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GEOLOGY AND THE SLATE INDUSTRY IN THE ARVONIA DISTRICT, BUCKINGHAM COUNTY, VIRGINIA

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The Arvonia slate district is located in northeastern Buckingham County, in central Virginia (Figure 1). During the course of an investigation of regional and economic geology in the Virginia Piedmont, geologists from the Virginia Division of Mineral Resources prepared a geologic map of the slate district, which shows the distribution of slate and adjacent rock units, as well as locations of geological features which affect quarrying of slate.

The Arvonia slate industry has been in continuous operation for more than 250 years. Large trees rooted in 100-foot-high piles of quarry waste attest to the long history of slate production in the district (Figure 2). In many places the waste piles are located on top of slate with potential commercial value. The intent of this report and map is to provide a geological framework which quarry operators can use to improve the efficiency of extraction and processing of slate.

The Arvonia district is economically significant not only for its slate reserves, but also because it coincides with the central Virginia gold-pyrite belt. The stratigraphic relationship of the Arvonia rocks to other crystalline rock units is critical to unraveling the geologic history of the Virginia Piedmont. This study provides insight into the stratigraphy of the Arvonia Formation, and the relationship of the Arvonia to surrounding units. Understanding the environment in which the Arvonia and adjacent rocks formed has important implications for mineral resources exploration. In addition to their economic significance, the Arvonia slates are one of the few known fossil-bearing rock units in the Virginia Piedmont.

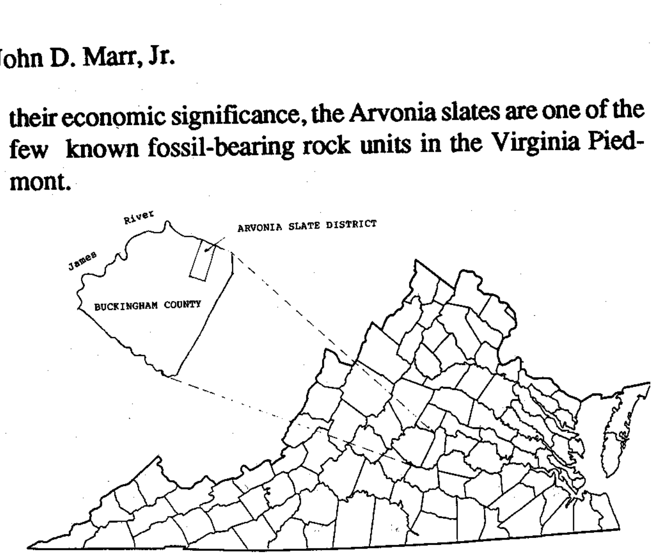

Figure 1. Location of the Arvonia Slate District northeastern Buckingham County, Virginia.

HISTORICAL OVERVIEW

The history of the Arvonia slate district dates from 1724 when King George I of England granted 400 acres on an unnamed river in what is today Buckingham County to James Shelton. In 1726, 1600 additional acres were granted to Mr.

Shelton. By this time, slate deposits had been discovered and the unnamed river had become the Slate River.

Figure 2. Large trees rooted in piles of quarry waste.

Many of the early quarrymen in the slate district immigrated to Virginia from Wales during the 19th century. These people brought to the New World quarry experience gained in the famous Welsh slate quarries. The name "Arvon" was given to the community that grew up around the quarries in Buckingham County, after the Welsh town of Caernarfon, former home of the early quarrymen. The name was later changed to Arvonia to avoid confusion among post offices with similar names.

Many buildings were roofed with slate from Buckingham County during the 18th and 19th centuries. Berkeley Plantation, along the James River east of Richmond and built in 1726, was covered with slate from the quarry near New Canton in 1790. In 1796, slate was ordered for the new capitol building in Richmond, but because of transportation difficulties, the slate roof was never installed. During the early 19th century, Arvonia roofing slate was used on buildings at the University of Virginia in Charlottesville. The slate was used also at the College of William and Mary in Williamsburg.

In his 1835 report of "Geological Reconnaissance of the State of Virginia," William Barton Rogers stated that the quarry near New Canton "yields a material which will bear comparison with the better qualities of imported roofing slate. In texture, density and capacity of resisting atmospheric agents, it can scarcely be excelled by a similar material in any part of the world" (Rogers, 1884).

Production of roofing slate reached a peak during the early part of the twentieth century, when as many as eight different companies operated quarries in the Arvonia district. At least 40 quarries have been opened and worked within the district over the years. Most are located to the northwest of the town of Arvonia, in an area about 2 miles long and 1500 feet wide. At the present time, slate is being quarried by one company, the Le Sueur-Richmond Slate Corporation of Richmond. The demand for roofing slate has declined in recent years, but there has been an increasing demand for slate to be used in other aspects of the building industry, including decorative facing stone (Figure 3), flooring material, door and window sills, tabletops, and countertops. Signs and plaques of slate from Arvonia are becoming increasingly popular across Virginia. Since 1947, the Solite Corporation has operated a plant in the northern part of the Arvonia district, where weathered slate is expanded in rotary kilns for use as lightweight aggregate in making concrete.

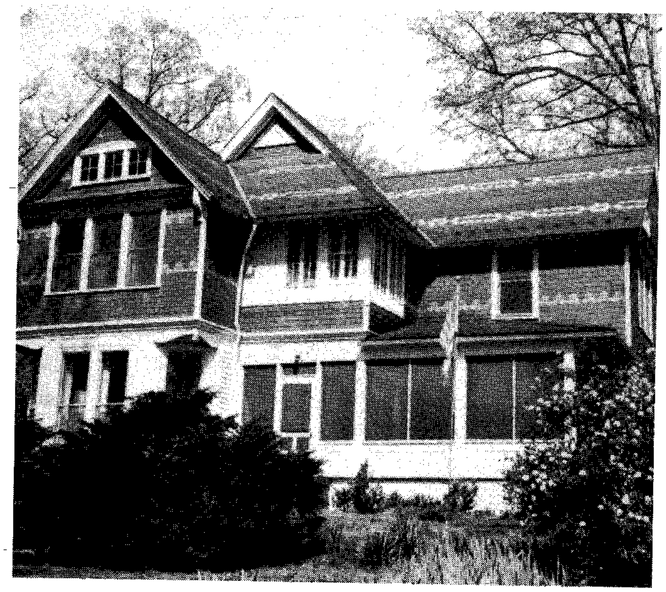

Figure 3. Slate used as decorative facing stone.

GEOLOGIC SETTING OF THE ARVONIA SLATES

The Arvonia slates occur within the Arvonia Formation, which is a sequence of metamorphosed sedimentary rocks. Fossils from the Arvonia have been examined and discussed by a host of geologists over the years; the weight of opinion favors an age of Late Ordovician (about 450 million years ago) for the slates (Darton, 1892; Watson and Powell, 1911; Tillman, 1970; Pavlides and others, 1980; Kolata and Pavlides, 1986).

The Chopawamsic and Buffards Formations are rock units adjacent to the Arvonia slate belt. The Chopawamsic is a sequence of metamorphosed volcanic rocks which crops out northwest of the commercial slates; these rocks are considered Cambrian in age (Pavlides, 1981). Most geologists who have worked in the Arvonia district have concluded that the Arvonia sediments were deposited on an erosional surface developed on older rocks including the Chopawamsic (Taber, 1913; Stose and Stose, 1948, Smith and others, 1964; Brown, 1969; Conley and Marr, 1980). The observations of this study are consistent with that interpretation.

The Buffards Formation of Brown (1969) crops out to the southeast of the commercial slate belt, and consists of metamorphosed conglomerate and graywacke. There has been some disagreement among geologists concerning the stratigraphic relationship of these rocks to the Arvonia Formation. Stose and Stose (1948) considered conglomerates along strike with Buffards Mountain to be the basal member of the Arvonia Formation. Brown (1969) named the Buffards Formation for conglomerates and schists exposed on Buffards Mountain, and, in contrast to Stose and Stose (1948), considered these rocks to be stratigraphically above the Arvonia slates. Conley and Marr (1980) agree with Stose and Stose (1948) and consider the Buffards to be a part of the Chopawamsic Formation, and stratigraphically below the Arvonia. The present study leans toward the interpretation of Stose and Stose (1948) because, in the vicinity of the commercial slate quarries, the Buffards Formation, as mapped by Brown (1969), includes rocks which are equivalent to basal units of the Arvonia Formation.

Most geologists who have worked in the Arvonia district would agree that the commercial slates are located in the northwest portion of a synclinal fold. Conley and Marr (1980) pointed out that the syncline which contains the slate quarries is not a simple fold, but one that has been refolded about a later-formed anticline southeast of the commercial slate belt. The detailed mapping of this study shows that several northeast-trending shear zones cut the northwest limb of the Arvonia syncline. These faults are of limited displacement on a regional scale, but are sufficient to cause repetition of the Arvonia stratigraphy across strike. The grade of regional metamorphism increases from northwest to southeast across the Arvonia district (Brown, 1969). As a result, Arvonia slates which occur southeast of the area shown on Figure 4 contain garnet and biotite porphyroblasts, and are not suitable for commercial use.

MAJOR ROCK-TYPES IN THE SLATE DISTRICT

CAMBRIAN(?)

Chopawamsic Formation

The Chopawamsic Formation contains several volcanic and volcaniclastic lithologies which are not mapped separately on Figure 4. These rocks include grayish-green amphibole schist, light-grayish-green dacite metatuff, and dark-brownish-gray ferruginous quartzite.

ORDOVICIAN

Arvonia Formation

Three lithologic members were mapped within the Arvonia Formation in this area. These are, from oldest to youngest, quartzite and quartz-muscovite schist, slate, and metagraywacke. A fourth unit, dacite metatuff, was mapped within the Arvonia slate. The Bremo quartzite occurs stratigraphically above the Arvonia metagraywacke southeast of the area shown in Figure 4. Rocks which were mapped as Buffards Formation in this area by Brown (1969) are included in two map units: conglomeratic chlorite-muscovite schist, and chlorite-muscovite schist and phyllite. These rocks occur locally at the base of the Arvonia Formation and are described in sequence with the Arvonia map units.

Quartzite and Quartz-Muscovite Schist

Quartzite is grayish orange (weathering to dark yellowish-orange), medium- to coarse-grained, and contains quartzite and phyllite clasts up to 1 inch in maximum dimension. Quartz-muscovite schist is pale yellowish-gray and contains grayish-blue quartz grains about 0.1 inch across. Primary sedimentary structures were not observed in this unit. The metamorphic mineral assemblage is quartz-muscovite-chlorite-plagioclase. Accessory minerals are magnetite, ilmenite, tourmaline, and zircon.

Conglomeratic Chlorite-Muscovite Schist (Buffards Formation)

Greenish-gray chlorite-muscovite schist contains numerous ellipsoidal clasts up to 6 inches in maximum dimension. Clasts are dominantly white quartz, dusky-red quartzite, dark-gray quartzite, and greenish-gray phyllite; other lithologies are also present. In some outcrops, the size of clasts grades from large to small across individual beds that are up to 3 feet thick. The metamorphic mineral assemblage in the matrix is quartz-plagioclase-chlorite-muscovite-magnetite. Kyanite is present in the matrix of some samples, as relict porphryoblasts largely replaced with chlorite and muscovite. Biotite, garnet, amphibole, zircon, and tourmaline are accessory minerals.

Chlorite-Muscovite Schist and Phyllite (Buffards Formation)

The schist and phyllite unit includes greenish-gray chlorite-muscovite schist with medium to fine, grayish-blue quartz grains, and grayish-green chlorite-muscovite phyllite.

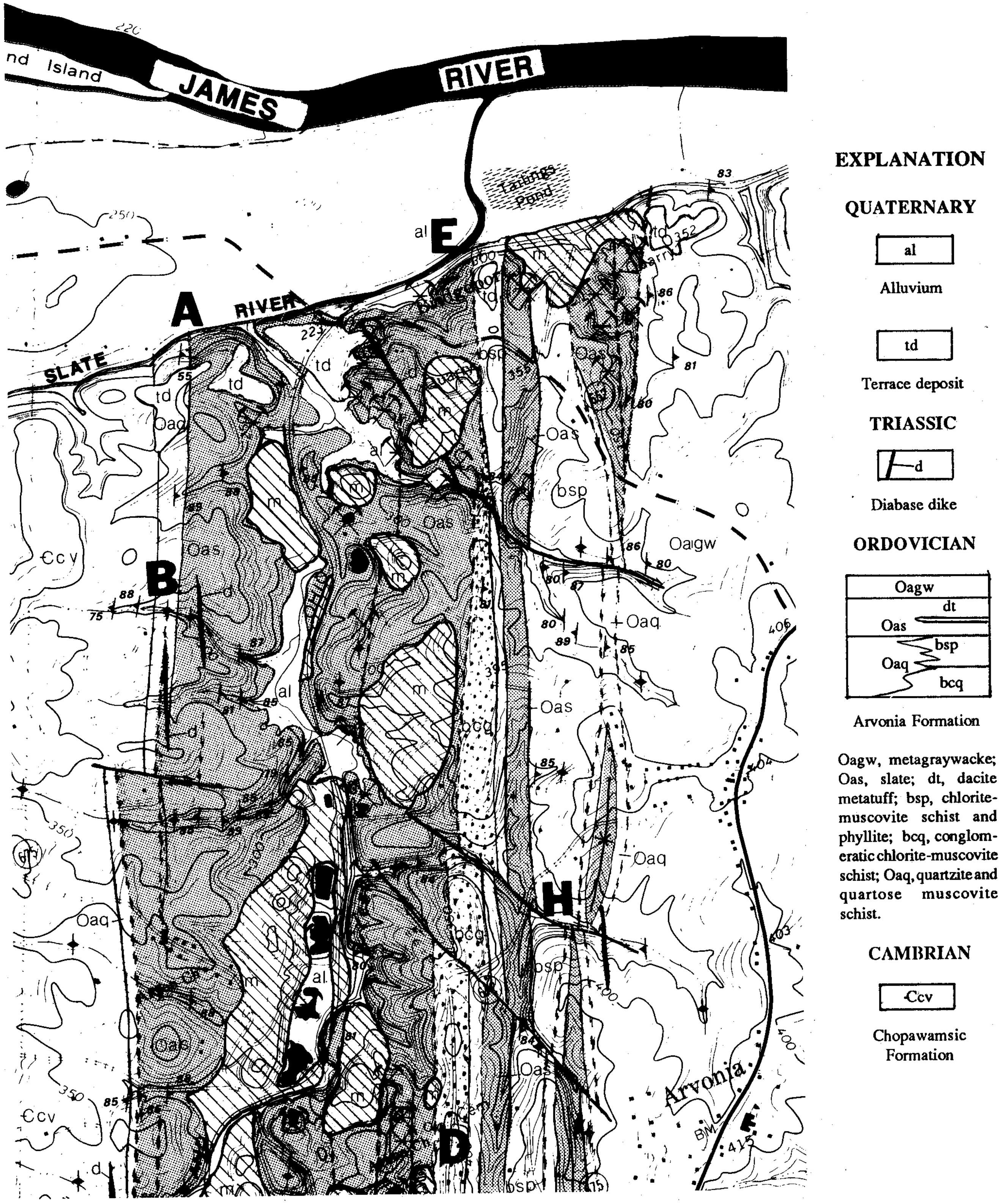

Figure 4. Geologic map of the Arvonia Slate District.

KEY

Contact Lines

Exposed or approximate

Faults

Exposed or approximate; arrows indicate direction of relative movement

Shear zone

Attitude of Rocks

78

Strike and dip of inclined beds

Foliation

72

Strike and dip of foliation

Vertical foliation

Factors Affecting Land Modification

Modified land; extensive cut and fill

Quarries

Active quarry

Abandoned or inactive quarry

Prime Exposures

A

Prime rock exposures referred to in text

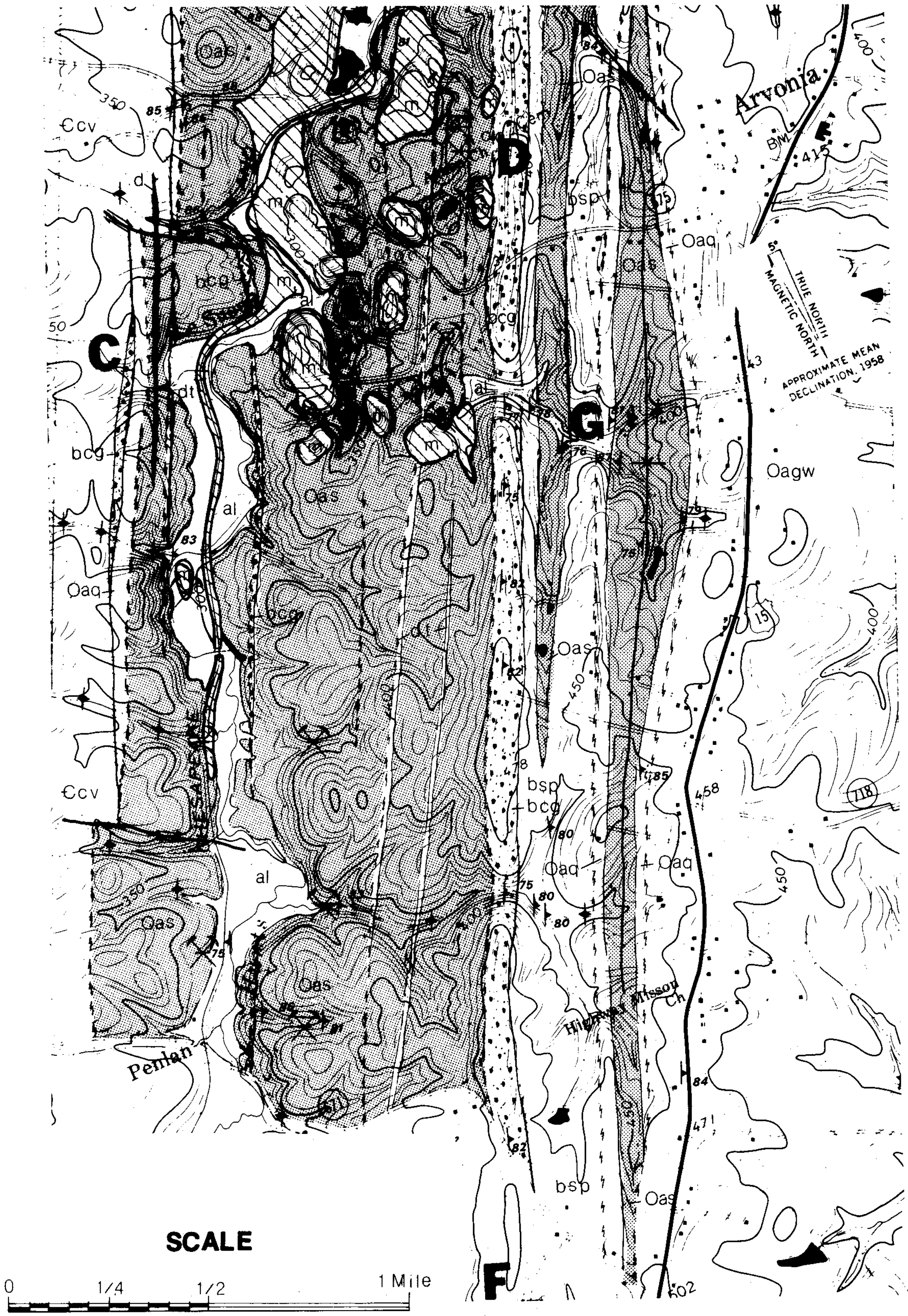

Figure 4. Geologic map of the Arvonia Slate District (continued).

Graded bedding is visible in some quartzose schists. The metamorphic mineral assemblage is quartz-plagioclase-chlorite-muscovite-magnetite. Accessory minerals are biotite, garnet, hornblende, tourmaline, and zircon.

Slate

The slate unit includes dark-gray (weathering to grayish-olive-green) cleavable slate, and dark-gray slate that contains pyrite porphyroblasts. Fresh slate gives a ringing sound when struck with a hammer; the fresh cleavage surface is highly lustrous. Primary bedding, indicated by alternating light and dark compositional bands, is visible in some outcrops and is oriented from low to high angles to the principal cleavage. The metamorphic mineral assemblage is quartz-muscovite-chlorite-plagioclase. Biotite, calcite, graphite, and pyrite are accessory minerals.

Dacite Metatuff

Greenish-black metamorphosed dacite tuff and tuffaceous breccia are dense rocks with poorly developed metamorphic cleavage, giving them an irregular, blocky fracture pattern. Major minerals are plagioclase and quartz in subequal proportions; minor amounts of muscovite, chlorite, and magnetite are present.

Metagraywacke Sequence

Metagraywacke consists of interlaminated light-gray calcareous metasandstone and metasiltstone, and dark-gray slate. Laminations 0.25 to 1 inch thick occur in graded cycles from 2 to 6 inches in thickness. The grain size in light-gray laminae grades stratigraphically upward from medium sand to silt; dark-gray slate laminae occur above silty horizons. The metamorphic mineral assemblage in light-gray horizons is quartz-muscovite-plagioclase-calcite. Dark-gray slate horizons lack calcite, and contain graphite. Biotite, pyrite, and magnetite are accessory minerals.

MESOZOIC

Diabase

Dense, grayish-black, non-foliated, fine- to medium-grained diabase weathers to a yellowish-orange spongy residuum. Diabase occurs in NNW-trending dikes less than 15 feet thick. Spheroidally weathered outcrops and boulders are typical.

RECENT

Terrace Deposits

Unconsolidated deposits, generally less than 30 feet thick, of boulders and cobbles occur in a stratified sand and silt matrix. These terrace deposits, found on tops of bluffs to the south of the James River flood plain, were deposited by the ancestral James River.

Alluvium

Unconsolidated deposits of pebbles and cobbles in a stratified sand and silt matrix occupy low-lying areas adjacent to major streams. Thickness is generally less than 30 feet.

MODIFIED LAND

This map unit consists of unconsolidated rock debris emplaced by man; thickness exceeds 150 feet in some places.

DISCUSSION: STRUCTURE AND STRATIGRAPHY IN THE SLATE DISTRICT

Detailed mapping of the commercial slate belt has given fresh insight into some old questions about the structure and stratigraphy of the Arvonia slate district. The geologic map (Figure 4) shows a far more complex structural setting within the commercial slate belt than was indicated by previously published maps drawn at smaller scales (Brown, 1969; Conley and Marr, 1980). The commercial slates are situated on the northwest limb of the Arvonia syncline. From Figure 4 it is apparent that the northwest limb of this structure is cut by numerous shear zones and brittle faults. In many places the contacts between lithologic units are faulted rather than conformable. Although the faults are not of sufficient displacement to disrupt the regional synclinal structure, the Arvonia stratigraphy is repeated several times across strike, by a combination of faulting and folding. If dacite tuff beds within the commercial slate belt represent a single stratigraphic marker, the outcrop width of the commercial slate belt is considerably greater than the true stratigraphic thickness of the slate unit.

The observations in this study support the conclusion of earlier workers that the Arvonia Formation is unconformable above the Chopawamsic Formation. In the places where the contact between these two formations is not faulted, there is invariably a section of quartzite, pebbly quartz-mica schist, or conglomeratic schist at the base of the Arvonia, between the slates and the volcanics. Contact relations can be examined in exposures along the Slate River upstream from State Road 652 ("A," Figure 4), and in other drainages ("B" and "C," Figure 4). The presence of dacite tuff in the slate sequence implies volcanism during the Late Ordovician, consistent with geologic evidence elsewhere in the Appalachians (Carol, 1959).

Our mapping and petrographic study indicates that within the area of this report, rocks which were mapped by earlier workers as Buffards Formation are stratigraphically above the Chopawamsic Formation, at or near the base of the Arvonia Formation. The main belt of conglomeratic chlorite-muscovite schist, the Buffards of Brown (1969), is separated from the Arvonia commercial slate belt to the northwest by a shear zone within the area of Figure 4. This contact can be examined in an exposure between the Le Seuer-Richmond milling shed and the Arvon Church (spelled Arbon on map) ("D," Figure 4). The same shear zone projects into a cut along the CSX Transportation railroad just west of the Solite plant ("E," Figure 4). There, the Buffards is not present, but Arvonia metagraywackes are in fault contact with Arvonia slates. According to the direction of stratigraphic "up" implied by graded beds in Buffards metaconglomerates (exposure at "F," Figure 4), this unit is overlain conformably to the southeast by finer-grained Buffards metagraywackes and phyllites. Farther southeast, these rocks are in contact with Arvonia slates which appear to occupy the trough of a syncline. The map pattern and facing criteria indicate that in this belt, Buffards rocks are stratigraphically below Arvonia slates. The best exposures of Buffards and Arvonia rocks along this trend occur in drainages "G" and "H" on Figure 4.

Two other belts of conglomeratic chlorite-muscovite schist which are lithologically similar to the Buffards metaconglomerate of Brown (1969), were found in the western part of the commercial slate belt. One of these conglomeratic belts occurs between volcanic rocks of the Chopawamsic Formation and micaceous quartzites near the base of the Arvonia Formation; there, the conglomeratic schist is clearly at the base of the Arvonia. Contact relations are exposed in the drainage labeled "C" on Figure 4.

GEOLOGIC FACTORS AFFECTING THE QUEST FOR COMMERCIAL SLATE

Arvonia slates were produced by the consolidation and recrystallization of the mud and silt portions of the Arvonia sedimentary column. The metamorphic minerals present in the slates equilibrated at pressures and temperatures which imply burial at depths of about 8 to 10 miles. During burial metamorphism, platy micas (muscovite, chlorite, biotite) crystallized in a plane which was perpendicular to the direction of principal compressive stress. The rocks were folded during metamorphism, with a result that the plane in which the platy minerals crystallized (the plane of slaty cleavage) is at a variable angle to the original depositional bedding. Subsequently, the rocks were uplifted, refolded, faulted, intruded by diabase, and uncovered by erosion. The most desirable slates for commercial purposes have slaty cleavage at a relatively small angle to the bedding (Figure 5). Commercial slate does not contain mineralogical impurities such as pyrite, or the sandy laminations characteristic of Arvonia metagraywackes, and has not been deformed by shear zones, minor folds, or brittle faults and joints.

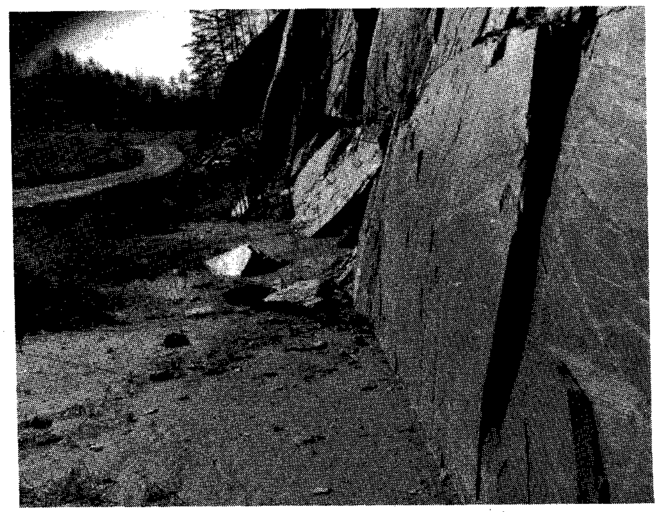

Figure 5. Commercial slate exhibiting slaty cleavage.

The most useful tool for the quarry operator seeking cleavable slate is an understanding of the bedrock geometry implicit in the geologic map. The map pattern suggests that slate units, as well as adjacent rock units, are elongate bodies of rock which trend N25° to 30° E and dip vertically, or nearly vertically. This geometry means that in the Arvonia slate belt, rock bodies tend to be continuous along a N25° to 30° E "structural grain," but are discontinuous across this "grain". A zone of good quality cleavable slate may be predicted to continue in the direction of the structural grain, but may pass abruptly into a less desirable rock type in any other direction. Because the rock units in this area and some geologic features such as shear zones are vertical or nearly vertical, observations at the surface may be projected below ground with some confidence, at least to the limit of likely quarry depths.

Throughout the commercial slate belt, both original bedding and slaty cleavage surfaces are generally oriented from N25° to 30° E and dip vertically or nearly vertically, so that in most places the angle between these two surfaces is small. Locally, however, in the hinge zones of minor folds, this angle can become large, and the slate crinkled, making the rock undesireable for slate quarrying. These hinge areas can be seen on NW to SE facing quarry walls and should be avoided in quarrying. The fold hinges are more likely to project along the structural grain than across the grain.

Shear zones from 3 to 15 feet thick occur within and between rock units throughout the commercial slate belt.

Where these zones cut cleavable slate, the slate is complexly folded and contains abundant vein quartz (Figure 6). This sheared material must be removed and disposed of when encountered in a slate quarry. Poor bedrock exposure makes it difficult to map these zones outside areas of current quarry activity. Sheared areas, however, can be located on quarry-walls that cut the structural grain (NW to SE), and are likely to project along the structural grain rather than across the grain.

Figure 6. Fault zone exhibiting vein quartz cutting cleavable slate.

Pyrite is the most common mineralogical impurity in the commercial slate belt. "Speck" slate, ill-suited for commercial use, occurs at various places throughout the belt, but consistently enough to warrant a separate map unit. Pyrite growth may be related to the development of shear zones; the presence of pyrite may also be related to chemical conditions unique to certain stratigraphic horizons. Either possibility implies that the zones of "speck" slate will tend to persist along the structural grain, and not across the grain.Several northwest-trending faults were mapped, at a high angle to the structural grain (Figure 4). These features may be associated with areas of jointed or fractured rock extending 30 or more feet on either side of the indicated fault trace. In addition, areas of jointed slate may occur locally in the slate belt well away from a mapped fault. The extent and projection of this kind of deformation are difficult to predict.

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SYMPOSIUM ABSTRACTS

The following are abstracts of papers presented at a symposium sponsored by the American Association of State Geologists and the U.S. Minerals Management Service on November 16, 1988 in Charlottesville, Virginia.

Reconnaissance of Sand, Gravel, and Heavy Mineral Resources in the New York Offshore

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In the New York City area, extraction of sand and gravel resources that are abundant in the glacial deposits of Long Island is becoming more difficult for reasons such as restrictive zoning, increasing land values, and actual construction upon reserves, making the development of new resources difficult if not impossible. Alternative sources of sand and gravel exist on the continental shelf south of Long Island and beneath Long Island Sound. Locating submerged deposits of materials suitable for aggregate is one aspect of this study. Data on 84 vibracores, taken just offshore of the north and south shores of Long Island, was obtained describing the grain size distribution and composition of the sediment contained therein to allow for the determination of its suitability for use as aggregate. Additionally, there exists the possibility that fossil placers may be present in the sand and gravel deposits on the continental shelf. Economically important heavy minerals which must now be imported, at least in part, and which are present on such placers include titanium minerals, zircon, monazite, aluminosilicates, staurolite, garnet, and several others usually found in trace concentrations. A second aspect of this study, is to determine the mineralogy of the heavy mineral fraction of the 84 cores. These minerals were separated from the light fraction of the core using spiralling methods, heavy-liquid, and magnetic techniques. The percent of each economically important heavy mineral has been quantified and a map made of their distribution in Long Island Sound. The study is continuing with the mineralogical and granulometric examination of core from the south shore of Long Island. Grain size analysis of the south shore cores is completed and petrologic composition of the gravels has been determined.

Recent Nonenergy Mineral Activity in the Atlantic Outer Continental Shelf

Roger V. Amato, Minerals Management Service

Large deposits of sand and gravel, phosphate, titanium-rich heavy minerals, and manganese in the Atlantic Outer Continental Shelf (OCS) are available as future alternatives to onshore mining and importing. Several new developments concerning nonenergy minerals have taken place on the OCS during the last two years. These include seabed prospecting by industry, establishment of two Federal-State Task Forces to assess the likelihood of offshore mining, and release of studies on the economic feasibility of mining offshore North Carolina and Georgia. Although there are currently no commercial mining operations on the Atlantic OCS, sand is being commercially extracted from channels in New York Harbor, and it is dredged in State waters periodically for beach nourishment projects.

The Geologic Framework of the Continental Shelf and Slope of Virginia - Emphasis on Petroleum Geology

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Stratigraphic intervals selected from publicly available seismic common depth point (CDP) reflection profiles from the Virginia Coastal Plain eastward to the continental rise were used to evaluate the oil and gas potential of the Virginia onshore-offshore area. Our reconnaissance seismic survey consisted of 729 statute miles (1176 km) of profiling across approximately 15,000 mi (24,000 km).

Four identified stratigraphic reflectors (top Upper Cretaceous, top Lower Cretaceous, top Upper Jurassic, and an acoustic basement reflector) were correlated with the COST (Continental Offshore Stratigraphic Test) B-2 well. Depths were calculated from the same travel times from which isopach and structure contour maps were constructed. Preliminary results from the Shell B-92-1 well, drilled through Cenozoic and Mesozoic strata, offshore Virginia, and from wells adjacent to our Virginia study area, indicate low source-rock quality and thermal immaturity for Cenozoic and Meso-

zoic rocks. Therefore, deposition was probably in an oxidizing, open-shelf environment.

On the continental shelf, the acoustic "basement" reflector (ABR) is generally the most dominant, continuous band of seismic energy on the seismic profiles. The band suggests a relatively dense, thick sequence of dolomite or limestone. The post-rift (probably Early to Middle Jurassic) ABR overlies older Triassic syn-rift basins, such as the Norfolk basin, offshore Virginia, and may act as a seal or trap.

Offshore Mesozoic basins, the Norfolk for example, and onshore concealed Mesozoic basins, such as the Taylorsville basin, may contain sandstones, shales, and interbedded carbonates analogous to the exposed Triassic basins of eastern Canada and the United States. The depth of burial of the basins is insufficient to create the thermal maturation temperatures necessary for the generation of liquid hydrocarbons. However, the basin's rocks could act as reservoirs if hydrocarbons migrated laterally from offshore strata of equivalent age or vertically from older Paleozoic strata.

Although defined seismically, and as yet untested, stratigraphic traps on the outer continental shelf may be important in future wildcat drilling. Recent offshore drilling indicates Middle to Upper Jurassic rocks as the most favorable hydrocarbon source rock. Thus, the updip pinch-out of the Jurassic, west of seismic CDP line 10 and east of the Virginia coastline, may be a suitable target for hydrocarbon exploration. Offshore from Virginia, additional stratigraphic, clastic-wedge traps near the shelf edge pinchout against the ABR and Upper Jurassic to Lower Cretaceous rocks which are reef or carbonate bank deposits on the continental slope. On the outer continental Shelf, horsts and grabens in older, pre-rift Paleozoic strata are identified as possible traps for hydrocarbon accumulations.

We rate the potential of the Virginia-continental-margin to contain commercially recoverable hydrocarbons as fair (moderate) to poor (low). Structural traps on the continental slope may continue as prime drilling objectives; however, we suggest employing a drilling program to evaluate stratigraphic traps on the continental shelf. In shelf waters, drilling at a depth of 20,000 ft (6100 m) is recommended to explore below the acoustic basement rocks for either locally derived or migrated hydrocarbons.

Virginia's Offshore Heavy-Mineral Potential

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The Virginia Division of Mineral Resources and the Virginia Institute of Marine Science have been investigating the occurrence of heavy minerals in the offshore sediments of Virginia over the past four years. Over $400,000 of funding was provided by federal (Minerals Management Service) and State sources. Samples are located along the entire Atlantic coastline and the entrance to Chesapeake Bay, and nearly all are within 5 nautical miles of land. 390 large-volume samples were analyzed, 284 of which came from vibracores; over 3 tons of sediment were processed. The total heavy mineral concentration of 78 samples is equal to or greater than 5 percent. 52 samples have concentrations of one or more economic minerals equal to or greater than threshold values for land-based deposits (ilmenite 45%, leucoxene 5%, rutile 2%, zircon 5%, monazite 1%, and total heavy mineral concentration 5%; Garnar, 1978). A report will be available in December, 1988.

Our investigation was initiated partially because of several high mineral concentrations reported from earlier reconnaissance studies. Our work not only confirms the previously reported mineral values but also has located additional high concentrations up to 20 nautical miles offshore. Furthermore, we have shown that potentially economic mineral values are not restricted to surficial sediments of the inner continental shelf, but are continuous throughout the upper 15 to 20 feet of shelf sediments in several vibracores. Several potentially economic samples from cores were clustered offshore of Hog Island, Smith Island, Virginia Beach, and False Cape. These areas are likely targets for future detailed studies for resource assessment not only for heavy minerals but also for sand to nourish eroding beaches. The high heavy-mineral concentrations suggest further investigations are warranted. The current effort to investigate resources offshore has only begun, because the area we have studied comprises only 3 percent of the Exclusive Economic Zone off Virginia.

Progress Report on the Investigation of the Non-energy Minerals and Surficial Geology of the Inner Continental Shelf of Maryland

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The Maryland Geological Survey has participated in the Minerals Management Services program since its inception in 1983. The first stage of our study was to define the geological framework of Maryland's inner continental shelf and to develop detailed information about the nature, stratigraphy, and geologic history of these sediments.

Sub-bottom profiling was begun in 1985 using the Maryland Geological Survey's research vessel Discovery equipped with a Raytheon RTT1000 seismic profiling system. This work was complemented with profiles from high-resolution seismic equipment furnished by the U. S. Geological Survey. In addition, 131 surficial sediment samples were collected.

During September of 1986, 28 4-inch diameter vibracores, most of which penetrated to about 6 meters, were taken at sites selected by use of the 1985 seismic data. The vibracores were cut into 1.5 meter samples and Xeroradiographed. The cores were then split lengthwise, one-half the section archived, and the remaining half, photographed, logged, and used for study. Sub-samples were split out for micropaleontology, C dating, and amino acid racemization age determination.

The second stage of this investigation began during the 1987 phase of the cooperative agreement and consists of an economic study of the sand, gravel, and heavy minerals.

The surficial samples were combined to make seven samples weighing approximately 1500 grams. The seven surficial samples along with 30 splits from the sand portion of the vibracore samples were then washed to remove salt, dried, weighed, and mechanically sieved into +32mm, +16mm, +8mm, +4mm, +2mm, +1mm, +0.5mm, +0.25mm, +0.125mm, +.063mm, and -.063mm fractions. Heavy minerals were then extracted from splits of the various samples using a Magstream magnetic separator followed by a cleaning with bromoform.

Heavy mineral concentrations in these samples range from 0.69% to 2.67%.

The Ancient Atlantic Reef Trend

Gary M. Edson, Minerals Management Service

In 1983 and 1984, Shell Offshore, Inc., drilled four petroleum exploration wells about 90 miles offshore from New Jersey, Delaware, and Maryland. This exploration program, at the time, established world deep-water drilling records; one drill hole was in 6952 feet of water. Shell's main exploration targets were the limestones of an ancient, buried platform margin, reef, and other associated rock units. These limestones extend discontinuously from Canada to Florida beneath the edge of the continental shelf and slope. Petroleum accumulations occur in many parts of the world in deeply buried reefs of former geologic ages, but the Shell drill holes encountered no significant amounts of oil or gas. Nevertheless, this exploration effort provided considerable information about previously untested rocks. The platform-edge limestones and reef do have reservoir characteristics and may contain petroleum at other locations offshore from the Atlantic seaboard.

Oil and Gas Discovery in the Atlantic OCS: Prophet for the Future of the Rift Morphology Exploration Model?

Frederick R. Keer, Minerals Management Service

The most significant Atlantic OCS hydrocarbon discovery (gas and minor oil) lies 80 miles off the New Jersey coast. Drilled in eight locations with a 63 percent success rate, this structure has sufficient proven gas resources to be a viable field if additional resources can be identified to support a pipeline and other infrastructure. Due to the economic outlook and difficulties in predicting hydrocarbon occurrences on the structure, exploration during the early 1980s was halted. The geologic origin of the structure and of the hydrocarbon source has major implications to the exploration potential of Atlantic offshore grabens. With current interest in East Coast graben-related traps on and offshore, the geologic history and hydrocarbon potential of this structure should be carefully considered.

Replacing a Minicomputer Based Mapping System with Microcomputers: A Case History

Frederick R. Keer and Robert E. Johnson,
Minerals Management Service

A regional Minerals Management Service office was faced with the problem of replacing a minicomputer-based mapping system. A microcomputer-based mapping system was chosen. Operated by geophysicists and non-ADP technical support personnel, the system is easy to use and cost effective. The design emphasis of the system is on universality and interchangeability of hardware, files, and the database manager. Use is expected to be intermittent at roughly 30 maps/year throughout.

Sedimentary Framework of the Muscongus Bay Region of Maine's Inner Shelf

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Muscongus Bay is a large, central Maine embayment which forms a border between two previously-defined coastal compartments: the Indented Shoreline to the south, and the Island-Bay Complex to the north. Approximately half of the bedrock in the area is Devonian granite, while the remainder is floored by Precambrian to lower Paleozoic meta-sedimentary rocks. One-hundred and thirty-nine bottom samples and more than 275 kilometers of side scan sonar and seismic reflection profiles were collected to define the central components of the Quaternary sedimentary framework. Glacial till crops out over an extensive area of the the seafloor in the outer portion of the bay. The till is typically a muddy, sandy-gravel deposit which possesses a "washboard" shape similar to moraines on land. Glaciomarine sediment overlies till, or rests directly on bedrock, and is the most common Quaternary deposit in the bay. It forms tabular-shaped bodies in Shelf Valleys and Nearshore Basins, which are bathymetrically low areas carved by rivers during a lower stand of sea level. Modern mud caps the stratigraphic section in almost all areas in which bedrock or till are not at the seafloor. Natural gas is occasionally recognized within the modern mud, and where abundant, it wipes out the underlying seismic record. Unlike other inner shelf areas in Maine, no sandy Nearshore Ramps or paleoshoreline deposits were recognized from Muscongus Bay. Because of this its mineral potential, despite the presence of nearby exploration sites on land, is minimal.

Non-energy Resources, Connecticut and Rhode Island Coastal Waters

Ralph S. Lewis, Connecticut Geological and Natural History Survey, University of Connecticut, Groton, Connecticut, and Nancy Friedrich Neff, Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island

Approximately 275 track km of high-resolution seismic reflection profile data and 200 track km of side scan sonar data were collected from offshore areas of Connecticut and Rhode Island. Data were analyzed in order to better characterize potential resources within each of the selected survey areas. In Rhode Island Sound, surficial Pleistocene glacial till, moraine, and outwash deposits have been identified as potential resources. In area RIS-1, this glacial unit is estimated to represent 80 million m^3. Outcrops of current-reworked glacial drift are marked by gravel, sand, and boulders. Elsewhere, the drift surface in Rhode Island Sound exhibits patchy, sandy gravel to gravelly sand. The most significant constraint on resource exploitation is fishing activity. In northern Block Island South (survey area BIS-1), a surficial Holocene marine deposit has been identified as a potential resource. The deposit, previously estimated to be 5-10 m thick over 18 km and 1 to 5 m thick over 40 km , consists of uniform gravel with smaller zones of sand and gravel patches. This deposit represents approximately 200 million m^3 of sediment. Fishing activities, although not documented, appear to be a constraint on exploitation in this area. In southern Block Island Sound (survey area BIS-2), surficial Holocene marine sediments and surficial Pleistocene glacial drift deposits have been identified as potential resources. The Holocene sediments, estimated to be 2.5 billion m^3 in volume, are characterized by sand, gravel, patchy sand and gravel, and bedforms. The Pleistocene glacial deposits, estimated to be 400 million m^3 in volume, are marked by gravel, sand, and boulders. Fishing activities and inhospitable tidal current velocities constitute constraints in BIS-2. In eastern Long Island Sound (survey area LIS-3), inferred glacial outwash delta deposits and overlying Holocene marine sand deposits have been identified as a potential resource. In combination, these facies are at least 5 m thick over 40 km (maximum thickness exceeds 40 m), yielding at least 200 million m^3 of sediment. Surficially, this resource is dominated by sand and gravel with sandwaves. A dredge disposal site, 3 km in area, lies within the identified resource area to the east.

Heavy Mineral and Sand Reconnaissance Study of Inner Continental Shelf Sediments, Cape Canaveral, Florida

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The inner continental shelf off Cape Canaveral is mantled by sizable sand shoal bodies that are potential sources for large quantities of sediment for beach replenishment and also valuable heavy minerals. Vibracore samples from 40 sites on and around these shoals were collected by the Army Corps of Engineers and these provide a total of 71 samples for analysis.

Granulometric analyses and compositional descriptions have been done on most of these samples. This information is useful in determining if the sediment is acceptable for use in beach replenishment projects and other aggregate needs. Heavy minerals were separated from the rest of the sediment by spiralling, heavy-liquid, and magnetic methods. The heavy-mineral suite found in these sediments is relatively simple, consisting mainly of ilmenite, epidote, zircon, staurolite, and sillimanite. Also present are monazite, tourmaline, pyroxene, amphibole, garnet, and phosphate. Preliminary analysis of recovered heavy minerals (RHM) from the spiral concentrate indicate percentages ranging from 0.02 to 1.1% with an average of approximately .25%*. Distribution maps will be made which show relative percentages and mineral associations.

Ongoing work will extend this study by collecting more samples and running a high-density seismic profile grid across the major shoal bodies as well as a low-density grid across the entire area. This work will more accurately characterize both the sediment bodies and their heavy-mineral content.

* Average total heavy mineral (THM) percentage by weight is 0.36%.

Coastal Plain and Basement Crustal Interpretation of the Buena 557 Vibroseis Line in the New Jersey Coastal Plain

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A 17.6 km Vibroseis line near Buena, New Jersey, crosses a linear positive Bouguer gravity and magnetic anomaly. Traceable from North Carolina, this anomaly follows the Taconic suture. Two reflectors at 1.4 and 1.7 sec under the positive gravity anomaly and beneath the coastal plain basement reflector at 1.1 sec are from interpreted ophiolitic crustal fragments (7.1 - 7.9 km/sec). A gently southeast dipping reflector (2.0 - 2.7 sec) is interpreted as the detachment thrust below the allochthonous ophiolites. A stratified sequence (5.4 - 6.3 km/sec) is interpreted as remnants of parautochthonous early Paleozoic drift-stage sedimentary rocks beneath the detachment thrust. The sedimentary rocks appear to lie on the early Paleozoic post-rift unconformity marked by truncated Precambrian basement reflectors. Below 3.0 sec (8 km depth), the reflectors are sub-horizontal all the way to the Moho reflector at 11.0 sec. On the northwest end of the Vibroseis line, a northwest tilted Mesozoic rift basin basement is seen as a reflector from 1.1 to 1.5 sec. These Mesozoic rocks (4.5 km/sec) are at least 1 km thick. The denser ophiolites and the less dense Mesozoic rocks explain almost all of the Bouguer anomaly. No significant lateral density variations are needed below 8 km depth. These results imply that the Taconic suture under the New Jersey coastal plain is rootless and underlain by parautochthonous Grenville age continental crust. Similar rootless Taconic suture fragments exposed in the Piedmont are interpreted to be synformal remnants of a transported suture deformed in the Alleghanian orogeny. A deep-seated Taconic suture and the edge of the Grenville North American basement must be southeast of the New Jersey coastal plain. This implies a greater amount of Taconic overthrusting and lesser amounts of accretion of the North American crust than previously proposed.

Six lower- and middle-Cretaceous depositional sequences occur above the basement reflector at 1.1 sec. The five lower sequences occur within the largely nonmarine Potomac Group. Two sequences onlap basement and are interpreted to contain highstand alluvial deposits. The deepest sequence possibly corresponds to Valanginian (LZB-2.1, Haq and others, 1987). A strong reflector marking the top of the second sequence is regarded as a type 1 unconformity which corresponds to an Aptian-Barremian lowstand event (LZB- 3.5/4.1) on the cycle chart. The top of the third sequence is also marked by a strong reflector, which is correlated with the Albian-Aptian type 1 unconformity between LZB-4.2/UZA-1.1.1 Highstand alluvial deposits in this sequence are indicated by coastal onlap. The top reflector of the fourth sequence is correlated with an upper Albian type 1 unconformity (UZA-1.5/2.1). Coastal onlap in the western part of the line indicates highstand alluvial deposits whereas downlap to the east suggests marginal marine deposits. A strong reflector and unconformity mark the surface of the fifth sequence which in a nearby well contains upper Albian inner shelf deposits. The unconformity corresponds to the type 1 middle-Cenomanian unconformity UZA-2.3/2.4. Only transgressive onlap is seen on the Vibroseis line. Absence of downlap suggests highstand deposits were eroded during sea level lowstand. The sixth sequence, upper Cenomanian-

Turonian, is separated from Coniacian? by a strong reflector and unconformity. Downlap of highstand shelf deposits is evident in the main part of the sequence but onlap of a coastal sand occurs at its base. The unconformity (UZA-2.7/3.1) corresponds to a late Turonian lowstand. Sequences showing downlap on the Vibroseis line appear to correlate on the long term eustatic curve (Haq and others) with times of high rates of sea level rise whereas sequences showing onlap correspond with low rates of rise on a subsiding margin.

Geologic Framework and Hydrocarbon Potential Offshore Delaware: Results of Borehole Oh25-02

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A stratigraphic test borehole, Oh25-02, was drilled near Lewes, DE to a depth of 1337 feet. Geophysical logging including gamma-ray, dual induction, resistivity, caliper, and formation density was performed to a depth of greater than 1200 feet. Cuttings samples were taken at 10-foot intervals. On the basis of lithologic and paleontologic examination of the cuttings and geophysical log signatures, units from Oligocene to Pleistocene age were recognized. Regional correlation indicates that glauconitic silts of Oligocene age in Oh25-02 also occur in fault contact with the middle-Eocene Piney Point Formation in updip areas. The fault zone may correspond to either a hinge zone of the Salisbury embayment or upward extensions from border faults of buried early Mesozoic rift basins. This interpretation emphasizes the role of faulting in control of sediment accumulation and preservation in the Atlantic Coastal Plain.

A 2-inch diameter well was constructed in hole Oh25-02 and screened in the Choptank Formation (screen 390-410 ft.) for the purpose of 1) determining water quality, especially chloride concentration, 2) estimating water-yielding capabilities, and 3) obtaining water levels and associated hydraulic gradients. An adjacent well was completed in the Manokin formation (Manokin aquifer, screen 210-220 and 232-240 ft.). Comparison indicates that the Choptank water contains high concentrations of chloride (600 mg/1) and other elements while that of the Manokin is much lower (14 mg/1). The results support the conclusion that water in the Manokin is generally good in inland areas while the Choptank in the same area is mineralized. The intervening St. Marys Formation functions as a confining unit.

Surface and near-surface deposits of sand in the vicinity of Oh25-02 are currently being evaluated for potential use for beach nourishment. The Columbia Formation (or Columbia Group) is subdivided into an overlying interbedded sand and mud unit, the Omar Formation, and underlying coarse sands of the Beaverdam Formation. The Beaverdam is considered to be a potential source of beach-nourishment sand. The regional stratigraphic, age, and genetic relationships between the Beaverdam and similar sand bodies updip (Columbia Formation) are at this time unclear.

Subsurface Stratigraphic Framework Studies of the Pamlico-Albemarle Sound, North Carolina: MMS Phase Four

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Objectives of this study are to develop a foraminiferal biostratigraphic framework via detailed examination of deep wells, and to integrate available information into a sequence stratigraphic model.

Existing subsurface stratigraphic interpretations for the Pamlico-Albemarle Sound are based on lithology, well logs, ostracode biostratigraphy, and limited documentation of foraminifera and palynomorphs.

New information generated in this study includes; 1) a foraminiferal biostratigraphic framework based on detailed examination of cuttings from five wells (33,600 feet); 2) a paleobathymetric model for each well; and 3) stratigraphic interpretations for 400 miles (16 lines) of recently acquired seismic data, plus an expanded seismic basement map.

Integration of lithologic, seismic, paleontologic, and well log data resulted in the interpretation of more than 20 sequence boundaries for a well log/seismic section through Pamlico-Albemarle Sound. Biostratigraphic intervals previously not recognized locally are documented, including lower Miocene, late Eocene, and a marine Santonian section.

Current work involves characterization of systems tracts within each depositional sequence, and resolving ages of the sequence boundaries.

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THE RICHARD SCOTT MITCHELL MEMORIAL VIRGINIA MINERAL COLLECTION

The late Dr. Richard S. Mitchell, Professor of Mineralogy, at the University of Virginia has bequeathed a generous sum of money to the James Madison University Mineral Museum. These funds were designated by Dr. Mitchell's will to further develop a premier collection and display facility of mineral specimens indigenous to the state of Virginia. The display will be available to the public and will stand as a lasting tribute to an outstanding Virginia mineralogist.

A trust fund has been established by the James Madison University Foundation to receive donations to add to Dr. Mitchell's bequest. The interest from this fund will assure a continued income to support the care and growth of the Virginia Mineral Collection. The museum is also seeking gifts of Virginia mineral specimens appropriate for display. All gifts will be acknowledged and are tax deductible.

Monetary tributes should be mailed to: The Richard S. Mitchell Memorial Fund, James Madison University Foundation, James Madison University, Harrisonburg, Virginia 22807.

Mineral specimens or inquires should be addressed to: Mineral Museum, Dr. Lance E. Kearns, Department of Geology and Geography, James Madison University, Harrisonburg, Virginia 22807.