STRATIGRAPHY AND PETROLOGY OF THE PUNGO RIVER FORMATION, CENTRAL COASTAL PLAIN OF NORTH CAROLINA

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ABSTRACT

Up to 30 m of phosphatic sediments of early and middle Miocene Pungo River Formation were deposited in the north-south-trending Aurora Embayment of North Carolina. These sediments thin to approximately 10 to 15 m over the Cape Lookout High, a pre-Miocene feature which forms the southern boundary of the Aurora Embayment. The western and updip limit of the formation parallels a regional north-south structural hingeline or White Oak Lineament. The formation thins to a feather-edge at this lineament and thickens rapidly to the east and southeast. Deposition of the Pungo River Formation extended some unknown distance to the west of the White Oak Lineament, the present updip erosional limit.

The Pungo River Formation consists of the four major sediment sequences in the Aurora Area (units A, B, C, and D as described by Riggs and others, 1982b) and three lateral facies (units BB, CC, and DD). Phosphate sedimentation was concentrated in units A, B, and C which are laterally correlative throughout most of the study area. However, the muddy phosphorite quartz sands of unit B and possibly the phosphorite quartz sands and carbonate sediments of unit C grade downdip to the southeast into an 11-m-thick diatomaceous facies (unit BB). Units A, B, and C grade into a slightly phosphatic, calcareous, quartz sand facies (unit CC) to the south, in the area of the Cape Lookout High, which probably represents a shoaling environment. Dolomitic unit D, of the northern and eastern portions of the Aurora Embayment, grades laterally into calcareous unit DD in the central portion of the embayment.

Allochemical phosphate grains of the intraclastic variety dominate all sediment units in the formation. However, unit A contains abundant pelletal phosphate in the fine to very fine sand-size fraction. The highest phosphate concentrations occur along the upper shelflike basin margin in the west-central portion of the Aurora Embayment. Updip to the west, the phosphate concentration decreases within each unit which also thins due to subsequent erosion. Major facies changes within the sediment units have resulted in decreased phosphate contents downdip to the east and south within the Aurora Embayment.

Within the Aurora Area, units A through C of the Pungo River Formation are generally characterized by cyclic deposition consisting of decreasing terrigenous and increasing phosphate sedimentation upward through the units; the deposition of each unit culminated with the formation of a carbonate cap-rock. The depositional pattern of these regionally persistent and cyclical lithologies suggests that units A through C were deposited during a major transgression. The overlying unit D was deposited during the early stages of a subsequent regressive phase. Truncation of the units by erosion took place prior to the deposition of the Pliocene Yorktown Formation. Thus, this extensive erosion has produced an apparent offlap configuration of the Pungo River units that actually represents a major transgressive or onlap sediment sequence and an early stage regressive sequence.

INTRODUCTION

The phosphorites and phosphatic sediments of the Pungo River Formation in the central Coastal Plain of North Carolina were orginally described by Brown (1958) and correlated with the middle Miocene Calvert Formation of Maryland and Virginia on the basis of benthic foraminifera. Subsequent work utilizing mollusks and benthonic and planktonic foraminifera has demonstrated that the Pungo River ranges in age from at least middle early Miocene and extends well into the middle Miocene (Gibson, 1967, in press; Katrosh and Snyder, 1982; Riggs and others, 1982a, 1982b). The Pungo River Formation is also equivalent to portions of the Hawthorn Group of Florida, Georgia, and South Carolina (Gibson, 1967; Riggs, 1979b).

The Pungo River Formation is found only in the subsurface of eastern North Carolina. Its westward updip boundary coincides with and parallels a major north-south structural hingeline recognized by Miller (1971). This hingeline is called the White Oak Lineament by S. W. P. Snyder and others (1982). Miller (1971) recognized several erosional outliers west of the White Oak Lineament which indicates that the formation extended beyond its present updip limit. The formation dips and thickens to the east. Miller (1971) has mapped the formation northward to Virginia, and eastward and southward to the coastline (Fig. 1). The northern and eastern extent of the formation is unknown. To the south, phosphatic sediments of the Pungo River have been recovered from holes drilled on Bogue Banks, Carteret County (Steele, 1980), and from vibracores across the continental shelf in Onslow Bay (Riggs and others, 1982a).

The study area is located in the east-central portion of the North Carolina Coastal Plain, covering the southern half of the Aurora Embayment (Figs. 1 and 2). The Pungo River Formation, within the study area, unconformably overlies either the 1) Eocene Castle Hayne Limestone (Brown and others, 1972; Miller, 1971); 2) Oligocene Trent Formation (Baum and others, 1978) or the River Bend Formation (Ward and others, 1978); or 3) the lower Miocene Silverdale Formation or the Haywood Landing Member of the Belgrade Formation (Baum and others, 1978; Ward and others, 1978) depending upon the location and one's choice of stratigraphic terminology. For the purposes of this paper, the underlying units will be designated only as *pre-Pungo River*

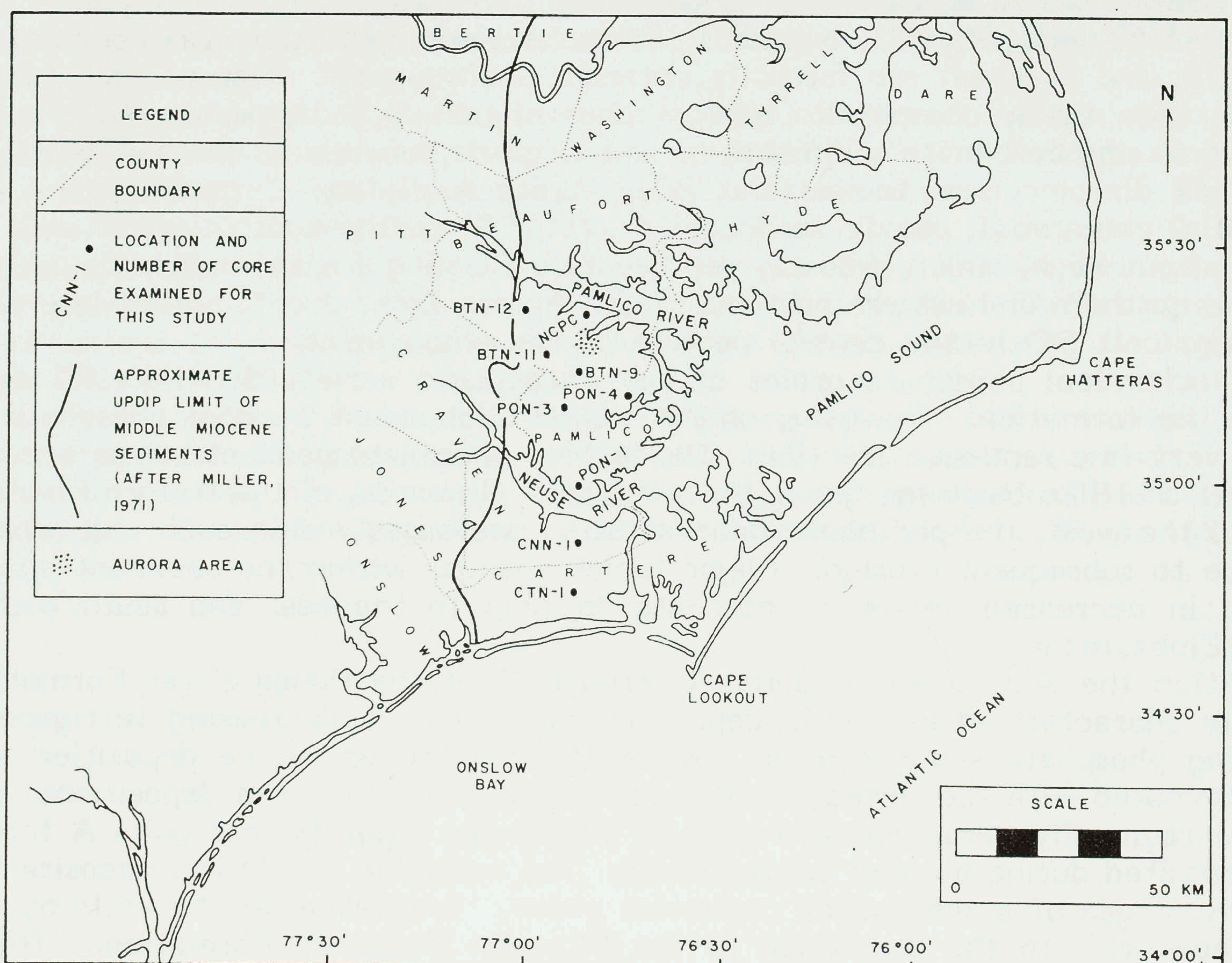

Figure 1. Map of study area showing core hole locations and western updip limit of the early to middle Miocene Pungo River Formation (from Miller, 1971).

sediments. The Pungo River Formation is unconformably overlain by the fossiliferous, gravelly, muddy, phosphatic, quartz sands of the Pliocene Yorktown Formation throughout most of the Aurora Embayment.

Core samples of the Pungo River Formation (Fig. 1) were gathered from two sources: eight cores drilled by International Minerals and Chemical Corporation in 1966 (Riggs, 1967) and several cores drilled in 1979 and 1980 by North Carolina Phosphate Corporation (NCPC) (Riggs and others, 1980). All samples were examined with a binocular microscrope to determine the mineralogy and texture, to assign lithologic names, and to identify the megascopic phosphate grain types. Thin sections from selected phosphate-rich intervals were examined to aid in the identification of phosphate grain types and to supplement mineralogic determinations. Textural analyses, performed on all samples, further characterized the interrelations of mineralogy, grain size, and phosphate grain types.

The major objective of this paper is to describe the lithostratigraphy of the Pungo River Formation within that portion of the Aurora Embayment extending from the Aurora Area, southward and westward to the embayment margins (Fig. 2). More specifically, the objectives are to 1) describe the lateral and vertical facies relationships within the formation and correlate the lithologic units and subunits throughout the study area, and 2) describe the phosphate petrology within the major phosphorite units.

STRUCTURAL CONTROLS

Miller (1971, p. 40) stated that "the location of economic or potentially economic phosphate deposits . . . shows that structural conditions in the basin of deposition played a prominent, perhaps dominant, role in deposition and concentration of the phosphate." The close relationship of structural elements to phosphate sedimentation and accumulation has been discussed by Freas and Riggs (1964), Riggs (1967, 1979b, and 1980a), and Miller (1971).

The structural features which have traditionally been recognized as controlling Tertiary sedimentation in the Coastal Plain of North Carolina are the Norfolk and Cape

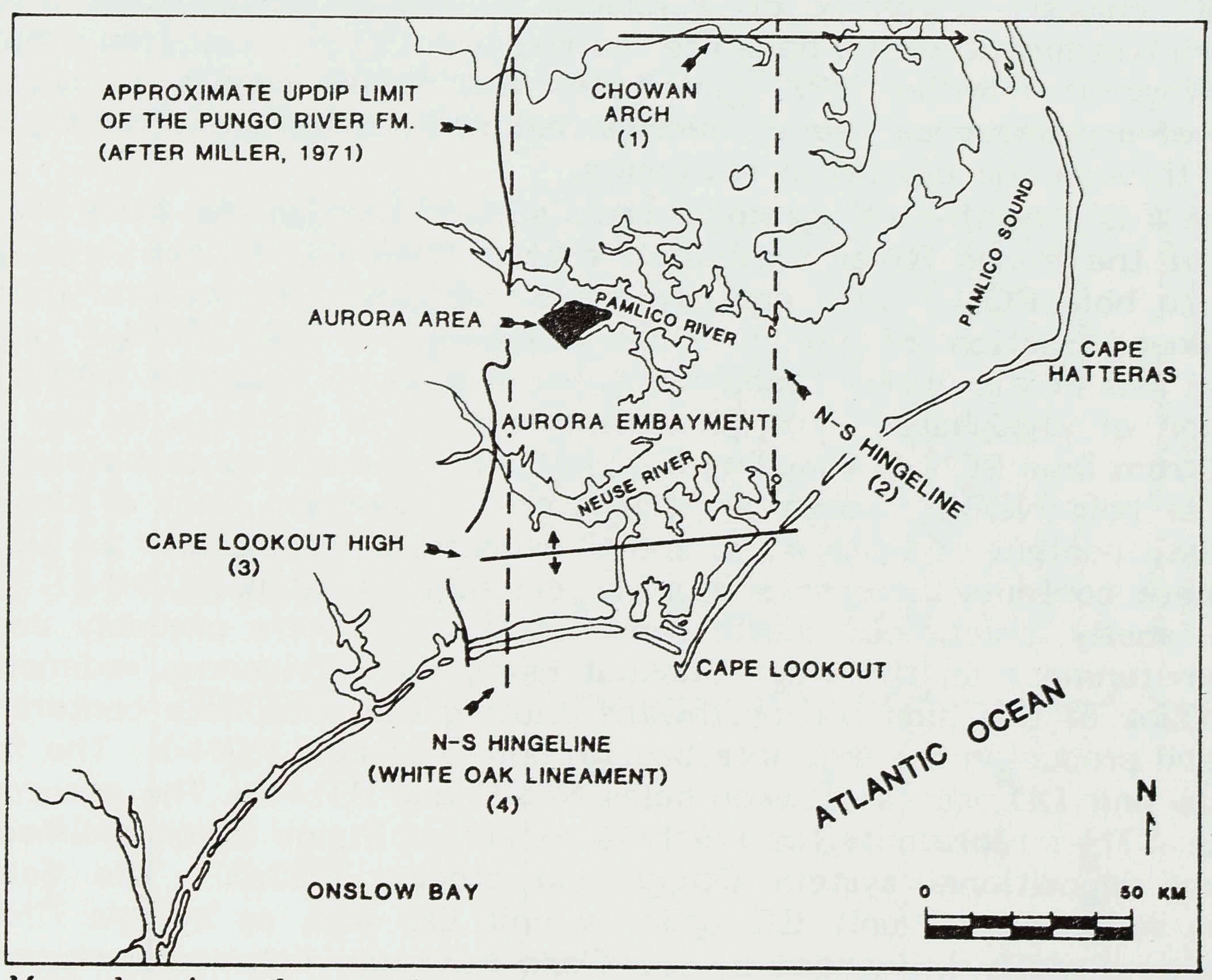

Figure 2. Map showing the north-south oriented Aurora Embayment which is defined by the structures from the following papers: 1) Miller, 1971; Riggs, 1967; 2) Brown and others, 1972; Miller, 1971; 3) Miller, 1971; Riggs, 1967; S. W. P. Snyder and others, 1982; 4) Brown and others, 1972; Miller, 1971; S. W. P. Snyder and others, 1982.

Fear Arches, with an associated intervening basinal area called the Albemarle Embayment (Gibson, 1967; Miller, 1971; Brown and others, 1972; Mauger, 1979). The thickest sequence of Tertiary sediments was deposited in this basin with the sediments thinning or absent over the positive features.

The Pungo River sediments were deposited in the Aurora Embayment, a smaller depositional basin contained within the Albemarle Embayment. The Aurora Embayment is delineated by four structural elements as shown in Figure 2. The western and eastern margins are delineated by north-south-trending hingelines defined by Miller (1971) and Brown and others (1972). The western hingeline is called the White Oak Lineament by S. W. P. Snyder and others (1982). The northern margin is delineated by the east-west-trending Chowan Arch of Riggs (1967), which is located just south of the Albemarle Sound (Fig. 2). The southern margin is defined by a positive feature located south of the Neuse River which has been recognized by many workers (Riggs, 1967; Gibson, 1967; Miller, 1971; Brown and others, 1972; S. W. P. Snyder and others, 1982). This east-west-trending topographic high, called the Cape Lookout High by S. W. P. Snyder and others (1982), has affected the deposition of the Pungo River Formation and younger sediments in the southern portion of the study area (holes PON-1, CNN-1, and CTN-1 in Fig. 4). Miller (1971) believes these four structural features created a restricted "Pungo River basin" or Aurora Embayment in which phosphate was precipitated and concentrated, primarily along and just to the west of the easternmost hingeline.

LITHOSTRATIGRAPHY

Within the Aurora Embayment, the Pungo River Formation consists of seven major sediment units (Fig. 3). Four of the sediment units (units A, B, C, and D) have been described from the Aurora Area by Riggs and others (1982b). These four units have persistent mineralogical and textural characteristics and are laterally correlative throughout most of the study area. Units BB and CC (Fig. 3) are lithologically distinct from units A through D, are restricted in occurrence, and are lateral facies of units A, B, and C (Figs. 4 and 5). Unit DD (Fig. 3) occurs in the central portion of the study area and is a lateral facies of unit D (Figs. 4 and 5). The facies change from unit D to unit DD consists primarily of a change in matrix composition. Unit D is a bioclastic-rich sediment with a dolomite matrix; unit DD is a calcareous bioclastic-rich sediment (Fig. 3). Miller (1971) attributes this facies change to secondary dolomitization of a primary calcite or micrite matrix by magnesium-bearing groundwater movement through the bioclastic sediments.

Figure 4 is a north-south geologic cross section through the study area. Units A, B, and C of the Pungo River Formation extend from the Aurora Area (hole NCPC) southward to hole PON-3 with consistent mineralogical and textural characteristics. The thickenend section of Pungo River sediments at hole PON-3 represents the depositional axis of the Aurora Embayment, but it does not coincide with the maximum accumulation of phosphate. The phosphate content of units A, B, and C increases northward from hole PON-1, reaching a maximum cumulative phosphate content in the formation at hole NCPC. South of PON-1, on the southern flank of the embayment, the phosphate content of units A, B, and C decreases dramatically as the terrigenous and carbonate contents increase and grade into unit CC at hole CNN-1. The slightly phosphatic, shelly, calcareous quartz sands of unit CC were probably deposited in a shoaling environment on the Cape Lookout High; the terrigenous sediments extended down the flank of this high and northward diluting the phosphate content of units A, B, and C and producing the mud interbeds in unit B at hole PON-1. The facies change of unit D to unit DD occurs between holes NCPC and BTN-9. The occurrence of unit DD in hole CTN-1 represents the northern extent of Pungo River sediments from the Onslow Bay depositional system (Riggs and others, 1982a). The calcareous and terrigenous sediments of unit CC underlie unit DD and, as in hole CNN-1, reflect sedimentation directly influenced by the Cape Lookout High.

Figure 5 is a northwest-southeast geologic cross section through the study area which shows 1) the sequential westward truncation of the vertical lithofacies of the Pungo River Formation by a late Miocene unconformity (Riggs and others, 1982b); and 2) the occurrence, in hole PON-4, of a diatomaceous facies that is considered

	CENTRAL FACIES: COMPOSITE SECTION, AURORA EMBAYMENT				SOUTHERN FACIES: HOLES PON-1, CNN-1, CTN-1			EASTERN FACIES: HOLE PON-4		
	UNIT	THICKNESS		LITHOLOGY	UNIT	THICKNESS	LITHOLOGY	UNIT	THICKNESS	LITHOLOGY
PUNGO RIVER FM	DD	0-7 M		White, slightly phosphatic and quartz sandy, calcareous bioclastic shell hash (barnacles, bryozoans) with less than 20 percent calcite mud			ABSENT	D	0-7 M	Yellowish-green, slightly phosphatic and quartz sandy, dolosilty bioclastic shell hash (bryozoans, barnacles, annelid tubes) to shelly dolomite muds
	C	0-9 M	0-5 M	Cream colored, nonindurated to indurated, fossiliferous and moldic, phosphatic and quartz sandy calcareous mud with limestone interbeds which decrease downward	CC	0-17 M	White to light gray to olive green, calcareous silty muds to very shelly, calcareous muddy, sometimes gravelly, slightly phosphatic (less than 10 percent) quartz sands	BB	0-11 M	Light grayish-green, slightly calcareous, slightly phosphatic and quartz sandy, diatomaceous mud; diatom fragments compose up to 70 percent of the sediment
			0-6 M	Very dark greenish gray, massive, burrowed to mottled, moderately muddy quartz phosphorite sand with minor shell material						
	B	0-12 M	0-7 M	Light olive green, indurated to semi-indurated, highly burrowed and locally silicified, slightly fossiliferous and moldic, phosphatic and quartz sandy dolomite mud Moderate olive green, burrowed to mottled, dolomite muddy, phosphorite quartz sand						
			0-7 M	Dark olive green, massive and mottled, muddy phosphorite quartz sand which is locally gravelly (phosphorite granules) near base				B	0-12 M	Dark green, gravelly (phosphorite granules), muddy, phosphorite quartz sand
	A	0-6 M	0-1 M	Light olive green, indurated to nonindurated, highly burrowed and locally silicified, slightly fossiliferous and moldic, phosphatic and quartz sandy dolomite mud				?		
			0-5 M	Moderate olive green, burrowed to mottled, dolomitic, muddy phosphorite quartz sand which is locally gravelly (phosphorite and quartz gravels) near base				A		NOT RECOVERED

Figure 3. Description of the lithofacies of the Pungo River Formation in the Aurora Embayment south of the Pamlico River, North Carolina.

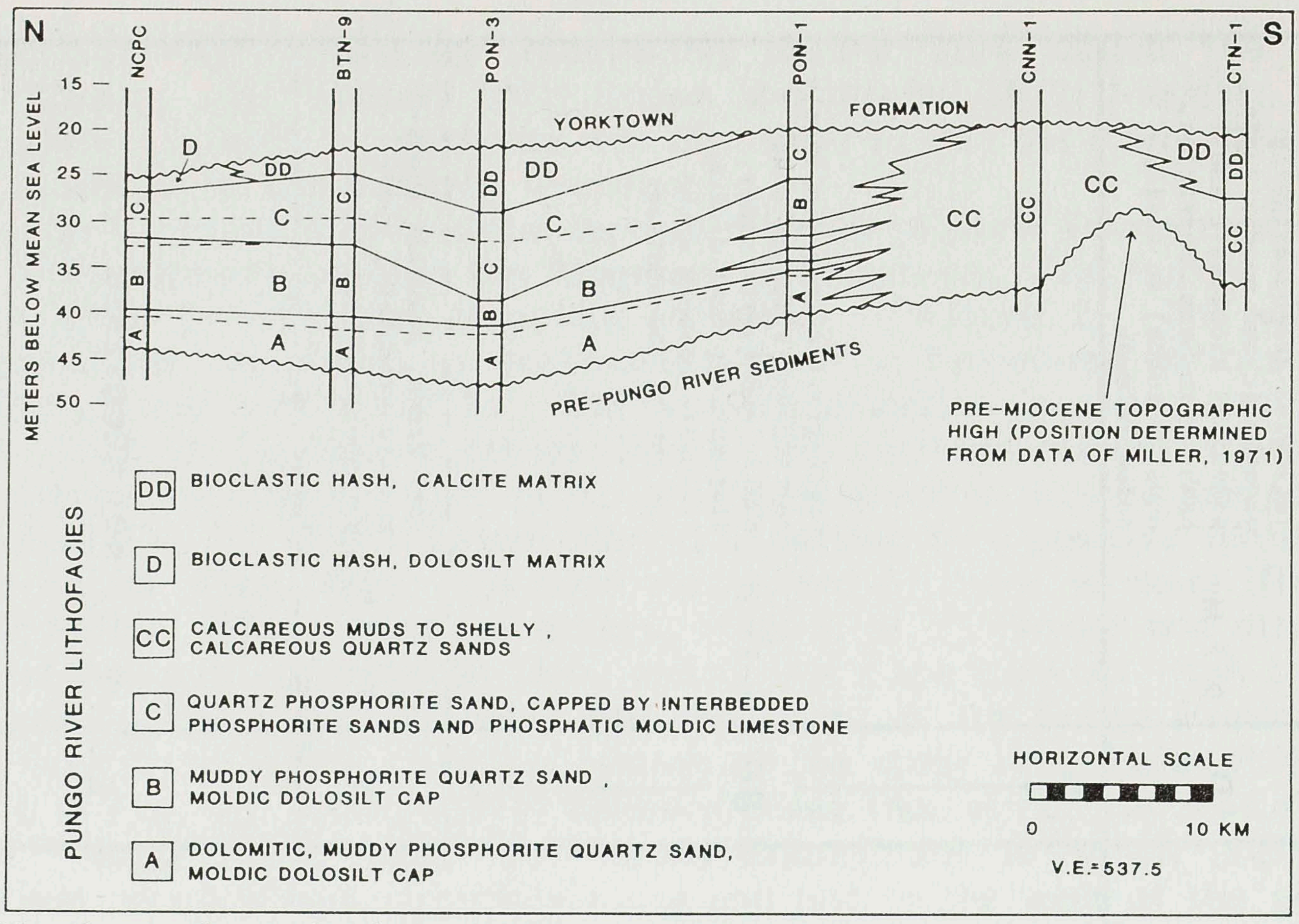

Figure 4. North-south geologic cross section of the Pungo River Formation through the study area; core hole locations are on Figure 1.

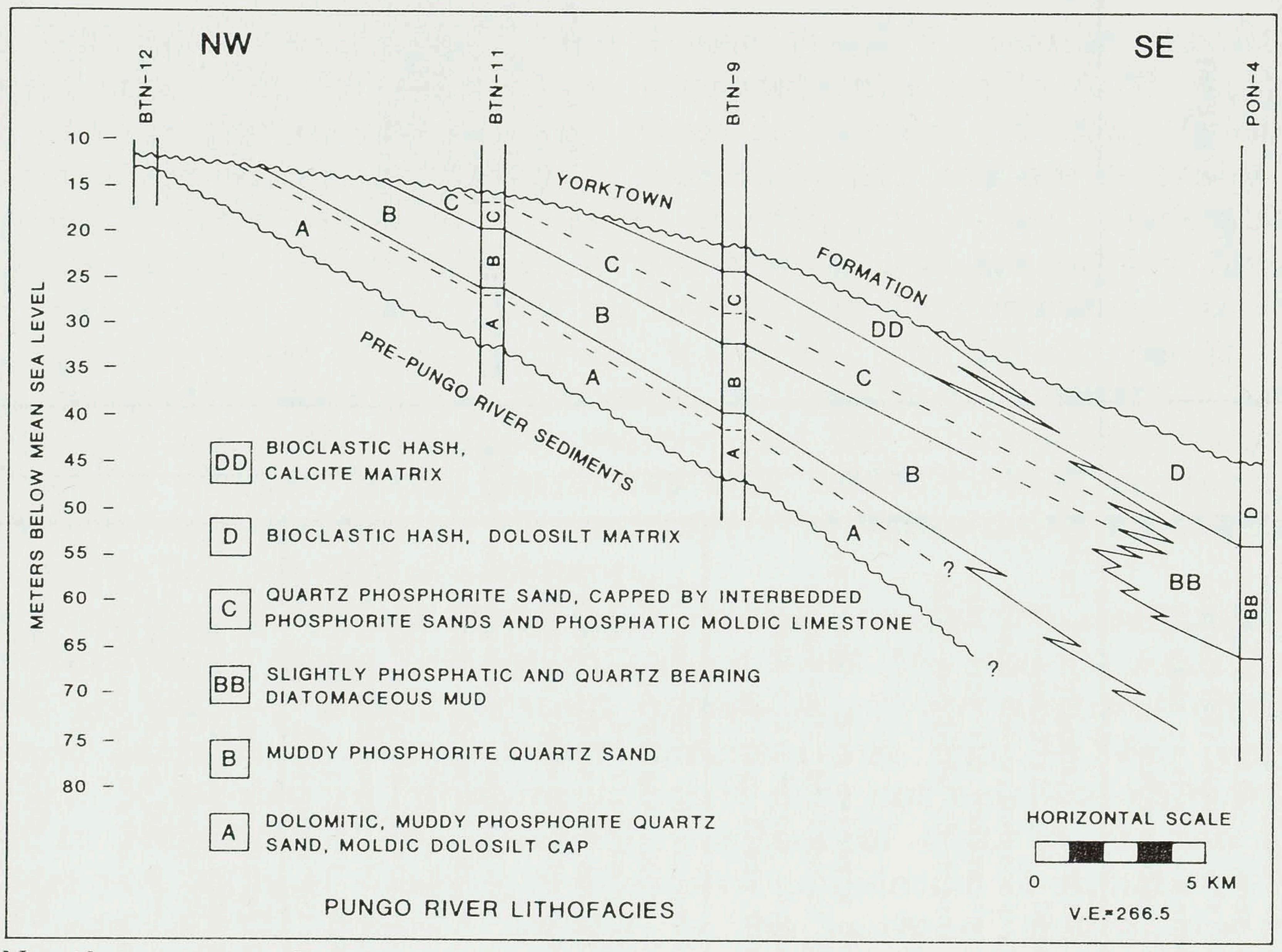

Figure 5. Northwest-southeast geological cross section of the Pungo River Formation through the study area; core hole locations are on Figure 1.

equivalent to the upper portion of unit B, and possibly all of unit C. Truncation of the Pungo River Formation prior to the deposition of the Pliocene Yorktown Formation was extensive and severe, eliminating the original western depositional extent of the formation, except for erosional outliers such as those noted by Miller (1971) west of the White Oak Lineament. Units A, B, and C on Figure 5 are characterized by consistent mineralogical and textural parameters. The calcareous matrix of unit DD at hole BTN-9 changes downdip to dolomite (unit D) at hole PON-4. Underlying unit D in hole PON-4 is the slightly sandy diatomaceous mud of unit BB. The diatomaceous sediments were probably deposited as a result of high organic productivity associated with upwelling currents and active phosphate sedimentation. This depositional regime existed during the later portions of the transgression when upwelling currents would have extended furthest into the Aurora Embayment and phosphate sedimentation would have been greatest (i.e., during deposition of units B and C). Gravelly, muddy, phosphorite quartz sands characteristic of the lower portion of unit B underlie unit BB at hole PON-4.

PHOSPHATE PETROLOGY

The megascopic phosphate grains (those greater than 0.063 mm in diameter) of the Pungo River Formation have been described according to the classification of sedimentary phosphorites proposed by Riggs (1979a). He subdivided authigenic phosphate into orthochemical phosphate mud (microsphorite), analogous to micrite in carbonates, and allochemical phosphate grains, analogous to carbonate allochemical grains. Phosphate allochems consist of intraclasts, pellets, oolites, and fossil skeletal material (Fig. 6). Lithochemical and metachemical phosphorites are products of secondary processes and have not been identified from the Pungo River Formation.

The majority of predominantly dark brown to black granule-sized and light to dark brown sand-sized phosphate grains of the Pungo River Formation possess the characteristics of intraclastic phosphate allochems. These characteristics include a cryptocrystalline carbonate fluorapatite matrix (Rooney and Kerr, 1967), terrigenous and authigenic mineral inclusions, laminae, mottles, and bored and burrowed sediment surfaces (Fig. 7). Intraclasts, which comprise approximately 80 percent of the phosphate grains in the Pungo River Formation, are angular to subrounded and irregular in shape, especially in the coarse-sand and gravel fractions. Rounding and sphericity increase with decreasing grain size, although some irregularity in shape, such as a flattened side, will persist down to the very fine sand-size fraction. The presence of inclusions and sedimentary structures diminishes with decreasing size of the intraclasts due to continued fragmentation of the grains during transport (Riggs, 1979a).

Inclusions constitute an important microscopic component of the Pungo River intraclast grains. The inclusions occur as disseminated particles throughout the carbonate fluorapatite matrix of the intraclasts. Of the inclusions found in the very fine to coarse sand-sized intraclasts, 50 percent are very fine sand to silt-sized quartz grains, 30 percent microfossil fragments, 10 percent phosphate allochems, 5 percent glauconite grains, approximately 1 percent each of feldspar, clay clasts, calcite allochems, dolomite rhombs, pyrite inclusions, and variable amounts of organic matter.

Pelletal allochems (Fig. 8) comprise the second major group of phosphate grain types, accounting for 20 percent of the phosphate in the Pungo River Formation. The uniformity in size and the regular geometric shapes of the pellets are the two main characteristics that distinguish pelletal phosphate grains from highly abraded fine to

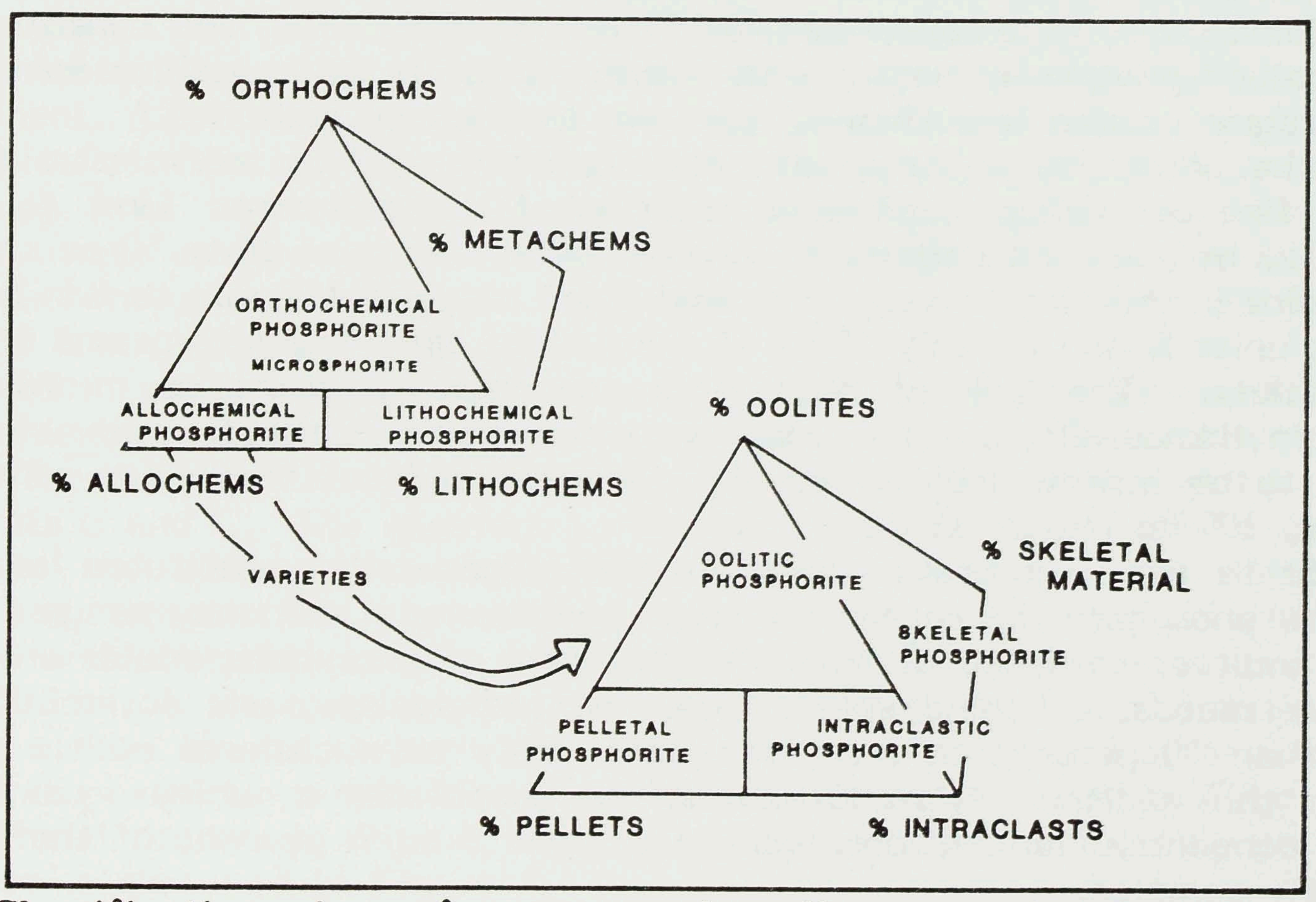

Figure 6. Classification scheme for megascopic sedimentary phosphate grains (modified from Riggs, 1979a).

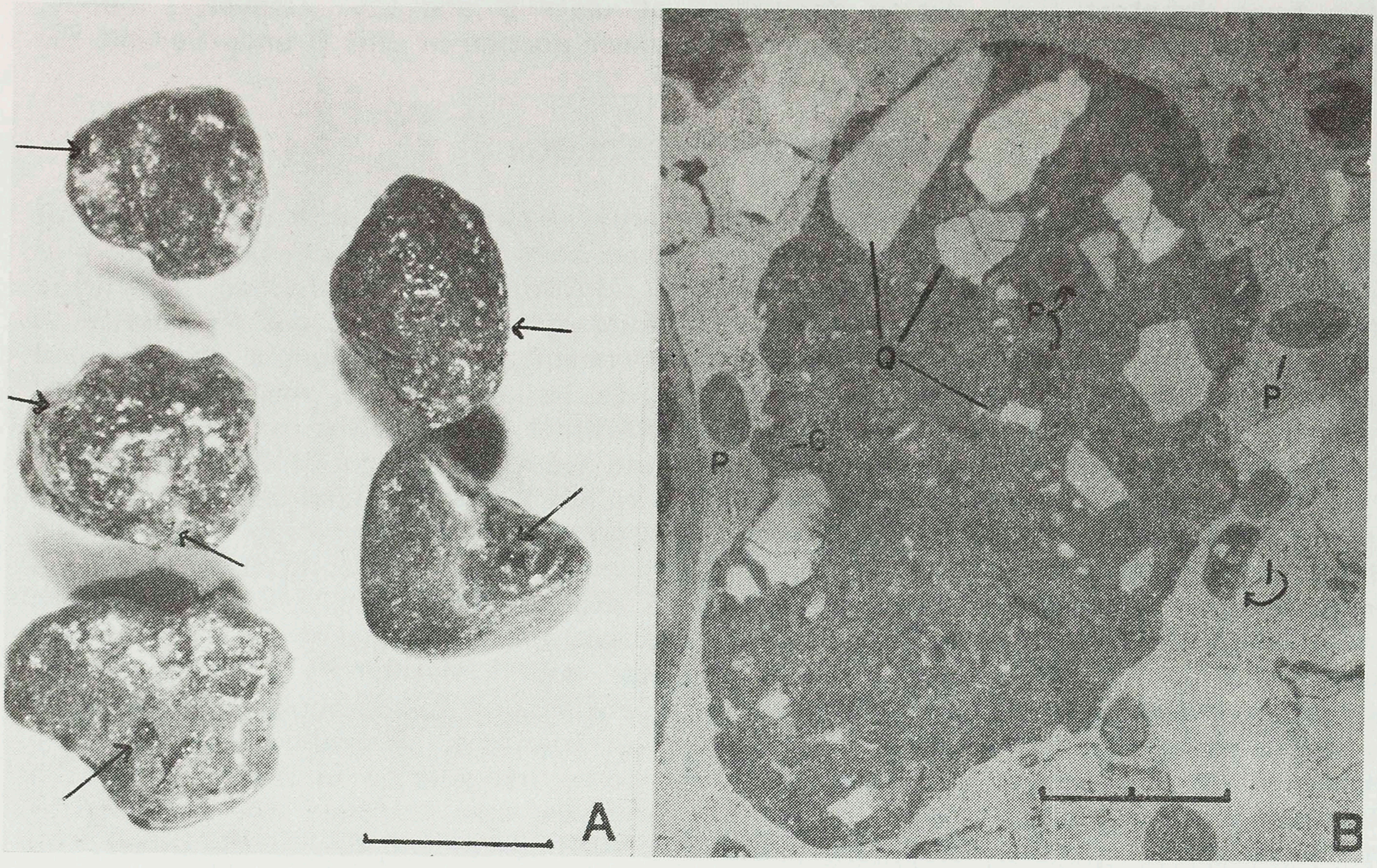

Figure 7. A) Coarse to very coarse sand-sized phosphate intraclasts. Notice the abundant inclusions of clear quartz; the subangular to subrounded, irregular surface texture of the intraclasts. Scale bar equals 1.0 mm. B) Thin section of a coarse sand-sized phosphate intraclast. The disseminated inclusions are dominantly bladed to angular, silt to fine sand-sized quartz grains (Q). Two very fine sand-sized phosphate pellets (P) and a glauconite grain (G) are also present as inclusions. Note the irregular surface of the intraclast which is partially due to the breaking out of the inclusions during transport. Very fine sand-sized phosphate pellets (P) and intraclasts (I) can be seen adjacent to the coarse sand-sized intraclast. Scale bar equals 0.2 mm.

very fine sand-sized intraclasts. The Pelletal phosphates are moderate to dark brown in color, extremely well sorted, and are ovoid, ellipsoidal, and rod-shaped. They are dominantly fine to very fine sand-sized (0.177 mm to 0.063 mm) and consist primarily of a cryptograined phosphate matrix with varying amounts of inclusions dominated by microfossil fragments and less than 10 percent terrigenous material.

All of the units within the study area are dominated by intraclastic phosphate grains in the fine to medium sand-sized fraction of the sediment. Unit A, however, is characterized by abundant pelletal allochems, which comprise 30 to 50 percent of the phosphate grains in the fine to very fine sand-sized range (0.177 mm to 0.063 mm). In the overlying units B and C, only 10 to 15 percent of the phosphate grains in this size range are pellets. The lack of observable concentric layering or microbotryoidal textures within the pellets, and the common occurrence of pelletal grains clustered in what appear to be burrow fillings, strongly suggest a fecal origin for some of the pellets (Riggs, 1979a; Riggs, 1980b).

Invertebrate and vertebrate skeletal material generally constitutes less than 15 percent of the phosphate macrograins in any given sample, but may range from 5 to 20 percent. Indirect evidence of fossils in the form of phosphatic molds and casts of pelecypods, ostracods, echonoid spines, diatoms, radiolarians, and foraminifera constitute less than 10 percent of most samples. Only an occasional oolitic grain was recognized in thin section. "Pseudo-oolites," which possess a nucleus grain but lack well-defined concentric laminations, comprise from 2 to 3 percent of the phosphate grains in many samples.

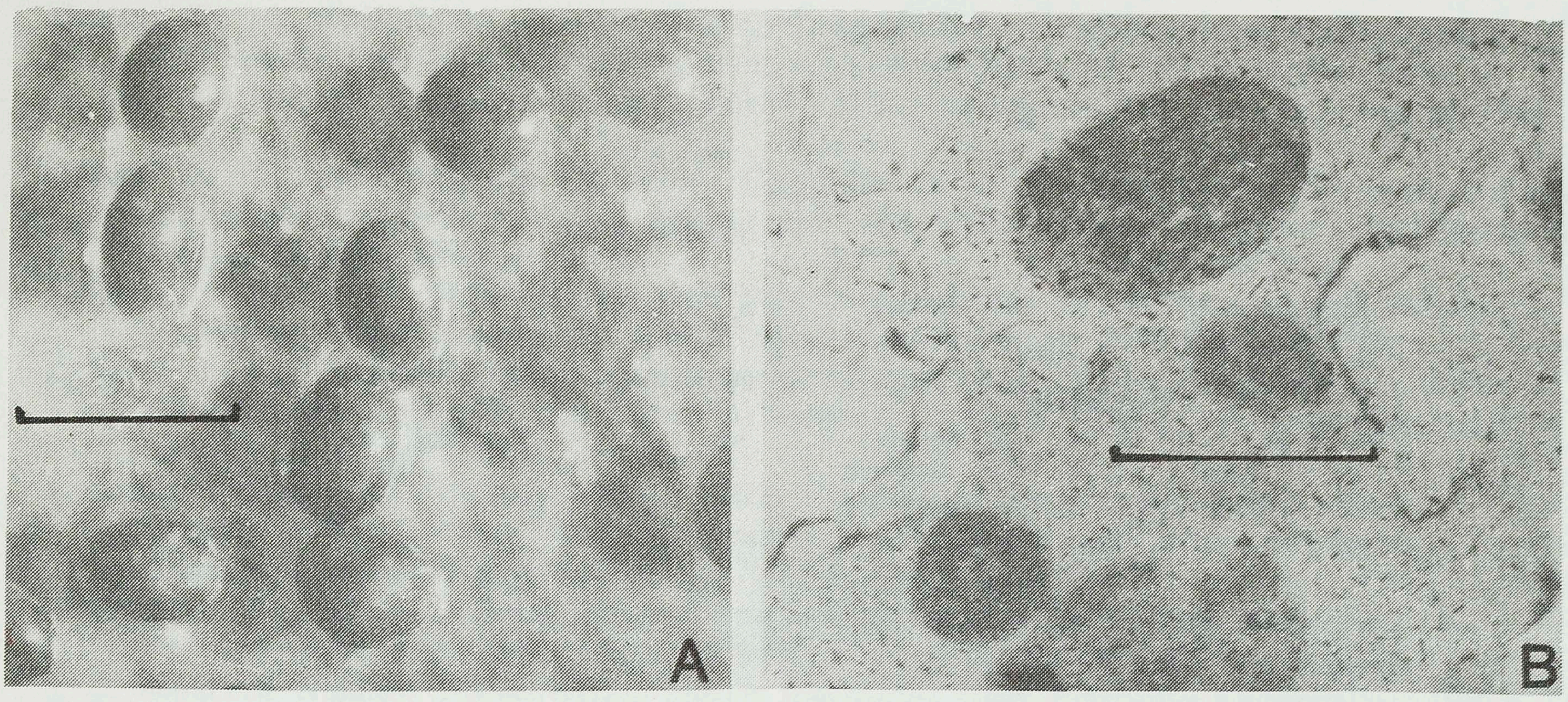

Figure 8. A) Very fine to fine sand-sized phosphate pellets. All grains illustrate the smooth and polished texture and the ovoid to spherical shape of the pellets. Scale bar equals 0.1 mm. B) Thin section of very fine to fine sand-sized phosphate pellets showing a regular outline, smooth surface, and a lack of terrigenous inclusions. The mottled interior of the grains results from the organic matter (bacterial rods, spheres, and aggregates) contained within the carbonate fluorapatite matrix (Riggs, 1979a). Scale bar equals 0.1 mm.

SUMMARY

The Aurora Embayment extends south from the Chowan Arch to the Cape Lookout High. The westward limit of the Embayment is a line approximately coincident with, and parallel to, the White Oak Lineament. Up to 30 m of phosphorites and phosphatic sediments of the Pungo River Formation were deposited in the eastern portion of the Aurora Embayment. The formation thins westward, pinching out at the White Oak Lineament, and thins southward to 10 to 15 m over the Cape Lookout High.

Seven major sediment units (units A, B, C, D, BB, CC, and DD) comprise the Pungo River Formation within the southern half of the Aurora Embayment. Throughout most of the study area, the formation consists of units A, B, C, and D or DD which are laterally persistent and correlative in terms of mineralogy and texture and reflect a distinct cyclical pattern of sedimentation as defined by Riggs and others (1982b) for the Aurora Area. These four units are erosionally truncated eastward from the White Oak Lineament. Units A, B, and C are the main phosphate-bearing units in the Aurora phosphate district. Vertical trends in sedimentation can be recognized throughout most of the study area and include: 1) decrease in phosphate content and increase in carbonate content upward within each of units A through C; 2) an overall increase in phosphate content upward from unit A through unit C; and 3) a slight decrease in grain size upward from unit A through unit C.

Unit BB is an 11-m-thick diatomaceous facies, which contains up to 70 percent diatom fragments, and occurs in the eastern portion of the Aurora Embayment. Facies BB is considered to be the downbasin equivalent of the shallower-water phosphorite sands of units B and C. The apparent contemporaneous depositon of the diatomaceous sediments in the east-central embayment area with the greatest development of phosphate sedimentation in the upslope area to the west suggests that both the phosphorite and diatomite were deposited in response to increasing organic productivity. Such a depositional regime could reflect the increasing influence of upwelling currents upward through the section and westward across the embayment in response to the early to middle Miocene transgression as described by Riggs and others (1982b). The depositional regime thought to have existed during this portion of the transgression is sketched in Figure 9.

Unit CC is a shelly calcareous medium-grained quartz sand facies that was deposited in the southern margin of the Aurora Embayment, forming contemporaneously

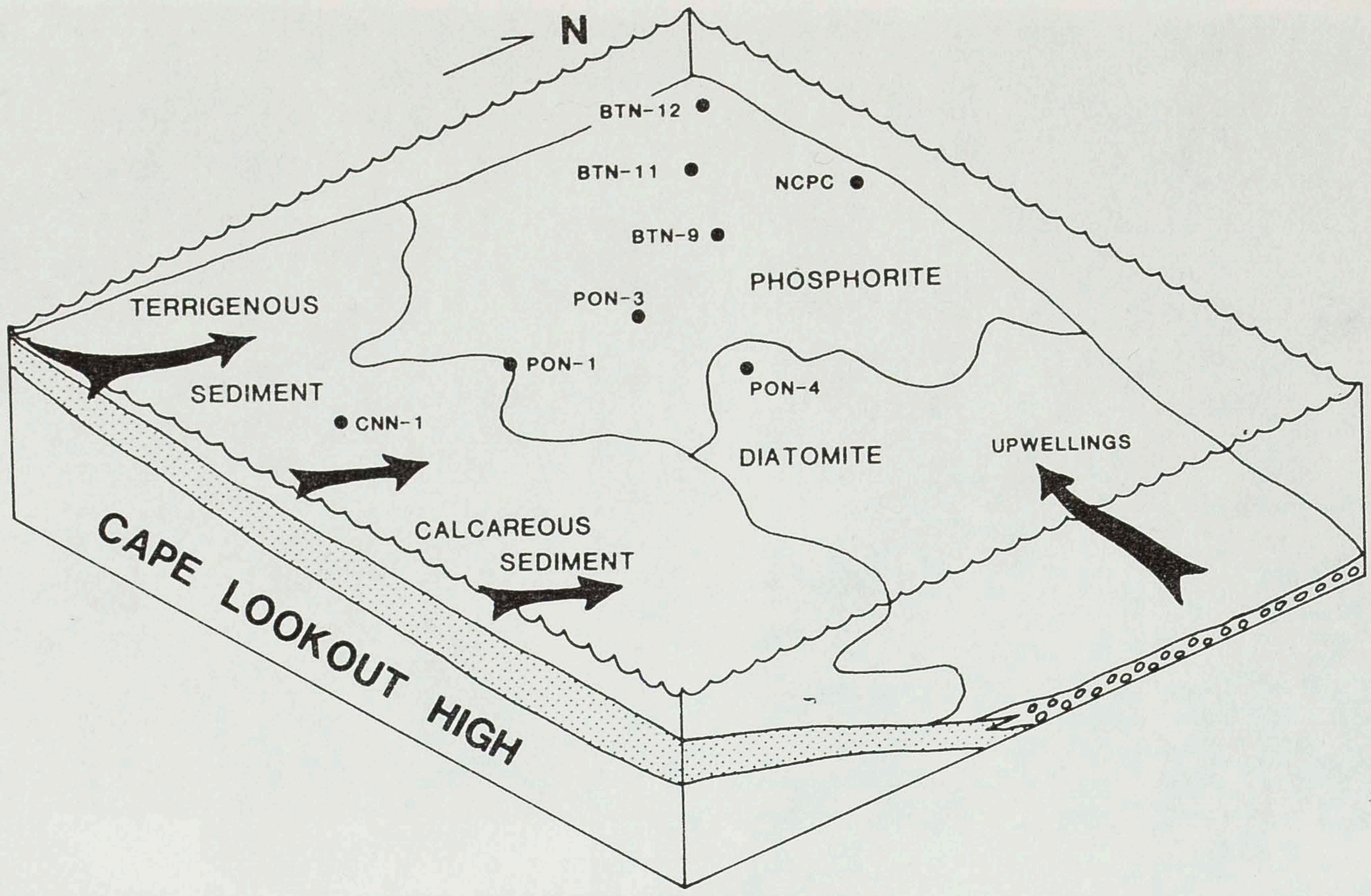

Figure 9. Depositional regimes which existed in the southern portion of the Aurora Embayment during the early to middle Miocene transgression which produced the Pungo River phosphorites and associated sediment facies. Phosphorites are forming in the central facies (units A, B, or C), diatomaceous sediments are forming in the eastern facies (unit BB), and terrigenous and calcareous-rich sediments are being deposited in the southern facies associated with the Cape Lookout High (unit CC).

with the phosphorites of units A, B, and C in the central portion of the embayment. Deposition of dominantly terrigenous and calcareous sediments on and adjacent to the Cape Lookout High effectively diluted and prohibited phosphorite sedimentation south of core hole PON-1 (Figs. 4 and 9).

The phosphate component of the Pungo River Formation is dominated by intraclastic allochemical grains. This suggests the development of orthochemical microsphorite muds within the Aurora Embayment; these muds were subsequently fragmented, transported, and deposited as intraclastic grains (Riggs, 1979a, 1980b). Unit A contains a significant concentration of pelletal phosphate grains. This may represent an environment in which the orthochemical phosphate mud remained in suspension and was biogenically extracted from the water, concentrated, and excreted as fecal pellets (Riggs, 1979a, 1980b). This interpretation supplies additional support for the in situ deposition of the phosphate in unit A as described by S. W. Snyder and others (1982).

Optimum conditions for the formation and deposition of phosphate occurred on the shelflike platform along the west-central embayment margin (Fig. 9). Downdip, to the east, is the axis of maximum thickness of units A, B, and C; phosphate deposition decreased rapidly downbasin while the deposition of diatomaceous sediments increased (Fig. 5). Along the southern margin of the embayment, increased terrigenous and carbonate sedimentation took place in association with the Cape Lookout High (Fig. 4). Updip, to the west, units A through D were sequentially truncated by post-Pungo River erosion (Fig. 5). Consequently, there is a narrow north-south zone of major phosphate concentration, which formed behind the Cape Lookout High and along the upper basin margin in the west-central portion of the Aurora Embayment (Fig. 9).

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