

The geomorphology, characteristics, and origin of the freshwater marl sediments in the Great Limestone Valley, Maryland, USA

J.N. Shaw^{a,*}, M.C. Rabenhorst^{b,1}

^a Department of Crop and Soil Science, University of Georgia, 3111 Miller Plant Sciences Bldg., Athens, GA 30602, USA

^b Department of Agronomy, University of Maryland, College Park, MD, USA

Received 26 April 1996; revised 20 December 1996; accepted 20 December 1996

Abstract

Certain calcareous soils occupying alluvial landscape positions in the Hagerstown (Great) limestone valley of western Maryland have developed from highly calcareous (60–100 g 100 g⁻¹) marl sediments of Holocene age. The limestone valleys of this region are located in the Ridge and Valley Province, which transcends the western portions of Maryland and Virginia. The sediments range from 0.5 m to over 8 m in depth. The soils developed from the marl have been mapped in the Great Valley in units named for the Warners series (fine-silty, carbonatic, mesic Fluvaquentic Haplaquolls) and the Massenetta series (fine-loamy, carbonatic, mesic Fluvaquentic Hapludolls) and typically have a high pH (7.5–8.5), low bulk density (1.00 g cm⁻³), and high porosity (0.5 to 0.6). The carbonate in the marl was developed through inorganic and biogenic processes. The marl was formed in ponds, as evidenced by the presence of certain gastropods, bivalves, algae, and the extremely high CaCO₃ content. The ponds are now extinct, but occurred in alluvial landscape positions during parts of the Holocene. Grain analyses and micromorphological evidence indicate that certain algae (*Chara sp.*) capable of accumulating carbonate internally and externally, were largely responsible for forming the marl. Periods of intermittent marl development are evidenced by the buried surface horizons within the marl sediments. The mechanisms responsible for damming and ponding of these alluvial landscapes were apparently destroyed, and then reformed prior to subsequent marl development. © 1997 Elsevier Science B.V.

Keywords: Marl; Ridge and valley; Travertine; Charophytes

* Corresponding author. Tel: (706) 542-0910; fax: (706) 542-0914. e-mail: Joeyshaw@uga.cc.uga.edu.

¹ Fax: (301) 433-1343; e-mail: MR1@umail.umd.edu.

1. Introduction

Marl has been defined as a 'soft, loose, earthy, material that consists of varying amounts of CaCO_3 , clay, and silt and is formed primarily in freshwater conditions' (Hubbard and Herman, 1990). Surficial freshwater marl deposits are found in the Ridge and Valley region in the mid-Atlantic portion of the United States (Fig. 1). The Great Limestone Valley (part of the Ridge and Valley province) transcends the western portion of Maryland and Virginia. Marl has been found adjacent to several major streams in the Hagerstown Valley (portion of Great Valley) of Washington County Maryland (Cloos, 1951) and along 60 streams in 18 counties in the Shenandoah Valley (portion of Great Valley) of Virginia (Sweet and Hubbard, 1990). The freshwater marl has been mined for liming materials in the Hagerstown and Shenandoah Valleys throughout the last century (Cloos, 1951). The majority of the marl-derived soils are utilized for row crops due to favorable soil nutrient and moisture conditions. When they are not adversely affected by seasonally high water tables, developmental pressure has led to the construction of shopping centers, parking lots, railroads, highways, and housing subdivisions on the marl sediments.

Several researchers have hypothesized modes and environments for the marl deposition. Workers in Virginia (French and Herman, 1990; Herman and Hubbard, 1990; McFarland and Sherwood, 1990; Mathews et al., 1965) have discussed the role of

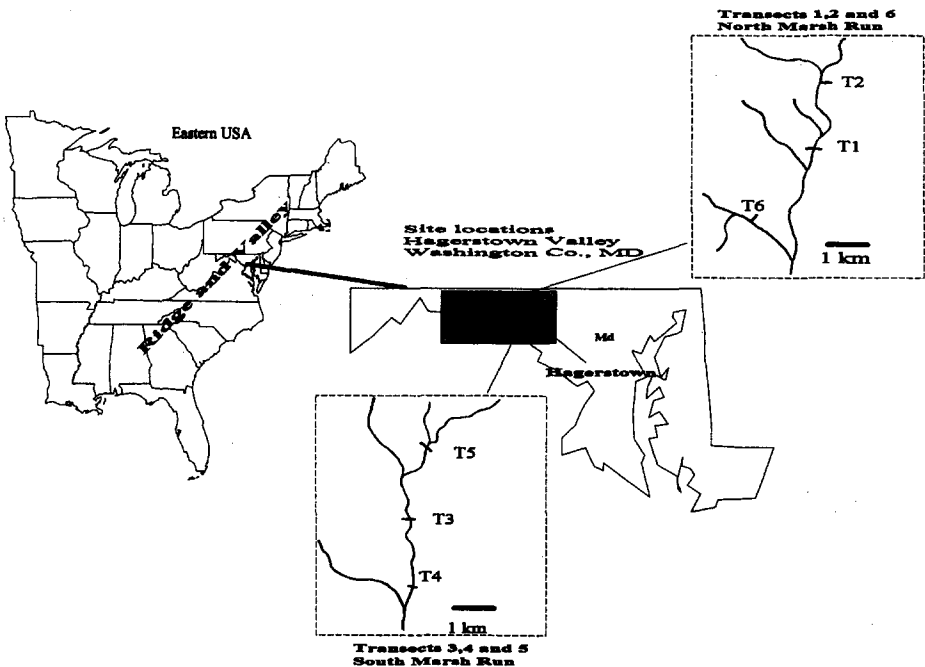
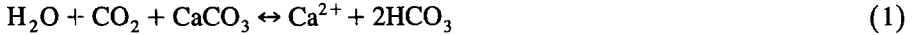


Fig. 1. Location of the Ridge and Valley Province in the eastern USA with inset showing the study sites in Maryland.

travertine formations in marl development. In the Mid-Atlantic portion of the Great Limestone Valley (Fig. 1), travertine is best described as freshwater carbonate deposits from supersaturated (with respect to CaCO_3) surficial (stream) waters (Hubbard and Herman, 1990). Travertine is formed from the out-gassing of CO_2 in turbulent portions of stream water, and initiating the precipitation of CaCO_3 :



The formation and presence of travertine deposits in streams today has been documented in portions of the Great Limestone Valley (Kirby and Rimstidt, 1990).

Investigators have hypothesized that the marl has developed: (1) from the formation of travertine dams and the gradual accumulation of carbonate sediments upstream from these buildups (Hubbard and Herman, 1990); (2) as alluvium from the wash down of carbonate materials from travertine formations (Mathews et al., 1965); or (3) from accumulations of secondary calcite in pre-existing marl or other (non-calcareous) alluvial sediments through desiccation (McFarland and Sherwood, 1990). It has been documented that travertines have been responsible for damming stream channels in karst environments in Spain and Turkey, forming pools containing carbonate components which can be attributed to vegetation (Charophytes and Miriophilaceae) developing over clastic sediments on the bottom (Julia, 1983).

Archeological studies have produced evidence that landscape positions containing marl in Washington County, Maryland, were once inundated and ponded for significant periods during the Holocene. Curry and Custer (1982) have found aboriginal artifacts circumscribing marl beds (pond-edge type settlement) in the Hagerstown Valley (dated at approximately 6500 BP–3700 BP). Curry and Stewart (1986) described stages of pond and marl development in Maryland using archeological evidence. Archeological work on marl sites in Virginia disclosed artifacts in two separate locations (dated approximately at 9200 BP to 8800 BP) that were related to a pool-water type settlement, with evidence of post marl formation settlements also being present (Gardner, 1990).

Biotic constituents are known to comprise significant portions of marl, which by definition, is a limnic material (Soil Survey Staff, 1994). The role of algal activity in marl development, however, is not completely understood. Algae are known to trigger precipitation of calcite by removing CO_2 from the aqueous environment and initiating calcite precipitation (Pentecost, 1984 and Pentecost, 1990). Algae also can initiate marl formation by trapping precipitated calcite particles, by providing substrates upon which precipitation can occur, and by providing nucleation sites for already precipitated calcium carbonate (Pentecost, 1990). The green algae *Chara sp.* is responsible for large amounts of carbonate deposition in certain lacustrine environments (Scholle et al., 1983). The Charophytes initiate CaCO_3 formation externally by the photosynthetic removal of CO_2 , and can also metabolically form large amounts of internal CaCO_3 within their cells (Scholle et al., 1983). Much of the calcite is not 'recognizable as biological remains, although the calcareous cortication tubules are sometimes preserved in low-energy environments' (Scholle et al., 1983). The reproductive organs (oogonia-displaying a radial fibrous calcite) and stems (thalli) of the Charophytes are often calcified with low-Mg calcite (Bathurst, 1971). Often, the thalli will act as nucleation sites for additional precipitated CaCO_3 to form and give rise to oncolitic (sub-rounded)

forms, which are visible and characteristic of these types of sediments (Scholle et al., 1983). The presence of *Chara sp.* year after year in hard, freshwater lakes, can often result in large amounts of marl being precipitated (Smith, 1933).

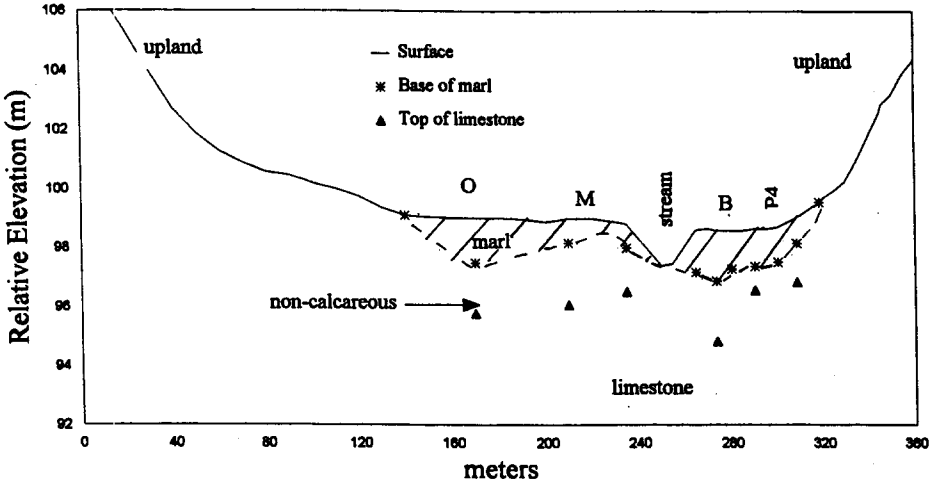
The objectives of this project were to: (1) to describe and characterize the marl deposits; and (2) to determine the mode of origin of the marl sediments in the Great Limestone Valley of Maryland.

2. Materials and methods

Soil map units of marl-derived soils (Warners soil series; fine-silty, carbonatic, mesic Fluvaquentic Haplaquolls) were transferred onto 1:24 000 USGS topographical quadrangles to relate the delineations to topographic position. This region is dominantly underlain by argillaceous limestones of Ordovician and Silurian age. The marl units in Washington County, MD, are located on the Mason-Dixon, Hagerstown, Williamsport, Keedysville and Funkstown quadrangle maps. A reconnaissance survey of the map units was conducted to: (1) determine the nature of the soils and underlying sediments; (2) identify the topographic position; and (3) locate potential areas for further study. Efforts were largely concentrated in Washington County, with investigative work also undertaken in adjacent counties of West Virginia and Virginia. Following these efforts, six representative study sites were selected (Fig. 1). Four (presented here) topographical transects (Transects 1, 3, 4 and 6) were established on these study sites, and were oriented perpendicular to the present-day channel flow (across the floodplain). Topographic Transects 1, and 6 (Fig. 2) were located just north of Hagerstown, MD (Fig. 1) on North Marsh Run. Transects 3 and 4 (Fig. 3) were located south of Hagerstown, MD (Fig. 1) on South Marsh Run, near the town of Lappans, MD. Relative elevation was determined along each transect using a rod and a surveyor's level, and deep borings were made along the transects for soil descriptions, samples, and to document stratigraphic relationships. Soil samples were air dried, crushed, and sieved through a 2 mm mesh. An ELE International Model MD-11 portable seismograph was utilized on Transects 1, 3, 4, and 6 to determine depths to bedrock beneath the alluvial sediments. Transect 1 (contains Pedon #P4) and Transect 6 (contains Pedon #P2) were selected for intensive observations and discussion.

Organic C was determined using dry combustion (Rabenhorst, 1988), and total C was determined using a LECO model CHN600 Carbon Analyzer (LECO Corp., St. Joseph, MI). Inorganic C was computed by taking the difference between organic and total C, and this value was converted to CaCO_3 equivalent using the stoichiometry of calcite. At selected points, non-carbonate residue was collected following the procedure of Rabenhorst and Wilding (1984). Particle size distribution (PSD) was determined utilizing a modification of the pipette method (Gee and Bauder, 1986). Carbonate-free clays and silts were separated by centrifugation for X-ray diffraction analysis (XRD). Clay specimens were oriented using the method of Drever (1973), and were examined using XRD following these treatments: Mg saturation/ glycerol solvation @ 25°C, K saturation @ 25°C, 300°C, and 550°C. Silt fractions were examined from random powder mounts utilizing double stick tape on glass slides. All XRD analyses were conducted

(a) Topographic Transect 1 (P4)
Marsh Run



(b) Topographic Transect 6 (P2)
North Marsh Run

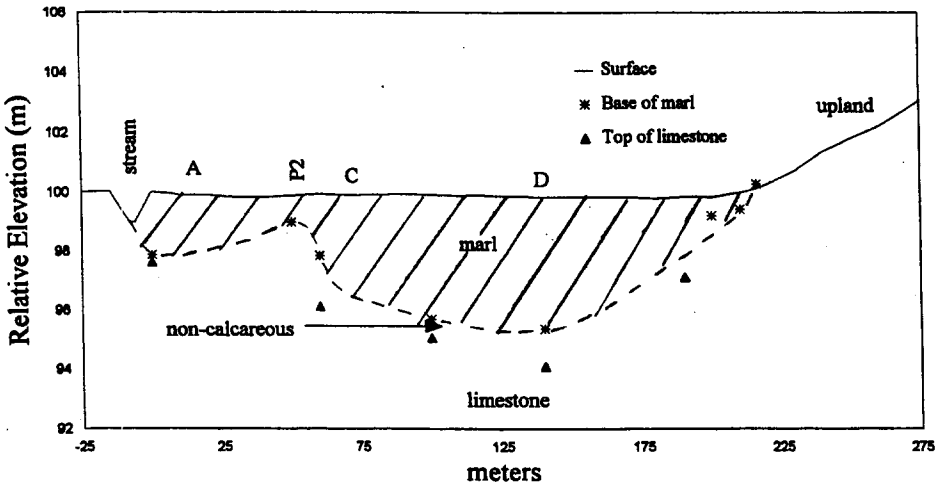


Fig. 2. Topographic Transects 1 (a) and 6 (b) across floodplain (North Marsh Run; Washington County, MD) showing the lower depths of marl and the depth to the top of the bedrock. P4 is on Transect 1, P2 is on Transect 6.

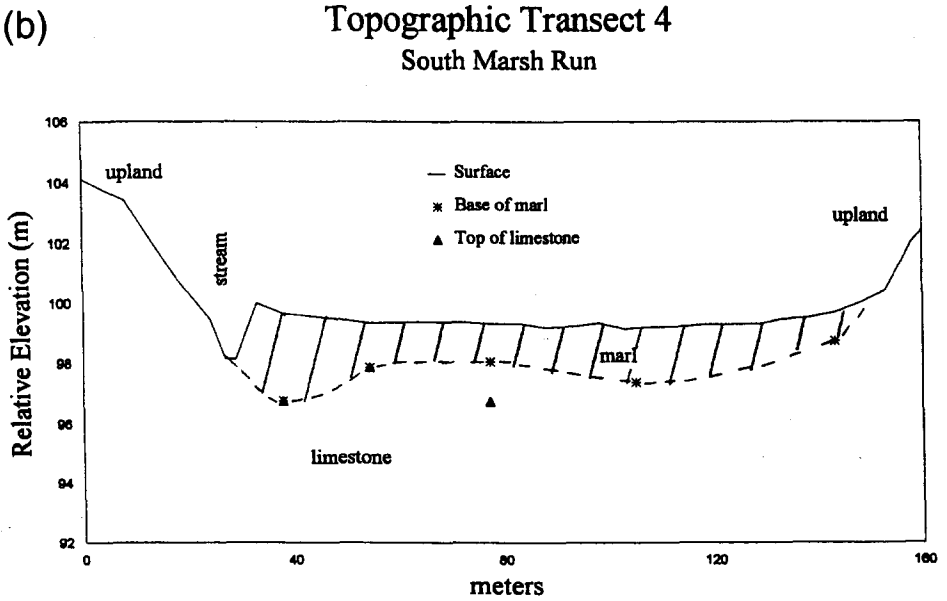
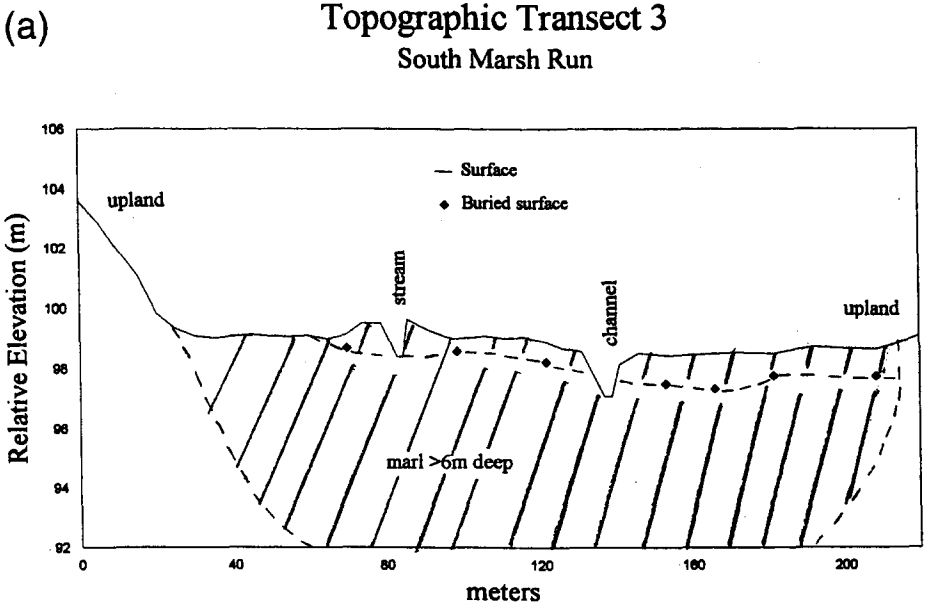


Fig. 3. Topographic Transects 3 (a) and 4 (b) across floodplain (South Marsh Run; Washington County, MD) showing the lower depths of marl, a continuous buried surface in Transect 3, and the depth to the top of the bedrock. P1 is on Transect 3.

using a Philips unit (Philips Electronic Instruments, Inc. Mahwah, NJ) with $\text{CuK-}\alpha$ radiation, and a graphite monochromator with a θ compensating slit, operated at $2^\circ 2\theta \text{ min}^{-1}$. Minerals were semi-quantitatively measured by comparing relative peak heights.

Uncrushed whole soil samples were chemically dispersed, and medium (0.25–0.5 mm), coarse (0.5–1 mm), and very coarse sands (1–2 mm), and gravels (> 2 mm) were collected. Grain counts were conducted on the fractionated carbonate particles to differentiate biogenic from inorganic carbonate forms, and to provide information on the carbonate depositional modes. Oriented soil clods were air dried, impregnated with a polyester resin under vacuum, and then hardened using a 5 Mrad dose of γ radiation prior to the preparation of thin sections. A wood sample was collected from a point in Transect 1 for ^{14}C dating to more accurately determine the age of the sediments.

3. Results and discussion

3.1. Marl geomorphology

Marl delineations occur on the Conococheaque and Rockdale Run limestone formations with smaller delineations occurring over the Elbrook and Stonehenge limestones. Therefore, groundwaters are saturated with respect to CaCO_3 . The marl sediments mainly occupy floodplain positions, some of which are in the annual floodplains, while others are in positions less frequently inundated. The marl sediments are typically 1–2 m in thickness (Fig. 2 and Fig. 3), but some delineations showed much deeper sediments (> 6 m). The marl sediments become thinner at the upstream and downstream margins of the marl delineation, where they grade into non-calcareous alluvium. The alluvial soils found adjacent to these marl beds are non-calcareous floodplain soils typical for the region. From the interior proceeding perpendicular toward the adjoining uplands, the marl sediments become thinner as the surface elevation begins to rise onto adjacent upland slopes (Fig. 2 and Fig. 3). The sediments extend across these alluvial valleys, where they intercept footslope positions of adjoining uplands.

In general, Transect 1 has marl sediments between 1–2 m, with sections along Transect 6 being deeper (Fig. 2 and Fig. 3). The thickness of marl observed in these sites was representative of most marl sites studied (90%), but a few of the sites contained marl sediments which are > 6 m in thickness. Transect 3 was in an area known to have unusually thick marl deposits and seismographic data showed that the sediments along this transect are typically 5–6 m thick. The marl delineations range in size from as small as one hectare, to as large as 50 ha. Some of the delineations exist as isolated units, while in other cases the marl delineations extend for several km along the drainage ways of streams.

In most cases, the marl is underlain by non-calcareous alluvium, but in a few delineations ($\approx 5\%$), it is underlain by bedrock (< 2 m). When moderately shallow bedrock (0.5 to 1 m) was observed, the marl sediments were more poorly drained (seasonally high water tables).

Table 1

The C content of sampling sites along Transects 1 and 6 with letters corresponding to the location of sampling points. Notice the extremely high CaCO_3 content of the sediments, as well as the irregular increases in Organic C indicative of intermittent periods of marl genesis

| Site | Hor. | Depth (cm) | CaCO ₃ (Org C) | | Site | Hor. | Depth (cm) | CaCO ₃ Org C | |
|------|------|---------------|---------------------------|------|------|------|---------------|-------------------------|------|
| | | | (g per 100 g) | | | | | (g per 100 g) | |
| T1B | Ap | 0–20 | 62.4 | 3.12 | T6A | Ap | 0–36 | 74.3 | 3.09 |
| | Bk | 20–45 | 74.5 | 1.96 | | A | 36–67 | 78.8 | 1.53 |
| | Ab1 | 45–65 | 81.5 | 3.05 | | Bk1 | 67–102 | 86.6 | 0.78 |
| | Ab2 | 65–75 | 83.0 | 4.13 | | Bk2 | 102–139 | 88.3 | 0.68 |
| | AB | 75–88 | 79.6 | 1.32 | | Bk3 | 139–174 | 85.4 | 0.53 |
| | Bkg | 88–125 | 75.5 | 1.10 | | Bk4 | 174–208 | 67.5 | 0.70 |
| | 2BC1 | 125–145 | 45.5 | 0.97 | | 2BC | 208–240 | 32.1 | 0.53 |
| | 2BC2 | 145–160 | 0.3 | 0.36 | | 2C1 | 240–265 | 11.8 | 0.25 |
| | 3C1 | 160–185 | 0.0 | 0.46 | | 2C2 | 265–320 | 2.7 | 0.10 |
| T1M | Ap | 0–19 | 63.1 | 3.20 | T6C | Ap | 0–29 | 82.6 | 2.46 |
| | Bkg1 | 19–44 | 76.6 | 1.27 | | Bk1 | 29–56 | 96.3 | 1.05 |
| | Bkg2 | 44–69 | 76.5 | 1.13 | | Bk2 | 56–102 | 97.5 | 0.81 |
| | Ab | 69–80 | 6.7 | 1.95 | | Bk3 | 102–170 | 99.9 | 0.46 |
| | 2Bg1 | 80–102 | 1.8 | 0.52 | | Ck1 | 170–253 | 100 | 0.26 |
| | 2Bg2 | 102–137 | 0.4 | 0.17 | | Ck2 | 253–320 | 99.4 | 0.21 |
| | 2C1 | 137–183 | 0.5 | 0.13 | | | | | |
| T1O | Ap | 0–30 | 49.3 | 2.89 | T6D | Ap | 0–38 | 81.6 | 1.62 |
| | Bkg1 | 30–58 | 82.8 | 1.31 | | AB | 38–64 | 93.4 | 0.91 |
| | Bkg2 | 58–75 | 84.7 | 0.78 | | Bk1 | 64–122 | 97.2 | 0.52 |
| | Bkg3 | 75–97 | 86.5 | 0.52 | | Bk2 | 122–182 | 99.2 | 0.29 |
| | Cg1 | 97–127 | 84.1 | 0.42 | | Bk3 | 182–216 | 97.9 | 0.30 |
| | Ab | 127–152 | 72.2 | 0.62 | | Ck1 | 216–267 | 93.5 | 0.32 |
| | 2Bwg | 152–220 | 31.9 | 0.21 | | Ck2 | 267–323 | 93.2 | 0.44 |
| | | | | | | Ab | 323–340 | 75.1 | 0.49 |

3.2. Composition of marl

Slightly lower amounts of CaCO_3 are common in the surface horizons of these soils. The lower amounts of CaCO_3 in the surface horizons (Tables 1 and 2) are thought to be due to the relatively high solubility of CaCO_3 , the more intensive chemical weathering in this zone, and modern contributions of non-calcareous alluvial sediments. The high carbonate content of the sediments deeper in the profile is evident from Tables 1 and 2. The soils in Transect 6 contain from 75 to 100 g 100 g⁻¹ CaCO_3 , with Transect 1 being slightly less calcareous (50–80 g 100 g⁻¹ CaCO_3) overall (Table 1). Data from other transects confirm the high carbonate content of the marl sediments in several other locations in the region. The lower quantities of CaCO_3 in marl-derived soils of Transect 1 may indicate that a greater quantity of non-calcareous sediment was eroding from uplands during the period of marl deposition. The slope of the adjacent uplands above the marl is steeper in Transect 1 than Transect 6 (Fig. 2 and Fig. 3), and this could cause the soils to contribute more non-calcareous colluvial materials during marl deposition.

Table 2
PSD, C content, ρ_b , and molar Mg/Ca ratios for the carbonate marls in P2 and P4

| Sample | Horizon | Depth (cm) | Sand (g kg ⁻¹) | Silt (g kg ⁻¹) | Clay (g kg ⁻¹) | CaCO ₃ (%) | Org. C (%) | Mg/Ca ratios (%) | ρ_b (g cm ⁻³) |
|--------|---------|------------|----------------------------|----------------------------|----------------------------|-----------------------|------------|------------------|--------------------------------|
| P2 | | | | | | | | | |
| | Ap | 0–29 | 218 | 451 | 331 | 77.2 | 3.42 | 0.6 | 1.28 |
| | Bk | 29–66 | 528 | 262 | 210 | 87.7 | 1.41 | 0.5 | 1.01 |
| | BC | 66–95 | 385 | 441 | 174 | 88.4 | 0.93 | 0.5 | 1.10 |
| | C1 | 95–128 | 326 | 494 | 179 | 86.1 | 0.92 | 0.6 | 1.07 |
| | C2 | 128–168 | 298 | 522 | 181 | 81.8 | 0.88 | 0.6 | 1.42 |
| | 2C3 * | 168–205 | 240 | 551 | 209 | 46.1 | 0.63 | 0.7 | 1.40 |
| | 2C4 * | 205–230 | 214 | 487 | 298 | 2.5 | 0.32 | - | 1.61 |
| | 2C5 * | 230–272 | 167 | 435 | 398 | 0.8 | 0.23 | - | 1.53 |
| | 2C6 * | 272–338 | 118 | 378 | 505 | 0.7 | 0.20 | - | 1.20 |
| P4 | | | | | | | | | |
| | Ap1 | 0–25 | 208 | 678 | 114 | 59.0 | 3.37 | 0.6 | 1.15 |
| | Ap2 | 25–41 | 297 | 571 | 132 | 66.6 | 1.52 | 0.5 | 1.19 |
| | Bk1 | 41–55 | 515 | 413 | 72 | 76.1 | 1.12 | 0.5 | 1.14 |
| | Bkm | 55–62 | 628 | 312 | 59 | 83.0 | 0.99 | 0.4 | na |
| | Ab1 | 62–90 | 217 | 704 | 78 | 82.5 | 2.83 | 0.5 | 1.05 |
| | Bkb1 | 90–110 | 516 | 422 | 62 | 82.0 | 0.79 | 0.4 | 1.27 |
| | Ab2 | 110–117 | 425 | 458 | 117 | 69.4 | 0.86 | 0.4 | 1.25 |
| | Ckg1 | 117–160 | 620 | 303 | 77 | 67.4 | 0.88 | 0.5 | 1.28 |
| | 2Ckg2 * | 160–195 | 157 | 608 | 235 | 3.6 | 0.23 | 0.4 | 1.67 |
| | 2Cg1 * | 195–240 | 213 | 548 | 239 | 1.2 | 0.25 | 0.5 | 1.61 |
| | 2Cg2 * | 240–280 | 270 | 481 | 249 | 5.2 | 0.00 | 0.6 | - |

* Denotes horizons which are non-calcareous, and thus the particle size data are for carbonate free soils.

Buried surface horizons were recognized morphologically by darker values (blackier colors), which is indicative of greater organic C content in these horizons. Organic C data confirm that these horizons are in fact slightly higher in organic C content (Tables 1 and 2). These horizons represent stable surfaces where vegetation grew during periods between marl development, and lead to a higher organic C content in these zones.

The high carbonate content of the marl sediments (> 95 g 100 g⁻¹ in some cases) precludes secondary carbonate formation within a non-calcareous matrix as the mode of marl formation for there would be a much greater non-calcareous component present. The presence of buried surfaces within the marl indicates that the carbonate accumulation was intermitted by periods of stable land surfaces.

3.3. Physical and chemical properties of the marl sediments

The marl deposits are dominantly silty (2–50 μm) in nature, with coarser strata sometimes present (Table 2). Carbonate sediments derived from *Chara sp.* tend to be fine grained and undifferentiated (Scholle et al., 1983), and these sediments exhibit this characteristic. In most of the calcareous sediments examined, the bulk density ranged from 1.08 g cm⁻³ to 1.39 g cm⁻³, with calculated porosities (n) between 0.60 and 0.49

($\rho_{s \text{ calcite}} = 3.00 \text{ g cm}^{-3}$). The marl portions of Pedon P2 had bulk densities that ranged from 1.01 g cm^{-3} to 1.28 g cm^{-3} , but the underlying non-calcareous material had a higher bulk density (approximately 1.50 g cm^{-3}) (Table 2). Underlying non-calcareous sediments in P4 had bulk densities near 1.60 g cm^{-3} , while bulk densities in the marl horizons ranged between 1.05 g cm^{-3} and 1.28 g cm^{-3} ($n = 0.60$ and 0.56 respectively) (Table 2). The porous nature and low density of the marl sediments is evident. Presumably, some of the carbonate has weathered out in the present day humid environment of this region, resulting in more porous carbonate sediments. However, much of the marl sediments (especially deeper in the sediments) do not show alteration (weathering) of carbonate forms (discussed below), thus the differences between the bulk densities of these marl soils and the underlying non-calcareous alluvium implies that these two sediments were deposited through different modes.

The carbonate in the marls was comprised of low Mg calcite (< 1 mole%) (Table 2). Molar Mg/Ca ratios collected from the Washington Co., MD. marls are similar to the marls investigated in Augusta County, VA (0.0025 to 0.0505) (McFarland and Sherwood, 1990). McFarland and Sherwood (1990) reported that these values are low for certain algal precipitated calcite. However, these values are similar to calcite precipitated by *Chara sp.* (Scholle et al., 1983).

3.4. Non-carbonate residue analyses

The residues were dominantly fine textured in all pedons (Fig. 4 and Fig. 5). The particle sizes of the underlying non-calcareous sediments are also shown for comparison. The predominance of silt and clay particles indicates that the non-calcareous compo-

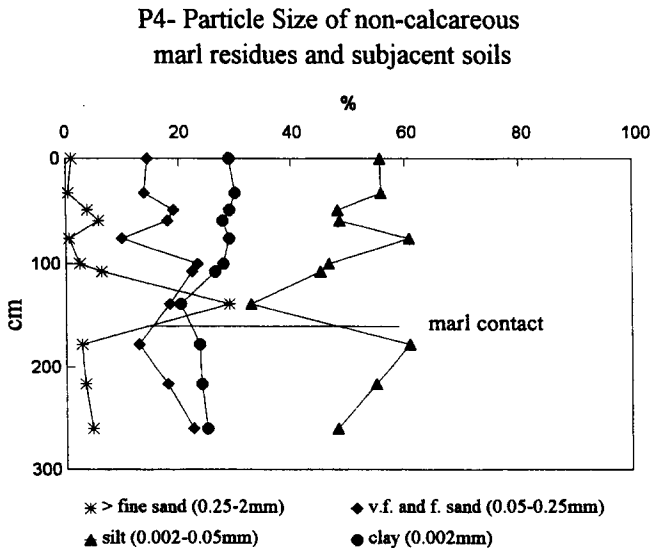


Fig. 4. PSD of P4 for the carbonate-free marl residues through the underlying non-calcareous soils. The marl/underlying sediment contact is shown.

P2- Particle Size of non-calcareous marl residues and subjacent soils

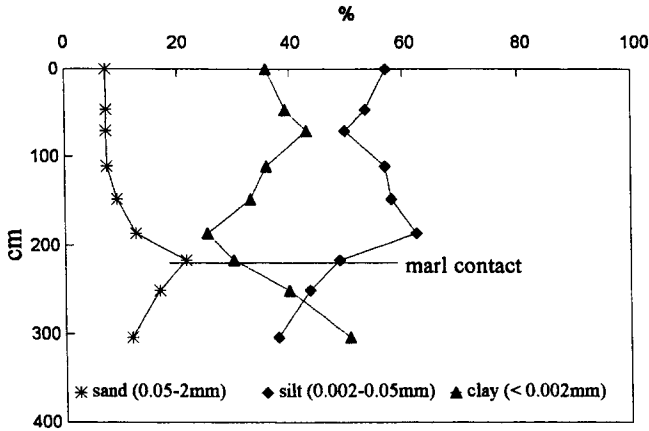


Fig. 5. PSD of P2 for the carbonate-free marl residues through the underlying non-calcareous soils. The marl/underlying sediment contact is shown.

nents of the marl were deposited under a low-energy environment. The source of the non-carbonate component of the marl sediment could either be alluvial material carried by the adjacent stream, colluvial (eroded) materials from the adjacent upland slopes, or aeolian sediments deposited during the period of marl accumulation. There is however, no clear evidence to exclude any of these sources. P4 is somewhat coarser than the other pedons, but this could be due to closer proximity to the channel flow during the period of marl deposition (Fig. 4). Because the sand in P4 consists mainly of very fine and fine sand, there may not be much of a depositional energy difference between this pedon and the other three pedons. The increase in sand content near the bottom of the marl in P4 indicates the zone where the coarser sediments settled during marl deposition. This is also evident in P2 (Fig. 5). The clay increase (relative to silt and sand) in the underlying soils on P2 may indicate more of a limestone residuum influence, as residuum from the argillaceous limestones tend to be high in clay (i.e. Hagerstown series: fine, mixed, mesic Typic Hapludalf) (Fig. 5).

The mineralogy of the residue clay from P2 and P4 (Table 3), as well as all sampled pedons, is very similar to the clay fractions of the Hagerstown soil (Rabenhorst et al., 1991; Johnson and Chu, 1983), the dominant soil series mapped in the uplands adjacent to the marl deposits. Kaolinite and quartz are the dominant minerals in all of the residues, with lesser amounts of mica, vermiculite, and chlorite and trace amounts of smectite and feldspars (Table 3). The mineralogy of the residues for all sampled pedons is similar. These particles have apparently been eroded from surrounding landscapes, and deposited into the marl sediments during periods of marl accumulation. The silt-size particles in P2 are dominantly composed of quartz and feldspars (orthoclase) with lesser amounts of mica and hornblende. The large quantity of feldspar in this fraction was of interest, but it is noted that Hagerstown soils contain high quantities of K-feldspars in

Table 3

Clay mineralogy of the silicate marl residues for P2 and P4, and silt mineralogy for P2

| Sample | Depth (cm) | kao | mica | verm | qtz | chl | smec | feld | qtz | feld | horn | mica |
|--------|---------------|------|------|------|-----|-----|------|------|------|------|------|------|
| | | Clay | Silt | | | | | | | | | |
| P2 | | | | | | | | | | | | |
| Ap | 0–29 | XX | XX | t | XX | XX | X | X | XXX | XXX | X | X |
| Bk | 29–66 | XX | XX | t | XX | XX | X | X | XXX | XXX | - | - |
| BC | 66–95 | XX | XX | t | XX | X | X | X | XXX | XXX | - | - |
| C1 | 95–128 | XX | XX | X | XX | X | X | X | XXX | XX | - | X |
| C2 | 128–168 | XX | XX | X | XX | X | X | X | XXX | XX | X | - |
| 2C3 | 168–205 | XX | XX | X | XX | X | X | X | XXXX | XX | - | - |
| 2C4 | 205–230 | XXX | XX | X | XX | X | X | - | XXX | XX | - | X |
| 2C5 | 230–272 | XXX | XX | X | XX | - | - | - | XXX | XXX | X | - |
| 2C6 | 272–338 | XXX | XX | X | XX | - | - | - | XXX | XXX | X | X |
| P4 | | | | | | | | | | | | |
| Ap1 | 0–25 | XX | XX | XX | XX | X | - | - | | | | |
| Ap2 | 25–41 | XXX | XX | XX | XX | X | - | - | | | | |
| Bk1 | 41–55 | XXX | X | XX | XX | X | - | - | | | | |
| Bkm | 55–62 | XXX | XX | X | XX | X | - | - | | | | |
| Ab1 | 62–90 | XXX | XX | X | XX | X | - | - | | | | |
| Bkb1 | 90–110 | XXX | X | X | XX | XX | t | - | | | | |
| Ab2 | 110–117 | XXX | X | XX | XX | X | t | - | | | | |
| Cg1 | 117–160 | XX | X | XX | XX | X | t | - | | | | |

t: trace; X < 10%, XX: 10–30%; XXX: 30–70%; XXXX > 70%. kao: kaolinite; verm: vermiculite; chl: chlorite; smec: smectite; qtz: quartz; feld: feldspar.

the silts, along with quartz and mica (Rabenhorst et al., 1991; Johnson and Chu, 1983). Therefore, due to the high amounts of feldspars in the adjacent soils, feldspars are abundant in the marls.

3.5. Macromorphic carbonates

Characterization of macromorphic carbonate forms was undertaken to gain information on the depositional environment of the sediments. In the upper portions of the pedons, many of the carbonate forms had been calcified to the extent that the original forms were not identifiable, as in Fig. 6. These carbonate forms have been affected by pedogenic alteration (dissolution or precipitation) of original carbonate forms. This is especially true at shallower depths (< 1 m) in the profile where carbonate could precipitate during alternating wetting and drying episodes. For example, the degree of secondary calcification of the carbonate forms in P2 is more extensive in the upper horizons of the profile than the lower horizons. This alteration gives rise to more undifferentiated, smooth-surfaced, nodular forms of carbonate in the shallower horizons (Fig. 7). The quantity of regular, smooth-surfaced oncolitic forms (indicative of pedogenic alteration) in the very coarse sand decreases from 56.0% in the Ap horizon to 2.3% in the C2 horizon. In contrast, the irregular, rough-surfaced oncolitic forms



Table 4

Quantity of coarse grained (> 0.25 mm) carbonate components in the horizons of the two pedons P2 and P4

| Sample | Horizon | Depth (cm) | Med. sand | Co. sand | V.c. sand | Gravel | Total |
|--------|---------|---------------|-----------------------|------------|-----------|--------|-------|
| | | | 0.25–0.5 mm (%) | 0.5–1.0 mm | 1–2 mm | > 2 mm | |
| P2 | Ap | 0–29 | 1.9 | 3.9 | 6.2 | 4.0 | 16.0 |
| | Bk | 29–66 | 2.1 | 3.9 | 4.3 | 2.8 | 13.1 |
| | BC | 66–95 | 3.1 | 5.0 | 4.4 | 1.9 | 14.4 |
| | C1 | 95–128 | 2.3 | 3.4 | 2.4 | 1.3 | 9.4 |
| | C2 | 128–168 | 2.3 | 3.7 | 2.5 | 3.1 | 11.6 |
| | 2C3 | 168–205 | 1.8 | 3.1 | 2.6 | 6.6 | 14.1 |
| | 2C4 | 205–230 | 1.0 | 1.8 | 2.7 | 9.0 | 14.5 |
| | 2C5 | 230–272 | 1.2 | 2.2 | 2.5 | 3.8 | 9.7 |
| P4 | Ap1 | 0–25 | 1.0 | 1.2 | 0.7 | 0.2 | 3.1 |
| | Ap2 | 25–41 | 1.6 | 1.5 | 0.3 | 0.2 | 3.6 |
| | Bk1 | 41–55 | 4.4 | 10.6 | 5.2 | 6.2 | 26.4 |
| | Ab1 | 62–90 | 2.1 | 4.1 | 2.6 | 0.5 | 9.3 |
| | Bkb1 | 90–110 | 4.4 | 10.0 | 8.5 | 2.4 | 25.3 |
| | Ab2 | 110–117 | 3.8 | 7.0 | 4.3 | 3.7 | 18.8 |
| | Ckg1 | 117–160 | 4.5 | 10.8 | 13.2 | 23.5 | 52.0 |
| | Ckg2 | 160–195 | 0.3 | 0.8 | 1.0 | 1.5 | 3.6 |

increase in the very coarse sand fraction from 2.7% in the Ap horizon to 30.3% in the C2 horizon (Fig. 7). Similar trends were also evident in several other size classes.

P2 possesses a fairly uniform quantity of coarse fragments throughout most of the profile while P4 contains more coarse carbonate forms than the other pedons (Table 4). P4 contains a horizon (Bkm 55–62 cm) which is strongly cemented, a feature documented in several other sampled pedons. Because of this, coarse fragment analysis of this horizon was not done. Some of these cemented zones possess carbonate shapes and algal constituents which resemble actively forming stream travertine, which display similar carbonate morphology and algal constituents.

Grain counts were conducted on the medium (0.25–0.5 mm) and very coarse sand (1.0–2.0 mm) sized carbonates. The constituents of the medium sands were very similar to the very coarse sands, thus only the very coarse sands will be discussed. Two of the dominant molluscs (gastropods) were *Lymnaea palustris* (freshwater gastropod: Swamp Pond Snail) and *Gyraulus sp.* (gastropod—Ram's Horn Snail), and were given special attention as indicators of a particular depositional environment because these species are known to inhabit ponded or low energy environments (Emerson and Jacobsen, 1976). *Lymnaea palustris* had also been documented as being common in marl sediments in Frederick County, VA (Giannini, 1990). Many other types of bivalves and snails were unidentifiable as species, and were classified together. Nodules were classified as 'oncolitic' (rounded or peanut shaped) forms, and these were either regular (oval) or irregular (mammillated) shaped with both smooth and rough surfaces. Oncolitic forms are common in *Chara sp.* deposited marls (Scholle et al., 1983). Tubules were separated



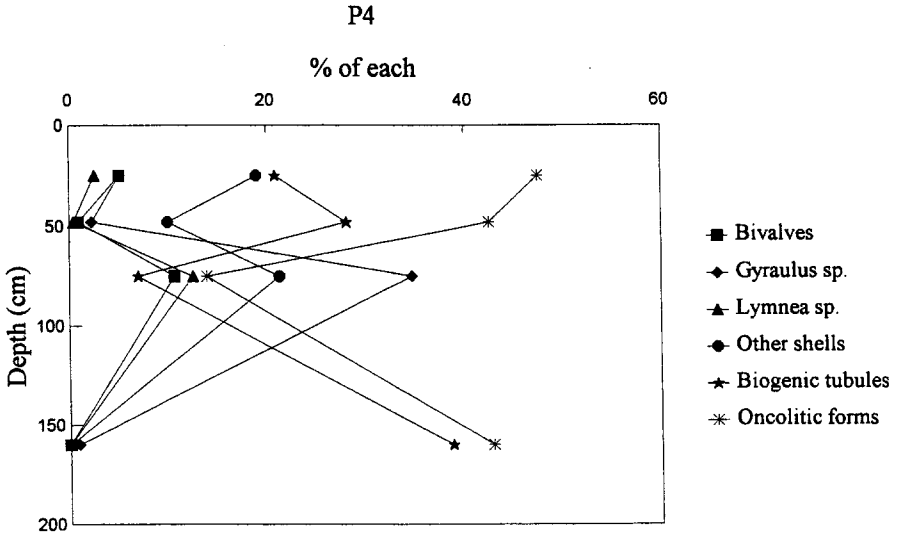


Fig. 9. Grain counts of biogenic components in the very coarse sand (1–2 mm) fraction of Pedon P4.

(algal forms), which was the largest quantity observed in this pedon. A photomicrograph from P1 (3.0 m) displays cross-sections from multiple thalli and stems of *Chara sp.* (Fig. 11). There were also a large number of the algal forms in the Bkm (55–62 cm) horizon of P4 (10%). An interesting observation in P4 was a zone of relatively unaltered algal constituents in horizon 2Ckg2, directly above the marl-clay contact. This observation coincides with trends showing less alteration of the carbonate forms with increasing depth.

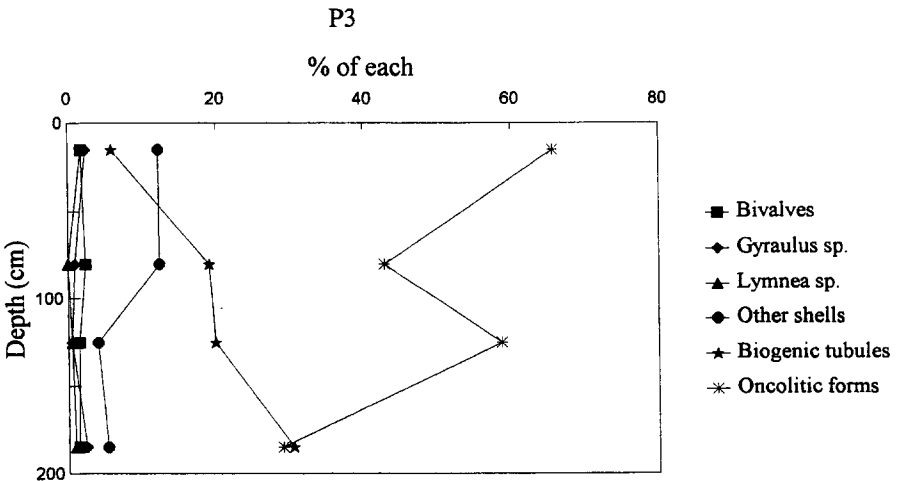


Fig. 10. Grain counts of biogenic components in the very coarse sand (1–2 mm) fraction of Pedon P3.



Fig. 11. Photomicrograph of deeper marl sediments (3.0 m) from P1. The x-sections of multiple thalli and stems from *Chara sp.* are evident. Line scale = 1 mm (cross-polarized light).

3.6. Age of marl sediments

A portion of a log was found buried within the marl in P4, and a sample was collected for ^{14}C dating at a depth of 140 cm; approximately 20 cm above the contact between the marl and the underlying sediment. The age of the sample was determined to be approximately 8520 BP (± 100 years). This places the age of the marl at this location in the early Holocene. This is similar to archeological findings of Gardner (1990) in the Shenandoah Valley of Virginia who estimated ceramic artifacts in marl sediments at 8000 BP. Curry and Stewart (1986) also used archeological evidence for hypothesizing that the marl sediments in the Hagerstown Valley were between 8500 to 5000 BP. Because it would require significant time for the marl sediments to accumulate (especially the deep marl), several thousand years may have passed between the beginning and end of the marl formation. Due to the sample's proximity to the bottom of the marl sediments (140 cm) the age of 8520 BP at P4 is taken as an estimate of when the marl accumulation was initiated in this region.

4. Conclusions

The extremely calcareous nature of the sediments precludes precipitation of carbonate from supersaturated (with respect to CaCO_3) waters into a non-calcareous matrix as a possible mode of origin of the marl. Therefore, other hypotheses could be either of an

alluvial origin, or a lacustrine sediment. Hypotheses on marl formation in this region have focused on abiotic factors in the past. However, evidence suggests that carbonate precipitating biota had a significant role in marl formation in Washington, Co., MD. The presence of the characteristic forms (calcified thalli and oogonia) of *Chara sp.* confirm the presence of this species during marl development. These submerged green algae are known to be a major contributor to marl formation, and are found in ponded or low-energy aquatic environments (Scholle et al., 1983). The fine particle size or 'calcareous mud' of the marl sediments in Washington Co., MD is characteristic of marl deposited by Charophytes in other places (Scholle et al., 1983). The marl sediments contain zones which are enriched in certain gastropods and bivalves which are associated with low energy or lacustrine environments. Therefore, we conclude that the marl sediments were deposited in a ponded or backwater environment.

In order to have a ponded landscape, a mode of damming these alluvial landscape positions must be proposed. A possible mechanism for ponding in these floodplain landscape are dams created by beavers (*Castor sp.*), which have played a significant roles in altering stream hydrology in recent ages (Holocene). Another possible cause of ponding is the formation of travertine dams, which can become quite extensive and create ponds behind the dams (Hubbard and Herman, 1990, Julia, 1983). Julia (1983) has documented this type of travertine damming in Turkey and Spain. Cemented carbonates identified in a few pedons have similar morphology to present day stream travertine. It is hypothesized that some of the cemented carbonates are pieces of extinct travertine dams washed into the sediments during non-ponded or dam break-up periods. The buried A horizons probably represent landscape surfaces which were exposed to weathering for periods of time in between periods of marl formation. Newly created dams would then reestablish the ponds (inundate the floodplains) and initiate another period of marl deposition. Curry and Stewart (1986) discussed the possible shrinking and swelling nature of these ponds, and related this to climatic changes. Therefore, due to periods of dam breakages (altered surficial hydrology), there were cyclical periods of marl formation punctuated by periods of exposure and pedogenesis. In this region, most of the marl genesis took place in the early Holocene, with the marl sediments in one location dated at 8520 BP.

References

- Bathurst, R.G., 1971. Carbonate Sediments and their Diagenesis. Elsevier, Oxford, 658 pp.
- Cloos, E., 1951. Washington County. Department of Geology, Mines, and Water Resources in the State of Maryland. Baltimore, MD.
- Curry, D.C. and Custer, J.F., 1982. Holocene climatic change in the Middle Atlantic area: Preliminary observations from archeological sites. *North Am. Archeol.*, 3 (4): 275–285.
- Curry, D.C and Stewart, R.M., 1986. Extinct ponds and prehistoric site distribution: Implications for paleoenvironments in the ridge and valley province. Paper presented at the 1986 Middle Atlantic Archeological Conference, Rehoboth Beach, DE.
- Drever, J.I., 1973. The preparation of oriented clay mineral specimens for x-ray diffraction analysis by a filter membrane peel technique. *Am. Mineral.*, 58: 553–554.
- Emerson, W.K. and Jacobsen, M.K., 1976. Guide to Shells: Land, Freshwater, and Marine, from Nova Scotia to Florida. Alfred A. Knopf, NY, 482 pp.

- French, K.J. and Herman, J.S., 1990. A CO₂ outgassing model for Falling Spring Run, Augusta County, Virginia. In: *Travertine-Marl: Stream Deposits in Virginia*; Virginia Division of Mineral Resources. Publication # 101: 5–16.
- Gardner, W.M., 1990. Travertine-marl deposits and prehistoric archeological association. In: *Travertine-Marl: Stream Deposits in Virginia*; Virginia Division of Mineral Resources. Publication # 101: 101–111.
- Gee, G.W. and Bauder, J.W., 1986. Particle size analysis. In: A. Klute (Editor). *Methods of Soil Analysis, Part I. Physical and Mineralogical Methods*, 2nd edn. Agronomy Monograph No. 9. ASA, SSSA, Madison, WI, pp. 377–382.
- Giannini, W.F., 1990. A commercial marl deposit near Winchester, Virginia. In: *Travertine-Marl: Stream Deposits in Virginia*; Virginia Division of Mineral Resources. Publication # 101: 93–99.
- Herman, J.S. and Hubbard, D.A., 1990. A comparative study of travertine-marl-depositing streams in Virginia. In: *Travertine-Marl: Stream Deposits in Virginia*; Virginia Division of Mineral Resources. Publication # 101: 43–64.
- Hubbard, D.A. and Herman, J.S., 1990. Overview of travertine-marl volume. In: *Travertine-Marl: Stream Deposits in Virginia*; Virginia Division of Mineral Resources. Publication # 101: 1–4.
- Johnson, L.J. and Chu, C.H., 1983. Mineralogical characterization of selected soils from northeastern United States. *Ag. Exp. Station, Penn. State Univ. Bulletin # 847*, November 1983.
- Julia, R., 1983. Travertines. In: *Carbonate depositional environments*. AAPG memoir 33. American Association of Petroleum Geologists, pp 64–72.
- Kirby, C.S. and Rimstidt, J.D., 1990. The geology and geochemistry of the Falls Hollow travertine deposit. In: *Travertine-Marl: Stream Deposits in Virginia*; Virginia Division of Mineral Resources. Publication # 101: 33–42.
- Mathews, H.L., Prescott, G.W. and Obenshain, S.S., 1965. The genesis of certain calcareous floodplain soils of Virginia. *Soil Sci. Soc. Proc.*, pp. 729–732.
- McFarland, E.R. and Sherwood, W.C., 1990. Description and origin of the calcite-rich Massanetta Variant Soil Series at Mount Crawford, Virginia. In: *Travertine-Marl: Stream Deposits in Virginia*; Virginia Division of Mineral Resources. Publication # 101: 43–64.
- Pentecost, A., 1990. The algal flora of travertine: an overview. In: *Travertine-Marl: Stream Deposits in Virginia*; Virginia Division of Mineral Resources. Publication # 101: 117–127.
- Pentecost, A., 1984. The growth of *Chara globularis* and its relationship to calcium carbonate deposition in Malham Tarn. *Field Studies*, 6: 53–58.
- Rabenhorst, M.C., 1988. Determination of organic carbon and carbonate carbon in calcareous soils using dry combustion. *Soil Sci. Soc. Am. J.*, 52: 965–969.
- Rabenhorst, M.C. and Wilding, L.P., 1984. Rapid method to obtain carbonate-free residues from limestone and petrocalcic materials. *Soil Sci. Soc. Am. J.*, 48: 216–219.
- Rabenhorst, M.C., Janicki, T.A., Maxwell, C. and Sverdrup, H., 1991. Maryland critical loads study. Volume III. Chesapeake Bay Research and Monitoring Division: CBRM-AD-95-9. Maryland Dept. of Natural Resources.
- Scholle, P.A., Bebout, D.G. and Moore, C.H., 1983. Carbonate depositional environments. *Am. Assoc. of Petroleum Geologists, Memoir 33*, 708 pp.
- Smith, G.M., 1933. *The Freshwater Algae of the United States*. McGraw-Hill, NY, 716 pp.
- Soil Survey Staff, 1994. *Keys to Soil Taxonomy*, 6th edn. U.S. Gov. Print. Office, Washington, DC.
- Sweet, P.C. and Hubbard, D.A., 1990. Economic legacy and distribution of Virginia's Valley and Ridge province travertine-deposits. In: *Travertine-Marl: Stream Deposits in Virginia*; Virginia Division of Mineral Resources. Publication # 101: 118–129.