MORPHOLOGICAL VARIATIONS IN THE AMMONITE GENUS SCAPHITES OF THE BLUE HILL MEMBER, CARLILE SHALE, UPPER CRETACEOUS, KANSAS

by

Rex E. Crick
B.S., University of Kansas, 1973

Submitted to the Department of Geology and the Faculty
of the Graduate School of the University of Kansas
in partial fulfillment of the requirements for the
degree of master of Science.

Curt Teichert
Professor in Charge

M. E. Bickford

Davis
Committee Members

Ernest E. Angino
For the Department

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ABSTRACT

The heteromorph ammonite genus, Scaphites, is investigated with respect to its occurrence, diversity, and reported variations in the Blue Hill Shale Member of the Carlile Shale Formation in Kansas.

Previous reports that the genus is abundant and ubiquitous throughout the stratigraphic range of the member are unfounded. The genus is rare except where it is common in a 3-4 meter zone in the upper part of the member.

The morphologic variations within the genus are investigated using descriptive and quantitative methods. The research indicates that most of the variation is due to the presence of six species of Scaphites instead of the single species previously reported. Scaphites hattini, S. inflexus, S. kansiensis, and S. mitchellensis are new species; S. arcadiensis Moreman has not been previously reported from the member; and S. carlilensis Morrow is endemic to the member. The remaining variation is attributable to sexual dimorphism. Each species can be divided into dimorphic pairs represented by macroconchs (females) and microconchs (male).

INTRODUCTION

For more than a century, workers investigating the Turonian Carlile Shale of Kansas have recognized morphological variations and differences in the relative size of specimens within the ammonite genus Scaphites. Presence of these variations is questioned on the basis of taxonomic differences and evidence of sexual dimorphism in ammonoids. Cobban (1951) has shown that morphological variations in ornamentation often suggest specific differences in Scaphites. Makowski (1962) and Callomon (1963) described convincing examples how sexual dimorphism could be used to explain much of the morphological variations and size differences within ammonite species and genera. From 1963 to the present only Cobban (1969) has dealt with sexual dimorphism in the genus Scaphites. The species of Santonian and Campanian age studied by Cobban were different from those of Turonian age described below.

Reexamination of the genus with regard to taxonomy and dimorphism indicates that Scaphites of the Blue Hill Shale Member of the Carlile Shale (late Turonian) is dimorphic with distinguishable sexes and that more than one species of the genus exists. In addition, Scaphites was found to be limited to a narrow "Scaphites zone" and not ubiquitous as previously reported.

ACKNOWLEDGEMENTS

Dr. Curt Teichert gave sound advice and constant encouragement throughout my years at the University of Kansas. He contributed much to the basic research described herein. I will continue to be especially grateful to him. Drs. Paul L. Hilpman, University of Missouri at Kansas City, and Donald E. Hattin, University of Indiana, were largely responsible for acquainting me with the problem; they have my enduring appreciation.

Dr. M. E. Bickford, of the Department, and Dr. John C. Davis, State Geological Survey of Kansas, read the manuscript and made many suggestions that led to improvement. Dr. Roger L. Kaesler, of the Department, and Dr. J. J. Sepkowski, University of Rochester, assisted in the application of numerical methods. Messrs. T. J. McClain and F. W. Wilson, State Geological Survey of Kansas, assisted with logistics and fruitful discussions. Joyce Barnhart, State Geological Survey of Kansas, assisted with editing and acted as an effective liaison between the Survey and the University of Rochester. Sharon K. Hagen, Barbara Welter, Marceline Younkin, and Pat Acker, State Geological Survey of Kansas, provided advice and assistance in preparation of plates and figures. Mrs. Kaye Long, State Geological Survey of Kansas, typed drafts and the final copy of the manuscript. I express my thanks to all these persons.

The State Geological Survey of Kansas provided financial support in the form of a research assistantship, field expenses, drafting, and typing for which I am extremely grateful. Additional research was funded by Sigma Xi in the form of a Grant-In-Aid of Research. Sigma Xi's contribution is sincerely appreciated.

GEOLOGIC AND GEOGRAPHIC SETTING OF THE CARLILE SHALE IN KANSAS

The Carlile Shale of late Turonian age crops out in two geographically separated areas in Kansas. The larger of the two outcrops extends in a southwest trending belt, approximately 320 kilometers from the southernmost part of central Nebraska to Finney and Ford Counties in Kansas. The maximum width of this belt is 160 kilometers (Hattin, 1962). The smaller belt of outcrops lies in Hamilton County, near the Colorado-Kansas border, and was not studied because exposures were poor (Fig. 1A).

Three members are recognized in the Carlile i.e., Fairport Chalk, Blue Hill Shale, and Codell Sandstone (Fig. 2). Of these only the Blue Hill Shale Member contains Scaphites specimens suitable for this study and it alone was studied.

In normal stratigraphic sequence, the Niobrara Chalk overlies the Carlile Shale. Regional dip on the top of the Dakota Formation is approximately 3.6 meters per kilometer toward the northeast (Merriam, 1957). In the west-central Kansas outcrop area of the Carlile, however, dip on the top of the Dakota is generally northward at about 2.4 meters per kilometer (Hattin, 1962).

The more resistant formations of the Colorado Group are responsible for the prominent eastward-facing escarpments which dominate local topography of the large outcrop area. The Carlile Shale, which crops out in the western portion of the Smokey Hills Section of the Great Plains, lies between two such escarpments (Hattin, 1965). An escarpment comprised of eroded upper Greenhorn strata marks the eastern boundary of

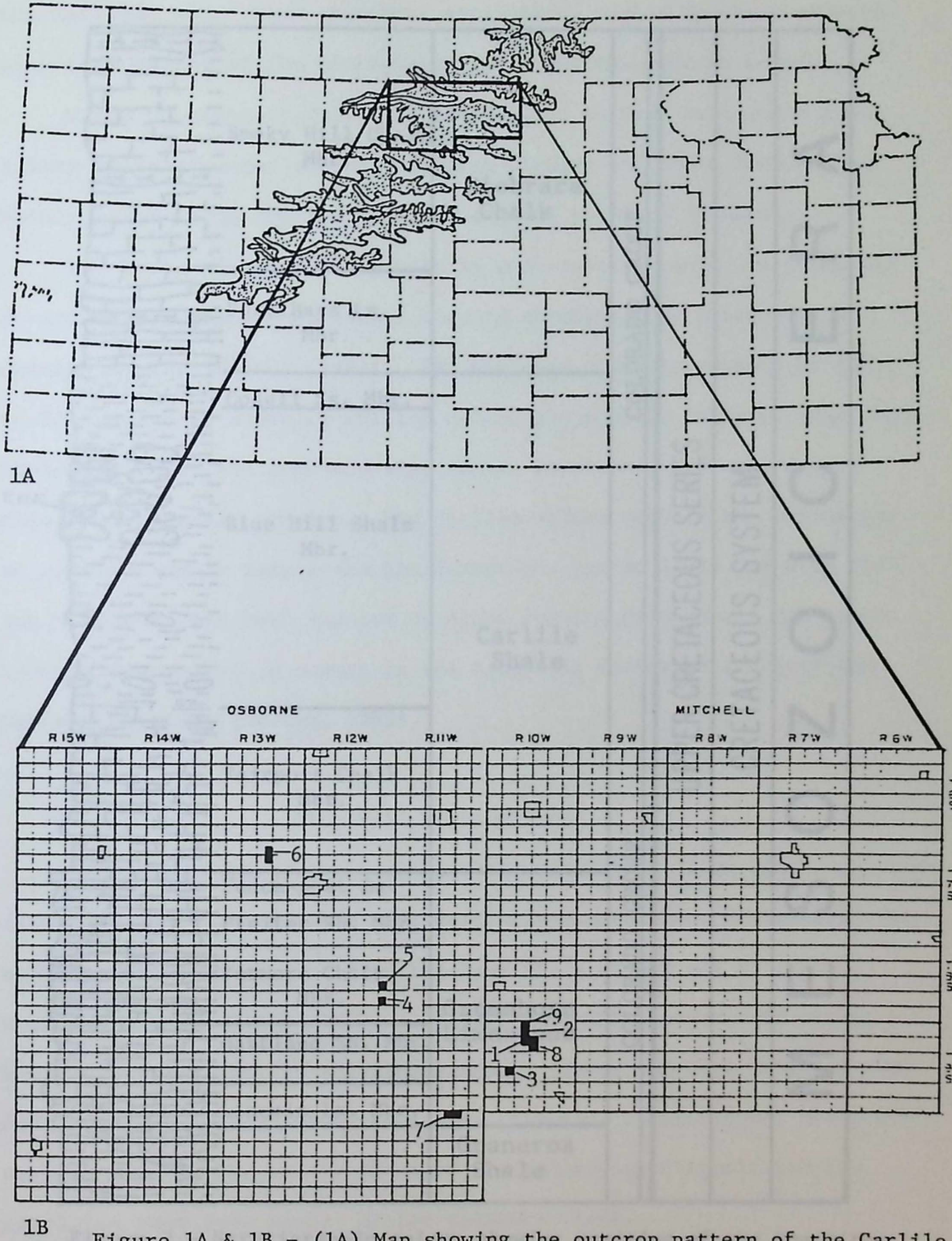

Figure 1A & 1B - (1A) Map showing the outcrop pattern of the Carlile Shale in Kansas. (1B) County index map showing the position of collecting localities. Description of each locality given on page 6.

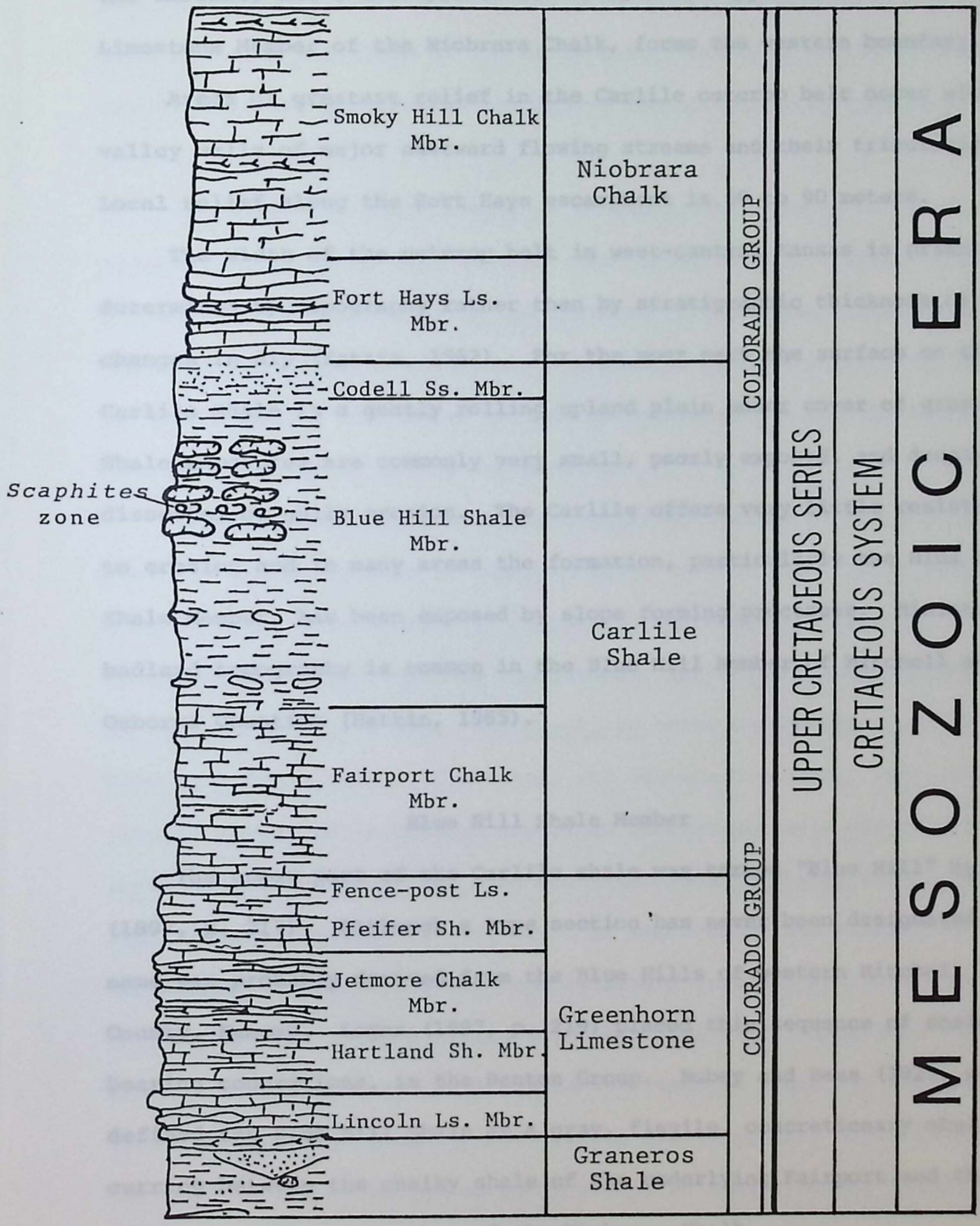

Figure 2 - Stratigraphic column showing position of the *Scaphites* zone within the Blue Hill Shale Member (modified from Zeller, 1968).

the Carlile, and a more prominent escarpment, capped by the Fort Hays Limestone Member of the Niobrara Chalk, forms the western boundary.

Areas of greatest relief in the Carlile outcrop belt occur along valley walls of major eastward flowing streams and their tributaries. Local relief along the Fort Hays escarpment is 60 to 90 meters.

The width of the outcrop belt in west-central Kansas is primarily determined by topography rather than by stratigraphic thickness or changes in dip (Hattin, 1962). For the most part the surface on the Carlile Shale is a gently rolling upland plain under cover of grassland. Shale exposures are commonly very small, poorly exposed, and deeply dissected by gully erosion. The Carlile offers very little resistance to erosion and in many areas the formation, particularly the Blue Hill Shale Member, has been exposed by slope forming processes. Miniature badland topography is common in the Blue Hill Member of Mitchell and Osborne Counties (Hattin, 1965).

Blue Hill Shale Member

The upper part of the Carlile shale was termed "Blue Hill" by Logan (1897, p. 217). Although a type section has never been designated, the name was probably derived from the Blue Hills of western Mitchell County, Kansas. Logan (1897, p. 219) placed this sequence of shale, bearing concretions, in the Benton Group. Rubey and Bass (1925, p. 33) defined the Blue Hill Shale as a gray, fissile, concretionary shale occurring between the chalky shale of the underlying Fairport and the overlying Fort Hays Member of the Niobrara Chalk.

The term Codell was later used by Bass (1926, pg. 28) to designate a thin sandstone unit near the top of the Blue Hill and the latter name was subsequently restricted to the lower shale and concretionary zones. This division and usage of the terms Codell and Blue Hill as members of the Carlile was accepted by the Kansas Geological Survey (Merriam, 1957, p. 8).

The Blue Hill Shale Member is a nondescript, blocky to fissile, slightly silty shale that weathers into small brittle flakes. Bedding planes are undefined even in the freshest of exposures. The predominant color of the shale is dark gray, although it is dark olive gray locally. In Jewell County the member attains an estimated maximum thickness of 66 meters, of which 59 meters are exposed.

Probably the single most distinguishing feature of the Blue Hill Shale is the occurrence of numerous large concretions. These can be grouped into three types: 1) calcareous septarian concretions; 2) noncalcareous clay-ironstone concretions; and 3) sandstone concretions. It is with the first type that Scaphites occur in the upper part of the Blue Hill Shale Member of Mitchell and Osborne Counties. Four stratigraphic levels of calcareous septarian concretions were observed at localities where Scaphites also occurred. The Scaphites zone begins just above the basal or first level of concretions and terminates approximately halfway between concretionary levels 2 and 3, a distance varying between 4 and 6 meters (Fig. 2). The Codell Sandstone is not always present and section measurements, used to place the fossils stratigraphically, used the base of the overlying Fort Hays Limestone. The base of the Scaphites zone was placed at approximately 34-36 meters below the top of the Blue Hill.

Approximately one-half meter below the base of the level-2 concretions, calcareous shale nodules occur ranging from 4 to 12 cm in diameter. The majority of these contain fossils, either Inoceramus or Scaphites, with the former being most abundant. These nodules yielded the best preserved and most complete material of the collection.

Field studies were limited to Mitchell and Osborne Counties because the stratigraphic horizon containing Scaphites is limited to these areas. Reports by Hattin (1952, 1962), Morrow (1935), and Stanton (1893) that Scaphites is abundant and ubiquitous throughout the Blue Hill Shale Member apparently are unfounded. Extensive efforts at collecting Scaphites from the entire stratigraphic range of the Blue Hill Shale were unsuccessful and have caused me to disclaim these previous reports for the following reasons. Previous authors claiming an abundance of Scaphites in the Blue Hill Shale (Logan, 1898; Morrow, 1931, 1935; Hattin, 1952, 1962) were apparently mislead by an abundance of "weathered-out" specimens that had accumulated during considerable time periods between visits by major collectors, i.e., 33 years between Logan and Morrow; 21 years between Morrow and Hattin. I formed the same opinion when first visiting the field area in 1974, 22 years after Hattin. However, on subsequent trips to the area I found that the fauna was indeed sparse.

A more disturbing discovery was made while attempting to collect throughout the stratigraphic range of the Blue Hill. Scaphites, previously reported to be ubiquitous in this Member, was found to occur only within a 4-6 meter zone coinciding with the basal level of large septarian concretions occurring in the upper Blue Hill Shale. This zone, which cannot be considered to contain abundant Scaphites, contains specimens of Scaphites in two modes of preservation. They may occur loose in the shale with preservation ranging from internal casts of body chambers to reasonably well preserved body chambers with an occasional complete specimen, or they may occur in calcareous shale nodules containing near perfect to perfectly preserved body chambers and complete specimens. The greatest percentage of specimens in the present collection occurs in these shale nodules.

List of Collecting Localities

Collecting localities are shown in Figure 1B. The stratigraphic horizon for each locality is the lower part of the upper Blue Hill Shale Member, Carlile Shale Formation, Colorado Group, early Turonian.

1. NE 1/4 sec. 9, T9S, R10W, Mitchell County. Gullies in slopes of Blue Hills, approximately 5.6 km (3 1/2 mi.) south-southeast of Tipton.
2. SE 1/4 sec. 4, T9S, R10W, Mitchell County. Gullies in slopes of Blue Hills, approximately 4.8 km (3 mi.) south-southeast of Tipton.
3. NE 1/4 sec. 20, T9S, R10W, Mitchell County. Gullies in north face of conspicous butte in Blue Hills, 8.9 km (5 1/2 mi.) south and 1.6 km (1 mi.) east of Tipton.
4. SW 1/4 sec. 25, T8S, R12W, Osborne County. Gullies near base of bluffs on north side of county road, approximately 13.7 km (8 1/2 mi.) south-southwest of Osborne.
5. SW 1/4 sec. 24, T8S, R12W, Osborne County. Gullies on south end of prominent mesa, 14.5 km (9 mi.) south-southeast of Osborne.
6. SE 1/4 SE 1/4 sec. 3 and NE 1/4 NE 1/4 sec. 10, T7S, R13W, Osborne County. Bluff on north valley wall of South Fork of Solomon River, approximately 3.2 km (2 mi.) north-northeast of Bloomington.
7. NW 1/4 sec. 2 and NE 1/4 sec. 3, T10S, R11W, Osborne County. Gullies on south face of Blue Hills, 24.1 km (15 mi.) south and 14.5 km (9 mi.) east of Osborne.
8. W 1/2 sec. 10, T9S, R10W, Mitchell County. Gullies in slopes of Blue Hills, approximately 6.4 km (4 mi.) south-southeast of Tipton.

9. NE 1/4 sec. 4, T9S, R10W, Mitchell County. Gullies in slopes of Blue Hills, approximately 3.2 km (2 mi.) south-southeast of Tipton.

PREVIOUS WORK ON SCAPHITES OF THE CARLILE SHALE

The first comprehensive work on the paleontology of the Upper Cretaceous of the western interior was by Meek (1876). Although Meek did not deal directly with Kansas faunas he described two species of Scaphites occurring in rocks of Turonian age from Nebraska and South Dakota, Scaphites larvaeformis and S. mullananus.

Stanton (1893) discussed the Colorado Group in Kansas and was the first to indicate that Scaphites occurred in concretions contained in a bluish-black or slate-colored shale (= Blue Hill Member). Stanton listed and illustrated several species of this genus, Scaphites larvaeformis, S. vermiformis, S. warreni, S. ventricosus, and S. mullananus. Unfortunately Stanton did not indicate the scale of magnification of his plate figures making impossible any comparison of illustrated specimens. In discussion of S. warreni Stanton referred to specimens which differed only in size and degree of volution compression. Meek (1876) considered such differences sufficient to assign a varietal name, S. warreni var. wyomingensis Meek and Hayden, to these smaller forms. Whitfield (1880), in discussing the same fauna, agreed with Meek, contending that although the two forms are associated at the same localities and even occur in the same hand specimen, it is not difficult to distinguish them. Stanton disagreed with this approach, placing both forms in the same species. In the discussion of S. ventricosus, Stanton stated that "in the style of its ornamentation this species [S. ventricosus] resembles S. warreni, but differs remarkably in form and size, being much larger, and proportionally very decidedly more gibbous, with a proportionally smaller umbilicus." Examination of Stanton's illustrated specimens, on loan from the U.S. National Museum, indicates that *S. warreni* and *S. ventricosus* are quite similar with the exception of size and robustness of the latter. Both holotypes were taken from the Fort Benton shales. Specimens of *S. larvaeformis*, *S. vermiformis*, and *S. mullananus* also on loan from the National Museum can be separated by dimorphic characters and grouped into dimorphic pairs.

Logan (1898) described the fauna of the Fort Benton Formation (Carlile Shale Formation) and included five species of *Scaphites* from shale of the Blue Hills, *Scaphites larvaeformis*, *S. mullananus*, *S. ventricosus*, *S. vermiformis*, and *S. warreni*. Logan reported these species from the "septaria" horizon (the septarian marker zones of the Blue Hill Shale Member). All descriptions were largely quoted from Meek (1876). Logan reported *S. larvaeformis* to be abundant in the "septaria" horizon of the Fort Benton (Carlile); *S. mullananus* to be associated with *S. warreni* in the Blue Hills shales of the Bort Benton (Carlile); *S. ventricosus* to occur abundantly in shale (Blue Hill Member) of the "septaria" division of the Fort Benton (Carlile), particularly in the upper Blue Hills shales in the vicinity of Williams Butte; *S. vermiformis* in the "septaria" horizon of the Blue Hills shales occurring not only free in the shale, but also in calcareous nodules; and *S. warreni* as moderately abundant in the "septaria" horizon, Fort Benton (Carlile). Logan reproduced Stanton's plates (see discussion, Stanton, 1893, this paper).

Reeside (1927a) in a general discussion listed *Scaphites mullananus*, *S. ventricosus*, and *S. vermiformis* as occurring in the Upper Colorado Formation (Coniacian), recognizing *S. larvaeformis* and *S.*

warreni as occurring in the Carlile (Turonian). This reassignment was made as a result of further definition of the Colorado Group and reexamination of the species in question.

Reeside (1927b) chose to give the small form of Scaphites ventricosus a varietal name, S. ventricosus var. stantoni. Although identical in every respect to the type, he felt the slender aspect of the shell significant enough to warrant assignment to a variety. Reeside handled Scaphites vermiformis in the opposite manner, assigning the large form the varietal name S. vermiformis var. binneyi. The basis for this assignment was the greater depression of whorls in the large form.

Morrow (1931) recognized only two species of Scaphites in the Carlile, S. larvaeformis and S. warreni. S. mullananus, previously reported by Logan (1898) and confirmed by Reeside (1927a) as occurring in the Carlile, was not reported. Morrow found that S. ventricocus and S. vermiformis did occur only in the Niobrara and reported that Reeside (in personal communication to Morrow) had determined S. ventricosus to have been misidentified by Logan, being actually S. larvaeformis. Morrow made no reference to any size differences or pairs in his material, illustrating only one specimen of each species.

Morrow (1935) described two new species "common in the concretionary zones of the upper Carlile shale in Kansas [Blue Hill Member]," Scaphites pygmaeus and S. carlilensis. These forms were collected by Morrow during work on his master's thesis (Morrow, 1931), but were not included in that report. Morrow recognized that "Scaphites pygmaeus and S. carlilensis are very much alike in many details, the principal difference being the size."

Jeletzky (1949) found that the name Scaphites pygmaeus Morrow, 1935, was preoccupied by that of a Senonian species, S. pygmaeus Holzapfel, 1888. Since he considered S. pygmaeus Holzapfel to be specifically distinct from S. pygmaeus Morrow of Turonian age, Jeletzky renamed the latter species S. morrowi. A review of Morrow's holotypes of S. carlilensis and S. morrowi indicates that S. morrowi is the microconch of S. carlilensis and is hereby placed in synonomy with the latter.

Cobban (1951) working with collections gathered from the western interior of the United States reported Scaphites carlilensis and S. morrowi to be the only forms present in the Carlile Shale of Kansas. He did, however, report S. larvaeformis and S. warreni as well as other scaphites from the Carlile Shale outside of Kansas. S. mullananus was not reported from any of the collections. In this work Cobban was aware of size differences that occur in Scaphites and chose to assign a varietal name to one of the forms. His most important contribution was the definition of adult specimens stating that "...adult specimens are here defined as those individulas with partly unrolled living chamber bearing a distinctive sculpture [ornamentation] and ending with a constricted aperture." Cobban further asserted that it was this ornamentation on the living chamber which readily distinguishes species in this genus in which the ornamentation of the early septate whorls is nearly identical.

Hattin (1952), in a master's thesis on the megascopic invertebrates of the Carlile Shale in Kansas, contended that an "apparent synonymy" existed among the names of many of the fossil groups, including Scaphites. This belief was based on the fact that many of the species came from a single bed in the Carlile shale. Hattin maintained that the species of Scaphites previously described from the Carlile (Blue Hill Member), namely Scaphites warreni, S. ventricosus, S. vermiformis, S. larvaeformis, S. mullananus, S. carlilensis, and S. morrowi, were assignable to only one species, S. warreni, for two reasons: 1) "The factor which tends to favor the placement of the extreme forms together in a single specific category is that by far the bulk of the specimens is from the same bed." 2) "...that the opposite extremes of variation are at a single locality seen to be completely gradational" (Hattin, 1952, p. 74). Hattin did not offer measurements other than overall length and width. He did recognize that size differences exist, but chose to treat these differences along with differences in ornamentation as variations within one species. To explain adult forms occurring at such a small size Hattin (1952, p. 70) considered the following possibilities:

1. "The small shells are environmentally stunted adults."
2. "The shells were flexible and coiled up as the septa were added."
3. "The body whorl [living chamber] was repeatedly discarded through the various growth stages as a moulting process."
4. "The shell was internal and the uncoiled portion was reworked continually as the animal grew in size."
5. "The shell was continually discarded and a larger one secreted."

Hattin favored the third possibility on the basis "that the septate portion of the shell [phragmocone] is more resistant to crushing by compaction than is the body whorl." This is actually the opposite of the conclusion reached by Cobban (1951, 1969) and myself. The phragmocones are seldom filled with matrix, crystalline dolomite or calcite, unless broken. If not broken the only avenue of entrance available to foreign material is the very small siphonal tube. The living chamber, however, is always filled with very fine-grained calcareous matrix which entered through the unrestricted aperture.

Hattin (1962) reported Scaphites to be the most abundant of all Blue Hill species in his collections. Without explanation he dropped Scaphites warreni from his faunal list and assigned all the scaphites of the Blue Hill to S. carlilensis. In doing so he discussed S. morrowi and its size difference in relation to S. carlilensis and considered the two to be conspecific. A comparison of the collections of Hattin and Morrow obtained from the Museum of Invertebrate Paleontology at the University of Kansas indicates that several of the forms assigned to S. carlilensis by Hattin are distinct from Morrow's holotype UKMIP 32027. These misidentified forms are hereby assigned to S. hattini (M) Crick, n. sp.

The above cited authors are inconsistent in their handling of the taxonomy of Scaphites. I propose that a large measure of this inconsistency was the failure of past workers to recognize the dimorphic affinities of the genus. Documentation of the presence of dimorphism among the Blue Hill species should assist in removing this inconsistency.

PURPOSE OF PRESENT INVESTIGATION

The purpose of this investigation is to reexamine Scaphites of the Blue Hill Shale Member of the Carlile Formation (late Turonian) with two principal objectives in mind:

1) To establish if previously reported size variations in Scaphites are attributable to sexual dimorphism and,
2) to determine if more than one species of Scaphites exists in the member.

Three principle interpretations have been used by earlier workers to explain variations within the genus:

1) Both large and small forms were placed in the same species but smaller forms were considered juveniles (Stanton, 1893; Logan, 1898; Hattin, 1952, 1962).
2) Different specific names were assigned to large and small forms (Morrow, 1931, 1935).
3) Both large and small forms were placed in the same species and a subspecific name was assigned to one of the forms (Meek, 1876; Whitfield, 1880; Reeside, 1927b; Cobban, 1951).

Criteria for recognition of sexual dimorphism are used to test the hypothesis that variations in the genus are a result of dimorphism. These criteria were those developed by Makowski (1962), Callomon (1963), Cobban (1969), and Lehmann (1971) and are described below in the section Sexual Dimorphism.

Criteria developed by Cobban (1951, 1969) for the distinction of species within the genus are here accepted and are described below in the section Sexual Dimorphism.

The criteria used in the investigation of the principal objectives were augmented by methods developed by myself, also described below.

SEXUAL DIMORPHISM

A. Historical Review

The possibility that sexual dimorphism existed in ammonites has been discussed by numerous authors and this view attained the height of its popularity at the beginning of the present century, notably among French paleontologists. It then suffered a decline until the early 1960's when it was independently resurrected by two workers in Europe. Since then studies of sexual dimorphism have grown in popularity, but in application to cephalopods they have been restricted almost exclusively to Jurassic Ammonoidea. Only the major works pertaining to sexual dimorphism in ammonites are discussed in this section. Others will be mentioned later.

The first author to suggest the possibility of sexual dimorphism in ammonites was de Blainville (1840, p. 8). In a short general work de Blainville studied sexual dimorphism in recent mollusks and concluded, by analogy with the extant Nautilus, that ammonites were almost certainly bisexual. He associated the probable development and function of ovaries in ammonites with the greater convexity of the venter of the female body chamber and with the larger dimensions of the female conch. The differences of inflation of the body chamber were used to distinguish the sexes.

The first reference to an actual case of dimorphism in ammonites was by d'Orbigny (1847). He more than once utilized dimorphism to interpret the variations observed within a group of forms considered by him to be conspecific. In describing Ammonites anceps, d'Orbigny (1847, p. 462-3) distinguished two types of shells differing in inflation and ornament, the thicker-whorled forms being the ones (transl.)

"that I regard as being related to the females." It should be noted that in the light of present day knowledge concerning the morphology of the ammonite conch, d'Orbigny's suggestions, even though partially correct, are without major significance. He made the error, perpetrated by many later authors, of mistaking males for juvenile forms.

Waagen (1869), in a classical paper, made the first attempt at establishing a phylogenetic, or at least a morphogenetic, classification in an ammonite group. In his arrangement of the Middle and Upper Jurassic ammonites of the family Oppeliidae into lineages ("Formenreihen"), he found that one of the lines was represented by large forms and the other by small, "dwarf" forms with a gerontic aperture. Waagen found distinct similarities of ornamentation on early portions of the phragmocones of those pairs of large and small forms occurring in contemporaneous beds. He firmly rejected the idea that his two series were merely dimorphic forms of a single lineage, basing his conclusion on the observation that a far greater number of species existed in the line of large forms than in that of the small forms.

Reynès (1879, p. 26; written before 1867-see Donovan, 1955) made the statement (transl.) "...in making a general study of ammonites one is easily convinced that most species have two distinct forms, whenever material is sufficient. To what to attribute this difference....if not to sex?" The distinguishing features of the forms studied by Reynès were differences in sizes of similarly ornamented conchs, differences of inflation of the whorls and, in some cases, minor differences of ornamentation and sutural pattern.

Douvillé (1880) discussed sexual dimorphism in the genus Morphoceras with all dimorphic forms having identical early septate whorls.

Quenstedt (1886) commented on the simultaneous occurrence of large and small forms, differing only in size and peristome, from the Dogger of Swabia.

Munier-Chalmas (1892), working with a group of Jurassic ammonites in which the last whorl was bent back toward the phragmocone (which he termed "formes scaphitoides") discovered that they occurred with other forms which were very similar but of larger size. Munier-Chalmas considered these groups to be dimorphic and assigned them to the same species. He further stated that sexual dimorphism existed in ammonites from early Bajocian to the early Neocomian in age.

Foord and Crick (1897) were the first to discuss sexual dimorphism in goniatites.

Glangeaud (1897) was the first to suggest that the methods used in systematics to distinguish ammonite genera (i.e., the character of the suture) be discarded and that study of the adult aperture would prove more useful. He reasoned that a reduction by one-half in the present number of ammonite species would greatly simplify the systematics and remove a large number of unreliable species which were mere varieties (dimorphs). Glangeaud was also the first to propose the introduction of nomenclature with the same specific name for both forms, distinguishing male and female forms by the proper zoological symbols and respectively.

Rollier (1913) interpreted small, aberrant forms in a Jurassic ammonite fauna as males. Finding large and small forms in the same bed he interpreted these forms as conspecific sexual dimorphs.

Coemme (1917) working with "somewhat scaphitoid" upper Bajocian ammonites, based his interpretation of large and small forms as female and male respectively on analogies with respect to the sex ratio in the extant cephalopods Rossia and Octopus. He believed the rare occurrence of small forms supported the supposition that they were males since the numerical minority of males is observable in extant forms. Thus, in Loligo, males represent 15 percent of the total population, in Octopus 25 percent.

Spath (1922, 1923-43, 1933), who studied and worked on a wider range of ammonites than any other paleontologist before or after him, was aware of the theory but ignored it.

Interest in the subject apparently waned until Arkell (1952) recognized the possibility of the occurrence of sexual dimorphism in a group of Bathonian ammonites. In the Treatise on Invertebrate Paleontology Arkell (in Arkell, et al., 1957, p. L90) expressed the following opinion" ...the theory of sexual dimorphism can only be shelved as unproved, until new evidence is forthcoming."

Makowski (1962), in his already classic monograph on the problem of sexual dimorphism, seems to have brought forth the evidence Arkell was awaiting and appears to have given final proof of dimorphism in ammonites. Agreeing in principle with Reynes, Munier-Chalmas, and Rollier, he set forth guidelines for the recognition of sexual dimorphism in ammonites. These guidelines together with others are discussed in detail later. Makowski was the first to discuss dimorphism as occurring in European and North American species of the genus Scaphites. Referring to the North American species of Turonion-Campanian age he stated (p. 34) "...that the excellently preserved material of the genus Scaphites from North America is so profuse that any attempts at clearing up the problem of dimorphism in this ammonite group which ignores the North American material will be greatly handicapped."

Publishing independently of Makowski (1962), Callomon (1963) produced a landmark paper on sexual dimorphism as it pertained to Jurassic ammonites. Perhaps of equal importance to the contribution of knowledge of dimorphism was the near perfect agreement of Callomon's and Makowski's views on the subject. Callomon's work is of a more philosophical nature, whereas Makowski's is more practical.

Westermann (1964, p. 69) in a very definitive discussion of the problem of sexual dimorphism in Ammonoidea stated that "...the determination of apparent dimorphism and its consideration in taxonomy by close categorial approximation of the supposed dimorphs - mostly as subgenera - is necessary; simplification of the taxonomic system and important phylogenetical implications are evident." He suggests that the numerically superior ratio of females to males in fossil populations (between 1.6:1 to 6:1) can be explained by the behavior of some extant cephalopods where the females have been observed to segregate temporarily from the males for spawning in shallower water. Extrapolation of this behavior to ammonites may explain the general numerical disproportion or even totally separate occurrence of dimorphs.

Birkelund (1965, p. 74-75) recognized that "...pairs of species or subspecies [of <u>Scaphites</u>] occur together..." in four horizons in the Upper Cretaceous of West Greenland. She noted further that each pair was comprised of an inflated form and a more slender form. Although the material studied contained repeated associations of <u>Scaphites</u> with living chambers of different shapes, Birkelund rejected sexual dimorphism as an explanation preferring instead to place the morphologically different forms in distinct species or subspecies.

Wiedmann (1965) presented an exhaustive study of the genus, its origin, limits, and systematic position. Wiedmann's evaluation of sexual dimorphism in the genus, as reported by Makowski (1962), was that it "... seems to have more ecologic and geographic reasons ..." than biologic ones (p. 420-421). The concern here was that, in the Cenomanian of France, he found the large and small forms together. In the north of France he found only the large forms that were restricted to the boreal region of Europe while the smaller forms favored the Tethyian and Indo-Pacific areas. The occurrence of both forms in France was explained as an overlap of these two populations.

Following the abortive 23rd International Geological Congress in Prague, Czechoslovakia, 1968, a symposium entitled Sexual Dimorphism in Fossil Metazoa and Taxonomic Implications, edited by G.E.G. Westermann (1969), was published. The bulk of the material contained in the symposium and applicable to this thesis is taxonomic in scope.

Cobban (1969) was the first to document the existence of sexual dimorphism in Scaphites of the western interior of the United States, excluding Kansas. He developed methods for determining the sexes in the genus and considered the large forms of each species to be female, the small forms male.

B. The Present Position

Knowledge of ammonoid ontogeny offers the key to the recognition of sexual dimorphism. It is essential to note that ammonites did not grow indefinitely. All forms which attained a well-defined adult stage bear the markings of deceleration and final cessation of growth. Analogous to many other animals, the sexes can only be determined from examination of adult specimens. Generally recognized features used to determine maturity in ammonoids are:

1) Approximation of the final few septa ("Lobendrangung"), caused by diminished growth rates (Arkell, 1957; Makowski, 1962; Callomon, 1963; Lehmann, 1971). This feature usually appears abruptly in males in the last two to three septa. Female forms usually have this approximation spread out over the final dozen or more septa with the distance between them diminishing gradually adaperturally. Mangold and Fioroni (1966), on the basis of work on recent coleoids, concluded that cessation of growth in females is much more gradual than in males, suggesting the difference is attributable to a slower growth of the gonads.

2) Modification of sculpture near the peristome (Arkell, 1957; Makowski, 1962; Callomon, 1963; Lehmann, 1971). This feature usually manifests itself in the form of coarsening and regeneration or degeneration (approximation) of ribbing. In addition, terminal constrictions and ventral collars are indicative of maturity.

3) Marked internal thickening of the test in the immediate vicinity of the aperture, marking a constriction of the aperture (Makowski, 1962a; Westermann, 1971).

4) Abnormal shape of the living chamber, uncoiling (scaphitoid) and other modificiations (Arkell, 1957; Callomon, 1963; Cobban, 1969; Lehmann, 1971).

Application of the above criteria has convinced most workers that the majority of ammonites found as fossils are adult. In fact, faunas which contain more than a few juveniles are rare. Westermann (1954) did not find a single juvenile in a collection of "several thousand specimens" of Bajocian Otoitidae; and Brinkman (1929, p. 43) was unable to distinguish one juvenile form from among 3,000 Kosmoceras specimens. Callomon (1963) considered such assemblages as normal faunas and those which are markedly micromorphic as abnormal faunas. These abnormal faunas appear to be a reflection of a peculiar biotope (Lehmann, 1971). Callomon (1963), citing the abundance of normal faunas and the paucity of abnormal faunas, concludes ..."that ammonites normally spent an appreciable part of their lives in the adult stage..." It is, therefore, essential to determine if a fauna in question is normal or abnormal.

In many normal faunas two groups of adults are recognizable, being indistinguishable in their inner whorls and differing only in size. These large and small forms were labelled by Callomon (1955, 1963) macroconch and microconch respectively, without regard to sex. Other authors, particularly Makowski (1962), Westermann (1964, 1969), Cobban (1969), and Lehmann (1966, 1971) have regarded the large forms (macroconchs) as females and the small forms (microconchs) as males. This assumption seems to be reasonable, since in recent extant dibranchiate cephalopods - in fact in almost all recent invertebrates with pronounced sexual dimorphism - it is the female which is the larger (Westermann, 1969). In addition, Lehmann (1966) found what he considered to be a lump of eggs in the body chamber of a macroconch of the Liassic ammonite Eleganticeras and Müller (1969) found a similar structure in the body chamber of a Triassic Ceratites.

General criteria for the presence of dimorphism in cephalopods have been proposed and utilized by numerous authors. The major points of these criteria may be summarized as follows:

1) Identical initial stages of ontogeny in macroconchs and microconchs, and identity of their phylogeny (Makowski, 1962; Callomon, 1963; Westermann, 1964; Cobban, 1969; Lehmann, 1971). Makowski (1962, p. 13) asserts that this "...pre-requisite must be applied in order to eliminate cases of far advanced convergence, most commonly observable in the adult stages."

2) Lack of intermediate forms in adult stages (Makowski, 1962). This criterion is essential because the presence of intermediates among supposed males and females of an extinct form would render the theory of sexual dimorphism unacceptable or place it in a very untenable position (Makowski, 1962).

3) Presence of both forms in the same strata (Makowski, 1962; Westermann, 1964; Lehmann, 1971). This criterion is subject to considerable interpretation because the meaning of "the same strata" is not clearly defined leaving the range flexible from layers whose thickness does not exceed that of an ammonite shell to much thicker beds (Makowski, 1963). Dana (1895 p. 91) defined a stratum as a stratigraphic unit that may be composed of a number of beds. Payne (1942, p. 1724) defined stratum as a layer greater than 1 cm in thickness and constituting a part of a bed. The general description of a stratum given in the Glossary of Geology (Gary, et al., 1972) is "...a single

and distinct layer, of homogeneous or gradational sedimentary material of any thickness, usually separable from other layers above and below by a discrete change in the character of the material deposited..." It is this latter definition which is employed in this study.

4) Numerical ratio of the two supposed sexes, comparable to that observed in extant forms (Makowski, 1962). Makowski reports that the average sex ratio for a large number of extant forms is approximately 1:1 and considers this figure to be representative. Mangold-Wirz (1963) and Westermann (1969) while reporting a variable sex ratio in extant cephalopods believed the deviations to be due to sampling errors or sex segregation within the populations or both. In an investigation of sixteen species, Mangold-Wirz (1963, p. 185) observed females to outnumber males in five species, while males had a numerical superiority in two species. The nine remaining species had a sex ratio of 1:1. Mangold-Wirz favored the hypothesis that a numerical equality exists between sexes in most cephalopod species.

5) New characters of ornamentation appear in macroconchs and microconchs of a genus more or less simultaneously (Callomon, 1963; Lehmann, 1971).

These then are the criteria which have to be considered in the classification or reclassification of ammonites irrespective of past worker's views on sexual dimorphism. The following section relates these criteria of dimorphism to the genus Scaphites.

C. Sexual Dimorphism in Scaphites

The theory of sexual dimorphism has received very little attention in studies of the genus Scaphites. In fact, very few Cretaceous ammonite faunas have been investigated with regard to possible dimorphism. This is unfortunate not only because the Cretaceous is the last period in which ammonites survived, but, more importantly, because Scaphites or one of its subgenera was one of the last surviving ammonoid forms in the latest Maastrichtian.

Earlier authors, and some later ones, usually recognized the large and small forms of Scaphites as occurring together but chose to place them in separate species or considered the small forms as juveniles. A history of this treatment was included in a preceeding section. Makowski (1962, p. 31-34) was the first to imply that sexual dimorphism existed in this genus. Although he did not implicitly state that he recognized males and females, he did include the zoological symbols ♂ and ♀ in the explanations of his plate IV of Scaphites constrictus (Sowerby).

Conclusive evidence of sexual dimorphism in this genus came from Cobban (1969) who was working with two species from the late Santonian and late Campanian of the western interior of the United States, excluding Kansas. In this study, Cobban recognized that assemblages of Scaphites were characterized by the presence of two forms in almost every collection: a large form which was involute and usually possessed an umbilical swelling, and a smaller, more evolute form. In conformance with the interpretation of Makowski (1962), Cobban considered the larger form to be female and the smaller form male. In addition, changes in size and ornamentation were reported by Cobban to affect both forms simultaneously. Cobban distinguished male and female forms of the same species by the following criteria:

Criterion	Male	Female
1. whorl growth:	evolute	involute
2. size :	small	large
3. form :	slender	robust
:	no umbilical swelling	umbilical swelling
:	slightly depressed whorls	depressed whorls
4. ornamentation:	males tend to have more ventral ribs	

Possibly all species of scaphites occur in two forms (Cobban, 1969), but these have received different treatment by different authors as pointed out in previous sections.

SYSTEMATICS

A. Introduction

Preservation of the Scaphites described below ranges from complete specimens possessing the original aragonitic shell (personal communication, Dr. G. E. G. Westermann, McMaster University, Hamilton, Ontario) to incomplete individuals which require estimation of size parameters by comparison with other measurable parameters. The bulk of my collection, however, consists of well-preserved, complete living chambers. Since it has been reported by others (Morrow, 1935; Cobban, 1951, 1969), and found to be true for my collections, that the initial whorls and probably all of the phragmocone is nearly identical, the living chamber serves the same purpose as a complete specimen. The living chamber contains all the taxonomic information at the subgeneric level (Cobban, 1951). By establishing a ratio of width of the overall specimen (W) to the length of the body chamber (LC) it has been possible to arrive at reasonable estimates of the overall lengths of the specimens (L). Where this was accomplished it is so indicated by an (*) in the measurements.

Abbreviations used throughout the remainder of the thesis are listed below with a brief explanation of each symbol. The majority of these symbols and their applications are illustrated in text-figures 3 and 4.

LC - Living chamber length
c - Radius of phragmocone
d - Radius of phragmocone + living chamber
e - Height of aperture
f - Width of aperture

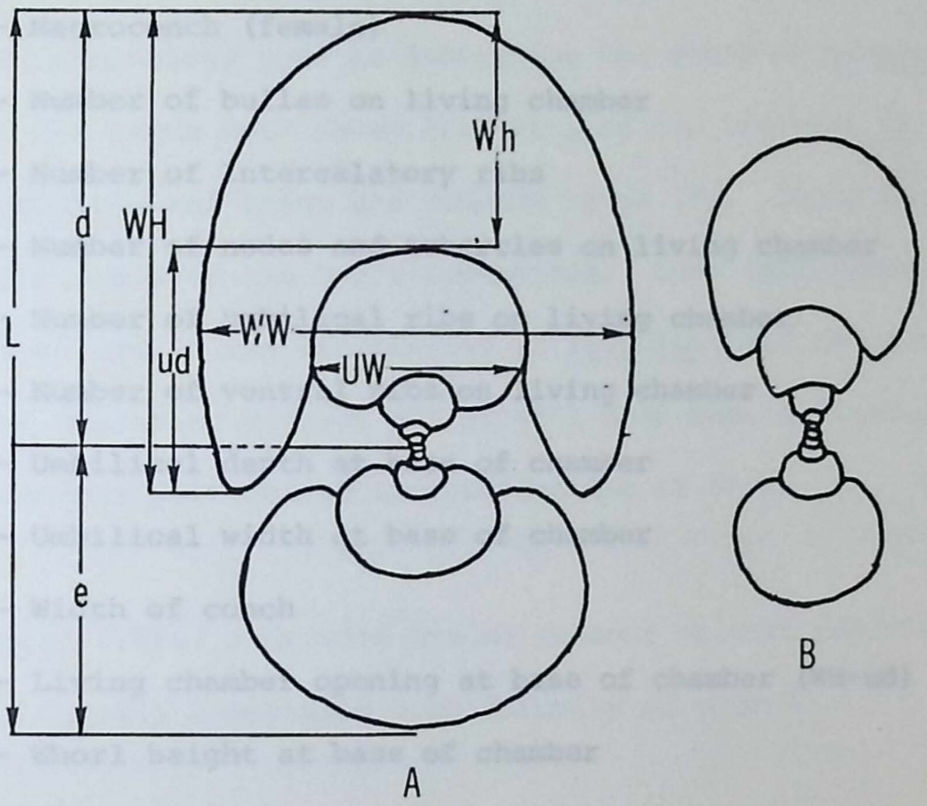

Figure 3 - Transverse sections through a typical macroconch (A) and microconch (B). Explanation of symbols on p. 28.

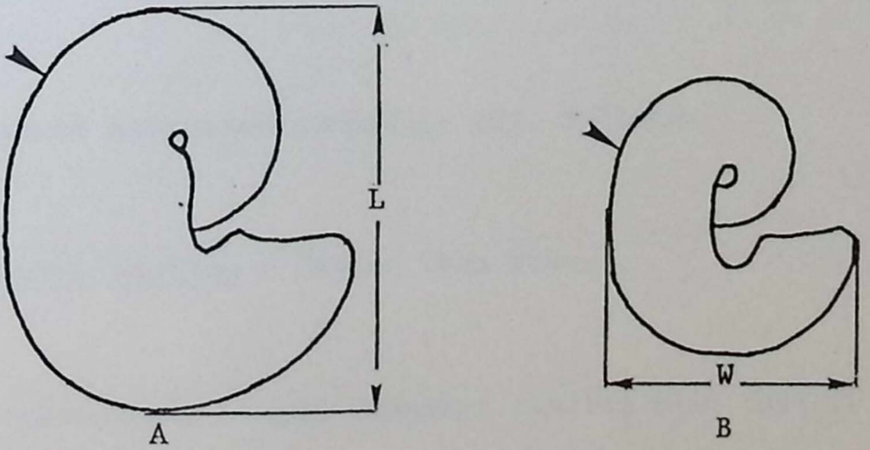

Figure 4 - Dorso-ventral illustrations of a typical macroconch (A) and microconch (B) showing involute and evolute shell form. Arrows mark the beginning of the living chamber. Explanation of (L) & (W) on p. 28.

L - Length of conch
m - Microconch (male)
M - Macroconch (female)
nB - Number of bullae on living chamber
nIR - Number of Intercalatory ribs
nN - Number of nodes and tubercles on living chamber
nUR - Number of umbilical ribs on living chamber
nVR - Number of ventral ribs on living chamber
ud - Umbilical depth at base of chamber
UW - Umbilical width at base of chamber
W - Width of conch
Wh - Living chamber opening at base of chamber (WH-ud)
WH - Whorl height at base of chamber
WW - Whorl width at base of chamber

B. Morphological Terms

A glossary of morphological terms was deemed a necessity due to the specialized terminology used in describing the conch of Scaphites. The majority of the terms were taken from Pt L of the Treatise of Invertebrate Paleontology and these are denoted by an (*). These terms are, in general, applicable to the Order Ammonoidea. Some additional terms are proposed as an aid in the description of Scaphites and are denoted by (**). Terms appearing without (*) or (**) have been defined elsewhere in the literature post-dating the publication of Pt L.

* approximated (ribs) - Crowded toward present or past position of aperture, usually associated with maturity of growth.

* biplicate ribs - Dividing into two branches toward venter.

* body chamber (living chamber - LC) - Large undivided space in shell extending adapically from aperture, inhabited by living animal.

* bulla - Tubercle elongated radially; adj. bullate.

* compressed whorl section - Higher than wide.

* contracted (peristome) - With diameter smaller than that of living chamber.

**contracted (rib) - Swung backward (adapically) at or near venter.

* <u>depressed whorl section</u> - Wider than high.

* <u>distant</u> (ribs) - Widely spaced.

* <u>intercalatory rib</u> (IR) - Ventral rib not attached to umbilical rib, bulla or node.

* <u>interspace</u> - Area between adjacent ribs, nodes or bullae.

<u>lateral flanks</u> - The convex or flat area between dorsolateral and ventrolateral margins of the conch.

<u>living chamber</u> (LC) - see body chamber.

<u>macroconch</u> (M) - female designation; large involute partner of dimorphic pair.

<u>microconch</u> (m) - male designation; small evolute partner of dimorphic pair.

* <u>node</u> - Tubercle circular-subcircular; usually blunt.

* <u>peristome</u> - Edge of aperture of living chamber; mouth border.

**<u>point of recurvature</u> - Apex of recurvature of the living chamber.

* <u>projected</u> (rib) - Swung forward (adaperturally) at or near venter.

* prorsiradiate (rib) - With general forward (adapertural) inclination from umbilical side toward venter.

* rectiradiate (rib) - In straight radial position, bending neither forward nor backward.

* rursiradiate (rib) - Inclined backward (adapically) proceeding from umbilical area toward venter.

scaphitoid living chamber - Heteromorphic living chamber recurved toward phragmocone; peristome nearly in contact with earlier whorls.

shaft - Portion of living chamber extending from the base to the beginning of recurvature.

* simple ribs - Unbranched.

* triplicate - Dividing into three branches toward venter.

* umbilical area - Inner part of whorl on each side, separating umbilical shoulder from umbilical seam.

* umbilical rib (UR) - Main stem or simple inward part of a branched rib never extending beyond the ventrolateral margin.

* umbilical seam - Helical line of overlap of successive whorls, comprising "line of involution".

* umbilical shoulder - Generally blunt angle between whorl side and umbilical area.

* ventral rib (VR) - Outer part of branched rib; originating at ventrolateral margins and extending across venter.

C. Major Morphological Features

The ten major morphological categories listed below contain twenty-seven morphological characters used in this study to describe and distinguish species of Scaphites. Each species described below has, as a formula, a unique combination of one character taken from each of these ten major categories. Figure 12 gives a graphic representation of the uniqueness of these combinations as well as those characters shared between species. It is important to note that Figure 12 lists thirty-six characters in R-mode. Twenty-seven of these are those mentioned above and listed below in this section, eight are dimorphic characters described in the following section, and the remaining one is the character necessary to balance the binary coding of the nominal data set (Tables I & V).

1. Living chamber loosely or tightly recurved.
2. Shaft of the living chamber slightly or well curved.
3. Umbilical ribs slightly, moderately, or greatly pronounced.
4. Umbilical ribs rursiradiate or rectiradiate.
5. Ventral and intercalatory ribs straight, projected, or straight and then projected adaperturally.
6. Ventral and intercalatory ribs distantly equispaced to the point or recurvature then approximated adaperturally, moderately equispaced to the point of recurvature then approximated adaperturally, closedly equispaced then approximated adaperturally, or approximated adaperturally over the length of the living chamber.

7. Living chamber without bullae, with greatly pronounced bullae, or moderately pronounced bullae.
8. Living chamber with very distantly spaced bullae, moderately spaced bullae, or normally spaced bullae.
9. Living chamber without nodes, with nodes or a combination of nodes and bullae.
10. Aperture which is normal* for the genus or depressed.

*Note - a normal aperture is defined for this study as one which has a height equal or nearly equal to its width.

D. Dimorphic Characters

Dimorphic characteristics pertaining to size, form, and sculpture used in the distinction of sexes will be summarized here to avoid repetition in the systematic descriptions.

Size: Each grouping of specimens of a particular species shows a distinguishable range in size of forms classed as males and females. The range in size is such that a few of the largest males are larger than the smallest females (Fig. 10 & 11). Cobban (1969) reported such an overlap in the size range. As weighed against other evidence of dimorphism such as slight overlap does not seem significant.

The ratio of the lengths of the largest and smallest adults of each sex within each species is commonly from 1:1.3 to 1:1.5. Few individuals of extraordinarily large or small size were found to exist. For incomplete or damaged specimens estimates of their original sizes were based on known ratios of existing characters. Ratios of sizes of large and small adults of species of the same sex have been reported as ranging from 1:4 to 1:1.5 for Scaphites from beds of Turonian, Coniacian, and Santonian age (Cobban, 1951, 1969).

Within the sexes the size of the whorls is subject to considerable variation. Where preserved, the protoconch and initial one to two whorls are nearly identical in all specimens, but subsequent whorls vary greatly in size. Males remain slender while females have a tendency toward robustness.

Form: The forms herein designated male and female both have a wide umbilicus at the base of the living chamber relative to their overall size. At that point, the distinction between the sexes is based on the depth of the umbilicus. The shells of females, known to be involute, have a deep umbilicus relative to their whorl height (WH) (see Fig. 3). The macroconchs have a more inflated living chamber than the microconchs and have a tendency to possess an umbilical swelling at the base of that chamber. The macroconch has a more robust form in comparison to the less robust or slender form of the microconch (Fig. 4). In addition, phragmocones of macroconchs, with the exception of the innermost whorls, are more depressed than those of the microconchs (Fig. 3).

Ornamentation: The macroconchs and microconchs of each species described in this thesis have the same general ornamental features. All specimens possess umbilical, ventral, and intercalatory ribs on the phragmocone and living chamber. Scaphites kansiensis Crick, n. sp., possesses both umbilical and ventrolateral nodes, others possess either ventrolateral nodes or bullae, S. hattini Crick, n. sp., possesses both ventrolateral nodes and bullae, and still others possess no nodes or bullae. Macroconchs differ from microconchs mainly in the number of nodes, bullae, or ribs on the body chamber although exceptions occur.

Umbilical ribs crossing the umbilical shoulder are either rectiradiate or rursiradiate. At or before approaching the ventrolateral margin the umbilical ribs may develop into biplicate or triplicate nodes or bullae. In some species the umbilical ribs do not carry nodes or bullae, but remain simple, biplicate or triplicate, becoming ventral ribs at the V-L margin. Nodes and bullae always produce at least two, but not more than three, ventral ribs. Situated between the ventral ribs are the intercalatory ribs which appear to be randomly interspersed without formula. Excepting S. kansiensis Crick, n. sp., all nodes and bullae begin at the base of the living chamber. In some species the nodes or bullae are developed all the way to the aperture, but in the majority of the species nodes or bullae terminate at the point of recurvature.

Orientation of ventral and intercalatory ribs is often quite distinctive between species. These ribs may be contracted on early portions of the body chamber changing to straight ribs toward the point of recurvature, then straight or projected adaperturally, or they may be initially straight to the point of recurvature then either straight or projected beyond this point to the aperture. This orientation does not assist in determining sexes but it does in distinguishing species. Macroconchs and microconchs of the same species must have the same ornamental patterns.

Adult and gerontic features: The importance of determining if a specimen is a true adult has been covered in a previous section. Cobban (1951, 1969) considered a scaphite to be mature when the living chamber is scaphitoid. In the collections studied by me, three juvenile Scaphites were discovered within living chambers of macroconchs. The length of the living chamber of a juvenile is three-fourths of a whorl and is decidedly not scaphitoid. In addition, all complete specimens were sectioned longitudinally to assure that approximation of septa and sutures did occur. All were found to be adults. Two questionable immature forms occur in the collections but the living chambers are not preserved.

A summation of criteria useful in the recognition of dimorphism in Scaphites leads to the following conclusions. Individuals occuring in the same stratum, bearing near identical ornamentation and exhibiting a definite grouping by size into two groups are considered dimorphic pairs of the same species.

The criteria for recognition of sexes (macroconch vs microconch) may be summarized as follows. Sexes within a dimorphic pair of the same species (criteria may also be applied if just one member of the pair is available) may be distingushed by a robust conch in the female and a slender conch in the male; females are invariably involute while males are invariably evolute; females possess an umbilical swelling at, and slightly adaperturally of, the base of the living chamber, which males do not have; females typically have a more depressed living chamber than males; females have a wide and deep umbilicus at the base of the body chamber, males a wide but shallow umbilicus; and females tend to exhibit a more prolonged approximation of septa and sutures as they approach the adult stage, while males tend to have rapid approximation in the last two to three septa.

The eight dimorphic characters chosen for this study are listed below in four major categories (M = macroconch; m = microconch). The eight characters are listed in Fig. 12 as numbers 21 through 28, in Table I as numbers 29 through 36, and in Table V as the last eight columns (or rows). Figure 12 lists the dimorphic characters in with the other characters due to the reordering of the original sequence by computational methods discussed in the Data Analysis section.

1. Specimen robust (M) or slender (m)
2. Specimen involute (M) or evolute(m).
3. The umbilicus swollen at the base of the living chamber (M) or not swollen (m)
4. The umbilicus deep at the base of the living chamber (M) or shallow (m).

E. Descriptions

Phylum MOLLUSCA
Class CEPHALOPODA Cuvier, 1798
Order AMMONOIDEA Agassiz, 1847
Suborder LYTOCERATINA Hyatt, 1889
Superfamily *SCAPHITACEAE* Meek, 1876
Family *SCAPHITIDAE* Meek, 1876
Subfamily *SCAPHITINAE* Meek, 1876
Genus *SCAPHITES* Parkinson, 1811

Type species: - *Scaphites equalis* Sowerby, 1813; by subsequent designation Meek, 1876] [*Anascaphites*, *Jahnnites* Hyatt, in von Zittel, 1900 (= Jahnites Hyatt in von Zittel and Eastman, 1913; *nom*. *van*.); *Yezoites* Yabe, 1910; *Holcoscaphites* Nowak, 1912 (obj.)]. Compressed to very inflated, more or less involute shells; early whorls invariably in contact; shaft short or moderately long, hook not curved over camerate whorls; aperture constricted and commonly collared, in some shells with long dorsal lappet; ribs normally branching or intercalated on coiled part, commonly single or joining at ventrolateral tubercles on shaft; umbilical and normally ventrolateral tubercles present on shaft; umbilical and normally ventrolateral tubercles present on shaft or hook. Suture ceases to be regularly lytoceratid in geologically younger species.

Scaphites has worldwide distribution in rocks of late Albian to Maastrichtian age (Cobban & Scott, 1972, p. 56).

The assignment of the following species to the genus *Scaphites* is based on the presence of scaphitoid living chambers, nature of the ribbing, and the general overall similarity to Scaphites equalis Sowerby (see Arkell, 1957, p. L228, figs. 256 3a-b).

The variability of sutures within individuals, making comparisons within and between species impractical, accounts for the absence of a sutural investigation in this study. The general habit of the sutural pattern of the species described below is that of the Turonian species Scaphites nigriocollensis Cobban, 1951, and can be described as less than lytoceratid in complexity. For a detailed account of the sutural pattern and its development in Scaphites see Wiedmann (1966, p. 444-450, and especially his text-fig. 14).

In the following descriptions the most complete and representative specimen of each new species is designated as the holotype, described and illustrated. The remaining specimens assigned to a species are paratypes of that species.

The repository for this collection is the Museum of Invertebrate Paleontology, the University of Kansas, herein designated UKMIP.

Scaphites arcadiensis (M) Moreman

Plate II, figures 1 & 2

1942. Scaphites arcadiensis Moreman, Jour. Paleontology, v. 16, no. 2, p. 216, pl. 34, fig. 3.

1951. Scaphites arcadiensis Moreman. Cobban, U.S. Geol. Survey Prof. Paper 239, p. 21, pl. 2, figs. 1-8.

1952. Scaphites warreni Meek and Hayden. Hattin, unpublished master's thesis, Univ. Kansas, p. 65, pl. 5, figs. 12, 13.

1962. Scaphites carlilensis Morrow. Hattin, Kansas Geol. Survey Bull. 156, p. 79, pl. 23, figs. B-D, G, H.

Moreman's original description contains terminology unlike that used in this thesis. In an attempt to retain continuity of style S. arcadiensis is redescribed below.

DIAGNOSIS: Conch robust and involute with depressed subovate whorl section. Venter broad and rounded, lateral flanks short, very convex, and rounded, umbilical shoulders rounded and well marked initially, weakly marked adaperturally, umbilicus wide, deep and swollen at base of living chamber.

Four specimens in the collection are macroconchs assigned to this species: UKMIP 108765, 108767, 108768, 108769.

MEASUREMENTS: See Table I.

DESCRIPTION: Specimen UKMIP 108765 is incomplete, consisting of a scaphitoid living chamber loosely recurved with well-curved shaft, expanding to the point of recurvature then tapering adaperturally. Ornamentation on the living chamber consists of umbilical, ventral, and intercalatory ribs and ventrolateral bullae. Umbilical ribs are moderately pronounced and rursiradiate crossing the umbilical shoulder gradually swelling into greatly pronounced and distant equispaced slightly prorsiradiate biplicate bullae. The bullae terminate adaperturally of the point of recurvature. Umbilical ribs adapertural of this point are simple and biplicate. Ventral and intercalatory ribs equispaced and straight to the point of recurvature becoming projected and approximated adaperturally. Aperture slightly depressed and arched ventrally.

Scaphites arcadiensis (m) Moreman

Plate II, figure 3-6

DIAGNOSIS: Conch slender and evolute with slightly depressed ovate whorl section. Venter broad, lateral flanks short, very convex, and rounded, umbilical shoulders rounded and well marked initially, weakly marked adaperturally, umbilicus wide and shallow at base of living chamber with no swelling.

Three specimens in the collection are microconchs assigned to this species: UKMIP 108766, 108772, 108773.

MEASUREMENTS: See Table I

DESCRIPTION: The microconch has the same features of ornamentation and morphology as the macroconch, differing only by characters associated with dimorphism and by size.

DISCUSSION

Taxonomically significant characters of this type, exclusive of dimorphic characters, are: living chamber - scaphitoid with subovate-ovate cross section, loosely recurved with a well-curved shaft expanding to the point of recurvature, then tapering adaperturally. Lateral flanks are short and very convex. Umbilical ribs are rursiradiate at the shoulder developing into greatly pronounced and distant equispaced slightly prorsiradiate biplicate bullae terminating at the point of recurvature. Ventral and intercalatory ribs are equispaced and contracted to the point of recurvature becoming projected and approximated adaperturally.

The above described dimorphic pair is indistinguishable from the holotype of Scaphites arcadiensis Moreman and is placed in that species. The combination of short and very convex lateral flanks and greatly pronounced, distant, equispaced, slightly prorsiradiate, and biplicate bullae terminating at the point of recurvature serves to distinguish S. arcadiensis from other species of Scaphites.

The comparison and correlation of morphological characteristics shared by Scaphites arcadiensis and the five other species described below will be in the following format. The numbers in parentheses immediately following the related species refer to those shared characters found in Figure 12 and explained there. Each character is further discussed in Section C, Major Morphological Features.

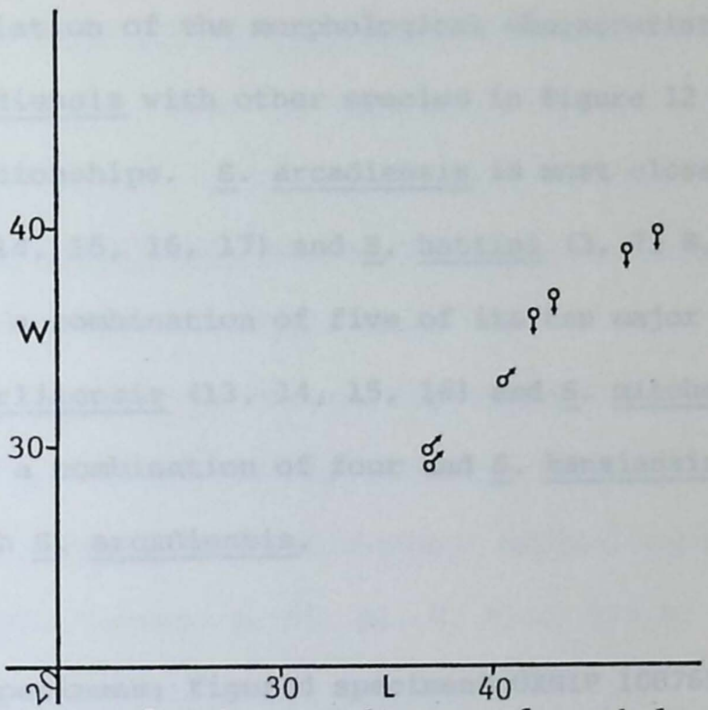

Figure 5 - Scatter diagram of conch length (L) and width (W) of *Scaphites arcadiensis*. Seven specimens are represented.

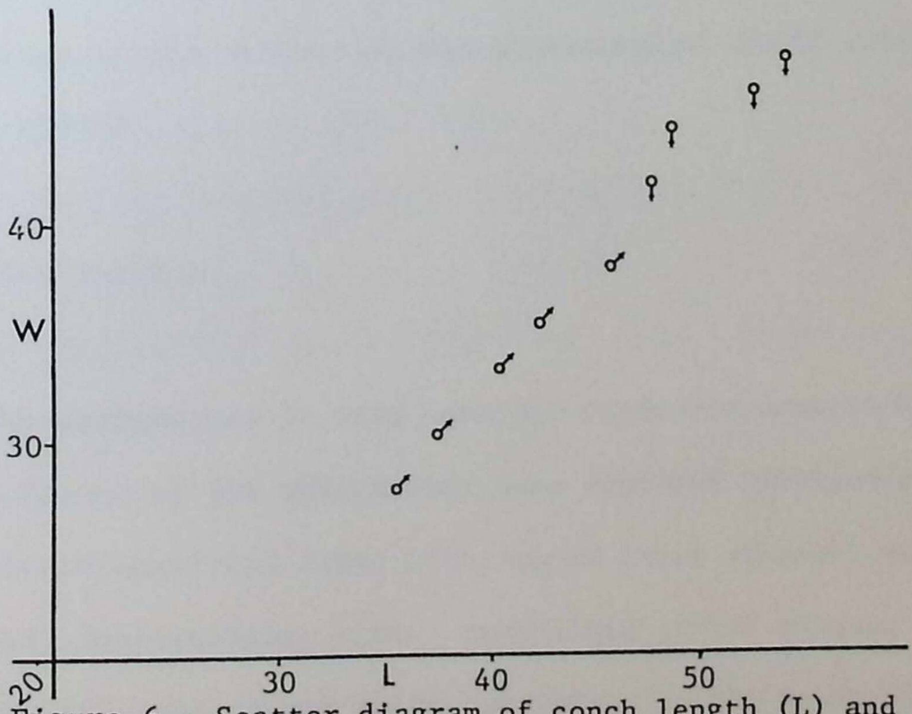

Figure 6 - Scatter diagram of conch length (L) and width (W) of *Scaphites carlilensis*. Nine specimens are represented.

The correlation of the morphological characteristics shared by Scaphites arcadiensis with other species in Figure 12 suggests the following relationships. S. arcadiensis is most closely related to S. inflexus (13, 14, 15, 16, 17) and S. hattini (3, 7, 8, 15, 17) based on the sharing of a combination of five of its ten major morphologic characters. S. carlilensis (13, 14, 15, 16) and S. mitchellensis (1, 2, 3, 16) each share a combination of four and S. kansiensis (1, 13, 14) three characters with S. arcadiensis.

MATERIAL: 7 specimens; figured specimens UKMIP 108765, 108772.

OCCURRENCE: Macroconch UKMIP 108765, in a calcareous shale nodule 35m below the top of the member, Locality 1; microconch UKMIP 108772, directly from the shale 36m below top of the member, locality 9.

Scaphites carlilensis (M) Morrow

Plate I, figure 1-5

1935. *Scaphites carlilensis* Morrow, Jour. Paleontology, vol. 9, no. 6, p. 466, pl. 50, figs. 4a-d.

1951. *Scaphites carlilensis* Morrow. Cobban, U.S. Geol. Survey Prof. Paper 239, p. 21, pl. 2, figs. 9-23.

1952. *Scaphites warreni* Meek and Hayden. Hattin, unpublished master's thesis, Univ. Kansas, p. 65, pl. 5, Figs. 1-3,5.

DIAGNOSIS: Conch robust and involute with depressed subovate whorl section. Venter broad and well-rounded, lateral flanks convex and well-rounded, umbilical shoulders rounded and well-marked, umbilicus wide, deep and swollen at base of living chamber.

Four specimens in the collection are macroconchs: UKMIP 108774, 108778, 108779, 108781.

MEASUREMENTS: See Table I.

DESCRIPTION: The phragmocone is very involute producing a markedly deep umbilicus. The flanks of the phragmocone bear distinct rectiradiate simple and biplicate umbilical ribs. The venter bears straight equi-spaced ventral and intercalatory ribs. Scaphitoid living chamber tightly recurved with well curved shaft, expanding to the point of recurvature then tapering adaperturally. Ornamentation on the living chamber consists of umbilical, ventral, and intercalatory ribs and ventrolateral bullae. Umbilical ribs are moderately pronounced and slightly prorsiradiate crossing the umbilical shoulder swelling into moderately pronounced normally equispaced and approximated prorsiradrate biplicate ventrolateral bullae. Adaperturally of the point of recurvature bullae are nonexistent and the umbilical ribs simple and biplicate. The moderately pronounced ventral and intercalatory ribs are straight and equispaced to the point of recurvature remaining straight after this point but approximated adaperturally. Aperture normal with highly arched but rounded ventrally peristome.

<u>Scaphites</u> <u>carlilensis</u> (m) Morrow

Plate 1, figures 6-11

1935. <u>Scaphites</u> <u>pygmaeus</u> Morrow, Jour. Paleontology, vol. 9, no. 6, p. 465, pl. 50, Figs. 2a-e,3.

1942. <u>Scaphites</u> <u>pygmaeus</u> Morrow, Moreman, Jour. Paleontology, vol. 16, no. 2, p. 216, pl. 34, Figs. 5,6.

1949. <u>Scaphites</u> <u>morrowi</u> Jeletzky, Jour. Paleontology, vol. 23, no. 3, p. 330.

1951. <u>Scaphites</u> <u>morrowi</u> Jeletzky. Cobban, U.S. Geol. Survey Prof. Paper 239, p. 21.

1952. <u>Scaphites</u> warreni Meek and Hayden. Hattin, unpublished master's thesis, Univ. Kansas, p. 65, pl. 5, fig. 4.

DIAGNOSIS: Conch slender and evolute with slightly depressed ovate whorl section. Venter rounded and disproportionately narrower than macroconch, lateral flanks convex and well rounded, umbilical shoulder round and well marked initially, weakly marked adaperturally, umbilicus wide and shallow at base of living chamber with no swelling.

Five specimens in the collection are microconchs assigned to this species: UKMIP 108775, 108776, 108777, 108780, 108782.

MEASUREMENTS: See Table I.

DESCRIPTION: The phragmocone is slightly evolute with a shallow umbilicus. The microconch has the same features of ornamentation and morphology as the macroconch, differeing only by characters associated with dimorphism and by size.

DISCUSSION

Taxonomically significant characters, exclusive of dimorphic characters, are: living chamber - scaphitoid with subovate to ovate cross section, tightly recurved with a well curved shaft and expansion to point of recurvature with taper to aperture. Umbilical ribs swell into moderately pronounced equispaced and approximated biplicate ventrolateral bullae. Bullae are not developed adaperturally of the point of recurvature. Ventral and intercalatory ribs straight, becoming approximated adaperturally of the point of recurvature. Aperture normal with peristome highly arched and rounded ventrally.

Scaphites carlilensis is distinguishable from other species of Scaphites by the combination of the above-mentioned taxonomically significant characters. Of these, the most distinctive are the moderately pronounced normally equispaced biplicate and ventrolateral bullae being somewhat approximated near the point of recurvature. Adapertural of this point the bullae are non-existent.

The correlation of the morphological characteristics shared by *Scaphites carlilensis* with other species in Figure 12 suggests the following relationships. *Scaphites carlilensis* is most closely related to *S. inflexus* (11, 12, 13, 14, 15, 16) based on the sharing of a combination of six of its ten major morphologic characters. *Scaphites arcadiensis* (13, 14, 15, 16) and *S. mitchellensis* (16, 29, 30, 31) each share four and *S. hattini* (11, 15) and *S. kansiensis* (13, 14) each share two characters with *S. carlilensis*.

The designation herein of forms previously assigned to *Scaphites morrowi* as microconchs of *S. carlilensis* is valid because these forms are indistinguishable from *S. carlilensis* (M) except in size. Application of dimorphic criteria readily indicates that the forms previously identified as *S. morrowi* are microconchs of *S. carlilensis*. Morrow (1935, p. 466), in his remarks pertaining to *Scaphites morrowi* (*pygmaeus*), stated "*Scaphites pygmaeus* and *S. carlilensis* are very much alike in many details, the principal difference being in the size."

Figure 6 represents intraspecific variations in conch size and living chamber length of macroconchs and microconchs. The lack of a convincing break between (M) and (m) and the linearity of (m) in Fig. 6 are thought to be an artifact of the scale of the figure (cf. Fig. 11A).

MATERIAL: 9 specimens; figured specimens UKMIP 108774, 108775, 108780.

OCCURRENCE: Macroconch UKMIP 108774 in a calcareous shale nodule 35m below top of member; locality 1; Microconch UKMIP 108780 in a calcareous septarian concretion 35.5m below base of member, locality 1.

Scaphites *hattini* (M) Crick, n. sp.

Plate II, figures 7-12

DIAGNOSIS: Conch robust and involute with depressed subovate whorl section. Venter broad and rounded, lateral flanks short, very convex and well rounded, umbilical shoulders rounded and well marked, umbilicus wide, deep and swollen at base of living chamber.

Two specimens in the collection are macroconchs assigned to this species: UKMIP 108807, 108809.

MEASUREMENTS: Table I

DESCRIPTION: The flanks of the phragmocone bear distinct rectiradiate simple and biplicate umbilical ribs. The venter bears straight equispaced ventral and intercalatory ribs. Scaphitoid living chamber tightly recurved with slightly curved shaft, expanding to the point of recurvature then tapering adaperturally. Ornamentation of the living chamber consists of umbilical, ventral and intercalatory ribs, and ventrolateral nodes and bullae. Umbilical ribs are moderately pronounced and rursiradiate crossing the umbilical shoulder, rapidly swelling into greatly pronounced prorsiradiate and biplicate bullae and moderately pronounced rectiradiate biplicate and triplicate nodes. The first five or six umbilical ribs develop into very distant bullae and the remaining three develop into three approximated nodes. Ventral and intercalatory ribs straight and distant to the point of recurvature becoming slightly projected and approximated adaperturally. Aperture depressed and highly arched ventrally.

Scaphites hattini (m) Crick, n. sp.

Plate II, figures 13-18

DIAGNOSIS: Conch slender and evolute with slightly depressed ovate whorl section. Venter broad for the overall size and rounded, lateral flanks convex and well rounded, umbilical shoulders rounded and well marked initially, weakly marked adaperturally, umbilicus wide and shallow at base of living chamber with no swelling.

Four specimens in the collection are microconchs assigned to this species: 108808, 108810, 108811, 108812.

MEASUREMENTS: See Table I

DESCRIPTION: The microconch has the same features of ornamentation and morphology as the macroconch, differing only by characters associated with dimorphism and by size.

DISCUSSION

Taxonomically significant characters, exclusive of dimorphic characters are: living chamber - scaphitoid with subovate to ovate cross section, tightly recurved with a slightly curved shaft expanding to the point of recurvature then tapering adaperturally. Umbilical ribs are rursiradiate over the shoulder swelling rapidly into greatly pronounced and very distant prorsiradiate biplicate bullae from the base of the living chamber to the point of recurvature. Adaperturally of this point the umbilical ribs swell into moderately pronounced and approximated nodes. Morphology of the bullae differs from others in the collection by approaching that of nodes. Ventral and intercalatory ribs are initially straight and distant from the base of the living chamber to the point of recurvature becoming slightly projected and approximated adapertural of this point.

Scaphites hattini differs from other species of Scaphites by possessing the combination of a tightly recurved living chamber, a slightly curved shaft, initial rursiradiate umbilical ribs, and the presence of both ventrolateral bullae and nodes. This type bears a strong resemblence to S. arcadiensis Moreman (Moreman, 1942, p. 216, pl. 34, Fig. 3). Although differing in size (Moreman's illustrated specimen is a male) S. arcadiensis has more distant and fewer umbilical and ventral ribs, and a lack of nodes (Moreman's nodes are tubercles) while tubercles are present. Moreman does not mention the existence of intercalatory ribs on the holotype but in the illustration they appear to exist.

The correlation of the morphological characteristics shared by Scaphites hattini with other species in Figure 12 suggests the following relationships. S. hattini is most closely related to S. arcadiensis (3, 7, 8, 15, 17) based on the sharing of a combination of five of its ten major taxonomic characters. S. inflexus (11, 15, 17) and S. mitchellensis (3, 4, 5) each share three; S. carlilensis, (11, 15) two; and S. kansiensis, no character(s) with S. hattini.

Figure 7 illustrates intraspecific variations in conch size and living chamber length of macroconchs and microconchs.

ETYMOLOGY: The species is named after Dr. Donald E. Hattin, of the University of Illinois, who has for many years contributed much to the understanding of the Cretaceous strata and fauna of Kansas.

MATERIAL: 6 specimens; figured specimens, holotype UKMIP 108807, paratypes UKMIP 108811, unfigured paratypes UKMIP 108808, 108809, 108810, 108812.

OCCURRENCE: Macroconch UKMIP 108807 and microconch UKMIP 108811 in calcareous shale nodules 35m below the top of the Member, locality 9.

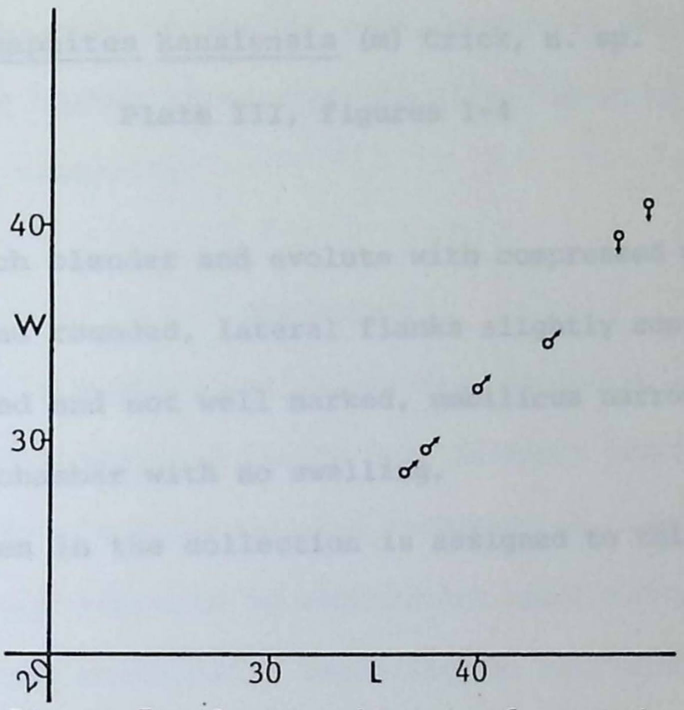

Figure 7 - Scatter diagram of conch length (L) and width (W) of *Scaphites hattini*, *n. sp.* Six specimens are represented.

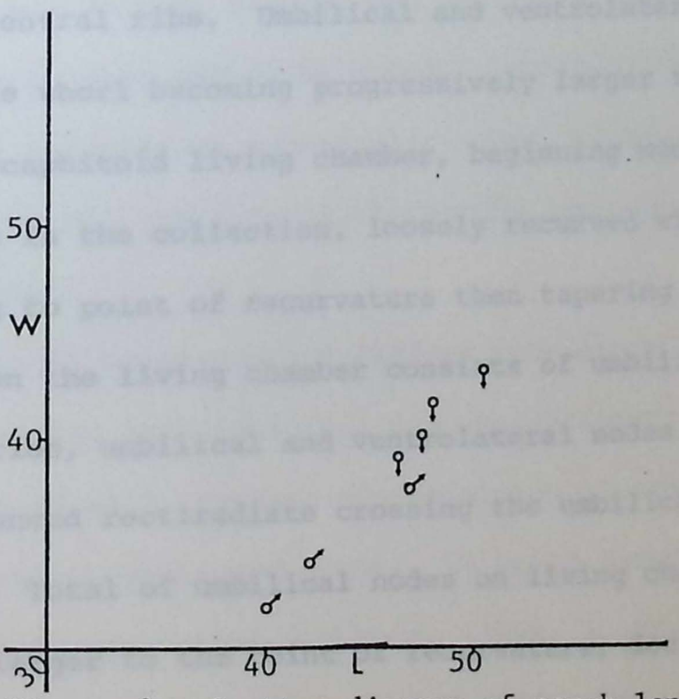

Figure 8 - Scatter diagram of conch length (L) and width (W) of *Scaphites mitchellensis*, *n. sp.* Seven specimens are represented.

Scaphites kansiensis (m) Crick, n. sp.

Plate III, figures 1-4

DIAGNOSIS: Conch slender and evolute with compressed whorl section. Venter narrow and rounded, lateral flanks slightly convex, umbilical shoulders rounded and not well marked, umbilicus narrow and shallow at base of living chamber with no swelling.

One specimen in the collection is assigned to this species: UKMIP 108770.

MEASUREMENTS: See Table I

DESCRIPTION: The flanks and venter of the phragmocone bear distinct umbilical and ventral ribs. Umbilical and ventrolateral nodes begin on the last septate whorl becoming progressively larger toward the living chamber. The scaphitoid living chamber, beginning much earlier than in other scaphites in the collection, loosely recurved with well-curved shaft expanding to point of recurvature then tapering adaperturally. Ornamentation on the living chamber consists of umbilical, ventral, and intercalatory ribs, umbilical and ventrolateral nodes. Umbilical ribs slightly pronounced rectiradiate crossing the umbilical shoulder than prorsiradiate. Total of umbilical nodes on living chamber becoming progressively larger to the point of recurvature, declining adaperturally. Circular-subcircular ventrolateral nodes, numbering six on the living chamber, also become progressively larger to the point of recurvature, declining adaperturally. The ventral ribs rise from the ventrolateral nodes, as many as six per node, projected as they cross the venter, becoming approximated adaperturally. Aperture, normal, thickened dorsally and ventrally.

DISCUSSION

Taxonomically significant characters, exclusive of dimorphic characters, are: phragmocone - flanks bear distinct adapically arched umbilical ribs at the shoulder then rectiradiate, simple and biplicate umbilical ribs and circular to subcircular umbilical nodes (nodes only on final one-third volution). Ventrolateral margin bears very distinct circular to subcircular nodes, again only on final one-third volution. Venter bears distinct and straight ventral and intercalatory ribs; living chamber -flanks bear distinct rectiradiate at the shoulder, then prorsiradiate, equispaced, simple, and biplicate umbilical ribs and circular to subcircular umbilical nodes. Ventrolateral margin bears very pronounced circular to subcircular nodes. Venter bears distinct and projected ventral and intercalatory ribs approximated adaperturally. Aperture is normal.

The species is monotypic and differs from other species of *Scaphites* by possessing both umbilical and ventrolateral nodes, uniquely on the phragmocone as well, extreme approximation of ribbing on the living chamber, and highly compressed conch. It bears resemblance to *Trachyscaphites praespiniger* Cobban and Scott (1964, p. E11, pl. 4, Fig. 1-13) especially in regard to the ribbing, but differs from that species by having fewer rows of nodes and a more compressed conch. *T. praespiniger* is Campanian in age. *Scaphites kansiensis* is as densely ribbed as *S. hippocrepis* Dekay (1927, pl. 5, Fig. 5) but differs by having a ribbed flank, umbilical and ventrolateral nodes on the living chamber, and a quadrangular cross section. *S. kansiensis* differs from *Acanthoscaphites reesidei* Wade (1926, p. 184, pl. 61, Fig. 3-7) in having umbilical nodes on the phragmocone whorl and a more quadrangular cross section.

The correlation of the morphological characteristics shared by *Scaphites kansiensis* with other species in Figure 12 suggest that this form does not bear a strong resemblence to other species in the collection. *S. inflexus* (13, 14, 19, 20) shares four; *S. arcadiensis* (1, 13, 14), three; *S. carlilensis* (13, 14) and *S. mitchellensis* (1, 6) each, two; and *S. hattini*, no character(s) with *S. kansiensis*.

ETYMOLOGY: The species name is derived from the State of Kansas where it is found.

MATERIAL: One specimen; figured specimen holotype UKMIP 108770.

OCCURRENCE: Microconch UKMIP 108770 calcareous shale concretion, 34m below top of the member, locality 1.

Scaphites _mitchellensis_ (M) Crick, n. sp.

Plate III, figures 5-9

DIAGNOSIS: Conch robust and involute with depressed subovate whorl section. Venter broad and rounded, lateral flanks convex and rounded, umbilical shoulders rounded and well marked, umbilicus wide, deep and swollen at base of living chamber.

Four specimens in the collection are macroconchs assigned to this species: UKMIP 108783, 108784, 108785, 108786.

MEASUREMENTS: See Table 1

DESCRIPTION: The phragmocone is very involute producing a markedly deep umbilicus at the base of the living chamber. The flanks of the septate whorls bear distinct rectiradiate simple and biplicate umbilical ribs. The venter bears straight equispaced ventral and intercalatory ribs. Scaphitoid living chamber loosely recurved, with slightly curved shaft and no expansion. Tapering occurs adaperturally of the point of recurvature. Ornamentation on the living chamber consists of umbilical, ventral and intercalatory ribs and moderately pronounced ventrolateral bullae. Umbilical ribs moderately pronounced and rectiradiate crossing the umbilical shoulder, the first nine rapidly swell into moderately pronounced blunt but stout and elongate, slightly prorsiradiate, biplicate bullae. The bullae are moderately distant and equispaced to the point of recurvature becoming approximated adaperturally. Ventral and intercalatory ribs are straight and equispaced to the point of recurvature remaining straight but approximated adaperturally of this point. Apertures are crushed on holotype and paratype. The aperture does, however, appear to be depressed.

Scaphites mitchellensis (m) Crick, n. sp.

Plate III, figures 10 & 11

DIAGNOSIS: Conch slender and evolute with slightly depressed ovate whorl section. Venter proportional for size and rounded, lateral flanks convex and rounded and well marked initially, weakly marked adaperturally, umbilicus wide and shallow at base of living chamber with no swelling.

Three specimens in the collection are microconchs assigned to this species: UKMIP 108787, 108788, 108789.

MEASUREMENTS: See Table I

DESCRIPTION: Microconchs have the same features of ornamentation and morphology, differing only by characters associated with dimorphism and by size.

DISCUSSION

Taxonomically significant characters, exclusive of dimorphic characters, are: living chamber - scaphitoid with subovate-ovate cross-section, loosely recurved with a curved shaft and no expansion. Lateral flanks are convex and well rounded bearing rectiradiate umbilical ribs over the shoulder and greatly pronounced, blunt, stout, and slightly prorsiradiate, biplicate, ventrolateral bullae. Ventral and intercalatory ribs are straight and equispaced to the point of recurvature, remaining straight but approximated adaperturally of that point adorally. Morphology of the aperture is uncertain.

Scaphites mitchellensis is distinguishable from other *Scaphites* by possessing the combination of a loosely recurved chamber, curved shaft, rectiradiate umbilical ribs over the shoulder, and greatly pronounced blunt, stout, and slightly prorsiradiate, biplicate, ventrolateral bullae. This latter feature is the most distinctive (Fig. 12).

The correlation of the morphological characteristics shared of *Scaphites mitchellensis* with other species in Figure 12 suggests the following relationships. *S. mitchellensis* is most closely related to *S. arcadiensis* (1, 2, 3, 16) and *S. carlilensis* (16, 29, 30, 31) based on the sharing of a combination of four of its ten major taxonomic characters. *S. hattini* (3, 4, 5) shares three and *S. kansiensis* (1, 6) shares two characters, and *S. inflexus* (16) one character with *S. mitchellensis*.

Figure 8 represents intraspecific variations in conch size and living chamber length of macroconchs and microconchs. Figure 8 exhibits a moderate case of size overlap. The microconch in this case has all the attributes of a male and happens to be a large form.

ETYMOLOGY: The species name is derived from Mitchell County, Kansas, where it is found.

MATERIAL: 7 specimens; figured specimens, holotype UKMIP 108783, paratypes UKMIP 108787, 108789; unfigured paratypes UKMIP 108784, 108785, 108786, 108788.

OCCURRENCE: Macroconch UKMIP 108783 from a dolomitic calcareous shale concretion 35m below top of the member, Microconch UKMIP 108787 from a calcareous shale nodule 35.5m below top of the member, locality 9.

Scaphites inflexus (M) Crick, n. sp.

Plate IV, figures 1-6

DIAGNOSIS: Conch robust and involute with depressed subovate whorl section. Venter broad and well rounded, lateral flanks convex and well rounded, umbilical shoulders rounded and well marked, umbilicus wide, deep and swollen at base of living chamber.

Nine specimens in the collection are macroconchs assigned to this species: UKMIP 108790, 108791, 108792, 108794, 108795, 108801, 108804, 108805, 108806.

MEASUREMENTS: See Table I

DESCRIPTION: The flanks of the phragmocone bear distinct rectiradiate simple and biplicate umbilical ribs. The venter bears straight equi-spaced ventral and intercalatory ribs. Scaphitoid living chamber tightly recurved with well curved shaft and no expansion adapertually tapering toward aperture. Ornamentation on the living chamber consists of umbilical, ventral, and intercalatory ribs. Umbilical ribs are moderately pronounced and rursiradiate crossing the umbilical shoulder becoming greatly pronounced toward the ventrolateral margin where they are simple and biplicate. In addition, the umbilical ribs form an adaperturally projected inflection (Pl. IV, Fig. 1,7) at the ventrolateral margin. Ventral and intercalatory ribs straight and approximated to the point of recurvature becoming slightly projected and approximated adaperturally. Aperture normal, but slightly depressed.

Scaphites inflexus (m) Crick, n. sp.

Plate IV, figures 7-11

DIAGNOSIS: Conch slender and evolute with slightly depressed ovate whorl section. Venter more round and narrow than macroconch, lateral flanks convex and well rounded, umbilical shoulders rounded and well marked initially, weakly marked aperturally, umbilicus side and shallow at base of living chamber with no swelling.

Eight specimens in the collection are microconchs assigned to this species: UKMIP 108793, 108796, 108797, 108798, 108799, 108800, 108802, 108803.

MEASUREMENTS: See Table I

DESCRIPTION: Microconchs share the same features of ornamentation and morphology as the macroconch, differing only by characters associated with dimorphism and by size.

DISCUSSION

Taxonomically significant characters exclusive of dimorphic characters, are: living chamber - scaphitoid with subovate to ovate cross section, tightly recurved with a well curved shaft and no expansion. Chamber tapers adaperturally from point of recurvature. Umbilical ribs are greatly pronounced, prorsiradiate, simple and biplicate, rursiradiate at the shoulder, inflected adaperturally at ventrolateral margin. Ventral and intercalatory ribs are greatly pronounced, straight to the point of recurvature then continuing straight becoming projected and approximated adaperturally. Lack of ventrolateral nodes or bullae.

Scaphites inflexus differs from other species of Scaphites by possessing the combination of a well curved shaft, very convex flanks and well rounded venter, rursiradiate ribs over the shoulder, greatly pronounced umbilical, ventral, and intercalatory ribs. The former being inflected adaperturally at the ventrolateral margin. The lack of nodes or bullae is the most distinctive features. Hattin (1962, p. 29, pl. 23, Fig, C, F-H) mistakenly identified S. inflexus as S. carlilensis. Comparison with Morrow's (1935) holotype of S. carlilensis shows sufficient dissimilarities in the type and nature of ornamentation to prevent confusion of the two.

The correlation of the morphological characteristics shared by of Scaphites inflexus with other species in Figure 12 suggests the following relationships. S. inflexus is most closely related to S. carlilensis (11, 12, 13, 14, 15, 16) based upon the sharing of a combination of six of its ten major taxonomic characters. S. arcadiensis (13, 14, 15, 16, 17) shares five; S. kansiensis (13, 14, 19, 20), four; S. hattini (11, 15, 17), three; and S. mitchellensis (16), one character with S. inflexus.

Figure 9 illustrates the intraspecific variation of conch size and living chamber length of macroconchs and microconchs. The one case of overlap is the reverse of Figure 8. The macroconch has all the attributes of a female, but is of small size. The distinction between (M) and (m) in this plot is because of a larger sample size than the other species.

ETYMOLOGY: The name inflexus alludes to the existence of inflected points in the umbilical ribs at the ventrolateral margin.

MATERIAL: 17 specimens; figured specimens, holotype UKMIP 108790, paratypes 108793, 108796, 108806, unfigured paratypes UKMIP 108791, 108792, 108794, 108795, 108797, 108798, 108799, 108800, 108801, 108802, 108803, 108804, 108805.

OCCURRENCE: Macroconch UKMIP 108790 and Microconch UKMIP 108793 in calcareous shale nodules, 34.5m below top of the Member, locality 1.

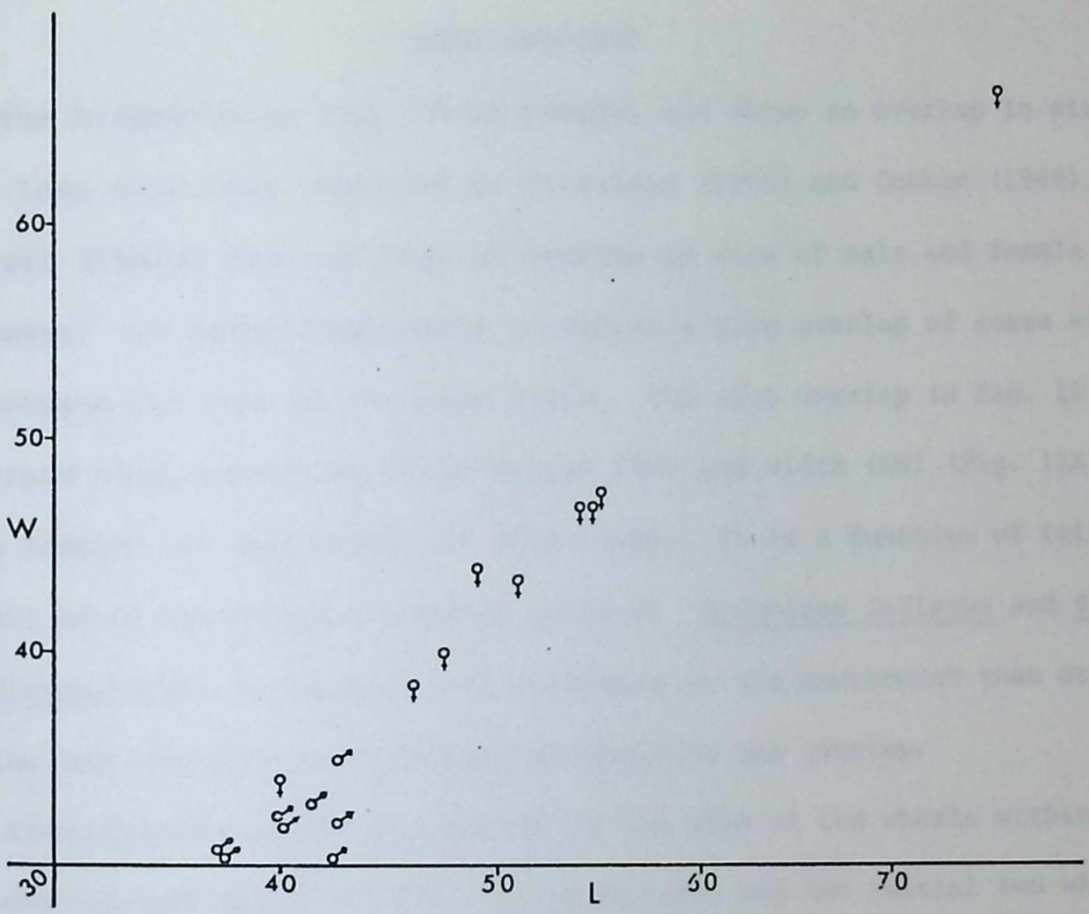

Figure 9 - Scatter diagram of conch length (L) and width (W) of *Scaphites inflexus, n. sp.* Seventeen specimens are represented.

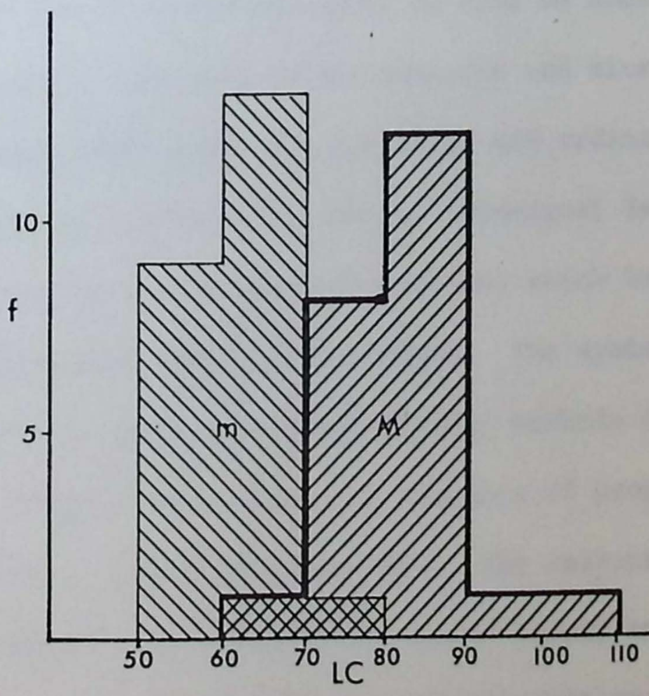

Figure 10 - Histogram illustrating the range in length of living chambers (LC) of microconchs (23) and macroconchs (23). f = frequency.

DATA ANALYSIS

The histogram in Fig. 10 is bimodal and shows an overlap in size range less than that observed by Birkelund (1965) and Cobban (1969). Makowski (1962a) did not find an overlap in size of male and female specimens. It seems reasonable to expect a size overlap of sexes within and between species of the same genus. The size overlap in Fig. 10 is explained when comparing whorl height (WH) and width (WW) (Fig. 11A) and conch length (L) and width (W) (Fig. 11B). It is a function of relative overall size differences between species. Scaphites inflexus and S. arcadiensis have a greater size variation in the macroconch than other species and contribute disproportionately to the overlap.

Considerable variation occurs in the size of the whorls within macroconchs and microconchs. The protoconch and the initial two whorls, where preserved, are of nearly the same size in all specimens. The subsequent whorls vary greatly in size. Unlike Makowski (1962a) and Cobban (1969) I did not find macroconchs to have an additional whorl when comparing sattigal sections of macroconchs and microconchs.

The nominal data (Table I) and the ratio and ordinal data (Table II) were analyzed quantitatively by NT-SYS (Numerical Taxonomy SYStem), a collection of multivariate statistical routines which have been organized to form a compatible system of programs. The system was developed by Rohlf et al. (1974), with the computational methods described in Sokal and Sneath (1963). The types and sequence of programs used in this investigation are listed in Table III. The reasons for chosing this particular sequence of programs are based solely on the function of each program and its method of handling nominal data or ratio and ordinal data. It is important to briefly explain why certain options such

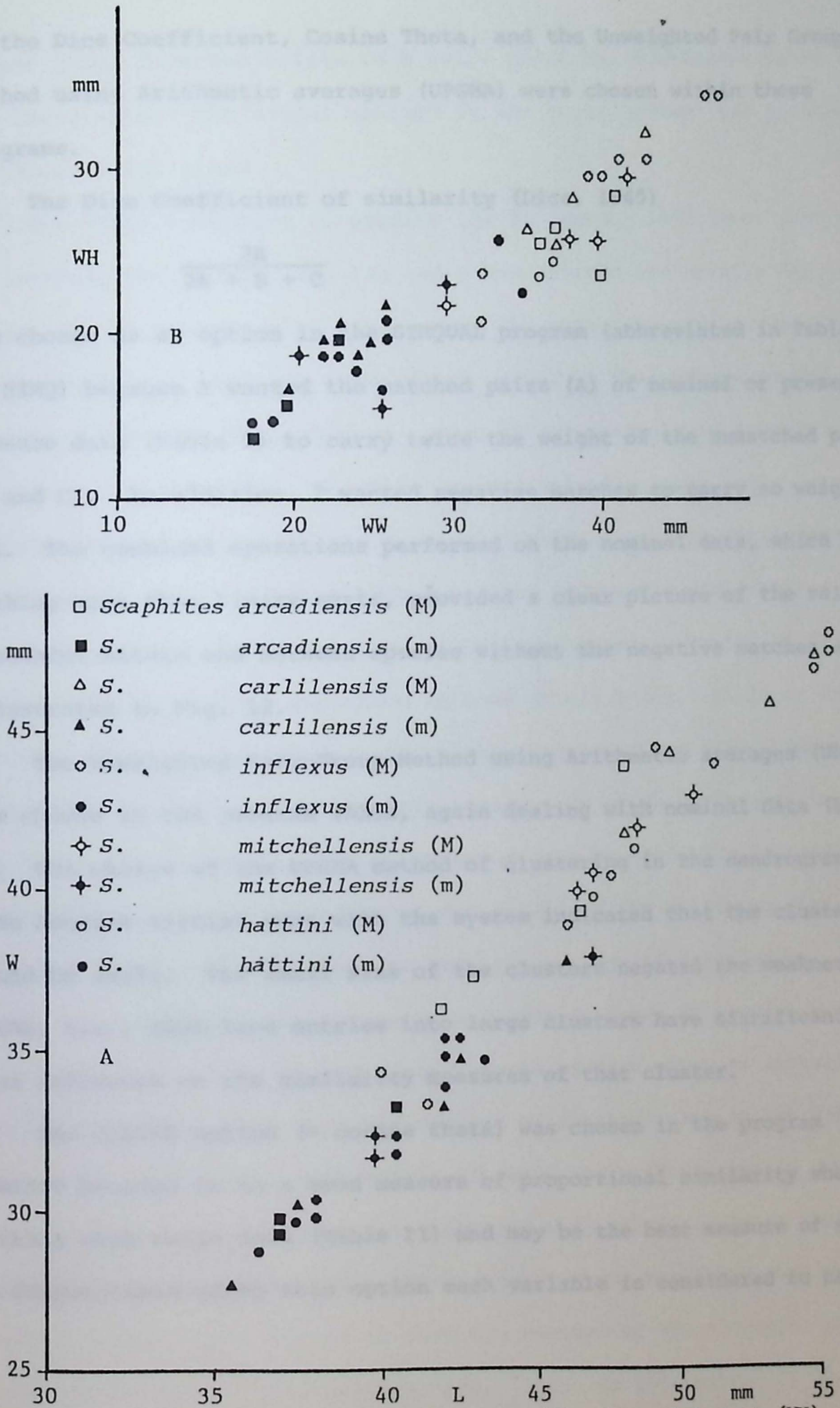

Figure 11A & 11B - Scatter diagrams (A) of whorl height (WH) and width (WW) and (B) conch length (L) and width (W) of 46 specimens excluding *Scaphites kansiensis*. The symbols for 11B are the same as 11A.

as the Dice Coefficient, Cosine Theta, and the Unweighted Pair Group Method using Arithmetic averages (UPGMA) were chosen within these programs.

The Dice Coefficient of similarity (Dice, 1945)

$$\frac{2A}{2A + B + C}$$

was chosen as an option in the SIMQUAL program (abbreviated in Table III as SIMQ) because I wanted the matched pairs (A) of nominal or presence-absence data (Table I) to carry twice the weight of the unmatched pairs (B and C). In addition, I wanted negative matches to carry no weight at all. The combined operations performed on the nominal data, which are nothing more than binary sorts, provided a clear picture of the relationships within and between species without the negative matches as illustrated in Fig. 12.

The Unweighted Pair-Group Method using Arithmetic averages (UPGMA) was chosen in the program TAXON, again dealing with nominal data (Table I). The choice of the UPGMA method of clustering in the dendrogram was made because initial runs with the system indicated that the clusters would be small. The small size of the clusters negated the weakness of UPGMA, i.e., that late entries into large clusters have significantly less influence on the similarity measures of that cluster.

The COSINE option (= cosine theta) was chosen in the program SIMINTV because it is a good measure of proportional similarity when working with ratio data (Table II) and may be the best measure of shape. In computations using this option each variable is considered to be a vector going from the origin to a point given by coordinates taken from the input data. The actual measure is the angle between two vectors in "n" dimensional space.

The steps necessary to produce the clustering techniques from which the dendrograms in Fig. 12, 13A and B are derived are briefly discussed below. It is necessary to standardize the ratio and ordinal data to ensure that each variable is weighted equally. This procedure was not necessary with the nominal data. Next it is necessary to compute measures of similarity. The Dice Coefficient, discussed above, was used for the nominal data with the results reproduced as correlation matrices in Tables IV and V. Cosine theta was used to compute similarities for ratio and ordinal data with the results reproduced in Tables VI and VII. These matrices will be explained in some detail below. It is on these matrices (Tables IV-VII) that the clustering technique called Unweighted Pair-Group Method with Arithmetric averages or UPGMA performed its manipulations to produce the dendrograms seen in Figs. 12, 13A and B. UPGMA initially searches each row and column of the matrix to find the mutually highest correlations to form the centers of the clusters. The matrix of correlated nominal data in Q-mode in Table IV shows a number of correlations at level 1.0 caused by the perfect match of certain specimens. These then form the centers of clusters seen in the Q-mode dendrograms (Fig. 12). The matrix of ratio and ordinal data in Q-mode in Table VI shows a more normal situation with correlations at many different levels. Here again UPGMA selects those specimens with the highest mutual correlations to form the centers of the clusters illustrated in the Q-mode dendrograms (Fig. 13A). In this matrix it is

Text-figure 12 explanations

Q - mode

A - *Scaphites carlilensis* (M)
a - *S. carlilensis* (m)
B - *S. inflexus* (M)
b - *S. inflexus* (m)
C - *S. arcadiensis* (M)
c - *S. arcadiensis* (m)
D - *S. hattini* (M)
d - *S. hattini* (m)
e - *S. kansiensis* (m)
F - *S. mitchellensis* (M)
f - *S. mitchellensis* (m)

R - mode

1. Living chamber loosely recurved.
2. Bullae distantly spaced.
3. Umbilical ribs moderately pronounced.
4. Living chamber shaft slightly curved.
5. Aperture depressed.
6. Umbilical ribs rectiradiate.
7. Ventral ribs distantly equispaced then approximated.
8. Bullae greatly pronounced.
9. Bullae very distantly spaced.
10. Both nodes and bullae present.
11. Living chamber tightly recurved.
12. Umbilical rib greatly pronounced.
13. Living chamber shaft well curved.
14. Aperture normal.
15. Umbilical ribs rursiradiate.
16. No nodes on the living chamber.
17. Ventral and intercalatory ribs straight and then projected.
18. Ventral and intercalatory ribs approximated from the base of the living chamber.

19 & 20. No bullae present on the living chamber.

21. Specimen robust.
22. Specimen involute.
23. Umbilical swelling present.
24. Umbilicus deep.
25. Specimen slender.
26. Specimen evolute.
27. No umbilical swelling.
28. Umbilicus shallow.
29. Ventral and intercalatory ribs straight.
30. Ventral and intercalatory ribs moderately equispaced and then approximated.
31. Bullae moderately pronounced.
32. Bullae normally spaced.
33. Umbilical ribs slightly pronounced.
34. Ventral and intercalatory ribs projected.
35. Closely equispaced and then approximated.
36. Nodes present on the living chamber.

NOTE: Dimorphic characters = 21-28.

Figure 12 - A two-way cluster analysis of the nominal data of six species of *Scaphites*. Figure explanations on preceding page.

Figure 13A explanation
Q - mode

A - *Scaphites carlilensis* (M)
a - *S. carlilensis* (m)
B - *S. inflexus* (M)
b - *S. inflexus* (m)
C - *S. arcadiensis* (M)
c - *S. arcadiensis* (m)
D - *S. hattini* (M)
d - *S. hattini* (m)
e - *S. kansiensis* (m)
F - *S. mitchellensis* (M)
f - *S. mitchellensis* (m)

Figure 13B explanation
R - mode

1. Specimen length
2. Specimen width.
3. Length of living chamber.
4. Radius of septate whorls.
5. Whorl width at the base of the living chamber.
6. Whorl height at the base of the living chamber.
7. Height of the living chamber opening at the base of the chamber (Whorl Height - Umbilical Depth = Height of the living chamber opening).
8. Radius of living chamber.
9. Height of the aperture.
10. Width of the aperture.
11. Number of umbilical ribs on the living chamber.
12. Width of the umbilicus at the base of the livng chamber.
13. Depth of the umbilicus at the base of the living chamber.
14. Number of nodes on the living chamber.
15. Number of bullae on the living chamber.
16. Number of ventral ribs on the living chamber.
17. Number of intercalatory ribs on the living chamber.

NOTE: See Figures 3 and 4 for the location of metric measurements.

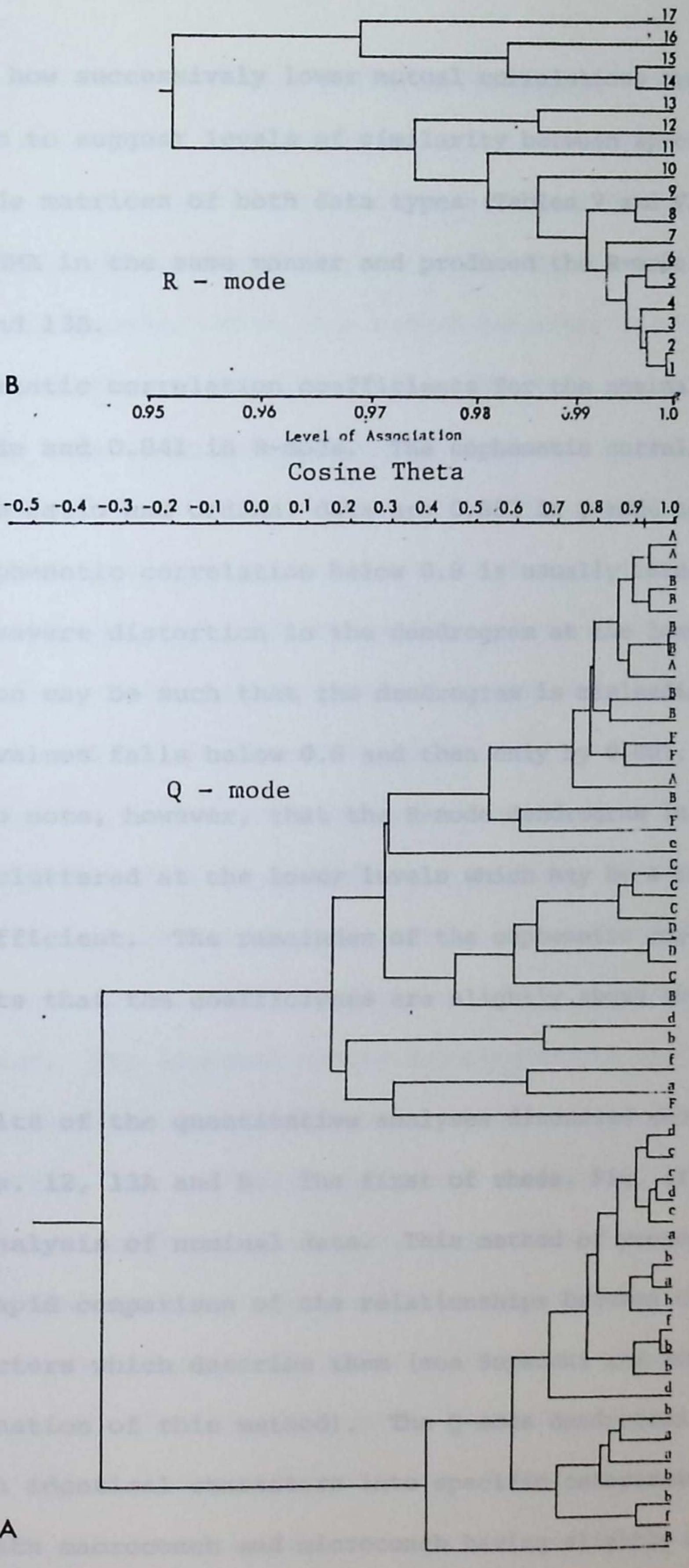

Figure 13A & 13B - Dendrograms produced from correlation matrices of ratio and ordinal data. Fig. 13A produced from Table VI and Fig. 13B from Table VII. Figure explanations on preceding page.

easier to see how successively lower mutual correlations are added to the dendrogram to suggest levels of similarity between specimens.

The R-mode matrices of both data types (Tables V and VII) were handled by UPGMA in the same manner and produced the R-mode dendrograms in Figs. 12 and 13B.

The cophenetic correlation coefficients for the nominal data are 0.815 in Q-mode and 0.841 in R-mode. The cophenetic correlation coefficients for the ratio and ordinal data are 0.852 in Q-mode and 0.793 in R-mode. A cophenetic correlation below 0.8 is usually interpreted as an indicator of severe distortion in the dendrogram at the lower linkages. This distortion may be such that the dendrogram is misleading. Only one of the above values falls below 0.8 and then only by 0.007. It is interesting to note, however, that the R-mode dendrogram in Fig. 13B is increasingly cluttered at the lower levels which may be a reflection of the lower coefficient. The remainder of the cophenetic correlation values suggests that the coefficients are slightly above average, but not superior.

The results of the quantitative analyses discussed above are presented in Figs. 12, 13A and B. The first of these, Fig. 12, is a two-way cluster analysis of nominal data. This method of presenting the data offers rapid comparison of the relationships between the species and the characters which describe them (see Sepkoski and Rex, 1974, for further explanation of this method). The Q-mode dendrogram groups those specimens with identical characters into specific categories A,a; B,b;...F,f, with macroconch and microconch having slightly different levels of association. Relationships at the subgeneric level are shown by lower levels of association. Scaphites kansiensis, indicated by "e", shows only the microconch category because it is represented by only one male specimen. Correlation between modes is represented by the dot pattern. Each dot represents the presence of that character in R-mode for a specimen in Q-mode. With this method the logic in the relationship of species at the subgeneric level can be seen. S. inflexus (B,b) is more closely related to S. carlilensis (A,a) than it is to S. arcadiensis (C,c) not only because they share six of the same characters (11-16) but because S. arcadiensis, while sharing five of the same characters (13-17) as S. inflexus, possesses five additional characters (1-3, 7-8) which are in a different subgroup at a much lower level of association. Categories 21-28 are dimorphic characters and since they occur in each species are not useful in this comparison.

The overriding influence of width and length of the specimens suggests a strong growth factor connected to size and shape. These variables did not allow results from the ratio and ordinal data which I would have liked. The somewhat random grouping of the specimens is explained as a function of similar or near similar size analagous to those seen in Figs. 11A and 11B. The Q-mode dendrogram clusters those individuals with similar overall measurements. Consequently, there are differences in the levels of association between specimens of the same species. The mixing of a few microconchs with macroconchs and vice versa is expected on the basis of previous statistical plots (see Fig. 11A and 11B). Separation of the genus into dimorphic groups is reasonably accurate. In R-mode the most strongly correlated characters are length and width of each specimen and length of living chamber (1-3) and whorl width and height (5 and 6). The measurement of only these five characters would have been sufficient to produce the same results, particularly regarding dimorphism. The counting of characters of ornamentation (11, 14-17) was only marginally important in the distinction of species as evidenced by the levels of association. Since the ornamentation of both sexes of the same species is the same, these characters were not at all useful in the recognition of dimorphism.

Representation of the correlation between modes as in Fig. 12 is not practical with ratio and ordinal data. The analysis illustrates that this type of data is decidedly inadequate for discerning species but reasonably reliable for determining dimorphism. Separation of specimens into two mutually almost exclusive groups based on size, supports the hypothesis that relative size differences within ammonite genera and species can be used as a rough estimation of sexual dimorphism.

Finally, I would like to add a disclaimer with reference to the occurrence in the ratio data of redundant variables such as a few of the dimorphic variables in the nominal data and especially specimen length (L), specimen width (W) and length of living chamber (LC). It is known that the existence of redundant or repetitous variables will influence the similarity coefficients and tend to inflate them. These variables affect the Dice Coefficient more than they would other measures of similarity because the Dice puts greatest emphasis on positive matches. In this case, I feel that the results would have been approximately the same with removal of these variables.

CONCLUSIONS

The forty-seven well preserved living chambers and conchs of scaphites examined in this study yielded the following information.

1) Six species of the genus Scaphites were found to exist in the Blue Hill Shale Member of the Carlile Shale. Two of these have previously been described as Scaphites arcadiensis Moreman and Scaphites carlilensis Morrow. Only the latter was previously reported from this member. The four remaining, Scaphites inflexus, S. kansiensis, S. mitchellensis, and S. hattini, are new.

2) All members of the six species were observed to be adult and dimorphic possessing characteristics attributable to either female or male forms. Specimens so observed were designated either macroconch for female or microconch for male. A few submacroscopic juveniles were found in macroconch living chambers.

3) The genus Scaphites was found to be limited to a narrow zone between two levels of large concretions and not ubiquitous throughout the member as previously reported.

Although the recognition of two previously described species and the establishment of four new species is based primarily on the forty-seven specimens listed and described above, nearly two hundred additional specimens ranging from fragmental living chambers to incomplete phragmocones were collected. While the majority of these fragmental living chambers can be identified as belonging to five of the above six species (S. kansiensis excluded), the incomplete phragmocones are useless for reasons outlined above. The fragmental living chambers did not form an integral part of this study because neither accurate measurements nor reasonable estimates could be made.

The occurrence of six species of the same genus randomly distributed over the three meter thickness of the zone requires an explanation other than sympatric speciation. The following four possibilities are considered.

1) Allopatric speciation with subsequent post mortem concentra tion.
2) Development of species as peripheral isolates with post mortem concentration.
3) Separation in the water column with subsequent concentration.
4) The punctuated equilibria model of Eldredge and Gould which would allow coexistence of species for a limited time.

There is no hard evidence supporting any of the four suggested explanations. They are all possible and could have operated simultaneously to produce the present fossil record of the genus <u>Scaphites</u> in the Blue Hill Shale.

Quantitative analysis of the data presented herein supports the descriptive methods in the assignment of the scaphite forms to six species and the placement of the large and small forms of each species in the macroconch (=female) and the microconch (=male) categories respectively. The previously observed variations within the genus in the Blue Hill Shale Member are shown to be attributable to the presence of six species and to sexual dimorphism.

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Table I

UKMIP No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
108774		+	+				+	+			+			+					+				+	+			+		+		+		+		+	
108765	+		+			+		+		+			+					+			+			+			+		+		+		+		+	
108787	+			+		+		+		+		+			+					+		+			+				+		+		+		+	
108810		+		+		+		+		+			+					+				+				+		+		+		+		+		+
108808		+		+		+		+		+			+					+				+				+		+		+		+		+		+
108794		+	+				+	+		+						+	+			+				+			+		+		+		+		+	
108766	+		+			+		+		+			+					+			+			+			+			+		+		+		+
108770	+		+		+				+			+			+		+			+					+		+			+		+		+		+
108793		+	+				+	+		+						+	+			+				+			+			+		+		+		+
108795		+	+				+	+		+						+	+			+				+			+		+		+		+		+	
108775		+	+				+	+			+			+					+				+	+			+			+		+		+		+
108789	+			+		+			+		+			+					+		+			+				+		+		+		+		+
108792		+	+				+	+		+						+	+			+				+			+		+		+		+		+	
108790		+	+				+	+		+						+	+			+				+			+		+		+		+		+	
108767	+		+			+		+		+			+					+			+			+			+		+		+		+		+	
108791		+	+				+	+		+						+	+			+				+			+		+		+		+		+	
108778		+	+				+	+			+			+					+				+	+			+		+		+		+		+	
108796		+	+				+	+		+						+	+			+				+			+			+		+		+		+
108797		+	+				+	+		+						+	+			+				+			+			+		+		+		+

Table I (cont'd)

UKMIP No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
108801		+	+				+	+		+						+	+			+				+			+		+		+		+		+	
108776		+	+				+	+			+			+					+				+	+			+			+		+		+		+
108799		+	+				+	+		+						+	+			+				+			+			+		+		+		+
108802		+	+				+	+		+						+	+			+				+			+			+		+		+		+
108803		+	+				+	+		+						+	+			+				+			+			+		+		+		+
108804		+	+				+	+		+						+	+			+				+			+		+		+		+		+	
108798		+	+				+	+		+						+	+			+				+			+			+		+		+		+
108781		+	+				+	+			+			+					+				+	+			+		+		+		+		-	
108768	+		+			+		+		+			+					+			+			+			+		+		+		+		+	
108800		+	+				+	+		+						+	+			+				+			+			+		+		+		-
108784	+			+		+			+		+			+					+		+			+				+	+		+		+		+	
108807		+		+		+		+		+			+					+				+				+		+	+		+		+		+	
108772	+		+			+		+		+			+					+			+			+			+			+		+		+		-
108806		+	+				+	+		+						+	+			+				+			+		+		+		+		+	
108811		+		+		+		+		+			+					+				+				+		+		+		+		+		-
108805		+	+				+	+		+						+	+			+				+			+		+		+		+		+	
108780		+	+				+	+			+			+					+				+	+			+			+		+		+		+
108812		+		+		+		+		+			+					+				+				+		+		+		+		+		+
108783	+			+		+			+		+			+					+		+			+				+	+		+		+		+	

Table I (cont'd)

UKMIP No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
108809		+		+		+		+		+			+					+			+					+		+	+	+		+		+		
108782		+	+				+	+			+			+					+				+	+			+			+		+		+		+
108777		+	+				+	+			+			+					+				+	+			+			+		+		+		+
108786	+			+		+			+		+			+					+		+			+				+	+		+		+		+	
108788	+			+		+			+		+			+					+		+			+				+		+		+		+		+
108785	+			+		+			+		+			+					+		+			+				+	+		+		+		+	
108773	+		+			+		+		+			+					+			+			+			+			+		+		+		+
108769	+		+			+		+		+			+					+			+			+			+		+		+		+		+	
108779		+	+				+	+			+			+					+				+	+			+		+		+		+		+	

Table I - Presence-Absence data taken from the most representative specimens in the collection. The symbol (+) indicates that the character is present for a particular OTU. 1. living chamber loosely recurved; 2. living chamber tightly recurved; 3. shaft well curved; 4. shaft slightly curved; 5. umbilical ribs slightly pronounced; 6. umbilical ribs moderately pronounced; 7. umbilical ribs greatly pronounced; 8. umbilical ribs rursiradiate; 9. umbilical ribs rectiradiate; 10. ventral ribs straight and projected; 11. ventral ribs straight; 12. ventral ribs projected; 13. ventral ribs distant, equispaced and approximated; 14. ventral ribs moderate, equispaced and approximated; 15. ventral ribs close, equispaced and approximated; 16. ventral ribs approximated; 17. no bullae; 18. bullae greatly pronounced; 19. bullae moderately pronounced; 20. bullae; 21. bullae distant; 22. bullae very distant; 23. bullae normal; 24. no nodes; 25. nodes; 26. nodes and bullae; 27. aperture normal; 28. aperture depressed; 29. robust; 30. slender; 31. involute; 32. evolute; 33. umbilical swelling; 34. no umbilical swelling; 35. umbilicus deep; 36. umbilicus shallow. Categories 29-36 are dimorphic indices.

Table II

UKMIP no.	M/m	L	W	WW	WH	UW	Wh	ud	e	d	c	f	LC	nN**	nB**	nUR**	nVR**	nIR**
108774	M	54.5	47.0	26.0	21.0	13.0	13.0	7.5	18.5	20.5	15.0	21.0	89.0	0	7	12	27	11
108765	M	46.5*	39.0	25.0	19.0	11.0	11.0	7.0	n/m	n/m	12.5	27.0	80.0	0	5	8	25	4
108787	m	47.0*	37.5	19.5	16.0	9.0	11.0	5.5	n/m	n/m	n/m	n/m	78.0	0	7	10	27	9
108810	m	37.5*	29.5	17.5	13.0	8.0	8.5	4.5	n/m	n/m	9.0	16.5	55.0	3	6	9	25	7
108808	m	43.5*	34.5	22.0	16.0	10.0	11.0	5.0	n/m	n/m	n/m	n/m	65.5	3	5	8	23	7
108794	M	75.5*	66.5	32.0	26.0	14.0	16.0	10.0	n/m	n/m	n/m	n/m	105.0*	0	0	21*	57*	15*
108766	m	37.0*	29.0	14.5	12.5	7.0	8.8	3.8	n/m	14.0	9.0	17.0	52.0	0	5	9	21	3
108770	m	56.0	53.5	8.5	18.5	4.0	15.0	3.5	18.0	18.0	18.5	18.5	100.0	0	16	15	70	20
108793	m	42.5*	32.0	17.5	14.5	7.0	11.0	3.5	n/m	n/m	n/m	n/m	57.5	0	0	11	25	9
108795	M	54.5*	47.0	28.5	22.5	15.5	13.0	9.5	n/m	n/m	13.0	21.0	95.5	0	0	13	35	9
108775	m	42.5	35.0	16.5	14.5	9.0	10.5	4.3	13.5	19.0	12.5	16.0	64.0	0	6	10	26	10
108789	m	40.0	32.0	16.5	13.5	9.0	10.3	3.3	13.0	16.0	n/m	n/m	56.0	0	6	10	26	5
108792	M	49.0*	44.0	24.0	19.5	12.0	12.0	8.0	n/m	n/m	14.0	18.0	86.0	0	0	14	35	10
108790	M	54.5	47.0	28.0	22.0	13.0	13.0	9.0	18.0	20.0	n/m	n/m	87.5	0	0	13	33	9
108767	M	42.0*	36.0*	23.0	18.0	11.0	11.0	7.0	n/m	n/m	n/m	n/m	77.0*	0	5	8*	25*	6*
108791	M	51.0*	43.5	24.5	19.0	12.0	11.0	8.0	n/m	n/m	13.0	17.0	86.0	0	0	13	30	6
108778	M	48.0	41.5	22.0	18.0	12.0	12.0	7.0	15.0	17.0	n/m	n/m	73.5	0	7	11	26	9
108796	m	41.5*	33.0	17.5	15.0	10.0	11.5	4.0	n/m	n/m	11.0	16.0	61.0	0	0	10	28	10
108797	m	40.0	32.0*	16.0*	14.0	10.0*	11.5	3.4	12.5	17.0	n/m	n/m	64.0	0	0	11	26	4
108801	M	55.0*	47.5	25.0	20.0	14.0	12.0	8.0	n/m	n/m	15.0	21.0	87.5	0	0	11	27	6

Table II (cont'd)

UKMIP no.	M/m	L	W	WW	WH	UW	Wh	ud	e	d	c	f	LC	nN**	nB**	nUR**	nVR**	nIP**
108776	m	40.5	33.0	16.5	15.0	8.0	10.0	4.5	n/m	n/m	10.0	15.0	62.5	0	6	9	26	10
108799	m	37.5*	30.0	14.5	12.0	7.0	9.5	4.5	n/m	n/m	n/m	n/m	62.5	0	0	12	30	4
108802	m	37.5*	30.0	16.0	14.5	9.0	10.0	4.5	n/m	n/m	n/m	17.0	58.0	0	0	12	27	8
108804	m	42.5*	35.0	16.5	14.0	10.0	9.5	4.5	n/m	n/m	n/m	n/m	64.0	0	0	14	30	10
108804	M	47.5*	20.0	26.0	20.0	10.0	11.0	6.0	n/m	17.0	n/m	n/m	78.0	0	0	13	28	6
108798	m	42.5*	35.0*	21.0	18.0*	10.0*	12.0	6.0	n/m	n/m	n/m	n/m	64.0	0	0	9	24	8
108781	M	49.0*	44.0	24.0	19.5	11.5	13.0	6.5	n/m	n/m	n/m	n/m	85.0	0	7	13	32	7
108768	M	43.0*	37.0*	25.0	17.0	9.5	10.0	6.5	n/m	n/m	n/m	n/m	75.0*	0	5	8*	25*	4*
108800	m	40.0*	32.0	17.0	14.0	8.5	10.5	3.5	n/m	n/m	n/m	22.0	61.0	0	0	11	25	6
108784	M	47.5*	40.0	24.0	18.0	11.5	12.0	6.0	n/m	n/m	n/m	n/m	83.0	0	9	11	28	8
108807	M	48.5	41.0	23.0	17.0	12.0	10.0	7.0	14.0	17.5	12.0	19.0	85.0	3	6	9	25	7
108772	m	40.5*	33.0	16.5	15.0	8.0	10.0	4.5	n/m	n/m	10.0	15.0	62.5	0	5	8	23	5
108806	M	40.0	34.0	21.0	15.5	10.0	9.5	5.5	14.0	15.0	n/m	n/m	72.0	0	0	13	30	6
108811	m	36.5	28.5	14.5	12.5	7.0	8.5	4.0	10.0	14.0	9.0	13.0	53.0	3	5	8	21	5
108805	M	46.0*	38.5	21.0	17.0	9.5	9.0	8.0	n/m	n/m	12.5	18.5	69.0	0	0	8	24	8
108780	m	46.0*	37.5	18.0	16.0	6.5	11.0	5.0	13.5	15.5	n/m	n/m	68.5	0	7	11	25	10
108812	m	40.5*	32.5	16.0	15.0	7.5	11.0	5.0	11.0	15.0	n/m	14.5	65.0	5	0	7	24	6
108783	M	48.0*	41.5	25.0	18.0	13.5	12.5	8.0	14.0	19.0	n/m	n/m	84.5	0	9	11	30	10
108809	M	47.0	39.5	23.5	17.5	12.0	10.0	7.5	n/m	n/m	n/m	n/m	77.0	3	6	9	25	7
108782	m	35.5*	27.5	15.0	13.5	7.5	9.0	4.5	n/m	n/m	10.0	16.5	57.0	0	7	12	25	5

Table II (cont'd)

UKMIP no.	M/m	L	W	WW	WH	UW	Wh	ud	e	d	c	f	LC	nN**	nB**	nUR**	nVR**	nIR**
108777	m	37.5*	30.0	16.5	14.5	9.5	11.0	5.0	n/m	n/m	n/m	n/m	56.0	0	0	9	23	5
108786	M	50.5*	43.0	26.0	20.0	9.0	13.0	7.0	n/m	n/m	7.0	22.0	74.0	0	6	11	28	9
108788	m	42.0*	34.0	16.0	14.0	9.0	10.0	4.0	n/m	n/m	10.0	16.0	61.0	0	0	12	29	10
108785	M	46.5*	39.0	20.0	16.0	9.0	10.0	7.0	n/m	n/m	11.0	14.5	77.0	0	8	11	25	8
108773	m	37.0*	29.5	14.0	12.0	6.0	9.5	2.5	n/m	n/m	n/m	n/m	51.5	0	6	7	19	6
108769	M	48.0	44.0	23.0	18.0	12.0	12.0	6.0	18.0	19.0	n/m	n/m	83.0	0	6	8	24	7
108779	M	53.0	45.5	23.0	18.5	13.0	12.0	7.5	18.0	19.5	13.5	20.0	89.0	0	7	12	31	13

Table II - Numerical data taken from the most representative specimens in the collection. All measurements in millimeters with exception of the meristic data designated by double asteriks (**).

(*) = estimates; n/m = not measurable. M = macroconch; m = microconch; L = length of specimen; W = width of specimen; WW = whorl width at base of LC; WH = whorl height at base of LC; UW = umbilical width at base of LC; Wh = LC opening at base of chamber (WH-ud); ud = depth of umbilicus at base of LC; e = height of aperture; d = radius of phragmocone + LC; c = radius of phragmocone; f = width of aperture; LC = length of living chamber; nN = number of nodes on LC; nB = number of bullue on LC; nUR = number of umbilical ribs on LC; nVR = number of ventral ribs on LC; nIR = number of intercalatory ribs on LC.

```
//DIMORPH1 JOB AGU31,'CRICK,RE'
***SETUP DISK,CCLIB2
***OPTIONS P=500,T=2,CLASS=C
// EXEC NTSYS,REGION=300K
//SYSUDUMP DD DUMMY
//FT11F001 DD DSN=&&TEMP,DISP=(NEW,DELETE),UNIT=DISK,
//   SPACE=(TRK,(10,5)),DCB=(RECFM=VBS,LRECL=404,BLKSIZE=812)
//SYSIN DD *,DCB=BUFNO=1 (SUPPLIED)
*FILES SCRSTK=11
*INPUT NAME='SEXDM1'(36,47),READ BY COLUMNS, STORE BY COLUMNS,
*ETC    OPTION=(LABELS)
*ETC    $SCAPHITES - PRESENCE-ABSENCE DATA$
*FORMAT(36F1.0)
*OUTPUT OPER='SEXDM1'
*SIMQ OPER='SEXDM1', D='SEX1'
*ETC POSITIVE=1.0,NEGATIVE=0.0
*OUTPUT OPER='SEX1'
*TAXON OPER='SEX1', COPH='SEX2', OPTION=(HIGH, UPGMA)
*OUTPUT OPER='SEX2'
*MXCOMP XMATRIX='SEX1', YMATRIX='SEX2'
*FINISH
*SIMQ OPER='SEXDM1', D='SEX3',OPTION=ROWS
*ETC POSITIVE=1.0,NEGATIVE=0.0
*OUTPUT OPER='SEX3'
*TAXON OPER='SEX3', COPH='SEX4', OPTION=(HIGH, UPGMA)
*OUTPUT OPER='SEX4'
*MXCOMP XMATRIX='SEX3', YMATRIX='SEX4'
*FINISH
*INPUT NAME='SEXDM2'(17,47), READ BY COLUMNS, STORE BY COLUMNS,
*ETC    NC = 11.1, OPTION = (LABELS)
*ETC           $ORDINAL DATA - MEASUREMENTS & COUNTS - SCAPHITES$
*FORMAT(6F5.1,F4.1,4F5.1,F6.1/5F8.1)
*OUTPUT OPER = 'SEXDM2'
*STAND OPER='SEXDM2', RESULT='SEX2A'
*OUTPUT OPER = 'SEX2A'
*SIMINTV OPER = 'SEX2A', COSINE='SEX2B'
*OUTPUT OPER = 'SEX2B'
*TAXON OPER='SEX2B', COPH='SEX2C', OPTION=(HIGH,UPGMA)
*OUTPUT OPER='SEX2C'
*MXCOMP XMATRIX = 'SEX2B', YMATRIX='SEX2C'
*FINISH
*SIMINTV OPER = 'SEXDM2', COSINE='SEX2D', OPTION=ROWS
*OUTPUT OPER = 'SEX2D'
*TAXON OPER = 'SEX2D', COPH='SEX2E', OPTION=(HIGH,UPGMA)
*OUTPUT OPER='SEX2E'
*MXCOMP XMATRIX = 'SEX2D', YMATRIX='SEX2E'
*FINISH
*FINALE
```

Table III - Listing of program DIMORPH1. Control cards are those required by the system at the University of Rochester, Rochester, New York.

Table IV

	4 1 02	4 1 12	4 1 13	4 1 19	4 1 24	4 1 26	4 1 28	4 1 30	4 1 35	4 1 49
4 1 02	1.000									
4 1 12	0.571	1.000								
4 1 13	0.286	0.286	1.000							
4 1 19	0.143	0.357	0.500	1.000						
4 1 24	0.143	0.357	0.500	1.000	1.000					
4 1 26	0.714	0.643	0.071	0.214	0.214	1.000				
4 1 28	0.286	0.714	0.571	0.643	0.643	0.357	1.000			
4 1 30	0.143	0.214	0.429	0.286	0.286	0.286	0.500	1.000		
4 1 35	0.429	0.357	0.357	0.500	0.500	0.714	0.643	0.571	1.000	
4 1 49	0.714	0.643	0.071	0.214	0.214	1.000	0.357	0.286	0.714	1.000
4 1 52	0.714	0.286	0.571	0.429	0.429	0.429	0.571	0.429	0.714	0.429
4 1 53	0.286	0.286	1.000	0.500	0.500	0.071	0.571	0.429	0.357	0.071
4 1 54	0.714	0.643	0.071	0.214	0.214	1.000	0.357	0.286	0.714	1.000
4 1 56	0.714	0.643	0.071	0.214	0.214	1.000	0.357	0.286	0.714	1.000
4 1 59	0.571	1.000	0.286	0.357	0.357	0.643	0.714	0.214	0.357	0.643
4 1 67	0.714	0.643	0.071	0.214	0.214	1.000	0.357	0.286	0.714	1.000
4 1 90	1.000	0.571	0.286	0.143	0.143	0.714	0.286	0.143	0.429	0.714
4 1 92	0.429	0.357	0.357	0.500	0.500	0.714	0.643	0.571	1.000	0.714
4 1 93	0.429	0.357	0.357	0.500	0.500	0.714	0.643	0.571	1.000	0.714
4 3 02	0.714	0.643	0.071	0.214	0.214	1.000	0.357	0.286	0.714	1.000
4 3 08	0.714	0.286	0.571	0.429	0.429	0.429	0.571	0.429	0.714	0.429
4 3 11	0.429	0.357	0.357	0.500	0.500	0.714	0.643	0.571	1.000	0.714
4 7 03	0.429	0.357	0.357	0.500	0.500	0.714	0.643	0.571	1.000	0.714
4 7 04	0.429	0.357	0.357	0.500	0.500	0.714	0.643	0.571	1.000	0.714
4 7 08	0.714	0.643	0.071	0.214	0.214	1.000	0.357	0.286	0.714	1.000
4 7 12	0.429	0.357	0.357	0.500	0.500	0.714	0.643	0.571	1.000	0.714
4 8 02	1.000	0.571	0.286	0.143	0.143	0.714	0.286	0.143	0.429	0.714
4 8 05	0.571	1.000	0.286	0.357	0.357	0.643	0.714	0.214	0.357	0.643
4 8 11	0.429	0.357	0.357	0.500	0.500	0.714	0.643	0.571	1.000	0.714
4 9 02	0.571	0.571	0.714	0.214	0.214	0.357	0.286	0.143	0.071	0.357
4 9 03	0.429	0.643	0.214	0.714	0.714	0.500	0.357	0.0	0.214	0.500
4 9 04	0.286	0.714	0.571	0.643	0.643	0.357	1.000	0.500	0.643	0.357
4 9 09	0.714	0.643	0.071	0.214	0.214	1.000	0.357	0.286	0.714	1.000
4 9 11	0.143	0.357	0.500	1.000	1.000	0.214	0.643	0.286	0.500	0.214
4 9 12	0.714	0.643	0.071	0.214	0.214	1.000	0.357	0.286	0.714	1.000
4 9 13	0.714	0.286	0.571	0.429	0.429	0.429	0.571	0.429	0.714	0.429
4 9 17	0.143	0.357	0.500	1.000	1.000	0.714	0.643	0.286	0.500	0.214
4 9 18	0.429	0.643	0.214	0.714	0.714	0.500	0.357	0.0	0.214	0.500
4 9 19	0.571	0.571	0.714	0.214	0.214	0.357	0.286	0.143	0.071	0.357
4 9 22	0.714	0.286	0.571	0.429	0.429	0.429	0.571	0.429	0.714	0.429
5 7 02	0.714	0.286	0.571	0.429	0.429	0.429	0.571	0.429	0.714	0.429
5 8 01	0.571	0.571	0.714	0.214	0.214	0.357	0.286	0.143	0.071	0.357
5 8 02	0.286	0.286	1.000	0.500	0.500	0.071	0.571	0.429	0.357	0.071
5 9 01	0.571	0.571	0.714	0.214	0.214	0.357	0.286	0.143	0.071	0.357
5 9 06	0.286	0.714	0.571	0.643	0.643	0.357	1.000	0.500	0.643	0.357
5 9 07	0.571	1.000	0.286	0.357	0.357	0.643	0.714	0.214	0.357	0.643
5 9 08	1.000	0.571	0.286	0.143	0.143	0.714	0.286	0.143	0.429	0.714

Table IV (cont'd)

	4 1 52	4 1 53	4 1 54	4 1 56	4 1 59	4 1 67	4 1 90	4 1 92	4 1 93	4 3 02
4 1 52	1.000									
4 1 53	0.571	1.000								
4 1 54	0.429	0.071	1.000							
4 1 56	0.429	0.071	1.000	1.000						
4 1 59	0.286	0.286	0.643	0.643	1.000					
4 1 67	0.429	0.071	1.000	1.000	0.643	1.000				
4 1 90	0.714	0.286	0.714	0.714	0.571	0.714	1.000			
4 1 92	0.714	0.357	0.714	0.714	0.357	0.714	0.429	1.000		
4 1 93	0.714	0.357	0.714	0.714	0.357	0.714	0.429	1.000	1.000	
4 3 02	0.429	0.071	1.000	1.000	0.643	1.000	0.714	0.714	0.714	1.000
4 3 08	1.000	0.571	0.429	0.429	0.286	0.429	0.714	0.714	0.714	0.429
4 3 11	0.714	0.357	0.714	0.714	0.357	0.714	0.429	1.000	1.000	0.714
4 7 03	0.714	0.357	0.714	0.714	0.357	0.714	0.429	1.000	1.000	0.714
4 7 04	0.714	0.357	0.714	0.714	0.357	0.714	0.429	1.000	1.000	0.714
4 7 08	0.429	0.071	1.000	1.000	0.643	1.000	0.714	0.714	0.714	1.000
4 7 12	0.714	0.357	0.714	0.714	0.357	0.714	0.429	1.000	1.000	0.714
4 8 02	0.714	0.286	0.714	0.714	0.571	0.714	1.000	0.429	0.429	0.714
4 8 05	0.286	0.286	0.643	0.643	1.000	0.643	0.571	0.357	0.357	0.643
4 8 11	0.714	0.357	0.714	0.714	0.357	0.714	0.429	1.000	1.000	0.714
4 9 02	0.286	0.714	0.357	0.357	0.571	0.357	0.571	0.071	0.071	0.357
4 9 03	0.143	0.214	0.500	0.500	0.643	0.500	0.429	0.214	0.214	0.500
4 9 04	0.571	0.571	0.357	0.357	0.714	0.357	0.286	0.643	0.643	0.357
4 9 09	0.429	0.071	1.000	1.000	0.643	1.000	0.714	0.714	0.714	1.000
4 9 11	0.429	0.500	0.214	0.214	0.357	0.214	0.143	0.500	0.500	0.214
4 9 12	0.429	0.071	1.000	1.000	0.643	1.000	0.714	0.714	0.714	1.000
4 9 13	1.000	0.571	0.429	0.429	0.286	0.429	0.714	0.714	0.714	0.429
4 9 17	0.429	0.500	0.214	0.214	0.357	0.214	0.143	0.500	0.500	0.214
4 9 18	0.143	0.214	0.500	0.500	0.643	0.500	0.429	0.214	0.214	0.500
4 9 19	0.286	0.714	0.357	0.357	0.571	0.357	0.571	0.071	0.071	0.357
4 9 22	1.000	0.571	0.429	0.429	0.286	0.429	0.714	0.714	0.714	0.429
5 7 02	1.000	0.571	0.429	0.429	0.286	0.429	0.714	0.714	0.714	0.429
5 8 01	0.286	0.714	0.357	0.357	0.571	0.357	0.571	0.071	0.071	0.357
5 8 02	0.571	1.000	0.071	0.071	0.286	0.071	0.286	0.357	0.357	0.071
5 9 01	0.286	0.714	0.357	0.357	0.571	0.357	0.571	0.071	0.071	0.357
5 9 06	0.571	0.571	0.357	0.357	0.714	0.357	0.286	0.643	0.643	0.357
5 9 07	0.286	0.286	0.643	0.643	1.000	0.643	0.571	0.357	0.357	0.643
5 9 08	0.714	0.286	0.714	0.714	0.571	0.714	1.000	0.429	0.429	0.714

Table IV (cont'd)

	4 3 08	4 3 11	4 7 03	4 7 04	4 7 08	4 7 12	4 8 02	4 8 05	4 8 11	4 9 02
4 3 08	1.000									
4 3 11	0.714	1.000								
4 7 03	0.714	1.000	1.000							
4 7 04	0.714	1.000	1.000	1.000						
4 7 08	0.429	0.714	0.714	0.714	1.000					
4 7 12	0.714	1.000	1.000	1.000	0.714	1.000				
4 8 02	0.714	0.429	0.429	0.429	0.714	0.429	1.000			
4 8 05	0.286	0.357	0.357	0.357	0.643	0.357	0.571	1.000		
4 8 11	0.714	1.000	1.000	1.000	0.714	1.000	0.429	0.357	1.000	
4 9 02	0.286	0.071	0.071	0.071	0.357	0.071	0.571	0.571	0.071	1.000
4 9 03	0.143	0.214	0.214	0.214	0.500	0.214	0.429	0.643	0.214	0.500
4 9 04	0.571	0.643	0.643	0.643	0.357	0.643	0.286	0.714	0.643	0.286
4 9 09	0.429	0.714	0.714	0.714	1.000	0.714	0.714	0.643	0.714	0.357
4 9 11	0.429	0.500	0.500	0.500	0.214	0.500	0.143	0.357	0.500	0.214
4 9 12	0.429	0.714	0.714	0.714	1.000	0.714	0.714	0.643	0.714	0.357
4 9 13	1.000	0.714	0.714	0.714	0.429	0.714	0.714	0.286	0.714	0.286
4 9 17	0.429	0.500	0.500	0.500	0.214	0.500	0.143	0.357	0.500	0.214
4 9 18	0.143	0.214	0.214	0.214	0.500	0.214	0.429	0.643	0.214	0.500
4 9 19	0.286	0.071	0.071	0.071	0.357	0.071	0.571	0.571	0.071	1.000
4 9 22	1.000	0.714	0.714	0.714	0.429	0.714	0.714	0.286	0.714	0.286
5 7 02	1.000	0.714	0.714	0.714	0.429	0.714	0.714	0.286	0.714	0.286
5 8 01	0.286	0.071	0.071	0.071	0.357	0.071	0.571	0.571	0.071	1.000
5 8 02	0.571	0.357	0.357	0.357	0.071	0.357	0.286	0.286	0.357	0.714
5 9 01	0.286	0.071	0.071	0.071	0.357	0.071	0.571	0.571	0.071	1.000
5 9 06	0.571	0.643	0.643	0.643	0.357	0.643	0.286	0.714	0.643	0.286
5 9 07	0.286	0.357	0.357	0.357	0.643	0.357	0.571	1.000	0.357	0.571
5 9 08	0.714	0.429	0.429	0.429	0.714	0.429	1.000	0.571	0.429	0.571

	4 9 03	4 9 04	4 9 09	4 9 11	4 9 12	4 9 13	4 9 17	4 9 18	4 9 19	4 9 22
4 9 03	1.000									
4 9 04	0.357	1.000								
4 9 09	0.500	0.357	1.000							
4 9 11	0.714	0.643	0.214	1.000						
4 9 12	0.500	0.357	1.000	0.214	1.000					
4 9 13	0.143	0.571	0.429	0.429	0.429	1.000				
4 9 17	0.714	0.643	0.214	1.000	0.214	0.429	1.000			
4 9 18	1.000	0.357	0.500	0.714	0.500	0.143	0.714	1.000		
4 9 19	0.500	0.286	0.357	0.214	0.357	0.286	0.214	0.500	1.000	
4 9 22	0.143	0.571	0.429	0.429	0.429	1.000	0.429	0.143	0.286	1.000
5 7 02	0.143	0.571	0.429	0.429	0.429	1.000	0.429	0.143	0.286	1.000
5 8 01	0.500	0.286	0.357	0.214	0.357	0.286	0.714	0.500	1.000	0.286
5 8 02	0.214	0.571	0.071	0.500	0.071	0.571	0.500	0.214	0.714	0.571
5 9 01	0.500	0.286	0.357	0.214	0.357	0.286	0.214	0.500	1.000	0.286
5 9 06	0.357	1.000	0.357	0.643	0.357	0.571	0.643	0.357	0.286	0.571
5 9 07	0.643	0.714	0.643	0.357	0.643	0.286	0.357	0.643	0.571	0.286
5 9 08	0.429	0.286	0.714	0.143	0.714	0.714	0.143	0.429	0.571	0.714

	5 7 02	5 8 01	5 8 02	5 9 01	5 9 06	5 9 07	5 9 08
5 7 02	1.000						
5 8 01	0.286	1.000					
5 8 02	0.571	0.714	1.000				
5 9 01	0.286	1.000	0.714	1.000			
5 9 06	0.571	0.286	0.571	0.286	1.000		
5 9 07	0.286	0.571	0.286	0.571	0.714	1.000	
5 9 08	0.714	0.571	0.286	0.571	0.286	0.571	1.000

Table IV - Q-mode correlation matrix of nominal data produced by SIMQUAL program (Table III) with Dice coefficient of similarity. Q-mode dendrogram in Fig. 12 was produced from this matrix.

Table V

	LC L RCD	LC T RCD	SHFT WCD	SHFT SCD	UMR SPRN	UMR MPRN	UMR GPRN	UMR RUPS	UMR RECT	VIR ST/P
LC L RCD	1.000									
LC T RCD	0.0	1.000								
SHFT WCD	0.327	0.799	1.000							
SHFT SCD	0.500	0.267	0.0	1.000						
UMR SPRN	0.125	0.0	0.057	0.0	1.000					
UMR MPRN	0.900	0.231	0.259	0.789	0.0	1.000				
UMR GPRN	0.0	0.897	0.867	0.0	0.0	0.0	1.000			
UMR RUPS	0.259	0.901	0.904	0.231	0.0	0.441	0.900	1.000		
UMR RECT	0.696	0.0	0.048	0.667	0.222	0.500	0.0	0.0	1.000	
VIR ST/P	0.311	0.742	0.750	0.279	0.0	0.520	0.607	0.870	0.0	1.000
VIR STGT	0.452	0.375	0.360	0.483	0.0	0.389	0.429	0.327	0.583	0.0
VIR PRJD	0.125	0.0	0.057	0.0	1.000	0.0	0.0	0.0	0.222	0.0
DST EQ/A	0.500	0.267	0.299	0.462	0.0	0.789	0.0	0.500	0.0	0.605
MOD EQ/A	0.452	0.375	0.360	0.483	0.0	0.389	0.429	0.327	0.583	0.0
CLS EC/A	0.125	0.0	0.057	0.0	1.000	0.0	0.0	0.0	0.222	0.0
APPRXMTD	0.0	0.694	0.667	0.0	0.0	0.0	0.701	0.607	0.0	0.773
N BULLAE	0.061	0.690	0.692	0.0	0.105	0.0	0.773	0.596	0.077	0.703
GT PRND	0.500	0.267	0.299	0.462	0.0	0.789	0.0	0.500	0.0	0.605
MD PRND	0.452	0.375	0.360	0.483	0.0	0.389	0.429	0.327	0.583	0.0
N BULLAE	0.061	0.680	0.692	0.0	0.105	0.0	0.773	0.596	0.077	0.708
* DSTNT	0.066	0.0	0.297	0.519	0.0	0.326	0.0	0.264	0.676	0.219
**DSTNT	0.0	0.316	0.0	0.672	0.0	0.462	0.0	0.267	0.0	0.333
NORMAL	0.0	0.439	0.419	0.0	0.0	0.0	0.514	0.375	0.0	0.0
NO NODES	0.509	0.722	0.892	0.264	0.0	0.467	0.789	0.835	0.292	0.655
NODES	0.125	0.0	0.057	0.0	1.000	0.0	0.0	0.0	0.222	0.0
NDSEBUL	0.0	0.316	0.0	0.632	0.0	0.462	0.0	0.267	0.0	0.333
APRTR NI	0.327	0.799	1.000	0.0	0.057	0.259	0.867	0.904	0.048	0.750
APRTR DP	0.500	0.267	0.0	1.000	0.0	0.789	0.0	0.231	0.667	0.279
*ROBUST	0.421	0.545	0.596	0.333	0.0	0.465	0.531	0.613	0.259	0.566
*SLENDER	0.359	0.607	0.586	0.379	0.090	0.455	0.520	0.635	0.250	0.556
*INVOLUT	0.421	0.545	0.596	0.333	0.0	0.465	0.531	0.613	0.259	0.566
*EVOLUTE	0.359	0.607	0.586	0.379	0.090	0.455	0.520	0.635	0.250	0.556
*UM SWI	0.421	0.545	0.596	0.333	0.0	0.465	0.531	0.613	0.259	0.566
*UM NSWI	0.359	0.607	0.586	0.379	0.090	0.455	0.520	0.635	0.250	0.556
*UM DEEP	0.421	0.545	0.596	0.333	0.0	0.465	0.531	0.613	0.259	0.566
*UM SHAL	0.359	0.607	0.596	0.379	0.080	0.455	0.520	0.635	0.250	0.556

Table V (cont'd)

```
              VIR STGT    VIR PRJD    DST EQ/A    MOD EQ/A    CLS EQ/A    APPRXMTD    N BULLAE    GT PRND     MD PRND     N BULLAE
  VIR STGT    1.000
  VIR PRJD    0.0         1.000
  DST EQ/A    0.0         0.0         1.000
  MOD EQ/A    1.000       0.0         0.0         1.000
  CLS EQ/A    0.0         1.000       0.0         0.0         1.000
  APPRXMTD    0.0         0.0         0.0         0.0         0.0         1.000
  N BULLAE    0.0         0.105       0.0         0.0         0.105       0.971       1.000
   GT PRND    0.0         0.0         1.000       0.0         0.0         0.0         0.0         1.000
   MD PRND    1.000       0.0         0.0         1.000       0.0         0.0         0.0         0.0         1.000
  N BULLAE    0.0         0.105       0.0         0.0         0.105       0.971       1.000       0.0         0.0         1.000
   * DSTNT    0.467       0.0         0.519       0.467       0.0         0.0         0.0         0.519       0.467       0.0
   **DSTNT    0.0         0.0         0.632       0.0         0.0         0.0         0.0         0.632       0.0         0.0
    NORMAL    0.720       0.0         0.0         0.720       0.0         0.0         0.0         0.0         0.720       0.0
  NO NODES    0.571       0.0         0.264       0.571       0.0         0.596       0.586       0.264       0.571       0.586
     NODES    0.0         1.000       0.0         0.0         1.000       0.0         0.105       0.0         0.0         0.105
  NDS&BUL     0.0         0.0         0.632       0.0         0.0         0.0         0.0         0.632       0.0         0.0
  APRTR NL    0.360       0.057       0.298       0.360       0.057       0.667       0.692       0.298       0.360       0.692
  APRTR DP    0.483       0.0         0.462       0.483       0.0         0.0         0.0         0.462       0.483       0.0
  *ROBUST     0.410       0.0         0.333       0.410       0.0         0.450       0.439       0.333       0.410       0.439
  *SLENDER    0.400       0.080       0.378       0.400       0.080       0.390       0.429       0.378       0.400       0.429
  *INVOLUT    0.410       0.0         0.333       0.410       0.0         0.450       0.439       0.333       0.410       0.439
  *EVOLUTE    0.400       0.080       0.378       0.400       0.080       0.390       0.429       0.378       0.400       0.429
  *UM  SWL    0.410       0.0         0.333       0.410       0.0         0.450       0.439       0.333       0.410       0.439
  *UM NSWL    0.400       0.090       0.378       0.400       0.080       0.390       0.429       0.373       0.400       0.429
  *UM DEEP    0.410       0.0         0.333       0.410       0.0         0.450       0.439       0.333       0.410       0.439
  *UM SHAL    0.400       0.090       0.379       0.400       0.090       0.390       0.429       0.379       0.400       0.429


              * DSTNT     **DSTNT     NORMAL      NO NODES    NODES       NDS&BUL     APRTR NL    APRTR DP    *ROBUST     *SLENDER
   * DSTNT    1.000
   **DSTNT    0.0         1.000
    NORMAL    0.0         0.0         1.000
  NO NODES    0.519       0.0         0.367       1.000
     NODES    0.0         0.0         0.0         0.0         1.000
  NDS&BUL     0.0         1.000       0.0         0.0         0.0         1.000
  APRTR NL    0.292       0.0         0.419       0.892       0.057       0.0         1.000
  APRTR DP    0.519       0.632       0.0         0.264       0.0         0.632       0.0         1.000
  *ROBUST     0.432       0.138       0.250       0.667       0.0         0.138       0.596       0.333       1.000
  *SLENDER    0.316       0.267       0.303       0.594       0.080       0.267       0.586       0.378       0.0         1.000
  *INVOLUT    0.432       0.138       0.250       0.667       0.0         0.138       0.596       0.333       1.000       0.0
  *EVOLUTE    0.316       0.267       0.303       0.594       0.080       0.267       0.586       0.378       0.0         1.000
  *UM  SWL    0.432       0.139       0.250       0.667       0.0         0.139       0.596       0.333       1.000       0.0
  *UM NSWL    0.316       0.267       0.303       0.594       0.080       0.267       0.586       0.378       0.0         1.000
  *UM DEEP    0.432       0.139       0.250       0.667       0.0         0.138       0.596       0.333       1.000       0.0
  *UM SHAL    0.316       0.267       0.303       0.594       0.080       0.267       0.586       0.379       0.0         1.000


              *INVOLUT    *EVOLUTE    *UM  SWL    *UM NSWL    *UM DEEP    *UM SHAL
  *INVOLUT    1.000
  *EVOLUTE    0.0         1.000
  *UM  SWL    1.000       0.0         1.000
  *UM NSWL    0.0         1.000       0.0         1.000
  *UM DEEP    1.000       0.0         1.000       0.0         1.000
  *UM SHAL    0.0         1.000       0.0         1.000       0.0         1.000
```

Table V - R-mode correlation matrix of nominal data produced by SIMQUAL program (Table III) with Dice coefficient of similarity. The R-mode dendrogram in Fig. 12 was produced from this matrix.

Table VI

	4 1 02	4 1 12	4 1 13	4 1 19	4 1 24	4 1 26	4 1 28	4 1 30	4 1 35	4 1 49
4 1 02	1.000									
4 1 12	0.377	1.000								
4 1 13	-0.075	-0.295	1.000							
4 1 19	-0.959	-0.260	0.100	1.000						
4 1 24	-0.415	0.410	-0.014	0.554	1.000					
4 1 26	0.803	0.047	-0.155	-0.906	-0.742	1.000				
4 1 28	-0.946	-0.149	0.024	0.925	0.572	-0.421	1.000			
4 1 30	0.374	-0.304	0.377	-0.490	-0.699	0.632	-0.557	1.000		
4 1 35	-0.724	-0.073	0.303	0.701	0.343	-0.594	0.702	0.028	1.000	
4 1 49	0.908	0.420	-0.312	-0.880	-0.505	0.855	-0.908	0.259	-0.894	1.000
4 1 52	-0.443	-0.594	0.434	0.082	0.396	-0.674	0.396	-0.060	0.862	-0.830
4 1 53	-0.906	-0.277	-0.028	0.050	0.559	-0.840	0.928	-0.420	0.772	-0.900
4 1 54	0.847	0.094	-0.250	-0.670	-0.703	0.429	-0.927	0.517	-0.740	0.095
4 1 56	0.947	0.412	-0.245	-0.930	-0.525	0.899	-0.938	0.324	-0.825	0.979
4 1 59	0.104	0.087	-0.247	-0.059	0.509	-0.230	0.040	-0.052	-0.545	0.259
4 1 67	0.705	0.239	-0.371	-0.745	-0.573	0.750	-0.708	0.100	-0.855	0.045
4 1 90	0.707	0.260	-0.253	-0.797	-0.291	0.690	-0.757	0.105	-0.600	0.555
4 1 92	-0.004	-0.031	0.249	0.011	0.433	-0.551	0.516	-0.034	0.779	-0.598
4 1 93	-0.756	-0.262	-0.10[illegible]	0.60[illegible]	0.465	-0.088	0.746	-0.390	0.605	-0.705
4 3 02	0.501	0.580	-0.207	-0.050	-0.327	0.710	-0.770	0.104	-0.495	-0.070
4 3 08	-0.807	-0.561	0.405	0.051	0.478	-0.778	0.730	-0.210	0.822	-0.069
4 3 11	-0.943	-0.410	0.045	0.016	0.165	-0.721	0.809	-0.251	0.609	-0.042
4 7 03	-0.851	-0.490	-0.021	0.047	0.247	-0.722	0.863	-0.254	0.775	-0.027
4 7 04	-0.513	-0.040	0.064	0.541	-0.225	-0.269	0.422	0.061	0.503	-0.514
4 7 06	0.498	0.470	-0.456	-0.562	-0.347	0.583	-0.452	0.042	-0.551	-0.031
4 7 12	-0.058	0.269	-0.152	0.133	0.008	-0.355	0.159	-0.380	0.159	-0.134
4 8 02	0.846	0.287	-0.249	-0.455	-0.541	0.674	-0.841	0.380	-0.441	0.081
4 8 05	-0.142	0.571	-0.230	0.182	0.640	-0.355	0.281	-0.050	-0.299	-0.076
4 8 11	-0.602	0.160	0.072	0.086	0.455	-0.011	0.772	-0.274	0.844	-0.719
4 9 02	0.755	0.215	-0.012	-0.708	-0.433	0.710	-0.791	0.411	-0.757	0.079
4 9 03	0.300	0.392	[illegible]	-0.2[illegible]1	0.159	0.177	-0.327	-0.342	-0.777	0.54[illegible]
4 9 04	-0.879	-0.220	0.124	0.250	0.717	-0.[illegible]40	0.921	-0.577	0.54[illegible]	-0.074
4 9 05	-0.358	-0.192	-0.357	0.513	-0.10[illegible]	-0.340	0.574	-0.3[illegible]3	0.105	-0.340
4 9 11	-0.755	-0.308	0.125	0.4[illegible]	0.613	-0.752	0.451	-0.519	0.717	-0.42[illegible]
4 9 12	-0.753	0.325	0.15[illegible]	0.249	0.302	-0.379	0.147	-0.415	-0.211	[illegible]43
4 9 13	-0.531	-0.510	0.652	0.384	[illegible]	-0.267	0.447	0.23[illegible]	0.835	[illegible]
4 9 17	-0.[illegible]45	-0.325	0.357	0.510	0.30[illegible]	-0.[illegible]73	0.4[illegible]4	-0.362	0.616	[illegible]
[illegible]	.717	[illegible]	-.11[illegible]	-.7[illegible]	-.4[illegible]	.73[illegible]	-0.445	0.315	-0.427	[illegible]
[illegible]	.554	.77[illegible]	-.2[illegible]	[illegible]	.2[illegible]	.1[illegible]1	-0.2[illegible]9	-0.512	-0.761	[illegible]
[illegible]	-.4[illegible]	-.3[illegible]2	[illegible]	[illegible]	.[illegible]11	-.[illegible]1[illegible]	0.9[illegible]3	-.370	.7[illegible]1	[illegible]
[illegible]	[illegible]	-.[illegible]1[illegible]	[illegible]	[illegible]	.[illegible]07	-.[illegible]9[illegible]	0.[illegible]07	-0.0[illegible]3	[illegible].5[illegible]3	[illegible]

Table VI (cont'd)

	4 1 52	4 1 53	4 1 54	4 1 56	4 1 59	4 1 67	4 1 90	4 1 92	4 1 93	4 3 02
4 1 52	1.000									
4 1 53	0.569	1.000								
4 1 54	-0.624	-0.890	1.000							
4 1 56	-0.650	-0.920	0.925	1.000						
4 1 59	-0.324	-0.124	-0.043	0.192	1.000					
4 1 67	-0.768	-0.781	0.830	0.876	0.232	1.000				
4 1 90	-0.574	-0.732	0.739	0.764	0.179	0.051	1.000			
4 1 92	0.857	0.679	-0.595	-0.709	-0.352	-0.817	-0.406	1.000		
4 1 93	0.500	0.697	-0.723	-0.752	-0.156	-0.604	-0.593	0.601	1.000	
4 3 02	-0.774	-0.773	0.735	0.887	0.309	0.826	0.824	-0.780	-0.582	1.000
4 3 08	0.871	0.715	-0.754	-0.691	-0.149	-0.615	-0.694	0.515	0.456	-0.916
4 3 11	0.601	0.655	-0.706	-0.855	-0.265	-0.597	-0.871	0.447	0.702	-0.793
4 7 03	0.791	0.835	-0.661	-0.649	-0.356	-0.722	-0.647	0.737	0.719	-0.870
4 7 04	0.674	0.595	-0.245	-0.540	-0.718	-0.424	-0.451	0.551	0.395	-0.629
4 7 08	-0.701	-0.510	0.595	0.635	0.151	0.756	0.346	-0.735	-0.421	0.001
4 7 12	0.126	0.155	-0.329	-0.104	0.507	-0.381	0.175	0.554	0.160	-0.128
4 8 02	-0.450	-0.754	0.455	0.694	0.623	0.004	0.676	-0.620	-0.460	[illegible]
4 8 05	-0.301	0.093	-0.275	-0.018	0.350	0.148	-0.150	-0.417	0.038	0.180
4 8 11	0.496	0.472	-0.700	-0.951	-0.294	-0.755	-0.805	0.453	0.845	-0.578
4 9 02	-0.711	-0.691	0.744	0.643	0.017	0.731	0.604	-0.549	-0.520	0.530
4 9 03	-0.434	-0.430	0.511	0.591	0.040	0.582	0.402	-0.650	[illegible]	0.591
4 9 04	0.555	0.061	-0.913	-0.505	0.233	-0.073	-0.725	0.565	[illegible]	-0.765
4 9 09	-0.301	0.493	-0.168	-0.487	-0.139	-0.037	[illegible]	[illegible]	0.345	-0.565
4 9 11	0.554	0.094	-0.804	-0.959	0.065	-0.092	-0.709	0.021	0.703	-0.532
4 9 12	-0.120	-0.101	-0.144	-0.073	0.524	0.062	0.906	[illegible]	-0.301	[illegible]
4 9 13	0.578	0.342	-0.459	[illegible]	-0.551	-0.042	-0.422	0.447	0.206	[illegible]
4 9 17	0.477	0.754	[illegible]	[illegible]	0.147	-0.092	[illegible]	0.591	0.641	[illegible]
4 9 1[illegible]	-0.401	-0.790	[illegible]	0.635	0.152	0.725	0.801	-0.485	-0.594	[illegible]
4 9 [illegible]	[illegible]	-0.433	[illegible]	[illegible]	0.745	[illegible]	0.455	[illegible]	[illegible]	[illegible]
4 9 2[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.245	-0.653	[illegible]	[illegible]	0.752	[illegible]
5 7 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.507	[illegible]	0.855	[illegible]
5 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table VI (cont'd)

```
          4 3 08    4 3 11    4 7 03    4 7 04    4 7 08    4 7 12    4 8 02    4 8 05    4 8 11    4 9 02
4 3 08    1.000
4 3 11    0.926     1.000
4 7 03    0.770     0.846     1.000
4 7 04    0.538     0.610     0.768     1.000
4 7 08   -0.756    -0.455    -0.558    -0.380     1.000
4 7 12    0.239    -0.157     0.108    -0.411    -0.186     1.000
4 8 02   -0.918    -0.087    -0.700    -0.491     0.711    -0.182     1.000
4 8 05   -0.101     0.003    -0.255    -0.037     0.257     0.298    -0.098     1.000
4 8 11    0.425     0.084     0.723     0.587    -0.495     0.106    -0.729    -0.041     1.000
4 9 02   -0.733    -0.020    -0.829    -0.603     0.625    -0.046     0.746    -0.109    -0.703     1.000
4 9 03   -0.401    -0.510    -0.452    -0.500     0.206    -0.171     0.233     0.520    -0.451     0.342
4 9 04    0.748     0.750     0.601     0.230    -0.557     0.310    -0.815     0.410     0.524    -0.773
4 9 09    0.101     0.073     0.563     0.064     0.134    -0.409    -0.298     0.085     0.496    -0.375
4 9 11    0.407     0.844     0.793     0.455    -0.538     0.189    -0.921     0.260     0.561    -0.812
4 9 12    0.116    -0.051    -0.097    -0.213    -0.145     0.152    -0.441     0.506    -0.138    -0.266
4 9 13    0.900     0.380     0.457     0.390    -0.333     0.022    -0.492    -0.380     0.453    -0.400
4 9 17    0.742     0.532     0.547     0.030    -0.596     0.459    -0.765     0.512     0.542    -0.093
4 9 18   -0.738    -0.845    -0.752    -0.481     0.347     0.003     0.717    -0.152    -0.978     0.855
4 9 19   -0.348    -0.497    -0.540    -0.517     0.200     0.662     0.146     0.607    -0.501     0.240
4 9 22    0.705     0.449     0.032     0.044    -0.425     0.017    -0.771     0.004     0.734    -0.040
5 7 02    0.555     0.739     0.704     0.265    -0.501     0.489    -0.727     0.228     0.440    -0.775
5 8 01   -0.345    -0.745    -0.738    -0.072     0.035     0.219     0.714     0.103    -0.371     0.475
5 8 02    0.434     0.710     0.800     0.567    -0.622    -0.141    -0.719    -0.540     0.545    -0.774
5 9 01    0.255     0.119     0.642     0.080    -0.011    -0.395    -0.102    -0.030    -0.421     0.102
5 9 06    0.375     0.774     0.765     0.383    -0.650     0.667    -0.842     0.151     0.901    -0.713
5 9 07   -0.536    -0.724    -0.748    -0.602     0.140     0.225     0.478     0.445    -0.509     0.513
5 9 08   -0.457    -0.044    -0.716    -0.242     0.270    -0.252     0.604    -0.300    -0.673     0.030


          4 9 03    4 9 04    4 9 09    4 9 11    4 9 12    4 9 13    4 9 17    4 9 18    4 9 19    4 9 22
4 9 03    1.000
4 9 04   -0.242     1.000
4 9 09   -0.146     0.254     1.000
4 9 11   -0.255     0.461     0.534     1.000
4 9 12    0.552     0.187    -0.041     0.215     1.000
4 9 13   -0.555     0.337     0.153     0.520    -0.031     1.000
4 9 17   -0.359     0.545     0.255     0.719     0.193     0.543     1.000
4 9 18    0.449    -0.003    -0.407    -0.193    -0.133    -0.364    -0.832     1.000
4 9 19    0.931    -0.156    -0.103    -0.144     0.845    -0.064    -0.324     0.433     1.000
4 9 22   -0.511     0.754     0.848     0.895     0.921     0.490     0.637    -0.770    -0.423     1.000
5 7 02   -0.462     0.881     0.512     0.375     0.184     0.193     0.859    -0.070    -0.209     0.808
5 8 01    0.141    -0.413    -0.82     -0.444    -0.112    -0.190    -0.547     0.510     0.179    -0.517
5 8 02   -0.646     0.54      0.422     0.712    -0.210     0.597     0.450    -0.695    -0.648     0.759
5 9 01    0.114     0.170     0.179     0.283     0.416     0.245     0.202     0.115     0.255     0.219
5 9 06   -0.407     0.927     0.245     0.953     0.140     0.567     0.945    -0.043    -0.375     0.012
5 9 07    0.551    -0.231    -0.602    -0.545     0.127    -0.022    -0.442     0.455     0.627    -0.742
5 9 08    0.373    -0.045    -0.557    -0.405    -0.050    -0.441    -0.838     0.767     0.331    -0.855


          5 7 02    5 8 01    5 8 02    5 9 01    5 9 06    5 9 07    5 9 08
5 7 02    1.000
5 8 01   -0.552     1.000
5 8 02    0.506    -0.435     1.000
5 9 01   -0.178    -0.237     0.191     1.000
5 9 06    0.849    -0.082     0.603    -0.035     1.000
5 9 07   -0.548     0.403    -0.778    -0.170    -0.399     1.000
5 9 08   -0.804     0.360    -0.517    -0.086    -0.800     0.583     1.000
```

Table VI – Q-mode correlation matrix of ordinal data produced by SIMINTV program (Table III) with Cosine Theta option. The Q-mode dendrogram in Fig. 13A was produced from this matrix.

Table VII

	LENGTH	WIDTH	WHORL W	WHORL H	UM WIDTH	HEIGHT W	UM DEPTH	RADII SP	RADII RC	WIDTH AP
LENGTH	1.000									
WIDTH	0.949	1.000								
WHORL W	0.943	0.992	1.000							
WHORL H	0.947	0.997	0.997	1.000						
UM WIDTH	0.903	0.981	0.990	0.987	1.000					
HEIGHT W	0.946	0.995	0.968	0.995	0.978	1.000				
UM DEPTH	0.978	0.979	0.969	0.985	0.966	0.960	1.000			
RADII SP	0.947	0.997	0.991	0.990	0.966	0.973	0.968	1.000		
RADII RC	0.947	0.994	0.959	0.994	0.978	0.995	0.971	0.994	1.000	
WIDTH AP	0.959	0.991	0.970	0.984	0.959	0.987	0.954	0.994	0.955	1.000
HIGHT AP	0.968	0.984	0.964	0.990	0.973	0.957	0.964	0.996	0.996	0.975
LNGTH RC	0.947	0.997	0.954	0.997	0.968	0.993	0.981	0.950	0.943	0.991
# NODES	0.966	0.982	0.943	0.947	0.934	0.982	0.941	0.940	0.959	0.990
# BULLAE	0.906	0.970	0.958	0.955	0.907	0.970	0.915	0.940	0.937	0.968
#UM RIBS	0.955	0.984	0.971	0.980	0.963	0.983	0.953	0.980	0.964	0.983
#V RIBS	0.917	0.980	0.956	0.970	0.938	0.970	0.936	0.950	0.943	0.972
#IN RIBS	0.956	0.959	0.931	0.945	0.913	0.955	0.912	0.946	0.925	0.947

	HIGHT AP	LNGTH RC	# NODES	# BULLAE	#UM RIBS	#V RIBS	#IN RIBS
HIGHT AP	1.000						
LNGTH RC	0.963	1.000					
# NODES	0.95[illegible]	0.980	1.000				
# BULLAE	0.915	0.980	0.996	1.000			
#UM RIBS	0.975	0.980	0.950	0.979	1.000		
#V RIBS	0.943	0.976	0.975	0.991	0.963	1.000	
#IN RIBS	0.910	0.951	0.962	0.974	0.955	0.972	1.000

Table VII - R-mode correlation matrix of ordinal data produced by SIMINTV program (Table III) with Cosine Theta option. The R-mode dendrogram in Fig. 13B was produced from this matrix.

PLATE I

All figures natural size except where indicated.

Arrows point to base of living chambers.

Figures 1-5. _Scaphites carlilensis_ (M) Morrow (p.48).

Side, front, back, and apertural views of a female from locality 1. UKMIP 108774.

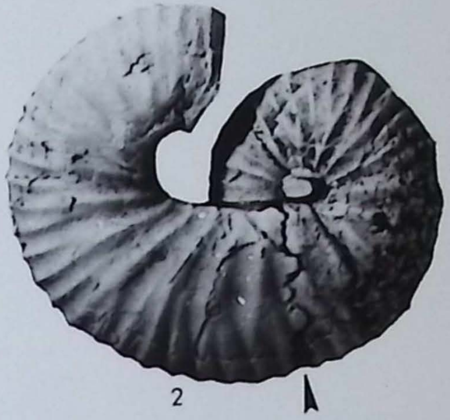
6-11. _Scaphites carlilensis_ (m) Morrow (p.49).

6-10. Side, front, back, apertural, and septate whorl views of male from locality 9. UKMIP 108780.

11. Sagittal section of a male (x1.5) from locality 9. UKMIP 108775.

PLATE I

1



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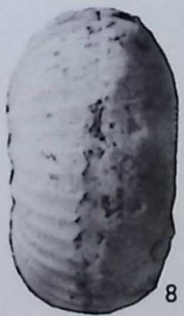

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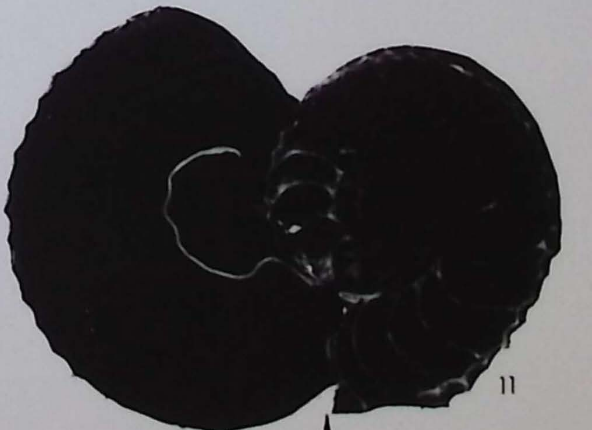

11

PLATE II

All figures natural size. Arrows point to base of living chambers.

Figures 1-2. Scaphites arcadiensis (M) Moreman (p.44)

Side and back views of a female living chamber from locality 1. UKMIP 108765.

3-6. Scaphites arcadiensis (m) Moreman (p.45).

Side, front, back, apertural, and septate whorl views of male from locality 9. UKMIP 108772.

7-12. Scaphites hattini (M) Crick, n. sp. (p.53).

Side, front, back, apertural, and septate whorl views of female from locality 9. Holotype UKMIP 108807.

13-18. Scaphites hattini (m) Crick, n. sp. (p.54).

Side, front, back, apertural, and septate whorl views of male from locality 9. Holotype UKMIP 108811.

PLATE 11


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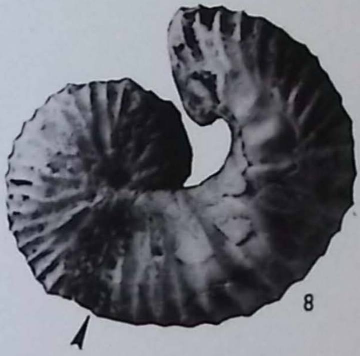
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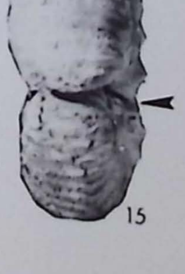
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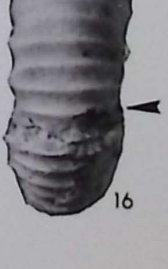
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17

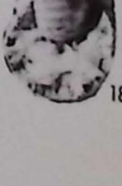
18

PLATE III

All figures natural size. Arrows point to base of living chambers.

Figures 1-4. Scaphites kansiensis (m) Crick, n. sp. (p.57). Side, front, and back views of a male from locality 1. Holotype UKMIP 108770.

5-9. Scaphites mitchellensis (M) Crick, n. sp. (p.60). Side, back, apertural, and septate whorl views of a female from locality 9. Holotype UKMIP 108783.

10-11. Scaphites mitchellensis (m) Crick, n. sp. (p.61).

10. Side view of a male living chamber from locality 9. Holotype UKMIP 108787.

11. Side view of smaller make from locality 1. Paratype UKMIP 108789.

PLATE III

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Plate IV

All figures natural size except where indicated.

Arrows point to base of living chambers.

Figures 1-6. Scaphites inflexus (M) Crick, n. sp. (p.64).

1-3. Side, sagittal (X1.5), and back views of a large female from locality 1. Holotype UKMIP 108790.

4-6. Side and back views of a smaller female from locality 9. Paratype UKMIP 108806.

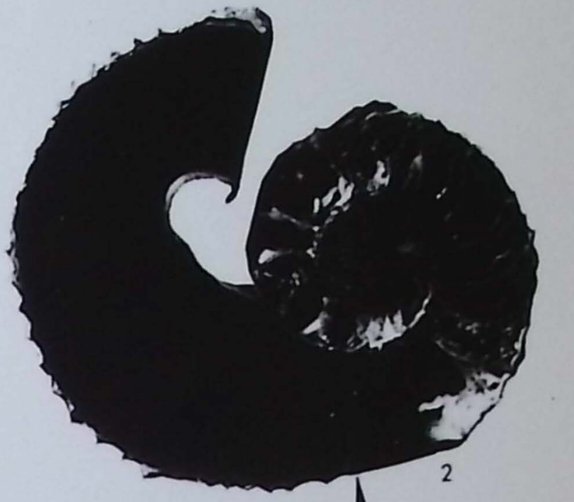
7-11, Scaphites inflexus (m) Crick, n. sp. (p.65).

7. Side view of a male from locality 1. Holotype UKMIP 108793.

8-11. Side, back, and apertural views of a male from locality 1. Paratype UKMIP 108792.

PLATE IV


1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