Geology and Paleontology of the Lee Creek Mine, North Carolina, I

Prologue

Clayton E. Ray

What's past is prologue; what to come,
In yours and my discharge.

–SHAKESPEARE
The Tempest
Act II, Scene 1

John Brickell, M.D., lived and practiced medicine some 250 years ago in Edenton, North Carolina, on the outer Coastal Plain less than 50 miles (80.5 km) north of the Lee Creek (phosphate) Mine. With apologies for any license taken with his intent, with allowances for the accumulated knowledge and altered perspective of our age of specialization, and the concomitant reduction in our scope to one aspect of the natural history of one place in North Carolina, the following excerpt from his preface to *The Natural History of North-Carolina* (Brickell, 1737:iv–vi) seems admirably apropos to introduce the "Geology and Paleontology of the Lee Creek Mine, North Carolina."

The Writings of many Learned Men may be seen on this Head, who after having search'd all the Records of Antiquity, shew much Erudiction, but nothing of certainty, concerning the Antient Affairs of America. *I know the Memory of a Deluge is preserved amongst these people, but whether it is to be understood of the universal Flood, or the Inundation of some particular Provinces, I leave it to others to discourse upon, for I am willing to lay aside all manner of Conjectures of this Nature, having enough of Truth to treat of.*

. . . .

But waveing these Discourses, we here present the World with a Natural-History *of* North-Carolina, *it being a compendious Collection, of most things yet known in that part of the World; wherein I have laid down every thing with Impartiality and Truth, in the most plain and easie Terms, which indeed is the Duty of every Writer, and preferable to a more eloquent Stile, accompanied with many Falsities.*

I have therefore endeavour'd in the following Sheets to give as faithful and exact Account of Carolina, *as discoveries yet made will Authorize . . . .*

But not to amuse the Reader any longer with Encomiums on Carolina, *I refer them to my Description of that Country, and it's Inhabitants, which they will find in the following* Natural History, *in which I have been very exact; and for Methods sake, have ranged each Species of* Animals, Vegetables, *etc. under distinct and proper Heads.*

A Collection of the Natural Curiosities of this spacious part of the World, will, I hope, not only give Satisfaction and Pleasure to each Reader, but likewise Profit, to all that are inclined to live in those Parts.

If these my Endeavours meet with this good success, I am thoroughly satisfied, having nothing more at Heart than to be in any Degree serviseable to the Publick; this being the principal Motive that induced me to undertake any Work of this Nature, (the Task being not only Laborious *but* Difficult) *and not out of any Praise I expected from it.*

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To conclude, Whatever Defects may be found in this Undertaking, we hope in time they will be supplied by the Labours and Industry of such as shall come after . . . and that their laudable Attempts may meet with just Encouragement, shall be my constant Wish and Desire. [Italics in original.]

Although not of primary concern here, and not detracting materially from his eloquent preface, Brickell's apparently wholesale plagiarism must be acknowledged whenever his book is mentioned. The subject has been reviewed recently by Simpson and Simpson (1981).

The project of which the present publication is the culmination may fairly be said to have had its inception early in 1967 when Remington Kellogg received "a small collection of vertebrate fossils from the Lee Creek Mine" from Jack H. McLellan (letter of 2 March 1967). With Kellogg's encouragement, specimens continued to trickle into the National Museum of Natural History, where he began work on the fossil whales and enlisted others into looking at materials pertaining to their specialties. From the beginning through 1970, I had accumulated only a handful of seal bones (my favorite fossils) from the mine. The locality appeared to me to fit the all-too-familiar pattern for the Coastal Plain, that of yielding pinniped remains too sporadically to justify the expense of collecting trips. However, Jack McLellan visited the Museum on 10 December 1970, handed me a monachine seal temporal bone, viewed our meager collection, and assured me that it could be augmented readily through more vigorous pursuit on our part at the mine. With his encouragement and upon cessation of other duties, I visited the mine for the first time in August 1971. Frank Whitmore, Robert Purdy (Department of Paleobiology), and I joined McLellan for two days of collecting, the results of which were very satisfactory. For my part, the collection included enough pinniped fragments to persuade me that intensive effort well might yield collections unprecedented in variety, quantity, and novelty for the Atlantic Coastal Plain. On the same trip and equally important in retrospect was our visit with Peter J. Harmatuk of Bridgeton, North Carolina, a widely known, avid, and able fossil collector, who at this writing has contributed more vertebrate fossils to the National Collections than any other person.

The pattern for subsequent work was set and continues to the present. I have now made more than 50 visits to eastern North Carolina, typically of a few days each, in company with small groups from Washington. These groups generally consist of colleagues from the Smithsonian Institution and the U.S. Geological Survey, local students, and volunteers; but they have also included colleagues from as far away as England, Romania, and Japan. On a typical trip we rendezvous at the mine with faculty and students from interested schools, Texasgulf employees, amateurs from the area, and always with Peter Harmatuk. A part of every trip is devoted to other related activities, including prospecting other localities, examining institutional and private collections, assisting with the Aurora Fossil Museum, and participating in "fossil fairs." The continuing addition of specimens to the National Collections from non-Smithsonian sources (resulting from the contacts established on these trips) has been responsible, far more than our own collecting, for turning the initial trickle into a torrent; one product of this is that the vertebrate fauna of the Yorktown Formation is now one of the world's largest.

As this prospect quickened my interest, I began to educate myself in the geology and paleontology of the region and of the mine. I soon discovered a remarkable reservoir of knowledge and continuing interest on the part of colleagues at the Smithsonian and U.S. Geological Survey, including Thomas Gibson, who had published the basic paper on the geology of the mine in 1967, Blake Blackwelder, Joseph Hazel, Porter Kier, Lauck Ward, Alexander Wetmore, Frank Whitmore, and Druid Wilson, all of whose expertise exceeded, and whose interest antedated, my own. The combination of that resource, the ease with which other specialists were recruited across a broad range of relevant topics, and the burgeoning collections, culminated on 23 March 1972 with my proposing this publication project.

During much the same period, I had been casting about independently for a suitable means

of honoring Remington Kellogg in published form. It had seemed to me that such a tribute was long overdue from the institution that he had served since 1928 as curator and administrator, and as the giant of his era in marine mammalogy. A typical festschrift, consisting of papers united primarily by the relationship between the contributors and the honoree, seemed less attractive than something on a unified topic. The fact that Kellogg had chosen at retirement in 1962 to devote his energies to curation, research, and publication on fossil marine mammals of the Neogene of the Atlantic Coastal Plain, that he had been directly responsible for initiating Smithsonian research on the Lee Creek Mine, and that marine mammals are among the most conspicuous components of its fossil assemblage, all combined to suggest that this publication would constitute an appropriate and substantial tribute to his paleontological career in general and to his seminal role for Lee Creek in particular. Thus, this publication is dedicated respectfully to the memory of Remington Kellogg, and these volumes therefore begin with his biography and will conclude with a list and index of his publications.

Between these "end pieces" an attempt has been made to be as comprehensive as possible with regard to the geology and paleontology of Lee Creek Mine. For vertebrates it was feasible to be essentially exhaustive, and the third volume will be made up exclusively of those contributions, with the exception of a concluding chapter, comprising what is today popularly called an "overview," by Gibson and Whitmore, plus the appendices devoted to Kellogg. The first volume begins with a chapter about the mine and the mining itself, intended primarily to place our studies in context by revealing the opportunities created by the existence of the mine and at the same time the limitations imposed on collecting by the exigencies of mining. This is followed by chapters on the geology, concentrating on the regional setting, age, correlation, stratigraphy, paleoecology, and genesis of the deposits. Obviously, we have emphasized the aspects of geology most intimately related to paleontology and neglected or excluded many other potentially interesting aspects. These chapters are followed by three paleobotanical contributions, limited in number and scope by the availability of materials. The balance of the volume is devoted to invertebrates other than mollusks, plus a chapter on fish otoliths. The second volume is devoted exclusively to the mollusks, reflecting their abundance and importance. We have emphasized groups of special biostratigraphic value or special prominence or novelty at the mine, but have of necessity been governed also by the availability of appropriate specialists. The invertebrate fauna is so rich that, for practical purposes, the possibilities are unlimited. Obvious gaps in our coverage include the lack of comprehensive chapters on bryozoans and barnacles. These remain for future studies.

Although it is hoped that the whole publication will be found greater than the sum of its parts, each chapter is largely self-contained to the extent that its contents will be intelligible without reference to the whole, so that special interests can be satisfied through author's separates. This objective inevitably has resulted in some repetition, especially in the citation of literature.

Harking back to Brickell's expression of the writer's duty to lay down "*every thing with Impartiality and Truth, in the most plain and easie Terms*," this goal often may be approached best through pictures, and I have accordingly urged contributors to illustrate their topics generously. By this means I hope that these volumes will have been made more useful not only to specialists, but also to the host of serious, dedicated amateurs and students who are starved for reliable information, but who may not have command of the jargon that too often obscures the intrinsic interest of our subject.

Having outlined what we intended to achieve through publication of these volumes and how we have attempted to do it, there remains the question of why. Why North Carolina? Why the Lee Creek Mine? Why the Yorktown Formation? Perhaps a thumbnail sketch of the history of development of our knowledge of the Neogene of the middle Atlantic Coastal Plain will aid in answering these questions.

Historical Perspective

The middle Atlantic Coastal Plain is especially significant to the early history of the sciences of North American geology and paleontology. Eastern North Carolina is particularly so, as it was the locale of the first efforts at permanent settlement by the English. The words and disciplines of geology and paleontology had yet to be defined, and the origin and significance of fossils would be debated for many decades (Ewan and Ewan, 1970:309–312; White, 1953a:137–138). However, explorers and colonists from the beginning had practical incentive to notice such matters because they were pertinent to their survival. Thomas Hariot (or Harriot), whom Sir Walter Raleigh sent to the Roanoke Island colony in 1585, recognized the essential distinction between the Coastal Plain and Piedmont, and probably also the nature of the fossil shell beds of the Coastal Plain (Hariot, 1590; White, 1952b:120; 1953a:136). The shell beds were of great importance as a source of lime for mortar (Bailey, 1938: 2). John Smith also recognized the distinction between the Piedmont and Coastal Plain, as evidenced by his map of 1612 (White, 1953b:125, 131), and William Strachey, first secretary of the colony at Jamestown, clearly characterized the fall line and demonstrated a surprisingly modern concept of the dynamics of the Coastal Plain (in Major, 1849:32):

> All the low land of South and North Virginia is conjectured to have bene naturally gayned out of the sea; for the sea, through his impetuous and vast revolution (who knowes not), savinge upon every coast, in some places wyns, and in other places looseth; and we find within the shoares of our rivers, whole bancks of oysters and scallopps, which lye unopened and thick together, as if there had bene their naturall bedd before the sea left them; likewise, the fashion of the earth is in smale rising mounts, which may well be supposed that the violence of the wynd hath cawsed, by dryving the light sand togither . . . .

He went on to comment upon the thin top soil and the lack of indurated rock in the subsurface, which he attributed to "want of tyme."[1]

The first explicit notice by Europeans of vertebrate fossils of the Coastal Plain Neogene was the entry of 3 August 1636 in Winthrop's journal (in Hosmer, 1908:185–186):

> Samuel Maverick, who had been in Virginia near twelve months, now returned . . . . It is very strange, what was related by him and many others, that, above sixty miles [97 km] up James River, they dig nowhere but they find the ground full of oyster shells, and fishes' bones, etc.; yea, he affirmed that he saw the bone of a whale taken out of the earth (where they digged for a well) eighteen feet [5.5 m] deep.

Simpson (1942:134; 1943:27) was curiously reluctant to accept these as bona fide fossils; but in fact from slightly above Hampton Roads to Richmond (well over 60 miles [97 km] up the James River) the Neogene strata are superlatively fossiliferous, most conspicuously in remains of whales (Baum and Wheeler, 1977) and mollusks (Blackwelder and Ward, 1976; Gardner, 1948). Thus, there is every reason to believe, and no reason to doubt, that Maverick saw fossils, most likely of Miocene, or, if the distance was exaggerated, at latest, early Pliocene (Yorktown), age.

Two scientist-clergymen lived on the Virginia Coastal Plain and made perceptive observations on its geology and fossils in the latter part of the seventeeth century, John Clayton from 1683 to 1686, and John Banister from 1678 to 1692. Clayton later lived in England and Ireland until 1725, and published rather extensively; Banister was shot (accidentally?) while exploring along the Roanoke River in 1692, and his enormous influence upon natural history in general and that of Virginia in particular has until recently not been widely appreciated. The analyzed and annotated works of each are now readily available in book form: Berkeley and Berkeley (1965) for Clayton, and Ewan and Ewan (1970) for Banister. In 1693 Clayton (Berkeley and Berkeley, 1965:57–59) commented at length on the extensive shell beds, speculated as to their derivation from living mollusks below sea level versus inorganic origin

[1] Although Strachey's writings were not published until much later, they were widely circulated in literary circles of London in the 1620s and probably were available to Shakespeare. They are thought to have provided at least part of the inspiration for "The Tempest," quoted at the beginning of this prologue (Kermode, 1958:xxv–xxxiv).

within the rock, and stated:

> Often, in the looser Banks of Shells and Earth, are found perfect Teeth petrefied, some whereof I have seen, could not be less than two or three Inches long, and above an Inch broad: Tho' they were not Maxilary Teeth, the part that one might suppose grew out of the Jaw, was polish'd and black, almost as Jett; the part which had been fasten'd in the Jaw and Gums, was brown, and not so shiningly polish'd, or smooth; if they were, as they seemed to be, really Teeth, I suppose, they must have been of Fishes [sharks?]. The Back-bone of a Whale, and as I remember, they told me of some of the Ribs, were digg'd out of the side of a Hill, several Yards deep in the Ground, about four Miles distant from James-Town, and the River. Mr. Banister, a Gentleman pretty curious in those things, shew'd me [in 1686; Ewan and Ewan, 1970:xx, 58] likewise the Joynt of a Whale's Back-bone, and several Teeth, some whereof, he said, were found in Hills beyond the Falls of James River . . . .

At least some of the teeth undoubtedly represented Pleistocene mammals from west of the Coastal Plain, as various authors have supposed (Ewan and Ewan, 1970:331), but the whale vertebra and probably some of the (shark?) teeth must have been local, especially in view of Banister's own writings, for example (in Ewan and Ewan, 1970:332):

> 20 or 30 miles [32 or 48 km] up ye freshes of James River I found great variety of petrified oysters, scallops, bones &c. among them these strange stones, which I am not so good an ichthyologist to assign to what fish or fishes they might belong, if they were ever reall teeth. & higher up yet within 12 miles [19 km] of ye falls, about 1/2 mile [0.8 km] from the River in a gully on ye side of a hill, near a small creek 40 or 50 foot [12 or 15 m] perpendicular above ye flowing of ye tyde, I met with another of these teeth, like ye first but smaller, its armature of ye colour of cinammon, the rest liver-colour'd, & with it ye like variety of ye sea shells &c. I am informed to[o] that divers of ye high banks downwards (tho out of ye tydes reach as it now flows) are compos'd almost wholly of them, & that they are found there also in many places remote from ye river.

He went on to debate whether the fossils indicate former presence of the sea or direct formation in the rock, and he made drawings of a shark tooth, fossil invertebrates, and a sting ray spine (Ewan and Ewan, 1970, figs. 65, 67, 68). There is no doubt that Banister aided and influenced Martin Lister, and his drawings, notes, and specimens may well have provided the basis for Lister's (1685–1692; in Ewan and Ewan, 1970:315) widely heralded first published illustrations and descriptions of American fossils (in Ward and Blackwelder, 1975:3; Wilson, in prep.; Ewan and Ewan, 1970:312 et sqq.).

In his widely known work, Mark Catesby (1731:second vii) made the following comments on Neogene fossils of the Coastal Plain:

> There is no Part of the Globe where the Signs of a Deluge more evidently appears than in many Parts of the Northern Continent of *America*, which, though I could illustrate in many instances, let this one suffice. Mr. *Woodward*, at his Plantation in *Virginia*, above an Hundred Miles [161 km] from the Sea, towards the Sources of *Rappahannock* River, in digging a Well about seventy Feet [21 m] deep, to find a Spring, discovered at that Depth a Bed of the *Glossopetrae* [shark teeth], one of which was sent me. All Parts of *Virginia*, at the Distance of Sixty Miles [96.6 km], or more, abound in Fossil Shells of various Kinds, which in *Stratums* lie imbedded a great Depth in the Earth, in the Banks of Rivers and other Places, among which are frequently found the *Vertibras*, and other Bones of Sea Animals.

Lewis Evans (in Gipson, 1939; White, 1952a) was a very perceptive mapmaker of the middle 1700s who understood the nature of fossils, and delineated physiographic features, including the Coastal Plain and the fall line.

One of the great unknowables of American geology is the impact that the works of Johann David Schöpf would have had, had they been widely available in English to his contemporaries and immediate successors. His American travels, published in 1788 in German and not translated until 1911, remained rare until reprinted recently (Morrison, 1968), and his American geology, published in 1787, was not published in translation until 1972 (Spieker, 1972). Although now widely appreciated and acknowledged as an accurate observer and clear thinker in a time of uncertainty in geology, his works had no known impact in America for well over a century after their publication, which is to say not until long after the progress of the science had passed them by. Schöpf was in America from 4 June 1777 to 29 March 1784, during most of which time he was closely limited to the vicinity of New York and Philadelphia as surgeon to German troops in service to the British. On 22 July 1783, however, he left New York on his generally southward

travels that took him through the Coastal Plain of Virginia and North Carolina. He went out of his way to visit Yorktown (Morrison, 1968 (2):82–85), because of its significance as a "remarkable theatre of a decisive military event, as well as by the wish to examine the great shell-banks there, which are an object of curiosity to every stranger"; he discussed in enthusiastic terms a shell bed exposed in a mill race halfway between Williamsburg and Yorktown, noting as well "large bone-fragments, presumably of whales." Continuing southward, he noted shell banks also on the Tar River (Morrison, 1968(2):125), where he had already mentioned that proboscidean remains had been found (Morrison, 1968(1):269). In his geological treatise (in Spieker, 1972:48–49) Schöpf made more generalized statements about the distribution of the shell bed and mentioned "sharks' teeth, whale and other bones" as well.

Intimations of things to come in the new republic, even without benefit of Schöpf's insights, are provided by three sets of observations published before 1800. Their significance lies not in their originality but in their suggesting fairly widespread geological sophistication and the development of a society in which homegrown investigations of rather narrow esoteric topics could find outlet in American journals. The first of these, published in 1785, by the American Academy of Arts and Sciences in Boston, consists of a detailed description of the geologic section in the vicinity of Yorktown, Virginia. This publication is based upon observations made by a revolutionary general, Benjamin Lincoln, during the last weeks of the war, prior to the British surrender at Yorktown on 19 October 1781.

In June 1786, the Reverend Samuel West with Dr. William Baylies and others visited Gay Head, Martha's Vineyard, the northernmost emergent outlier of the Coastal Plain. Both West (1793) and Baylies (1793) published accounts of the visit. West had been "appointed by the Academy to be a committee, to examine the mineral production of Gay Head." According to West (1793:148), "the inhabitants presented us with a petrified bone, said to be one of the vertebrae of the whale, which they told us they found in the cliff: It is very heavy, owing, I apprehend, to a metallick impregnation. They also brought us two shell fish, which were petrified: These were taken out of the cliff." Baylies (1793:155) added: "The bones of whales, sharks' teeth, and petrified shellfish, are frequently picked up, scattered up and down the cliff, at a considerable distance above the surface of the water."

The third example is that of Benjamin Henry Latrobe, a prominent architect and engineer who directed construction of the U.S. Capitol and the White House, and designed many other buildings, as well as municipal water systems and canals (Lintner and Stapleton, 1979). He made practical use of geology in his profession, as reflected by the section through Richmond, Virginia, in his journal for 4 May 1798 in connection with construction of the penitentiary of his design (Lintner and Stapleton, 1979, fig. 1). On the same pages he recorded a detailed log to a depth of 71 feet [21.6 m] of the well at the penitentiary, and in 1799 published commentary in the *Transactions of the American Philosophical Society* on

> the fossil teeth and bones, which accompany this memoir,* and which with many hundred more, were dug out of a well at Richmond, from the depth of 71 feet . . . .
>
> * The teeth appear to be those of a shark. They are highly enamelled and extremely sharp: their roots are perfectly sound and entire, and the minute and almost transparent jags of many of them are as perfect as the rest. They are found in every well, dug in or near Richmond, to a sufficient depth; and, *as I am informed*, in every deep well for many miles below the city. The stratum in which they lie consists of highly sulphurated blue clay, abounding in pyrites, and which has the appearance of having been mud. They were first discovered in the beds of rivulets, which had worn their channels to the depth of this stratum; and obtained the name of *Indian Dart-points*, in the same manner, as the immense oysterbeds, which have been quitted by the ocean, are vulgarly called *Indian* oyster-banks.
>
> The bones were dug from the same stratum. Among them are two out of six bones, which formed a *paw* of some animal unknown to me. Many very sound vertebrae of fish, and a remarkably perfect thigh bone of a large bird have been in my possession.

The paper is accompanied by well-executed drawings (reproduced by Lintner and Stapleton,

1979, fig. 2) of four shark teeth, the two recovered bones, and an outline of a third bone. The bones are indeed those of the paw, or forelimb, of a small porpoise, well known in the Miocene deposits of the Coastal Plain, including Richmond (Ray, 1976:10). The two recovered are the humerus and ulna of a mature individual, and the bone outlined is the radius. The reference to the fossil bird bone may be the first for the Coastal Plain.

It is interesting to note that on 16 April 1818, Latrobe advised on the proposed construction of a canal in North Carolina without going there, based on extrapolation from his knowledge of geology from New York to the Roanoke River (Lintner and Stapleton, 1979:112). It is equally interesting, and perhaps not entirely coincidental, that in April of the following year, Latrobe's fellow surveyor and engineer, William Smith (also the founder of stratigraphic paleontology), seriously considered an offer to come to North Carolina as an advisory engineer; he declined, however, and by June found himself instead in debtor's prison (Eyles, 1969:157). Might the subsequent history of geology in the Coastal Plain of North Carolina have been significantly altered had he decided otherwise? Probably the approaches to both Latrobe and Smith stemmed from the Board of Internal Improvements of the state, which concerned itself with surveys of rivers, and for railroads, turnpikes, canals, and swamp drainage (Merrill, 1920:363).

Samuel Latham Mitchill (1818), in what may be regarded as one of the last major publications of the classical period, reviewed fossil records in North America. Among many others he noted several of interest for the Neogene of the middle Atlantic Coastal Plain, including some occurrences of fossil wood and the following of vertebrates:

> I remember, that petrified bones, apparently of a whale, were brought from the shore of Chesapeake Bay, near the place where the river Patuxent enters it, to the City of Washington, by Mr. O'Neale. (Mitchill, 1818:394)
>
> Shark's teeth, or glosso-petrae, are often raised on digging wells, further down the [Potomac] river, as at Diggas's point, for example. (Mitchill, 1818:396)
>
> Mr. Chevallié brought me, from Richmond, entire triangular teeth, apparently of sharks, and pieces of bones, probably of whales, dug from the depth of between sixty and one hundred feet [18 and 30 m], in the city of Richmond .... in the neighborhood of Williamsburgh, in 1802, a considerable portion of a whale's skeleton was discovered. It was about four or five feet [1.2 or 1.5 m] under ground; two miles [3.2 km] distant from the shore of James' river, and fifty [80.5 km] from the Atlantic ocean. Among other parts were fragments of the ribs, and all the vertebrae regularly arranged, and very little impaired as to its figure. (Mitchill, 1818:397)
>
> At a place called Fishing creek, 150 miles [241 km] from the sea coast, and almost four [6.4 km] from Tarborough, in digging some little depth, they found a part of the skeleton of a whale, with sea shells in abundance .... The skeleton of another whale, together with a petrified portion of a shark's jaw with teeth, has been found at a place called Williamstown, more than 100 miles [161 km] from the sea coast.
>
> About a year ago, the skeleton of a huge animal was found on the bank of the Meherrin river, near Murfreesborough. It was dug out of a hill, distant sixty miles [97 km] from the ocean. Capt. Neville and Dr. Fowler, who visited the spot, gathered the scattered vertebrae which the negroes had thrown out, and laid them in a row thirty-six feet [11 m] in length. If to this the head and tail be added, the creature must have been perhaps fifty feet [80.5 m] or more in length. The former of these gentlemen enriched my collection with two of the teeth and a joint of the back bone that he brought away. The teeth weigh sixteen ounces [0.45 kg] each. They are covered with an ash-coloured enamel, except at the roots where they were fastened in the jaws. Their figure is triangular, the sides towards the apex measuring six inches [15.24 cm] each, and the base four inches and a half [10.16 cm] across. The joint of the back is not cartilaginous, but actually bony. It is in some degree petrified, and weighs twelve pounds and a half [5.7 kg]. It, in all likelihood, belonged to a shark or a sea-serpent. (Mitchill, 1818:400–401)

Although the distances from the sea are exaggerated, the records of large whales from the vicinity of Tarboro and Williamstown probably apply to mysticetes preserved in the Yorktown Formation; however, the "petrified portion of a shark's jaw with teeth" is more suggestive of an archaeocete, which could only have come from the Eocene Castle Hayne Formation. Similarly, if the large triangular teeth from near Murfreesboro were indeed from the same animal as the skeleton, they could scarcely represent any animal

other than a large archaeocete. However, it seems unlikely that the Castle Hayne Formation would have been penetrated in that area, at that time, but likely that the skeleton was that of a mysticete and the teeth those of *Carcharodon* associated in the same Neogene strata.

These early investigations and reports were an essential prelude to the subsequent development of geology. For example, the creation by Benjamin Silliman of the *American Journal of Science*, which was the first American periodical of broad scope devoted primarily to geology, could scarcely have come into being earlier than 1818, because the ground rules of the science were only then being laid. Without the preceding primitive efforts as a substrate, there would have been neither authors nor audience for such a journal.

Beginning in the 1820s and continuing apace through the next two decades, American science underwent rapid expansion and developing professionalism, characterized in geology by the first official state geological surveys and in paleontology by the development of increasingly standardized procedures, including adoption of Linnaean systematics. It is neither feasible nor necessary to attempt to chronicle the burgeoning developments from this time onward, for the history and literature have been thoroughly covered in standard sources such as Darton (1896), Gregory et al. (1973, and volumes cited therein, by Camp et al.), Hay (1902), Hazen and Hazen (1980), Merrill (1906, 1920, 1924), Nickles (1923, 1924), and Schneer (1979). For the individual states the literature for Maryland is covered by Clark (1897), Mathews (1897), and Shattuck (1904); for Virginia, Clark and Miller (1912), and Roberts (1942); for North Carolina, Laney and Wood (1909), Clark, et al. (1912), and Stuckey (1965), and Riggs and O'Connor (1975).

The first official state geological survey of North Carolina was conducted by Denison Olmsted and Elisha Mitchell, 1824–1827, and may be regarded with some justification as the first for any state (Back, 1959; Merrill, 1920:363). Following closely were the surveys of Julius Timoleon Ducatel for Maryland, 1833–1842, and of William Barton Rogers for Virginia, 1835–1841 (Aldrich and Leviton, 1982). These surveys, all including some work on the Coastal Plain, were followed by others in the nineteenth century. In North Carolina surveys were made by Ebenezer Emmons in the 1850s (Johnson, 1982) and Washington Caruthers Kerr from the Civil War to 1885, and were supplemented by other work, conducted in part by the same geologists but also by others in increasing numbers. Serving as the capstone for nineteenth century efforts and as the foundation for all subsequent work on middle Atlantic Coastal Plain geology are the unifying, comprehensive publications by William Bullock Clark and his coworkers: for Maryland, Clark, Shattuck, and Dall, 1904: for Virginia, Clark and Miller, 1912; for North Carolina, Clark et al., 1912.

By 1830, Timothy Conrad, Samuel G. Morton, and a few others had begun the work that would result in monumental publications (e.g., Conrad, 1830, 1842, and in Dall, 1893; Morton, 1829, 1834) in systematic and stratigraphic paleontology, based almost entirely on invertebrates, although Morton also published on vertebrates, mostly of Cretaceous age. Richard Harlan, characterized as America's first professional vertebrate paleontologist (Simpson, 1942:161), began work in the 1820s, and in 1842 he published the first formal description of a fossil cetacean from the Neogene of the Coastal Plain, *Delphinus calvertensis* (later transferred to *Lophocetus*). Work on the fabulously rich invertebrate faunas by numerous subsequent researchers, among whom Julia Gardner (1948) may be mentioned as a leading practitioner, continues as reflected in the present volumes. For the vertebrates, Harlan's small beginning was followed by the extensive work, primarily on cetaceans, of Joseph Leidy, Edward Drinker Cope, Frederick William True, and above all Remington Kellogg. Perusal of their many publications on fossil vertebrates of the Chesapeake Series (Hay, 1902; Gregory et al., 1973; Knapp, in prep.) reveals very little on the Yorktown Formation and relatively little on North Carolina. The reasons are readily apparent; in spite of the occasional notice of large whale skeletons since early colonial times and the

superabundance of invertebrates, natural exposures have produced an unreliable crop of vertebrate material. Of that, very little of adequate quality reached the hands of researchers, as compared, for example, to the abundance of good specimens from the Calvert Formation of Maryland. Beds of Calvert age are unknown in outcrop in North Carolina.

All of this changed dramatically and suddenly with the opening of the Lee Creek Mine, which provided the first exposure in North Carolina of deposits in part equivalent to the Calvert Formation (the Pungo River Formation) and continuously renewed access to the Yorktown Formation. With respect to vertebrates, publication of the present volumes will transform the Yorktown Formation from virtual terra incognita to one of the richest known deposits.

Conclusion

Much is made these days of a priori research design, of deciding first on a significant problem to be pursued, then going forth to select an appropriate vehicle to carry the scholar to his goal. For this reason it is argued that museums should not be cluttered up with collections unless there is a specific proximate purpose in mind. Although there is some justification for this reaction to traditional methods ("stamp collecting" to some), it is all too characteristic of our culture to lurch from one extreme to another, to lose interest in and even discontinue an activity because it is not new. In fact, however, the great work of discovering and deciphering the record of life on earth has barely begun. If there is a loss of confidence in museum science, if it collapses, it will not be through indifference or hostility from without (the National Museum of Natural History had 5,464,229 visitors in 1979), but by implosion, when museums are no longer populated by museum scientists. A colleague recently stated that a good museum scientist should have a "subclinical obsession" with collections, seemingly more appropriate than a fear of pursuing our profession too vigorously. There will be no lack of external forces to set practical limits to growth of collections, not the least of which is availability in the case of vertebrate fossils. A strong element of self-deception creeps in if we deny the often dominant opportunistic factor in our research design. After his more than 40 years of productive research on marine mammals of the Atlantic Coastal Plain that had yielded virtually nothing from the Yorktown Formation or from North Carolina, Remington Kellogg understood the importance of capitalizing on the opportunity presented.

Before the Lee Creek Mine existed, there was no possible means to learn about the Pungo River Formation except through limited access by drilling, and there was no prospect of significant extension of knowledge of vertebrates of the Yorktown Formation. Although to my mind, the traditional goal of increasing and diffusing knowledge of earth history is adequate justification for the study of the geology and paleontology of any place, it may be pointed out also that only through multiplication of richly documented points in space and time will we be able to perceive general patterns of distribution, evolution, and correlation. It is hoped, therefore, that these volumes will demonstrate the utility of being ready to exploit opportunities as they arise. There can be no doubt that we could have done more and better. There remains a great need for better stratigraphic control, more comprehensive taxonomic coverage, and better quality materials, especially of the vertebrates, but these needs can be satisfied only by future work, most especially by more extensive and leisurely access to sections in place, perhaps through setting aside a research reserve. That, however, remains for another time and possibly for other hands. I can only refer again to John Brickell's felicitous concluding words quoted at the beginning of this prologue, "*that their laudable Attempts may meet with just Encouragement shall be my constant Wish and Desire.*"

Acknowledgments

Among the scores of people whose efforts have furthered this project, mention can be made here only of those whose contributions have been the most comprehensive and sustained. Most of these

same individuals and many others are thanked in appropriate chapters for specific contributions.

First and foremost, it is my duty and pleasure to acknowledge the patience and forbearance of each contributing author, many of whom completed their manuscripts literally years ago, and, through unfortunate delays have been forced to revise and update their chapters repeatedly. My grandiose planning and naive expectations have cost them dearly. If the neophyte traveler should never visit a place for the first time, then neither should the novice attempt to edit a collection of research papers for the first time.

Texasgulf Inc. has been cooperative and hospitable from the beginning, and many employees have taken active interest in our work. Above all, Jack H. McLellan must be singled out, not only as the catalyst who set the entire process in motion, but as a constant advisor and stimulator, an avid and perceptive collector, and a scholarly contributor. The breadth and depth of his knowledge and his mastery of concise explication have enabled him to move as comfortably in museum sciences as in engineering and mining circles, while his personal friendship and unpretentious capability have made the years of this project an experience to savor.

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I have saved until last my expression of thanks to Peter J. Harmatuk, for he is truly in a class by himself. At the end of 1975 he retired early, at financial loss, from a successful career because it interfered with his paleontological field work. Yet he is the antithesis of the monomaniac misfit hiding an inadequate personality among fossils, for he is a leader in his community and pursues other, nonpaleontological interests with similar vigor. I would regard his acquaintance as one of life's rare pleasures had he never collected a fossil. However, that is far from the reality. In the course of hundreds of collecting days at the Lee Creek Mine, to say nothing of numerous other localities in eastern North and South Carolina, he has collected with unflagging enthusiasm more fossils of more kinds for science than anyone who has

ever worked the middle Atlantic Coastal Plain. In many cases he has been the first to bring a locality to the attention of paleontologists, to influence other collectors toward a scientific orientation, to recognize an unusual stratigraphic occurrence, or to discover specimens unprecedented in kind, quantity, or quality. More than once his tenacious curiosity has forced me to pay attention at length to something of interest previously brushed aside. His rare combination of self-effacing humility and constitutional inability to accept glib answers based on faulty reasoning from vested authority has made our association a source of continuing satisfaction and education for me. If one ever needed a reminder that paleontology traditionally has been and remains largely a field science, the enjoyment and advancement of which is open to Everyman to the extent of his ability, effort, and interest, Pete Harmatuk provides irrefutable proof. With little of the externally conferred advantages of education, opportunity, and funding, his contributions demonstrate that there is no substitute for innate intellect and good character.

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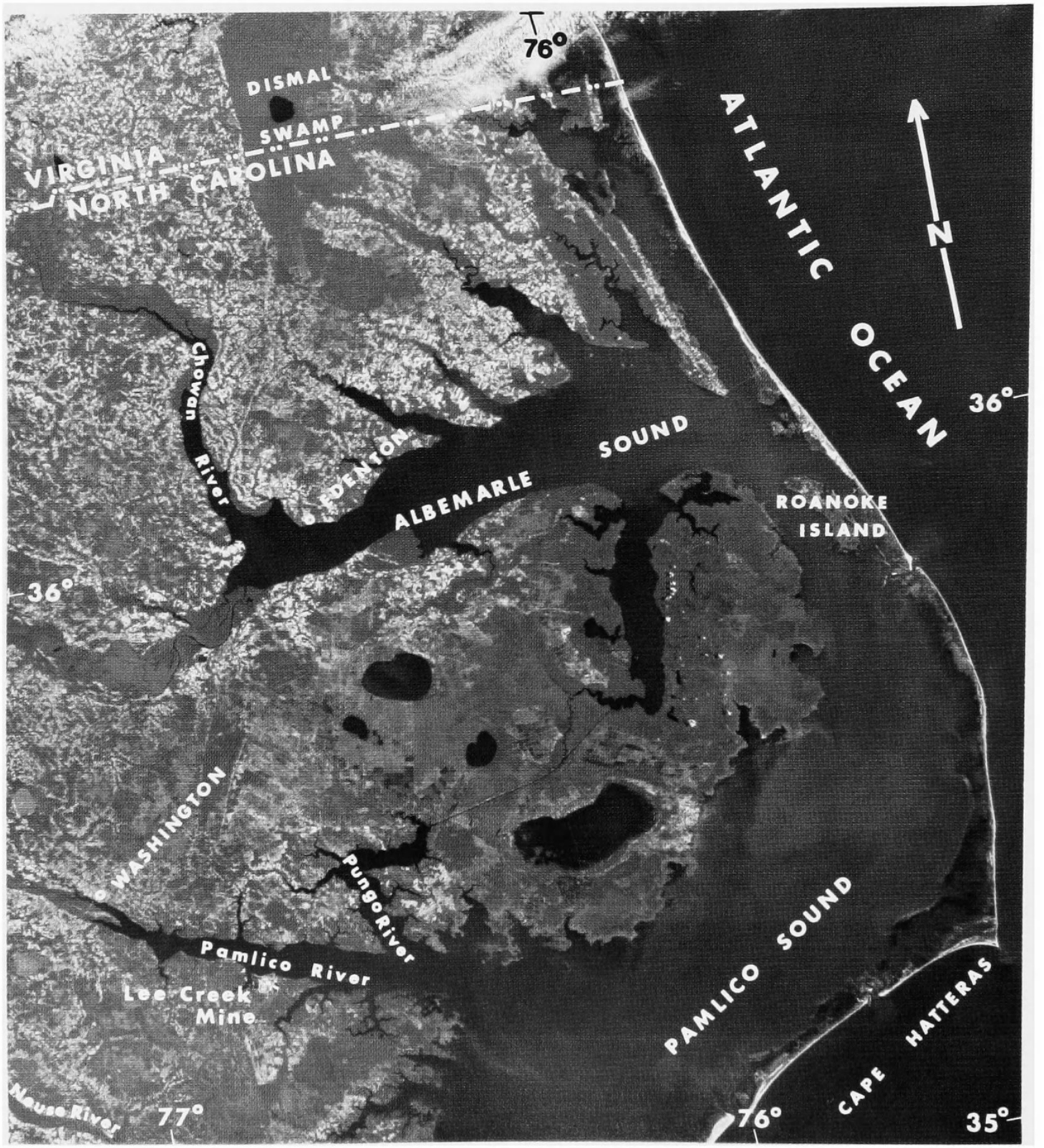

FRONTISPIECE.—Annotated false color composite image by NASA satellite (LANDSAT-3, image E-30116-15030), from altitude of approximately 915 km (568 mi), of part of southeastern Virginia and eastern North Carolina, 29 June 1978. Scale 1:1,000,000. Courtesy of United States Department of the Interior, U.S. Geological Survey.