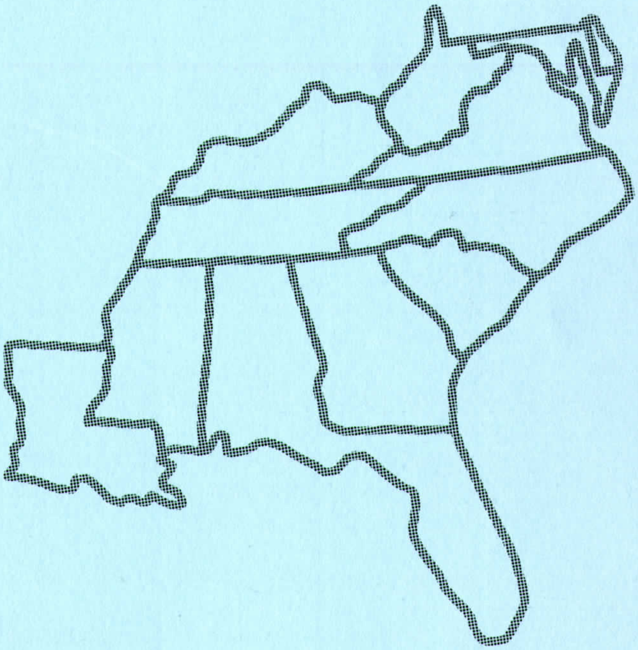
Southeastern Geology: Volume 13, No. 4
December 1971

Edited by: S. Duncan Heron, Jr.

Abstract

Academic journal published quarterly by the Department of Geology, Duke University.

SOUTHEASTERN GEOLOGY



PUBLISHED AT DUKE UNIVERSITY DURHAM, NORTH CAROLINA

VOL. 13 NO. 4 DECEMBER, 1971

SOUTHEASTERN GEOLOGY

PUBLISHED QUARTERLY

AT

DUKE UNIVERSITY

This journal welcomes original papers on all phases of geology, geophysics, and geochemistry as related to the Southeast. Transmit manuscripts to S. DUNCAN HERON, JR., BOX 6665, COLLEGE STATION, DURHAM, NORTH CAROLINA. Please observe the following:

(1) Type the manuscript with double space lines and submit in duplicate.
(2) Cite references and prepare bibliographic lists in accordance with the method found within the pages of this journal.
(3) Submit line drawings and complex tables as finished copy.
(4) Make certain that all photographs are sharp, clear, and of good contrast.
(5) Stratigraphic terminology should abide by the Code of Stratigraphic Nomenclature (AAPG, v. 45, 1961).

Proofs will not be sent authors unless a request to this effect accompanies the manuscript.

Reprints must be ordered prior to publication. Prices are available upon request.

* * * * * *

Subscriptions to Southeastern Geology are $5.00 per volume. Inquiries should be addressed to WM. J. FURBISH, BUSINESS AND CIRCULATION MANAGER, BOX 6665, COLLEGE STATION, DURHAM NORTH CAROLINA. Make check payable to Southeastern Geology.

SOUTHEASTERN GEOLOGY

Table of Contents

Vol. 13, No. 4

1971

POST-YORKTOWN EROSIONAL SURFACE, PAMLICO RIVER AND SOUND, NORTH CAROLINA

By

Charles W. Welby
Department of Geosciences
North Carolina State University at Raleigh
Raleigh, North Carolina

ABSTRACT

Results of a High Resolution Boomer survey in the Pamlico River and in Pamlico Sound show that the Pamlico and Pungo Rivers follow depressions eroded into the Yorktown Formation during post-Miocene time. Pleistocene sediments provide the fill for the channels. Paleotopography appears to have influenced the ultimate location of some of the present-day shoal areas, and it is speculated that the positions of Ocracoke Island and Ocracoke Inlet may be related to the configuration of the erosion surface etched into the Yorktown beds. The convex-to-the-sea form of the Outer Banks north of Cape Hatteras may be related to the presence of an erosional high extending eastward from the Pungo River.

INTRODUCTION

Outcrops of the Late Miocene Yorktown Formation are scattered over a large area of the Atlantic Coastal Plain in northeastern North Carolina. East of the main outcrop belt (Stuckey, 1958) wells and pits encounter the formation at varying depths beneath the present land surface, and, in general, the exact configuration of the contact between the Yorktown and the overlying deposits is not known. Results from a High Resolution Boomer study of the Pamlico River-Pamlico Sound area of North Carolina (Figure 1) permit description of the erosion surface developed on the Yorktown beds and a discussion of the influence of post-Miocene, and presumably pre-Pleistocene erosion, on post-Miocene sedimentation and on the present geomorphology. The boundaries of the area surveyed are indicated by the limits to the contours of Figure 2.

In 1967 and 1969 High Resolution Boomer surveys utilizing equipment owned by Edgerton, Germerhausen, and Greer were made in the Pamlico River and in Pamlico Sound. A total of approximately 700 line-miles of continuous profiles were obtained. Well logs from

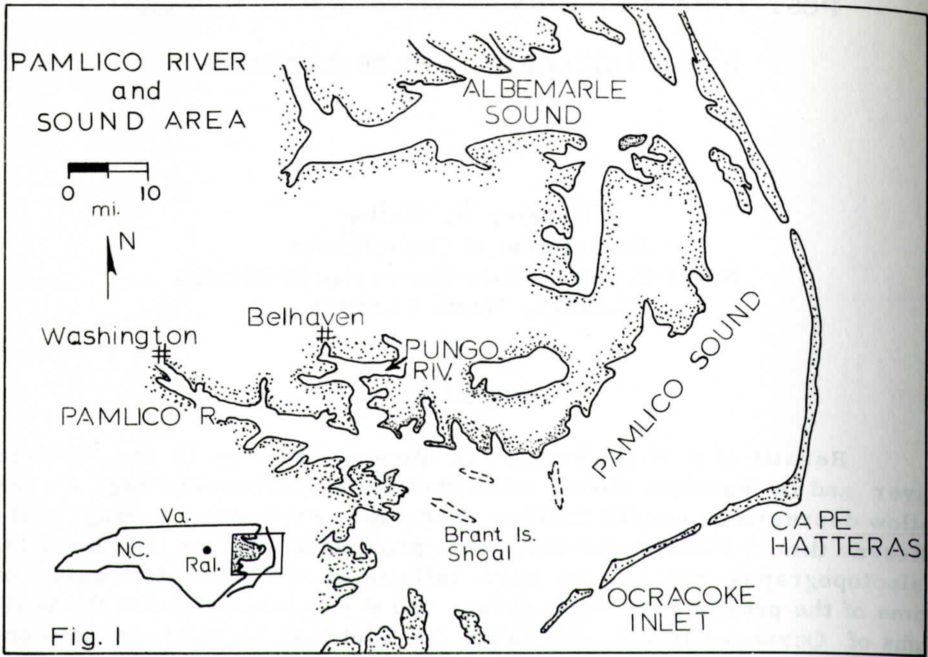


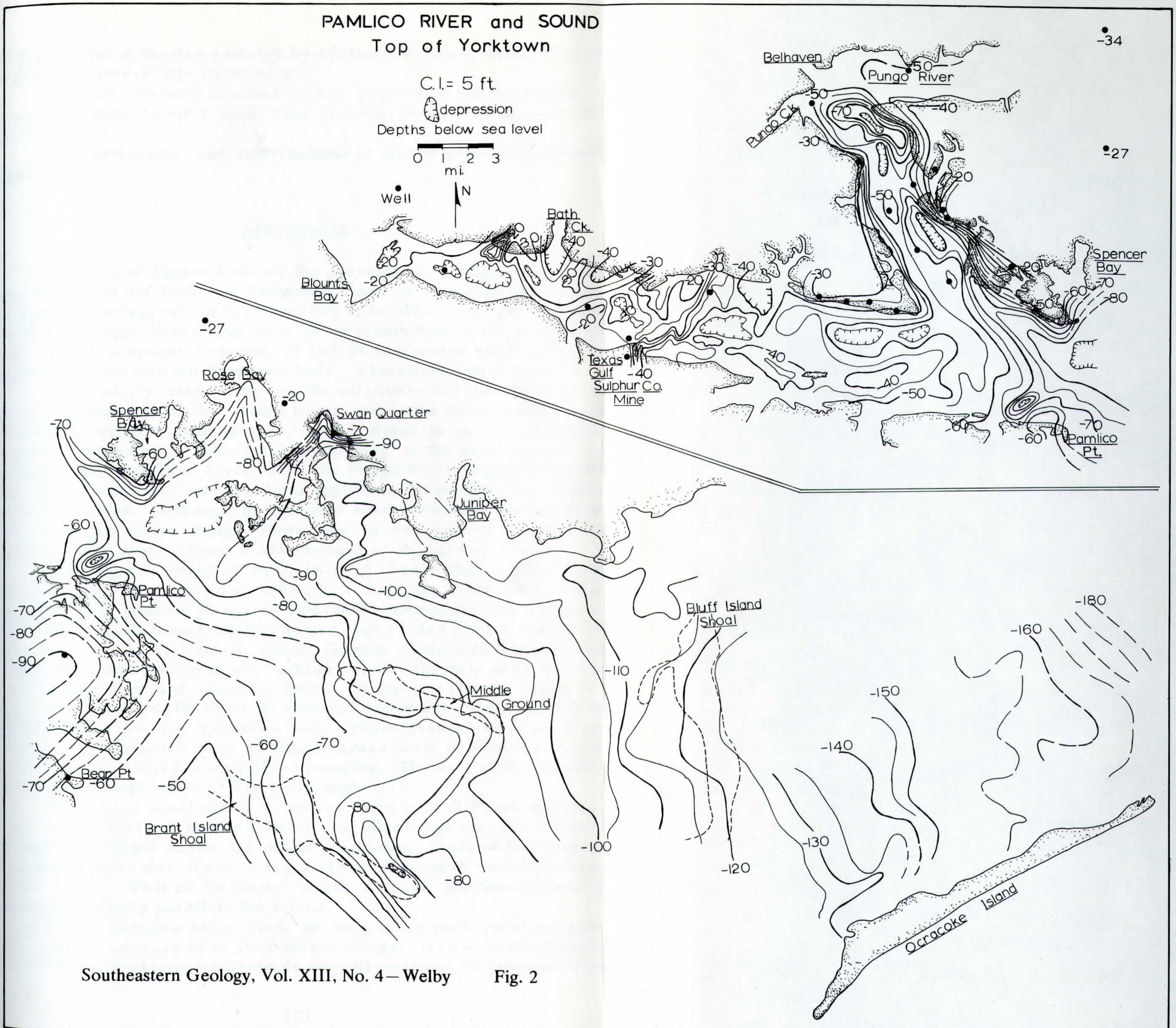
Figure 1. Pamlico River and Sound area.

published sources (Kimery, 1965) as well as information supplied by Texas Gulf Sulphur Company, F. M. C. Corporation, and Dresser Minerals were utilized in identifying the reflector that marks the top of the Yorktown Formation in the region. Traverses were run to wells drilled in the Pamlico and Pungo Rivers and close inshore near wells drilled on land. The top of the Yorktown Formation is a good reflector throughout the area studied, and little difficulty was found in tracing it away from the well control. Near the eastern edge of the area the depth to the top of the Yorktown caused the reflection to be weak although it is still recognizable at depths of 150 to 180 feet.

Acknowledgments

The financial support given by the North Carolina Board of Science and Technology and Texas Gulf Sulphur Company to the author and C. J. Leith (Welby and Leith, 1968) made possible the 1967 work in the Pamlico River, and a grant to the author from the National Science Foundation (Grant No. 10692) made possible the work in the Pungo River and in Pamlico Sound in 1969.

Several people have contributed ideas and information to various parts of the overall project: C. J. Leith, J. M. Hird, G. Harrigan, P. M. Brown, and J. Sampair. R. B. Daniels and E. Gamble of the U. S.


PAMLICO RIVER and SOUND
Top of Yorktown
C.I.= 5 ft.
depression
Depths below sea level
0 1 2 3
mi.
N
Well
Belhaven
Pungo River
Pungo Ck.
Bath Ck.
Blounts Bay
Texas Gulf Sulphur Co. Mine
Spencer Bay
Pamlico Pt.
Rose Bay
Swan Quarter
Juniper Bay
Bluff Island Shoal
Middle Ground
Bear Pt.
Brant Island Shoal
Ocracoke Island

Soil Conservation Service assisted by drilling five power auger holes in the Swan Quarter-Pungo River area.

Students who have assisted in data acquisition and record interpretation include Lewis Brown, John Watson, Bobby Wilson, and John Sherrill.

The assistance and contributions of all are gratefully acknowledged.

DISCUSSION

The map of Figure 2 shows the present-day configuration of the contact between the Yorktown Formation and the overlying sediments. Relief on the surface varies from locality to locality but is greater adjacent to the Pungo River and east of its mouth than in the area to the west. Relief averages between 40 and 50 feet where erosion has cut relatively deeply into the Yorktown beds. Elsewhere relief is less.

Particularly noteworthy are the relatively narrow channels cut into the Yorktown along the Pungo River and in the Swan Quarter area and the general restriction of the Pamlico River to an area channeled into the Yorktown beds. The local steepening of the gradient near the junction of the Pamlico River with the Pungo River suggests that the Pungo River may have been the dominant stream at the time the surface was being eroded. Although no Boomer traverses were run eastward from Belhaven in the Pungo River, sparse well control suggests that this part of the river follows a well-defined erosional depression.

Well log data supplied by J. Hird of Texas Gulf Sulphur Company (personal communication, 1969), by J. Sampair of the North Carolina Division of Mineral Resources (personal communication, 1970), together with information from five power auger holes drilled east of the Pungo River by R. B. Daniels and E. Gamble of the Soil Conservation Service show that the top of the Yorktown rises abruptly near the edge of the Pungo River and Pamlico Sound. It appears that the major indentations on the north shore of Pamlico Sound are related to stream valleys carved into the Yorktown beds. These channel-ways were apparently drainage paths from the higher areas north of Pamlico Sound into the Pamlico River-Pungo River complex. The axis of the complex lies near the north shore of Pamlico Sound.

Two major shoal areas in the western part of Pamlico Sound, Brant Island Shoal and Middle Ground, are situated geographically over and near local highs on the top of the Yorktown. Study of the Boomer records indicates that these irregularities influenced post-Yorktown sedimentation. West of Ocracoke Island a local, northeast-trending high approximately parallels the island.

In the Pamlico Sound area, the bulk of the post-Yorktown geologic column appears to be Pleistocene in age. It is believed that the erosion of the Yorktown occurred during Pliocene and Pleistocene time.

The exact dating of the period of erosion requires more information about the age of the sediments lying directly upon the erosion surface in the Swan Quarter area and beneath Pamlico Sound.

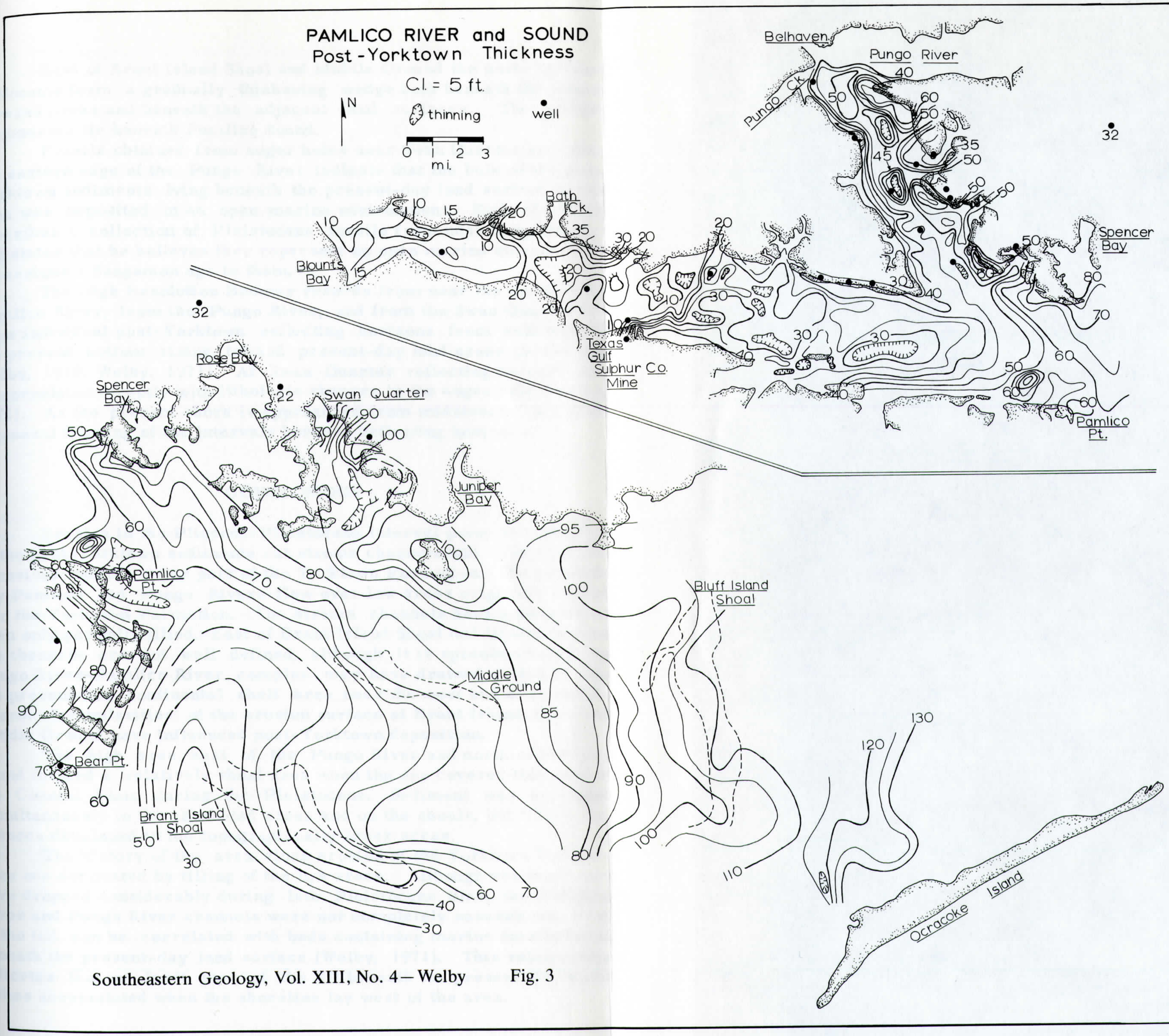
The lowest post-Yorktown sediments of the Brant Island Shoal area pinchout against the high. Where individual reflecting horizons can be traced across Brant Island Shoal, intervals between two horizons usually thin beneath the shoals. Also the horizons are slightly higher in the vicinity of the shoals than they are to the north. The reflecting horizon marking the base of the present shoals, both Brant Island Shoal and Middle Ground, is slightly higher beneath the present shoals than in adjacent areas.

The picture in the Middle Ground area is less clear. However, the individual intervals between reflecting horizons appear to thin where they cross beneath Middle Ground, and the depressions on the Yorktown surface, shown in Figure 2, appear as low areas on various local reflecting horizons as well as on reflecting horizons that extend away from the Middle Ground area.

Although the present configurations of Brant Island Shoal and Middle Ground cannot be attributed directly to the relief at the top of the Yorktown, it appears that the topography etched into the Yorktown beds has indirectly exercised some control on the location of these two shoals. In general, the effects of the irregularities at the top of the Yorktown decrease upward in the section.

Well data supplied by J. Sampair (personal communication, 1970) for two wells, one approximately four miles southwest of Pamlico Point and the second at Bear Point west of Brant Island Shoal, indicate that the Yorktown surface reverses from a northerly slope to a southwesterly slope near the western edge of Pamlico Sound. East of Brant Island Shoal and Middle Ground the trend of the Yorktown surface shifts from approximately north to a northwesterly direction with a corresponding change in slope direction from east to northeast.

Figure 3 shows the variations in thickness of the post-Yorktown sediments. In general, the thickness of the post-Yorktown sediments seems to reflect the relief of the erosion surface. Of particular note is the fact that the post-Yorktown sediments thin sharply at or near the boundary between the Pungo River and the adjacent land areas. Near Swan Quarter thinning takes place adjacent to the northern shore of Pamlico Sound. The influence of the topographic irregularities on the erosion surface at Middle Ground and Brant Island Shoal appears chiefly as changes in rates of thickening, reflected in the spacing of the contours on the isopach map across Brant Island Shoal and at the western end of Middle Ground. Along a line from near the center of Brant Island Shoal to a point about two miles west of the west end of Middle Ground the lower approximately one-quarter of the post-Yorktown section pinches out against the eroded Yorktown beds. Data presently available do not permit determination of whether or not the pinchout extends northwestward beyond the latitude of Middle Ground.



Southeastern Geology, Vol. XIII, No. 4—Welby Fig. 3

East of Brant Island Shoal and Middle Ground the post-Yorktown sediments form a gradually thickening wedge both beneath the water-covered areas and beneath the adjacent land surfaces. The greater thicknesses lie beneath Pamlico Sound.

Fossils obtained from auger holes near Swan Quarter and along the eastern edge of the Pungo River indicate that the bulk of the post-Yorktown sediments lying beneath the present-day land surface in this area was deposited in an open marine environment. Richards (1966) describes a collection of Pleistocene fossils from near Swan Quarter and states that he believes they represent an open marine environment. He assigns a Sangamon age to them.

The High Resolution Boomer records from near the mouth of the Pamlico River, from the Pungo River, and from the Swan Quarter area show individual post-Yorktown reflecting horizons from well beneath the present bottom rising toward present-day land areas (Brown and Welby, 1970; Welby, 1971). At Swan Quarter reflecting horizons can be correlated directly with lithologic changes in the auger hole (Welby, 1971). As the present shore is approached from midstream, one finds a general thinning of the intervals between reflecting horizons.

CONCLUSIONS

Erosion in the Pliocene-Pleistocene interval prior to deposition of the post-Yorktown sediments cut stream channels and irregular depressions into the upper part of the Yorktown Formation. The present-day Pamlico and Pungo Rivers flow over low areas originally eroded into the Yorktown Formation. The stream channels have subsequently been only partially filled. East of Brant Island Shoal and Middle Ground, the channels are not well defined, although it is speculated that the Pungo River-Pamlico River complex may have drained eastward onto the present-day continental shelf area near the west end of Ocracoke Island. Irregularities of the erosion surface at Brant Island Shoal and Middle Ground have influenced post-Yorktown deposition.

The high area east of the Pungo River and north of Pamlico Sound formed a relatively shoal area when the sea covered this part of the Coastal Plain during the Pleistocene. Sediment was deposited simultaneously in the channeled areas and on the shoals, but thicker sequences developed in the topographically lower areas.

The history of the area since erosion of the Yorktown beds has been one dominated by filling of the low areas. Although sea level may have dropped considerably during late Pleistocene time, the Pamlico River and Pungo River channels were not completely scoured out. Part of the fill can be correlated with beds containing marine fossils found beneath the present-day land surface (Welby, 1971). This relationship indicates that at least part of the fill beneath the present-day water bodies accumulated when the shoreline lay west of the area.

The current geomorphology of the region reflects the control exercised by the results of the erosional episode occurring between the Miocene and the deposition of the sediments filling the low areas; this fact is especially true of the location of the Pamlico River and the Pungo River and some of the indentations extending northward from Pamlico Sound.

Some interesting speculation arises as a result of the geophysical work and associated investigations. The top of the Yorktown is topographically higher north of Pamlico Sound than beneath the Sound. This relationship appears to extend eastward. Examination of the regional geomorphology shows that the seaward convexity of the Outer Banks barrier islands north of Cape Hatteras occurs opposite the seaward extension of this relative high on the Yorktown beds. Further geophysical work and drilling will be required to prove or disprove the idea, but it is tentatively concluded that the convexity is related to the presence of the high at the top of the Yorktown beds. A structural cause may underlie the presence of the high.

The reversal of the erosional surface slope west of Brant Island Shoal suggests the possibility of faulting in this particular area. The sharp bend in the Pungo River near Belhaven may also reflect a structural feature, for the bend originated during the erosional interval preceding deposition of the post-Miocene sediments.

That the topography of the surface carved into the Yorktown beds is reflected upward through the post-Yorktown sediments was suggested in the discussion of the Brant Island Shoal and Middle Ground areas. The thinning of the post-Yorktown sediments as they rise from beneath the Sound onto the land area in the vicinity of Swan Quarter also records the effects of the Pliocene-Pleistocene erosion. Speculation suggests that the locations of Ocracoke Inlet and Ocracoke Island are related to the paleotopography developed on the Yorktown beds. A high area reflected up through the Pleistocene sediments could be a factor in formation of the island, and a topographically low area would favor location of rivers or tidal channels in it. The contour patterns on both the top of the Yorktown and the post-Yorktown isopach maps lend some credence to this idea.

REFERENCES CITED

Brown, L. H. and C. W. Welby, 1970, Subsurface channels in the Pamlico-Pungo River area: Jour. Elisha Mitchell Scientific Society, v. 86, p. 177.

Kimery, J. O., 1965, Description of the Pungo River Formation in Beaufort County, North Carolina: N. C. Department of Conserv. and Development, Division of Mineral Resources, Bull. No. 79, 131 p.

Richards, H. G., 1966, Notes on five marine Pleistocene localities in northeastern North Carolina: Southeastern Geology, v. 7, p. 135-139.

Stuckey, J. L., 1958, Geologic Map of North Carolina: N. C. Dept. of Conserv. and Development, Division of Mineral Resources.

Welby, C. W. and C. J. Leith, 1968, The bedrock surface beneath the Pamlico River channel, Beaufort County, North Carolina: Final Report to N. C. Board of Science and Technology, 28 p. and maps.

Welby, C. W., 1971, Post-Miocene history of Pamlico Sound: Geol. Society America, Abst. with Programs, v. 3, No. 5, p. 359.

CARTILAGINOUS FISHES OF THE TRINITY GROUP AND RELATED ROCKS (LOWER CRETACEOUS) OF NORTH CENTRAL TEXAS

By

John T. Thurmond*
Shuler Museum of Paleontology
Southern Methodist University

ABSTRACT

Bulk washing of over 20 sites in the Trinity Group (?Aptian-Albian) has produced varied fish faunas, including many specimens of sharks, rays and sawfishes. These are here described and figured in nine taxa, including three new species (Hybodus butleri, Lonchidion anitae, and Hypolophus? mcnultyi) and one new subspecies (Onchopristis dunklei praecursor). The faunas include the latest varied assemblage of hybodont sharks, the earliest hypolophid rays and the earliest sawfishes.

INTRODUCTION

In the course of an intensive search for Albian mammal remains from the Trinity Group of North Central Texas (Patterson, 1951, 1955, 1956; Slaughter, 1965, 1968a, 1968b, 1969; Zangerl and Denison, 1950), the Shuler Museum of Paleontology has collected extensive ichthyofaunas from over 30 sites (Figure 1). More than 20 of these yielded remains of cartilaginous fishes, mostly in the form of isolated teeth. This report describes and illustrates much of this material.

The Trinity Group comprises three formations (Figure 2): the Travis Peak Formation (including the Twin Mountains Formation and lower part of the Antlers Formation of Fisher and Rodda, 1966 and 1967), the Glen Rose Formation and the Paluxy Formation. This study will also cover material from the Walnut Formation, the basal unit of the overlying Fredericksburg Group.

The Travis Peak Formation is a clastic unit, consisting of gravels, sands, siltstones and clays. It is normally considered to be a transgressive unit marking the onset of Trinity deposition. The age is

*Present Address: Department of Geology, Birmingham-Southern College, Birmingham, Alabama.

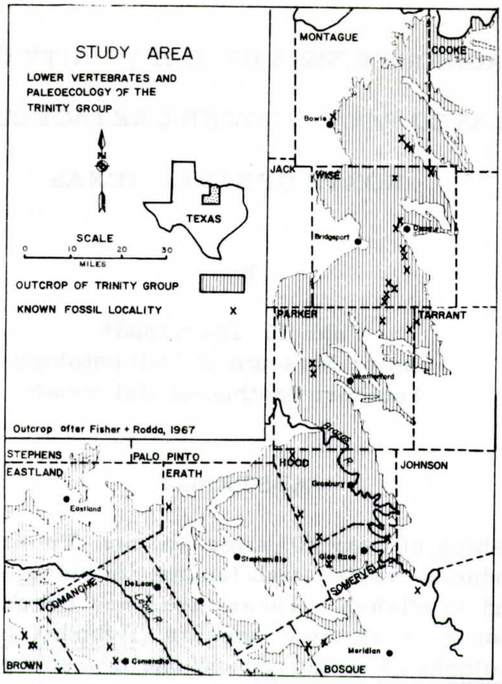


Figure 1. Index map of study area.

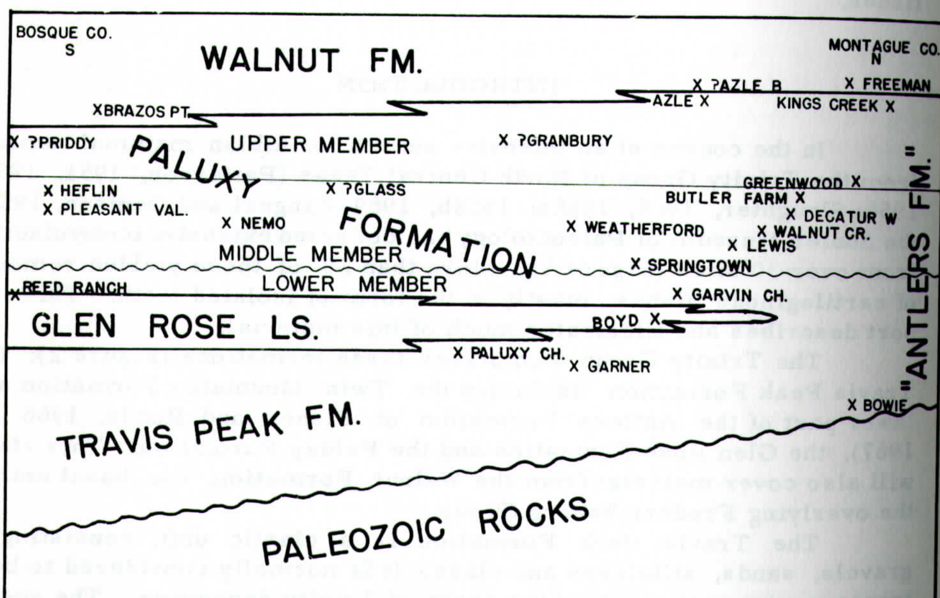


Figure 2. Generalized stratigraphy, Trinity Group, North Central Texas.

debatable: the upper part appears to be earliest Albian while many authors have considered the rest of the unit to be Aptian (Hendricks, 1967).

The Glen Rose Limestone, a predominately carbonate unit, marks the climax of the Trinity transgression and the beginning of the regressive phase. The Paluxy Formation is a complex clastic unit, comprising both the regressive phase of the Trinity and the beginnings of the Fredericksburg transgression. The boundary between the Trinity and Fredericksburg depositional phases is marked by a disconformity that appears both in the stratigraphy (Rodgers, in Hendricks, 1967) and in the fossil records.

Acknowledgments

This work was done under the support of several grants. Collections were made under National Science Foundation grants GB-2092, GB-3805 and GB-6102, and under National Park Service salvage contract 931-142. A museum visitation for comparison of material was supported by a Penrose Fund grant from the Geological Society of America.

LOCALITIES

The sites from which fossil sharks, rays and sawfishes were recovered will be listed by stratigraphic interval, and located by county and by latitude and longitude to the greatest practical precision. Location of all known vertebrate fossil sites in the Trinity Group is shown in Figure 1. In most cases, these data will be sufficient to allow these sites to be found in the field. More precise locality data will be on file at the Shuler Museum of Paleontology, Southern Methodist University. All specimens here described are in the collections of the Shuler Museum, and all catalog numbers refer to that collection.

Travis Peak Formation

Garner local fauna — Parker Co.

32°50'49" N., 97°57'38" W.

- *Hybodus butleri* sp. nov. (62190)
- *Lamna* sp. aff. *L. sulcata* (Geinitz) (62230)
- *Hypolophus? mcnultyi* sp. nov. (62211)
- *Onchopristis* sp. (62199)

Paluxy Church local fauna — Hood Co.

32°16'25" N., 97°54'22" W.

- *Hybodus* sp. aff. *H. parvidens* Woodward (62193-5)
- *Hypolophus? mcnultyi* sp. nov. (62243)

Glen Rose Limestone

Boyd local fauna — Wise Co.

$33^{o}05'09''$ N., $97^{o}31'12''$ W.

Hybodus sp.

Hypolophus ? mcnultyi sp. nov. (62226)

Paluxy Formation

Lower Paluxy — Bosque Co.

Reed Ranch local fauna

$31^{o}57'06''$ N., $97^{o}53'22''$ W.

Lamna sp. aff. L. sulcata (Geinitz) (62231)

Hypolophus? mcnultyi sp. nov. (62218)

Garvin Church local fauna — Wise Co.

$33^{o}04'59''$ N., $97^{o}38'09''$ W.

Hybodus sp.

Hypolophus? mcnultyi sp. nov. (62213)

Middle Paluxy

Butler Farm local fauna — Wise Co.

$33^{o}16'38''$ N., $97^{o}37'30''$ W.

Hybodus butleri sp. nov. (62087, 62150-62186)

Lonchidion anitae sp. nov. (62144-62149)

Lewis local fauna — Wise Co.

$33^{o}08'13''$ N., $97^{o}34'02''$ W.

Hybodus butleri sp. nov. (SMUSMP uncat.)

Hypolophus? mcnultyi sp. nov. (SMUSMP uncat.)

Walnut Creek A local fauna — Wise Co.

$33^{o}09'13''$ N., $97^{o}34'17''$ W.

Hybodus butleri sp. nov. (62189)

Hypolophus? mcnultyi sp. nov. (62215)

Keeter local fauna — Wise Co.

$33^{o}02'03''$ N., $97^{o}36'04''$ W.

Lamna sp. aff. L. sulcata (Geinitz) (SMUSMP uncat.)

Hypolophus? mcnultyi sp. nov. (62220)

Springtown local fauna — Parker Co.

$32^{o}56'49''$ N., $97^{o}41'22''$ W.

Hybodus sp. aff. H. parvidens Woodward (62197)

H. sp. cf. H. brevicostatus Patterson (62198)

Lamna sp. aff. L. sulcata (Geinitz) (62229, 62237)

Hypolophus? mcnultyi sp. nov. (62208-62210)

Weatherford local fauna — Parker Co.
32°47'17" N., 97°56'14" W.
Hybodus sp.
Hypolophus? mcnultyi sp. nov. (62214)

Heflin local fauna — Brown Co.
31°52'32" N., 98°54'55" W.
Hybodus sp.
Hypolophus? mcnultyi sp. nov. (62224)

Pleasant Valley local fauna — Brown Co.
31°55'23" N., 98°55'07" W.
Lamna sp. aff. *L. sulcata* (Geinitz) (62234)
Hypolophus? mcnultyi sp. nov. (62225)

Upper Paluxy
Greenwood local fauna — Montague Co.
33°29'49" N., 97°35'04" W.
Hybodus butleri sp. nov. (62188)

Kings Creek local fauna — Montague Co.
33°34'00" N., 97°30'50" W.
Hybodus butleri sp. nov. (62197)
Hypolophus? mcnultyi sp. nov. (62216)

Decatur West local fauna — Wise Co.
33°14'14" N., 97°36'04" W.
Hybodus sp. cf. *H. brevicostatus* Patterson (62238)
? *Lamna* sp.
Hypolophus? mcnultyi sp. nov. (62219)

Paluxy Formation (undifferentiated)
Gerber local fauna — Wise Co.
32°59'52" N., 97°40'46" W.
Hypolophus? mcnultyi sp. nov. (62221)

Granbury local fauna — Hood Co.
32°21'37" N., 97°59'40" W.
Hybodus sp. aff. *H. parvidens* Woodward (62196)
Lamna sp. aff. *L. sulcata* (Geinitz) 62232)

Glass local fauna — Somervell Co.
N side of road cut on U. S. 67, 100 ft. E of bridge over Ice Branch
Hypolophus? mcnultyi sp. nov. (62212)
Onchopristis dunklei praecursor ssp. nov. (62203)

Blanket local fauna Brown Co.
31°47'34" N., 98°49'39" W.

Lamna sp. aff. L. sulcata (Geinitz) SMUSMP uncat.)
Hypolophus? mcnultyi sp. nov. (62228)

Routh A local fauna Brown Co.
31°52'07" N., 98°51'42" W.

Hypolophus? mcnultyi sp. nov. (62222)

Routh B local fauna Brown Co.
31°52'07" N., 98°51'33" W.

Hybodus butleri? sp. nov. (62191)
Lamna sp. aff. L. sulcata (Geinitz) (62235)
Hypolophus? mcnultyi sp. nov. (62223)

Walnut Formation
Brazos Point local fauna Bosque Co.
97°34'52" N., 32°09'03" W.

Hybodus sp.
Lamna sp. cf. L. arcuata Woodward (62227)
L. sp. aff. L. sulcata (Geinitz) (62234, 62236)
Hypolophus? mcnultyi sp. nov. (62217)
Onchopristis dunklei praecursor ssp. nov. (62200-62202)

SYSTEMATIC PALEONTOLOGY

CLASS CHONDRICHTHYES

ORDER SELACHII

Family HYBODONTIDAE

Genus Hybodus Agassiz

Hybodus Agassiz, 1837, iii, 41.
numerous synonyms. See Woodward (1916, p. 3) and Romer (1967, p. 349).

Type species: Hybodus reticulatus Agassiz, by subsequent designation (Woodward, 1916, p. 4).

Diagnosis: See Woodward (1916, p. 4) and Patterson (1966).

Hybodus butleri sp. nov.
(Figures 3-6)

Holotype: Complete tooth, 62150, Butler Farm local fauna.

Referred material: From the type locality: 62151-62179, teeth with roots; 62180-62183, cephalic spines; 62184 and 62186, dorsal fin spines; 62187, several hundred fragmentary teeth. From Greenwood

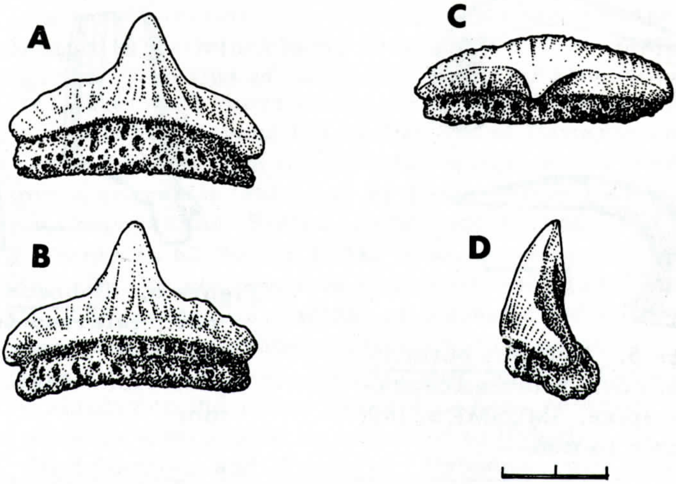


Figure 3. *Hybodus butleri* sp. nov., holotype, SMUSMP 62150, anterior tooth. A. Lingual view; B. labial; C. occlusal; D. lateral. Scale in mm.

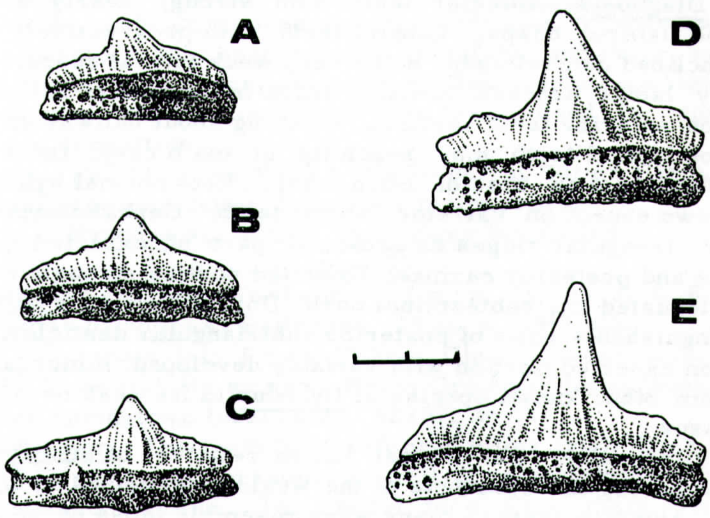


Figure 4. *Hybodus butleri* sp. nov., labial views of paratypes from Butler Farm local fauna (all SMUSMP specimens). A. 62171; B. 62172; C. 62175; D. 62159; E. 62153. Scale in mm.

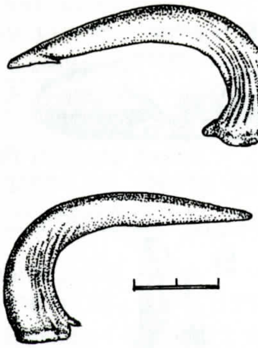


Figure 5. Hybodus butleri sp. nov., referred cephalic spine, SMUSMP 62180. Scale in mm.

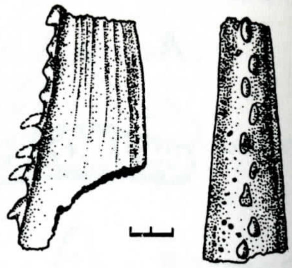


Figure 6. Hybodus butleri sp. nov., referred dorsal spine, SMUSMP 62184, lateral and posterior views. Scale in mm.

local fauna: 62188, teeth. From Walnut Creek A local fauna: 62189, teeth. From Garner local fauna: 62190, two teeth. From Routh B local fauna: 62191, questionably referred tooth fragments. From Kings Creek local fauna: 62192, teeth.

Diagnosis: Anterior teeth with strong, nearly erect central cusp, no lateral cusps. Lateral teeth with progressively weaker and more inclined central cusp, no or very weak lateral cusps, and a rudimentary labial process (usually little more than an enlarged ridge). Striae on anterior teeth vertical, reaching about halfway up main cusp. Striae on lateral teeth may reach tip of main cusp, and 1 or 2 striae may bifurcate near base of main cusp. Root normal hybodont, lower than crown except on extreme lateral teeth. Cephalic spines with trifid base, irregular ridges on proximal part of exserted portion, and anterior and posterior carinae. Exserted portion strongly curved, with very attenuated tip, subterminal barb. Dorsal fin spines with two barely distinguishable rows of posterior subtriangular denticles, 3-5 major striae on exserted portion with variably developed minor striae. Differs from other known species of Hybodus in its weak or absent accessory cusps.

Discussion: The closest known relatives of this species are to be found among the hybodonts of the Wealden described by C. Patterson (1966). Anterior teeth in many ways resemble those of the whole complex of Hybodus basanus, H. ensis and H. parvidens except for differences in the striae and the lack of lateral cusps. In particular, H. butleri seems closely related to H. parvidens Woodward, as indicated by the presence of a labial process, the comparatively coarse striation and the basal bifurcation of some striae.

The material from Butler Farm indicates that some of the spines referred by Patterson (1966) to Lonchidion may belong to some Hybodus, possibly H. parvidens. In particular, a cephalic spine (BMNH P.

47207, Patterson, 1966, fig. 26C) appears identical to Butler Farm specimens. Patterson tentatively restored this spine as comparatively blunt and lacking a subterminal barb, a conclusion that cannot be justified by his figures. The tips of complete Butler Farm spines (62180, Figure 5; 62181) are much more attenuated, and show a subterminal barb placed considerably beyond the broken end of Patterson's specimen. The base is trifid (62182) with the lateral wings much less expanded than in the spines correctly referred by Patterson to Lonchidion. The only difference between the Butler Farm spines and BMNH P. 47207 may be the presence in 62180 and 62182 of an anterior carina on the exserted portion. This is not mentioned by Patterson (1966) for the British material. The posterior carina on cephalic spines of H. butleri ends at the barb, and is not found proximal to that point.

The dorsal fin spines referred to Lonchidion by Patterson (1966) are also very similar to the spines (Figure 6) here referred to Hybodus butleri, and perhaps also should be referred to Hybodus.

Age, Distribution, and Ecology: Hybodus butleri is thus far known only from the Travis Peak (?Aptian-Albian) and Paluxy (lower Albian) Formations in north-central Texas. In general, this species seems to have been restricted to fresh and brackish waters, and is replaced by Hybodus sp. aff. H. parvidens in open marine conditions and to some extent in brackish conditions. At Routh B, however, much worn teeth that are here doubtfully referred to H. butleri are associated with galeoids, indicating open marine conditions. These specimens cannot be referred to this species with certainty, and their worn condition (in contrast to the excellent preservation of other specimens from Routh B) suggests that they may have been transported for some distance prior to deposition.

Name: For Mr. Lee Butler, the owner of Butler Farm, for his extensive and generous cooperation over many years.

Hybodus sp. aff. H. parvidens Woodward

(Figure 7)

Hybodus parvidens Woodward, 1916, p. 12, pl. 2, f. 8-14.

Hybodus parvidens, Patterson, 1966, p. 296-300.

Referred material: From Paluxy Church local fauna: 62193, teeth; 62194-5, dorsal fin spines. From Granbury local fauna: 62196, teeth. From Springtown local fauna, 62197, teeth.

Discussion: The teeth here referred differ from those of Hybodus butleri sp. nov. in the presence of well-developed lateral cusps and more widely spaced striae. The lingual face of the main cusp may be almost smooth, lacking striae. These characters are similar to those which distinguish H. butleri from H. parvidens. The presence of a weak labial process on some teeth also suggests affinities to H. parvidens.

Associated fin spines are again very similar to those of H. butleri, but show more inclined and recuved denticles.

Age, Distribution, and Ecology: H. parvidens ranges, in

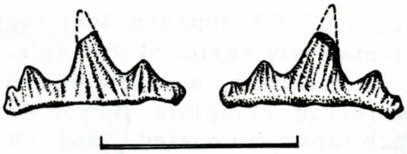


Figure 7. Hybodus sp. aff. H. parvidens Woodward, tooth, SMUSMP 62193, Paluxy Church local fauna. Labial and lingual views. Scale is 5 mm.

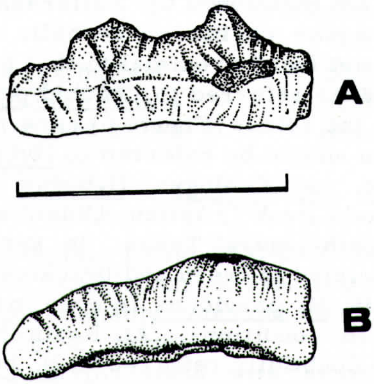


Figure 8. Hybodus sp. cf. H. brevicostatus Patterson. Tooth, SMUSMP 62198, Springtown local fauna. A. occlusal views; B. lingual view. Scale is 5 mm.

England, from the Middle Purbeck to the Weald Clay (Patterson, 1966), while the Trinity specimens are considerably later (Albian). In the Trinity, this form seems to have been fully marine, as galeoids are almost invariably present in the associated fauna. However, the faunas which yield H. sp. aff. H. parvidens also show brackish affinities, indicating that this shark may have been an inhabitant of nearshore waters.

Hybodus sp. cf. H. brevicostatus Patterson
(Figure 8)

Hybodus brevicostatus Patterson, 1966, p. 300-309; fig. 10-13; pl. 3, fig. 1-3; pl. 2.

Referred material: Tooth fragment, 62198, Springtown local fauna; worn tooth crown, 62238, Decatur West local fauna.

Discussion: These fragmentary remains represent a hybodont which cannot be referred to either of the above species. 62238 is a complete, though badly abraded, crown. The cusps are very indistinct, but there are five prominent labial processes. Striae cannot be distinguished on the worn surface. 62198 consists of about a third of a

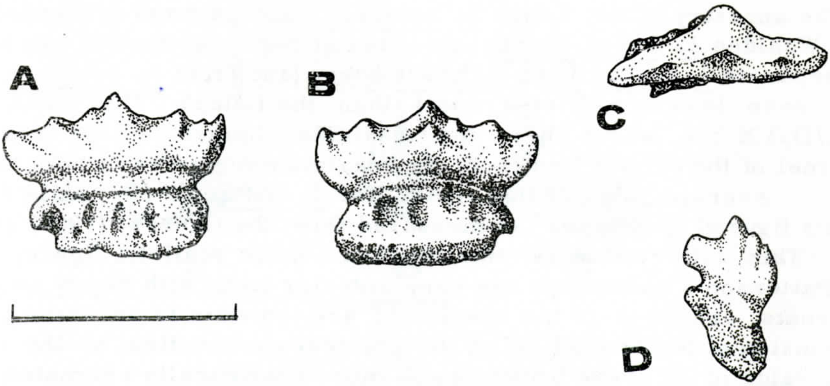


Figure 9. Lonchidion anitae sp. nov., holotype, SMUSMP 62144, tooth, Butler Farm local fauna. A. lingual; B. labial; C. occlusal; D. lateral views. Scale is 1 mm.

tooth, with two indistinct lateral cusps with strong corresponding labial processes. Strong striae radiate from the cusp apices and from the crestal carina of the crown. This pattern of striation and the presence of multiple labial processes suggest that this shark is closely related to H. brevicostatus Patterson, although the latter has much more prominent cusps.

This form is the largest of the Trinity hybodonts, as 62198 would be nearly 1.5 cm in transverse diameter if complete. This is similar to the size of H. brevicostatus. Because this form is exceedingly rare, no attempt will be made to discuss its ecology.

Genus Lonchidion Estes

Lonchidion Estes, 1964, p. 7.
Type species: Lonchidion selachos Estes.
Diagnosis: See Estes (1964) and Patterson (1966)

Lonchidion anitae sp. nov.
(Figure 9)

Holotype: Tooth with root, SMUSMP 62144, Butler Farm local fauna.

Referred material: Five isolated crowns without roots, 62145-62149, Butler Farm local fauna.

Diagnosis: A minute Lonchidion closely resembling L. selachos and L. breve breve Patterson, but differing from both in the greater constriction of the crown base and stronger development of accessory cusps. Lacks ridges on lingual face of crown found in L. breve breve, but not in L. selachos.

Discussion: This is the third report of teeth of the genus Lonchidion. The Butler Farm specimens seem to represent a form close to the ancestry of the Lance L. selachos, and perhaps descended from the Wealden L. breve breve. An index of root constriction can be used to separate L. anitae from L. breve breve (and from L. selachos, which has even less constricted roots than the latter). This index is: $I = (D_b/D_c) \times 100$, where D_b is the maximum diameter at the base of the enamel of the crown, and D_c is the maximum diameter of the crown.

Average value of this index for L. anitae is 66, while Patterson's figured specimens (as measured from the figures) (1966) average 69. This latter value is smaller than a more realistic figure, as two of Patterson's specimens are very anterior teeth with highly constricted roots, and most of his specimens are too worn to preserve a slight expansion of the enamel below the greatest constriction of the crown. The value of L. breve breve can be more realistically estimated at 75, probably larger.

Lonchidion anitae is the smallest species of Lonchidion yet reported, unless Lonchidion rhizon Patterson actually pertains to that genus, a dubious hypothesis (Estes, personal communication). Rather, those specimens may pertain to a primitive skate. The holotype of L. anitae has a maximum diameter of 1.01 mm, and the largest tooth 62149) measures 1.65 mm.

None of the cephalic or dorsal fin spines from Butler Farm seem referrable to Lonchidion (see discussion above).

Age, Distribution, and Ecology: Known only from the middle Paluxy Formation at Butler Farm. Lonchidion is generally agreed to have been restricted to fresh water.

Name: For Miss Anita Freefield (now Anita Thurmond), without whom this study would not have been completed.

Family LAMNIDAE

Genus Lamna Cuvier

Lamna Cuvier, 1817, ii, 126. (fide Woodward, 1894).

Lamna sp. cf. L. arcuata Woodward

(Figure 10)

Lamna arcuata Woodward, 1894, p. 198; pl. vi, fig. 10.

Lamna arcuata, Woodward, 1910, p. 208; pl. xliv, fig. 8-9.

Referred Material: Two teeth, 62227, Brazos Point local fauna.

Discussion: These teeth are very similar to those figured by Woodward (1902-12, pl. xliv, fig. 8-9). Both faces of the crown are smooth, lacking any striations. Normal lamnids, represented by this form, seem to have been late arrivals in Texas; they are represented only at Brazos Point, the latest fauna here considered. Throughout Trinity time, the dominant galeoid in Texas was Lamna sp. aff. L. sulcata (Geinitz).

Lamna sp. aff. L. sulcata (Geinitz)

(Figure 11)

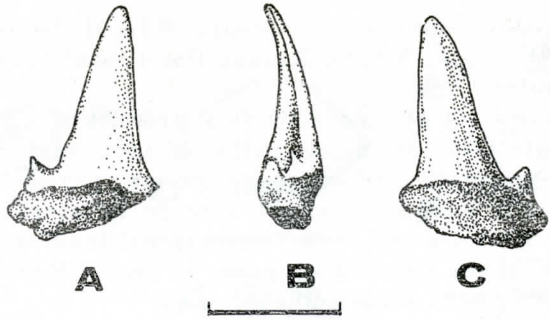


Figure 10. Lamna sp. cf. L. arcuata Woodward, SMUSMP 62227, Brazos Point local fauna. A. labial; B. lateral; C. lingual views. Scale is 5 mm.

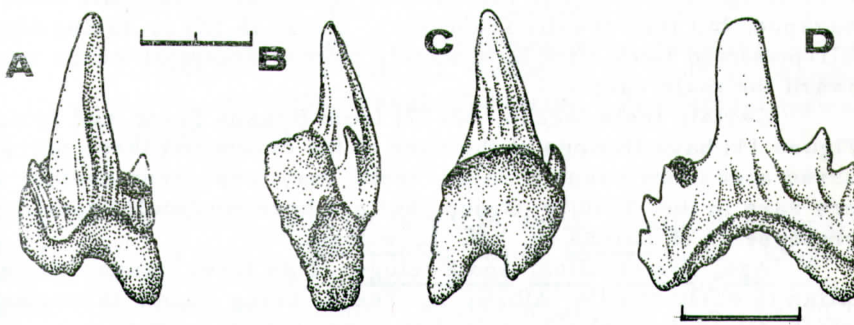


Figure 11. Lamna sp. aff. L. sulcata (Geinitz). Tooth, SMUSMP 62229, Springtown local fauna: A. labial; B. lateral; C. lingual views. D. doubtfully referred ? symphyseal tooth, SMUSMP 62236, Brazos Point local fauna, labial view. Scales in mm.

Otodus sulcatus Geinitz, 1843, Charakt. Schicht. und Petrifakt. sachs. -bohm. Kreidegeb., Nachtr., 5, pl. iv, fig. 2 [fide Woodward, 1910].

Otodus divaricatus Leidy, 1873, p. 305, pl. xviii, fig. 26-28.

Lamna sulcata, Williston, 1900, p. 248; pl. xxiv, fig. 1-1b. Woodward, 1910, p. 209; pl. xliv, fig. 12-13.

Referred material: Teeth of normal type: 62229, Springtown local fauna; 62230, Garner local fauna; 62231, Reed Ranch local fauna; 62232, Granbury local fauna; 62233, Pleasant Valley local fauna; 62234, Brazos Point local fauna; 62235, Routh B local fauna. Doubtfully referred ?symphyseals: 62236, Brazos Point local fauna, 62237, Springtown local fauna.

Diagnosis: A galeoid with two prominent cutting edges on an acute main cusp; one or more pairs of accessory cusps; very strong flutings on both main and accessory cusps, particularly prominent on labial face; main cusp with slight flexure in lateral view, sometimes sigmoidal. Doubtfully referred ?symphyseal teeth with flutings at base of crown only, three pairs of accessory cusps. Roots of normal teeth deeply bifurcate, with strong lingual shelf.

Discussion: The teeth referred here apparently represent a very primitive lamnid, possibly near the ancestry of typical L. sulcata. The flutings are much stronger than those of L. sulcata as figured by Woodward (1902-12), particularly on the lateral cusps, and reach much further up the crown, almost to the tip of the main cusp in some individuals. Also, the flutings are equally coarse across the crown, rather than being finer on the lateral cusps. A few individuals show an additional accessory cusp that is very weak, and this cusp may be worn off on other specimens. The accessory cusps are generally blunt in appearance, but this results from wear, either in life or during deposition. Well-preserved teeth often have acutely pointed accessory cusps recurved toward the main cusp.

Certain teeth (62236, 62237) from Brazos Point and Springtown (Figure 11) have flutings at the base of the crown and three pairs of recurved accessory cusps. These teeth may represent another shark, very rare in the Trinity Group, but are here doubtfully considered as symphyseals of Lamna sp. aff. L. sulcata.

Age, Distribution, and Ecology: This form ranges from ?late Aptian to early middle Albian in Texas, being found throughout the Trinity Group in rocks deposited in open marine conditions.

ORDER BATOIDEA

Family HYPOLOPHIDAE

Genus ?Hypolophus Muller and Henle

Hypolophus? mcnultyi sp. nov.

(Figure 12)

"hypolophid teeth" McNulty, 1964.

Holotype: SMUSMP 62208, tooth, Springtown local fauna.

Referred material: 62209, several hundred teeth, Springtown local fauna; 62210, six thin sections of teeth, Springtown local fauna; 62211, teeth, Garner local fauna; 62212, tooth, Glass local fauna; 62213,

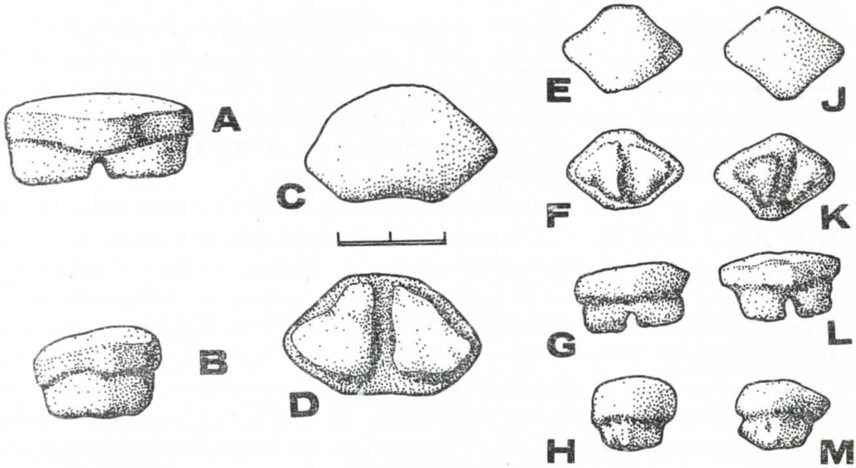


Figure 12. Hypolophus? mcnultyi sp. nov., teeth, Springtown local fauna. A-D, holotype, SMUSMP 62208, ?anterior, lateral, occlusal, and basal views of a tooth of distorted hexagonal type. E-M, two teeth from 62209: E-H, tooth of symmetrical hexagonal type, occlusal, basal, ?anterior, and lateral views; J-M, tooth of rhombic type, occlusal, basal, ?anterior, and lateral views. Scale in mm.

teeth, Garvin Church local fauna; 62214, teeth, Weatherford local fauna; 62215, teeth, Walnut Creek A local fauna; 62216, tooth, Kings Creek local fauna; 62217, teeth, Brazos Point local fauna; 62218 teeth, Reed Ranch local fauna; 62219 tooth, Decatur West local fauna; 62220, tooth, Keeter local fauna; 62221, teeth, Gerber local fauna; 62222, teeth, Routh A local fauna; 62223, teeth, Routh B local fauna; 62224, teeth, Heflin local fauna; 62225 teeth, Pleasant Valley local fauna; 62226, teeth, Boyd local fauna; 62228, teeth, Blanket local fauna. Also specimens referred by McNulty (1964).

Diagnosis: Hexagonal or rhombic teeth with biparted root; no central cavity. Root slightly smaller than crown, not offset in hexagonal teeth but offset in rhombic specimens. Crown almost entirely of orthodentine, with osteodentine in root only; no pulp cavity. See also McNulty (1964).

Discussion: These teeth from the Trinity Group and basal Walnut Formation are identical to those described by McNulty (1964) from the upper Woodbine Formation (late Cenomanian) of Tarrant County, Texas. The largest sample is from the Springtown local fauna (middle Paluxy Fm.) and shows more individual variation than the Woodbine specimens. This can be attributed to the larger sample.

In general, rhombic teeth are smaller than hexagonal or distorted hexagonal teeth, and have proportionally taller roots that are offset anteriorly. In H. sephan (Recent), rhombic teeth are located near the jaw symphyses. Lateral to the symphyses are distorted hexagonal teeth, succeeded by symmetrical hexagons, then by more distorted hexagons. H.? mcnultyi may have had a similar pattern, as distorted hexagons are the most abundant teeth.

Layering of orthodentine is apparent in some thin sections (particularly 62110-3). This suggests a possible mechanism by which this species may have altered its unique histology to that of other Hypolophus species. The outermost layer of orthodentine corresponds well with this thin pallial dentine shown in McNulty's (1964) figure of the histology of H. sylvestris White. If this outermost layer is laid down first in the formation of the tooth, deposition of osteodentine similar to that of the root could commence immediately, giving H. sylvestris histology. The external morphology of H.? mcnultyi is apparently identical to that of H. sylvestris, despite their different histologies.

Myledaphus bipartitus Cope (see Estes, 1964), can be fitted into this concept of the Hypolophidae as a specialized descendant of a lineage that retained the histology of Hypolophus? mcnultyi.

It has been suggested by Slaughter (oral communication) that the teeth described here might be oral teeth of Onchopristic dunklei McNulty and Slaughter (1962). This hypothesis is tempting for two reasons. First, the temporal ranges of the two forms are identical, both ranging from the Travis Peak Formation to the Woodbine Sandstone. Second, sites which yield O. dunklei invariably yield H.? mcnultyi (the converse is not always true, but could be explained in terms of differential preservation). However, the abundance of the two forms is not correlated. The Springtown local fauna yielded hundreds of teeth of H.? mcnultyi and many other specimens in a generally excellent state of preservation (including some very delicate specimens), but no rostral teeth of O. dunklei. On the other hand, the Glass local fauna produced a very well-preserved rostral tooth of O. dunklei, but only a single tooth of H.? mcnultyi. Perhaps oral teeth of O. dunklei are too small to be recovered by normal screens.

Age, Distribution, and Ecology: Known only from the Cretaceous of north-central Texas, ranging from the Travis Peak Formation (?late Aptian) to the Woodbine Formation (late Cenomanian). This species is nearly ubiquitous in the Trinity Group faunas, as long as there is any suggestion of marine affinities. Pycnodonts are almost invariably associated, but in a few cases H.? mcnultyi is the only marine form present. It is lacking from strictly terrestrial faunas such as Greenwood and Butler Farm. Apparently H.? mcnultyi inhabited both offshore marine and brackish bay waters.

Name: For Dr. Charles McNulty, Department of Geology, University of Texas at Arlington, who first noted the distinctness of this species.

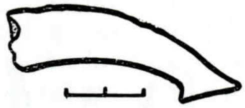


Figure 13. Onchopristis sp., rostral tooth, SMUSMP 62199, Garner local fauna. Scale in mm.

Family PRISTIDAE

Genus Onchopristis Stromer

Onchopristis Stromer, 1917, p. 5.

Type species: Onchopristis numidus (Haug).

Diagnosis: Rostral teeth enamelled nearly to base, with at least a terminal barb. Base saddle-like.

Onchopristis sp.

(Figure 13)

Referred material: Rostral tooth, SMUSMP 62199, Garner local fauna.

Discussion: This tooth consists of a nearly complete crown, without base. It is unusual for ganopristine teeth to break at this point, as the weakest point on the tooth is some distance distal to the base. However, the tooth may be immature, as unerupted rostral teeth of Sclerorhynchus may be baseless (Slaughter and Springer, 1968). The radial histology of the crown is visible at the broken end, and precludes referral of the tooth to either of the bony fishes Eurypholis (Enchodontidae) or Trichiurus (Trichiuridae), which have oral teeth of similar morphology (McNulty, oral communication). This tooth shows a single terminal barb on a curved shaft, much like those of O. numidus, and unlike O. dunklei (see McNulty and Slaughter, 1962 and Slaughter and Steiner, 1968). However, it resembles the latter in its lack of strong parallel ridges on the crown, a character of O. numidus. Anterior and posterior carinae are present.

While a single specimen is insufficient to allow definite statements, the age and morphology of this form suggest that it might be close to the common ancestry of both previously described species of Onchopristis. It is also the oldest known sawfish.

Onchopristis dunklei praecursor ssp. nov.

(Figure 14)

Onchopristis cf. dunklei, Slaughter and Steiner, 1968, p. 233, fig. 3J [non O. dunklei McNulty and Slaughter, 1962]

Holotype: SMUSMP 62200, rostral tooth, Brazos Point local fauna.

Referred material: All rostral teeth. From Brazos Point local

Figure 14. Onchopristis dunklei praecursor ssp. nov., holotype, SMUSMP 62200, rostral tooth, Brazos Point local fauna, dorsal and anterior views. Scale in mm.

fauna: 62201, 62202 (3 teeth), 62377 (specimen figured by Slaughter and Steiner, 1968, fig. 3J). From Glass local fauna, 62203.

Diagnosis: Barb distance index (Slaughter and Steiner, 1968) 90 or more. Probably only two barbs on complete tooth, widely separated.

Discussion: The new material added here to that of Slaughter and Steiner (1968) confirms their hypothesis that this represents a form distinct in time and morphology from typical O. dunklei. As the new form is closely related to typical Cenomanian material, and transitional forms occur in the PawPaw Formation (Slaughter and Steiner, 1968), this seems best expressed as of subspecific rank.

The holotype is a rostral tooth complete except for the presumed terminal barb. There is enough of the shaft distal to the proximal barb to show that the two barbs were widely separated. The proximal barb is large and prominent. In PawPaw material of transitional type, the most proximal barb is small, suggesting that it is a new addition, and that the second barb is the homologue of the proximal barb of O. dunklei praecursor.

Barb distance indices (Slaughter and Steiner, 1968) for the new specimens of this subspecies are somewhat lower than those reported by Slaughter and Steiner (1968) for "Paluxy" specimens of O. cf. dunklei. The holotype has an index of 94 and 62201 gives a value of 100. Previously published values are 160, 143, and 129. However, these specimens appear to represent more posterior rostral teeth than the holotype.

The possibility exists that material described here as Hypolophus? mcnultyi sp. nov. represents oral teeth of Onchopristis. See above for discussion of this hypothesis.

Age, Distribution, and Ecology: Known only from the lower Albian (Paluxy and Walnut Formation) of Bosque and Somervell Counties, Texas. Transitional forms to O. dunklei dunklei occur in the middle Albian (PawPaw Formation) of north-central Texas. There appears to be an unknown ecologic control on the distribution of this form, as it appears in only two of the four extensive open marine faunas of the Paluxy and Walnut, but the subspecies is found only in association with galeoids.

CONCLUSIONS

The specimens reported here constitute an important connecting link between the well-known faunas of the Wealden (Woodward, 1916-1919, Patterson, 1966) and the Lance (Estes, 1964).

Resemblances to the Wealden faunas are particularly striking among the hybodonts. All four Trinity hybodonts find their closest known relatives in the Wealden material described by Patterson (1966). This may be partly due to the previous position of the Wealden faunas as the only well-known freshwater-brackish-marine assemblage of these primitive sharks. The very limited hybodont fauna of the Lance (Lonchidion selachos only) does not show such striking parallels, but its sole species appears very close to the Trinity Lonchidion anitae. The hybodonts described here at present are the latest known varied assemblage of this group, predating their total restriction in Cenomanian and later times to very specialized niches.

The present state of knowledge of Trinity galeoids does not permit detailed examination of their relations to other faunas. The primitive character of Lamna sp. aff. L. sulcata suggests that it may be near the ancestry of that group, despite its comparatively late date. The late appearance of Lamna sp. cf. L. arcuata presages the expansion of normal lamnids in the later Cretaceous of North America, with the attendant reduction of the role of the L. sulcata group.

Hypolophus ? mcnultyi at present is the earliest representative of an extant lineage, providing a potential morphological ancestor of the modest radiation of this group in the later Cretaceous.

The single tooth of Onchopristis sp. is the earliest known sawfish. Its position in relation to later species of Onchopristis has been discussed above. The possible lineage Onchopristis sp. - Onchopristis dunklei praecursor - Onchopristis dunklei dunklei appears to summarize the North American history of this genus.

The fishes described here are often useful in the reconstruction of past environments, and have been used in a study of the paleoecology of the Trinity Group (in preparation). In general, the use of bulk washing techniques provides an approach to the ever-present problem of biostratigraphy and paleoecology of generally unfossiliferous continental/marine complex rock units.

REFERENCES

Agassiz, J. L. R., 1833-44, Recherches sur les poissons fossiles: Neuchatel, 5 vol., p. 1-1420, pl. 1-396, with supplement [issued in separate parts in 1833-44; the portion here cited, for taxonomic purposes, as Agassiz, 1840, was published in that year].

Estes, R. E., 1964, Fossil vertebrates from the late Cretaceous Lance Formation, Eastern Wyoming: Univ. Calif. Publ. Geol. Sci., v. 49, p. 1-180, 7 tbls., 73 figs., 5 pls.

Fisher, W. L. and Rodda, P. U., 1966, Nomenclature revision of basal Cretaceous rocks between the Colorado and Red Rivers: Univ. Texas Bur. Econ. Geol. Rept. Invest. no. 58, p. 1-20, 2 tbls., 8 figs., 1 pl.

____________, 1967, Lower Cretaceous sands of Texas: stratigraphy and resources: Univ. Texas Bur. Econ. Geol. Rept. Invest. no. 59, p. 1-116, 5 tbls., 12 figs., 4 pl.

Hendricks, L., (ed.), 1967, Comanchean (Lower Cretaceous) stratigraphy and paleontology of Texas: Soc. Econ. Paleontologists and mineralogists, Permian Basin Sec., Publ. 67-68, p. 1-392.

Leidy, J., 1873, Contributions to the extinct vertebrate fauna of the Western Territories: U. S. Geol. Surv. Terr. Rept., v. 1, p. 14-358.

McNulty, C. L., 1964, Hypolophid teeth from the Woodbine Formation of Texas: Ecl. Geol. Helv., v. 57, no. 2, p. 537-540, 1 pl.

McNulty, C. L., and Slaughter, B. H., 1962, A new sawfish from the Woodbine Formation (Cretaceous) of Texas: Copeia, 1962, no. 4, p. 775-777, 1 fig.

Patterson, B., 1951, Early Cretaceous mammals from northern Texas: Am. Jour. Sci. (5), v. 49, p. 31-46, 3 fig.

__________, 1955, A symmetrodont from the early Cretaceous of Northern Texas: Fieldiana: Zoology, v. 37, p. 689-693, fig. 145.

__________, 1956, Early Cretaceous mammals and the evolution of mammalian molar teeth: Fieldiana: Geology, v. 13, p. 1-105, 17 fig.

Romer, A. S., 1967, Vertebrate paleontology (3rd ed.): Univ. Chicago Press, p. vIII + 1-468, 4 tbls., 443 figs.

Patterson, C., 1966, British Wealden sharks: Brit. Mus. (N. H.) Bull., Geology, v. 11, no. 7, p. 281-350, 5 pls., 31 figs.

Slaughter, B. H., 1965, A therian from the lower Cretaceous (Albian) of Texas: Yale Peabody Mus. Nat. Hist. Postilla, no. 93, p. 1-18, 6 figs.

__________, 1968a, Earliest known marsupials: Science (n. s.), v. 162, no. 3850, p. 254-255, 1 fig.

__________, 1968b, Holoclemensia instead of Clemensia: Science (n. s.), v. 162, p. 1306.

__________, 1969, Astroconodon, the Cretaceous triconodont: Jour. Mamm., v. 50, p. 102-107, 1 tbl., 1 fig.

Slaughter, B. H., and Springer, S., 1968, Replacement of rostral teeth in sawfishes and sawsharks: Copeia, 1968, no. 3, p. 499-506, 8 figs.

Slaughter, B. H., and Steiner, M. B., 1968, Notes on rostral teeth of ganopristine sawfishes, with special reference to Texas material: Jour. Paleont., v. 42, p. 233-238, 4 fig.

Stromer, E., 1917, Ergebnisse der Forschungsreisen Prof. Stromers in den Wüsten Ägyptens. Die Säge des Pristiden Onchopristis: Abh. bayer. Akad. Wiss., v. 28, pt. 8, p. 1-21, 1 pl.

Williston, S. W., 1900, Cretaceous fishes: selachians and pycnodonts: Univ. Geol. Surv. Kansas, v. 6, p. 237-258, pls. 24-32.

Woodward, A. S., 1894, Notes on the shark teeth from British Cretaceous Formations: Proc. Geol. Assoc., v. 13, p. 190-200, pl. 5-6.

__________, 1902-1912, The fossil fishes of the English Chalk: Mon. Palaeontogr. Soc., p. i-viii + 1-264, 79 figs., 54 pls. [this paper and the following were issued in separate parts over a period of years. Where a precise publication date seems advisable, the parts have been cited separately].

__________, 1916-1919, Fossil fishes of the English Wealden and Purbeck Formations: Mon. Palaeontogr. Soc., p. 1-148, 41 figs., 26 pls. [See remarks on Woodward, 1902-1912].

Zangerl, R., and Denison, R. H., 1950, Discovery of early Cretaceous mammals and frogs in Texas: Science (n. s.), v. 112, p. 61.

FORTRAN PROGRAM FOR MISSING DATA FACTOR-VECTOR ANALYSIS (IBM 360-75): WITH TEST EXAMPLE

By

George W. Lynts
Department of Geology
Duke University
Durham, North Carolina 27708

and

Neal L. Paris
Computation Center
Duke University
Durham, North Carolina 27706

ABSTRACT

A computer program is presented for the factor-vector analysis of a data matrix in which some of the elements of the matrix may be missing. The missing elements are identified and the row or column removed from the matrix only when the missing element enters into the computational procedure. A text example utilizing ecological data, in which some of the environmental observations are missing, is included to illustrate the use of the program. This test example illustrates the analysis and modeling of the physical part of the ecosystem in the marine environment (Buttonwood Sound, Florida Bay).

INTRODUCTION

The electronic computer is becoming almost as familiar a tool of the geologist as is his hand lens or geologic hammer. Rather than being an extension of his senses or giving him a mechanical advantage, the computer is an extension of his brain. The brain is itself a remarkable "computer" in that it can store bits of information, logically manipulate this information and visualize this information in terms of meaningful patterns. The brain does have the limitations of operating at relatively low speeds and being able to manipulate and visualize Euclidian space in few dimensions. The electronic computer operates at relatively high speeds and has less severe dimensional restrictions. The electronic computer therefore permits the manipulation of much longer problems and relatively large matrices.

In many areas of geology, the geologist accumulates large masses of information. This information may be recorded on various types of scales (Stevens, 1946, 1968) that can be organized into data matrices. The factor-vector analysis program presented here is used for defining simple, meaningful patterns in these data matrices.

Acknowledgments

Development of the program was supported in part by grants from the Public Health Service, PHS 5-TI-DE-132-02, National Science Foundation, NSF GA-1258 and GA-1664, and Duke University Computation Center. We wish to thank John Imbrie for supplying the COVAP program, helping the senior author in his understanding of factor-vector analysis and for reading the manuscript.

BACKGROUND OF PROGRAM

Factor analysis finds its origin in the concept of latent factors suggested by Galton (1888), but the actual mathematical model was formulated by Spearman (1904). Thurstone (1931, 1947) extended the model to include many common factors. The reader may obtain additional background on factor analysis by referring to Cattell (1952), Harman (1960) or Lawley and Maxwell (1963).

Factor analysis is a linear mathematical model in which response variates are resolved into a small number of significant component factors. Imbrie (1963) augmented factor analysis with vector analysis in which the component factors are given in terms of actual variables or samples (reference vectors) judged to be significant in the spectrum of variance being studied. See Imbrie (1963) and Manson and Imbrie (1964) for a discussion of vector analysis. The objective of factor-vector analysis is to account for a large amount of the problem's total variance in terms of a simple causal scheme. Multivariate relationships among variables, R-mode, and between cases, Q-mode, may be analyzed using factor-vector analysis. The application of factor-vector analysis to geologic problems is discussed by Imbrie (1963, 1964), Manson and Imbrie (1964) and Gould (1967).

DUVAP (Duke University Vector Analysis Program) is a modification of COVAP (Manson and Imbrie, 1964) that permits the use of data matrices containing missing data. The advantages and disadvantages of DUVAP over COVAP are:

1) There may be missing data in the data matrix of DUVAP.
2) There is no plot subroutine for the varimax factor matrix in DUVAP.

MISSING DATA IN DATA MATRIX

In the accumulation of any large number of observations, which are to be organized into data matrices, from time to time certain observations will be missed. These missing data may result from either observational or mechanical errors. Missing observations in the data matrix will affect the method of analysis (Cochran and Cox, 1957).

There are two ways in which missing observations in a data matrix may be treated. First, one may "estimate" the missing values to complete the data matrix (see discussions given in Cochran and Cox, 1957, or Steel and Torrie, 1960). This method is essentially a computational technique that enables the completion of the data matrix to permit relatively simple computations. Substitution of "estimates" in the data matrix in no way recovers the lost information (Cochran and Cox, 1957).

Secondly, removal of a row or column from the data matrix prior to computation also completes the data matrix allowing relatively simple analysis. But this may have the disadvantage of losing a variable or case from the analysis. This disadvantage may be avoided by removing the row or column from the matrix only when the missing observation enters into the computational procedure. In statistical analysis, this reduces the degrees of freedom of the row and column in which the missing data occurs. DUVAP uses the latter technique in handling missing data.

The missing observations in the data matrix of DUVAP are identified. Every computation in which missing data is involved is multiplied by zero removing it from the row or column, while all computations involving real data are multiplied by one, thereby retaining it. In a similar manner the number of variables or cases (N) in either the column or row are adjusted for each computation. This simple arithmetic operation removes the missing data from the row or column only when it enters into the computational procedure.

ECOLOGIC EXAMPLE

Lynts (1966) published environmental data measured at 19 stations located in Buttonwood Sound, Florida Bay (Figure 1). Four sets of environmental data (August 14th, 17th, 20th, 1962, and February 9th, 1963) were given, but only one of these sets, February 9th, 1963, contained missing data. The environmental parameters measured at each station were: 1) depth, 2) temperature, 3) salinity, 4) pH, 5)Eh and 6) sediment size of the sediment-water interface.

The February 9th, 1963, environmental observations illustrates both types of errors mentioned above. Measurements of Eh were not recorded for stations 1-3, while the pH-Eh meter was not working at station 13. Stations 5 and 14 were not included in the analysis because

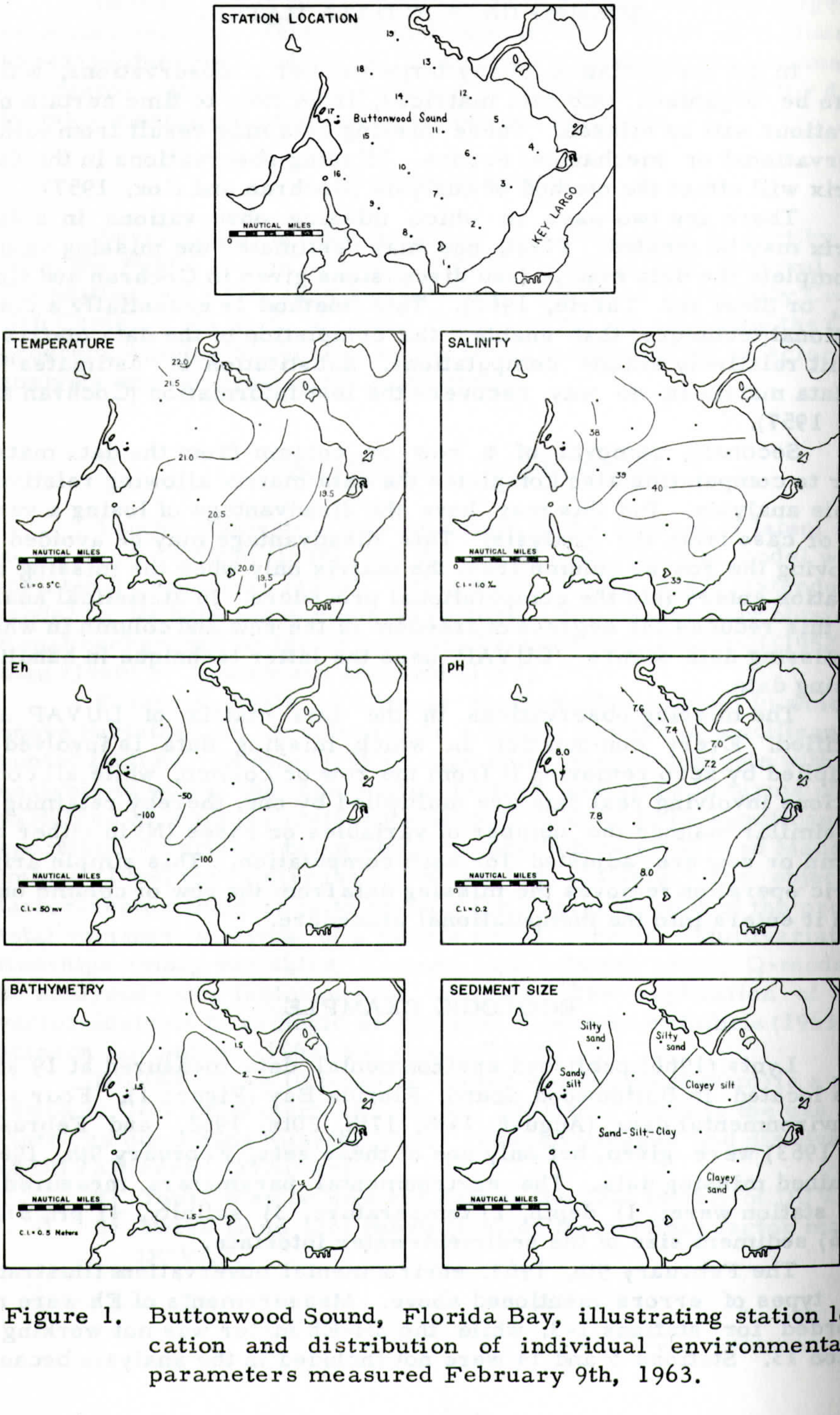


Figure 1. Buttonwood Sound, Florida Bay, illustrating station location and distribution of individual environmental parameters measured February 9th, 1963.

of loss of other information in the ecological survey.

A R-mode analysis was made of the linear multivariate relationships among environmental variables (Tables 2-9).

1) Table 4 shows that seven reference vectors account for 100.1 percent of the total variance contained in the data matrix. The first reference vector accounts for 34.6 percent of the variance, the second for 24.5 percent and each of the succeeding five vectors a correspondingly smaller percentage.

2) Inspection of V Matrix (Table 7) values along the diagonal, indicated that the seven reference vectors were highly independent. The absolute values along the diagonal (-0.9472, 0.8238, 0.9692, 0.9727, 0.9510, -0.9663, 0.9323) all approach one, thereby indicating an independence between vectors. A lack of independence (interchangability of vectors) would have been indicated by any of these values approaching zero.

3) Tables 8 and 9 indicate that these seven reference vectors were: 1) clay, 2) temperature, 3) pH, 4) depth, 5) Eh, 6) silt and 7) salinity. Only sand was indicated as being strongly related, inversely, to silt (Table 9). This strong inverse relationship in sediment was expected because percentages of sand, silt and clay form a closed number system (Chayes, 1960). No other strong linear relationships were indicated in this multivariate scheme.

A Q-mode analysis investigated the linear multivariate relationships between cases (Tables 10-17).

1) Table 12 indicated that three reference vectors accounted for 100.7 percent of the total information (Manson and Imbrie, 1964) in the data matrix. It can be seen that the first reference vector accounted for the vast majority of this total information, 90.5 percent, and that the second accounted for 6.7 percent.

2) Inspection of the last iterated V Matrix (Table 15) indicates that the reference vectors are highly independent.

3) Two stations, 8 and 11, were identified as having the most divergent environmental composition and used as reference vectors (Tables 16 and 17). Inspection of either of these reference vectors indicates that they are essentially the inverse of one another, e.g., row one of Table 16 indicates that station 1 is resolved into contributions from the two reference vectors (stations 9 and 11) in the proportion 0.659:0.441.

Interpretation of the factor-vector analysis was first directed to results of the R-mode analysis. This tells us of the large degree of independence between the measured environmental parameters, with the exception of sediment size which has a strong relationship built in as the result of the closed number system. Even though some of the parameters, i.e., pH and Eh, have theoretical dynamic relationships, these relationships were not indicated in the data from Buttonwood Sound (Lynts, 1966).

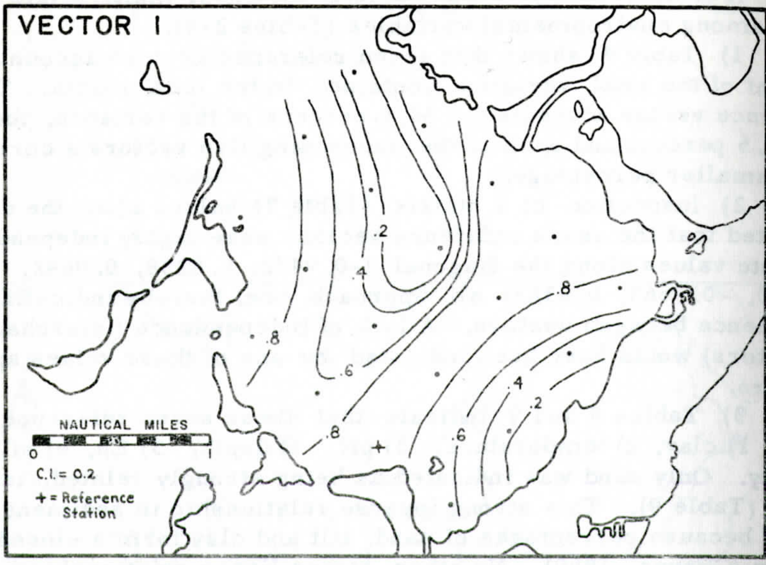


Figure 2. Factor-vector model of physical part of the ecosystem on February 9th, 1963.

The ecologic implications of the Q-mode analysis may be interpreted in two ways. First, in terms of the actual composition of the reference stations. The primary difference between stations 8 and 11 was in redox potential. Station 8 had an Eh of -140 mv, while station 11 had an Eh of -10 mv. Secondly, sediment size at station 8 was finer than at station 11, even though both were classified as sand-silt-clay in Shepard's (1954) nomenclature. The other environmental parameters were quite similar.

Secondly, the proportional contribution of each reference vector for each station (Table 16) was contoured. Since the second reference vector was essentially the inverse of the first, only the factor-vector map of the first reference vector is illustrated in Figure 2. This map represents column one of Table 16.

A factor-vector map of this nature is an attempt to integrate available environmental information and to display systematic patterns of geographic variations in the physical part of the ecosystem (Lynts, 1971). Comparison of the model of the physical part of the ecosystem (Figure 2) with the distribution of individual environmental parameters (Figure 1) results in some interesting observations. There are some discernable relationships between the two sets of maps. First, the influence of sediment size adjacent to Key Largo on the model is readily observed. Second, the influence of salinity and Eh are much less obvious, but still can be seen. One thing that is brought out quite vividly in the factor-vector model is the importance of currents on the physical part of the ecosystem, especially the exchange of water between Florida Bay to the northwest and Buttonwood Sound (Figure 2). The importance of currents is emphasized even though currents were not one of the measured environmental parameters. Factor-vector maps should be used in conjunction with other kinds of maps displaying specific information because the former maps may express phenomena not readily discernable in the latter maps.

MACHINE OUTPUT FOR ECOLOGIC EXAMPLE

Table 1 is a print out of the card setup used as input in the analysis of the Buttonwood Sound environmental data. The program was set to perform both a R- and Q-mode analysis of the data, extracting seven reference vectors in the R-mode and two reference vectors in the Q-mode (see operating instructions below). Missing pH observations were identified by 99 and Eh observations by 99999 in the data matrix. Tables 2-17 are the machine output.

Tables 2-9 are output of R-mode analysis.

Table 2 gives the code numbers, code names and statistics (mean, standard deviation, skewness and kurtosis) computed for eight environmental parameters.

Table 3 is a correlation matrix. Entries represent product moment correlations computed for each pair of environmental parameters.

Table 4 tabulates positive eigenvalues. Indicates percentage of total variance on eight environmental parameters retained as successively more end members were used. Seven reference vectors retain 100. 1 percent of total variance.

Table 5 is the principal components factor matrix. See Harman (1960) for a discussion of the principal components factor matrix.

Table 6 is the varimax matrix. Illustrates for each parameter its proportional composition in terms of seven theoretical, mutually orthogonal vectors. Theoretical orthogonal vectors selected to fit data best in a least-squares sense.

Table 7 represents intermediate output recording the search and identification of seven most extreme vectors in varimax configuration. Absolute values along the diagonal approaching one identify independent vectors.

Table 8 is the oblique projection matrix in which rows record proportional relationships in terms of the seven reference vectors. Code number and name of each parameter given in order of code number.

Table 9 gives the reordered oblique projection matrix. Adjacent vectors are grouped in the table. Code name and number of each reference vector (parameter) printed at top of table.

Tables 10-17 are output of Q-mode analysis.

TABLE 1

```
BSD RQ   8    17 1          7 1     OR  Q  1 0      0                2 0
R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FE
BRUARY 9TH, 1963 DATA.
DEPTH TEMPERSALINIPH    EH    SAND  SILT  CLAY
(8F5.1)
   99   999   999   9999999  999   999   999                       MISSDATA
   12   200   386   7899999  250   320   430                       BWSF9 01
   23   195   400   7999999  740   110   150                       BWSF9 02
   24   200   408   7899999  700   120   180                       BWSF9 03
   15   195   393   79-1000  440   290   270                       BWSF9 04
   27   202   400   77-1300  350   400   250                       BWSF9 06
   27   203   393   80-1400  340   440   220                       BWSF9 07
   24   205   393   80-1400  180   350   470                       BWSF9 08
   26   205   393   80 -700  410   380   210                       BWSF9 09
   26   207   408   77 -500  400   390   210                       BWSF9 10
   26   210   393   78 -100  290   470   240                       BWSF9 11
   15   209   386   70-1000  180   420   400                       BWSF9 12
   24   207   386   9999999  440   390   170                       BWSF9 13
   24   209   386   78-1000  260   540   200                       BWSF9 15
   18   211   393   79-1000  450   350   200                       BWSF9 16
   15   212   393   80 -900  410   470   120                       BWSF9 17
   26   213   379   78-1100  410   400   190                       BWSF9 18
   26   220   386   76 -300  520   280   200                       BWSF9 19
    1     2     3     4      6     7     8     9    10    11    12    13
   15    16    17    18     19
FINISH
```

TABLE 2

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

VARIABLE NO. NAME	MEAN	ST DEV	SKEW	KURTOSIS
1 DEPTH	2.224	0.506	-0.975	-0.649
2 TEMPER	20.606	0.653	0.061	0.107
3 SALINI	39.271	0.786	0.562	0.180
4 PH	7.794	0.243	-2.482**	7.802**
5 EH	-90.000	40.208	0.718	-0.134
6 SAND	39.824	15.473	0.788	0.745
7 SILT	36.000	11.325	-1.022	1.157
8 CLAY	24.176	9.876	1.392*	1.079

SE - SKEW # 0.550
SE - KURTOSIS # 1.063

* SIGNIFICANT AT .05 LEVEL
** SIGNIFICANT AT .01 LEVEL

TABLE 3

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

MATRIX TO BE FACTORED

VARIABLE NO. NAME	1	2	3	4	5	6	7	8
1 DEPTH	1.000							
2 TEMPER	0.193	1.000						
3 SALINI	0.221	-0.466	1.000					
4 PH	0.195	-0.260	0.191	1.000				
5 EH	0.138	0.475	0.093	-0.169	1.000			
6 SAND	0.189	-0.242	0.454	0.253	0.341	1.000		
7 SILT	0.053	0.488	-0.438	-0.076	-0.054	-0.771	1.000	
8 CLAY	-0.358	-0.181	0.210	-0.315	-0.340	-0.683	0.061	1.000

Table 4

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

TABLE OF POSITIVE EIGENVALUES

NO.	EIGENVALUE	PERCENT OF COMMUNALITY OVER ALL (8) FACTORS		PERCENT OF COMMUNALITY OVER 7 ROTATED FACTORS	
1	2.765	34.6	34.6	34.5	34.5
2	1.960	24.5	59.1	24.5	59.0
3	1.247	15.6	74.6	15.6	74.6
4	0.817	10.2	84.9	10.2	84.8
5	0.557	7.0	91.8	7.0	91.7
6	0.451	5.6	97.5	5.6	97.4
7	0.210	2.6	100.1	2.6	100.0

TRACE OF ORIGINAL MATRIX		8.000
COMMUNALITY OVER	8 FACTORS *	8.000
	7 FACTORS *	8.007

Table 5

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

UNROTATED FACTOR MATRIX

VARIABLE NO.	NAME	COMMUNALITY 7 FACTORS	1	2	3	4	5	6	7
SUM SQUARES DOWN COLUMNS			2.765	1.960	1.247	0.817	0.557	0.451	0.210
1	DEPTH	1.000	0.307	0.469	0.480	0.563	-0.338	0.130	-0.090
2	TEMPER	1.000	-0.421	0.829	-0.083	-0.048	-0.053	0.094	0.339
3	SALINI	1.000	0.701	-0.210	-0.000	0.494	0.414	-0.134	0.180
4	PH	1.000	0.423	-0.093	0.717	-0.360	0.217	0.345	0.050
5	EH	1.000	0.227	0.712	-0.473	0.037	0.329	0.266	-0.193
6	SAND	1.004	0.931	0.145	-0.210	-0.206	-0.169	-0.040	-0.006
7	SILT	1.002	-0.733	0.357	0.427	0.043	0.291	-0.231	-0.121
8	CLAY	1.001	-0.607	-0.587	-0.214	0.282	0.007	0.403	0.025

Table 6

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

ROTATED FACTOR MATRIX

VARIABLE NO.	NAME	COMMUNALITY 7 FACTORS	1	2	3	4	5	6	7
SUM SQUARES DOWN COLUMNS			1.343	0.827	1.027	1.028	1.089	1.653	1.039
1	DEPTH	1.000	0.159	0.085	0.090	0.973	0.051	-0.013	0.103
2	TEMPER	1.000	0.100	0.824	-0.148	0.133	0.322	-0.295	-0.285
3	SALINI	1.000	0.106	-0.195	0.075	0.121	0.051	0.242	0.932
4	PH	1.000	0.163	-0.098	0.969	0.091	-0.097	0.045	0.069
5	EH	1.000	0.177	0.204	-0.101	0.051	0.951	0.085	0.050
6	SAND	1.004	0.584	-0.108	0.118	0.079	0.205	0.747	0.173
7	SILT	1.002	0.005	0.174	-0.007	0.047	-0.003	-0.966	-0.188
8	CLAY	1.001	-0.947	-0.099	-0.166	-0.174	-0.157	-0.080	-0.072

Table 10 gives code numbers, code names and statistics (mean, sum of squares, square root of sum of squares, skewness and kurtosis) computed for seventeen stations.

Table 11 is the cosine θ matrix. Entries represent cosine of angles between vectors for each pair of stations. Cosine θ is the

TABLE 7

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

V MATRIX

NAME	INDEX	8	2	4	1	5	7	3
CLAY	8	-0.9472	-0.0995	-0.1660	-0.1744	-0.1569	-0.0803	-0.0724
TEMPER	2	0.0996	0.8238	-0.1483	0.1333	0.3221	-0.2945	-0.2851
PH	4	0.1633	-0.0975	0.9692	0.0913	-0.0969	0.0455	0.0690
DEPTH	1	0.1587	0.0846	0.0901	0.9727	0.0505	-0.0132	0.1030
EH	5	0.1774	0.2043	-0.1006	0.0509	0.9510	0.0847	0.0504
SILT	7	0.0053	0.1742	-0.0073	0.0466	-0.0031	-0.9663	-0.1880
SALINI	3	0.1059	-0.1953	0.0752	0.1214	0.0510	0.2419	0.9323

INVERSE OF V MATRIX

-1.1719	-0.1539	-0.2188	-0.1561	-0.1508	0.1040	-0.0755
0.1149	1.5970	0.1932	-0.2258	-0.5158	-0.4162	0.4520
0.2084	0.1338	1.1090	-0.0880	0.1079	-0.0006	-0.0212
0.1395	-0.1401	-0.0870	1.1001	0.0113	-0.0252	-0.1528
0.2029	-0.3290	0.1204	0.0147	1.2153	0.1633	-0.1282
-0.0030	0.2178	0.0257	0.0469	-0.0688	-1.1486	-0.1686
0.1119	0.3210	-0.0760	-0.1787	-0.1498	0.1935	1.2483

TABLE 8

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

OBLIQUE PROJECTION PROGRAM

OBLIQUE AXES

NAME	INDEX	8	2	4	1	5	7	3
DEPTH	1	0.000	0.000	0.000	1.000	0.000	0.000	0.000
TEMPER	2	0.000	1.000	0.000	0.000	0.000	0.000	0.000
SALINI	3	0.000	0.000	0.000	0.000	0.000	0.000	1.000
PH	4	0.000	0.000	1.000	0.000	0.000	0.000	0.000
EH	5	0.000	0.000	0.000	0.000	1.000	0.000	0.000
SAND	6	-0.602	-0.106	0.015	0.017	0.154	-0.687	-0.043
SILT	7	0.000	0.000	0.000	0.000	0.000	1.000	0.000
CLAY	8	1.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 9

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

REORDERED OBLIQUE PROJECTION MATRIX

NAME		CLAY	TEMPER	PH	DEPTH	EH	SILT	SALINI
	INDEX	8	2	4	1	5	7	3
CLAY	8	1.000	0.000	0.000	0.000	0.000	0.000	0.000
TEMPER	2	0.000	1.000	0.000	0.000	0.000	0.000	0.000
PH	4	0.000	0.000	1.000	0.000	0.000	0.000	0.000
DEPTH	1	0.000	0.000	0.000	1.000	0.000	0.000	0.000
EH	5	0.000	0.000	0.000	0.000	1.000	0.000	0.000
SILT	7	0.000	0.000	0.000	0.000	0.000	1.000	0.000
SAND	6	-0.602	-0.106	0.015	0.017	0.154	-0.687	-0.043
SALINI	3	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Table 10

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

CASE NO.	NAME	MEAN	SUM SQ	SQ RT SUM SQ	SKEW	KURTOSIS
1	1	23.943	5450.240	73.826	-0.342	-1.189
2	2	24.243	7869.950	88.713	1.623*	2.380
3	3	24.429	7499.240	86.598	1.459	1.790
4	4	8.525	15495.400	124.481	-2.302**	5.788**
5	6	5.075	22424.620	149.749	-2.494**	6.564**
6	7	3.787	25203.870	158.757	-2.508**	6.648**
7	8	3.775	25392.500	159.350	-2.465**	6.496**
8	9	12.550	10501.500	102.477	-2.001**	4.551**
9	10	15.225	8221.180	90.671	-1.626*	3.080*
10	11	20.088	5779.090	76.020	-0.194	-0.761
11	12	8.500	15666.020	125.164	-2.244**	5.556**
12	13	26.950	5670.210	75.301	-0.546	-1.184
13	15	8.712	15985.370	126.433	-2.140**	5.387**
14	16	8.762	15705.350	125.321	-2.263**	5.652**
15	17	10.000	14194.180	119.139	-2.034**	4.797**
16	18	7.450	17699.700	133.040	-2.359**	6.023**
17	19	17.600	6826.480	82.623	-0.751	1.143

SE - SKEW # 0.752
SE - KURTOSIS # 1.481

* SIGNIFICANT AT .05 LEVEL
** SIGNIFICANT AT .01 LEVEL

coefficient of proportional similarity; ranging from zero for a pair lacking anything in common to unity for a pair with identical proportional composition.

Table 12 is a table of positive eigenvalues. Three reference vectors retain 100.7 percent of total information.

Table 13 is the principal components factors matrix (Harman, 1960).

Table 14 gives the varimax matrix. Similar to Table 6, but illustrates proportional composition of each station in terms of two

TABLE 11

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

MATRIX TO BE FACTORED

NO.	CASE NAME	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1.000											
2	2	0.740	1.000										
3	3	0.774	0.999	1.000									
4	4	0.943	0.912	0.930	1.000								
5	6	0.955	0.829	0.852	0.987	1.000							
6	7	0.940	0.808	0.830	0.980	0.999	1.000						
7	8	0.994	0.661	0.699	0.962	0.983	0.981	1.000					
8	9	0.930	0.875	0.893	0.979	0.954	0.944	0.912	1.000				
9	10	0.932	0.865	0.884	0.933	0.891	0.877	0.842	0.986	1.000			
10	11	0.946	0.759	0.784	0.666	0.602	0.582	0.556	0.799	0.885	1.000		
11	12	0.986	0.660	0.696	0.967	0.978	0.973	0.987	0.950	0.904	0.680	1.000	
12	13	0.902	0.886	0.901	0.982	0.987	0.987	0.860	0.998	0.997	0.970	0.892	1.000

NO.	CASE NAME	1	2	3	4	5	6	7	8	9	10	11	12
13	15	0.912	0.705	0.730	0.968	0.983	0.982	0.959	0.969	0.928	0.707	0.981	0.952
14	16	0.916	0.905	0.921	0.997	0.988	0.983	0.952	0.984	0.941	0.681	0.962	0.998
15	17	0.876	0.835	0.850	0.979	0.974	0.971	0.927	0.988	0.957	0.733	0.953	0.992
16	18	0.919	0.867	0.884	0.993	0.995	0.993	0.963	0.975	0.925	0.655	0.970	0.999
17	19	0.888	0.951	0.962	0.841	0.759	0.737	0.690	0.916	0.959	0.899	0.766	0.983

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

MATRIX TO BE FACTORED

NO.	CASE NAME	13	14	15	16	17
13	15	1.000				
14	16	0.977	1.000			
15	17	0.987	0.990	1.000		
16	18	0.986	0.997	0.990	1.000	
17	19	0.793	0.847	0.857	0.812	1.000

TABLE 12

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

TABLE OF POSITIVE EIGENVALUES

NO.	EIGENVALUE	PERCENT OF COMMUNALITY OVER ALL (17) FACTORS		2 ROTATED FACTORS	
1	15.392	90.5	90.5	93.1	93.1
2	1.138	6.7	97.2	6.9	100.0
3	0.594	3.5	100.7		
4	0.194	1.1			
5	0.100	0.6			
6	0.010	0.1			
7	0.002	0.0			
8	0.000	0.0			
9	0.000	0.0			
10	0.000	0.0			
11	0.000	0.0			
12	0.000	0.0			
13	0.000	0.0			

TRACE OF ORIGINAL MATRIX 17.000
COMMUNALITY OVER 17 FACTORS * 17.000
2 FACTORS * 16.530

TABLE 13

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

UNROTATED FACTOR MATRIX

CASE NO.	CASE NAME	COMMUNALITY 2 FACTORS	FACTOR NUMBER 1	FACTOR NUMBER 2
SUM SQUARES DOWN COLUMNS			15.392	1.138
1	1	0.924	0.961	-0.024
2	2	0.899	0.880	0.353
3	3	0.920	0.900	0.331
4	4	0.995	0.993	-0.092
5	6	1.001	0.976	-0.223
6	7	0.998	0.967	-0.251
7	8	1.000	0.928	-0.373
8	9	0.988	0.994	0.021
9	10	0.967	0.971	0.156
10	11	0.885	0.794	0.505
11	12	0.983	0.950	-0.283
12	13	1.033	1.006	0.144
13	15	0.977	0.963	-0.223
14	16	0.996	0.994	-0.085
15	17	0.973	0.983	-0.081
16	18	0.996	0.988	-0.143
17	19	0.995	0.904	0.422

TABLE 14

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

ROTATED FACTOR MATRIX

CASE NO.	CASE NAME	COMMUNALITY 2 FACTORS	FACTOR NUMBER 1	FACTOR NUMBER 2
SUM SQUARES DOWN COLUMNS			9.549	6.981
1	1	0.924	0.753	0.597
2	2	0.899	0.450	0.835
3	3	0.920	0.480	0.831
4	4	0.995	0.822	0.565
5	6	1.001	0.892	0.454
6	7	0.998	0.903	0.426
7	8	1.000	0.952	0.307
8	9	0.988	0.750	0.652
9	10	0.967	0.646	0.742
10	11	0.885	0.286	0.896
11	12	0.983	0.911	0.391
12	13	1.033	0.681	0.755
13	15	0.977	0.882	0.446
14	16	0.996	0.818	0.571
15	17	0.973	0.807	0.567
16	18	0.996	0.851	0.522
17	19	0.995	0.424	0.903

Table 15

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

V MATRIX

NAME	INDEX	7	17
8	7	0.9517	0.3074
19	17	0.4239	0.9032

INVERSE OF V MATRIX

1.2384	-0.4214
-0.5812	1.3050

ITERATION CYCLE 1. HIGHEST LOADING IN C MATRIX IS 0.049 IN EXCESS OF 1.000

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

V MATRIX

NAME	INDEX	7	10
8	7	0.9517	0.3074
11	10	0.2864	0.8962

INVERSE OF V MATRIX

1.1716	-0.4018
-0.3744	1.2442

theoretical end members.

Table 15 is similar to Table 7, but illustrates iterative search and identification of two most extreme vectors in varimax configuration.

Table 16 is the same as Table 8, but reference vectors here represent cases.

Table 17 is the same as Table 9, but reference vectors here represent cases.

Table 16

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

OBLIQUE PROJECTION PROGRAM

OBLIQUE AXES

NAME	INDEX	7	10
1	1	0.659	0.441
2	2	0.215	0.858
3	3	0.251	0.941
4	4	0.752	0.373
6	5	0.876	0.206
7	6	0.899	0.168
8	7	1.000	0.000
9	8	0.635	0.511
10	9	0.479	0.664
11	10	0.000	1.000
12	11	0.921	0.121
13	12	0.515	0.666
15	13	0.867	0.200
16	14	0.745	0.383
17	15	0.733	0.382
18	16	0.801	0.308
19	17	0.159	0.954

PROGRAM DESCRIPTION AND OPERATING INSTRUCTIONS

In the R-mode DUVAP will process up to 112 variables observed on any number of cases up to 112. In the Q-mode, it will process up to 112 cases each characterized by up to 112 variables. Up to 10 factors can be extracted. A listing of DUVAP is given in Appendix I and a flow chart in Figure 3. DUVAP utilizes up to 300K of an IBM 360 System, Model 75 computer. Standard deviations are computed with the (N-1) formula.

Program Options

<u>Data matrix format option.</u> There are two ways in which the data matrix may be punched on the cards. First, in the <u>standard data matrix format</u> variables characterizing each case are punched across one card, or set of cards; each card field representing one variable. Second, in the <u>transpose data matrix</u> cases corresponding to each variable are punched across one card, or set of cards; each card field

Table 17

R AND Q MODE TESTS OF DUVAP PROGRAM ON BUTTONWOOD SOUND, FLORIDA BAY, FEBRUARY 9TH, 1963 DATA.

REORDERED OBLIQUE PROJECTION MATRIX

NAME	INDEX	8 / 7	11 / 10
8	7	1.000	0.000
12	11	0.921	0.121
7	6	0.899	0.168
6	5	0.876	0.206
15	13	0.867	0.200
18	16	0.801	0.308
4	4	0.752	0.373
16	14	0.745	0.383
17	15	0.733	0.382
1	1	0.659	0.441
9	8	0.635	0.511
11	10	0.000	1.000
19	17	0.159	0.954
2	2	0.215	0.858
3	3	0.251	0.841
13	12	0.515	0.666
10	9	0.479	0.664

representing one case. The following rules must be noted:

1) The standard data matrix format must be used in a R-mode analysis.

2) Either data matrix format may be used in a Q-mode analysis.

3) The standard data matrix format must be used if both a R- and Q-mode analysis is desired on one deck of data cards.

Modal sequence option. There are four operating sequences possible on one machine pass. Options 1-3 use input in the standard data matrix format, while option 4 uses input in the transpose data matrix option.

1) The R sequence option performs only a R-mode analysis.

2) The Q sequence option performs only a Q-mode analysis. Input must be in the standard data matrix.

3) The RQ sequence option performs both a R- and Q-mode analysis from the same deck of data cards.

4) The QQ sequence option performs a Q-mode analysis. Input must be in the transpose data matrix format.

Transformation options. There are three ways in which raw data may be transformed.

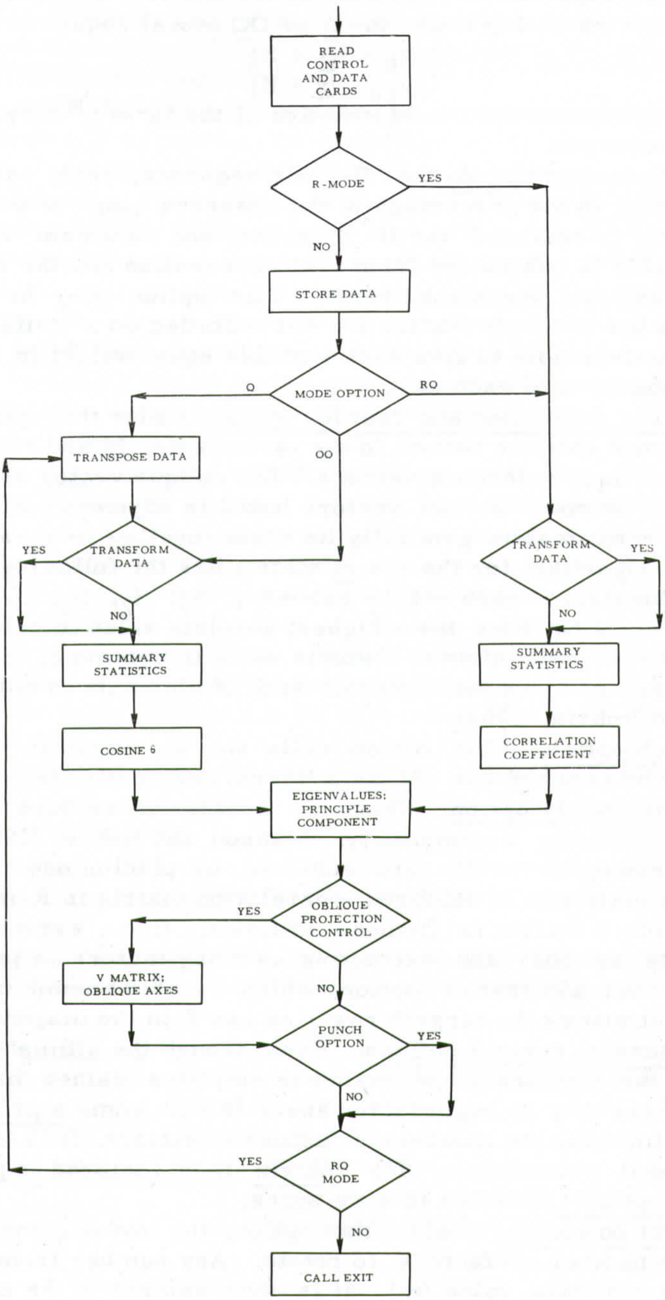


Figure 3. Flow chart of DUVAP program.

1) Two logarithmic transformation functions are available when the program is operating under the R or QQ modal sequence options:

$$\log_e \quad (\underline{x} + K)$$

$$\log_{10} \quad (\underline{x} + K)$$

2) An exponential transformation of the form $\underline{x}^K$ may be used in any modal sequence.

3) Operating in only the Q-mode sequence, each variable may be transformed to the percentage of the observed range of the variable. Each variable is searched for its maximum and minimum value. The minimum value is subtracted from each observation and the result divided by the maximum diminished value. This option may be used when variables in the raw data matrix are not recorded on a uniform scale, or when it is desirable to give each variable equal weight in determining the composition of each case.

Oblique projection and reorder option. Under this option DUVAP finds the m most extreme vectors in the varimax matrix and resolves each vector into oblique reference vectors. The oblique vector matrix is also reordered by rows so that vectors listed in adjacent portions of the reordered vector matrix generally lie close together in m-space. The reordering algorithm for the n x m matrix has the following steps: 1) Form m submatrices each with m columns, S_1, S_2, S_3, ... , S_m, so that all rows of S_1 have their highest absolute value in column 1, all rows of S_2 have their highest absolute value in column 2, etc. 2) Reorder the rows of S_1 by the algebraic rank of elements in column 1, etc. (Manson and Imbrie, 1964).

Punch option. This option calls for the varimax and oblique matrices to be punched out. Make a liberal card estimate.

Communality option. There is a large literature on the best means of estimating communality. Manson and Imbrie (1964) believe the most meaningful results are achieved by placing ones in the diagonal of the matrix to be factored, correlation matrix in R-mode analysis and cosine θ matrix in Q-mode analysis, (i.e., estimating each communality as one) and extracting as many factors as judged to be significant. An alternative option, which is also commonly used, is provided that places the largest row $\underline{r}$ or cos θ in the diagonal.

Dimension control options. Even though the ultimate criterion for judging the significance of factors is empirical rather than statistical, it is necessary to begin factor analysis with some a priori procedure for estimating the numbers of factors to extract. DUVAP provides three optional procedures. The matrix to be factored is printed out only under option 1 in order to save space.

1) Preselection option. Under this option, the investigator selects in advance the number of factors to rotate. Any number from 1-10 may be selected for this value (m). It is then entered in the appropriate columns (26-27 and/or 69-70) of the control card. If the cummulative value of the m positive eigenvalues does not exceed unity, m factors will be extracted. When the cummulative eigenvalues exceed unity the

value of m is diminished by one, the eigenvalues recalculated until a value of m is found that satisfies the cummulative criterion. The same cummulative eigenvalue criterion is also applied to the dimension control options described below.

CAUTION: When the maximum number specified for rotation is greater than the number of variables, an eigenvalue equal to zero may be given as an extra eigenvalue. This will cause a column of zeros to be factored out and rotated. This will result in the first variable being used as the high variable for this column. If the first variable is the highest for any other column, two identical rows will appear in the vector matrix. When the vector matrix is inverted, this will result in an overflow because the argument is over the fixed point range in fixfloat. Thus to be safe: When specifying a maximum rotation greater than the number of variables use at least a one percent option minimum (z) (see discussion of this option below). In other words, punch 100 in columns 45-47 of the control card.

2) Minimum value option. This option permits the investigator to select m, the maximum number of dimensions that might be of possible significance, and z, the minimum absolute value desired in any column of the rotated varimax factor matrix. For example, if z is chosen as 0.223 it assures that no factor will be retained that does not contribute at least z^2 (5 percent) to one item in the data matrix.

3) Trial series option. This option allows the investigator to select m, the maximum number of factors to be rotated, and w, the total number of factor-vector analyses to be performed in a series with m, m-1, m-2, . . . factors.

Multiple problem processing option. This permits any number of problems, each with separate control cards and data decks, to be run on one machine pass.

Operating Instructions

The following cards are submitted in order immediately following the JOB CARD and PROGRAM DECK. The symbol b below signifies a blank.

(1) Control Card

Col.	
1-6	Problem name (alphanumeric characters).
7-9	Number of variables.
10-15	Number of cases.
17	Communality option. 1 Program puts one in diagonal. 3 Program puts largest row r, or largest cosine θ, in diagonal.
26-27	The value of m. In the R and RQ sequence options, the number of factors to rotate for R-mode analysis; in the QQ sequence option the number of factors to rotate for Q-mode analysis.

Maximum number possible to rotate is 10.

29 Number of variable format cards (any number from 1-8).

35 0 (zero)

36 R-mode control.

- R For R-mode analysis (in R or RQ sequence options)
- b To suppress R-mode analysis leave blank (Q and QQ sequence options).

39 Q-mode control.

- Q For Q-mode analysis (in Q, RQ or QQ sequence options).
- b To suppress Q-mode analysis leave blank (R sequence option).

42 Oblique projection control.

- 0 Suppress oblique projection option.
- 1 Oblique projection and reorder option.

44 Punch control.

- 0 Suppress punch option.
- 1 Varimax and oblique matrices written on logical tape number 2 for card punch.

45-47 Dimension control options. Value(s) of $\underline{m}$ punched in columns 26-27 and/or 69-70 represent maximum number of factors to rotate.

- b Preselection option. Values of $\underline{m}$ punched in columns 26-27 and 69-70 determine number of factors to be rotated.
- $\underline{z}$ Minimum value option. Punch desired three-digit value of $\underline{z}$ without decimal point, e.g., for $\underline{z} = 0.223$ punch 223
- $-\underline{w}$ Trial series option. Punch minus sign followed by desired integer value of $\underline{w}$, right justified. For series of four analyses punch b-4

50 Percent range data transformation option.

- 0 Option suppressed.
- 1 Data transformed to percent range in Q sequence only.

Nonlinear data transformations. Punch value of $\underline{K}$ with decimal point to call desired option. For example, 0.5 in columns 66-68 will cause program to take square root for every value in a R-mode sequence. For no transformations leave columns 51-68 blank.

51-56 $\log_e(\underline{x} + K)$; R and QQ sequences only.

57-62 $\log_{10}(\underline{x} + K)$; R and QQ sequences only.

63-65 $\underline{x}^K$ for Q-mode sequence.

66-68 $\underline{x}^K$ for R-mode sequence.

69-70 The value of m. In the Q, RQ and QQ sequence options, the number of factors to rotate for Q-mode analysis. In the QQ sequence option only, the same value is punched in columns 26-27. Leave blank for R sequence option.

72 Data matrix format option.

0 Standard data matrix format (R, Q and RQ sequences).

1 Transpose data matrix format (QQ sequence).

(2) Page Heading Cards (2 cards)

Information punched in columns 1-72 of the first and columns 1-54 of the second of these cards is printed on the top line of each page of output. Use blank cards if no title is desired.

(3) Name Card(s)

Code names in order (12A6 format code) are specified for each variable in the R or RQ sequence options. In the Q or QQ sequence options code names of cases are specified. Twelve items are described per card. The number of cards required is equal to the integral value of [(N - 1)/12] + 1, where N is the number of variables or cases. Use blank cards if no code names are desired.

(4) Variable Format Code Card(s)

Format in which data cards were punched is described using the number of cards given in column 29 of the Control Card. Data must be read under a F format code. The X format code may be used for spacing. Field of each variable format card consists of columns 1-72.

(5) Card(s) Identifying Missing Data

Numbers that are to be used to identify missing data in data matrix are punched in format given in (4). Any number not occurring in data matrix may be used to identify missing data. Numbers identifying missing data must be given for each variable, even if there is no data missing from variable field. Total number of cards needed is equal to number of cards used to punch all variables, in standard data matrix format, or cases, in transpose data matrix format. For example, in punching in a standard data matrix format of 12F6.2, 15 variables would require two cards. Card(s) must be included even if data matrix contains no missing data.

(6) Data Deck

(7) Name Card(s)

Code names in order (12A6 format code) are specified for each case in the RQ sequence option. Twelve items are described per card. The number of cards required is equal to the integral value of $[(N - 1)/12] + 1$, where N is the number of cases. Omit these cards if R, Q or $Q\overline{Q}$ sequence options are used.

(8) Multiple Problem Processing
Repeat cards (1) through (7) to process more than one problem on one machine pass.

(9) Finish Card
End of job card. Punch FINISH in columns 1-6.

REFERENCES CITED

Cattell, R. B., 1952, Factor analysis: Harper and Bros., New York, p. 1-462.

Chayes, F., 1960, On correlation between variables of constant sum: Jour. Geophys. Res., v. 65, p. 4185-4193.

Cochran, W. G., and Cox, G. M., 1957, Experimental designs: John Wiley and Sons, New York, p. 1-611.

Galton, F., 1888, Co-relations and their measurement, chiefly from anthropometric data: Proc. Roy. Soc., v. 45, p. 135-140.

Gould, S. J., 1967, Evolutionary patterns in pelycosaurian reptiles: a factor-analytic study: Evol., v. 21, p. 385-401.

Harman, H. H., 1960, Modern factor analysis: Univ. Chicago Press, Chicago, p. 1-469.

Imbrie, J., 1963, Factor and vector analysis programs for analyzing geologic data: Tech. Rpt. No. 6, ONR Task No. 389-135, Office of Naval Research, Geography Branch, p. 1-83.

__________, 1964, Factor analytic model in paleoecology, in Approaches to paleoecology, Imbrie, J., and Newell, N., eds.: John Wiley and Sons, New York, p. 407-422.

Lawley, D. N., and Maxwell, A. E., 1963, Factor analysis as a statistical method: Butterworths, London, p. 1-117.

Lynts, G. W., 1966, Relationship of sediment size distribution to ecologic factors in Buttonwood Sound, Florida Bay: Jour. Sed. Petrology, v. 36, p. 66-74.

__________, 1971, Distribution and model studies on foraminifera living in Buttonwood Sound, Florida Bay: Miami Geol. Soc. Mem. 1, p. 73-115.

Manson, V., and Imbrie, J., 1964, Fortran program for factor and vector analysis of geologic data using an IBM 7090 or 7094/1401 computer system: Kansas Geol. Surv. Special Dist. Publ. 13, p. 1-46.

Shepard, F. P., 1954, Nomenclature based on sand-silt-clay ratios: Jour. Sed. Petrology, v. 24, p. 151-158.

Spearman, C., 1904, General intelligence objectively determined and measured: Amer. Jour. Psych., v. 15, p. 201-293.

Steel, R. G. D., and Torrie, J. H., 1960, Principals and procedures of statistics: with special reference to the biological sciences: McGraw-Hill, New York, p. 1-481.

Stevens, S. S., 1946, On the theory of scales of measurement: Science, v. 103, p. 677-680.

__________, 1968, Measurement, statistics, and the schemapiric view: Science, v. 161, p. 849-856.

Thurstone, L. L., 1931, Multiple factor analysis: Pysch. Rev., v. 38, p. 406-427.

__________, 1947, Multiple factor analysis: Univ. Chicago Press, Chicago, p. 1-535.

APPENDIX I

```
C
CDUVAP DUKE VECTOR ANALYSIS PROGRAM BY LYNTS AND PARIS 1969
C
C
CPROGRAM PERFORMS COMPLETE FACTOR-VECTOR ANALYSIS (1) IN THE R-MODE,
CCALCULATING MEAN, ST. DEVIATION, SKEWNESS, KURTOSIS, AND CORRELATION
CMATRIX ON UP TO 112 VARIABLES. (2) IN THE Q-MODE, CALCULATING MEAN,
CSUM OF SQUARES, SQUARE ROOT OF SUM OF SQUARES, SKEWNESS, KURTOSIS, AND
CCOSINE THETA MATRIX ON UP TO 112 CASES. OR (3) IN BOTH R AND Q MODES.
COUTPUT GIVES POSITIVE EIGENVALUES, PRINCIPAL COMPONENTS AND VARIMAX
CFACTOR MATRICES, MATRIX OF OBLIQUE PROJECTIONS ON EXTREME VECTORS,
CAND REORDERED OBLIQUE MATRIX. DUVAP WILL TAKE INTO CONSIDERATION
CMISSING DATA IN THE DATA MATRIX.
C
C
      IMPLICIT REAL*8 (A-H,O-W)
      COMMON /Y/   A,B,C,FMT,MM,        HEAD,ANAME
      REAL*8 Q(30)/'     NC',' DATA ','FINISH','    YES',' ERROR',
     1     '  ONES','SQ M R',' MAX R',' INPUT','    Q  ','R      ',
     2     'R  Q  ','LOG E ','( X+K)','LOG 1 ',' (X+K)','EXP.  ',
     3     '(X**K)',' VARIA','BLE   ','    CAS','E      ','PERCT.',
     4     ' RANGE','**     ','*      ','      ','UNROTA','TED   ',
     5     '  ROTA'/
      REAL*8 A(112,112),B(112,112),C(112),FMT(112),
     1              HEAD(21),DC(7),ANAME(112)
      REAL*8 XXX
      REAL XN(112),DFMT(144)
      INTEGER MM(114),IFMT(112)
      INTEGER*2 Z(112,112),ZZ,VORP,PUN
C
C
C     MASK CUT INTERRUPTS.
      CALL FIMSK(589)
C
   10 READ(1,900)DDR,NV,N,NRN,RBIG,CUT,NRO,NN,ISIR,IDRAW,AM,VORP
     1,PUN,MINBIJ,PMAX,ALOGE,ALOG10,EXPO,EXP,NROQ,IFQPMT
  900 FORMAT (A6,I3,I6,I2,F4.2,F3.2,I3,2I2,2XI2,A6,I1,I2,I3,F3.0,2F6.3,
     12F3.0,2I2)
      W1=Q(1)
      W2=Q(2)
          MCDEA = 1
          MCDE = 1
        AMA = AM
      REWIND 4
      WORD1=C(3)
      IF(DDR-WORD1)11,400,11
   11 CONTINUE
      READ(1,901)  (HEAD(I),I=1,21)
          NNRN = NRN
      ARN=DIB
         AREIG = RBIG
         ACUT = CUT
         ISIRA = ISIR
         IDRAWA = IDRAW
         NY = NN
      WORD1=C(4)
      DC(1)=C(5)
      DC(2)=C(6)
      DC(3)=C(7)
      DC(4)=C(8)
      DC(5)=DC(2)
      DC(6)=DC(4)
      DC(7)=C(9)
         IF (NRN) 13,13,12
   12    IF(NRN-7)    14,13,13
   13 WORD2=DC(1)
      GOTO15
   14 WORD2=DC(NRN+1)
         WORD9 = WORD2
   15 CONTINUE
      IF(ISIR)16,17,16
   16 CONTINUE
      WORD1=C(1)
   17 CONTINUE
      WRITE(3,950) HEAD
      IF(AM .EQ. Q(10)) GO TO 2020
      WRITE(3,902) DDR,NN,NV,N,WORD1,WORD2,NRO
      GO TO 2021
 2020 WRITE (3,902) DDR,NN,NV,N,WORD1,WORD2,NROQ
 2021 CONTINUE
         WORD8 = WORD1
      IF(NN)19,19,18
   18 IF(WORD2-DC(1))20,19,20
   19 WRITE(3,974)
      GOTO400
   20 CONTINUE
      RNN=REIG
      NP = NV
      WORD3=C(10)
         IF (AM-WORD3) 2026 ,2025,2026
 2025    NP = N
 2026 READ(1,901)  (ANAME(I),I=1,NP)
      IF(MODE-2) 2027,96,2027
 2027 NN=NN*18
      NP = N
      READ(1,921)(DFMT(I),I=1,NN)
C
C     READ IN NUMBERS TO BE USED IN CHECKING FOR MISSING DATA.
C
      READ (1,DFMT)  (FMT(I),I=1,NV)
```

```
      GOTO(21,21,21,1235,1235,1235),NRN                                 DUVA0101
   21 CONTINUE                                                          DUVA0102
       IF(IFQFMT)24,26,24                                               DUVA0103
   24 N=NV                                                              DUVA0104
      NV=NP                                                             DUVA0105
      NROT = NROQ                                                       DUVA0106
      NRO=NRCQ                                                          DUVA0107
      AM=Q(11)                                                          DUVA0108
   26 DO 25 I=1,NV                                                      DUVA0109
      A(I,2)=0.0                                                        DUVA0110
      A(I,3)=0.0                                                        DUVA0111
      A(I,4)=0.0                                                        DUVA0112
      A(I,5)=0.0                                                        DUVA0113
      DO25J=1,NV                                                        DUVA0114
      B(I,J)=0.0                                                        DUVA0115
   25 CONTINUE                                                          DUVA0116
C                                                                       DUVA0117
   96 DO 690 I=1,NV                                                     DUVA0118
  690 XN(I)=0.                                                          DUVA0119
C                                                                       DUVA0120
C     DO LOOP WHICH READS IN DATA CARDS.                                DUVA0121
C                                                                       DUVA0122
      DO 42 I=1,N                                                       DUVA0123
      WORD3=Q(11)                                                       DUVA0124
       IF(MODE-2) 27,800,27                                             DUVA0125
   27 READ(1,DFMT) (C(J),J=1,NV)                                        DUVA0126
C                                                                       DUVA0127
C     CHECK FOR MISSING DATA.                                           DUVA0128
C                                                                       DUVA0129
      IF(IFQFMT .EQ. 1) GO TO 542                                       DUVA0130
      DO 541 J=1,NV                                                     DUVA0131
      IF(C(J) .EQ. FMT(J)) GO TO 540                                    DUVA0132
      B(I,J)=C(J)                                                       DUVA0133
      Z(I,J)=1                                                          DUVA0134
      XN(J)=XN(J)+1.                                                    DUVA0135
      GO TO 541                                                         DUVA0136
  540 Z(I,J)=0                                                          DUVA0137
      C(J)=0.                                                           DUVA0138
      B(I,J)=0.                                                         DUVA0139
  541 CONTINUE                                                          DUVA0140
      GO TO 546                                                         DUVA0141
C                                                                       DUVA0142
  542 DO 545 J=1,NV                                                     DUVA0143
      IF(C(J) .EQ. FMT(I)) GO TO 544                                    DUVA0144
      B(I,J)=C(J)                                                       DUVA0145
      Z(I,J)=1                                                          DUVA0146
      XN(J)=XN(J)+1.                                                    DUVA0147
      GO TO 545                                                         DUVA0148
  544 Z(I,J)=0                                                          DUVA0149
      C(J)=0.                                                           DUVA0150
```

```
      B(I,J)=0.                                                         DUVA0151
  545 CONTINUE                                                          DUVA0152
C                                                                       DUVA0153
  546 CONTINUE                                                          DUVA0154
       IF(AM-WORD3)700,704,700                                          DUVA0155
  700 WRITE (4) (C(J),J=1,NV)                                           DUVA0156
      WORD3=Q(12)                                                       DUVA0157
       IF (AM-WORD3) 42,703,42                                          DUVA0158
  703     MODEA = 2                                                     DUVA0159
      AMA=Q(11)                                                         DUVA0160
  704  IF(ALOGE)705,710,705                                             DUVA0161
  705  DO 706 J=1,NV                                                    DUVA0162
  706 C(J)=DLOG(C(J)+ALOGE)                                             DUVA0163
      W1=Q(13)                                                          DUVA0164
      W2=Q(14)                                                          DUVA0165
  710  IF(ALOG10) 711,720,711                                           DUVA0166
  711  DO 712 J=1,NV                                                    DUVA0167
  712 C(J)=DLOG(C(J)+ALOG10)*0.43429D+0                                 DUVA0168
      W1=Q(15)                                                          DUVA0169
      W2=Q(16)                                                          DUVA0170
  720  IF(EXP) 721,28,721                                               DUVA0171
  721  DO 722 J=1,NV                                                    DUVA0172
  722   C(J) = C(J)**EXP                                                DUVA0173
      W1=Q(17)                                                          DUVA0174
      W2=Q(18)                                                          DUVA0175
   28 DO 40 J=1,NV                                                      DUVA0176
      A(J,2)=A(J,2)+C(J)                                                DUVA0177
      A(J,3)=A(J,3)+C(J)**2                                             DUVA0178
      A(J,4)=A(J,4)+C(J)**3                                             DUVA0179
      A(J,5)=A(J,5)+C(J)**4                                             DUVA0180
      IF (IFQFMT) 40,40,31                                              DUVA0181
   31 A(J,12)=DSQRT(A(J,3))                                             DUVA0182
      A(J,13) = A(J,3)                                                  DUVA0183
   40 CONTINUE                                                          DUVA0184
   42 CONTINUE                                                          DUVA0185
C                                                                       DUVA0186
C                                                                       DUVA0187
      W3=Q(19)                                                          DUVA0188
      W4=Q(20)                                                          DUVA0189
       IF(AM-WORD3)801,41,801                                           DUVA0190
  800    MODEA= 1                                                       DUVA0191
         IDRAW = IDRAWA                                                 DUVA0192
         ISIR = ISIRA                                                   DUVA0193
         RBIG =-ARBIG                                                   DUVA0194
         RNN = RBIG                                                     DUVA0195
         CUT = ACUT                                                     DUVA0196
      WRITE(3,950) HEAD                                                 DUVA0197
      WRITE(3,902) ARN,NY,NV,N,WORD8,WORD9,NROQ                         DUVA0198
      AMA=Q(10)                                                         DUVA0199
C                                                                       DUVA0200
```

```
C     RECOMPUTE N'S FOR EACH ROW INSTEAD OF COLUMN.
C
  801 DO 97 I=1,N
      XNN=0.
      DO 97 J=1,NV
      XNN =XNN+Z(I,J)
   97 XN(I)=XNN
      NSAV=N
       REWIND 4
           NRO = NROQ
      W3=Q(21)
      W4=Q(22)
           NROT = NROQ
         N = NV
         NV = NSAV
       DO 802 J = 1,NV
  802 READ (4) (A(IA,J),IA=1,N)
       REWIND 4
       IF (PMAX) 810,810,803
  803   DO 805IB = 1,N
         ALARG = A(IB, 1)
       SMALA = A(IB,1)
       DO 804 JB= 1,NV
      ALARG=DMAX1(A(IB,JB),ALARG)
  804 SMALA=DMIN1(A(IB,JB),SMALA)
       DIFA = ALARG - SMALA
       DO 806 JB = 1,NV
  806      A(IB,JB) = (A(IB,JB)-SMALA)*100./DIFA
  805 CONTINUE
      W1=Q(23)
      W2=Q(24)
  810  DO 811 IA=1,N
  811 WRITE (4) (A(IA,J),J=1,NV)
        REWIND 4
      DO29K=1,NV
      A(K,2)=0.0
      A(K,3)=0.0
      A(K,4)=0.0
   29 A(K,5)=0.0
       DO 840 I=1,N
      READ (4) (C(J),J=1,NV)
      DO 829 J=1,NV
  829 B(I,J)=C(J)
      IF (EXPQ) 830,839,830
  830 DO 831 J = 1,NV
  831 C(J) = C(J)**EXPQ
      W1=Q(17)
      W2=Q(18)
  839  DO 840 J=1,NV
         A(J,2)=A(J,2)+C(J)
         A(J,3) = A(J,3)+ C(J)**2
         A(J,4) = A(J,4) +C(J)**3
         A(J,5) = A(J,5) +C(J)**4
      A(J,12)=DSQRT(A(J,3))
         A(J,13) = A(J,3)
  840 CONTINUE
   41 CONTINUE
      NORMAT = 0
         AM = AMA
      WRITE (3,985) AM,W1,W2
           MODE = MODEA
C
C     COMPUTE MEAN, STD. DEV., SKEW, KURTOSIS AND THEN WRITE OUT.
C       NOTE THAT XN ARRAY NUMBERS ARE DIFF. VALUES OF N FOR DIFF. COLS.
C
      DO50I=1,NV
      CM0=XN(I)
      CM1=CM0-1
      CM2=CM0-2
      CM3=CM0-3
      CP1=CM0+1
      CP3=CM0+3
      CP5=CM0+5
      SEG1=DSQRT((6.*CM0*CM1)/(CM2*CP1*CP3))
      SEG2=DSQRT((24.*CM0*CM1*CM1)/(CM3*CM2*CP3*CP5))
      FMT(I)=A(I,2)/CM0
   43 S2=A(I,3)-FMT(I)*A(I,2)
   44 IF (S2) 48,48,45
   48 S2=0.0000001D+0
      S3=0.0000001D+0
      S4=0.0000001D+0
      GO TO 49
   45 S3=A(I,4)-3.0*FMT(I)*A(I,3)+2.0*FMT(I)**3*CM0
      S4=A(I,5)-4.0*FMT(I)*A(I,4)+6.0*FMT(I)**2*A(I,3)-3.0*FMT(I)**4*CM0
   49 A(I,3) = S2/CM1
      A(I,4)=((CM0*S3)/(CM1*CM2))/(A(I,3)**1.5)
      A(I,5)=(CM0*(CP1*S4-3.0*CM1*S2*S2          /CM0)/(CM1*CM2*CM3))/(A(I
     1,3)*A(I,3))
      WORD3=Q(10)
      A(I,11)=DSQRT(A(I,3))
      A(I,11)=A(I,11)/DSQRT(CM0)
      IF (AM-WORD3) 47,50,47
   47 A(I,13)=DSQRT(A(I,3))
      XXX=.5+.25*A(I,5)
      IF(XXX .GE. 0.D+0) GO TO 46
      WRITE (3,940) I,XXX
      XXX=0.D+0
   46 A(I,12)=A(I,11)*DSQRT(XXX)
   50 CONTINUE
      DO8CKK=1,NV,50
```

```
      KKEND=MINO(KK+49,NV)
      WRITE (3,950) HEAD
       IF(AM-WORD3)53,51,53
   53 WRITE (3,903) W3,W4
       GO TC 54
   51 WRITE (3,990) W3,W4
   54 DO 75 I=KK,KKEND
      CM0=XN(I)
      CM1=CMC-1
      CM2=CMC-2
      CM3=CMC-3
      CP1=CMC+1
      CP3=CMC+3
      CP5=CMC+5
      SEG1=DSQRT((6.*CM0*CM1)/(CM2*CP1*CP3))
      SEG2=DSQRT((24.*CM0*CM1*CM1)/(CM3*CM2*CP3*CP5))
      IF(DABS(A(I,4)/SEG1)-2.576D+0)55,52,52
   52 WORD1=C(25)
      GOTC61
   55 IF(DABS(A(I,4)/SEG1)-1.96D+0)60,57,57
   57 WORD1=C(26)
      GOTO61
   60 WORD1=C(27)
   61 IF(DABS(A(I,5)/SEG2)-2.576D+0)65,62,62
   62 WORD2=C(25)
      GOTO71
   65 IF(DABS(A(I,5)/SEG2)-1.96D+0)70,67,67
   67 WORD2=C(26)
      GOTO71
   70 WORD2=C(27)
   71    IF (AM-WORD3) 72,73,72
   72 WRITE(3,904) I,ANAME(I),FMT(I),A(I,13),A(I,4),WORD1,A(I,5),WORD2
       GO TC 75
   73 WRITE(3,995) I,ANAME(I),FMT(I),A(I,13),A(I,12),A(I,4),WORD1,
     X                 A(I,5),WORD2
   75 CONTINUE
   74 WRITE(3,905) SEG1,SEG2
   80 CONTINUE
      WORD3=C(11)
      NN=NV-1
C
C     COMPUTE MATRIX TO BE FACTORED.   BRANCH TO STM. 174 IF IN R MODE.
C     METHOD BELOW USED BECAUSE OF MISSING DATA FEATURE.
C
      IF(AM .EQ. WORD3) GC TC 174
      IF(IFCFMT .EQ. 1) GO TO 162
      LMN=MAXO(N,NV)
      DO 16C I=1,LMN
      II=I+1
      DO 16C J=II,LMN
      ZZ=Z(I,J)
      Z(I,J)=Z(J,I)
  160 Z(J,I)=ZZ
  162 DO 17C K=1,NV
      DO 17C J=K,NV
      DX=0.
      DY=0.
      AAA=0.
      DO 165 I=1,N
      ZZ=Z(I,K)*Z(I,J)
      DX=DX+B(I,K)**2*ZZ
      DY=DY+B(I,J)**2*ZZ
  165 AAA=AAA+B(I,K)*B(I,J)*ZZ
  170 A(K,J)=AAA/DSQRT(DX*DY)
      GO TO 181
C
  174 DO 18C K=1,NV
      DO 180 J=K,NV
      BN=C.
      AX=0.
      AY=0.
      DX=0.
      DY=0.
      AAA=0.
      DO 175 I=1,N
      ZZ=Z(I,K)*Z(I,J)
      BN=BN+ZZ
      AX=AX+B(I,K)*ZZ
      AY=AY+B(I,J)*ZZ
      DX=DX+B(I,K)**2*ZZ
      DY=DY+B(I,J)**2*ZZ
  175 AAA=AAA+B(I,K)*B(I,J)*ZZ
  180 A(K,J)=(AAA-AX*AY/BN)/DSQRT((DX-AX**2/BN)*(DY-AY**2/BN))
C
  181 CONTINUE
      GOTO(215,142,215,1235,1235,1235),NRN
  142 WRITE(3,145)
  145 FORMAT('1'/'0'/'0'/'0STOP PROGRAM!!!!     NRN HAS BECOME 2 SOMEHOW.
     X   CALI NEAL FARIS AT COMPUTATION CENTER.')
      RETURN
  215 DO 226 I=1,NN
      NK=I+1
      DO226J=NK,NV
  226 A(J,I)=A(I,J)
      GOTO(1254,1227,1260,1235,1235,1235),NRN
 1227 WRITE (3,145)
      RETURN
 1235 DO124CI=1,NV
      READ (1,DFMT)  (A(I,J),J=1,NV)
 1240 CONTINUE
```

```
      GO TO 1243
 1241 CONTINUE
       NRC = NRO -1
       NROT = NROT - 1
      DO 1242 I=1,NV
 1242 READ (5) (A(I,J),J=1,NV)
       NRN = NRN+3
 1243 IF(NRN-5)1254,1260,1280
 1254 DO1255I=1,NV
      A(I,I)=1.0
 1255 CONTINUE
      GOTO1280
 1260 DO1265I=1,NV
      A(I,I)=0.0
 1265 CONTINUE
      DO1275I=1,NV
      RBIG=DABS(A(I,1))
      DO1270J=1,NV
      RBIG=DMAX1(DABS(RBIG),DABS(A(I,J)))
 1270 CONTINUE
      A(I,I)=RBIG
 1275 CONTINUE
 1280 CONTINUE
      IPAGE=0
       IF(MINBIJ)1285,1290,1285
 1285 REWIND 5
      DO 1286 I=1,NV
 1286 WRITE (5) (A(I,J),J=1,NV)
      REWIND 5
C
      NORMAT = NORMAT + 1
      IF(NORMAT) 1290,1290,2371
 1290 DO2370KK=1,NV,12
      KKEND=MINO(NV,KK+11)
      DO2370JSTART=1,KK,12
      JSTOP=MINO(NV,JSTART+11)
      IPAGE=IPAGE+1
      IF(MOD(IPAGE,2))2353,2353,2350
 2350 CONTINUE
      WRITE (3,950) HEAD
      WRITE (3,954)
      GOTO2354
 2353 CONTINUE
      WRITE (3,911)
      WRITE (3,911)
 2354 CONTINUE
      WRITE (3,951) W3,W4,(J,J=JSTART,JSTOP)
      IF(KK-JSTART)2360,2360,2355
 2355 DO2358I=KK,KKEND
      WRITE (3,952) I,ANAME(I),(A(I,J),J=JSTART,JSTOP)
 2358 CONTINUE
      GOTO2370
 2360 DO2365I=KK,KKEND
 2365 WRITE (3,952) I,ANAME(I),(A(I,J),J=JSTART,I)
 2370 CONTINUE
 2371 CONTINUE
      TRACR=0.0
 2374 DO2375I=1,NV
      TRACR=TRACR+A(I,I)
 2375 CONTINUE
      CALL JACOBI (NV,IWARN)
      IF(RNN-99.99D+0) 11103,11102,11102
11102 RNN=DABS(FMT(NV))
11103 DO243I=1,NV
      IF(FMT(I)-RNN) 242,243,243
  242 NZ1=I-1
      GOTO244
  243 CONTINUE
      NZ1=NV
  244 CONTINUE
      DO250I=1,NV
      DO248J=1,NV
      IF(DABS(A(J,I))-CUT) 248,250,250
  248 CONTINUE
      NZ2=I-1
      GOTO255
  250 CONTINUE
      NZ2=NV
  255 IF(NRO)257,257,258
  257 NRO=20
  258 CONTINUE
      SUMT=0.0
      KK=NV
      DO265I=1,NV
      SUMT=SUMT+FMT(I)
      IF(FMT(I))265,265,260
  260 KK=I
  265 CONTINUE
      JSTOP=20
      C(1)=0.0
      DO270I=1,NV
      C(1)=C(1)+FMT(I)
      IF(SUMT-C(1))267,267,270
  267 JSTOP=I
      GOTO275
  270 CONTINUE
  275 NRO=MINO(NRO,NZ1,NZ2,JSTOP,20)
      SUMR=0.0
      DO280I=1,NRO
      SUMR=SUMR+FMT(I)
```

```
280 CONTINUE                                                DUVA0501
    C(2)=0.0                                                DUVA0502
    C(4)=0.0                                                DUVA0503
    DO300J=1,KK,50                                          DUVA0504
    WRITE(3,950) HEAD                                       DUVA0505
    WRITE(3,955) NV,NRO                                     DUVA0506
    WRITE(3,912)                                            DUVA0507
    NZ1=MINO(J+49,KK)                                       DUVA0508
    DO300I=J,NZ1                                            DUVA0509
    C(1)=(FMT(I)/SUMT)*100.0                                DUVA0510
    C(2)=C(2)+C(1)                                          DUVA0511
    C(3)=(FMT(I)/SUMR)*100.0                                DUVA0512
    C(4)=C(4)+C(3)                                          DUVA0513
    IF(I-NRO)295,295,285                                    DUVA0514
285 IF(I-JSTOP)297,297,299                                  DUVA0515
295 WRITE(3,956) I,FMT(I),C(1),C(2),C(3),C(4)               DUVA0516
    GOTO300                                                 DUVA0517
297 WRITE(3,956) I,FMT(I),C(1),C(2)                         DUVA0518
    GOTO300                                                 DUVA0519
299 WRITE(3,956) I,FMT(I),C(1)                              DUVA0520
300 CONTINUE                                                DUVA0521
    WRITE(3,957) TRACE,NV,SUMT,NRO,SUMR                     DUVA0522
    WORD1=C(28)                                             DUVA0523
    WORD2=C(29)                                             DUVA0524
    IEXIT=1                                                 DUVA0525
    IPLAW=IDRAW/10                                          DUVA0526
305 CONTINUE                                                DUVA0527
    DO307I=1,NV                                             DUVA0528
    C(I)=0.0                                                DUVA0529
    DO307J=1,NRO                                            DUVA0530
    C(I)=C(I)+A(I,J)**2                                     DUVA0531
307 CONTINUE                                                DUVA0532
    DO310KK=1,NV,40                                         DUVA0533
    KKEND=MINO(NV,KK+39)                                    DUVA0534
    DO310JSTART=1,NRO,10                                    DUVA0535
    JSTOP=MINO(NRO,JSTART+9)                                DUVA0536
    WRITE (3,950) HEAD                                      DUVA0537
    WRITE (3,960) WORD1,WORD2,(J,J=JSTART,JSTOP)            DUVA0538
    WRITE (3,961) (FMT(J),J=JSTART,JSTOP)                   DUVA0539
    WRITE (3,962) W3,W4,NRO                                 DUVA0540
    WRITE (3,911)                                           DUVA0541
    DO310I=KK,KKEND                                         DUVA0542
    WRITE (3,963) I,ANAME(I),C(I),(A(I,J),J=JSTART,JSTOP)   DUVA0543
    WORD3=C(30)                                             DUVA0544
     IF (WORD1 - WORD3 )310,308,310                         DUVA0545
308  IF (PUN) 309,310,309                                   DUVA0546
309 WRITE (2,964) I,(A(I,J),J=JSTART,JSTOP)                 DUVA0547
310 CONTINUE                                                DUVA0548
    IF(NRO-1)311,311,312                                    DUVA0549
311 WRITE (3,950) HEAD                                      DUVA0550
    WRITE (3,927)                                           DUVA0551
    GOTO10                                                  DUVA0552
312 CONTINUE                                                DUVA0553
    GOTO(315,313),IWARN                                     DUVA0554
313 WRITE (3,950) HEAD                                      DUVA0555
    WRITE (3,970) MAXIT                                     DUVA0556
    GOTO10                                                  DUVA0557
315 CONTINUE                                                DUVA0558
    IF(IPLAW-1)320,500,320                                  DUVA0559
500 CONTINUE                                                DUVA0560
C     XA(1)=0.0                                             DUVA0561
C     YA(1)=0.0                                             DUVA0562
C     NG=1                                                  DUVA0563
C     NNRO=NRO-1                                            DUVA0564
C     DO520I=1,NNRO                                         DUVA0565
C     II=I+1                                                DUVA0566
C     DO520J=II,NRO                                         DUVA0567
C     DO510K=1,NV                                           DUVA0568
C     FMT(K)=A(K,I)                                         DUVA0569
C     C(K)=A(K,J)                                           DUVA0570
C 510 CONTINUE                                              DUVA0571
C                                                           DUVA0572
C     APLOT SUBROUTINE HAS NOT BEEN CONVERTED TO 360 FORTRAN.  DUVA0573
C                                                           DUVA0574
C     WRITE (3,950) HEAD                                    DUVA0575
C     WRITE (3,980) WORD1,WORD2,I,NG,J                      DUVA0576
C     CALL APLOT(1,NV,1,1,XA,YA)                            DUVA0577
C     NG=NG+1                                               DUVA0578
C 520 CONTINUE                                              DUVA0579
  320 CONTINUE                                              DUVA0580
      GOTO(321,330),IEXIT                                   DUVA0581
  321 IF(ISIE) 330,325,330                                  DUVA0582
  325 CALLROTATE(NV,NRO)                                    DUVA0583
      IEXIT=2                                               DUVA0584
      IPLAW=MOD(IDRAW,10)                                   DUVA0585
      WORD1=C(30)                                           DUVA0586
      DO324KK=1,NRO                                         DUVA0587
      SUM=0.0                                               DUVA0588
      DO323I=1,NV                                           DUVA0589
  323 SUM=SUM+A(I,KK)**2                                    DUVA0590
  324 FMT(KK)=SUM                                           DUVA0591
      GOTO305                                               DUVA0592
  330  IF (VCEP) 600,331,600                                DUVA0593
  600    DO 605J=1,NRO                                      DUVA0594
           J10 = (J-1) *10+1                                DUVA0595
         DO 601 I=1,NV                                      DUVA0596
  601 MM(I)=IABS(A(I,J))*1000.                              DUVA0597
       CALL HIGHC (MM,LARGEI,NV,LARGEC)                     DUVA0598
       IF(LARGEC-MINEIJ) 1241,605,605                       DUVA0599
  605    IFMT(J10) = LARGEI                                 DUVA0600
```

```
      CALI CCVCRP(NV,NRO,PUN,IFMT)                                      DUVA0601
      IF (MINBIJ+1)332,331,331                                          DUVA0602
  332 MINBIJ = MINBIJ + 1                                               DUVA0603
      GO TO 1241                                                        DUVA0604
  331 WRITE (3,950) HEAD                                                DUVA0605
      WRITE (3,975)                                                     DUVA0606
       NEN = NNRN                                                       DUVA0607
       IF(MCDE-2)899,2026,899                                           DUVA0608
  899 GO TO 10                                                          DUVA0609
  400 CALLEXIT                                                          DUVA0610
  901 FORMAT(12A6)                                                      DUVA0611
  902 FORMAT(1H0,10X,44HDUKE VECTOR ANALYSIS PROGRAM LYNTS AND PARIS    DUVA0612
     1         /1H0,10X,12HPRCBLEM NAME ,24X,A6,1X/1H0,10X,             DUVA0613
     2          22HNUMBER OF FORMAT CARDS,10X,I10/1H0,10X,19HNUMBER OF VARIDUVA0614
     3ABLES,13X,I10/1H0,10X,11HSAMPLE SIZE, 21X,I10/1H0,10X,8HROTATION,2DUVA0615
     48X,A6/1H0,10X,13HCCMMUNALITIES,23X,A6/                            DUVA0616
     5                                                                  DUVA0617
     6       1H0,10X,27HMAXIMUM NUMBER FCR ROTATION,5X,I10)             DUVA0618
  903 FORMAT(  3H0    ,2A6     /12H  NO.  NAME ,12X,4HMEAN,9X,2H   ,12X,DUVA0619
     16HST DEV,8X,2H   ,13X,4HSKEW,17X,8HKURTOSIS//)                    DUVA0620
  904 FORMAT(1H I4,1X,A6,2(F17.3, 11X ),2(F17.3,A6))                    DUVA0621
  905 FORMAT(2H0 ,  15HSE - SKEW     =F9.3,55X,27H*  SIGNIFICANT AT .05 DUVA0622
     1LEVEL /2X,15HSE - KURTOSIS =F9.3,54X,28H**  SIGNIFICANT AT .01 LEVDUVA0623
     2EL)                                                               DUVA0624
  911 FORMAT(1H0)                                                       DUVA0625
  912 FCRMAT(1H )                                                       DUVA0626
  921 FCRMAT(18A4)                                                      DUVA0627
  927 FORMAT(1H0,10X,24HMATRIX CANNOT BE ROTATED,/1H0,10X,28H- - -  CHECDUVA0628
     1K YCUR PROB. CARD)                                                DUVA0629
  940 FORMAT('1IN CCMPUTING MEAN, STD. DEV., ETC., NEGATIVE SQ. ROOT'/  DUVA0630
     +         'ENCOUNTERED IN STATEMENT NO. 46.   SET TO ZERO AND CONTINDUVA0631
     +UE.'/'CI=',I3,4X,'ARGUMENT=',D15.7)                               DUVA0632
  950 FORMAT(1H1,21A6 /)                                                DUVA0633
  951 FORMAT(3H0    ,2A6     ,/11H  NO.  NAME,12I10)                    DUVA0634
  952 FORMAT(1H0,I4,1X,A6,12F10.3)                                      DUVA0635
  954 FORMAT(1H0, 50X,22HMATRIX TO BE FACTORED )                        DUVA0636
  955 FORMAT(1H0, 9X,29HTABLE CF POSITIVE EIGENVALUES//36X,27HPERCENT OFDUVA0637
     1 COMMUNALITY OVER/10X,25HNO.   EIGENVALUE     ALL (,I4,9H) FACTORS,DUVA0638
     2I7,16H ROTATED FACTORS)                                           DUVA0639
  956 FORMAT(I12,F12.3,F13.1,F8.1,F14.1,F8.1)                           DUVA0640
  957 FORMAT(1H0,9X,24HTRACE OF CRIGINAL MATRIX,F16.3/10X,16HCOMMUNALITYDUVA0641
     1 OVER,14,10H FACTORS =,F10.3/I30,10H FACTORS =,F10.3)             DUVA0642
  960 FORMAT(1H0/27X,A6,A6,14HFACTOR  MATRIX/1H0,14X,13HFACTOR NUMBER,I8DUVA0643
     1,9I10)                                                            DUVA0644
  961 FORMAT(28H  SUM SQUARES DOWN  COLUMNS ,10F10.3)                   DUVA0645
  962 FORMAT(3H0   ,2A6,      11HCCMMUNALITY/12H   NO.  NAME,I5,8H FACTORSDUVA0646
     1)                                                                 DUVA0647
  963 FORMAT(1H ,I4,2X,A6,F10.3,F15.3,9F10.3)                           DUVA0648
  964  FORMAT (I3,9F7.4)                                                DUVA0649
  970 FORMAT(1H0,//10X,I10,2X,49HITERATIONS AND STILL NO CONVERGENCE -- DUVA0650
```

```
     1I QUIT....)                                                       DUVA0651
  974 FORMAT(1H0//1H0,19HPROB. CANNOT BE RUN/1H050HCHECK NO. OF FORMAT CDUVA0652
     1ARDS AND COMMUNALITIES OPTICN)                                    DUVA0653
  975 FORMAT(1H0,//20X,19HPRCBLEM IS FINISHED)                          DUVA0654
  980 FORMAT(1H0,4X,2A6,7HFACTCRS,35X,17HORDINATE - FACTOR,I4/7X,8HPLOT DUVA0655
     1NO.,I5,39X,17HABCISSA -- FACTOR,I4)                               DUVA0656
  985 FORMAT(1H0,10X,A6,21HMODE FACTOR ANALYSIS /1H0,10X,A6,A6,15H TRANSDUVA0657
     1FORMATICN  )                                                      DUVA0658
  990 FORMAT (2H0   2A6  ,     /12H  NO.  NAME ,12X,4HMEAN,9X,2H   ,12X, DUVA0659
     16HSUM SQ,4X,12HSQ RT SUM SC ,7X,4HSKEW,17X,8HKURTOSIS //)         DUVA0660
  995 FORMAT  (1H ,I4,1X,A6,F17.3,11X,F17.3,F11.3,2(F17.3,A6))          DUVA0661
      END                                                               DUVA0662
      SUBROUTINE COVORP(N,M,PUN,ITEST)                                  DUVA0663
      IMPLICIT REAL*8 (A-H,O-Z)                                         DUVA0664
      COMMCN /Y/B,V,C,BFAKE,C1,DUM1,DUM,       NAME,TAG                 DUVA0665
      REAL*8 NAME(21),TAG(112),VARTAG(10),TAGA,                         DUVA0666
     *    B(112,10),V(10,10),C(112,11),          BFAKE(10,1),           DUVA0667
     *    C1(10,112,11),DUM1(10530)                                     DUVA0668
      INTEGER INDEX(112),ITEST(10,10),DUM(114)                          DUVA0669
      INTEGER*2 PUN                                                     DUVA0670
C FORM   V   MATRIX                                                    DUVA0671
          NCRD = 1                                                      DUVA0672
       KIT = 1                                                          DUVA0673
          M1 =(M+1)*2                                                   DUVA0674
        R = 10000.                                                      DUVA0675
   25  IF (KIT - M1)26,221,221                                          DUVA0676
  221   IF (R-1.)    223,232,223                                        DUVA0677
  223    R = R/10.                                                      DUVA0678
  232    KIT = 1                                                        DUVA0679
   26    DO 33 K = 1,M                                                  DUVA0680
         LINE = ITEST(KIT,K)                                            DUVA0681
         VARTAG (K) = TAG(LINE)                                         DUVA0682
      DO  33  J = 1, M                                                  DUVA0683
   33 V (K, J)  =  B (LINE, J)                                          DUVA0684
C                                                                       DUVA0685
C WRITE   V MATRIX                                                      DUVA0686
      WRITE(3,3)  (NAME(K),K=1,20)                                      DUVA0687
      WRITE(3,679)                                                      DUVA0688
  679 FORMAT(1H0   / 55X,9HV   MATRIX ///)                              DUVA0689
      WRITE(3,4)  (ITEST(KIT,J),J=1,M)                                  DUVA0690
      DO   951 K = 1, M                                                 DUVA0691
         INO = ITEST(KIT,K)                                             DUVA0692
         TAGA = TAG(INO)                                                DUVA0693
  951 WRITE(3,952) TAGA,INO,(V(K,J),J=1,M)                              DUVA0694
  952 FORMAT(//1X,A6,3X,I3,2X,10F9.4)                                   DUVA0695
      WRITE(3,691)                                                      DUVA0696
  691 FCRMAT   ( 1H0///)                                                DUVA0697
C                                                                       DUVA0698
C INVERT   V  MATRIX                                                    DUVA0699
      DO 10 I = 1, 10                                                   DUVA0700
```

```
   10 BFAKE ( I, 1) = 0.
      MFAKE = 1
      CALL  MATINV ( V, M, BFAKE, MFAKE, DET )
C
C    WRITE  C INVERSE
      WRITE(3,678)
  678 FORMAT ( 1H0  49X  22HINVERSE  OF  V  MATRIX///)
      DO  953 J = 1, M
  953 WRITE(3,954)  (V(J,K),K=1,M)
  954 FORMAT  (1H0,14X,10F9.4 )
       CALL MEROD (N,M)
C
C     CHECK AWNSERS
        IF (R-1.)    216,233,216
  216  DO 22C J = 1,M
         DO 218 I = 1,N
  218 INDEX(I)=DABS(C(I,J))*R
       CALL FIGHC (INDEX,LARGEI,N,LARGEC)
            CK = LARGEC
       IF (CK-R) 215,22C,215
  215  IF (CK-CL) 214,220,214
  214  IF(ITEST(KIT,J)-LARGEI) 219,220,219
  219   KIT = KIT + 1
       DO 217 JO = 1,M
         KIN = KIT - 1
  217  ITESI(KIT,JO) = ITEST(KIN,JO)
           IARG = ITEST(KIT,J)
         ITESI(KIT,J) = LARGEI
         CL = LARGEC
         RR = (CL/R)-1.
      WRITE(3,704) KIN,RR
  704 FORMAT(1H0 ,6X,15HITERATION CYCLE  ,I4,35H.  HIGHEST LOADING IN C
     1MATRIX IS  ,F5.3,20H IN EXCESS OF  1.000  /)
         GO TO 25
  220 CONTINUE
C
C RCUND  C  MATRIX
         GO TO 233
  233 DO  234 K = 1, M
      DO  234  I = 1, N
  234 C(I,K)=C(I,K)+.0004D+0
C WRITE  ANSWERS
  222 WRITE(3,3)  (NAME(K),K=1,21)
    3 FORMAT (1H1,21A6 // 12X,28HOBLIQUE PROJECTION PROGRAM  //55X,14H
     1OBLIQUE AXES    ////)
      WRITE(3,4)  (ITEST(KIT,K),K=1,M)
    4 FORMAT (6H NAME  ,2X,6H INDEX ,10(6X,I3))
      WRITE(3,5)
    5 FORMAT (1H0)
      DO  77 I = 1,  N
   77  INDEX (I) = I
      DO  88 I = 1,  N
   88 WRITE(3,6)  TAG(I),INDEX(I),(C(I,K),K=1,M)
    6 FORMAT ( 1H0,A6,I5,2X,10F9.3)
      IF(PUN)777,777,89
   89    DO  90  I = 1,N
   90 WRITE(2,9) INDEX(I),(C(I,K),K=1,M)
    9 FORMAT ( I3,2X,10F6.3/5X,5F6.3)
  777    IF (NORD) 778,778,779
  778  GO TC 111
  779 WRITE(3,8)  (NAME(K),K=1,21)
      WRITE(3,702)  (VARTAG(I),I=1,M)
      WRITE(3,703)  (ITEST(KIT,I),I=1,M)
    8 FORMAT (1H1,21A6 //40X,36HREORDERED OBLIQUE PROJECTION MATRIX   /)
  702 FORMAT (1H0,14H  NAME          ,10(2X,A6,2X))
  703  FORMAT (1H0,1X,10H       INDEX ,10( 3X,I5,2X)/12H NAME    NO.    )
       CALL REORD (N,M)
      DO 10CC I=1,112
      INDEX(I)=0.
      DO 998 K=1,10
  998 B(I,K)=0.
      DO 10CC L=1,11
 1000 C(I,L)=0.
      DO 1001 K=1,10
      BFAKE(K,1)=0.
      V(K,K)=0.
 1001 ITEST(K,K)=0.
  111 RETURN
      END
      SUBROUTINEJACOBI(NV,IWARN)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /Y/ R,E,C,VAL,MM
      REAL*8 R(112,112),B(112,112),C(112),VAL(112),IFMT(112)
      INTEGER MM(114)
       EQUIVALENCE (VAL,IFMT)
      CALL SLITE(0)
      IWARN=1
      FNV=NV
      RCRIT=C.0
      ROOT2=C.7071C678D+0
      MAXIT=3*NV*NV
      CMIN=C.0C1D+0
      CMAX=1.0D+8
      NNV=NV-1
      ITER=C
      ICYCLE=0
      CRIT=C.5D-05
      DO20I=1,NNV
      B(I,I)=1.0
```

```
      II=I+1                                                            DUVA0801
      DO20J=II,NV                                                       DUVA0802
      B(I,J)=0.0                                                        DUVA0803
      B(J,I)=0.0                                                        DUVA0804
      IF(RCRIT-DABS(R(I,J))) 15,20,20                                   DUVA0805
   15 RCRIT=DABS(R(I,J))                                                DUVA0806
   20 CONTINUE                                                          DUVA0807
      RCRIT=RCRIT*0.9D+0                                                DUVA0808
      B(NV,NV)=1.0                                                      DUVA0809
   25 CONTINUE                                                          DUVA0810
      ICYCLE=ICYCLE+1                                                   DUVA0811
      DO5555IDEX=1,NNV                                                  DUVA0812
      IPLUS=IDEX+1                                                      DUVA0813
      DO5555JDEX=IPLUS,NV                                               DUVA0814
      IF(RCRIT-DABS(R(IDEX,JDEX)))45,5555,5555                          DUVA0815
   45 CALL SLITE(2)                                                     DUVA0816
      ITER=ITER+1                                                       DUVA0817
      RIJ=R(IDEX,JDEX)                                                  DUVA0818
      RII=R(IDEX,IDEX)                                                  DUVA0819
      RJJ=R(JDEX,JDEX)                                                  DUVA0820
      SFAC=1.0                                                          DUVA0821
      D=(2.0*RIJ)/(RII-RJJ)                                             DUVA0822
      CALL DVCHK(IDV)                                                   DUVA0823
      IF(IDV .EQ. 1) GO TO 90                                           DUVA0824
   65 AC=D                                                              DUVA0825
      IF(D) 70,125,75                                                   DUVA0826
   70 AC=DABS(D)                                                        DUVA0827
      SFAC= -1.0                                                        DUVA0828
   75 IF(AC-CMIN) 125,125,80                                            DUVA0829
   80 IF(AC-CMAX) 85,90,90                                              DUVA0830
   85 CONTINUE                                                          DUVA0831
      CDC=1./DSQRT(1.+D*D)                                              DUVA0832
      BCOS=ROOT2*DSQRT(1.+CDC)                                          DUVA0833
      BSIN=SFAC*ROOT2*DSQRT(1.-CDC)                                     DUVA0834
      GOTO199                                                           DUVA0835
   90 CONTINUE                                                          DUVA0836
      BCOS=ROOT2                                                        DUVA0837
      BSIN=ROOT2                                                        DUVA0838
      GOTO199                                                           DUVA0839
  125 CONTINUE                                                          DUVA0840
      BSIN=D/2.0                                                        DUVA0841
      BCOS=1.0-(BSIN*BSIN)/2.0                                          DUVA0842
  199 CONTINUE                                                          DUVA0843
      DO220I=1,NV                                                       DUVA0844
      CELL=BCOS*R(I,IDEX)+BSIN*R(I,JDEX)                                DUVA0845
      R(I,JDEX)=BCOS*R(I,JDEX)-BSIN*R(I,IDEX)                           DUVA0846
      R(JDEX,I)=R(I,JDEX)                                               DUVA0847
      R(I,IDEX)=CELL                                                    DUVA0848
      R(IDEX,I)=CELL                                                    DUVA0849
      CELL=BCOS*B(IDEX,I)+BSIN*B(JDEX,I)                                DUVA0850
      B(JDEX,I)=BCOS*B(JDEX,I)-BSIN*B(IDEX,I)                           DUVA0851
      B(IDEX,I)=CELL                                                    DUVA0852
  220 CONTINUE                                                          DUVA0853
      CELL=BCOS*BSIN                                                    DUVA0854
      COS2=BCOS**2                                                      DUVA0855
      SIN2=BSIN**2                                                      DUVA0856
      R(IDEX,JDEX)=COS2*RIJ-SIN2*RIJ+(RJJ-RII)*CELL                     DUVA0857
      R(JDEX,IDEX)=R(IDEX,JDEX)                                         DUVA0858
      CELL=2.0*RIJ*CELL                                                 DUVA0859
      R(IDEX,IDEX)=COS2*RII+SIN2*RJJ+CELL                               DUVA0860
      R(JDEX,JDEX)=SIN2*RII+COS2*RJJ-CELL                               DUVA0861
      IF(ITER-MAXIT)5555,1313,1313                                      DUVA0862
 1313 CONTINUE                                                          DUVA0863
      IWARN=2                                                           DUVA0864
      WRITE (3,899)                                                     DUVA0865
      DO1315I=1,5                                                       DUVA0866
      WRITE (3,900) ITER                                                DUVA0867
 1315 CONTINUE                                                          DUVA0868
      GOTO350                                                           DUVA0869
  899 FORMAT(1H1)                                                       DUVA0870
  900 FORMAT(1H0,//10X,I10,2X,49HITERATIONS AND STILL NO CONVERGENCE -- DUVA0871
     1I QUIT....)                                                       DUVA0872
 5555 CONTINUE                                                          DUVA0873
      CALL SLITET(2,ISL)                                                DUVA0874
      CALL SLITE(0)                                                     DUVA0875
      IF(ISL .EQ. 1) GO TO 25                                           DUVA0876
  300 IF(RCRIT-CRIT) 350,350,310                                        DUVA0877
  310 RCRIT=RCRIT/5.0                                                   DUVA0878
      GOTO25                                                            DUVA0879
  350 CONTINUE                                                          DUVA0880
      DO380I=1,NV                                                       DUVA0881
      VAL(I)= -5000.0                                                   DUVA0882
      DO370J=1,NV                                                       DUVA0883
      IF(R(J,J)+999999.0) 360,370,360                                   DUVA0884
  360 IF(VAL(I)-R(J,J)) 365,365,370                                     DUVA0885
  365 VAL(I)=R(J,J)                                                     DUVA0886
      MM(I)=J                                                           DUVA0887
  370 CONTINUE                                                          DUVA0888
      K=MM(I)                                                           DUVA0889
      R(K,K)= -999999.0                                                 DUVA0890
  380 CONTINUE                                                          DUVA0891
      DO400I=1,NV                                                       DUVA0892
      K=MM(I)                                                           DUVA0893
      SFAC=DSQRT(DABS(VAL(I)))                                          DUVA0894
      DO400J=1,NV                                                       DUVA0895
      R(J,I)=B(K,J)*SFAC                                                DUVA0896
  400 CONTINUE                                                          DUVA0897
      MAXIT=ITER                                                        DUVA0898
 1500 RETURN                                                            DUVA0899
      END                                                               DUVA0900
```

```
      SUBROUTINE REORD (N,M)                                          DUVA0901
      IMPLICIT REAL*8 (A-H,O-Z)                                       DUVA0902
      COMMON /Y/B,V,C,BFAKE,C1,DUM1,DUM,        NAME,TAG              DUVA0903
      REAL*8 NAME(21),TAG(112),                                       DUVA0904
     *     B(112,10),V(10,10),C(112,11),          BFAKE(10,1),        DUVA0905
     *     C1(10,112,11),DUM1(10530),NZ(10)                           DUVA0906
      INTEGER DUM(114)                                                DUVA0907
            NV1 = M  + 1                                              DUVA0908
       DO 19 K = 1,10                                                 DUVA0909
   19       NZ(K)  = 0                                                DUVA0910
       DO 40 I = 1,N                                                  DUVA0911
            C(I,NV1)  = I                                             DUVA0912
      SAVE=DABS(C(I,1))                                               DUVA0913
       K = 1                                                          DUVA0914
       DO 21 J = 2,M                                                  DUVA0915
      AF=DABS(C(I,J))                                                 DUVA0916
         IF  (SAVE - AF )  20,20,21                                   DUVA0917
   20      SAVE = AF                                                  DUVA0918
           K = J                                                      DUVA0919
   21   CONTINUE                                                      DUVA0920
         NZ(K)  = NZ(K)  + 1                                          DUVA0921
         NN  = NZ(K)                                                  DUVA0922
       IF  (NN - 99)  39,39,38                                        DUVA0923
   38      NZ(K)  = NZ(K)  - 1                                        DUVA0924
   39  DO 30 JK = 1,NV1                                               DUVA0925
        C1  (K,NN,JK)  = C(I,JK)                                      DUVA0926
   30 CONTINUE                                                        DUVA0927
   40  CONTINUE                                                       DUVA0928
       DO 100 K = 1, M                                                DUVA0929
            NL  =NZ(K)                                                DUVA0930
        DO 61 KK=1,NL                                                 DUVA0931
          DO 60   JJ  = 1,NV1                                         DUVA0932
   60        C(KK,JJ)  =C1(K,KK,JJ)                                   DUVA0933
   61 CONTINUE                                                        DUVA0934
             NF = 1                                                   DUVA0935
       CALL CRDCOL (C,NF,NL,M ,K)                                     DUVA0936
       DO 90 KK = 1,NL                                                DUVA0937
           IK = C(KK,NV1)                                             DUVA0938
   90 WRITE  (3,1)  TAG(LK),LK,(C(KK,J),J=1,M)                        DUVA0939
    1 FORMAT  (1H0,A6,I3,2X,10F10.3)                                  DUVA0940
  100 WRITE  (3,2)                                                    DUVA0941
    2 FORMAT(1H0)                                                     DUVA0942
      RETURN                                                          DUVA0943
      END                                                             DUVA0944
       SUBROUTINE MPROD  (N,M)                                        DUVA0945
      IMPLICIT REAL*8  (A-H,O-Z)                                      DUVA0946
      COMMON /Y/ B,V,C                                                DUVA0947
      REAL*8 B(112,10),V(10,10),C(112,11)                             DUVA0948
      DO 99   K = 1, M                                                DUVA0949
      DO   99   I = 1, N                                              DUVA0950
      C ( I, K)   =   0.0                                             DUVA0951
      DO  99  J = 1, M                                                DUVA0952
   99 C (I, K)   =   C ( I,K)   +   B ( I,J)  * V ( J, K)             DUVA0953
      RETURN                                                          DUVA0954
      END                                                             DUVA0955
      SUBROUTINE MATINV(A,N,B,M,DETERM)                               DUVA0956
      IMPLICIT REAL*8 (A-H,O-Z)                                       DUVA0957
C                                                                     DUVA0958
      REAL*8 A(10,10),B(10,1),PIVOT(10)                               DUVA0959
      INTEGER IPIVOT(10),INDEX(10,2)                                  DUVA0960
      EQUIVALENCE (IROW,JROW), (ICOLUM,JCOLUM), (AMAX, T, SWAP)       DUVA0961
C                                                                     DUVA0962
C     INITIALIZATION                                                  DUVA0963
C                                                                     DUVA0964
   10 DETERM=1.0                                                      DUVA0965
   15 DO 20 J=1,N                                                     DUVA0966
   20 IPIVOT(J)=0                                                     DUVA0967
   30 DO 550 I=1,N                                                    DUVA0968
C                                                                     DUVA0969
C     SEARCH FOR PIVOT ELEMENT                                        DUVA0970
C                                                                     DUVA0971
   40 AMAX=0.0                                                        DUVA0972
   45 DO 105 J=1,N                                                    DUVA0973
   50 IF (IPIVOT(J)-1) 60, 105, 60                                    DUVA0974
   60 DO 100 K=1,N                                                    DUVA0975
   70 IF (IPIVOT(K)-1) 80, 100, 740                                   DUVA0976
   80 IF(DABS(AMAX)-DABS(A(J,K))) 85,100,100                          DUVA0977
   85 IROW=J                                                          DUVA0978
   90 ICOLUM=K                                                        DUVA0979
   95 AMAX=A(J,K)                                                     DUVA0980
  100 CONTINUE                                                        DUVA0981
  105 CONTINUE                                                        DUVA0982
  110 IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1                                 DUVA0983
C                                                                     DUVA0984
C     INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL               DUVA0985
C                                                                     DUVA0986
  130 IF (IROW-ICOLUM) 140, 260, 140                                  DUVA0987
  140 DETERM=-DETERM                                                  DUVA0988
  150 DO 200 L=1,N                                                    DUVA0989
  160 SWAP=A(IROW,L)                                                  DUVA0990
  170 A(IROW,L)=A(ICOLUM,L)                                           DUVA0991
  200 A(ICOLUM,L)=SWAP                                                DUVA0992
  205 IF(M) 260, 260, 210                                             DUVA0993
  210 DO 250 L=1, M                                                   DUVA0994
  220 SWAP=B(IROW,L)                                                  DUVA0995
  230 B(IROW,L)=B(ICOLUM,L)                                           DUVA0996
  250 B(ICOLUM,L)=SWAP                                                DUVA0997
  260 INDEX(I,1)=IROW                                                 DUVA0998
  270 INDEX(I,2)=ICOLUM                                               DUVA0999
  310 PIVOT(I)=A(ICOLUM,ICOLUM)                                       DUVA1000
```

```
  320 DETERM=DETERM*PIVOT(I)
C
C     DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
  330 A(ICOLUM,ICOLUM)=1.0
  340 DO 350 L=1,N
  350 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT(I)
  355 IF(M) 380, 380, 360
  360 DO 370 L=1,M
  370 B(ICOLUM,L)=B(ICOLUM,L)/PIVOT(I)
C
C     REDUCE NON-PIVOT ROWS
C
  380 DO 550 L1=1,N
  390 IF(L1-ICOLUM) 400, 550, 400
  400 T=A(L1,ICOLUM)
  420 A(L1,ICOLUM)=0.0
  430 DO 450 L=1,N
  450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
  455 IF(M) 550, 550, 460
  460 DO 500 L=1,M
  500 B(L1,L)=B(L1,L)-B(ICOLUM,L)*T
  550 CONTINUE
C
C     INTERCHANGE COLUMNS
C
  600 DO 710 I=1,N
  610 L=N+1-I
  620 IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630
  630 JROW=INDEX(L,1)
  640 JCOLUM=INDEX(L,2)
  650 DO 705 K=1,N
  660 SWAP=A(K,JROW)
  670 A(K,JROW)=A(K,JCOLUM)
  700 A(K,JCOLUM)=SWAP
  705 CONTINUE
  710 CONTINUE
  740 RETURN
      END
      SUBROUTINE  ORDCOL ( A, NF, NL, M, K)
C
C     GIVEN AN N X MM MATRIX A (112 X 11) WITH ROW INDEX GIVEN AS
C     LASTCOLUMN OF A, THE FIRST AND LAST ROW SEQUENCE  NUMBER  OF
C   SUBMATRIX SUBA, NF AND NL, PROGRAM WILL REORDER SUB A BY RANK OF EL
C  EMENT IN A COLUMN K. ANSWER IN A.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 A(112,11),SAVE(11)
      MM = M + 1
      NL1 = NL - 1
      DO 333 I = NF, NL1
      NEXT = I + 1
      DO  11 J = 1, MM
   11 SAVE (J) = A ( I, J)
      DO  333  II = NEXT, NL
      IF  ( A (I,K)  -  A (II, K))   444, 333, 333
  444 DO  22 J = 1, MM
      A ( I,J) = A(  II, J)
      A (II, J) = SAVE (J)
   22 SAVE (J) = A ( I, J)
  333 CONTINUE
      RETURN
      END
      SUBROUTINE HIGHC (INDEX,LARGEI,N,LARGEC)
      IMPLICIT REAL*8 (A-H,O-Z)
      INTEGER INDEX(114)
      LARGEI = 1
         LARGEC = INDEX(1)
       DO 20 I = 2,N
       IF (LARGEC -INDEX(I)) 10,20,20
   10 LARGEC = INDEX(I)
         LARGEI = I
   20 CONTINUE
      RETURN
      END
      SUBROUTINEROTATE(N,L)
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /Y/ A,P,H,TV
      REAL*8 A(112,112),P(112,112),H(112),TV(112),IFMT(112)
       EQUIVALENCE(H,IFMT)
      EPS=0.C0116D+0
      JTEST=3
      Q=1.0
      NCOUNT=0
      MM=(L*(L-1))/2
      TV(1)=C.0
      LL=L-1
      NV=1
      NC=0
      FN=N
      FFN=FN**2
      CCNS=1./1.414214D+0
      ZERO=1.D-4
      DO 3 I=1,N
    3 H(I)=C.0
      DO 4 I=1,N
      DO 4 J=1,L
    4 H(I)=H(I)+A(I,J)*A(I,J)
      DO 5 I=1,N
      H(I)=DSQRT(H(I))
```

```
      DO 5 J=1,L
    5 A(I,J)=A(I,J)/H(I)
  222 NV=NV+1
      TV(NV)=0.0
      LV=NV-1
      DO 88 J=1,L
      AA=0.C
      BB=0.C
      DO 77 I=1,N
      CC=A(I,J)*A(I,J)
      AA=AA+CC
   77 BB=BB+CC**2
   88 TV(NV)=TV(NV)+(FN*EE-AA**2)/FFN
      IF(NV-5C)9,999,999
    9 IF(DAES(TV(NV)-TV(LV))-1.D-7) 11,11,13
   11 NC=NC+1
   12 IF(NC-JTEST)13,13,999
   13 DO 50C J=1,LL
      II=J+1
      DO 50C K=II,L
      IF(NCCUNT-MM)32,500,500
   32 IF(DAES(Q)-ZERO)14,14,10
   10 NCOUNT=0
   14 AA=0.C
      BB=0.C
      CC=C.C
      DD=0.C
      DO15I=1,N
      U=(A(I,J)+A(I,K))*(A(I,J)-A(I,K))
      T=A(I,J)*A(I,K)
      T=T+T
      CC=CC+(U+T)*(U-T)
      DD=DD+2.0*U*T
      AA=AA+U
   15 BB=BB+T
      T=DD-2.0*AA*BB/FN
      B=CC-(AA**2-BB**2)/FN
      Q=.25*DTAN(T/B)
      IF(DAES(Q)-ZERO)7,7,69
    7 NCOUNT=NCOUNT+1
      GO TO 500
   69 TAN4P=T/B
      IF(T-E)1041,1433,1042
 1433 IF(T+E-EPS)50C,1043,1043
 1043 COS4T=CCNS
      SIN4T=CCNS
      GOTO5CC0
 1041 TAN4T=DABS(T)/DABS(B)
      IF(TAN4T-EPS)8000,1100,1100
 1100 COS4T=1./DSQRT(1.+TAN4T**2)
      SIN4T=TAN4T*COS4T
      GOTO5CC0
 8000 IF(E)1150,5C0,500
 1150 SINP=CCNS
      COSP=CCNS
      GOTC1CC0
 1042 CTN4T=DAES(T/B)
      IF(CTN4T-EPS)9000,1200,1200
 1200 SIN4T=1./DSQRT(1.+CTN4T**2)
      COS4T=CTN4T*SIN4T
      GOTO5CC0
 9000 COS4T=C.0
      SIN4T=1.0
 5000 COS2T=DSQRT((1.+COS4T)/2.)
      SIN2T=SIN4T/(2.0*COS2T)
      COST=DSQRT((1.+COS2T)/2.)
      SINT=SIN2T/(2.0*COST)
      IF(B)1250,1250,1300
 1300 COSP=CCST
      SINP=SINT
      GOTO7CC0
 1250 COSP=CCNS*COST+CONS*SINT
      SINP=DABS(CONS*COST-CONS*SINT)
 7000 IF(T)1400,1400,1000
 1400 SINP=-SINP
 1000 DO 10C I=1,N
      AA=A(I,J)*COSP+A(I,K)*SINP
      BB=-A(I,J)*SINP+A(I,K)*CCSP
      A(I,J)=AA
  100 A(I,K)=BB
  500 CONTINUE
      GO TO 222
  999 DO 6 I=1,N
      DO 6 J=1,L
    6 A(I,J)=A(I,J)*H(I)
      RETURN
      END
```

ERYOPSID REMAINS FROM THE CONEMAUGH GROUP, BRAXTON COUNTY, WEST VIRGINIA

By

James L. Murphy
Case Western Reserve University
Cleveland, Ohio

ABSTRACT

Well-preserved skull, pectoral girdle, limb and vertebral elements of an *Eryops* specimen have been found in a roadcut near Sutton, Braxton County, West Virginia. The amphibian remains occurred in a green siltstone of unquestionable mid-Conemaugh age. Taxonomic difficulties involving the genus *Glaukerpeton* Romer and speciation within the genus *Eryops* are briefly discussed.

INTRODUCTION

The amphibian specimen described in this paper was discovered by the author in July, 1969, in a roadcut between one and 1.1 mile southeast of the southern end of the Elk River bridge at Sutton, Braxton County, West Virginia. Hennen (1917) published a stratigraphic section measured along this highway (now U. S. Route 19) by R. M. Gawthorp. Numerous changes in the path of the highway, uncertainties regarding the aneroid elevations cited in Hennen's description of the section, a strong down section dip component, vagueness of the upper limit of the described section and lack of key or marker beds of distinctive lithology have made reinterpretation of this section difficult. A second visit to the region was made in May, 1971, to confirm the stratigraphic occurrence of the fossil.

STRATIGRAPHIC OCCURRENCE

The 545 foot sequence measured by Gawthorp consists primarily of sandstone, siltstone and variegated shale and clay. The only coal in the section (Brush Creek coal, elevation 950') is no longer exposed. The "Ewing Limestone" can still be seen in the ditch on the west side of the road, a few feet below the 1200 foot contour. Hennen's identification of this limestone with the Ewing Limestone Member is suspect, however, and the nodular limestone probably represents the Rock

Riffle Run Limestone Member associated with the Harlem underclay. Hennen's "Pittsburgh red shale" occurring 15 feet below this freshwater limestone probably represents the Round Knob Shale Member (Pittsburgh redbeds of some authors). In any case, the Round Knob Shale Member lies above the Ewing Limestone Member and not below it.

The only bed higher in the section that can be deemed of any stratigraphic value is a thin, impure freshwater limestone referred to the Elk Lick Limestone Member by Hennen. If this identification is correct, then the overlying redbeds (30 feet in thickness), "massive sandstone" (10 feet in thickness) and "greenish-gray shale" (5 feet in thickness) represent respectively the Morgantown Redbed and Morgantown Sandstone Members. These units are well exposed in the lower part of the extensive roadcut at the top of the hill, elevation of the Elk Lick Limestone Member being approximately 1280 feet.

The amphibian remains were found within one to two feet of the top of the "massive sandstone" unit, elevation approximately 1340 feet, on the east side of the highway, four to five feet above the pavement. Accepting the correlations and elevations of Hennen and Gawthorp, this unit is the Morgantown Sandstone Member of the mid portion of the Conemaugh Group.

Although a few fragmentary eryopsid remains have been described previously from strata of the Conemaugh Group (Case, 1908; Romer, 1952), referrable to either Eryops or Glaukerpeton, the present specimen is better preserved than previously described material; it is, in fact, the finest eryopsid specimen yet discovered in rocks of this age in the Appalachian Basin.

PRELIMINARY DESCRIPTION

Preparation

Only a small portion of the left side of the skull roof and right mandible were exposed in the siltstone matrix. The specimen was carefully prepared, largely with a White air abrasive unit, by Mr. Peter Hoover, Cleveland Natural Science Museum. Additional elements were discovered during the course of the preparation work and these are also noted below.

Skull

(Plate 1, figures 1-3)

The skull roof was badly crushed and considerably distorted, particularly on the right side, making accurate measurements impossible (Plate 1, figure 2). Maximum length of the skull is estimated at 200 mm from muzzle to the tip of the left quadrate. Interorbital width, the parameter least distorted by crushing, is 45 mm. The specimen is thus considerably smaller than even the holotype of Eryops avinoffi (Romer) and much smaller than E. megacephalus (Cope), E. willistoni (Moodie) and E. grandis (Marsh). The entire skull roof is ornamented by a fine reticulation or pitting. There are about 60-70 pits per square inch, as counted on the right postfrontal at mid orbit.

The left nostril lies about 20 mm from the tip of the muzzle. The distance between the nostril and the orbit (left side) is approximately 77 mm.

The median parietal foramen is obscured by crushing and overriding of the left postparietal. Individual bones of the dermal roof are not always easily delineated, due to the crushed nature of the skull, faintness of the sutures, and difficulty of distinguishing post-mortem breaks from sutures. In some instances the specimen has broken along sutures, though not to such a degree as to indicate that this is necessarily a consequence of immaturity in the individual. The sutures, in so far as they can be discerned, do not differ materially from the pattern described by Sawin (1941) for E. megacephalus.

Unfortunately, the area occupied by the interfrontal is not exposed. The right anterior portion of the skull, including the right premaxillary and nasal, appear to have been shoved posteriorly so that the right nasal completely overlaps the interfrontal. The interparietal and interfrontal suture can be traced easily enough anteriorly to the point where it is overlapped by the dislocated right nasal. In photographs and even upon cursory examination of the specimen, it appears that the median suture continues anteriorly, uninterrupted by an interfrontal element. Close inspection, however, suggests that the right nasal has been pushed some 15 to 20 mm posteriorly and an undetermined distance sinistrally. This dislocation is thought to be sufficient to cover the interfrontal. Even so, belief in the presence of an interfrontal in this specimen is necessarily somewhat subjective, based as it is upon the hypothetical restoration of various dermal elements to their original positions. It can be argued that the right nasal only slightly overlaps the left nasal, that a median internasal suture continues anteriorly and an interfrontal element is absent. Although the nasofrontal margin is readily discerned, there does not seem to be a pronounced indentation that would provide space for the interfrontal; on the other hand, the lateral margin of the nasal is not nearly so straight as that indicated for "Glaukerpeton" avinoffi Romer, in which the interfrontal is presumed to be absent. Removal of the right nasal may be necessary to settle this important point concerning the West Virginia specimen.

Posterior elements of the cranial roof are poorly preserved and incomplete in some instances. The right temporal cannot be satisfactorily located, and the right quadratojugal is badly crushed, shoved dorsally and anteriorly, severely damaging the right squamosal. The right postorbital is almost entirely isolated, having been shoved into the orbit, and there is a wide gap between the right postorbital and the right postfrontal. The postparietal of the right side and the posterior part of the parietals have not been identified and are apparently entirely, or in large part, missing.

Ventrally, most of the bones of the palate are well preserved. (Plate 1, figure 3) The brain case, though dislocated, is intact, with the right stapes nearly in place. The anterior extension of the paraspenoid and the sphenethmoid are badly crushed, and the sutural surfaces adjacent to the pterygoid are entirely exposed.

The posterior part of the brain case is broken away from the rest of the brain case, and only the lower part of the exoccipitals, and the basioccipital and the foramen magnum can be readily seen. The dorsal part of the exoccipitals and the otic are missing. The fenestra ovalis is present on either side of the ventral surface of the otic, but no trace of the Nvii foramen can be seen anterior to the fenestrae. Nx and Nxii foramina are visible on the left exoccipital, but the rest of that element has been broken away posteriorly.

Anteriorly the sphenethmoid region and the anterior part of the parasphenoid are badly crushed, exposing the vomeronasal nerve canal or first cranial nerve canal. The preorbital flare and anterior end of the sphenethmoid region are poorly preserved.

The prevomerine tooth craters and posterolateral elevations are well displayed though disoriented by crushing. An unusual feature is the presence of a double ectopterygoid tooth and pit on the right side. The left ectopterygoid crater is developed normally.

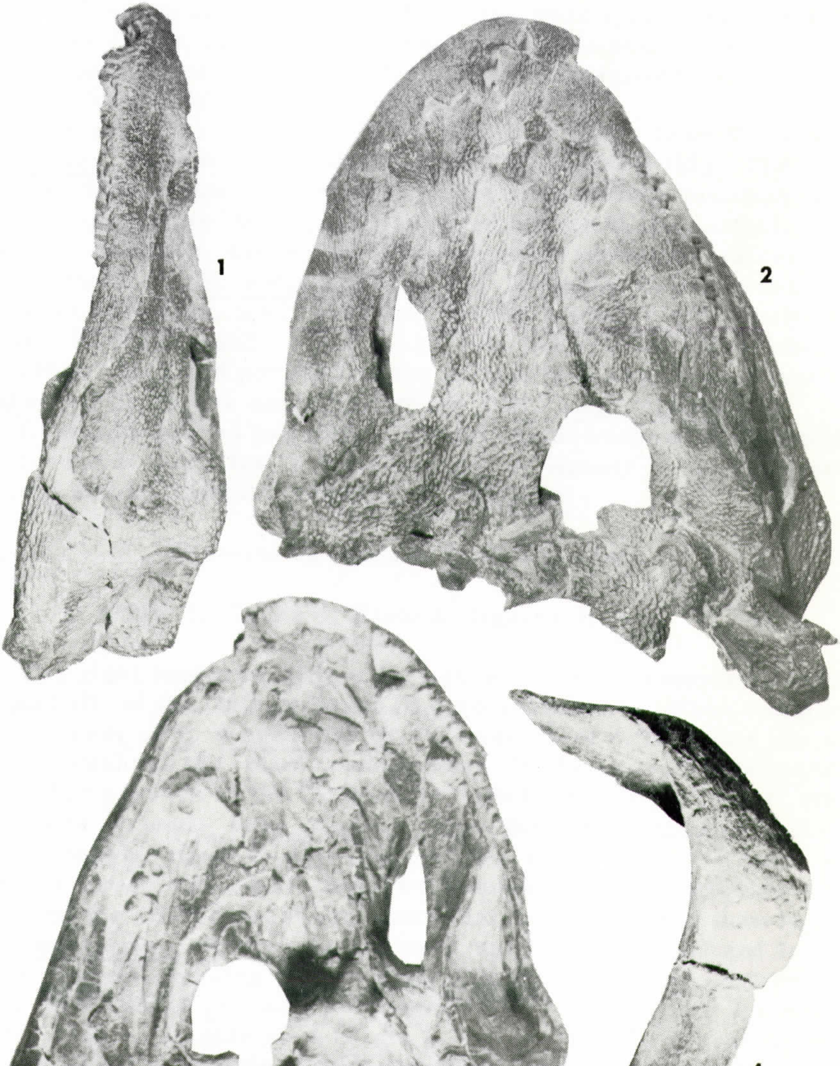
The premaxillaries are not well exposed ventrally, although their common suture can be seen along the margin of the left premaxillary. The number of premaxillary teeth and tooth pits cannot be counted precisely; it is estimated, on the left side, at 12, but may have been 13, as in E. megacephalus.

Maxillary teeth are estimated at 37 on the right and left sides, with about two-thirds of the pits filled. Teeth are largest in the "canine" region of the anterior part of the maxillary, some of these attaining the size of the larger of the premaxillary teeth. Posteriorly, the maxillary teeth decrease rather gradually in size.

The right pterygoid has been crushed posteriorly into the adductor fenestra. The left adductor fenestra is well preserved, but the right is crushed and obscured by the right mandible.

PLATE 1 - Eryops cf. E. avinoffi (Romer) from the Morgantown Sandstone Member, near Sutton, Braxton County, West Virginia. Cleveland Museum of Natural History, no. 11025.

1. Left lateral view of skull, X 0. 4.
2. Dorsal view of skull, X 0. 4.
3. Ventral view of skull, with left mandible removed, X 0. 4.
4. Right clavicle, X 0. 9.


1
2
3
4

Mandibles

(Plate 1, figure 3; Plate 2, figures 1, 2)

The right mandible is preserved nearly in its natural position, though forced upward under the maxilla (Plate 1, figure 3). Though it is virtually complete, none of the teeth are exposed. The left mandible has been folded over under the skull, its base lying along the inner margin of the right pterygoid, cutting across the prevomerine lateral ridge, and jutting out beneath the maxillary-premaxillary suture. The anterior 45-50 mm of the left mandible is missing.

Both mandibles differ only in minor respects from those of E. megacephalus, as described and illustrated by Sawin (1941). There are the obvious differences of smaller size and finer surface ornamentation. Also, the mandibular foramen occurs relatively more posteriorly on the present specimen, posterior to the angular posterior extension of the precoronoid. In E. megacephalus the foramen occurs beneath the precoronoid extension, well anterior to the acutely pointed posterior extremity; at least such is the case with the specimen described by Sawin (1941). Size and position of the mental foramen, dental foramen and inframecklian fossa agree with those of E. megacephalus.

Coronoid sutures are difficult to recognize because of the battery of fine coronoid denticles, a feature noted by Romer in the holotype of E. avinoffi and by Langston (1953) in E. grandis.

Pectoral Girdle and Limb Elements

(Plate 1, figure 4; Plate 2, figures 3, 4, 6, 7)

The right humerus (Plate 2, figures 3, 4) is complete, while the distal half of the left humerus is also preserved. When compared with the humeri of E. megacephalus, a number of differences are observable. Perhaps the most conspicuous is the less oblique trend of the supinator process in the Conemaugh specimen. In posterior view, this process extends only slightly above the ectepicondylar process; the ectepicondylar notch is thus confined to a rather narrow groove best seen in a view of the outer side of the humerus. The latissimi dorsi process and the deltoid crest are somewhat less developed than typical of E. megacephalus though the former has been damaged and is still partially covered, making observation difficult. The articulatory surface for the radius is quite pronounced in the Conemaugh specimen, distinctly bulbous in side view (Plate 2, figure 3). The entepicondylar process does not extend downward much beyond the ectepicondylar process and the radial articulatory surface, making the lower part of the humerus decidely more transverse than in E. megacephalus. As a consequence of the development of the radial articulatory surface, the lower outline of the humerus, in anterior and posterior views, is distinctly convex rather than concave as in E. megacephalus. On the posterior side, the articulatory surface for the ulna is confined to a small patch on the periphery of the distal edge of the humerus.

Neither Cope's (1888) illustrations of the humerus of E. megacephalus nor Moodie's (1910) drawing of the humerus of E. willistoni permit detailed comparison. A fragmentary, poorly preserved humerus of E. grandis is noted by Langston (1953) but is too poorly preserved for comparison. Miner's (1925) study of the pectoral girdle of E. megacephalus has been relied upon heavily both here and in the following description.

The right scapulocoracoid (Plate 2, figure 6, 7) is very well preserved in the West Virginia specimen, similar in nearly all respects to that of E. megacephalus and E. grandis, except for the much smaller size. It is also relatively shorter than illustrated scapulocoracoids of those two species. No trace of the cleithrum has been recognized in the collection from Sutton. The right clavicle is present (Plate 1, figure 4), slightly crushed ventrally, so that the ventrolateral angulation is nearly 90°. The rather coarse sculpture of the exterior surface is well shown.

A considerable quantity of isolated rib and vertebral elements are in the collection from Sutton. Neither the axis nor atlas has been recognized, and most of the vertebrae appear to represent the cervical and perhaps part of the dorsal section of the spinal column. There are about seven relatively complete neural arches (Plate 2, figure 5) and five readily identifiable intercentra. Numerous small fragments may represent pieces of pleurocentra, though some of these fragments are definitely pieces of neural arch. None of the vertebral elements were found articulated.

TAXONOMIC ASSIGNMENT

The Sutton specimen is so well preserved and relatively complete that all but two previously described rhachitome genera are immediately removed from consideration. In so far as discernible, this Conemaugh specimen agrees in every particular with the well known Permian genus Eryops Cope. As discussed above, there is some

PLATE 2 - Eryops cf. E. avinoffi (Romer) from the Morgantown Sandstone Member, near Sutton, Braxton County, West Virginia. Cleveland Museum of Natural History, no. 11025.

1, 2. Mesial and lateral view of left mandible, X 0.5.

3, 4. Outer and anterior views of the right humerus, X 0.8.

5. Posterior view of cervical neural arch, X 1.1.

6, 7. Inner and outer lateral views of right scapulocoracoid, X 0.7.


1
2
3
4
5
6
7

question about the nature of the bones of the skull, specifically the presence of an interfrontal element. Uncertainty on this point is especially critical for, while all known Eryops specimens possess an interfrontal, Romer (1952) has erected the genus Glaukerpeton, distinguished from Eryops primarily by its smaller size, finer ornamentation and the absence of an interfrontal. The holotype of Glaukerpeton, G. avinoffi, is a fragmentary skull from a stratigraphic position somewhere in the Pittsburgh Limestone Member, at the very top of the Conemaugh Group, found within the city of Pittsburgh. A variety of small, isolated bones from the Round Knob Shale Member at Pitcairn, Pennsylvania, originally referred to Eryops by Case (1908) were transferred to Glaukerpeton by Romer. This latter material comes from strata slightly lower stratigraphically than the Sutton occurrence. Romer surmised from the dearth of unquestionable Eryops material in the Conemaugh Group that the genus does not occur in rocks as old as Conemaugh. This appears to have been his major reason in referring much of the Conemaugh eryopsid material to his new genus. It is regrettable that only the holotype of Glaukerpeton shows the most diagnostic feature of the genus-- the lack of an interfrontal-- and even this has been seriously questioned. Vaughan (1958) has clearly shown that the small size and fine reticulation cited by Romer in his diagnosis of Glaukerpeton are of doubtful value at the generic level. Vaughan also restores the Glaukerpeton skull fragments in such a manner that an interfrontal seems to be present. He places Glaukerpeton in synonymy with Eryops and concludes that Eryops does indeed occur in the Conemaugh Group.

In light of the uncertainty regarding the presence or absence of an interfrontal element in the Sutton specimen, there must remain some question about the generic identity of the specimen, just as there must remain a modicum of uncertainty about the synonymy of Glaukerpeton with Eryops. Nonetheless, the close degree in which the Sutton rhachitome matches the many known features of Eryops preponderates so greatly over the possibility that it differs from Eryops in a single character (absence of the interfrontal) that the most suitable assignment of the Sutton amphibian is to Eryops. In view of the fact that this one distinguishing character is not certainly known to exist in even the genoholotype of Glaukerpeton, this assignment seems to be the best solution for the present.

Romer may well be correct in his belief that there is a Conemaugh rhachitome identical with Eryops in every respect except the presence of an interfrontal; it is even possible that both genera occur in the Conemaugh. Such parallelism is perhaps not unknown, but it would be very difficult to prove on the basis of only two or three specimens. The very rarity of relatively well preserved eryopsid remains in the Conemaugh Group of the Appalachian Basin makes it inadvisable to erect new taxa on the basis of unique specimens which differ from previously described material in only a single character, especially when the presence or absence of even that one character is in doubt.

At the species level, assignment of the Sutton specimen is less difficult. The small size of the individual and perhaps the relative proportions of the scapulocoracoid and the humerus suggest that the specimen is immature; but it is remarkable that of the half dozen or so Eryops specimens thus far recovered from the upper Pennsylvanian and Dunkard strata of the Appalachian Basin all are considerably below the average size of Eryops megacephalus. It is difficult to believe that all of these are immature specimens, and it is much more probable that a distinct species is represented, one characterized in part by a considerably smaller size and finer ornamentation.

In view of the stratigraphic and geographic proximity of the Sutton occurrence to the holotype of Eryops avinoffi, the two may well be conspecific. The poorly preserved nature of the holotype of E. avinoffi precludes the removal of all doubt on this point, as it has also injected a certain element of doubt at the generic level. Nevertheless, assignment or comparison to E. avinoffi seems the best course in this preliminary study of the Sutton amphibian.

Eryops avinoffi, as interpreted here, differs from other described species of Eryops by virtue of its small size and finer surface ornamentation. The sole exception is E. grandis, which Langston (1953) gives reason to believe is distinctly smaller than typical E. megacephalus. Other minor characteristics noted by Langston include a "dense shagreen" of coronoid denticles, quite like that of E. avinoffi; a mandible relatively more slender than that of E. megacephalus; a thinner, less robust scapulocoracoid. The Sutton specimen herein compared to E. avinoffi differs from E. grandis in being even smaller-- only one-half to two-thirds as large-- with a mandible more like that of E. megacephalus in proportions, and a scapulocoracoid that is stouter, wider, than that of either of the other two species.

As Langston notes, evaluations of such criteria will not be possible until a thorough restudy of all known Eryops material is undertaken. But for the present there is no reason to believe that E. grandis and E. avinoffi are conspecific.

CONCLUSIONS

Preliminary study of a rhachitomous amphibian from the Conemaugh Group near Sutton, Braxton County, West Virginia, suggests that the specimen represents Eryops avinoffi (Romer). The specimen is the best preserved example of Eryops known from the Appalachian Basin, but a critical taxonomic character-- the presence or absence of an interfrontal-- remains uncertain.

It is believed, following Vaughan (1958), that the genus Glaukerpeton Romer is a junior synonym of Eryops. The Sutton specimen thus confirms the presence of Eryops in rocks as old as mid-Conemaugh in age.

REFERENCES CITED

Case, E. C., 1908, Description of vertebrate fossils from the vicinity of Pittsburgh, Pennsylvania: Ann. Carnegie Mus., v. 4, p. 234-241, 8 text-figs., 1 pl.

Cope, E. D., 1888, On the shoulder girdle and extremities of Eryops: Am. Phil. Soc. Trans., v. 16, p. 362-367, 1 pl.

Hennen, R. V., 1917, Braxton and Clay Counties: W. Va. Geol. Survey, Co. Rept., 883 p., 2 maps, 16 figs., 29 pls.

Langston, W., Jr., 1953, Permian amphibians from New Mexico: Univ. California Publ. in Geol. Sci., v. 29, p. 349-416, 24 text-figs.

Miner, R. W., 1925, The Pectoral limb of Eryops and other primitive tetrapods: Am. Mus. Nat. Hist., Bull., v. 51, p. 145-312, 104 figs.

Moodie, R. L., 1910, The Temnospondylus amphibia and a new species of Eryops from the Permian of Oklahoma: Kansas Univ. Sci. Bull., v. 5, no. 3, p. 235-253, pls. 49-54.

Romer, A. S., 1952, Late Pennsylvanian and early Permian vertebrates of the Pittsburgh-West Virginia region: Ann. Carnegie Mus., v. 33, p. 47-113, 13 text-figs., 2 pls.

Sawin, H. J., 1941, The Cranial anatomy of Eryops megacephalus: Bull. Mus. Comp. Zool., v. 88, p. 407-463, 6 text-figs., 12 pls.

Vaughan, P. P., 1958, On the geologic range of the labyrinthodont amphibian Eryops: J. Paleontology, v. 32, p. 918-922.

DISTRIBUTION OF K, MG, SR, FE, MN AND ZN IN CRASSOSTREA VIRGINICA SHELLS

By

Herbert L. Windom
Ralph G. Smith

and

Frank Bousquet
Skidaway Institute of Oceanography
Savannah, Georgia

ABSTRACT

Concentrations of K, Mg, Sr, Fe, Mn and Zn in a population of oyster shells (Crassostrea virginica) collected from a variety of environments along the Georgia coast are normally (K, Mg, Sr) or log-normally (Fe, Mn, Zn) distributed. Natural variations in metal concentrations appear to be large enough to obscure any environmentally influenced variations that might exist.

INTRODUCTION

Studies of trace metals in the calcareous exoskeletons of marine organisms have been directed at establishing the relationship between trace metal concentrations, temperature, salinity, and the concentrations of the given metal in the environment. These relationships have also been tested to determine their usefulness in paleoecological studies. Some have indicated a possible correlation between environmental factors and the concentration of some trace metals (Gordon, et al., 1970; Rucker and Valentine, 1961; Pilkey and Goodell, 1963). Others have shown that changes in trace metal concentrations occur during diagenesis or weathering, therefore limiting their paleoecological applicability (Pilkey and Goodell, 1964; Ragland, 1969). Regardless of the difficulties in applying these observations to paleoecology, it is still of continued interest to establish if environmental conditions influence other trace metal concentrations in the shells of other organisms. This information may be useful in establishing if any recent changes in an organisms's environment have occurred due to natural or man-made causes.

In the following discussion the following assumptions can be

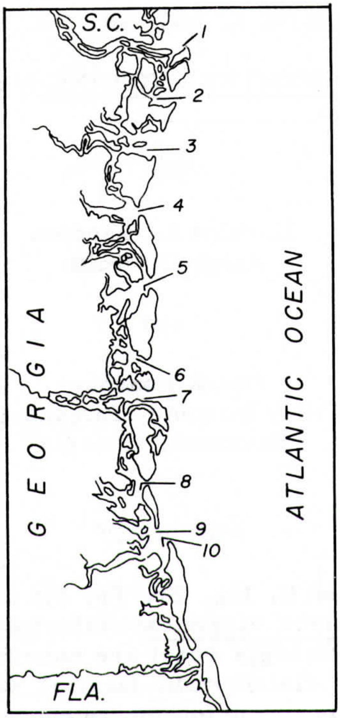


Figure 1. Location of sample stations.

applied. If the concentration of a given trace metal in the calcareous tissues of individuals of a given species does not reflect environmental conditions from place to place then its natural distribution in a population of individuals from a range of environments should follow some normal pattern. If, on the other hand, the metal is concentrated in response to environmental variables, its distributions in a population from a wide range of environments will not follow a normal pattern but will vary with a given parameter. Using this approach the concentrations of several trace metals in oysters, Crassostrea virginica (Gmelin), were studied to see if any were related to environmental variables. Forty-eight individual shells of Crassostrea virginica from ten stations along the coast of Georgia (Figure 1) were analyzed for the concentrations of potassium, magnesium, strontium, iron, manganese and zinc. These data were used to establish the distribution of these metals in the population to determine if the distribution patterns were normal or log normal, as expected (Ting and Vega, 1969), or whether irregularities result from response to the environment. The only environmental parameter considered to be significantly different at samples locations is salinity since the seasonal range in temperature at these locations will

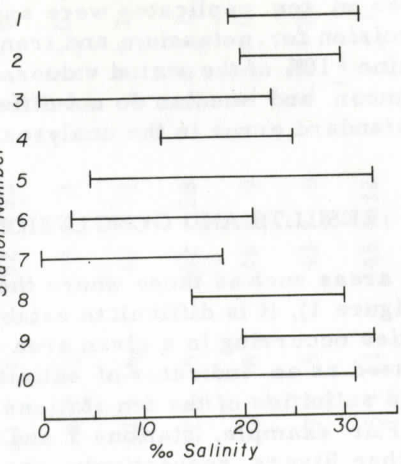


Figure 2. Salinity range for sample locations based on monthly determinations for past four years (R. Reimold, personal communication).

be very similar. The range of salinities found at each location is shown in Figure 2. These are based on monthly measurements over the past four years (R. Reimond, personal communication).

Acknowledgment

We wish to thank Robert Reimold and Charles Durant of the University of Georgia Marine Institute at Sapelo Island, Georgia for kindly providing the oyster samples and information on salinity variations at the various locations.

METHODS

The shells were thoroughly cleaned of organic matter and detritus and crushed so that only the interior of the shell was sampled. Approximately 0.5 g of each shell was digested in concentrated hydrochloric acid and brough to 10 ml volume using double distilled water. Standard solutions were made by digesting reagent grade calcium carbonate in a like manner and spiking the resulting solutions with known amounts of metals. Both the samples and standards were analyzed by atomic absorption spectrophotometry on the undiluted solution for zinc, and on diluted aliquots for potassium, magnesium, strontium, manganese and iron. Precision in the analyses for magnesium, strontium, and manganese based on ten replicates were approximately $\pm 5\%$ of the stated values. Precision for potassium and iron analyses was between $\pm 5\%$ and $\pm 10\%$ and zinc $\pm 10\%$ of the stated values. Normal distributions are assumed when mean and median do not differ by more than 5% or approximately the standard error in the analyses.

RESULTS AND CONCLUSIONS

In intertidal areas such as those where the oysters were collected for this study (Figure 1), it is difficult to establish the mean salinity. The range of salinities occurring in a given area can be estimated however, and then be used as an indicator of salinity differences between areas. The range in salinities of the ten stations studied showed fairly large differences. For example, stations 3 and 7 at the mouths of the Altamaha and Ogeechee Rivers respectively are generally expected to have lower salinities than stations 4, 5 and 6 which in turn are expected to have lower salinities than the remaining stations. Even though there are differences in salinity, the mean concentrations of the six metals studied were found to be similar in the three sets of sample stations (Table 1). Only Mn at Station 1 appears to be significantly higher than at those stations. Iron, manganese and zinc are log normally distributed while potassium, magnesium and strontium are normally distributed (Figure 3). No pertubations in the distribution patterns caused by environmental effects are apparent. The mean values of each set of samples also indicate no significant environmental effects. As shown in Figure 3, if a given sample has a trace metal concentration an order of magnitude greater than another samples, it is difficult to identify what part of this difference, if any, can be attributed to environmental conditions. The distribution patterns of the metals observed are probably natural and would be observed no matter what the salinities of the individual stations were.

CONCLUSIONS

Data on the Recent calcareous shells of oysters indicates that the trace metal concentrations of a number of individuals collected throughout a wide range of environments follow an expected normal or log normal distribution. The normal range in trace metal concentrations in a given population of shells may mask salinity or temperature relationships that might influence individual organisms unless small changes in these parameters result in very large changes in the uptake of a given metal. For the six metals studied, the environmental effect is not large enough to be identified.

Table 1. Mean Concentration and Standard Deviation of Metals in Recent *Crassostrea virginica*

Station No.	No. of Samples	K (ppm)	Mg (ppm)	Sr (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
1	5	30 ± 22	1510 ± 330	1020 ± 123	38 ± 30	121 ± 36	3.0 ± 1.4
2	3	60 ± 36	1980 ± 690	720 ± 96	31 ± 31	52 ± 30	2.6 ± 0.5
3	5	28 ± 14	1410 ± 160	880 ± 105	18 ± 11	33 ± 3	2.2 ± 0.6
4	5	68 ± 18	1810 ± 600	910 ± 110	27 ± 16	42 ± 11	1.9 ± 1.2
5	5	58 ± 31	1660 ± 600	890 ± 54	12 ± 5	62 ± 28	2.2 ± 1.2
6	5	46 ± 16	1560 ± 500	900 ± 230	14 ± 8	46 ± 9	1.5 ± 0.9
7	5	49 ± 10	1750 ± 400	1070 ± 60	17 ± 5	43 ± 9	4.6 ± 2.4
8	5	40 ± 24	1050 ± 400	890 ± 50	15 ± 11	45 ± 12	2.7 ± 1.9
9	5	70 ± 25	1630 ± 100	810 ± 67	79 ± 60	70 ± 23	8.1 ± 4.5
10	5	65 ± 14	2210 ± 900	870 ± 55	34 ± 14	36 ± 14	5.9 ± 1.7

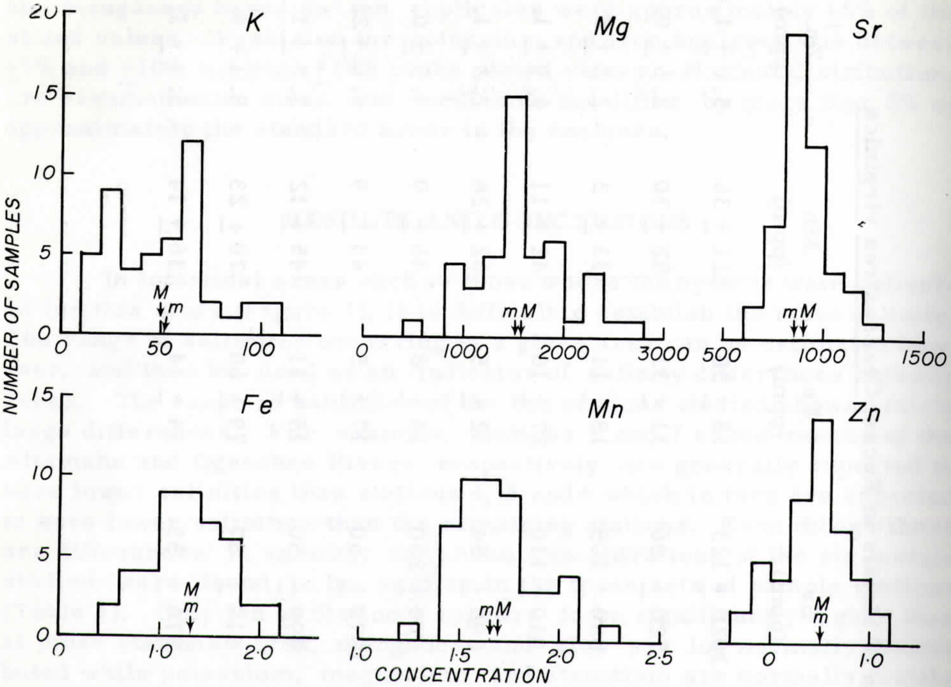


Figure 3. Frequency distribution of trace metals in oyster shells. For K, Mg and Sr the abscissa is concentrations expressed in ppm. For Fe, Mn and Zn the abscissa is log-concentration in ppm. M and m denote the locations of the mean and median respectively.

REFERENCES

Gordon, C. M., Carr, R. A. and Larson, R. E., 1970, The influence of environmental factors on the sodium and manganese content of barnacle shells: Limnol. Oceang., v. 15, p. 461-465.

Pilkey, O. H. and Goodell, H. G., 1963, Trace elements in recent mollusk shells: Limnol. Oceang., v. 8, p. 137-148.

__________, 1964, Comparison of the composition of fossil and recent mollusk shells: Bull. Geol. Soc. Am., v. 75, p. 217-228.

Ragland, P. C., Pilkey, O. H. and Blackwelder, B. W., 1969, Comparison of the Sr/Ca ratio of fossil and recent mollusc shells: Nature, v. 224, p. 1223-1224.

Rucker, J. B. and Valentine, J. W., 1961, Salinity response of trace element concentration in Crassostrea virginica: Nature, v. 190, p. 1099-1100.

Ting, R. Y. and de Vega, V. R., 1969, The nature of the distribution of trace elements in longnose anchovy (Anchoa lamprotaenia Hildebrand), Atlantic thread herring (Opisthonema oglinum LaSueur) and alga (Udotea flabellum Lamourox): In P. J. Nelson and F. C. Evand (Ed.) Radioecology, Proc. 2nd Nat. Symp., USAEC-CONF-670503, p. 527-546.