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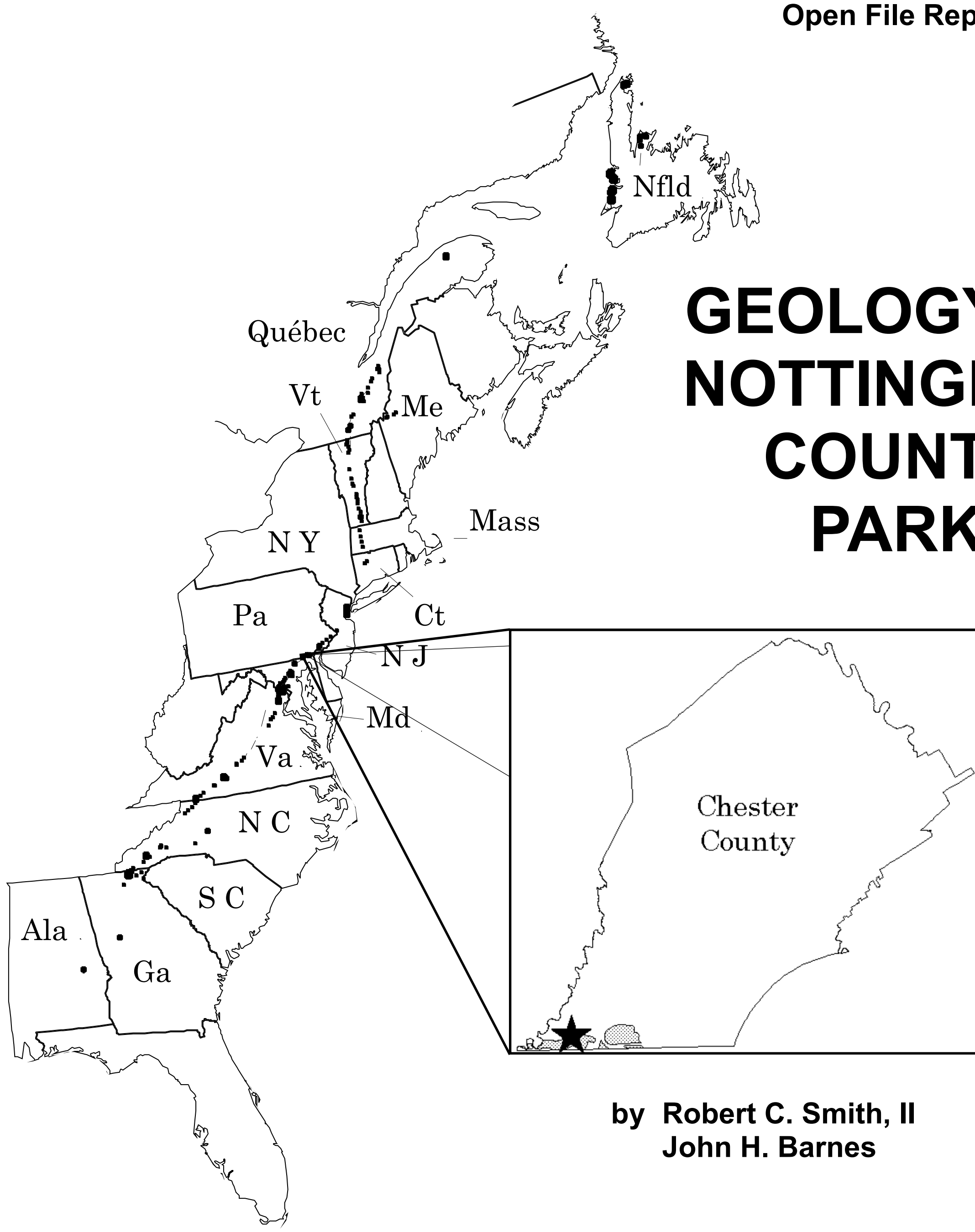

GEOLOGY OF NOTTINGHAM COUNTY PARK

by Robert C. Smith, II
John H. Barnes

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES
BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY
In cooperation with
CHESTER COUNTY BOARD OF COMMISSIONERS
and
DEPARTMENT OF PARKS AND RECREATION

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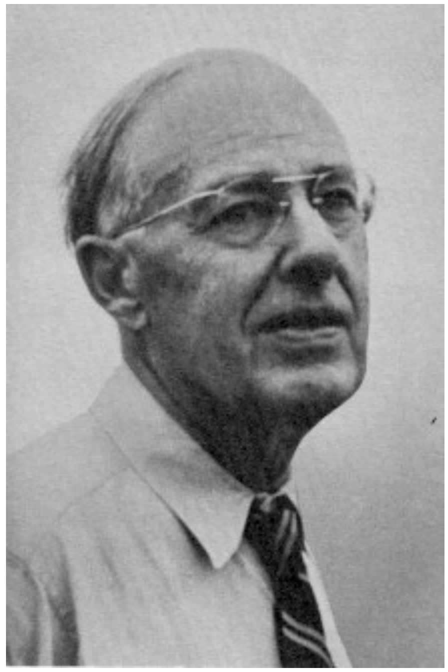

Edgar Theodore Wherry
1885–1982
Pennsylvania's premier naturalist

Photo taken by F. Harold Evans in 1955 on a field trip of the Mineralogical Society of Pennsylvania

This summary of the geology, bedrock mineralogy and chemistry, economic geology, and the influence of all of these on the flora of Nottingham County Park is dedicated to the life and studies of Edgar T. Wherry. Although he never relinquished his studies of mineralogy, geology, chemistry, economic geology, and especially botany, Wherry died about the time when plate tectonic theory and readily available trace-element analyses were beginning to make new interpretations of serpentine barrens possible. This did not preclude his interpreting the geochemical basis for the serpentine barrens (Wherry and others, 1979). He was a nationally recognized authority on ferns and recognized his favorite, the Aleutian maidenhair fern, in the park. This fern graced the cover of his 1937 *Guide to the Eastern Ferns*, and he fully understood its significance.

The present authors can only aspire to Wherry's integration of the natural sciences, but it is hoped that the data and concepts in this booklet, coupled with an appreciation of Wherry's contributions (Hooker and Montgomery, 1975), will inspire present and future naturalists in their appreciation and study of serpentine barrens.

With good stewardship, the barrens in Nottingham County Park will provide an interesting outdoor learning opportunity until the climate dramatically changes. Before then, as new techniques and theories become available, our understanding of this unusual environment will grow closer to the truth.

ACKNOWLEDGEMENTS

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On the front cover: The locations of ophiolitic rock associated with the Taconic mountain-building episode of about 450 million years ago are shown on the map of eastern North America. Ophiolites are unusual rocks derived from material that originated in the Earth's mantle and erupted onto the ocean floor, mixing with other materials found there. Most of the ophiolites have been altered to serpentinite. Ophiolites associated with the Taconic orogeny are found in the 13 states and 2 Canadian provinces that are labeled on the map. The inset map shows the location of Taconic ophiolites in Chester County. Nottingham County Park is marked by the star.

On the rear cover: A 1946 aerial photograph of the area that now encompasses Nottingham County Park. Most of the park occupies the rough, wooded area that makes up most of the photograph. McPherson Lake, which did not exist when the photograph was taken, occupies the western part of the triangular treeless area in the northwestern part of the photograph. The small, dark, elongated object south of that area is the water-filled Brandywine Quarry, also known as the Mystery Hole. (US Department of Agriculture photograph AHK–4D–174, November 18, 1946.)

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Pennsylvania Geological Survey

Birth of the Barrens

The barrens of southeastern Pennsylvania were born approximately 510 million years ago beneath an island arc in the Iapetus Ocean. Less commonly known as the Theic Ocean, the Iapetus Ocean itself was born as continents separated 575 million years ago but closed up 450 million years ago, or 250 million years before the Atlantic Ocean opened! As a result, all unsolicited vacation offers to lounge on the beautiful shores of the Iapetus/Theic Ocean should be viewed with great suspicion.

The island arc was formed from a variety of igneous rocks derived mainly from the Earth's mantle and remelted slabs of ocean floor, some of which were mixed with sediments washed off the continent of Laurentia, the forerunner of North America. Together with its deep geologic roots, such a mixture of island arc and oceanic rocks is known as an ophiolite complex. Ophiolite is a interesting word derived from the Greek word o*phi*, meaning reptile. We shall come back to other geologic words relating to reptiles as we discuss the rocks at Nottingham County Park (NCP). The portion of the park that naturalists find most interesting formed mainly from a mantle-derived magma, which is molten material that can eventually crystallize to form igneous rocks. This magma crystallized to form a rock composed mostly of the mineral olivine, but also containing trace to minor amounts of an odd and useful mineral called chromite. The history of chromite mining in the NCP area will be discussed later.

Olivine is a relatively high-pressure, high-temperature, yellowish green, somewhat unstable magnesium silicate which usually contains some iron. The old name for olivine is "chrysolite," which is derived from the Greek words for yellow-green and stone. When pure and formed in large clear crystals, olivine is known as peridot, the birthstone for August. Egypt and Arizona are the best sources for gem peridot. Alas, no gem peridot is ever likely to be found in Pennsylvania or Maryland. As the olivine here crystallized into 1/16-inch grains beneath the island arc, it settled to the bottom of the magma chamber because it was more dense than the magma itself. Upon cooling, the olivine coalesced to form a type of rock known as dunite (after Dun Mountain, New Zealand) or, where certain other igneous minerals are a bit more abundant, peridotite. Today, tiny fresh cores of yellow-green olivine occur in some of the rocks south of Black Run, especially northwest of Feldspar Trail. Consider asking a NCP staff member to show you a sample.

Long after the olivine in the dunites and peridotites crystallized in the magma chamber, it

Figure 1. Serpentine at NCP showing the scaly habit that, in addition to its green color, gives the mineral its reptilian name.

reacted with warm water. The reactions partly converted the olivine, along with some of the associated minerals, into three minerals that form the serpentine group; lizardite, antigorite, and chrysotile. The serpentine group minerals are hydrous magnesium silicates lacking iron. The name "serpentine" is derived from the green color and scaly habit the mineral sometimes shows (Figure 1). Olivine containing minor iron reacted with water and silica to yield the serpentine group minerals plus a magnetic iron oxide known as magnetite. The conversion of olivine to serpentine likely occurred during several different geologic stages. Lizardite is by far the most common of the serpentine minerals at NCP. In fact, lizardite is *the* most common mineral in the park.

Lizardite was named after The Lizard, a peninsula in England composed largely of serpentine. Lizardite forms by reaction of olivine with warm meteoritic (atmospherically derived) water. The lizardite probably replaced the higher temperature serpentine mineral, antigorite, which formed much earlier from metamorphic fluids (Wenner and Taylor, 1974).

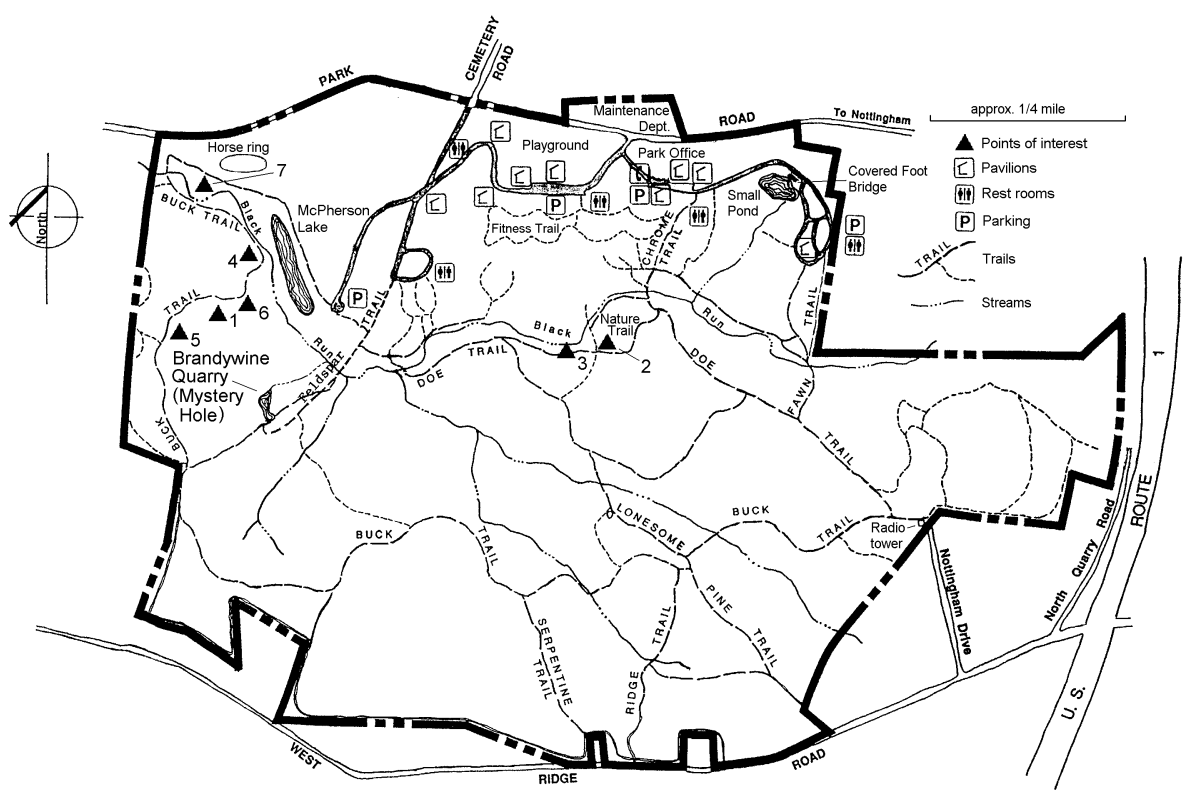


Figure 2. Map of Nottingham County Park showing some points of interest that are identified and discussed later in this booklet. Some additional points of interest are described in the free brochure *Geology of Nottingham Park* (Barnes and Smith 1998), available at the park office.

Antigorite is still common in the serpentine barrens to the west, in Lancaster County. In NCP, partly serpentinized peridotites form the hill on the southeast side of Buck Trail as it ascends southwest from the plain of Black Run (Figure 2, Point 1), at the northwest edge of the serpentine barrens. Most serpentinite is covered by soil and plants, but some can be seen in a manmade exposure along the Nature Trail (Figure 2, Point 2).

Deep within the Earth where the magma chamber originally formed, cooling of the magma beneath the island arc gradually resulted in crystallization of a second group of magnesian silicate minerals called pyroxenes. Like the earlier formed olivine, these pyroxenes were also water-free magnesium silicates, but contain more silica than the olivine. Progressively younger pyroxenes contained increasing amounts of elements such as calcium, aluminum, and iron. These pyroxenes collected on top of the olivine that had settled toward the bottom of the magma chamber. Because the magma chamber that formed the barrens is tipped to the southeast a bit but was never overturned, the rocks that were possibly once pyroxenes are generally found in the southeastern third of the park. If you go there, however, it will be extremely difficult, if not impossible, to recognize any remaining pyroxene. As far as is presently known, nearly all of the pyroxenites in NCP have been largely serpentinized just like the peridotites. Serpentinite generated from pyroxenite may only have faint remains of cleavage traces to give away its ancestry. To date, only one piece of pyroxenite is known to have been found. Pyroxenites and their serpentinized offspring contain relatively small amounts of elements, such as magnesium, chromium, nickel, and cobalt, which might, in larger amounts, be deleterious to plants. They do contain significant amounts of the elements, such as calcium, potassium, and phosphorus, which are likely to be helpful to plants. Thus, the pyroxenites tend to yield soils which are less impoverished than soils derived from serpentinized peridotites if you are a farmer, or more impoverished if you are a naturalist interested in the exotic flora of serpentine barrens.

A Stressful Middle Age

The rocks derived from the ophiolite complex that today form the NCP barrens suffered two serious midlife crises and possibly a moderate crisis during youth. Scars from the two later crises, which geologists call orogenies, reshaped the character of the ophiolite complex twice as continents collided and created mountains by folding and faulting. These two serious orogenies left such deep scars that little evidence remains intact from the possible crisis during its youth. The youthful stress and new growth was more clearly enjoyed by rocks south of the Mason-Dixon line, which are said to have undergone the Potomac orogeny.

Evidence for the Potomac orogeny, which occurred in the ophiolite complex before it was pasted (most geologists prefer the term “obducted”) onto the forerunner of the North American continent, Laurentia, is at present incomplete in NCP. No evidence for the Potomac orogeny in Pennsylvania outside NCP has yet been reported. This makes several outcrops and pits in NCP worthy of study of the Potomac orogeny.

The pegmatite rib outcrop in the Dunlap and Martin quarry is an example of rock that was probably formed during the Potomac orogeny. It was first described by Stone and Hughes (1931, p. 30) in their digression about how that quarry furnished much of the serpentine for

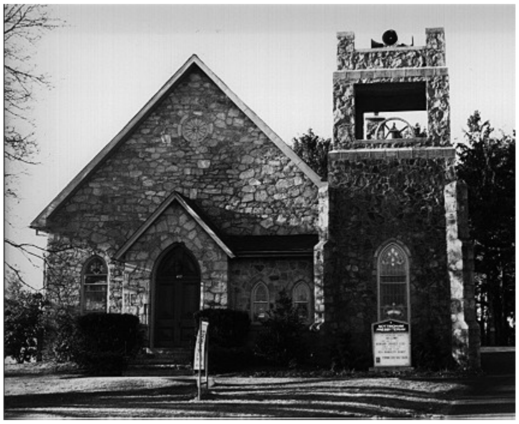


Figure 3. Nottingham Presbyterian Church, constructed of serpentine from the Dunlap and Martin quarry in Nottingham County Park.

the Presbyterian Church in Nottingham in 1878 (Figure 3), and for the William Galbrath house in New Oxford the year before they conducted their field work in 1928. Pegmatites like the one in the rib outcrop are very coarse grained, light colored igneous rocks and tend to form linear dikes which may swell in zones weakened by earlier deformation. As noted in the section on economic geology that follows, pegmatites were extensively mined for feldspar within NCP. The fact that this rib was left intact is clear evidence that the Dunlap and Martin (Rhodewalt) quarries were never worked for pegmatite. Even a thin pegmatite rib like this one would have been excavated to see if it widened into an economically mineable width. The pegmatite rib consists of a dike (tabular intrusion) of feldspar-rich rock that is a yard thick and chest-high. It was left by dimension-stone miners as they removed the serpentinite surrounding it. The rib trends roughly south-southeast from the quarry floor to the 25-foot higher south wall of the quarry.

The age of the pegmatite dike isn't directly known at present because the two serious midlife crises tended to reset the clocks in most radiometrically datable minerals. Indirect lines of evidence must be used to estimate its age. Within NCP, some of the similar pegmatite dikes occur in folds which have strange orientations that do not correspond to folds resulting from the two best known orogenies. For example, the pegmatite in pit UU (Figure 2, Point 3), on the north edge of Doe Trail about 300 feet east of the intersection with Lonesome Pine Trail, forms an arc that trends from northwest to southwest, thus defining a steeply west-plunging fold. Another somewhat larger pegmatite in NCP has a crescent shape which appears to define a steeply southwest-plunging fold. Pegmatites in NCP aren't known to cross the northwest serpentine contact into the adjacent schists, suggesting that they formed before the orogeny that pasted the serpentine into its present position. Presumably similar pegmatites located 15 miles to the northeast near Avondale cut across, and are therefore younger than, the rocks there that are assumed to be about 500 million years old. Considering these and other bits of evidence, it seems likely that the pegmatite dikes in NCP and southeastern Pennsylvania in general formed in response to the Potomac orogeny. During this series of events, several other ophiolite complexes in Theia were compacted and pushed onto and perhaps even over the various microcontinents collectively called Brandywine massifs (Faill, 1977). Some of these ophiolite complexes overloaded the Brandywine massifs and sank them deep enough to cause portions of the Brandywine massifs to melt and form hydrous pegmatitic magma. These melts intruded upward into zones of weakness resulting, in part, from earlier folding and faulting. Because such magmas were so different in composition from the serpentinites, chemical reactions occurred along the contacts, typically leaving zones of "contact rock" that are as wide as your hand. Contact rock affects the flora in NCP and is discussed further in Appendix V.

A pair of fracture sets that cut through the pegmatite rib in Dunlap and Martin quarry C makes this a useful site for research and teaching geology. When viewed from above, the fractures form X-shaped patterns with the fractures dipping to the south. Those fractures observable near the northwest end of the dike show that the far side of each fracture has moved an inch or so to the left. Logically, these fractures could be called left-handed fractures, but then geologists would have let one of their secrets out of the bag. To avoid this, geologists use the term "sinistral" (from the Latin word for "left") and then wonder why nongeologists sometimes think they are sinister! Those fractures near the southeast, or uphill, end of the dike show that the far side of each fracture has moved to the right. Geologists similarly call these fractures dextral. Taken as a group, these fractures show that the direction of maximum stress which created the fractures was from the east-northeast and west-southwest. This orientation, and the fact that the fractures are still somewhat planar, suggest that the fracturing of this pegmatite dike occurred during the Early Mesozoic Era, around 200 million years ago, when the Atlantic Ocean was born and dinosaurs were in their heyday.

Figure 4. In this view near McPherson Lake, evergreens grow on ophiolitic sea floor serpentinites while, in the background, deciduous trees that shed their leaves for the winter mark the area underlain by sediments derived from the former continent of Laurentia.

A walk along the edge

Thanks to the Taconic orogeny, we can enjoy NCP without the expense of taking a boat far out into the Theic Ocean. During this orogeny, which peaked around 458 million years ago, the Theic Ocean closed up and drove the ophiolite complex toward the former continent of Laurentia. In the process, pieces fell off its crumpled northwest side into sea sediments forming a mixture, called a mélange (French for "mixture"). This mélange was forced ahead of the ophiolite complex, now broken into slices, as it was pushed northwest during the closing of Theia. Today, Buck Trail, as it rises from the plain of Black Run in the western portion of NCP (Figure 2, between points 4 and 6), follows the contact between the ophiolitic sea floor serpentinites and sediments derived from Laurentia! You can see this contact as you look southwest from near the east end of McPherson Lake (Figure 4). This same geologic contact formed during the Taconic orogeny is also observable in

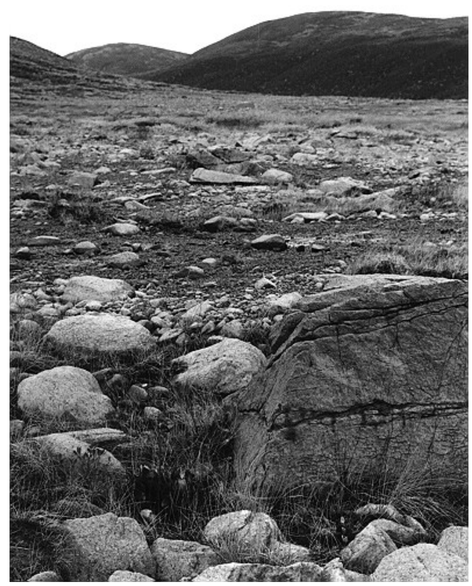


Figure 5. Ophiolitic rock exposed at Tablelands, Gros Morne National Park, Newfoundland.

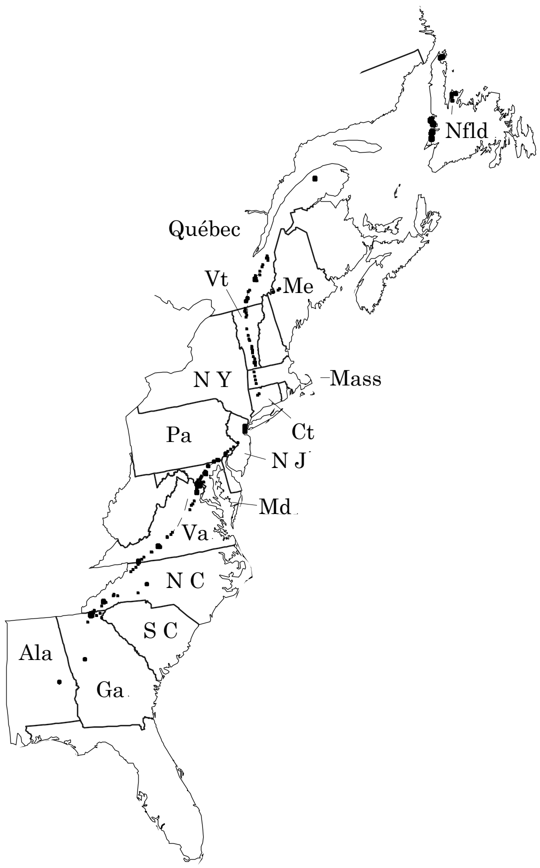


Figure 6. Map of eastern North America showing the locations of ophiolitic rocks associated with the Taconic orogeny. Most of the ophiolites have been altered to serpentinite.

western Newfoundland, Canada (Figure 5), but you have to take a boat or airplane ride to get there. You can see ophiolitic rocks related to the Taconic orogeny in many locations in eastern North America from Newfoundland to Alabama (Figure 6).

Another reason we don't have to take a boat ride to visit NCP is a result of a period of growth that occurred during the Taconic orogeny. This process, which prevented reverse movement on this talc-rich contact when Taconic forces subsided, is the emplacement of stitching granites. Although you cannot observe them in NCP itself, they have been described to both the northeast and southwest. As the name stitching granite implies, two different pieces of material (the ophiolite complex and the old continental plate) are bound together by a third material (granite intrusions) that passes through their overlapping edges. The best studied of these granites is the Ellicott City Granodiorite of Howard County, Maryland. At Ellicott City, the thread is of geologic strength, made of rock, and nearly a mile thick. Based on examination of thin slices of rock with a microscope, a nearly identical stitching granite thread occurs at Lima, Delaware County, Pennsylvania, but is merely 1/4 mile thick. Like the presumably older pegmatites in NCP, the stitching granites formed when one rock type was obducted over another, depressing the latter into the hot interior of the Earth enough to melt, or sweat out, the fraction of the underlying rock having the lowest melting point.

In addition to creating the stitching granites, the same Taconic loading metamorphosed (recrystallized at depth under heat and pressure) many of the rocks that were already in southeastern Pennsylvania, killed the algae and other small sea creatures that had happily spent about 100 million years building a limestone shelf on the southeast margin of Laurentia, and depressed the edge of the continent into an immense inland basin. This basin accumulated sediments derived from erosion of the new Taconic Mountains on the southeast edge of Laurentia for nearly 200 million years. If you live in southeastern Pennsylvania, the Taconic was *the* orogeny that gave many of the rocks that you see today their distinct characteristics.

The metamorphism of the sedimentary rocks that underlay the obducted ophiolite complex can best be observed in NCP at Pit H (Figure 2, Point 4). This small pit is located 18 yards to the southwest of the bend in Buck Trail, where it starts to gain elevation above the flood plain of Black Run. It stands out mostly because, like many of the old mine pits in NCP, it provides a favorable substrate for *Polypody* ferns. (A way to recognize *Polypody* ferns is that they remain green throughout the year.)

The pit was probably dug to provide large, flat slabs that may have been used to protect the integrity of spring water or even food and beverage being preserved in springs. In any case, it exposes a hard layered rock, perhaps best called gneiss, composed of quartz, feldspars, muscovite (white mica), biotite (black mica), chlorite (a greenish mica-like mineral), and sparse red-brown garnets. The Taconic metamorphism not only converted the original sedimentary minerals into this metamorphic assemblage, but also made them much coarser in grain size and changed their orientation. The gneiss breaks more easily along the layers following the micaceous flakes than it does across them. This direction of breakage is called schistosity and it, too, formed during the Taconic orogeny. The schistosity (or cleavage) in rocks still in place at Pit H, which are part of the Peters Creek Formation, dips to the southeast at about 40 degrees.

With so many different pieces of the Earth's crust, and even of the upper mantle for that matter, brought together near NCP by the Taconic orogeny, it will take geologic mapping beyond the park boundaries to correctly identify and piece everything back together.

One more stressful episode, but it's little strain for NCP

The most recent, but probably not the last, period of major stress to affect southeastern Pennsylvania is called the Alleghany orogeny. No effects of the Alleghany orogeny have been identified within NCP proper. Effects of the orogeny that have been identified 11 miles west of NCP have been dated at 278 ± 6 million years ago (Smith and Faill, 1994, p.185). As one might suspect from the fact that this orogeny was caused by Africa hitting North America, the Alleghany orogeny was a significant event. Many geologists in central Pennsylvania tend to think of it as *the* great granddaddy of orogenies. Certainly folding and

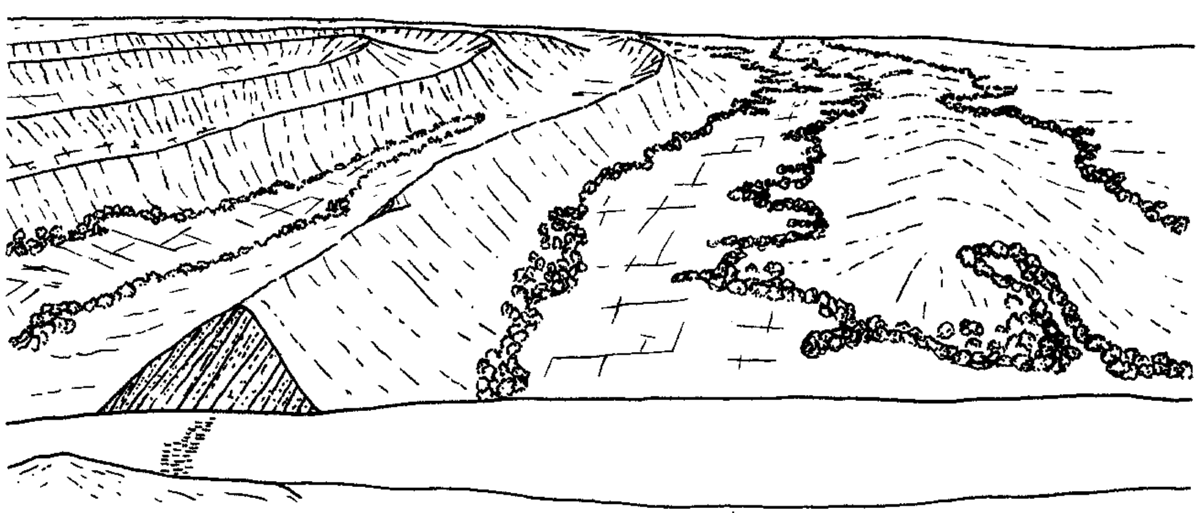


Figure 7. The Alleghany orogeny had little effect in Nottingham County Park, but extensive folding of sedimentary rocks created a mountain range in central Pennsylvania. The erosional remnants of those mountains now form long, impressive ridges where units that are resistant to erosion, such as the Tuscarora Quartzite, Pocono Sandstone, or Pottsville Conglomerate, are present.

faulting during the Alleghany orogeny gave us the impressive ridges in central Pennsylvania (Figure 7), but even these might not be as impressive as the results of the Taconic orogeny when they reach their 458 millionth birthday.

In southeastern Pennsylvania, fine-grained sedimentary rocks, already metamorphosed by the Taconic burial, were sheared along roughly east-west, high-angle fault zones. This Alleghany shearing resulted in the formation of commercial quality slate in York and Lancaster counties known as Peach Bottom Slate. Very likely, it would have been used to roof any substantial buildings that might have existed within NCP. Indeed, this particular slate, which lasts for more than 275 million years in the ground, lasts for up to 200 years exposed on a roof.

Except for the brittle extension fractures in the pegmatite dike at Dunlap and Martin's dimension stone quarry which resulted from the separation of Africa from North America approximately 200 million years ago, no orogenic forces are known to have operated in southeastern Pennsylvania since the Alleghany orogeny. Instead, the landscape was slowly sculpted, primarily by the forces of water and climatic change as described by Barnes and Sevon (1996, p. 27–30). The primary methods and rates of sculpting varied widely over time, but for the last 200 million years material is estimated to have been eroded at the rate of about an inch every 2,500 years (Way and others, 1986).

Climates Change, but Serpentine Flora Endures

The most recent glaciation approached Nottingham County Park from the northeast and advanced nearly to Hazleton, about 85 miles north of the park (Figure 8). This glacier retreated from Pennsylvania about 18,000 years ago and an irregular but overall warm-up continued until approximately 10,000 years ago, by which time the flora and climate of Pennsylvania somewhat approximated that of the present. This overall warming trend continued, however, and from about 10,000 to 6,000 years before the present, the climate was warmer and drier than it is now and prairies expanded eastward into Pennsylvania (Webb and others, 1993). Since then, the climate has cooled slightly, nearly all of the prairies have retreated westward, and Pennsylvania has endured only "Little Ice Ages" which are roughly 1,500 years apart. These

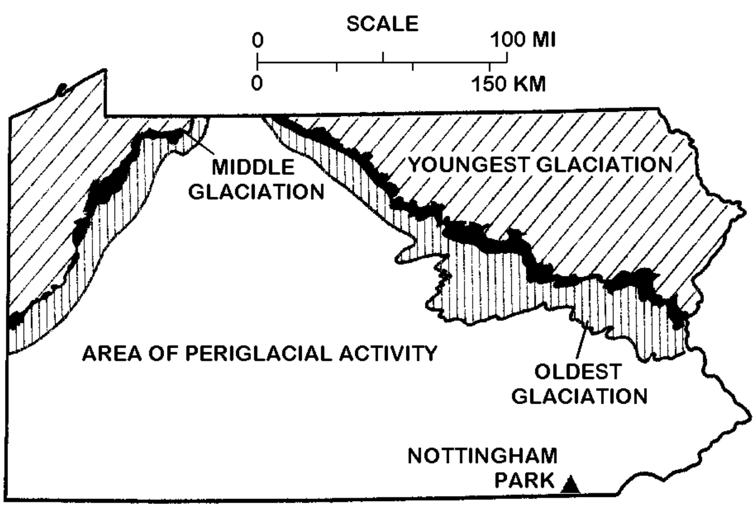


Figure 8. Repeated glaciations of northern Pennsylvania ended about 18,000 years ago. Although the glaciers never reached as far south as NCP, the park was in the area of periglacial activity, where the climate was greatly affected by the proximity of the glaciers.

1,500-year cycles of cooling and warming, which have been going on throughout the longer term trends over geologic time, are somewhat irregular. Hence, we do not know exactly where we are in the warm-up part of the cycle right now. We only know that the most recent Little Ice Age gradually ended about 300 years ago.

Figure 9. Aleutian maidenhair fern continues to fluorish on serpentine in NCP long after having disappeared from the surrounding region.

During both long- and short-term climatic cycles, floral ranges moved across Pennsylvania, almost like vacationers in search of a climate pleasing to their preferences. On most rock types in Pennsylvania the floral ranges for many species were in a constant state of change in response to shifting climatic conditions. On serpentine bedrock, however, plants were slow to establish. This is not too surprising because of the poor soils on serpentinite related to typically elevated amounts of Mg, Cr, Ni, and Co and low amounts of Ca, K, and P (See Table AI–4.) What is astounding to most of us, however, is that once the climate became less favorable for a given floral assemblage, it continued to flourish on the serpentine long after the same species had disappeared from surrounding areas having traditionally more favorable rock types and more fertile soils (Figure 9). It is almost like someone sticking out bad weather during a vacation because they had worked so hard to get there. Surely, the plants can't be smarter than people in recognizing that both extremely cold and extremely warm climatic cycles are going to return to Nottingham County Park! Instead, there appears to be a poorly understood combination of geologic, mineralogic, geochemical, physical, and biologic factors, which we call the "serpentine factor," that interact to yield a habitat suitable for the interesting plants that grow on the serpentine. (A list of 336 species and varieties of plants in the park was compiled by W.D. Vanderwerff and is available at the park office.)

Figure 10. Aleutian maidenhair fern growing in a rocky niche at NCP. Such niches in mine dumps emulate the fern's natural habitat, broken rock known as talus.

Barrens are typically areas that cannot be farmed and do not support the types of plants that grow naturally in the region around them, usually because they are underlain by an unusual rock type that yields a poor soil. At present we do not know which of the unusually abundant or unusually deficient elements is responsible for the lack of competition and hence the distinct serpentine barrens flora in portions of the park. What is known is that the park occupies one of the most extensively mined and disturbed areas of serpentine or any rock type in Pennsylvania (Figure 10). The park is unusual even when compared to most serpentine areas in that calcium (Ca) is not uniformly deficient. Indeed many areas of the park are laced with albite feldspar pegmatite dikes containing 2% CaO compared to 0.1% in normal, peridotite-derived serpentine. In other places in the park, the serpentinites contain dolomite, a calcium-magnesium carbonate, that elsewhere is mined and heated to make dolomitic lime for agriculture. In NCP, the dolomite was naturally formed by the CO_2-bearing fluids that converted pyroxene-bearing peridotites into serpentine. Some of these areas contain 3 to 5% readily available CaO, mainly as dolomite, and are not likely to support a diverse serpentine flora, especially if disturbed. Other serpentinites in the park may have been derived from pyroxenites and likely contain 1 to 5% CaO; the soils derived from them are also not likely to support a diverse serpentine flora once disturbed. When rocks such as these are disturbed, the leaching of CaO by naturally acid rainfall (pH 5.1) is likely to continue for at least a few hundred years. Some ravines in the southeastern part of the park have accumulated boulders of gabbro that were eroded from adjacent, topographically higher areas. These gabbro boulders likely contain approximately 10% CaO. These ravines may never have supported a diverse serpentine flora. As a result of this unusual and variable bedrock, the park offers a rare opportunity for researchers to study the role of Ca and other variables in the serpentine floral factor. Ca is frequently considered to be an excellent blocker to protect plants from an overabundance of Mg and possibly Ni as well (Brooks, 1987).

Figure 11. Plants growing on serpentine in the harsh climate of Gros Morne National Park, Newfoundland. Note the lizard-skin appearance of the serpentine rock just above the center of the photograph.

Today, the Aleutian maidenhair fern seems to prefer selected niches in the park where mining removed soil and exposed fresh Ca-bearing rock (Figure 10). This same type of fern today thrives in the harsh climate of western Newfoundland *on serpentine* in protected spots where seeps provide a little calcium beyond that normally available from serpentine! Perhaps this boreal relict at Nottingham is telling us is that the sparsely vegetated Tablelands in Newfoundland provides us with a glimpse of what Nottingham Park looked like a few thousand years after the most recent glacier retreated from Pennsylvania (Figures 5 and 11).

Figure 12. The dense growths of *Smilax*, or greenbriar, at Nottingham Park would have provided great cover for Robin Hood, but his men would not have been very merry.

Although the scarcity of potash, K_2O, in serpentine rocks is not generally considered to be part of the cause of the serpentine barrens factor, the serpentines in NCP contain less than 100 *parts per million* K_2O. For comparison, quartz-mica gneiss underlying "normal" flora in NCP contains about 3%. Any process that makes more potash available to the flora growing over the serpentinites is likely to reduce the competitive edge that serpentine flora once had over more aggressive floral relatives. Processes that might make potash more available in NCP include past spreading of feldspar-mining waste that probably contained around 1.5 to 2.0% potash. Fortunately, nearly all of the potash in the feldspar mining waste is present in silicate minerals such as biotite (a dark mica), muscovite (white mica), and microcline (the less common of the two feldspars mined), from which the potash is not readily available to plants. Only when the feldspar waste is heated by burning is the rock broken down more rapidly, making the potash available sooner. Stone and Hughes (1931), for example, describe how feldspar at the Sparvetta Mine, 0.5 mile south of the southwest corner of Nottingham County Park, was heated to shatter the rock prior to grinding. Another process that would increase the availability of potash to greenbriar (S*milax*, Figure 12) is the burning of vegetation, particularly trees. This won't increase the total amount of potash in NCP which might fertilize S*milax*, but it will make it available much more quickly by converting the potash stored in the forest canopy into soluble potash lye (KOH, an extremely alkaline chemical formerly extracted from fresh wood ashes and cooked with animal fat to make soap). Unless timber is removed from NCP, fires will increase the rate of potash recycling. Without fire, trees are capable of storing potash for up to a few hundred years.

Figure 13. An area of the serpentine barren in NCP that is free of greenbriar and is classed as savannah.

On the better drained spurs, where greenbriar does not thrive, the serpentine today provides a suitable local habitat for grasses which otherwise now thrive only in warmer, more southerly locations (Figure 13). What a queer rock this serpentine must be to provide a sanctuary for floral refugees from climates today found *both* to the north and the south. These same serpentine barrens may have been providing a refuge to northern species for nearly 18,000 years and southern species for up to 6,000 years.

Figure 14. Moss phlox (*Phlox subulata*) develops a pendulous habit in abandoned dimension-stone pits at NCP, where competition is minimal.

Today, some of the most interesting plants thrive on the areas most disturbed by mining. Mining for the feldspar mineral albite in the period roughly from 1890 to 1920 has produced steep-sided pits and trenches where *Polystichum* and *Polypody* ferns thrive rather than the more ubiquitous greenbriar. Also, as noted above, disturbing the albite has released Ca, enabling some plants to expand their territory beyond Ca-bearing seeps. Sunny ledges in abandoned dimension-stone pits provide ideal niches for moss phlox (*Phlox subulata*, Figure 14) to develop an extravagant pendulous habit. Dumps of coarse, chromite-bearing rock excavated as recently as World War II seem to provide sites resistant to greenbriar because of their rapid drainage. Unfortunately, even these dumps will become choked with water-retaining humus in less than one hundred years.

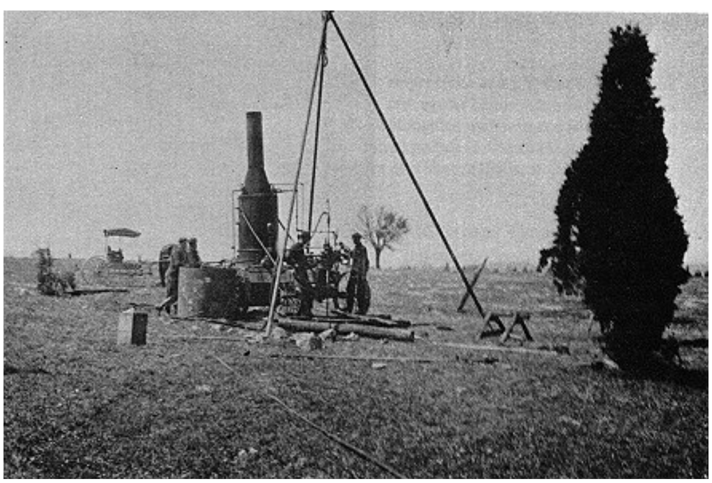


Figure 15. Diamond-core drilling for chromite at Wood's Mine, Lancaster County, circa 1920 (Smith, 1978, Figure 85). Note the absence of thick growths of greenbriar on the serpentine barrens at that time. One hundred years earlier, the mineralogist H. H. Hayden (1814) wrote of this area: "The mind seems involuntarily to feel the impulse of melancholy. … A gloomy silence pervades around, while every road … bears the most decided marks of sterility."

Other than some mined areas, it is only on the better drained spur tops, which perhaps mimic the dry conditions that prevailed from 10,000 to 6,000 years ago, that greenbriar does not appear to be rapidly encroaching. The reasons for the rapid encroachment elsewhere are not known for sure. Certainly, greenbriar is a native species to this region, but aerial photographs and a few surviving old photographs of the serpentine barrens in general (Figure 15) suggest that it is becoming a threat to the more charismatic species (Figure 16). If it is expanding more

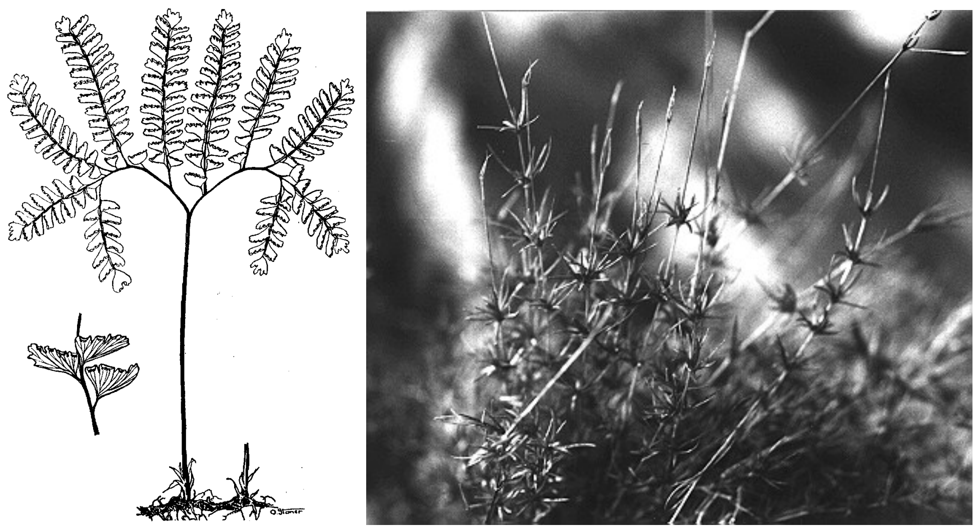


Figure 16. Aleutian maidenhair fern (*Adiantum aleuticum* (Rupr.) Paris, left) and moss phlox (*Phlox subulata*, right) are among the species threatened by the spread of greenbriar in serpentine barrens. (Drawing at left from Wherry, 1937.)

rapidly in NCP, then perhaps one could blame the albite mining and other calcium- and nutrient-releasing practices for making the soils less infertile. Such processes might increase competition from species introduced from beyond the serpentine. Certainly albite mining has disrupted natural drainage and expanded or even created wetlands where none likely existed before. For example, this appears to have occurred at several places in the hollow just east of Feldspar Trail and south of Black Run where waste rock from albite mining was placed in dumps partly blocking natural drainage in the hollow. People as well as gravity tend to move rocks downhill, and when people do it new habitats are rapidly created. But other, only indirectly geological, factors also need to be considered to understand the apparent expansion of greenbriar. For example, might rabbits have more effectively controlled greenbriar in the past than now?

Yet another property of serpentinite that might contribute to the barrens effect is its greater solubility than that of schistose gneiss. As a result, soils over serpentine are thinner, and can dry out thoroughly because of their thinness and the scarcity of deeply rooted large trees to provide shade and to pump water to the near-surface. The dark color of serpentine that allows it to absorb heat, combined with its ability to hold heat, may play an additional role in creating a hospitable environment for species that normally grow in warmer climates.

You can clearly see the pronounced effect of the geology on the flora along Buck Trail to the south of McPherson Lake and Black Run (Figure 2, Point 5; Figure 4). Here, as Buck Trail gains elevation above Black Run, it tends to follow the geologic contact between serpentine to the southeast and the more normal schistose gneiss to the northwest. A composite sample of gneiss analyzed for this study contains approximately 2% CaO (lime), 3% K_2O (potash), and 0.1% P_2O_5 (phosphorus). This gneiss yields fairly fertile soils that support a healthy deciduous forest and provide a nice contrast to the serpentine barrens. Buck Trail may be a very old trail that followed the contact between pasture and barrens. The floral contrast here is so great that most geologists would use the presence of pitch pine (*Pinus rigida)* and greenbriar to map the limits of the serpentine just as early farmers would have two hundred or more years ago. What other species do you think reveal the geologic contact in this area? Note that greenbriar continues westward at creek level along the south side of Black Run.

Figure 17. Modern serpentine carvings. From top: walrus by ᐁᐃᓂᕐ, Inuit, Canada; turtle by Freeman Owle, Cherokee Nation; seal by Irene Kator, Repulse Bay, NWT, Canada.

Why do you think the greenbriar senses that the serpentine continues west along the creek? If you are not sure, consider asking a Nottingham Park staff member.

A more subtle floral anomaly occurs in the area of Point 6 (Figure 2). Here, there is a vague line of rhododendron in an area expected to be underlain by serpentine. Rhododendron is common on the gneiss across the hollow, but scarce on serpentine elsewhere in the park. However, the serpentine with rhododendron growing on it is different than most of the serpentine in the park. Someone long ago must have thought so, too, because they dug around it leaving several small, vague pits. This digging reveals that the rock has been naturally broken (brecciated) into small fragments and recemented with a group of brown ferric iron minerals that is commonly called limonite. To date, no one has studied this to be sure, but it is possible that the additional supply of iron makes this area of serpentine more favorable for rhododendron than serpentine usually is. Conversion of the original ferrous iron in the partly serpentinized peridotite to ferric iron also would have tended to make the soil in the area more acidic, another condition which is generally favorable for plants such as rhododendron. (For additional information, see Appendix 3, page 34.)

Economic Geology and Mining

Quarrying in southeastern Pennsylvania began about 11,500 years ago. This was before the climate had fully recovered from the retreat of the most recent glaciers from northeastern Pennsylvania around 18,000 years ago. Metarhyolite for making cutting tools was extensively quarried beginning around 11,500 years ago a few miles west of Gettysburg, Adams County, and was likely traded to Native Americans living in the area around and far beyond the NCP area. At about the same time, jasper from less developed quarries in Berks and Lehigh counties was also likely used for tools over a wide area (Hatch and Miller, 1985). A warm and dry period that was to last 4,000 years began about 10,000 years ago. Following that, steatite, typically a mixture of talc, serpentine, and chlorite, was carved to make ornaments and rodent-resistant bowls by Native Americans in the Late Archaic period from approximately 3500 B.C. to around 1000 B.C. Two areas known to have produced steatite for bowl carving were located about 10 miles west and 15 miles north of NCP, so it is very likely that such bowls were used in the area of NCP. Scars on outcrops caused by removal of material for bowl carving have not yet been found within NCP, but the potential exists. Serpentine was, and still is, a favorite carving medium for Native Americans, among others (Figure 17). Their carvings along the Susquehanna River at Bald Friar, Maryland, were so spectacular that geologists of the Second Pennsylvania Geological Survey couldn't resist violating the Mason-Dixon line to include them in their report on Lancaster County, Pennsylvania (Figure 18).

Most likely, early settlers from Europe probably avoided all but the open savannah portions of the barrens. These savannahs may have provided unobstructed views for hunting, but little else. The soil was not suitable for farming. Of the minerals that were of greatest interest to colonists in Pennsylvania, limestone is usually associated with far more fertile soils, and any attempt to utilize chromite cobbles found in the creeks for iron ore would have resulted in serious frustration.

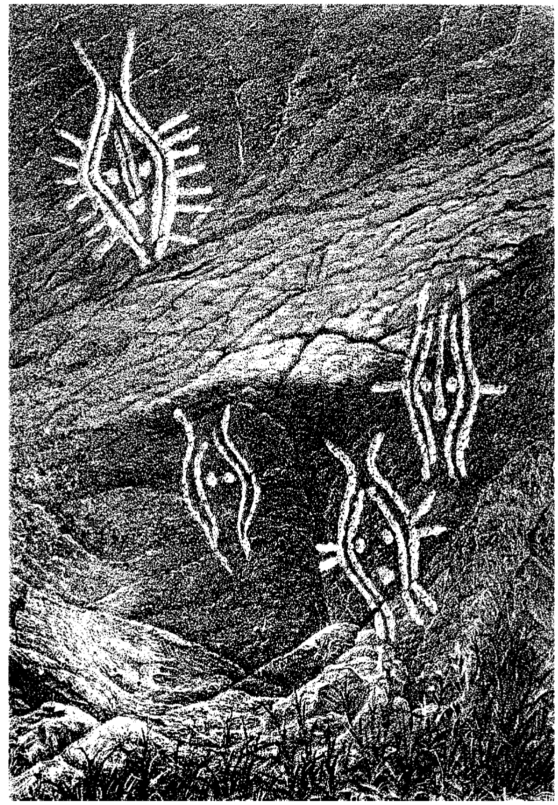


Figure 18. Native American carvings in serpentine near the Susquehanna River about a half mile south of the Pennsylvania–Maryland state line. (Frazer, 1880, Plate 1)

Chromite mining

Mining for chromite probably began by 1810 at Bare Hills, Maryland, when yellow paint made from the chromite sold for $2.00 per ounce. The discovery of chromite is credited to an Englishman named Henfrey, possibly the Benjamin Henfrey who, in 1797, promoted the deposit in Lancaster County that became known as the Gap Nickel Mine, although he never recognized nickel at that deposit (Smith, 1978, p. 275–282)! In 1811, a gentleman identified only as Mr. Smith discovered a chromite deposit in Chester County, Pa. (Pearre and Heyl, 1959). By 1832, chromite was discovered at the site in NCP that was to become the William Scott Mine.

Most of the early chromite exploration and development revolved around Isaac Tyson, Jr. According to Pearre and Heyl (1960, p. 731), "…between 1828 and 1850 the world's supply of chromium came almost entirely from Isaac Tyson's mines." This Tyson accomplished by recognizing the association of chromite with the barren nature of serpentine terrane and then purchasing or leasing every property where chromite might be found in commercial amounts. Much like a master chess player, he attempted to control the board with the least exposure. On July 4, 1835, he bought the rights to Scott's vein in NCP for $5,000 (Anonymous, 1935–6). This, no doubt, set the precedent for the spectacular 4th of July celebrations in NCP! Pearre and Heyl (1959) report that Scott then opened a new mine, presumably on a different vein, but so close to Tyson's Scott Mine that it drained into it. Tyson doesn't seem to have enjoyed pumping water from Scott's second mine for free, so when litigation failed he closed his mine. Exactly what happened next isn't known, but if William Scott didn't enjoy pumping either, we can make a pretty good guess. Pearre and Heyl (1959) suggest that the Scott Mine in NCP produced between 3,000 and 6,000 tons of massive chromite and reached depths of approximately 200 feet. Eleanor B. Knopf (1922) reports that the larger chromite dumps in this area were being used for road aggregate in 1917 and implies that paving roads with chrome ore was not an astute business decision. Back to William Scott, he and a new partner named Joshua Lowe sold the Lowe-Line pit on the Pennsylvania-Maryland border in Lancaster County to Tyson in 1838. The Line Pit yielded very high quality ore, and, being a bit farther from a geologic contact, might have required less pumping. Being a shrewd entrepreneur, these factors were probably more than enough to convince Isaac Tyson to put aside past differences.

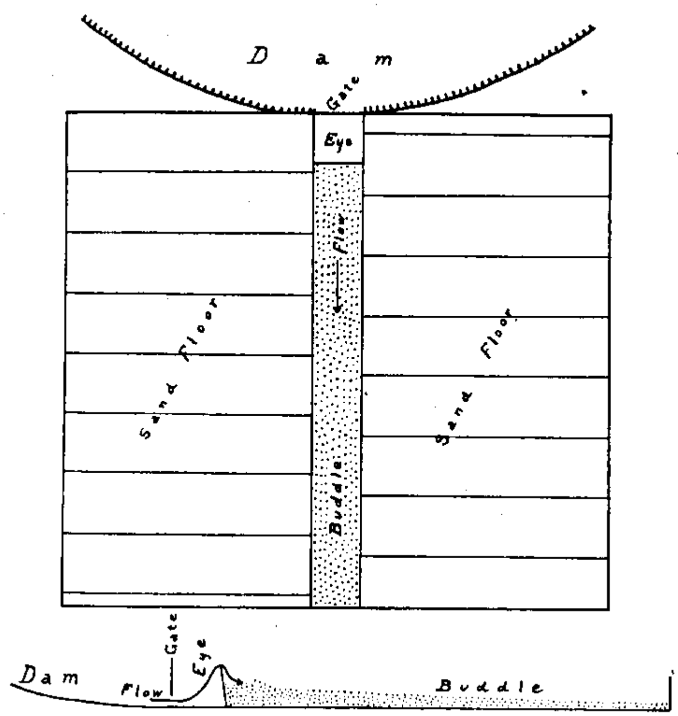


Figure 19. Diagram of a buddle, a device that was used to wash chrome-bearing sand. The stippled central part was usually 1 foot wide. (Singewald, 1919, Figure 16)

Placer chromite mining in the area of NCP was considered to be worthwhile if "a thimble full of chromite could be taken from a shovel full of sand" (Mr. Burt, personal communication to P. A. Dunn, 1961). Extensive areas along Black Run ran better than a thimble full and unconsolidated stream placer deposits were worked by E. Mortimer Bye of Wilmington, Delaware, at least as early as 1874. Bye had been the mining superintendent at the Moro Phillips (Pine Grove) mine, just northeast of NCP, since the late 1860's (Pearre and Heyl, 1959). At this Moro Phillips mine, which Isaac Tyson had acquired in 1839, Bye encountered serious water problems and installed new pumps in 1872. (Pearre and Heyl (1960) found old equipment indicating that water had to be pumped through a hefty 10-inch pipe. Today the mine is reported to be used as a good source of water for food processing.) Perhaps because of the excess water, Bye closed the Moro Phillips mine before the summer of 1874 after having produced only 250 tons of chromite (Anonymous, 1935–6). F.A.L.K.W. Genth (1875, p. 41) reports that the Moro Phillips (Pine Grove) mine was 100 feet deep and had galleries (stopes or drifts) about 80 feet long. It appears that Bye had apparently had enough problems with water at this Moro Phillips mine and now decided to recover placer chromite, this time having the water work for, instead of against, him. Where moral principles are not involved, it was better then, as now, to "Join 'em if you can't lick 'em."

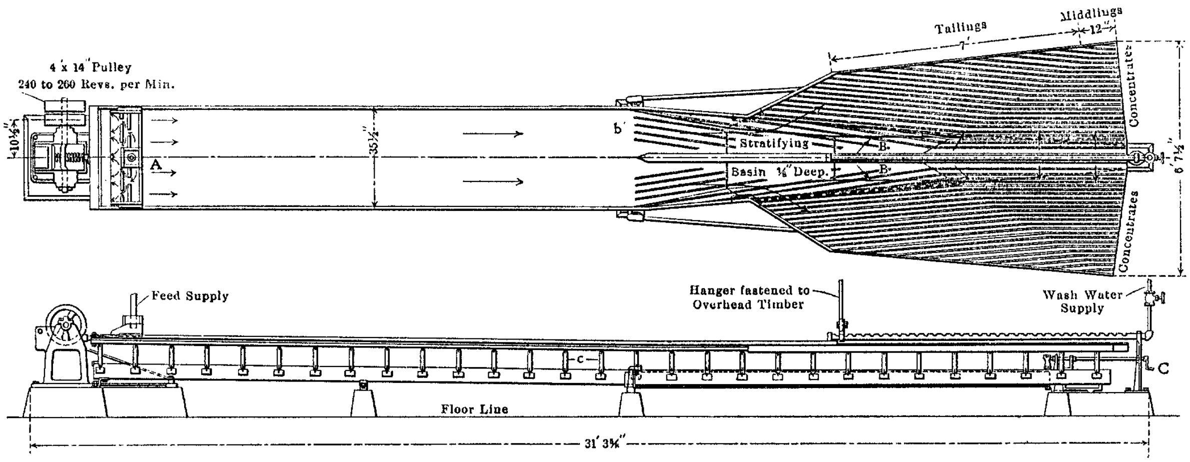
Technology likely varied from chrome placer to chrome placer and, because of the low cost of the materials involved, was likely a tinker's delight. When water was abundantly available in the springtime, sluicing was probably used in the early stages of placer mining along Black Run. Lower water conditions resulted in use of an open trough, known as a buddle (Figure 19). The operator shoveled sand that had been screened to less than 0.1 inch from the raised sand floor on one side of the buddle into the upper end of the trough. The sand was spread out by a stream of water released from a dam. After several washings, the water carried the lighter minerals away and the heavy minerals remained in the trough. The heavy-mineral concentrate was then shoveled onto the other sand floor. (Singewald, 1919). Because chromite typically has a density of around 4.6 (meaning that chromite weighs 4.6 times as much as an equal volume of water) and associated magnetite has a density of around 5.2, it was possible to wash away the chromite and accidentally concentrate the magnetite. This was especially a problem in the early days when electromagnets were unavailable to improve the chromium content of the concentrate by removing the highly magnetic magnetite (Fe_3O_4).

Figure 20. Concrete foundation piers of a mill constructed in NCP during World War I for the recovery of placer chromite.

Figure 21. Manufacturer's plate for a James separator that was operated at the chromite placer mill in NCP.

We do not know when Mortimer Bye stopped working chromite placers along Black Run, but by 1881 he was working placers in the White Barrens, 5 miles east of NCP. The *Coatesville Weekly Times*, April 7, 1894, proclaimed Bye to be the "chrome king of Chester County," just as Isaac Tyson had been the chrome king of Pennsylvania and Maryland from approximately 1810 to 1865. In 1875, Genth reported that the Pine Barrens of West Nottingham Township had provided at least 1,500 tons of sand chromite and that there were still reserves of 10,000 tons of placer chromite containing 40 to 50% chromic oxide remaining on a 20-acre tract near the Octarara (sic) Creek. The production data likely included Pine Run, but the reserves probably referred exclusively to the area of Black Run in NCP. Knopf (1922) reports that placer chrome mining took place in Chester County from 1897 to about 1900, but does not give a precise locality.

Additional efforts to recover placer chromite from Black Run were made during World War



PLAN AND ELEVATION, JAMES SLIME CONCENTRATING TABLE

Figure 22. Diagram of a James separator, or "James Slime Concentrating Table," as was used at Nottingham County Park during World War I. (Hoster, 1908, p. 1149)

I, when chromium was desperately needed to make hard-steel armaments. This demand resulted in construction of a mill to recover placer chromite on the north side of Black Run, approximately 200 yards west-northwest of the north end of McPherson Lake (Figure 2, Point 7; Figure 20). If you visit the site today, you can see the concrete foundation piers and partly sunken flooring that remain. In 1974, John Orcutt found the copper manufacturer's plate (Figure 21) for a James separator at the site. NCP staff have traced this to patent drawings and a scale model has been built. The modern equivalent of a James separator is called a Wilfley or Deister Table. Tables such as this have a sloped, oscillating surface over which a slurry of water and relatively uniformly sized (prescreened) sand is fed at a uniform rate (Figure 22). By World War I, such tables were generally powered by electric motors. When properly "tuned", such tables separate minerals by density and, to a lesser degree, by particle shape. The heaviest materials climb up to the far side of the table, opposite the side where the slurry was introduced. A barrel placed where the chromite "train" passed off the end of the table caught the chromite concentrate and allowed the carrier, which was water, to simply overflow. The various lighter minerals, such as quartz, serpentine, and mica, came off the two long sides of the table and were disposed of by a variety of means. Such tables generally only work with grains less than about 3/16 inch and much valuable chromite might have been lost at the screening stage. Whether the coarse, screened-off chromite was recovered by the older, less size-dependent procedures, such as sluicing or buddling, is not known. You will probably be able to see some of these processes for separating chromite demonstrated at NCP during the annual Industrial Heritage Day celebration for years to come. Detailed information is presently lacking, but it appears the James Table along Black Run was barely tuned when the Armistice ending World War I was declared on November 11, 1918.

The National Minerals Company, having Henry S. Pyle, grandnephew of Mortimer Bye, as one of its co-operators, reopened the Scott and Kirk mines during World War I, but little if any new ore was mined at these or their other mines. Pearre and Heyl (1959) also report that between 1932 and 1937 the Bethlehem Steel Company and the U.S. Bureau of Mines

Figure 23. A portion of U.S. Department of Agriculture aerial photograph AHK–4D–174, taken on November 18, 1946. NCP today includes the rugged, wooded area that makes up most of this section of the photograph. Vegetation scars suggest that the Scott (A) and Engine (B) shafts were reexcavated shortly before the photograph was taken. The Scott Mine was one of the six largest producers of chromite in Pennsylvania (Pearre and Heyl, 1960, p. 735).

conducted a magnetic survey over much of the State Line Chromite District and an electrical resistivity survey over one of the Moro Phillips (Pine Grove) mines just east of NCP. Substantial drilling was done at the Moro Phillips mine in 1937, but this probably only increased the ability of the old mine to collect water.

World War II triggered the most recent phase of chrome prospecting in the NCP area. Based on U.S. Department of Agriculture aerial photograph number AHK–4D–174 (Figure 23), taken November 18, 1946, both the Scott and Engine shafts were cleaned out and prospected shortly before the photo was taken. When two such adjacent photos are viewed in stereo, it is possible to look down the freshly cleaned out shafts! The Scott Mine shaft shown in this photo plunges to the south-southeast and is located 548±10 feet east-southeast of the intersection of Park and Cemetery Roads and 215±10 feet south of the center of Park Road. In addition to the shaft, a recent mineral-exploration trench 35 feet wide by 98 feet long extended just south of east from the shaft. An older trench trending S30°W extended 130 feet from this same shaft. A second, smaller shaft having a 50-foot-long, N50ºW trending trench is located 90 feet northeast of the main shaft. This smaller shaft might be William Scott's second shaft which drained into the first shaft, which Scott sold to Tyson in 1835. The

Engine Shaft, shown on the 1946 airphoto, is wider at the top, nearly vertical, and located 1840±25 feet east-southeast of the intersection of Park and Cemetery Roads and 337 feet south of the center of Park Road. A narrow trench, 210 feet long, trends slightly north of west from the Engine shaft.

The 1946 airphoto also suggests that another pit exists on the north side of Park Road, approximately along the north contact of the serpentine. It is located 970±10 feet east-northeast of the intersection of Park and Cemetery Roads. (Allen V. Heyl, personal communication, November 1998, notes that he and Nancy C. Pearre observed a small mine or prospect in this general area in the mid 1950's.) A group of three possible pits, each somewhat elongated in a north-south direction, is centered 1135 feet east of the same intersection. Because these are within the area believed to be underlain by serpentine, it is tempting to equate them with Genth's (1875, p. 41) mention of Lewis Merath's three pits which yielded about 50 tons of lode chromite around 1845 in West Nottingham Township. Title searches for the whole NCP area might resolve this and other issues.

The Kirk Mine is unmentioned by Genth (1875) and Gordon (1922). Knopf (1922) noted that as of 1918 the Kirk Mine was about 45 feet deep and that Edward Kirk was unwatering it with horsepower. Pearre and Heyl (1960, p. 780) note that at the Kirk Mine one old shaft was about 65 to 75 feet deep and a second, about 20 feet to the southwest, was reported to have a southeast trending drift. Pearre and Heyl (1959) report that the Kirk Mine was unwatered by J.A. Wilson in 1941, and that about 300 tons of rock and debris were removed. B.C. Warnich and Company of Wilmington may also have unwatered the Kirk Mine at about the same time. No significant, recent vegetation scars are visible in the Kirk mine area on the 1946 aerial photograph.

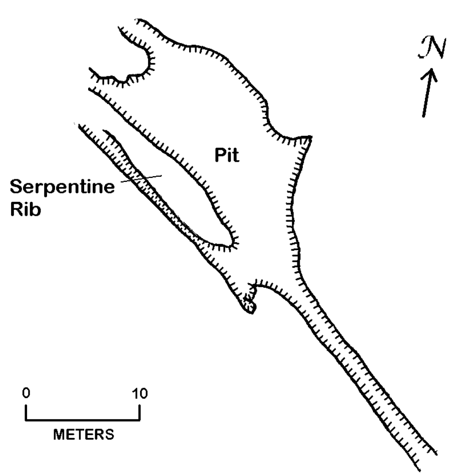


Figure 24. Plan view sketch of pegmatite quarry AVH 3.73, modified from Figure 3 of Stone and Hughes (1931). This may be the Mansell Tweed quarry of Hopkins (1898, p. 17), making it the oldest feldspar quarry in Nottingham County Park.

Feldspar mining

In general, nonmetallic mineral resources do not seem to have gotten as much attention from historians and economic geologists as their more glamorous metallic brethren. In part, this may be due to a primal attraction toward shiny materials and perhaps also to their higher unit value. Whatever the cause, the mining of feldspar, a group of nonmetallic minerals used in ceramics, does not seem to have been as carefully documented as that of chromite. In its brief heyday, however, Pennsylvania was probably one of the three largest producers of feldspar in the United States.

The presently available geologic literature does not mention feldspar in the NCP area until 1898 (Hopkins, 1898, p. 16–17). Hopkins, an assistant professor of economic geology at the Pennsylvania State College, refers to the area as the Sylmar district and notes that the name of the town, which straddles the Mason-Dixon Line, is derived from one syllable each from

"Pennsylvania" and "Maryland." In this district he describes three active quarries, one for serpentine and two for feldspar. The Campbell serpentine quarry is reported to be located midway between Sylmar and the feldspar quarries. Based on its geological description, which includes mention of the serpentine being cut by a pegmatite dike 1 to 2 feet thick, and its location, this is very likely the Dunlap and Martin serpentine dimension stone quarry, also known as the Harry Rhodewalt quarry in 1927.

As of 1898, the largest feldspar quarry in the Sylmar district was owned by Mansell Tweed of Newark, Delaware. This quarry was described as working a N50°W trending pegmatite divided by a tongue of serpentine at the "south" end. The quarry was 150 feet long, 30 feet wide, and 60 feet deep. It is very likely the location sketched in Figure 24. The second feldspar quarry noted by Hopkins was operated by Eugene Monahan of Avondale, Pennsylvania. Hopkins locates it 600 feet *southeast* of Tweed's Quarry on the line of direction of the vein, but *northwest* makes more sense. If so, then Monahan's quarry, "recently opened" as of 1898, evolved into the large Brandywine Quarry operation. This is the quarry known as the "Mystery Hole" that you can visit along the Feldspar Trail, (Figure 2).

Figure 25. Buhrstones, waste piles, and ruins of a mill at the Sparvetta Mining Company, south of NCP, where part of the output from the Brandywine Quarry was ground. (Stone and Hughes, 1931, Plate III)

Bastin's (1910, p. 68–70) report on field studies made in 1907 describes three quarries in the Sylmar district. Two of these, Sparvetta and Keystone, lie to the southwest of NCP, and the third is the Brandywine Quarry. Because Bastin was summarizing the feldspar deposits of the whole United States, one cannot rule out the existence of smaller, active feldspar quarries in NCP in 1907. Bastin describes the Brandywine workings as 200 feet long by 70 to 80 feet wide by 90 to 100 feet deep and having a long axis of N10°W. The pegmatite was reported to be 12 feet wide at the south end of the pit but widening to the north. Part of the output from the Brandywine Quarry was shipped to the nearby Sparvetta Mining Company for grinding (Figure 25). All three quarries are reported to have been producing only soda feldspar, known today as the mineral species "albite" after the Latin word *albus* for its white color. Bastin (p. 69) notes that, as of 1907, the equipment consisted of a derrick, steam hoisting engine, steam pump, and steam drills. Fifteen to 18 men were employed.

Watts (1916, p.156–158) notes that the Brandywine Quarry was abandoned and water-filled during his visit and that the dike was 80 feet wide at the north end. Presumably because of its abandoned state, Watts refers to this as the "Old Brandywine Quarry." The quarry Watts referred to as the Brandywine Quarry is likely the area of AVH 8.79, located in the eastern part of the park. Watts noted that the pegmatite dike at this eastern quarry is about 20 feet wide and that it was being mined over a surface length of about 100 feet and to a depth of 60 to 80 feet. Pure picked albite from this quarry is reported to be unusually sodian: 9.74% Na_2O and only 0.24% CaO. One half mile southwest of AVH 8.79 and one quarter mile east of the "Old Brandywine Quarry," a "New Brandywine Quarry" was reported to be under development on pegmatite stringers that were 6 to 10 feet thick.

Figure 26. Feldspar pit in NCP described as "near Cooper log house in The Barrens, showing swell and pinch of the dike." (Stone and Hughes, 1931, Plate IV) (Close examination will reveal what appears to be a meteorite about to make impact. This image appeared in all copies of Stone and Hughes' report. Is it purely coincidental that, one year after the publication of this report, Ralph Stone teamed up with Eileen Starr to publish *Meteorites Found in Pennsylvania*?)

Stone and Hughes (1931) described eight areas of feldspar quarries and pits in the NCP area in addition to the nearby Keystone and Sparvetta mines. In 1927, primary mining had ceased at the Brandywine Quarry, but the dumps had undergone secondary recovery of albite, possibly for use as a filler in linoleum and aggregate for surfacing private roads. Stone and Hughes (p. 26) note that Mr. Rhodewalt informed them that the final depth of the Brandywine Quarry was 115 feet based on information from the former superintendent. Also, as of 1927, dump material from feldspar pit AVH 4.74 of the present usage (Figure 26), "… just north of a log house known as the Cooper place," was being used for road aggregate and that, nearby, sugary sand was being recovered for building sand. Stone and Hughes noted that Mr. Rhodewalt had recently screened some good albite from the north end of the feldspar pit AVH 6.77 (Jones Pit). Stone and Hughes (1931, p. 30) further confirm the location and identity of the serpentine dimension-stone quarry known as Dunlap and Martin in the present usage by conversation with Mr. Rhodewalt, noting that it is located on a small branch of Black Run 200 yards north of the Martin Ferguson house.

Note: Pearre and Heyl (1960, p. 816–818) summarized the available feldspar mining literature. The numbers that they assigned occurrences in their text (1. through 8., p. 817) and on their plate (most of the series 70 to 79 on plate 41) have been combined to designate the occurrences in the present study. For example, AVH 4.74 is occurrence number 4 described on page 817 of Pearre and Heyl and located as occurrence 74 on their plate 41. In addition to the nine feldspar pits summarized by Pearre and Heyl, there are probably more than 50 additional feldspar quarries and pits in NCP. Most are not described here for the

APPENDIX I

Bedrock of Nottingham County Park

Composite rock samples for laboratory analysis were collected at 11 sites in NCP. In addition, single samples were collected from what appear to be two late ultramafic dikes. Because of the dense vegetation, nearly ubiquitous serpentinization of ultramafic rocks, and, except for stream beds, lack of natural outcrop, bedrock sample sites were selected primarily to maximize geographic spread within the park. Consideration was also given to obtaining fresh, *i.e.*, unweathered samples. All samples therefore had to be collected from artificially created exposures.

Two samples were collected from albite pegmatites because perhaps 90% of the mining in NCP was done in pursuit of albite. Dumps from albite mining are widespread and were, in the past, widely used for road aggregate. Furthermore, albite is a potential source of calcium which might degrade the serpentine flora factor. Seven samples of serpentinite were collected because serpentinite, of whatever protolith, appears to underlie most of NCP and is the ultimate cause of the unique flora. Two of the serpentine samples were collected from small quarries used by NCP for fill, both because they provided sampling opportunities and because of concern over possibly introducing unnecessary calcium. (In the senior author's semi-Pennsylvania Dutch, they are wonderfully low in calcium.) Three of the serpentinite samples were from dumps associated with pits or shafts dug in search of chromite, but care was exercised to ensure that only barren, development rock was sampled. The two remaining serpentinite samples were from excavations dug either to produce or search for serpentine dimension stone. One sample of anthophyllite-bearing rock from the extreme southeastern part of NCP was composited from boulders blasted to improve West Ridge Road. The last composite sample was collected from a small gneissic dimension-stone pit. The two single samples of ultramafic dike rock were collected from the side of a pegmatite-producing trench (sample NN) and the dump to a chromite mine (sample Kirk 3).

The samples of albite pegmatite were true channel samples cut across dikes and weighing approximately 7 kg each. The serpentinite and anthophyllite-bearing composite samples weighed 2.2 to 3.5 kg each. They were collected by gathering 15 of the freshest appearing blocks from a mine dump or quarry pile, reducing the blocks to cores that were 8 to 10 cm across, and bagging the 12 freshest cores. The gneissic dimension-stone sample was obtained from the 10-cm cores of only five slabby blocks. Brief descriptions and weights of these eleven samples are listed in Table AI–1.

The mineralogy of this same set of bedrock samples is summarized in Table AI–2. These identifications are based on X-ray diffraction scans. X-ray diffraction is a technique that indirectly reveals the presence of mineral species based on the mineral's interatomic spacings. We attempted to divide the minerals into three abundance groups based on the relative intensity of the characteristic spacings for each mineral in the X-ray diffraction patterns. This approach is rather empirical and only approximates grouping the minerals as major (>20%), minor (5 to 20%), and trace (< 5%) components. The X-ray data for samples NCP 1 and NCP 2 suggest that they are somewhat normal granitic pegmatites. Based on other observations, it appears that at least portions of the larger, commercial pegmatites would have been more albitic and less rich in potash-bearing species. For example, 2 of 3 composites of 12 nearly pure feldspar chips, each 3 to 4 cm, from AVH 1.70, AVH 6.77 (Jones), and the fenced pit (G) on the south side of the Nature Trail were estimated by X-ray diffraction to consist almost entirely of plagioclase feldspar containing approximately 97 to 100% of the albite end member. Sample AVH 6.77 is from the pegmatite located farthest to the southeast in NCP. It contains albite and potash feldspar at a ratio of approximately 6:1. Also, the albite in this sample appears to be much more calcic (anorthite-rich) than the other two. The details of the feldspar mineralogy are presented in Table AI–3.

Samples NCP 3 through 9 are all ostensibly serpentinite but are rather different mineralogically. Sample NCP 3 contains the most relict forsterite (magnesian olivine) and is closest in composition to the original ultramafic rock. Sample NCP 4 is only slightly more altered from forsterite to lizardite serpentine. No forsterite was detected in sample NCP 5, but neither were any secondary carbonate minerals. Samples NCP 6, 7, and 8 contain progressively larger amounts of naturally occurring, secondary dolomite. Where originally present, this dolomite has been leached from near-surface, undisturbed areas by naturally acid rain. However, it is likely to be present at depths greater than a few meters. Because dolomite contains large, equal amounts (mol %) of CaO and MgO, its presence may preclude the presence of a serpentine flora because of its probable degradation of the serpentine factor by the CaO (lime). Thus, areas underlain by dolomite-bearing serpentine might not support serpentine flora if disturbed. Burning of such an area would likely convert near-surface dolomite into dolomitic lime, making the CaO even more available to the flora. Fortunately, the serpentine quarries along US 1 used for road maintenance (Samples NCP 5 and 9) do not appear to contain detectable dolomite. (If the senior author's intuition as to the inimical behavior of CaO on the serpentine flora is correct, then perhaps steps should be taken to remove any spilled limestone aggregate from NCP and consideration should be given to the removal of the concrete waste from the demolition of the old US 1, which was placed at the headwaters of Black Run. With time, the stream and groundwaters derived from this area may spread the CaO away from the stream valley by processes as simple as trees falling away from streams.)

Samples NCP 10 and NCP 11 are mineralogically mafic and granitic rocks, respectively, and are capable of supporting flora that contrast to that in the serpentine areas. Cobbles and small boulders of metagabbro carried by streams from the southeastern part of NCP are expected to contain up to approximately 50% labradorite plagioclase. Because it was not observed in outcrop in NCP, such metagabbro was not studied in detail, but geochemical intuition suggests that most would contain on the order of 10% CaO as the labradorite species of the plagioclase group. Labradorite is not readily soluble from a geologic or floral perspective, but it is unlikely that metagabbro-bearing gullies in the southeastern part of NCP would support an interesting serpentine flora. Because of their mineralogy as well as their location in stream valleys, metagabbro boulders are not likely to be of much concern as an enhanced CaO source following a fire.

The major, minor, and selected trace-element compositions of the thirteen bedrock samples are presented in Table AI–4. Except for likely having lost some silica by reaction with the forsterite and/or lizardite serpentine, samples NCP 1 and NCP 2 are reasonably normal granitic pegmatites. Because they contain slowly available CaO, K_2O, and P_2O_5, caution might be exerted in distributing them in areas where serpentine flora are desirable and possible. Likewise, an even greater caution might be appropriate in avoiding accelerated release of these elements by thermal fracturing. The role of the micronutrient boron (B) is unknown in this environment, but should be considered in managing these and other rocks where it is detected because it is scarce in serpentinite but relatively abundant in pegmatites and gneiss. Samples NCP 3 through 9 are geochemically rather normal serpentinites except for the secondary CaO present in NCP 6, 7, and 8. These CaO analyses, independent of the X-ray diffraction data, tend to confirm the availability of previously unsuspected CaO in some of the serpentinites in NCP. It should be noted that both of the geologically derived nutrients potash and phosphorous are below the detection limit of 0.01% in all seven of the serpentinite composite samples. This apparent absence of nutrients should inhibit the growth of nonserpentine flora over such bedrock independent of Cr, Ni, Co, and CaO/MgO ratios. The fact that lush nonserpentine flora grow anyway suggests the effect of human-influenced factors, such as rapid recycling of potash by the burning of trees without prior logging to remove the potash burden. Other nutrients, such as nitrate and especially sulfate, may be deposited in NCP via precipitation in greater quantities than 100 years ago. Certainly lightning has always contributed nitrate and volcanoes have contributed sulfate to rain and snow, but the additional amounts of these components added to the atmosphere by human activities may be promoting unwanted plants to grow in areas such as NCP where their scarcity formerly limited growth. Natural sulfide minerals are conspicuous by their near absence in NCP. Because the ratio of the two common isotopes of sulfur in the atmosphere and in the bedrock of the park are likely quite different, the changing role of sulfur may be examined by studying the sulfur isotopes preserved in the annual growth rings of trees.

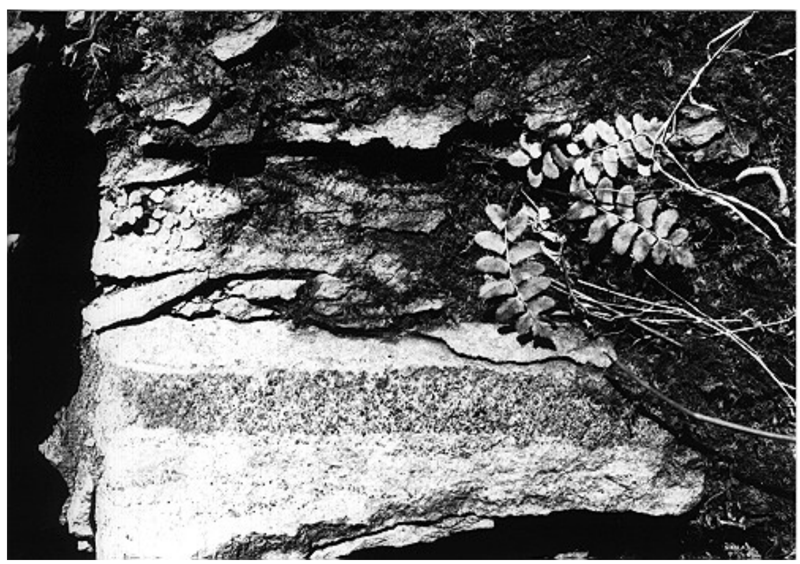


Figure AI–1. Ferns growing adjacent to a rock containing a prominent band of chromite.

Serpentine samples NCP 3 through NCP 9 contain traditional amounts of elements which have been considered in interpreting the serpentine factor. For example, the median contents of Co, Ni, and Cr are 120, 1700, and 3600 ppm, respectively. Chromium is normally discounted from the serpentine factor by mineralogists and geochemists because of the extreme insolubility of the chief carrier mineral, chromite. Indeed, this insolubility is one of the principal reasons why chromite forms placers and ferns grow very well on chromite in NCP (Figure AI–1). In NCP, however, lavendar chromian clinochlore (“kämmererite” of older usage) is locally fairly abundant in association with chromite and once was common on the Scott Mine dumps. Clinochlore is far less stable than the chromite group of minerals, and uptake of a trace amount of chromium cannot presently be ruled out for all microenvironments in NCP. As perhaps implied by Brooks (1987), MgO/CaO weight percent ratios may be adequate to induce the serpentine factor either alone or in concert with one or more of the elements Co, Cr, and especially Ni. Being as MgO/CaO weight percent ratios for serpentine bedrock in NCP vary from approximately 10 to 400, other things being equal, it may be easiest to sustain serpentine flora in areas having freshly exposed (avoiding duff accumulation), well-drained rock having such a high ratio. Thus, specially created mounds of coarse rock could become the dry analogs of artificial reefs!

Table AI–1. Descriptions of bedrock samples collected in Nottingham County Park.

Sample number	Description	Weight (grams)
NCP 1	Albite pegmatite, 1.7±0.1-m channel sample from SSW end of AVH 2 (“Coyote”) for chemical analysis.	6,952
NCP 2	C = Dunlap and Martin pegmatite, 35±5-cm channel sample across a rib.	7,120
NCP 3	Serpentinite composite Cr 5 (“Rabbit Hole”).	2,337
NCP 4	Serpentinite composite for analysis, Cr 3 W and SW dumps.	2,481
NCP 5	Serpentinite composite for analysis, quarry east of Nottingham County Park and west of US 1.	3,527
NCP 6	Serpentinite composite for analysis, Dunlap and Martin SE quarry = D = Cr 8.	2,431
NCP 7	Serpentinite composite, B = Cr 16.	2,176
NCP 8	Serpentinite composite for analysis, dump to SSS.	3,282
NCP 9	Serpentinite composite for chemical analysis, W face of active N quarry along US 1.	2,433
NCP 10	Anthophyllite-bearing rock composite from both sides of West Ridge Road, ±10 m W of projection of Lonesome Pine Trail.	3,363
NCP 11	Peters Creek Fm., Pit H, ~110 m SW of center of McPherson Lake.	3,632

Table AI–2. Bedrock mineralogy at selected sites in Nottingham County Park as determined by X-ray powder diffraction.

Mineral	NCP 1	NCP 2	NCP 3	NCP 4	NCP 5	NCP 6	NCP 7	NCP 8	NCP 9	NCP 10	NCP 11
quartz	maj[1]	min-maj									maj
albite	maj	maj									maj
microcline	min	min-maj									
muscovite		min									maj
biotite											tr?
smectite	min?										
clinochlore			min	min	tr-min		tr	tr		maj	tr
corrensite	min?	min?									
forsterite			maj	min		tr	tr?	tr-min	min		
lizardite			maj	maj	maj	maj	maj	maj	maj		
clinochrysotile				min	tr-min?	tr-min?	?	tr-min	tr		
magnesio-hornblende?	min										
actinolite					tr					maj	
anthophyllite										maj	
talc				tr	min	min					
chromite-magnetite			tr-min	tr	tr	tr?	tr-min	tr	tr		tr?
awaruite						tr??			tr??	tr?	
dolomite						min	maj	maj			
magnesite			tr-min			tr?	tr?				
pyroaurite			min	min?							

[1]As used here: maj: Major component, estimated to be greater than approximately 20 percent.
min: Minor component, estimated to be approximately 5 to 20 percent.
tr: Trace component, estimated to be less than approximately 5 percent.

Table AI–3. Composition of feldspar produced from three widely spaced pits in Nottingham County Park as estimated by X-ray powder diffraction. Each sample is a composite of twelve nearly pure cleavage fragments, each 3 to 4 centimeters.

Sample	"K-spar" peak height	"Albite" peak height	Plagioclase composition[1]
G	No peak detected	9,600 counts/sec.	An0
AVH 1.70	No peak detected	14,200 counts/sec.	An3
AVH 6.77 (Jones)	900 counts/sec	5,200 counts/sec.	An22

[1]Plagioclase composition based on the method of Smith and Yoder (1956), which is dependent on the measured spacings of the 131 and $1\bar{3}1$ peaks (Deer, Howie, and Zussman, 1963, p. 103).

Table AI–4. Bedrock composition at selected sites in Nottingham County Park as determined by commercial analyses.

Sample	SiO_2 %	Al_2O_3 %	CaO %	MgO %	Na_2O %	K_2O %	Fe_2O_3 %	MnO %	TiO_2 %	P_2O_5 %	LOI %
NCP 1	68.8	13.3	2.13	6.04	2.24	1.69	0.93	0.02	0.04	0.04	4.3
NCP 2	54.6	10.6	0.65	21.0	1.93	2.08	0.25	0.05	0.01	0.04	9.0
NCP 3	34.4	0.72	0.12	40.5	0.07	<0.01	10.7	0.11	0.01	<0.01	13.3
NCP 4	35.2	0.85	0.10	39.8	0.08	<0.01	9.78	0.12	0.01	<0.01	11.0
NCP 5	38.8	0.55	0.32	35.7	0.07	<0.01	8.32	0.06	0.01	<0.01	12.9
NCP 6	37.7	0.36	1.06	36.4	0.06	<0.01	8.35	0.10	0.01	<0.01	13.9
NCP 7	32.1	0.41	3.32	34.1	0.05	<0.01	10.2	0.16	0.01	<0.01	16.5
NCP 8	30.6	0.67	4.55	33.3	0.06	<0.01	9.82	0.17	0.01	<0.01	17.8
NCP 9	36.1	0.39	0.09	37.8	0.06	<0.01	12.0	0.15	0.01	<0.01	12.2
NCP 10	50.3	1.64	2.77	27.1	0.09	<0.01	10.5	0.20	0.12	<0.01	3.15
NCP 11	67.1	13.4	1.88	1.78	2.53	2.89	6.08	0.11	1.04	0.14	0.9
NN	40.6	13.9	13.85	8.35	2.29	0.36	17.62	0.20	1.29	0.02	1.0
Kirk 3	38.4	12.9	10.36	9.82	2.17	0.37	20.04	0.27	1.59	0.01	2.8

Sample	As ppm[1]	Au ppb[2]	B ppm	Ba ppm	Be ppm	Co ppm	Cr ppm	Cs ppm	Cu ppm	Hf ppm	Nb ppm	Ni ppm
NCP 1	2	8	<10	540	2	3	210	2	2.4	2	7	17
NCP 2	<2	240	60	170	7	2	40	5	2.9	1	16	9
NCP 3	31	7	20	50	<1	130	5,100	<1	37	1	2	1,700
NCP 4	4	<5	<10	20	<1	120	6,400	<1	5.0	<1	<2	2,200
NCP 5	2	<5	<10	40	<1	95	2,600	<1	12	<1	5	2,100
NCP 6	<2	<5	20	30	1	110	2,500	<1	6.6	<1	4	1,800
NCP 7	3	5	<10	30	1	110	2,700	<1	5.9	<1	<2	1,700
NCP 8	2	22	30	30	<1	120	6,100	<1	120	<1	<2	1,600
NCP 9	<2	<5	<10	<20	1	140	3,600	<1	7.8	<1	3	1,700
NCP 10	2	5	<10	<20	1	76	2,400	<1	42.6	<1	<2	600
NCP 11	<2	<5	10	570	3	15	250	2	28	10	16	44
NN	<5	<2	—	121	3	63	103	<0.2	273	<0.2	<0.5	68
Kirk 3	<5	4	—	25	3	57	105	0.4	105	<0.2	<0.5	151

[1]ppm = parts per million
[2]ppb = parts per billion

Table AI–4. Bedrock composition at selected sites in Nottingham County Park as determined by commercial analyses (continued).

Sample	Pb ppm	Rb ppm	Sc ppm	Sr ppm	Ta ppm	Th ppm	U ppm	V ppm	W ppm	Y ppm	Zn ppm	Zr ppm
NCP 1	9	36	1.6	165	1	19	1.1	6	3	6	12	110
NCP 2	9	126	1.5	26	2	4.2	3	2	<3	13	8.7	49
NCP 3	<2	<2	4.9	<2	<1	<0.5	<0.5	16	3	<2	42	48
NCP 4	2	<2	5.3	<2	<1	<0.5	<0.5	25	<3	<2	50	40
NCP 5	<2	<2	6.0	4	<1	<0.5	<0.5	14	<3	<2	40	25
NCP 6	2	<2	5.6	11	<1	<0.5	<0.5	12	<3	<2	30	27
NCP 7	4	<2	4.7	43	<1	<0.5	<0.5	12	<3	<2	31	19
NCP 8	<2	<2	4.8	51	<1	<0.5	<0.5	29	<3	<2	40	24
NCP 9	4	<2	5.1	3	<1	<0.5	<0.5	13	<3	<2	45	19
NCP 10	<2	<2	37	3	<1	<0.5	<0.5	100	<3	<2	70	21
NCP 11	2	105	13	171	1	10	2.5	85	<3	28	92	380
NN	9	3.5	55	95	<0.01	0.06	<0.05	652	0.2	4	53	7
Kirk 3	11	1.4	61	35	<0.01	<0.05	<0.05	625	0.5	7	116	9

Sample	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Tb ppm	Yb ppm	Lu ppm
NCP 1	56	94	31	4.8	1	0.5	0.4	0.05
NCP 2	7.1	15	7	1.5	<0.2	<0.5	1.4	0.23
NCP 3	<0.5	4	<5	<0.1	0.2	<0.5	<0.2	<0.05
NCP 4	0.5	3	<5	<0.1	<0.2	<0.5	<0.2	<0.05
NCP 5	<0.5	<3	<5	<0.1	0.2	<0.5	<0.2	<0.05
NCP 6	<0.5	<3	<5	<0.1	<0.2	<0.5	<0.2	<0.05
NCP 7	0.7	<3	<5	<0.1	<0.2	<0.5	<0.2	<0.05
NCP 8	<0.5	<3	<5	<0.1	<0.2	<0.5	<0.2	<0.05
NCP 9	<0.5	<3	<5	<0.1	<0.2	<0.5	<0.2	<0.05
NCP 10	<0.5	<3	<5	0.1	<0.2	<0.5	0.3	0.06
NCP 11	17.4	40	17	3.9	0.6	0.6	3.3	0.51
NN	0.4	1	1	0.4	0.4	0.2	0.5	0.09
Kirk 3	0.6	2	2	0.8	0.5	0.3	1.0	0.15

APPENDIX II

Nottingham County Park Bedrock Chromite

Bedrock chromite exploration and mining was the most romantic and adventurous mineral-industry activity in and near Nottingham County Park (Figure AII–1). NCP lies in the State Line chromite district, the largest podiform chromite mining district in North America (A.V. Heyl, personal communication, November 17, 1998). Partly because of that and partly because the composition of bedrock chromite can be used to help interpret the geology of the area, five samples of bedrock chromite were collected in the park for commercial analyses. Dumps to the Scott and Engine shaft areas were obscured during recontouring in the early development of NCP, but the dumps to one chromite mine remained, as well as those to three of the chromite prospects. One chromite-bearing outcrop created during mining for another commodity was also sampled. Because the dumps were scavenged for chromite ore during one or both world wars, and possibly for mineral specimens prior to establishment of the park, the samples collected are believed to be barely representative. The original goal of fifteen 4-cm chips having a total weight greater than 1 kg could not be met for two of the four dumps.

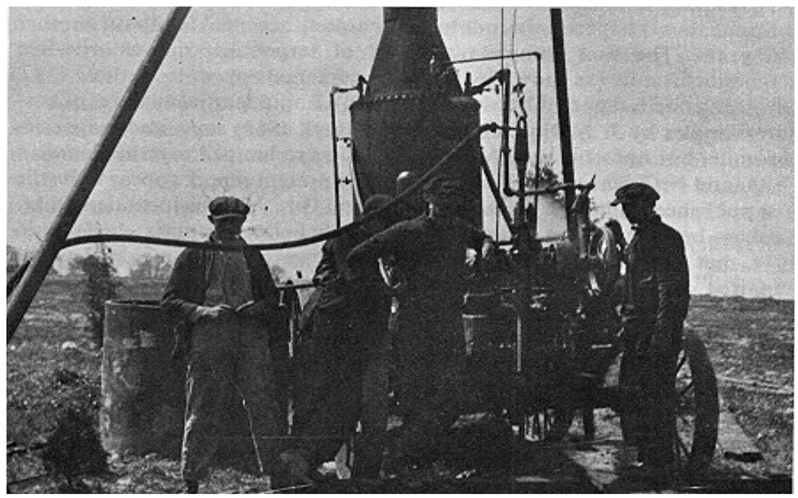


Figure AII–1. Core-drilling circa 1920 at Wood's Chrome Mine in Lancaster County. About three miles west of NCP, it was the world's leading producer of chromite prior to the Civil War, when it produced 400 to 500 tons of chromite per month (Pearre and Heyl, 1960). (Photo by S. G. Gordon from Smith, 1978, Figure 85.)

Also, funds were not available to obtain analyses of pure chromite, which would have enabled definite classification of the chromite into proper mineral species and interpretation of the deposits using the system of Stowe (1994). Analyses of 6 purified chromites from the same Baltimore Mafic Complex (BMC) to the west of NCP by C.O. Ingamells (McKague, 1964) can, however, be interpreted using Stowe's scheme, which empirically relates chromite composition to the geologic setting in which they form. As interpreted by B.C.S., II, and confirmed by C.W. Stowe (personal communication, 9/29/94), the BMC chromites likely initially formed in flat-lying layers beneath a volcanic arc. For four of five of the NCP chromites, analyses were obtained on composites of chips exhibiting evidence of enrichment exceeding normal (1-percent range) chromite dissemination. Thus, each chip in the four composites contained significant areas of chromite streaks and or massive chromite. The fifth NCP chromite sample consisted of a slice through a single chromite band. Because of past scavenging of the best material from the dumps, all but the last analysis likely underrepresents the grade of shipped ore.

Bedrock chromite sample data and analyses are presented in Table AII–1. From these, it appears that the chromite remaining on dumps in NCP is not rich enough to be considered ore. Ore grade for chromite varies with demand, anticipated use, and ratios of other elements, but would rarely be below 40% Cr_2O_3.

Data for the platinum group elements (PGE) were also obtained on the chromite composites via an extremely sensitive nickel sulfide fire-assay preconcentration and final determination via instrumental neutron activation analysis. This procedure yielded data for osmium (Os), iridium (Ir), ruthenium (Ru), rhodium (Rh), platinum (Pt), and palladium (Pd), as well as for gold (Au), at the parts per *billion* level (Table AII–1). When such data are compared (or normalized) to the concentrations believed to be present in the Earth's mantle, two separate but related groupings appear (Figure AII–2). All of the samples contain moderately high levels of Os, Ir, and Ru. Comparison with the PGE in chromites from better-understood deposits suggests that chromites in NCP formed beneath volcanic island arcs or in fore arcs. In addition, samples Cr–7 and Cr–16 have relatively high levels of Pt and Pd. Pt and Pd have stronger affinities for sulfur than the other platinum group elements, suggesting that the parent molten rocks that formed these two chromites never lost a sulfide-rich component. Based on the available PGE data, an unusual group of magmas, sometimes described as boninitic, might have been involved in the formation of the chromites in NCP. Previously, boninitic rocks have only been suspected in Pennsylvania for the informal grouping "Conowingo metabasalt" (Smith and Barnes, 1994). Sample Cr–8, derived from a single slice through a chromite band, might not be adequately representative or might have lost a small amount of Pt and most of its Pd, the most sulfur-loving of the platinum group elements, when a trace of sulfide was lost prior to final emplacement.

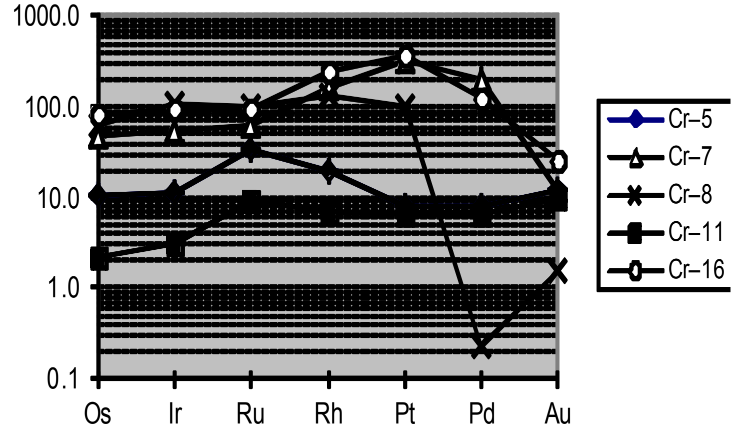


Figure AII–2. Analyses of platinum group elements in chromites collected in Nottingham County Park, normalized to the concentrations believed to be present in Earth's mantle.

Table AII–1. Analytical and sample data for chromite samples collected in NCP.

Sample name	Cr_2O_3 %	Os ppb[1]	Ir ppb	Ru ppb	Rh ppb	Pt ppb	Pd ppb	Au ppb	Weight grams	Sample description
Cr–5	24.0	45	50	190	31	68	35	12	912	15 4-cm pieces
Cr–7	32.2	200	240	360	262	2,770	860	12	1,006	16 4-cm pieces
Cr–8	35.5	260	460	570	208	847	<2	1.6	~150	1x7.5x5-cm slab
Cr–11	16.2	9	14	50	11	56	28	10	1,030	15 4-cm pieces
Cr–16	30.6	350	410	530	398	2,970	550	25	329	20 2-3-cm pieces

[1]ppb = parts per billion

APPENDIX III

Nottingham County Park Placer Chromite

In an attempt to help interpret the geology and mining history of the area, chromite placer concentrates were collected from 15 sites in small streams and their still smaller tributaries during winter "high-water" conditions. The 15 samples were generally collected at 250-m (1/4 km) intervals and upstream from confluences. Where possible, the material for each site was dug from 6 subsites approximately 3 m apart, but this was not always practical. Subsites were biased towards those likely to be good heavy-mineral traps. Panning of each subsample in the field ceased when it appeared that significant black heavy minerals were starting to be lost. Using these procedures, the dry weights of samples returned to the laboratory ranged from 215 to 862 g, with most being 300 to 600 g. Panning of the minus 10 mesh fraction (grains smaller than approximately 0.07 inch) of each of the 15 composites in the laboratory ceased when it appeared that nearly all of the light-colored gangue (non-ore) minerals had been washed out. This procedure yielded from 50 to 470 g of concentrate consisting of roughly 2/3 opaque oxides which, in turn, consisted of approximately 2 to 3 parts chromite to 1 part magnetite. These visual estimates are based on chromite being nonmagnetic and blacker than magnetite, having a much higher luster, and lacking reddish and brownish oxidized surfaces.

Chemical analyses for the 15 composites are presented in Table AIII–1. Most concentrate samples from the present study contain approximately 20 to 25% Cr_2O_3 versus the 40 to 45% reported for the placer mine area, presumably along Black Run west of the north end of McPherson Lake (Figure AIII–1). The grades observed upstream of McPherson Lake in this study suggest that the concentrates could correspond to *roughly* 35 to 45% of a theoretical chromite containing 55% Cr_2O_3. If one assumes that this theoretical chromite also contained approximately 15% iron (Fe) and some simple calculations are performed, then the ratio of chromite to magnetite in the concentrates is typically 2:1 to 3:1. This suggests that magnetic removal of most of the magnetite would still not have brought the concentrate grade up to the reported production grades of 40 to 45% Cr_2O_3. (Further panning of the concentrates to remove more gangue might have lowered the percent Cr_2O_3 because magnetite is slightly denser than chromite.)

Figure AIII–1. View, looking southeast, of the floodplain of Black Run in the early 1960's. Much of this area is now the lakebed of McPherson Lake. The stream channel is at the extreme right. The stream flows toward the observer. This area was a source of placer chromite mining prior to the creation of the lake. (Dunn, 1962, Figure V)

Table AIII–1. Analyses and calculated theoretical amount of chromite in 15 panned concentrates from Black Run and its tributaries.

Sample name	Cr %	Fe %	Theoretical chromite[1] %	Co ppm[2]	Ni ppm	Sc ppm	Zn ppm	Pd ppb[3]	Pt ppb
HMC 1	16	22.5	42	360	<200	6.7	1,520	15	23
HMC 2	15	21.2	40	340	770	11	1,220	26	37
HMC 3	16	20.9	42	360	<200	7.4	1,690	16	27
HMC 4	20	19.8	53	360	1,300	13	1,660	23	32
HMC 5	16	16.8	42	320	920	11	1,690	25	41
HMC 6	20	22.9	53	370	980	15	1,800	15	36
HMC 7	15	15.7	40	350	730	8.5	1,370	19	29
HMC 8	14	17.1	36	280	<200	13	1,390	12	47
HMC 9	13	20.0	35	300	700	14	1,820	12	24
HMC 10	14	20.5	36	370	1,000	6.9	1,460	17	21
HMC 11	15	20.4	40	370	<200	7.1	1,610	15	21
HMC 12	14	19.7	36	340	1,000	7.6	1,770	24	30
HMC 13	18	20.4	47	380	970	7.8	1,940	29	33
HMC 14	19	20.3	51	370	1,000	6.1	2,070	12	18
HMC 15	10	18.3	27	250	1,500	14	907	18	25

[1]The amount of theoretical chromite is a number calculated from the Cr data based on the assumption that chromite contains 55% Cr_2O_3. It is not a measurement of the grade of observed chromite.
[2]ppm = parts per million
[3]ppb = parts per billion

There are at least five possible reasons for the apparent discrepancy: 1) The original chromite placer miners were able to utilize the somewhat more euhedral shape (smoother crystal faces) of magnetite compared to chromite to aid its removal on a James Table (Figures 21 and 22). 2) The original chromite placer miners found a size fraction (see Dunn, 1962) having a higher Cr_2O_3 content. 3) Prior to establishment of the Securities and Exchange Commission, entrepreneurs might not have underestimated the quality of their products. 4) Prior to European settlement, streams were less disturbed and included only indigenous, highly weathered materials. Naturally weathered, disseminated chromite would likely have contained more Cr_2O_3 than mined, more massive, and less easily transported chromite. (Also, unweathered, dense serpentine would have been sparse.) 5) The placer ore west of McPherson Lake was naturally beneficiated via dissolution of serpentine, magnetite, and other minerals that are more soluble than chromite. The correct answer is likely 6) All of the above. However 4) and 5) may have been the most important processes, based on the belief that the mined floodplain materials are much older than the material in the active bed of the present stream and the fact that olivine, serpentine, and magnetite are much more soluble than chromite. In other words, some of the magnetite, but not the chromite, might have been leached from the older alluvial deposit.

Apparently natural "ferricrete" (a concrete-like mass of gravel and sand cemented by orange, rusty iron oxides) is common in serpentine barrens, especially near the margins of the barrens where ferrous iron dissolved from the bedrock and gravel is aerated as it passes over small stream riffles such as those you can see a few yards upstream from where Black Run crosses Feldspar Trail. This aeration results in oxidation of the iron to ferric oxyhydroxides which precipitate out of the water as yellow boy. This yellow boy likely removes many potentially toxic heavy metals from solution by adsorption, in the process making them much less available to plants and animals. As these ferric oxyhydroxides form by removing hydroxide [$(OH)^-$] from water, which chemically is hydrogen hydroxide (HOH or H_2O), free hydrogen ions (H^+) are left and suddenly make the water more acidic. (See page 14 for a discussion of the association of acid-loving plants such as rhododendron growing on serpentine that contains limonite. Limonite, in a sense, is geologically aged yellow boy. Small seeps of ferrous-iron-bearing water may account for what otherwise appear to be local anomalies of acid- and iron-loving flora. You can see one approximately 400 feet southeast of the Brandywine mine.) Such slightly acidified, chemically reducing, waters may be able to leach iron out of old placers somewhat better than the more alkaline waters typically found within serpentine areas, which may even contain dolomite, $CaMg(CO_3)_2$, or brucite, $Mg(OH)_2$. Unfortunately, such naturally treated waters would be less likely to be able to support serpentine floral effects.

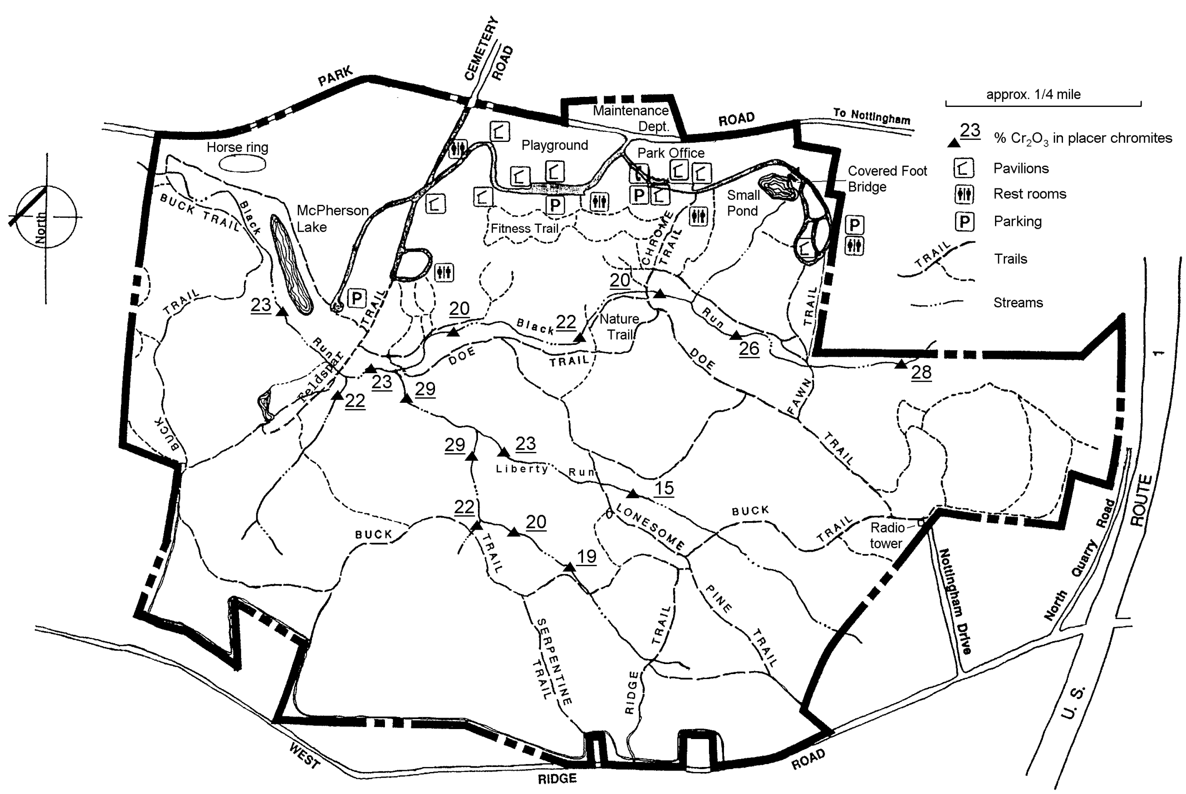


Figure AIII–2. Percent Cr_2O_3 in heavy-mineral concentrates panned from streams in Nottingham County Park.

Dunn (1962), in his study of chromite placers in Pennsylvania, found that the average grade of the "old" alluvial placer west of McPherson Lake was 1.4% Cr_2O_3. By using panning, heavy-liquid separation, and a sophisticated laboratory device known as a Frantz Isodynamic Magnetic Separator, he was able to produce a concentrate containing approximately 44% Cr_2O_3 from such raw material. This suggests that such a grade *might* have been achieved occasionally on a commercial basis. Perhaps some future researcher will compare the composition of pure chromite versus "commercial quality" concentrates from the old alluvial placer deposit identified by Dunn (1962) and from corresponding samples produced by exactly the same methods from the active bed of Black Run. In addition to answering some interesting historical questions, it might be possible to determine if magnetite leaching (5, above) was significant.

From the distribution of Cr_2O_3 in heavy-mineral concentrates shown on Figure AIII–2, one can conclude from the relative uniformity and overall trends that the field and laboratory procedures in this study were carried out in a consistent manner. Other potential interpretations suggested by the data include the following: 1) The heavy minerals in the bed of Black Run where it leaves the serpentine contain 23% Cr_2O_3. 2) The chromium content of heavies is greater upstream (to the east) on Black Run. 3) Although relatively rich near its northwest end, the chromium content of heavies on the tributaries of "Liberty Run" is lower to the southeast. This latter is interpreted as suggesting that the tributaries to "Liberty Run" are receiving a significant amount of heavy minerals from gabbroic rocks, which lack chromite, rather than from serpentinite, which typically contains about 1% chromite.

APPENDIX IV

Mineral Species in Nottingham County Park

Although no extensive study was made to identify mineral species from NCP, the following are likely present. Those verified by X-ray powder diffraction are marked by an asterisk. The names of mineral groups to which the species belong are in parentheses.

Unlike the case at other serpentine barrens in southeastern Pennsylvania, sulfide minerals are conspicuous by their absence at Nottingham County Park.

actinolite* (amphibole)
albite* (plagioclase feldspar)
almandine (garnet)
anorthite (plagioclase feldspar)
anthophyllite* (amphibole)
augite (pyroxene)
awaruite?
biotite (mica)
calcite
chromite (spinel)
chrysotile* (serpentine)
clinochlore* (chlorite)
corrensite?
“deweylite”
dolomite*
epidote (epidote)
fluorapatite (apatite)
forsterite* (olivine)
goethite
lizardite* (serpentine)
magnesiochromite (spinel)
magnesiohornblende?
magnesite*
magnetite (spinel)
microcline* (feldspar)
montmorillonite* (smectite)
muscovite* (mica)
pyroaurite?
quartz*
schorl (tourmaline)
smectite group? (creek-bottom clay?)
spessartine (garnet)
talc*
titanite (also known as sphene)
tremolite (amphibole)
vermiculite
zircon
zoisite* (epidote)

APPENDIX V

"Contact Rock"—Where Pegmatite and Serpentinite Met

"Contact rock," a type of "blackwall," formed where the intruding magma that formed granitic pegmatites reacted with the colder and older "country rock," that is, the rock that was already there. In this case, the country rock is serpentinite. Initial reaction likely occurred during the intrusion of the molten pegmatite. Anthophyllite may be a remnant of this stage. Later reactions involving regional metamorphic fluids, perhaps at about 300°C, likely formed antigorite, chlorite, actinolite-tremolite, and talc (Wenner and Taylor, 1974). Lizardite and clinochrysotile formed via alteration of the antigorite by warm meteoritic fluids at about 100°C. Elsewhere in the park, the mineraloid "deweylite" is likely forming from cool meteoritic water as you read this (Wenner and Taylor, 1974).

Because pegmatites were extensively mined for feldspar, such contact rock was likely exposed in nearly all of the walls of the feldspar pits. Such contact zones are typically 10 to 20 cm (4 to 8 inches) thick. In a general way, their thickness seems to correlate with that of the pegmatite.

The two rock types on each side of the contact rock behaved quite differently during the tectonic deformations that affected Pennsylvania long after the pegmatites were in place. Serpentinite is plastic, meaning that it was relatively easily squeezed and bent into new shapes by the forces of mountain building without rupturing. Pegmatite is more rigid. It will tend to break rather than bend when subjected to such forces. Because of their position between such different rock types, the contact rocks appear to be more deformed than either the serpentinite or the pegmatite.

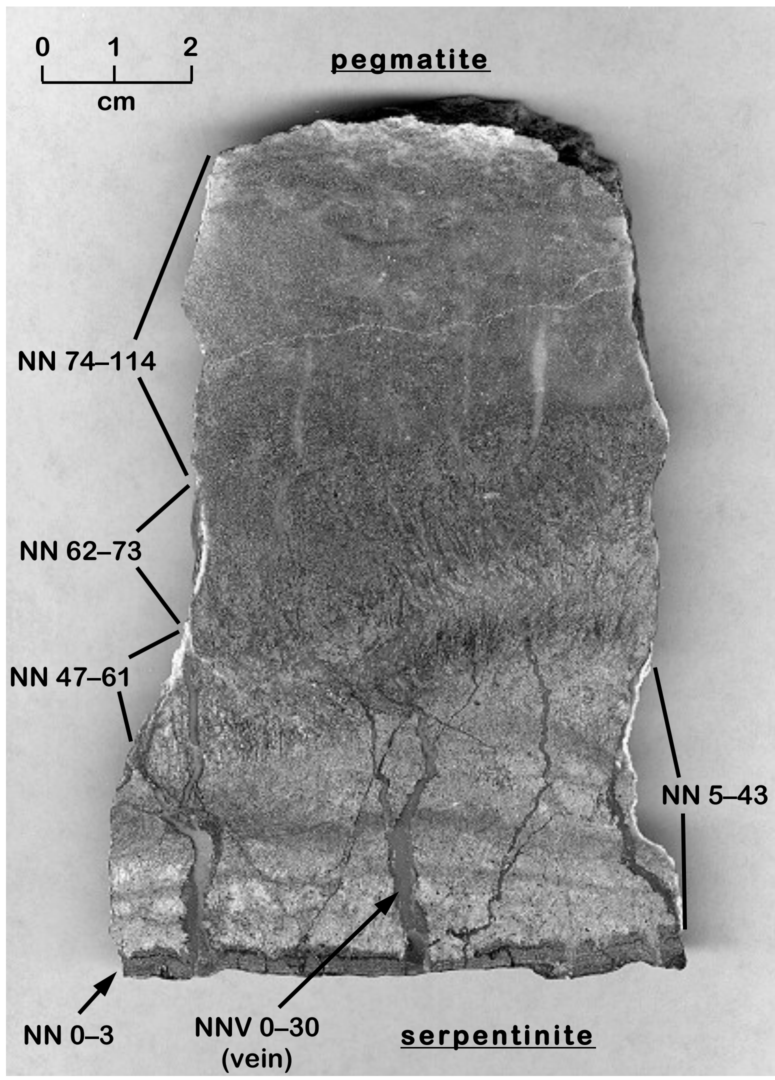


Figure AV–1. Zoned sample of contact rock between serpentinite (bottom) and pegmatite (top). Sample is from feldspar pit NN at Nottingham County Park. The labels indicate the zones corresponding to the sample numbers in Table AV–1.

The contact rocks are important for several reasons:

1) They are the most abundantly exposed bedrock type in NCP. This is amazing considering that they make up an almost insignificant volume of all the bedrock in the park.

2) Because of their fractured nature and occurrence in pit walls, they provide microenvironments that were not available prior to feldspar mining. They seem to support rock ferns and inhibit *Smilax*, possibly by virtue of rapid drainage or possibly as a result of the presence of fern-produced plant toxins.

3) The mining of feldspar left extremely slippery (talc-bearing), poorly attached veneers on the pit walls. These combine to yield poor footing and the risk of localized rock falls. Such rock falls are especially likely after heavy rains or during spring thaws. Because these veneers are so unstable, microenvironments based upon them, especially on south-facing surfaces, are likely to change rapidly. A series of small, localized rock falls could result in the loss of a great deal of habitat in a few decades.

4) Observations of such thin veneers give one a misleading impression and might have led to false hopes of mining talc or fibrous minerals.

The mineralogy of one sample of contact rock is summarized in Table AV–1. This sample (Figure AV–1) was collected from feldspar trench NN about 240 meters southwest of the Brandywine Quarry and about 75 m east of the intersection of Buck and Feldspar Trails.

Table AV–1. Mineralogy of a zoned sample of contact rock from feldspar pit NN.

Sample Name	Distance from serpentinite contact	Color	Major minerals	Minor minerals	Trace minerals
NN 0–3	0–3 mm	very dark greenish gray	talc antigorite	clinochlore	chromite goethite(?)
NN 5–43	5–43 mm	light gray	talc clinochlore	clinochlore lizardite	lizardite (trace to minor)
NN 47–61	47–61 mm	dusky yellow green (fibrous)	anthophyllite clinochrysotile	actinolite-tremolite clinochlore	
NN 62–73	62–73 mm	grayish green	clinochlore lizardite	possible clinochrysotile	
NN 74–114	74–114 mm	pale olive (mottled)	lizardite	probable chlorite possible antigorite	
NNV 0–30	0–30 mm veinlet cutting NN 0–3 and NN 5–43	light olive gray	talc lizardite	clinochlore	

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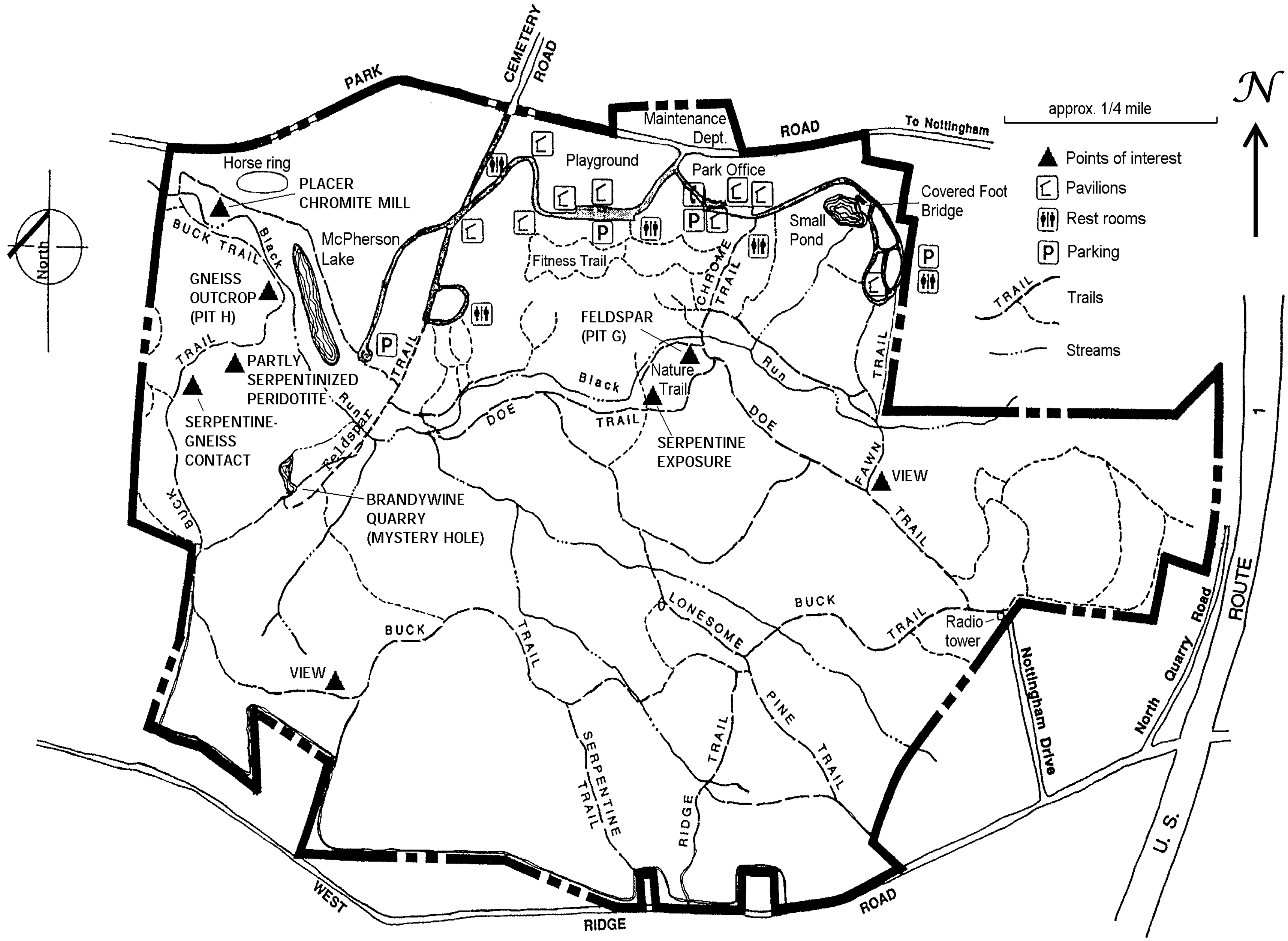
approx. 1/4 mile
Points of interest
Pavilions
Rest rooms
Parking
Trails
Streams
N
North
PARK
CEMETERY ROAD
ROAD
To Nottingham
Maintenance Dept.
Playground
Park Office
Covered Foot Bridge
Small Pond
Horse ring
PLACER CHROMITE MILL
McPherson Lake
GNEISS OUTCROP (PIT H)
PARTLY SERPENTINIZED PERIDOTITE
SERPENTINE-GNEISS CONTACT
BRANDYWINE QUARRY (MYSTERY HOLE)
Fitness Trail
FELDSPAR (PIT G)
Nature Trail
SERPENTINE EXPOSURE
CHROME TRAIL
Black Run
Feldspar Run
Black TRAIL
BUCK TRAIL
DOE TRAIL
FAWN TRAIL
VIEW
LONESOME
PINE TRAIL
RIDGE TRAIL
SERPENTINE TRAIL
Radio tower
Nottingham Drive
North Quarry Road
ROUTE 1
U. S.
WEST RIDGE ROAD


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