere near original levels in paleosols, granular ped structure and fine root networks can be preserved as evidence of a mollic epipedon (Retallack, 1991). More could be done with modern soils to find and quantify features that are robust enough to be used to identify paleosols within classifications of modern soils. Although perhaps premature, a simplified set of criteria designed as proxies for the U.S. Soil Taxonomy can already be envisaged (Fig. 3).

There is precedent for such an approach in paleontology, where proxy indicators are used to identify fossils. For example, the paleontological definition of mammals among the continuum of bones representing the evolution of mammals from reptiles is taken at the point when the dentary becomes the only bone of the lower jaw, or mandible. A zoological definition of mammals in contrast would be based on their hair, suckling or warm blood. A variety of lines of evidence now indicate that many dinosaurs had hair or feathers and were warm blooded (Benton, 1990). This example is instructive because zoologists have reassessed their concepts of mammals and reptiles from the perspective of extinct groups of animals, including dinosaurs. This would not have been achieved if classification of the fossils had been eschewed or if alternative non-biologically oriented classifications had been proposed.

From this perspective, classifications designed specifically for paleosols (for example by Mack *et al*., 1993) may simplify communication between paleosol workers, but do not lead to comparative data on soils useful for interpretation. Other approaches to the interpretation of paleosols are feasible, such as descriptive local classification analogous to mapping soil series (Retallack, 1991), or interpretations using factor-functions of the sort popularized by Hans Jenny (Retallack, 1993). These independent approaches do not diminish the value of using the vast store of experience with soils encapsulated in soil classifications. Soil scientists have shown commendable flexibility in allowing Soil Taxonomy to be modified and grow (Soil Survey Staff, 1990). Now is the time to meld the unique perspective of geological sciences with the established experience of soil sciences for the benefit of both disciplines.

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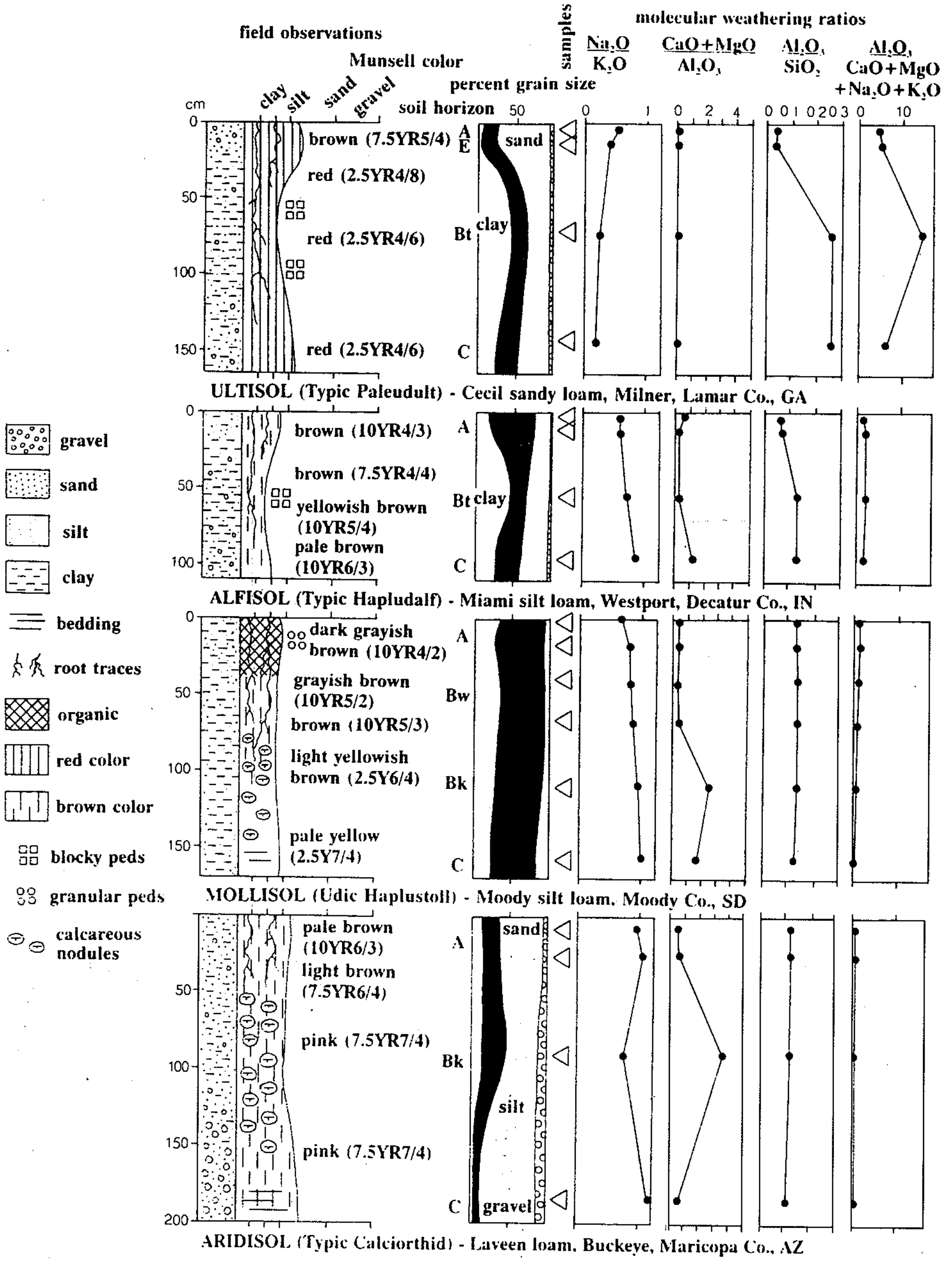

FIG. 1. Differences in grain size distribution and molecular weathering ratios of bulk chemical composition for four typical profiles of surface soils (data from Marbut, 1935). These petrographic and chemical measures can also be obtained from paleosols (Retallack, 1990, 1991).

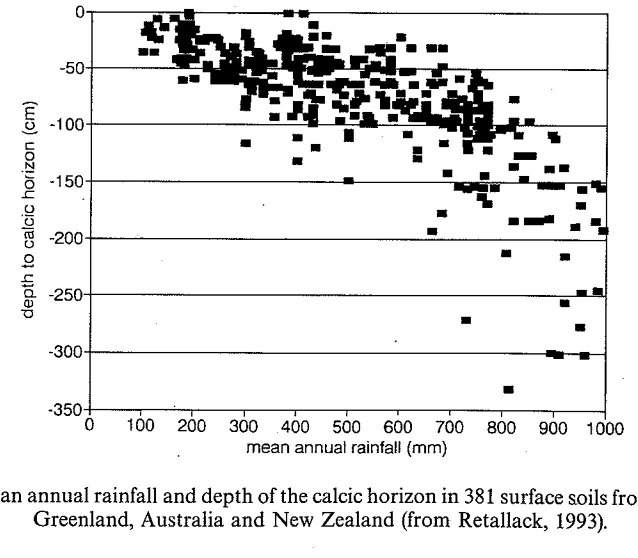

FIG. 2. The relationship between mean annual rainfall and depth of the calcic horizon in 381 surface soils from all continents including Antarctica, Greenland, Australia and New Zealand (from Retallack, 1993).

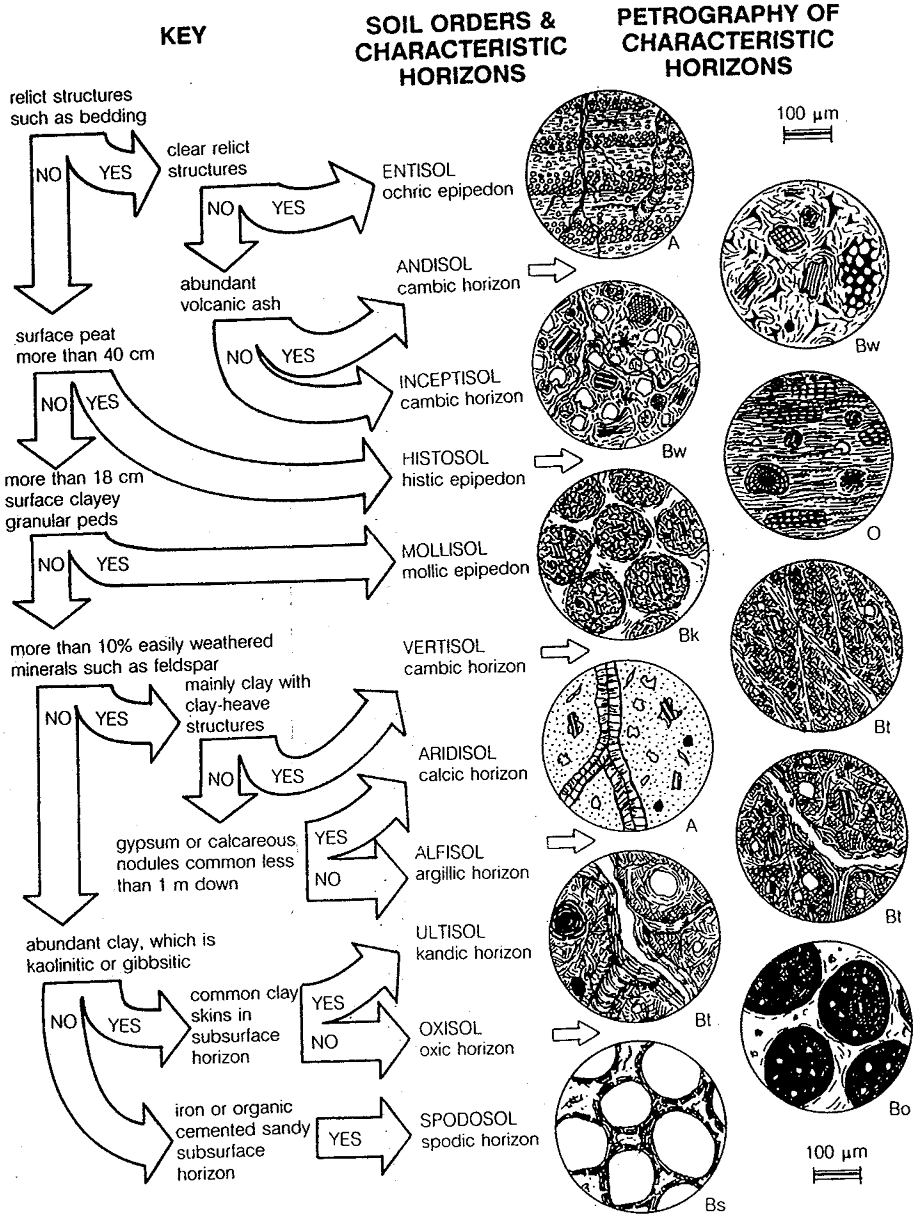

FIG. 3. A simplified key to order the U.S. soil taxonomy for use with paleosols, with emphasis on petrographic and bulk chemical criteria (data from Retallack, 1988, 1990, 1993). Each order has a characteristic appearance in petrographic thin section (after Douglas and Thompson, 1985).

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