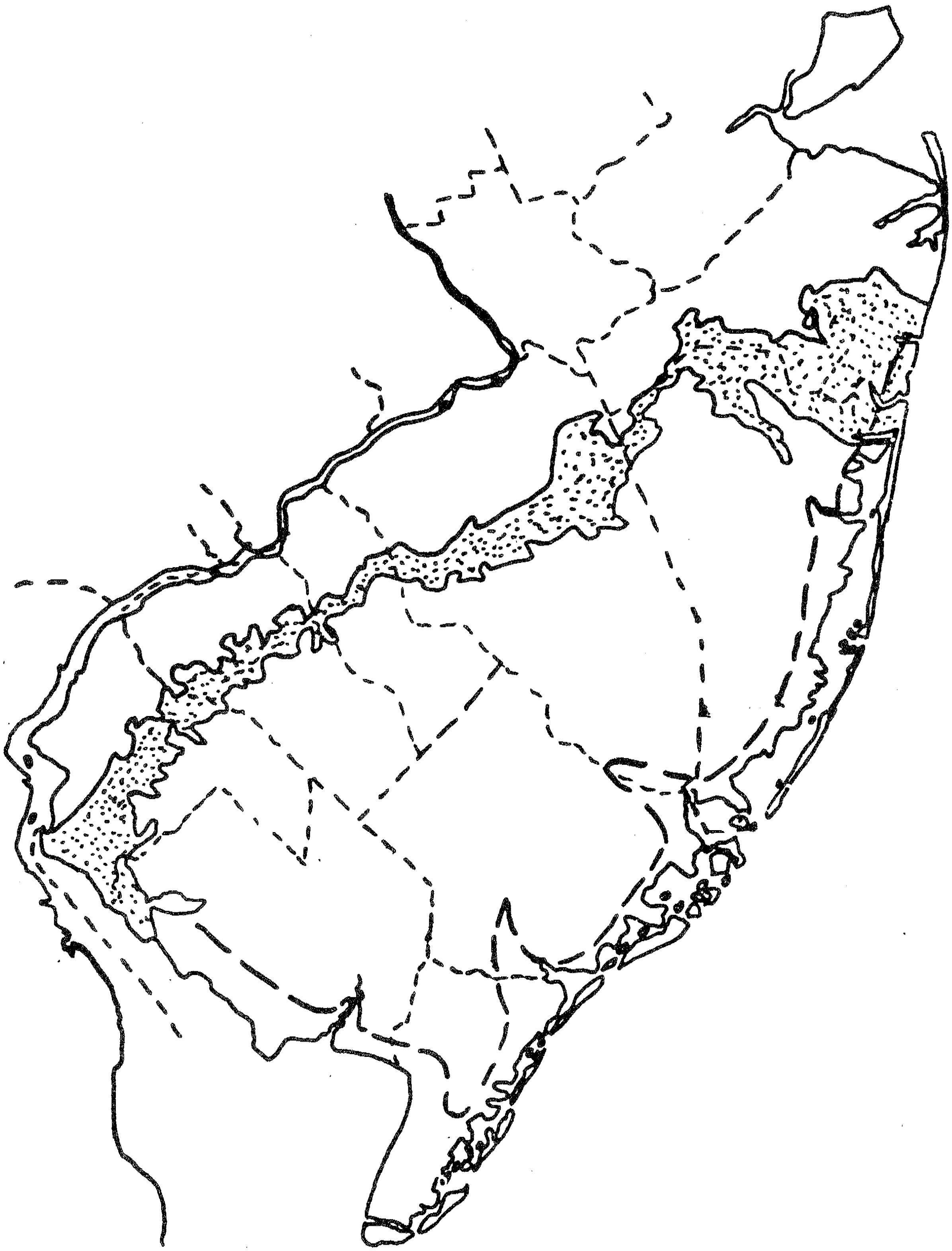


Fig. 1. The Cohansey sand outcrop. The Cohansey sand overlies the Kirkwood Formation which outcrops west and north of it (shaded area) and underlies the thick Quaternary deposits which are to the south and east, delineated here by the heavy dashed line. (from the Pinelands Commission, draft Comprehensive Management Plan, June, 1980, Fig. 2.2).

York and on Long Island (Whittaker 1979) may suggest that this type of vegetation was at one time more extensive than it is now. It persists where local conditions such as low nutrients, dryness, or frequent fires prevent the surrounding vegetation from becoming established. However, the extensiveness of this type of vegetation in the New Jersey Pine Barrens has allowed the fuller expression of the entire combination of ecosystems, including lowlands and a large number of animal species which do not survive in the smaller areas.

The vegetation in the New Jersey Pine Barrens today reflects not only topography and geology but also human history. Whether fire, a very common occurrence in this area, was a major force before the advent of man in the region is unknown. The dryness of the uplands and the inflammability of the trees might allow a lightning-set fire to burn, but lightning-set fires are rare in this part of North America, since most thunderstorms are accompanied by heavy rain (Schroeder and Buck 1970). Indians used fire and at least inadvertantly must have set some fires. The major influence of fire has been felt since European colonization. There is evidence that fires were set on purpose in the 18th and 19th centuries, for example to create pasturage. (Wacker 1975, pp.115-116). The advent of the steam locomotive in the mid-19th century added another major source of fires. More than one third of the fires in this area in 1902-1904 were caused by sparks from locomotives. Many of the others were caused by fires being used to clear brush. None was attributed to lightning (Meier, 1903, 1904, 1905). As fire control became more effective in the 20th century the size of fires and the area burned decreased, to a relatively constant amount by about 1940 (Forman and Boerner 1980).

In addition to fire, these forests have been subjected to heavy cutting for charcoal and timber and clearing for agriculture. Cedar trees have been harvested from swamps and bogs, and bogs have been flooded for cranberry production; many of these have since been deserted and reverted to wooded swamps. The landscape is thus a complex pattern of varied human disturbance superimposed on a natural landscape in which minor topographic variations are associated with major vegetational variation (Forman 1979). Although the ancient age of the landscape with its low topography and rare flooding creates a fairly stable geological system, with little downward erosion of streambeds, the human and climatic factors have produced a highly disturbed vegetational pattern. This field trip visits sites demonstrating both the stability of the geologic landscape, and a specific result of this stability in the formation of bog iron ore (Fig. 3), and the variability and instability of the local vegetational patterns.

Fig. 2. Soil profiles of New Jersey Pine Barrens podzols.

a. A podzol developed on a well-drained site.

b. A podzol developed in the presence of a high, seasonally-fluctuating water table.

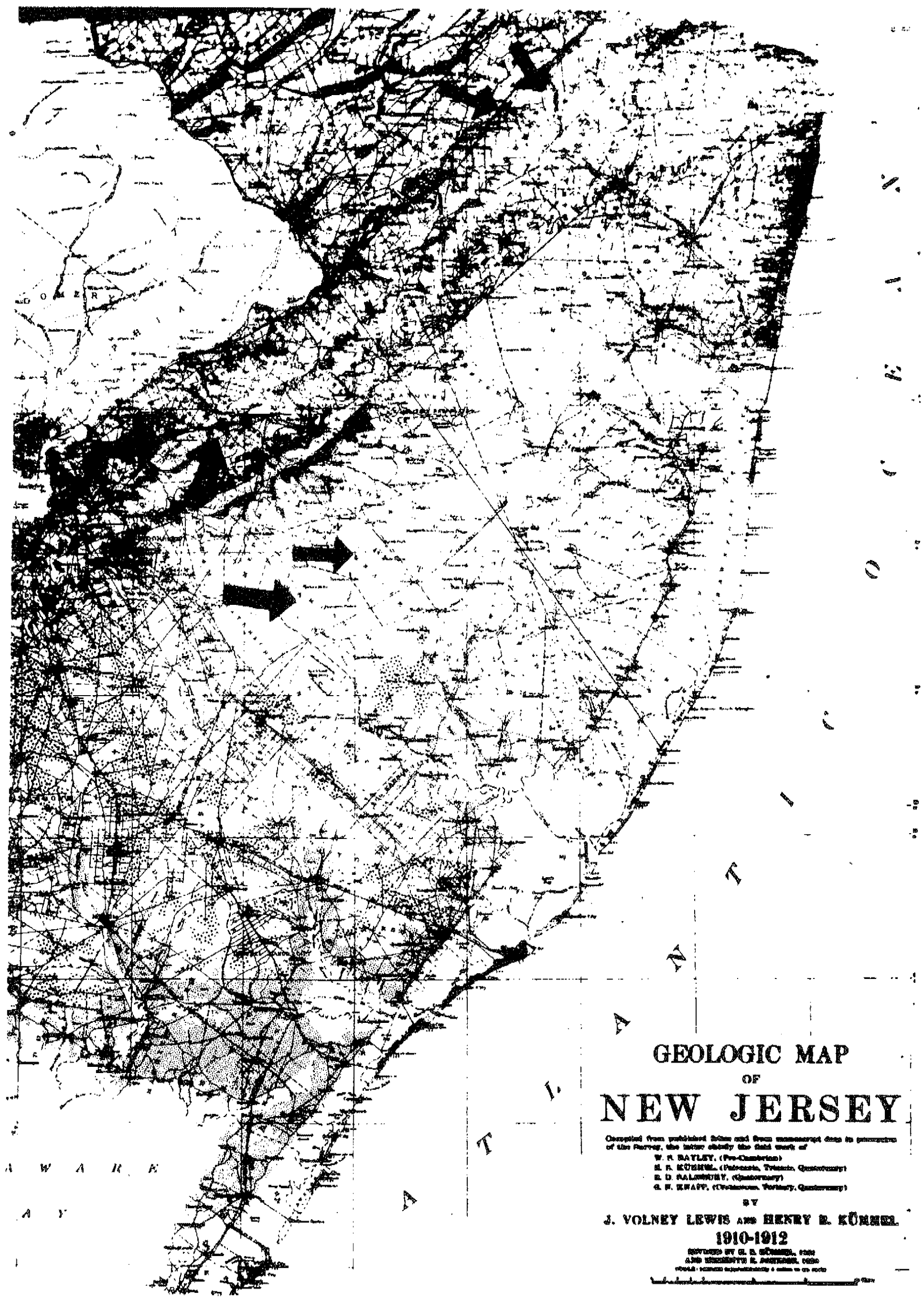


Fig. 3. Geologic Map of New Jersey.
Arrows indicate areas of bog iron ore.

BOG IRON FORMATION

Topography

The Coastal Plain of New Jersey is a raised plain whose parent materials have been laid down and reworked by numerous marine transgressions and regressions; stream and aeolian agencies have also reworked these materials. Examination of U.S. Geological Survey 7.5 minute topographic quadrangle maps indicates that the Coastal Plain may be divided into two topographic categories on the basis of stream downcutting: where streams have made significant down-cutting in the plain and where they have made little or no mapable down-cutting. Interestingly enough, the latter category exclusively contains the bog iron mining iron centers of the past (Krug, 1980). Here topographic relief is usually slight and river flow sluggish, e.g. surface gradients of 3 to 10 feet per mile are typical of the Wharton Tract (Rhodehamel, 1973) and the Mullica and Great Egg Harbor Rivers drop 5 feet in 16 and 23 miles, respectively (Crerar, *et al,* 1979).

Impedance of drainage and concomitant formation of fluviatile and related base-level swamps are the result of such slight topographic relief. The numerous streams and small rivers of these areas commonly develop slight (several feet high), semi-continuous levees and relatively broad, sandy alluvial plains, generally better drained and higher riverside and lower and swampy away from the stream.

Topography and the acidic, quartzose, sandy parent materials have promoted the formation of podzol soils as the predominant soil type of the bog iron area (Tedrow, 1962, 1979) while sandy, extremely acidic (pH 3.6-4.4), alluvial soils commonly occupy the flood plains. The sandy alluvial soils are described as having their water tables controlled by the streams and in places "cemented iron is in forms ranging from small spherical concretions to 6-inch layers of ironstone" (Soil Survey, Burlington County, New Jersey, 1971).

Iron sandstones form in, and were mined from, the low discontinuous levees and similar low (2½ to 5 feet of relief above low stream flow level) flat lands abutting the stream (Figure 4, 5a, b, c, and d). Groundwaters of these landscape features are recharged during droughty periods by the streams that they embank and not from adjacent lands from which they are hydrologically isolated or remote. Iron deposits do not form in, or were mined from, any of the other landscape features associated with the streams or groundwater podzols.

Bog iron does not form in appropriate landscape features where the surface waters are not the brown, tea-colored waters typical of the Pine Barrens. Therefore, the formation of the pedogenic bog iron is related to both topography and surface water quality (Krug, 1980).

GENESIS: A GEOCHEMICAL SOIL CATENA

Strakhov (1966) related the formation of lake ores (which are sesquioxide deposits formed in open waters) and surface water quality to the podzolization process. "Rust waters" (waters rich in iron flocs), from which lake ores form, are the result of an intermediate stage of the podzolization process. Brown waters, from which lake ores can not form, are the result of the end product of this pedogenic process, the mature podzol soil (Figure 2a, b).

Podzols form on acidic, quartzose, generally very permeable parent materials in temperate climates. What is particularly critical for podzol development is the formation of non-flocculated humic acids that are free to percolate through the soil enabling them to react with and transport cations through the soil profile. The presence of even moderate amounts of basic materials, especially containing iron, creates a flocculated humus and hinders podzol formation (Duchaufour and Souchier, 1978).

Organic acids in podzols complex strongly with Fe^{3+} and Al^{3+}, and relatively weakly with Fe^{2+} and other common cations. Iron is bound as cationic ferric hydroxide.

This organometal becomes immobilized in the presence of reactive sesquioxides. Thereby, iron is mobilized by these organic acids in the leached, iron-poor, upper horizon and immobilized in the underlying, sesquioxide-richer horizon (Schnitzer and Skinner,

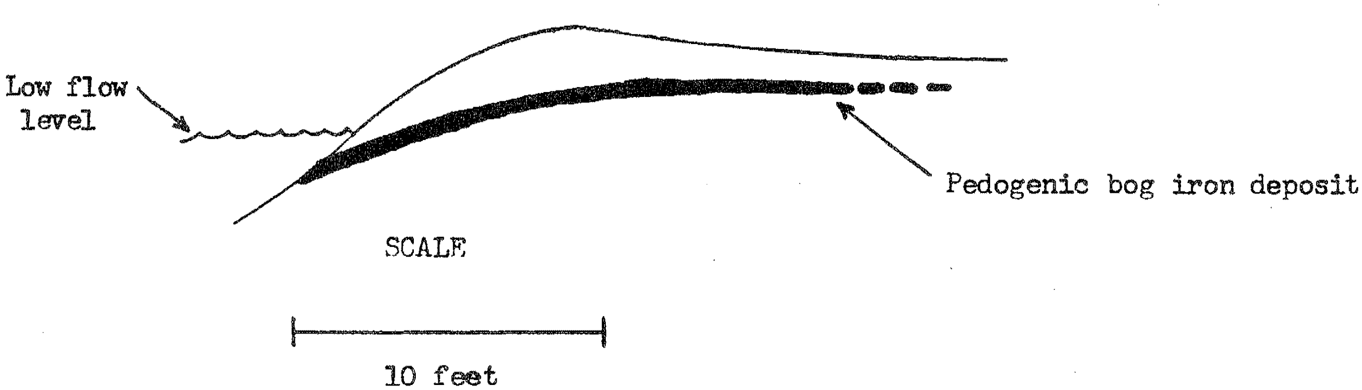
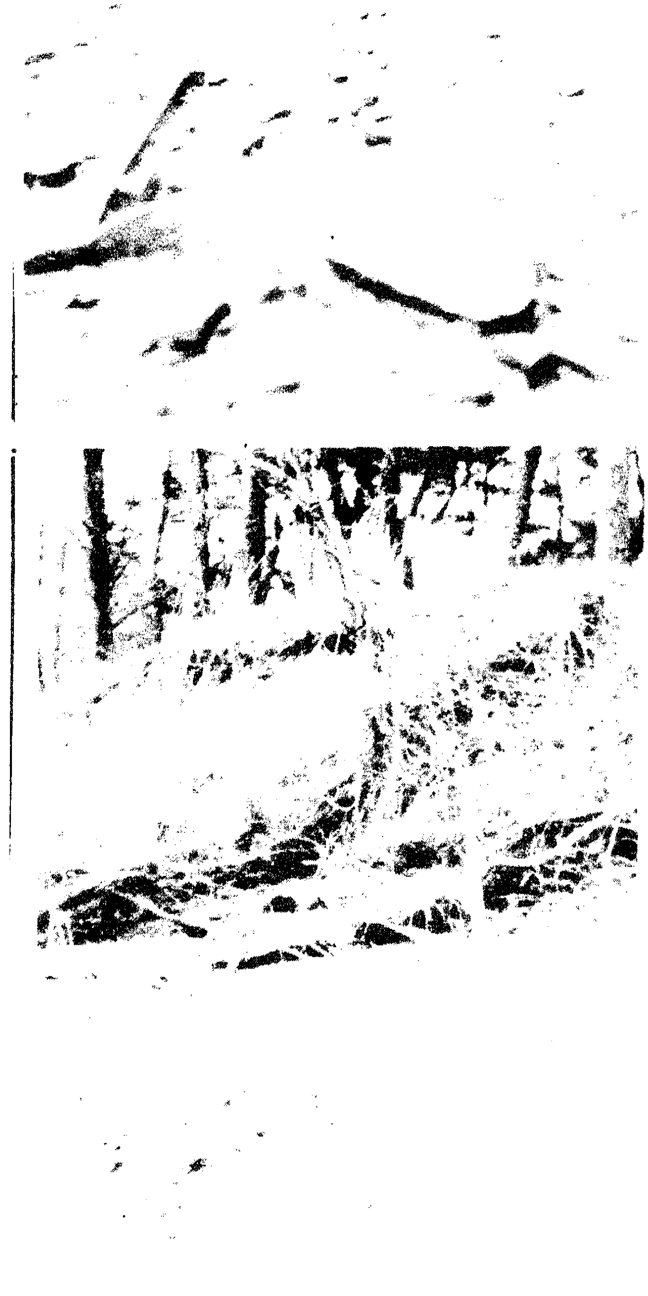


Fig.4. Idealized crossectional profile of pedogenic bog iron ore.

Fig.5. A pictoral essay on the relationship between bog iron formation and topography.
A unique bog iron deposit located at Rancocas State Park, stop no. 3 of the field trip. Tidal fluctuation of this freshwater river enables viewing of the bog iron deposit at low tide. It is seen that the higher the landscape feature, the lesser the influence of river water on groundwater, and the lesser the magnitude of the bog iron phenomenon.



1963a, b; and Schnitzer, 1969). Mössbauer spectroscopic studies have recently shown that ferric iron exists in combination with, and is preferrentially bound to, humic acids even in strictly anaerobic conditions (pure N_2 atmosphere) down to pHs even more acidic than is experienced in podzol soils (Goodman and Cheshire, 1978).

Reactive sesquioxide surfaces saturated with organoiron are probably regenerated, and more sesquioxides made, by soil microbial metabolizing of the organic fraction of organometals that leave metal oxides as wastes (Krug, 1980). Indeed, *Pedomicrobium sp.*, which is ubiquitous in podzol soils, will not grow even on simple organoiron substrates like iron ammonium citrate and other simple media proposed for iron bacteria cultural determination; they are known only to grow on iron humates, with some species known to specialize on manganese humates (Aristovskaya and Zavarzin, 1971). Therefore it is unlikely that these organisms are not metabolizing such substrates in podzol soils.

Much of the organoiron not immobilized in the soil profile is carried in solution and eventually emerges to form the brown waters that are characteristic of podzol watersheds. The coloring agent of these waters is ferric organoiron colloids, 0.1 to 0.2 microns in diameter (Moore and Maynard, 1929; Shapiro, 1957, 1966, and 1969; and Coonley, *et al*, 1971). Soil and limnological studies suggest that organoiron complexes peptize through cationic ferric hydroxide bridging of carboxy groups, the process beginning in the lower podzol soil profile (Shapiro, 1966; and Dawson, *et al*, 1978).

Surface waters pulled, by evaporation and transpiration, during droughty periods into select landscape features result in the concentration of organoiron colloids and the formation of pedogenic "bog iron ore". Organoiron immobilization and iron concentration is by the same mechanism that is in operation in podzol soils.

Laboratory examination of in situ pedogenic bog iron shows that hydrous organic matter is the cementing agent of the stone and that the iron oxides are porous and very friable being a poor cementing material (Figure 6, 7a, b, and 8). Organoiron colloids become immobilized and create a cementing plasma across the smaller void spaces. The large void spaces fill up with the iron oxide residue, if given enough time because these iron oxides are porous thus permitting solution movement which enables continuing supply and metabolism of organoiron (Krug, 1980).

CONCLUSIONS

Iron mobilized from podzol soils of the Pine Barrens enters surface waters as ferrihumates. The resulting organoiron colloids from these surface waters are concentrated in select landscape features to form bog iron ore creating a geochemical soil catenary sequence.

The formation of bog iron ores have been, and are, largely explained as being controlled by Eh/pH parameters: iron is solubilized from underlying ferruginous strata or non-apparent iron mineral-bearing materials, transported in reduced form in groundwaters and becomes oxidized and precipitated as these solutions approach oxidizing surfaces; oxidation may be aided by iron-oxidizing bacteria. Nevertheless, this generally-accepted hypothesis of bog iron formation does not explain the inability of it to form in areas of such emerging groundwaters, why it forms where it does and why it takes on the form that it has.

Bog iron researchers have been faced with special problems besides today's lack of economic interest in bog iron deposits. One problem is the unlikely fact that iron mobilization requires such iron-poor parent materials. This is probably what had led many investigators to hypothesize obscure, or somewhat removed, sources of iron rather than the white sands covering the watershed, from which iron has, and is, being removed. Another is that, until recently, the only accepted chemical models for iron movement were various Eh/pH models, even for organically-complexed iron.

Furthermore, the bog iron literature is extremely confused. For example, generation times estimated for lake ores, as little as 20 years, have been given as those of bog iron ores, including the bog ores of New Jersey. However, none of the examined mined sites (140 to 200 years ago) in the Pine Barrens give any indication of renewal. A similar observation as to lack of regeneration of bog iron has been made by Crerar, *et al*, (1979).

Additional research suggests that the development of podzol soils from the parent materials of the Coastal Plain first resulted in the formation of lake ores during an intermediate soil development stage, as described for the lake ores of Fennoscandia and the Soviet Union by Strakhov (1966). The development of pedogenic bog iron came with the predominance of mature podzol soils in Pine Barrens watersheds. Apparently both lake ores, probably buried fossil lake ores, and pedogenic bog iron ores were mined in the Pine Barrens (Krug, 1980).

Fig.6. A photomicrograph of a flat, polished pedogenic bog iron surface (secondary electron).

Fig.7a. A slightly higher magnification photomicrograph of the same surface viewed in Figure 6 after one week of vacuum desiccation (secondary electron). Hydrous organic matter plasma cement shrivels up under vacuum desiccation. Large iron oxide-rich plasma body at lower edge of picture has not lost volume.

Fig.7b. Photomicrograph of large iron oxide-rich plasma body/dehydrated organic matter/quartz sand grain interfaces (secondary electron).
Higher magnification view of the large iron oxide-rich plasma body viewed in Figure 7a. Quartz grains occupy upper right and lower central, dehydrated organic matter central and lower right, and the iron oxide-rich plasma occupies the central and upper left portions of the photomicrograph.

Fig.8. Iron elemental map of a flat, polished pedogenic bog iron surface (secondary electron).
Central white mass is a large iron oxide plasma body. White lines at edges of view are iron oxide coatings of quartz sand grains. Electron microprobe analysis shows these iron oxide coatings and plasma body to be almost pure iron oxide. Sand sized, ferruginous, lower left particle is ilmenite, $FeTiO_3$.

ROAD LOG

Mileage

0.0 Start at Rutgers University, Newark Campus. Enter New Jersey Turnpike at Interchange 14.

24.0 Exit New Jersey Turnpike at exit 9, East Brunswick. At the toll booths bear right to take Rt. 18 west towards New Brunswick.

24.6 Rt. 18 goes over Westons Mill Pond and curves left passing over Rt. 1. Keep right on Rt. 18 overpass of Rt. 1 to take Rt. 1 south exit.

26.4 Proceed south on Rt. 1, make right onto jughandle about 0.1 mi. after going under the second overpass. Bear left on jughandle to cross Rt. 1 to Rt. 130.

31.4 After going south on Rt. 130 for a little over 4 mi. a pond and a motel are seen on the left. Ahead is farmland on both sides of the highway. Past the farmland is woods on both sides of the highway. When you get to the woods travel slowly on the shoulder of the highway. Stop when you find the stream that goes under the highway.

STOP 1. PEDOGENIC BOG IRON FORMATIONS OF PIGEON SWAMP, SOUTH BRUNSWICK.

Unmined bog iron site that shows the relationships of podzol soils, surface water quality, and pedogenic bog iron formation . This is posted private land. Viewing of bog iron is best achieved by walking in the stream itself. The south bank of the stream is disturbed by dredgings (parts of this stream were straightened) and by bedding of long-abandoned dirt roads.

54.4 From Stop #1 continue down Rt. 130 south to the intersection of Rt. 206.

66.4 Take Rt. 206 south to Vincentown Diner and make a right. Sign says "To 38".

68.7 Continue down highway to first fork in the road; the main highway bears left, you go right.

68.9 Shortly you come to a stop sign. A school is on your right. Make a right turn at this stop sign and proceed down Pine Street.

69.5 After going over railroad tracks look to take last right before going over a small river, North Branch Rancocas Creek. Make this right and you are now in Iron Works Park, Mount Holly.

69.7 Drive towards the green foot bridge going over the river. Stop vehicle in parking space available nearest the bridge. On the other side of the bridge are the two large trees growing over the remains of an iron ore dump.

STOP 2 BOG IRON DUMP, MOUNT HOLLY.

The remnants of an iron ore dump still exist under two large trees growing at the edge of the North Branch Rancocas Creek, Iron Works Park, Mount Holly. Both lake and bog ores are in these piles. The ores were presumably used by the Mount Holly Iron Works which was destroyed in 1778 by the British Army and never rebuilt.

70.6 Leave Iron Works Park, making a left onto Pine Street and proceed to the traffic light at the Rt. 38 intersection. Make a right onto Rt. 38.

72.7 Proceed west to the traffic light at Hainesport-Lumberton Road. Make a right onto Hainesport-Lumberton Road. If this turn is missed you will pass over the Southeast Branch Rancocas Creek in 0.1 mi.

73.0 Follow this road to the first stop sign. Make a left here onto Rt. 537 (Marne Highway).

73.1 Make the first right onto Rancocas Avenue.

73.8 Proceed down this road to the entrance of Rancocas State Park. This park is open to 8pm in the summer and 5pm for the rest of the year. Check sign for open hours. Continue straight.

74.3 View swamp on left at the first fork in the road. Swamp water is not brown nor is it rust stained in the summer. Soils of the area are not the bleached white sands characteristic of podzols.

74.4 Take right fork in the road. Road forks again almost immediately, bear left and stay on "main" dirt road. Park in clearing by the river. Walk left along beach at low tide to view iron formation and its relation to topography. At its maximum extent, ironstone goes 80 feet inland. Iron formation continues to the right of the clearing under rubble and shoring. The tides here are about 3 hours ahead of those of Sandy Hook.

STOP 3 WATER QUALITY, SOILS, AND TOPOGRAPHIC RELATIONSHIPS TO PEDOGENIC BOG IRON FORMATION OF RANCOCAS STATE PARK, HAINESPORT.

Soils are extremely acidic, pH approximately 4, but are not podzols, the vegetation is typical of that of the Pine Barrens. Water draining this land is clear, not organic stained or rusty, not participating in significant iron cycling. At low tide the relationship of pedogenic bog iron formation to topography is easily observable. River water is the source of iron, the brown river waters coming from the upstream podzols. Shallow groundwaters of the Pine Barrens (podzol zone) are also brown (and ferruginous). Therefore this site is unique in that pedogenic bog iron is visible on the surface because of tides and formed in an area where there is little doubt that the local groundwaters can not supply iron for deposition. This iron deposit is unusual in that ocherous earth forms both above and below the ironstone layer whereas it usually only forms below. This sandwiching effect is probably due to the tidal variation.

78.0 Return to Rt. 38 and turn left (east). After passing Mt. Holly in a couple of miles the route number will change to Rt. 530.

STOP 4

81.5 In the middle of the field on the south side of the road is a typical pingo, a common local land feature. Similar structures with raised edges are formed in areas of permanently frozen soils in the Arctic, by a complex process of thawing, erosion and deposition (Tedrow, 1969). The permanently wet center here prevents cultivation and is thus seen by the brush growing there. Pingos appear to have attracted Indians and frequently have artifacts on their raised edges. They may also account for the existence of small bogs where the ground water table is well below the surface, since they are usually underlain by clay lenses.

82.0 Cross Rt. 206.

84.5 Traffic light. Go straight. You are now on Rt. 644

90.5 Traffic circle. Take Rt. 72 east. Lebanon State Forest with typical Pine Barrens upland forests is on the left, interrupted in places by streams.

94.0 Right on Rt. 563 towards Chatsworth.

98.5 Village of Chatsworth, locally known as the "capitol of the Pine Barrens."

109.5 Note large cranberry bogs along the way. These are located where the water table is at the surface and are periodically flooded to protect the plants from frost in the spring and to assist in the harvest in the fall, when the berries are knocked off the vines and floated off. Bear left on Rt. 579.

STOP 5

111.0 Harrisville Pond. This is the site of an old iron works. Evidence for mining of bog iron ore can be seen along the river. Much of the lowland forest here is pitch pine, with a canopy of almost pure pine. The understory is dense and includes many shrubs of the heath family (Ericaceae), for example sheep laurel (*Kalmia angustifolia*) and blueberry (*Vaccinium* spp.). These lowland areas occur often along streams with low levees, the same conditions conducive to the formation of bog iron ore.

The Oswego River here has a drainage area of 64 mi^2 and discharge of 18.7 in/yr (Pinelands Commission, Draft Comprehensive Management Plan, June, 1980).

Just up on the left is an exposed soil profile and upland forest. The canopy here is mainly pitch pine (*Pinus rigida*) but also includes the typical blackjack oak (*Quercus marilandica*). Tall shrubs are mainly scrub oak (*Q. ilicifolia*); other prominent shrubs are black huckleberry (*Gaylussacia baccata*) and lowbush blueberry (*Vaccinium vacillans*). The litter is thin and scattered where there have been frequent fires. Sandiness and leaching show in the podzol. Without fire the upper humic horizon would be deeper. Below this is the bleached zone. A zone of accumulation of the leached iron and humic compounds may form below this, just above the parent material or Cohansey sand. In places this yellow sand is brought to the surface and deposited on the white sand by ants.

Turn around and return to Rt. 563. Turn right.

112.5 Turn right toward Oswego Lake.

116.0 **STOP 6** Oswego Lake (Penn State Forest).

There are two types of swamps in this vicinity, hardwood and cedar. Note the pointed tops of the cedar trees (*Chamaecyparis thyoides*) compared with the flat tops of the pines. The short gradation between these two indicates the small changes in elevation associated with the change from upland to lowland vegetation. The understory here includes highbush blueberry (*Vaccinium corymbosum*) and swamp azalea (*Rhododendron viscosum*). In openings the sphagnum moss mat also includes the tiny plants of cranberry (*Vaccinium macrocarpon*). Both of these species of *Vaccinium* are grown here commercially.

In places in the cedar swamp, red maple (*Acer rubrum*) and black gum (*Nyssa sylvatica*) form an understory which may eventually replace the cedars. Such an area of hardwood swamp can be seen shortly downstream from Oswego Lake. The red maple and black gum are here accompanied by sweet bay (*Magnolia virginiana*). Continue on past the lake.

125.0 Turn left on Rt. 72. At the Burlington and Ocean County line there is a pull over on the right shortly after you get on Rt. 72.

STOP 7 Pine Plains

These dwarf forests are the most distinctive feature of the Pine Barrens. There are no other such forests approaching the areal extent of these elsewhere in the world. Stunted, many-trunked blackjack oak and pitch pine dominate the low canopy. Broom crowberry (*Corema conradii*), a species which reaches its southern geographical limit in the Pine Barrens, is found here. It is a species which probably migrated south along the exposed coastal area during the Pleistocene and has since been isolated from northern populations by the rise in sea level. Note also that the soil here is coarser than in the other upland site, a characteristic of the Pine Plains which may increase dryness and thus fire frequency.

Turn around and go east on Rt. 72.

133.0 Garden State Parkway. Go north.

STOP 8

141.0 Oyster Creek rest area.

Oyster Creek with 7.43 mi^2 of drainage area has a flow of 51.4 in/yr. Compare this with the values for Oswego River. This difference is caused by interbasin transfer of ground water. Much of the water that falls in the Oswego River watershed soaks quickly down into the aquifer below the bed of the river and flows past it, to come to the surface eventually in such streams as Oyster Creek.

205.0 New Jersey Turnpike. North to Newark.

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NOONDAY HACKENSACK MEADOWS
by Mrs. M. Nimmo Moran
American Etchings, Part XVIII, 1881