



ELSEVIER

Sedimentary Geology 105 (1995) 51–62

SEDIMENTARY
GEOLOGY

Micromorphology and dissolution of quartz sand in some exceptionally ancient soils

Jeffrey L. Howard^a, Dan F. Amos^b, W. Lee Daniels^b

^a Department of Geology, Wayne State University, Detroit, MI 48202, USA

^b Department of Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA

Received 7 February 1995; revised version accepted 6 October 1995

Abstract

Scanning electron microscopy (SEM) was used to study the effect of prolonged weathering on the micromorphology of quartz sand. Three soil chronosequences in the southeastern United States (Virginia), with weathering profiles ranging in age from ~90 ka to ~10 Ma, were studied. Detrital sand grains from soil B horizons show that dissolution features are crystallographically controlled and develop progressively over time from smaller to larger etch pits, then to an interconnected network of grooves and crevasses, and finally to bulk grain decomposition. SEM also shows that disintegrating quartzite clasts in the oldest gravelly soils have been preferentially leached of silica cement, possibly due to selective weathering along 'dust lines' and spalling-off of quartz overgrowths. Severely etched quartz, usually attributed to tropical weathering, is an unreliable paleoclimate indicator because similar features can form as a result of prolonged weathering under a temperate climate. However, the well-defined relationship between quartz micromorphology and duration of weathering suggests that SEM is a useful tool for soil correlation and geomorphic analysis.

1. Introduction

Many attempts have been made with scanning electron microscopy (SEM) to correlate quartz sand micromorphology with sedimentary processes and depositional environments, the goal being paleoenvironmental reconstruction. Both modern (e.g. Krinsley and Donahue, 1968; Krinsley and Doornkamp, 1973), and ancient (e.g. Margolis and Kennett, 1971; Higgs, 1979) sediments from a wide range of environments have been studied. Although mechanically formed microscopic surface features are recognized as useful paleoenvironmental indicators (Krinsley and Doornkamp, 1973; Margolis and Krinsley, 1974), the significance of features formed by chemical dissolu-

tion is not well established. Previous studies have shown that climate, time and organic acids are important factors controlling quartz weathering (Crook, 1968; Doornkamp and Krinsley, 1971; Coch and Krinsley, 1971; Douglas and Platt, 1977; Little et al., 1978; Eswaran and Stoops, 1979; Al-Saleh and Khalaf, 1982; Pye, 1983; Bennett, 1991; Pye and Mazzullo, 1994). However, the nature and extent of processes involved, and their implications for paleoenvironmental interpretations remain to be determined.

The purpose of this study was to examine the effects of time on quartz dissolution. SEM was used to examine quartz sand micromorphology in three alluvial soil chronosequences in Virginia (Fig. 1).

These soils are ideal for an investigation of quartz weathering because they represent as much as 13 Ma of pedogenesis (Howard et al., 1993), and in a soil chronosequence, all soil-forming factors except time are essentially constant (Buol et al., 1980). We expected to see quartz dissolution because the oldest soils of the chronosequences have lateritic properties, and are so deeply weathered that even chemically resistant quartzite clasts are decomposing. Thus, the objectives of the study were to examine: (1) the dissolution of quartz sand in soil horizons; and (2) the mechanism of quartzite clast solution.

Few studies of the micromorphology of quartz in soils have been carried out previously in the eastern United States. Coch and Krinsley (1971) studied samples from Pleistocene coastal terrace soils in the outer Coastal Plain of Virginia, and Douglas and Platt (1977) examined soils developed from Pleistocene glacial till in New Jersey. Cleary and Conolly (1972) examined quartz sand in old residual soils developed from crystalline and sedimentary bedrock in the Piedmont and inner Coastal Plain of South Carolina, but only using a petrographic microscope. We are unaware of any previous SEM studies of

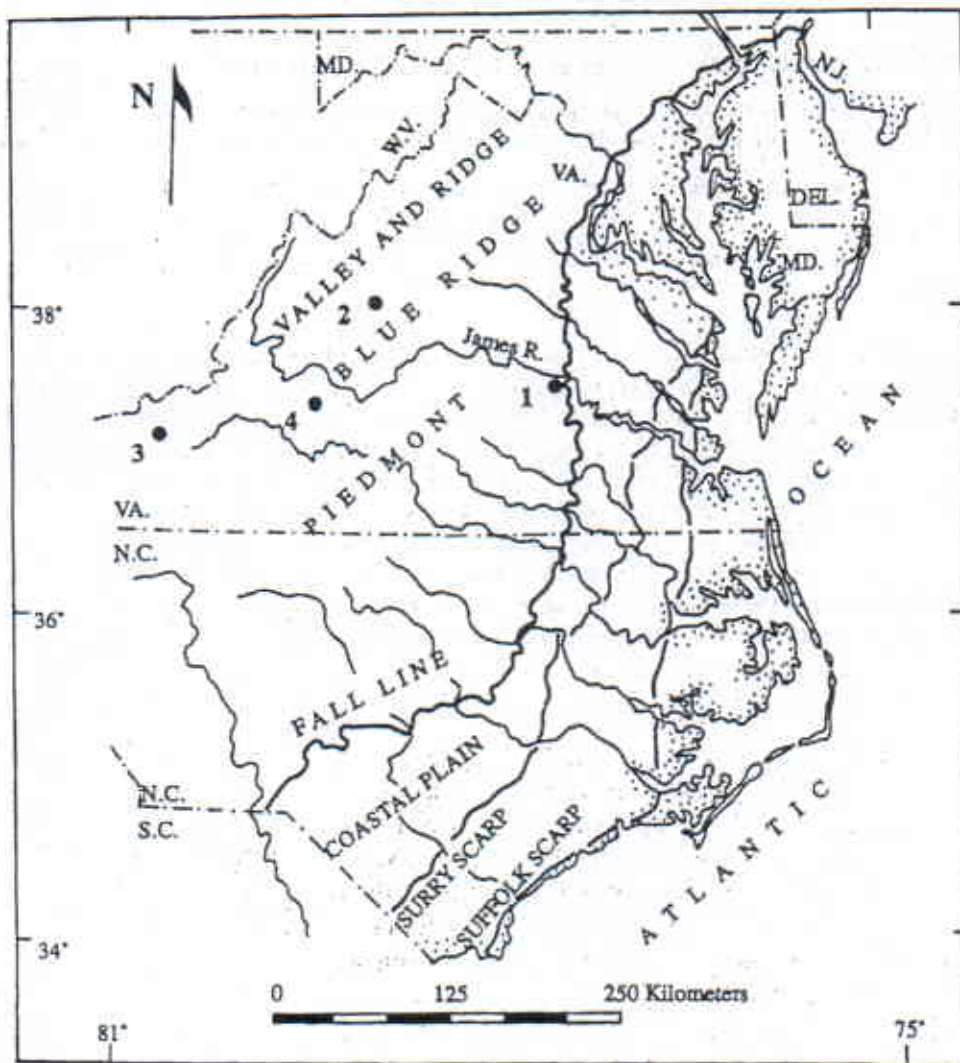


Fig. 1. Geological provinces of the southeastern United States, and locations of areas studied in Virginia: 1 = James River chronosequence; 2 = Shenandoah River chronosequence; 3 = New River chronosequence; 4 = alluvial soil grab sample.

quartz sand micromorphology in pre-Pleistocene soils of the southeastern United States.

Our study focused on the James River chronosequence (Fig. 1) because a large number of geomorphic surfaces is present, and stratigraphic relations with fossiliferous marine units provide some degree of chronostratigraphic control. We later expanded the study to include two other soil chronosequences, both located in the Valley and Ridge province, and an alluvial soil profile in the Blue Ridge, the goal being to investigate the effects of geographic variation. In this short paper, we evaluate some of the possible sedimentologic and geomorphic implications of quartz dissolution interpreted to be caused by prolonged chemical weathering.

2. Geological setting

Major geological provinces of the southeastern United States include the Blue Ridge and Piedmont provinces (Fig. 1), composed mainly of igneous and metamorphic rocks, and the Valley and Ridge province where sedimentary rocks predominate. The rocks in all these areas are severely deformed and principally of pre-Mesozoic age. The Coastal Plain province is composed of a seaward-thickening sequence of weakly deformed clastic sedimentary rocks and sediments of late Mesozoic to Holocene age that lap westward onto Piedmont basement rocks. Larger drainage systems generally flow eastward across the Piedmont and Coastal Plain provinces. At the eastern edge of the Piedmont, rapids in these streams define the Fall Line, which is sometimes taken as the Piedmont/Coastal Plain boundary. However, because Coastal Plain sediments extend west of the Fall Line in many places, the term Fall Zone is also commonly used for this gradational and ill-defined Piedmont/Coastal Plain boundary.

The Coastal Plain landscape is composed of gently east-sloping coastal terraces that descend progressively in elevation seaward. The highest geomorphic surfaces in the inner Coastal Plain and Fall Zone are clearly the oldest because they are the most deeply weathered and dissected. Weathering and relief decrease progressively eastward, and in the outer Coastal Plain, coastal terraces are bounded by well-

preserved northeast-trending scarps (Fig. 1) that mark the positions of middle and late Pleistocene paleoshorelines (Flint, 1966; Oaks and Coch, 1973). The coastal terraces and scarps are both entrenched by east-flowing streams flanked by fluvial terraces. Some of these fluvial terraces are colateral with Pleistocene coastal terraces and were formed as estuaries during high stands of sea level (Pebbles et al., 1984).

The old coastal terrace surfaces of the inner Coastal Plain and Fall Zone are generally underlain by gravelly surficial deposits of fluvial/deltaic origin that rest disconformably on nearshore marine rocks of Miocene and Pliocene age. Although it was suspected for many years that these deeply weathered upland gravel deposits were simply the upland nonmarine equivalents of fossiliferous marine Miocene and Pliocene rocks to the east (Hack, 1955), this was verified by direct fossil evidence only recently (McCartan et al., 1990). It now seems clear that these coastal terraces are formed on cyclic transgressive/regressive sequences, each culminating in deposition of gravelly nonmarine surficial deposits, that overall represent a progressive lowering of relative sea level during the late Cenozoic (Pazzaglia, 1993). Daniels et al. (1970, 1978) noticed that, although deeply dissected, interfluvial upland surfaces in the inner Coastal Plain and Fall Zone are often remarkably flat and apparently uneroded. Based on the ages of the underlying strata, they concluded that these must represent original depositional surfaces formed shortly after the end of sedimentation in Miocene and Pliocene time. These relations imply that the soils associated with such geomorphic surfaces are incredibly old, in comparison to most North American soils, perhaps reflecting as much as 13 Ma of pedogenesis.

The area studied most intensively here is located along the James River in the Fall Zone of central Virginia (Fig. 1). The river is at sea level, and tidal, as far west as the Fall Line; it is flanked by fluvial terraces that are contiguous with coastal marine terraces farther east. Above the fluvial terraces are interfluvial upland surfaces that are the dissected remnants of much older coastal terraces. In assigning ages to these landforms, and their associated soil landscapes, the following assumptions were made (see Howard et al., 1993 for further detail): (1) that

the flat upland surfaces are original depositional surfaces created when sedimentation ceased at the end of each successively lower regressive (progradational) cycle; and (2) that marine hiatuses mark times of sea level lowstands and thus exposure of each preceding depositional surface to subaerial weathering. Six allostratigraphic units are recognized (Table 1), three of pre-Pleistocene age. We also studied in reconnaissance one soil chronosequence along the New River (Fig. 1) in southwestern Virginia (Whitethorne area, Valley and Ridge province) described previously by Harris et al. (1980); and another along the Shenandoah River in northwestern Virginia (Elkton area, Valley and Ridge province) examined earlier by King (1949) and Hack (1965). The parent material for the soils in both areas is alluvium derived mainly from metasedimentary and mafic to felsic crystalline rocks in the Blue Ridge province. An old alluvial soil of similar provenance in the Blue Ridge of central Virginia (Bedford County) was also studied. The climate at all of these locations is humid-temperate.

3. Materials and methods

We studied five soils in the Fall Zone chronosequence: one representing each of the five pre-Holocene units of Table 1; soils from three different terraces in the New River chronosequence; three more from the Shenandoah River chronosequence; and one grab sample from the Blue Ridge locality. The -2 mm fraction of the B_2 horizon of each soil was dispersed in 10% NaHCO_3 solution, and the medium to fine sand fractions ($-0.5 + 0.06$ mm) collected by sieving. Iron-oxide grain coatings were removed by the dithionite–citrate–bicarbonate method (Mehra and Jackson, 1960), and the light fraction was then obtained by gravitational settling in bromoform. We also analyzed quartz in the medium to fine sand fraction of a disintegrating *Scolithus*-bearing quartzite clast obtained from the B_2 horizon of the soil developed on the oldest terrace studied along the Shenandoah River. This site was used because the source of the clast was definitely silica-cemented quartzites of the Chilhowee Group exposed in the nearby Blue Ridge province. The

quartzite clast was compared with an unweathered sample of Silurian quartzite from the Valley and Ridge province that was crushed and sieved to obtain the medium to fine sand fraction. Each sample consisted of about 100 gold-coated sand grains mounted on gold tape for analysis by scanning electron microscopy (SEM). Mineral identifications were verified with an EDAX unit. Soil terminology follows that currently used in the United States (Soil Survey Staff, 1975).

4. Quartz micromorphology in soil samples

Because our study was intended to be purely reconnaissance in nature, we simply looked over all of the grains in each sample using SEM without any attempt at quantifying their morphology. However, despite this obviously qualitative approach, the samples are so strikingly different that there is no doubt about the progressive nature of the weathering features observed (Table 1). While perusing each sample, we attempted to determine first the micromorphology of the average sort of quartz grain, and then that of what appeared to be the most severely weathered grain. We expected to always be able to find less weathered grains in any sample, having perhaps escaped dissolution in a location beneath some gravel-sized particle, but we anticipated that the greatest degree of weathering would be a function of age. We did not expect reworking of older grains to be a problem because study of heavy mineral suites in the Fall Zone samples had already showed that a continual influx of fresh detritus of Piedmont provenance occurred during deposition of the soil parent material (Howard et al., 1993).

Fig. 2A is a scanning electron micrograph showing some typical quartz sand grains in the youngest Pleistocene Fall Zone soil sample studied (Table 1, Qpt₂). The grains are very angular with smooth, fresh unetched conchoidal fracture surfaces. Silica 'plastering' is evident on the surfaces of some grains (Fig. 2B). These microscopic surface textures are characteristic of unweathered crystalline bedrock source materials (Krinsley and Doornkamp, 1973; Margolis and Krinsley, 1974; Mazzullo and Magenheimer, 1987). Quartz grains in the older Pleistocene

soil (Qpt₁) show more surficial etching and pitting (Figs. 2C and D), accompanied by reprecipitated silica, than the soil described above. Mechanically formed features have been totally obliterated, and the grains have been rounded slightly by chemical dissolution. Almost all of the grains in these two samples have the general appearances seen in the photos, although a few slightly more etched (reworked?) grains are present. The micromorphological features seen in these Pleistocene river terrace soils are like those reported previously for soils developed on Pleistocene coastal terrace landscapes of the outer Coastal Plain of Virginia (Coch and Krinsley, 1971). They also resemble quartz sand microtextures found

in Wisconsinan and Illinoian/Kansan glacial deposits of New Jersey (Douglas and Platt, 1977).

Figs. 2E and 2F are representative of the most severely weathered quartz grains found in the soil developed on Tug₃. The grains show chemical dissolution features far more extensive than those described above, but this is expected because there is a significant time gap between the pre-Pleistocene and younger soils (Table 1). The Tug₃ grains tend to be subrounded, their surfaces are completely altered by etching and pitting, and they have a distinctly platy morphology. The hexagonal or rhombic outline of some of the etch surfaces suggests a crystallographic control over dissolution. Smoother areas between

Table 1
Weathering characteristics of alluvial depositional geomorphic surfaces in the central Virginia Coastal Plain

Allostratigraphic units	Estimated age, 10 ³ years B.P.	Soil characteristics	Quartz micromorphology
<i>Pleistocene river terraces</i>			
Qpt ₂	60–120	Weak-moderately well developed, yellowish-brown light clay loam. Abundant weatherable minerals. Weak alteration of weatherable clast types.	Very angular grains with smooth unetched conchoidal fracture surfaces. Silica 'plastering'.
Qpt ₁	700–1600	Moderately well developed, reddish-brown, heavy clay loam. Greatly depleted in weatherable minerals. Strong alteration of clasts in upper 1 m.	Surficial etching and pitting. Abundant reprecipitated silica. Mechanically formed features totally obliterated.
<i>Pliocene–Miocene upland gravel units</i>			
Tug ₃	3400–5300	Strongly developed, dark reddish-brown clay. Stable mineral suite. Incipient plinthite, duripan and ferricrete development. Weatherable clasts depleted. Quartzite clasts intact with thin weathering rinds.	Strong grain rounding, solution pits interconnected by network of grooves and crevasses. Strong selective dissolution along planar crystal structures.
Tug ₂	10,800	Very strongly developed, red clay. Very stable mineral suite. Moderate-strong plinthite, duripan and ferricrete development. Some disintegrating quartzite clasts.	Large, deep solution cavities and channels. Large-scale grain decomposition.
Tug ₁	13,000	Exceptionally well developed red clay. Ultrastable mineral suite. Strong plinthite, duripan and ferricrete development. Most quartzite clasts disintegrating.	Very large-scale grain decomposition. Deep grooves and channels. Perforated grains permeated with tubes and holes. Bulk grain decomposition

