TAXONOMY AND PALEOECOLOGY OF A NEW SPECIES OF *SPHENIA* (BIVALVIA; MYIDAE) FROM THE PLEISTOCENE OF FLORIDA

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ABSTRACT

The new species, *Sphenia tumida,* is described from the Pleistocene of Flagler County, Florida, an occurrence believed to represent the last known appearance of the genus in the western Atlantic waters immediately adjacent to the North American continent. Taxonomic characters of the genus are reviewed, as are the geographic distribution and ecology of living species and the geologic distribution of fossil species in eastern North America. Paleoecological inferences drawn from this occurrence suggest a progressive shallowing of the Pamlico embayment or lagoon in Flagler County, with a proportional increase in the amount of sand being transported to the depositional site.

I. INTRODUCTION

While investigating the paleoecology of a Pleistocene marine fauna from Flagler County, Florida (Lewis, 1966), the writer encountered three articulated individuals and 85 disarticulated complete valves of a species of bivalve, all of which possess characteristics in common quite unlike those of any species currently inhabiting the coastal waters of the southeastern United States or the northern Gulf of Mexico. The specimens were collected from a bed of blue, highly fossiliferous, argillaceous, medium sand which constitutes part of the Pamlico Formation and is exposed in the SW 1/4, SW 1/4, Sec. 5, T 12 S, R 29 E; this site, designated University of Florida Locality 5, is approximately eight miles west of Bunnell. Although the specimens were assigned tentatively to the genus *Cuspidaria* in the original report (Lewis, 1964), their true affinities are with species of *Sphenia,* a genus whose living representatives are found in the western Atlantic only in the vicinity of Puerto Rico. It is known in eastern North America, however, from fossils in coastal plain deposits of Miocene and Pliocene age. The purpose of this paper is to report the youngest fossil occurrence of the genus in this region, to review the ecology and distribution of selected living species, and to discuss the paleoecological implications of this Pleistocene occurrence. The classification of higher taxa follows, generally, that proposed by Newell (1965) for inclusion in Part N (Bivalvia) of the Treatise on Invertebrate Paleontology. Terms relating to the morphology of the chondrophore are those employed by MacNeil (1964) in his discussion of the genus *Mya.*

Acknowledgments: The writer acknowledges with deep thanks the comments and suggestions made by the members of the editorial committee for this paper. He is especially grateful to Dr. H. E. Vokes, Tulane University, for his assistance and encouragement, for providing specimens of the type species *Sphenia binghami* Turton, for comparison, and for making available por-

tions of his catalog of bivalve genera prior to its publication (Vokes, 1967). Appreciation is extended also to Dr. David Nicol, University of Florida, Dr. R. H. Parker, Texas Christian University, and Dr. T. E. Pulley, Houston Museum of Natural Sciences, who examined the material and whose observations and comments greatly clarified the writer's thinking. Dr. J. F. Bridgman, Tulane University, translated a portion of a reference from the original Japanese. Dr. Joseph Rosewater, U.S. National Museum, kindly provided access to the literature and collections of the Museum's Division of Mollusca; Mr. Druid Wilson, U.S. Geological Survey, Washington, D.C., did likewise with the Tertiary invertebrate collections of the Survey; and Mr. J. C. Britton, Jr., U.S. National Museum, supplied otherwise inaccessible information regarding the ecology of the Puerto Rican species *S. antillensis*. Financial support was received under U.S. Public Health Service Grants 3 T1 ES 27 03SI and 5-TO1 ES 00027-04, administered by the Tulane University Program in Environmental Biology, which enabled the writer to study both Recent and fossil material at the U.S. National Museum during the summer of 1967.

II. Systematic Paleontology

Class Bivalvia Linné, 1758

Subclass Heterodonta Neumayr, 1884

Order Myoida Stoliczka, 1870

Suborder Myina Newell, 1965

Superfamily Myacea Lamarck, 1818

Family Myidae Lamarck, 1818

Genus Sphenia Turton, 1822

Sphenia Turton, 1822, Conchylia Insularum Britannicarum, pp. xvii, 36; A. Adams, 1851, Proc. Zool. Soc. London, p. 86; H. and A. Adams, 1856, The Genera of Recent Mollusca, v. 2, p. 357; Dall, 1898, Wagner Free Inst. Sci., Trans., v. 3, pt. 4, p. 859; Grant and Gale, 1931, San Diego Soc. Nat. Hist., Mem. 1, p. 419.

Type species: *Sphenia binghami* Turton, 1822 [p. 36, pl. 3, figs. 4, 5, pl. 19, fig. 3], by subsequent designation, Stoliczka, 1870, Palaeontologia Indica, Ser. 6, v. 3, p. xv; Recent, Torbay, England.

Sphaena Blainville, 1824, Dictionnaire des Sciences Naturelles, v. 32, p. 344.

Type species: *Sphaena Birghami* Blainville, by monotypy.

"Shaenia," "Spaeria," "Spenia," "Sphaenia," "Sphena," "Sphenica," and *"Syphonia"* ("Turton, 1822" or "Blainville, 1824"), *auct.* [see Vokes, 1967].

Description: Shell small, thin, elongate, with left valve slightly smaller than right; shape varyingly irregular because of customary nestling habit, but generally with narrowed and produced posterior extremity slightly reflexed or twisted and with or without slight gap between valves; anterior margin broadly rounded; external prosopon* dominated by irregular concentric growth lines; hinge teeth degenerate; ligament internal; chondrophore narrow and directed obliquely posteriorly from its insertion posterior to umbo on hinge plate of left valve, terminating beneath corresponding oval to asymmetrically bisigmoidal depression in hinge plate of right valve; adductor muscles anisomyarian, anterior scar oval to elongate and anterior to antero-ventral in position close to margin, posterior scar circular to subcircular, partially beneath or immediately adjacent to posterior extension of hinge plate; pallial line irregular; pallial sinus broad and shallow to widely rounded; valve interior and internal ventral margin usually smooth.

Discussion: Superficially, some characteristics of *Sphenia* approximate those of other genera, particularly some of those included within the Anomalodesmata, a subclass composed largely of forms also adapted to a burrowing habit. In external form, *Sphenia* resembles another eulamellibranch, *Thracia* Blainville, 1824, but differs by hav-

* "Prosopon" is an inclusive term referring to the surface appearance of a living or fossil organism. Gill (1949, p. 572) introduced the term to replace "ornamentation," observing that "ornamentation" implies "something merely decorative, . . . something additional to essentials" and, thus, is inappropriate when applied to an inherent, often functionally significant, "genetically maintained," biological character. "External" prosopon, in the sense used here, refers to that prosopon on the exterior surface of the valves, as opposed to that on the interior surface which, on some bivalves, such as members of the Amusiidae, may be prominent and diagnostic.

ing an internal ligament, both umbones prominently and equally developed, and the umbo of the right valve neither pierced nor eroded by that of the left. Unlike the septibranch *Poromya* Forbes, 1844, *Sphenia* is not subequilateral to subtrigonal in shape and lacks a granulose exterior, radial external prosopon, a pearly interior, and unequal cardinal teeth intimately associated with the chondrophores in both valves. Its greatest similarity among the Anomalodesmata, however, is with the septibranch *Cuspidaria* Nardo, 1840, a fact implied by Dall (1898, p. 859) in noting the correct generic identity of two species from Cuba which d'Orbigny assigned initially to "*Sphena*" (1846, p. 324). Recent authors place both of d'Orbigny's species in the subgenus *Cardiomya* A. Adams, 1864, which exhibits strong radial ribbing, unlike the smooth or concentric sculpture typical of *Cuspidaria* s.s.; it is with the latter that *Sphenia,* especially the new species described herein, may be confused. However, unlike *Cuspidaria* s.s., *Sphenia* lacks a posterior lateral tooth in the right valve, has no internal posterior buttress reinforcing the beaks, and the ligament is not located anterior to the beaks.

Although somewhat similar hinge-line structures occur also in some of the genera discussed above, the hinge plate and associated features of *Sphenia* are most typical of those in genera of the Myidae, and among these, *Sphenia* resembles most closely *Cryptomya* Conrad, 1843. However, the valves of *Cryptomya* are generally larger and more nearly equilateral, the chondrophore is larger, and the pallial sinus, if not completely obsolete, is short and narrow. Although Dall (1898, p. 859) reported the universal occurrence of a "deep sinus" on *Sphenia,* Grant and Gale (1931, p. 419) cited an exception in which the pallial sinus is more like that on *Cryptomya,* being "obsolete or very short" (p. 416), and this observation agrees well with Keen's comment (1958, p. 206) that *Sphenia* has "a shallow but wide pallial sinus." On the basis of these comments, study of the photographs or line drawings presented by Adams and Adams (1855, pl. 95, fig. 4b), Brann (1966, pl. 6, fig. 35), Dall (1898, pl. 35, fig. 9), Palmer (1958, pl. 15, figs. 9, 10), and Tebble (1966, fig. 90), and personal observation of the pertinent features exhibited by specimens of *S. fragilis* and the type species, *S. binghami,* this writer must join in rejecting Dall's diagnosis of the pallial sinus characteristic of *Sphenia* as reflected in the generic description above.

Keen (written communication, March 1968) observed a close resemblance between the new species of *Sphenia* and another myid, *Tugonia* Gray, 1842. The two are similar in shell outline and shape, pallial line and sinus, and adductor muscle scar characteristics; however, *Sphenia* lacks *Tugonia*'s reticulated prosopon, broad posterior gap, and chondrophore in the right valve, and the beaks on species of *Sphenia* are neither opisthogyrate nor located near the posterior shell extremity.

Extant species of *Sphenia* appear to be confined to Mediterranean, eastern Atlantic, Puerto Rican, and Pacific shallow coastal waters. Tebble (1966, p. 169) reported the occurrence of the type species, *S. binghami,* in the Mediterranean and in the eastern Atlantic from Morocco north to the British Isles, where it lives "attached by its byssus threads . . . just offshore to moderate depths . . . frequently in [crevices and] holes previously bored and occupied by *Hiatella arctica* and in the holdfasts of *Laminaria.*" The living individuals utilized in Yonge's (1951) study of this species were collected from *Hiatella*-bored limestone blocks recovered south of the Calf of Man at a depth of 20 fathoms; however, Yonge (1951, p. 387) also cited the inclusive bathymetric range of *S. binghami* as five to 25 fathoms, figures taken from earlier published reports (Forbes and Hanley, 1853, p. 193; Jeffreys, 1865, pp. 71-72). In the mid-1850's, Adams and Adams (1856, p. 358) noted the characteristic burrowing habit of the genus "in oyster shells and limestone."

In the western Atlantic, Warmke and Abbott (1961, p. 206) reported that *S. antillensis* Dall and Simpson, 1901, is "Reasonably common from shallow dredgings on the west and south coasts of Puerto Rico," a locality to which this minute species is apparently endemic; although Britton (1965) collected dead shells from the north coast as well (p. 81), he found live specimens only in the southwestern, southern, and southeastern coastal waters at depths from ten to 75 feet, where they inhabit sand (>80% sand) to sandy mud (50-80% mud) bottoms at salinities ranging from 35.14‰ to 35.71‰ (p. 13).

Of the two species inhabiting eastern Pacific waters, *Sphaenia ovoidea* Carpenter, 1864, has been reported to occur from the Aleutians southward to San Diego, California (Palmer, 1958, p. 116), although Abbott (1954, p. 456) cited Panama as the southernmost limit; *Sphaenia fragilis* Carpenter, 1857, has been reported from Oregon to northern Peru (Olsson, 1961, p. 425) and throughout its range it is "common" from "low tide to 46 fathoms in mud" (Abbott, 1954, p. 455), "Nestling in cavities such as worm burrows in other shells" (Keen, 1958, p. 207), especially in "abandoned worm burrows" (Olsson, 1961, p. 425). However, Keen (written communication, March 1968) has cautioned that published distributional data for these two species may be somewhat misleading, observing that both species "are uncommon throughout their range and rare north of southern California." A western Pacific form, *S. coreanica* Habe, 1951, was reported by Habe (1961, p. 140) to live nestled around the roots of seaweed in waters from five to 20 meters deep on the south shore of Kyushu, although the later edition of this work, in English (Habe, 1964, p. 205), cited additional uncommon occurrences "in shallow waters from Sagami Bay, Honshû to the west coast of Kyûshû and Korea."

In eastern North America, the genus is represented only by three fossil species, the first two of which were reported by Dall (1898) as *S. dubia* (H. C. Lea), 1845, from the Miocene of Virginia and North Carolina (p. 859), and *S. attenuata* Dall, 1898, from the Caloosahatchee Marl, a deposit of Pliocene age exposed in southern Florida (p. 860). The third, *S. senterfeiti* Gardner, 1936, was described from the Oak Grove Sand of Miocene age in northwestern Florida (Gardner, 1936, p. 45). These fossil forms will be discussed more fully following the species description.

Sphenia tumida Lewis, sp. nov.
Pl. 1, figs. 1-4

Cuspidaria? sp. Lewis, 1964, Paleoecological Study of a Pleistocene Marine Fauna, Flagler County, Florida [M.S. thesis, University of Florida], pp. 32, 34.

Sphenia? sp. Lewis, 1966, Gulf Coast Assn. Geol. Socs., Trans., v. 16, p. 321.

Description: Valves small, white, tumid, extremely fragile, brittle, and always slightly longer than high; antero-central or central portion of disc markedly inflated; posterior extremity narrowed and attenuated, almost always forming a short rostrum reflexed slightly to the left, inclined dorso-posteriorly, and truncated obliquely; posterior gap narrow; right valve slightly larger and more convex than left. Shape variable; small specimens usually suboval with broadly rounded anterior and antero-ventral margins, a straight to gently curving postero-ventral margin, and a comparatively long and wide, gently tapering, abruptly terminated rostrum; large specimens either essentially the same with proportionately narrower rostrum, or more or less uniformly subcircular with disc more inflated and rostrum more pronounced, more steeply inclined, proportionately shorter, and often set off from postero-ventral margin of disc by a shallow indentation. Beaks prosogyrate and strongly enrolled, that on the right valve partly obscured by the strongly raised antero-dorsal valve margin;

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PLATE 1
Sphenia tumida Lewis, sp. nov.

Figures

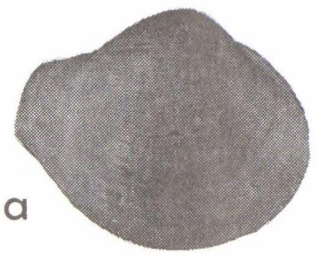
1 Holotype. Left valve, USNM 645663. 1a. exterior, X 3; 1b. interior, X 3; 1c. detail of chondrophore, X 4

2 Paratype A. Right valve, USNM 645664. 2a. exterior, X 3; 2b. interior, X 3; 2c. detail of ligamental pit, X 4

3 Paratype B. Left valve, USNM 645665. 3a. exterior, X 3; 3b. detail of chondrophore, X 4

4 Paratype C. Right valve, USNM 645666. Exterior, X 3

1 a



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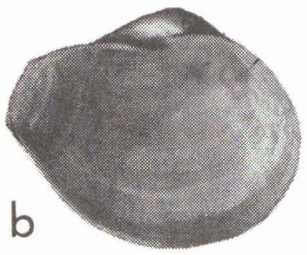

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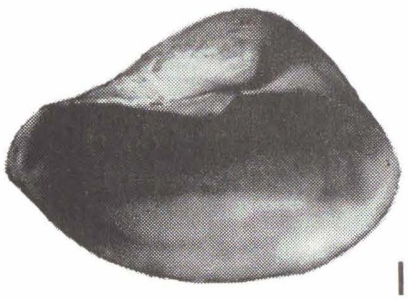

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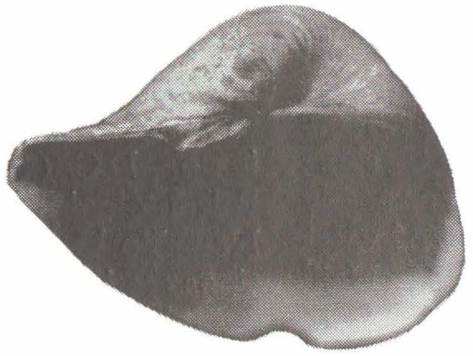
2 c



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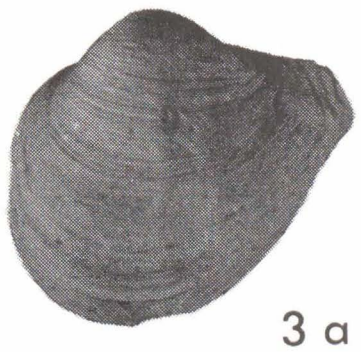

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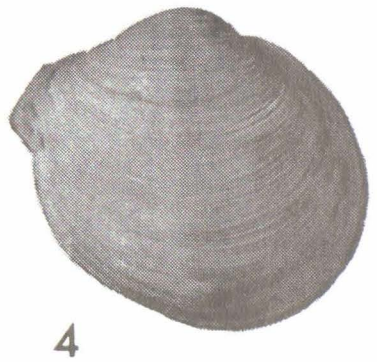

4

PLATE 1

usually located near midpoint of the length on large specimens, slightly anterior to midpoint on small specimens. Umbones elevated and prominent, convex to somewhat flattened, and expanding rapidly.

External prosopon variable, tending to be smoother with numerous, comparatively fine and regular, concentrically incised incremental lines on small specimens and over earlier, central portions of disc on large specimens; growth increments on later portions coarser and increasingly irregular and elevated. Prosopon stronger near anterior, postero-ventral, and posterior margins, becoming wavy and strongly wrinkled on rostrum, particularly of large specimens. Gray-brown periostracum usually preserved near margins of both valves, although most extensive on rostrum. Low ridge emerging from strong posterior slope of umbo and extending to postero-ventral extremity of rostrum, generally well developed on left valves of large individuals, less so on right valves. Umbones and central part of discs occasionally bisected by a shallow, radial groove, generally directed postero-ventrally to valve margin.

Hinge teeth lacking. Hinge line of right valve gently curved to almost straight, that of left valve somewhat straighter although seemingly depressed immediately posterior to beak, where chondrophore projects obliquely posteriorly. Chondrophore short and narrow with a shallow, elongate, nearly parallel-sided, troughlike depression of varying depth ("fibrum receptacle" of MacNeil, 1964, p. 22) originating beneath the beak and terminating in a slightly to moderately elevated lip ("ventral margin"). Chondrophore continuous with, but set off by one or two low ridges ("posterior ridge") from, a short, slightly to moderately raised flange ("posterior furrow") projecting inward from the hinge line and upward; presence of two ridges (compound "posterior ridge") most common on larger specimens, with the anterior, lower ridge separated from the posterior, higher one by a marginal notch and a shallow, narrow trench curving uninterruptedly forward to the hinge line. Ligamental pit on right valve, usually asymmetrically bisigmoidal and recessed into hinge plate. Slopes of postero-dorsal margins of both valves usually unchanged from those of hinge lines, although occasionally slope near dorsal extremity of rostrum more highly curved. Postero-dorsal border of right valve overlapping chondrophore and its associated flange on left valve.

Anterior adductor scar faint, an elongated crescent near anterior valve margin; posterior scar subcircular to quadrilateral; if the latter, dorso-anterior and ventro-posterior margins frequently slightly concave upward; irregular, often rough, secondary deposits of shell material occasionally at or near dorsal extremities of both scars. Pallial line approximately parallel to ventral margin, the two converging somewhat posteriorly; line generally regular and weakly defined, becoming fainter anteriorly. Pallial sinus occasionally weak but usually moderately strong; straight or slightly convex inward; and extending postero-ventrally from point at or near anterior extremity of posterior scar. Internal surface smooth or reflecting faintly the external growth increments, especially near ventral margin and on small specimens; chalky to subporcellaneous dorsal to pallial line, usually the latter between line and ventral margin; surface dorsal to line seldom granular. Thin, buttress-like secondary shell deposits rarely inserted irregularly beneath hinge plate of either valve.

Type depositories and dimensions: The holotype and four paratypes have been deposited at the U.S. National Museum, Washington, D.C. (USNM), four paratypes at the Paleontological Research Institution, Ithaca, New York (PRI), as listed below; dimensions are in millimeters.

Holotype: USNM 645663 (a left valve); length 9.0, height 7.0, thickness 3.2. Paratype A: USNM 645664 (a right valve); length 9.0, height 7.1, thickness 3.1. Paratype B: USNM 645665 (a left valve); length 10.6, height 9.9, thickness 4.6. Paratype C: USNM 645666 (a right valve); length 11.2, height 10.0, thickness 4.3. Paratype D: USNM 645667 (a left valve, not figured); length 8.2, height 6.5, thickness 2.6. Paratype E: PRI 27628 (a right valve, not figured); length 6.0, height 5.2, thickness 2.0. Paratype F: PRI 27629 (a left valve, not figured); length 10.5, height 8.4, thickness 3.8. Paratype G: PRI 27630 (a right valve, not figured); length 10.6, height 8.1, thickness 3.3. Paratype H: PRI 27631 (a left valve, not figured); length 11.1, height 9.7, thickness 3.7.

Hypodigm: Three articulated specimens;

disarticulated complete valves (3/4 or more of entire valve), 46 left, 39 right; fragments (primarily hinge plates with associated beaks), 114 left, 105 right. Other than types, most specimens are housed in the paleontological collections of the Florida State Museum, University of Florida, Gainesville, although a few representative individuals have been placed in the Cenozoic Research Collection, Department of Geology, Tulane University.*

Range of dimensions of complete specimens, in millimeters: Articulated (only one measurable): length 9.0; height 7.3; thickness 5.4. Disarticulated left: length 12.1 (maximum), 5.6 (minimum); height 10.9 (maximum), 4.5 (minimum). Disarticulated right: length 11.7 (maximum), 6.0 (minimum); height 9.2 (maximum), 4.9 (minimum).

Etymology: From Latin, *tumidus* (swollen), referring to the outstanding disc characteristic.

Discussion: Due to the similarity in external shape and prosopon exhibited by several unrelated bivalves which have assumed a burrowing or nestling existence, *Sphenia tumida* resembles externally some species of those genera discussed earlier, but differs in internal characteristics. Among extant species of *Sphenia,* it differs from *S. binghami, S. antillensis, S. ovoidea,* and *S. fragilis* in being more inflated anteriorly, proportionately less elongate, and in having a more conspicuous, narrower rostrum; internally, its pallial sinus is generally less broadly rounded and shallower. In addition, *S. tumida* is much larger than the specimens of *S. antillensis* in the U.S. National Museum collections, the largest of which approximates the dimensions of the figured holotype (USNM 160495), the length measuring 4.0 mm, height 2.5 mm, diameter 1.5 mm (Dall and Simpson, 1901, p. 474, pl. 55, fig. 14). Although the internal characteristics and details of the hinge plate and chondrophore of *S. coreanica* are not sufficiently clear in the original description and figures to permit ready comparison (Habe, 1951, p. 76, text-figs. 3-5), its external prosopon and shape, which is seen to be more rostrate posteriorly in the excellent, later photograph by Habe (1961, pl. 63, fig. 10), appear to approach most closely those of *S. tumida;* however, unlike the exterior of the latter, the umbo of the left valve of *S. coreanica* does not appear as highly elevated as, or subequal to, that of the right valve.

Relative to the three fossil species reported from eastern North America, *S. tumida* is appreciably larger than the Miocene forms, *S. dubia* and *S. senterfeiti,* and is more regular in shape and more tumid anteriorly than the latter; its valves differ from those of the Pliocene form, *S. attenuata,* in being lighter and thinner, in possessing a shallower pallial sinus which is not highly and broadly convex inward, and in the position of the postero-ventral extremity of the pallial sinus which terminates far back, beneath the posterior adductor scar, rather than anteriorly at a point slightly behind the midpoint of the length of the valve. The posterior extremity of *S. attenuata* valves is proportionately longer and its margin more symmetrically and broadly convex, while the rostrum of *S. tumida* originates dorsally and is obliquely truncated. Although described originally from the banks of the Caloosahatchee River (Dall, 1898, p. 860), DuBar (1958, 1962) found no trace of *S. attenuata* there and reported only *"Sphenia* cf. *S. attenuata* Dall" from the Locklin Shell Creek collection made farther north, in Charlotte County (1962, p. 65). Still farther north, from the Pliocene deposits of North St. Petersburg, Olsson and Harbison (1953, p. 150) reported only a single small shell, 4.4 mm long, of this species.

Of all the Caloosahatchee bivalves, *S. tumida* is perhaps closest to the form referred by Olsson and Harbison (1953, p. 65, pl. 13, fig. 1) to a new species, *Poromya ? floridana,* but it differs in being more inflated and in having a more conspicuous rostrum. As mentioned by those authors, *P. ? floridana* is known only from three right valves and, hence, the critical nature of the left hinge plate and chondrophore is unknown. However, the ligamental pit and

* Three additional valves (two right and one left) were found in the uncatalogued collections at the U.S. National Museum in material received from The Johns Hopkins University. The label reads *"Cuspidaria* n. sp., Caloosahatchie beds, Fla., Pliocene," but evidently these specimens were never described and the inadequate locality data are probably incorrect. Also found in the U.S. Geological Survey collections at the National Museum were nine other disarticulated valves, which will be discussed more fully at the conclusion of the discussion section.

other details resemble comparable features of *S. tumida,* and *P. ? floridana* may well represent an earlier form in an evolutionary lineage which terminated with *S. tumida.* Pending discovery of the crucial missing left valve, the designation of Olsson and Harbison should be upheld, but this writer feels that the generic identity of *P. ? floridana* will ultimately prove to be *Sphenia.*

Although Richards (1936, 1938, 1939a, 1939b) analyzed, evaluated, and synthesized distributional data concerning the Pleistocene marine invertebrate faunas from the Atlantic and Gulf coastal plains, he recorded no occurrences of species of *Sphenia.* Among the unidentified specimens in the U.S. Geological Survey collections, however, are two closely similar forms from a formation in southern Florida called "Unit A" by Olsson and Petit (1964, p. 521) and considered by Druid Wilson to be lowermost Pleistocene in age (written communication, March, 1968). Recovered from USGS Locality 22603 near Bermont in Charlotte County, two comparatively poorly preserved disarticulated valves (one right and one left) appear identical to *S. tumida,* and from USGS Locality 22846 near Bluefield in St. Lucie County, seven additional valves (four right, two left, and one right fragment) resemble closely the new species. However, the St. Lucie valves are thicker and heavier; the incised lines of their external prosopon are finer, shallower, and more regular; their umbones are more gently rounded with borders, especially anterior, less sharply defined; their chondrophores are shorter and terminated more abruptly; and their ligamental pits are not deeply recessed but are borne posteriorly on an elongated, somewhat spoon-shaped structure projecting strongly postero-ventrally. These specimens may represent a separate species or subspecies but are considered here to be an ecotypic variant of *S. tumida,* pending accumulation of additional material.

III. Paleoecological Implications

Among the quantitative analytical methods employed by the writer in investigating the paleoecology of the fauna at University of Florida Locality 5 (Lewis, 1966) were analyses of excess valves and relative abundance; as the study sample was subdivided for ease in processing and analysis into four subequal units (designated successively intervals A, B, C, and D from the top of the sample to the bottom), the writer was able to note changes in these parameters vertically through the sample. To illustrate, the percentage of excess valves (complete right valves relative to the total number of complete disarticulated valves) computed for *Sphenia tumida* in each sample interval was, from A through D, respectively, 16.7, 56.3, 50.0, and 50.0 (p. 325); the unusually low value in interval A was interpreted as due to sorting by physical agencies, although the species was believed to be indigenous in the remainder of the sample, especially in its lowermost two-fifths, represented by intervals C and D. Comparably, abundance data computed for *S. tumida,* relative to all mollusks in each interval and expressed also in percent, were (again from A through D, respectively) 0.38, 0.85, 1.78, and 2.21 (p. 323); clearly, the species became progressively less common upward through the sample. It is this fact, coupled with the unequivocally indigenous nature of the species in the lowermost intervals, which can be correlated with the habits and habitats of living species of *Sphenia* to interpret further the paleoecological conditions at the Flagler County depositional site.

The overall faunal evidence from the study sample enabled the writer (Lewis, 1966, p. 326) to postulate the following conditions at the depositional site: "a high-salinity, shallow-water bay environment, with a predominantly sand or sand-mud substrate; considerable wave action; weak currents; and a minimum water temperature of 50° to 55° F." Expanding on this in light of knowledge regarding the substrate preference of Recent relatives of *S. tumida* discussed earlier, this genus appears to be well adapted to nestling or burrowing in mud and, presumably, *S. tumida* filled the same ecological niche during the Pleistocene; further, this species probably represents one of the most conclusive examples in this deposit of preservation essentially in place.

If the deposit represents rapid sedimentation and accumulation, as under storm conditions in a depression on the bay floor, the greater relative abundance of this species near the bottom of the sample would have necessitated a deeper burrowing habit than has been reported or observed among living

species of *Sphenia.* Further, although storm-induced bottom turbulence may produce deposits of mixed particle sizes, most of the coarser sand particles settle earlier and are covered subsequently by sediments in which the finer silt and clay fractions predominate; should this have occurred here, it is extremely unlikely that indigenous specimens of *S. tumida* would be concentrated, as they are, nearer the bottom of the sample. Thus, the deposit probably does not represent rapid deposition of this type, and an interpretation of comparatively slow sedimentation and accumulation seems more reasonable. Under these conditions, specimens of *S. tumida* would have lived in the sandy mud at or slightly beneath the water-substrate interface, more in accord with the observed preference of its living relatives, and its abundance would have diminished upward and through time due to a decline in the proportion of mud in the sediments being introduced to the depositional site. These conditions are explained best by postulating an increasingly higher energy environment through time, such as would result from shallowing, or, less likely, from seasonal changes.

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REVIEWS

HISTORY OF HYDRAULICS; HISTORY OF THE EXPEDITION UNDER THE COMMAND OF LEWIS AND CLARK

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HISTORY OF HYDRAULICS, by Hunter Rouse and Simon Ince. Published by Dover Publications, Inc., New York, 1963, xii + 269 pp., 179 illus., $2.00

This is a reprint of the 1957 edition, the first general history of hydraulics—that branch of science concerned with flow of fluids. The authors begin with primitive efforts to control and regulate waters in Mesopotamia, Greece and Egypt, continue through the classic Roman period to the Middle Ages and the Renaissance. They then trace in more detail the subsequent development of experimental and observational hydraulics from Castelli and Torricelli in the early 17th century through the succeeding two centuries, review hydraulic trends in the early 20th century and recent progress in fluid mechanics, and conclude with *An Appraisal of the Science at mid-Century.*

The reference value is enhanced by insertion of biographical material and portraits of significant individuals in the development of hydraulics. The text is well illustrated with reproductions of original diagrams from primary sources. Lists of pertinent references follow each chapter and a *Chronological Table of the Leaders in Hydraulics and Related Fields* is appended to the volume.

HISTORY OF THE EXPEDITION UNDER THE COMMAND OF LEWIS AND CLARK, edited by Elliott Coues. Published by Dover Publications, Inc., New York, 1965, 3 vols., cxlv + 1364 pp., 8 maps, index, $6.75

As early as 1792, Thomas Jefferson formulated plans for an expedition to the vast western territories and selected Meriwether Lewis as the leader; this early attempt failed. In 1801, Jefferson assumed the presidency. By 1803, he succeeded in gaining support from congress for his expedition. On May 14th, 1804, the party set out from St. Louis and for two years traveled westward, up the Missouri River to the continental divide, across the divide to the Columbia River, and descended to the Pacific Ocean. Lewis and Clark were acute observers and filled thousands of pages with the most complete journal of any exploring venture in history. After the death of Lewis in 1809, Nicholas Biddle undertook the task of writing the authorized history of the expedition; it appeared in 1814. In 1893, Elliott Coues by recourse to the original journals and field notebooks much improved the narrative. This is an unabridged republication of the 1893 Coues edition. It is handsomely done.