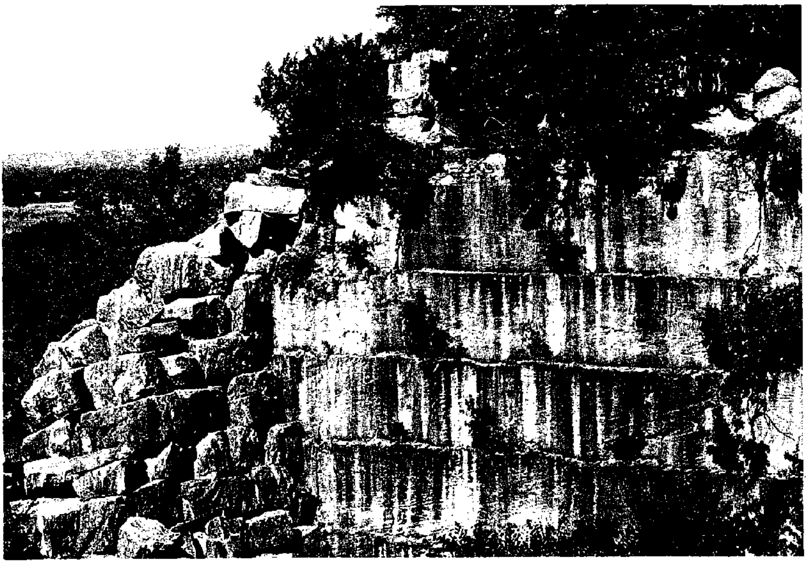
OKLAHOMA
GEOLOGY NOTES

OKLAHOMA GEOLOGICAL SURVEY
THE UNIVERSITY OF OKLAHOMA • NORMAN, OKLAHOMA



$2.00 per year, $0.25 per copy

JULY 1963

Volume 23, Number 7

Cover Picture

PENNSYLVANIAN ROCKS IN OKLAHOMA

WAPANUCKA LIMESTONE IN THE EASTERN ARBUCKLE MOUNTAINS

The cover photograph is of an abandoned quarry in the Lower Pennsylvanian Wapanucka Formation (Morrow Series) 1 mile southeast of Bromide, Oklahoma, in the eastern part of the Arbuckle Mountains. The quarry is in the north-south trending ridge formed by the Wapanucka Limestone where it is cut by Delaware Creek, along the south line of sec. 4, T. 2 S., R. 8 E., in Johnston County. The view is to the southwest across the smaller of two quarries.

The quarry is in the oölite facies in the upper part of the Wapanucka Formation. This oölitic limestone is about 70 feet thick in the immediate area of the quarry but thins to the north and south. Large-scale cross-bedding is prominent in the oölite and can be seen in the photograph. The stone blocks at the left side of the quarry face apparently were stacked for loading but were not used.

This stone was quarried for building purposes during the first two decades of this century by the Bromide Oolitic Stone Company. Several buildings in the nearby town of Bromide are made of this limestone and it was transported elsewhere in the State for building and ornamental purposes by the old Missouri, Oklahoma and Gulf Railroad, which had a branch line to the quarry. Photographs by B. F. Wallis (1915, pl. VI) show that the quarry was operative in 1914. Wallis stated (1915, p. 78):

> The stone is of a uniformly fine texture and may be easily milled and carved for use as a high-grade ornamental stone. It may be polished for use as a marble, the oölitic texture yielding a very pleasing effect. When taken from the quarry the stone is dark in color. In a very short time, however, it bleaches to a chalk white and remains so permanently. From an aesthetic standpoint, this may be said to be its most distinctive and valuable quality. Many high-grade oölitic limestones, as is well known, soon become dark, and assume a cement color. The dead white of the stone is relieved by a subdued blue venation which adds a pleasing quality.

Analyses of the limestone by Wallis (1915, p. 80) indicated that it compared favorably as a building stone with the well-known limestones from Bedford, Indiana, and Bath, England. His analyses also show that the stone is practically iron-free and very low in magnesium content.

One of the earlier, if not the first, use of the oölite as a building stone was for the erection of the Chickasaw Rock Academy for Indian girls in 1854, 109 years ago. The ruins of this building can still be seen a short distance southeast of the quarry and the blocks of stone still bear the marks of the dressing tools.

Reference Cited

Wallis, B. F., 1915, The geology and economic value of the Wapanucka Limestone of Oklahoma: Okla. Geol. Survey, Bull. 23, 102 p.

—P. K. S. and C. L. R.

Techniques of Palynology — Part I. Collection and Preparation of Modern Spores and Pollen*

L. R. Wilson and G. J. Goodman

INTRODUCTION

The science of palynology includes the study of both fossil and modern spores and pollen. When fossil forms are studied, generally an effort is made to relate them to modern types for better understanding the evolution and paleoecology of the parent plants from which the spores or pollen were derived. Because these fossils are seldom found organically associated with the parent plants, they are commonly referred to an artificial group designated as the "Sporae dispersae." The phylogenetic relations of these fossil spore and pollen species are known only in general; therefore continued study of modern spores and pollen is necessary if a natural classification is to be developed. The geological history of most modern plant genera extends well back into the Tertiary, and fossils of certain living plant families occur in Mesozoic and Upper Paleozoic rocks.

Palynological studies of modern plants have shown that spores and pollen are remarkably conservative in their general morphology. Orders, families, and genera of plants commonly have peculiar spore or pollen structures that are characteristic of the taxa. Species generally vary only in ornamentation of the walls or in size of the spores or pollen grains. In some of the younger families, such as the grasses, minor variations are commonly found at generic level of taxonomy, and many of the species in these genera are not, by the pollen, recognizable as different. It is possible, by knowing modern spore and pollen morphology, to trace the geological history of many plant groups and to determine the ages of their enclosing sedimentary rocks and the ecological conditions under which the parent plants grew.

Fossil spores and pollen can be identified with modern types by reference to books or monographs that describe living spore and pollen morphology and taxonomy. Some of these are listed in the selected bibliography at the end of this paper. However, for research in palynology, whatever the objectives, it is desirable to maintain a collection of modern spores and pollen for comparison with the materials being investigated. This collection may be secured from other laboratories or may be developed by palynologists themselves. In the following paragraphs are described the preparation technique and curating procedure for modern spore and pollen studies used by the Oklahoma Geological Survey. This procedure is diagrammatically illustrated in figure 1.

*A study related to the investigation of modern pollen of Oklahoma, supported by National Science Foundation Grant G-19593.

A spore or pollen collection to be most useful should be documented by identifiable specimens of the plants from which it came. The specimens should be pressed, dried, mounted on lightweight cardboard, and preserved in an insect-proof herbarium case (fig. 1). The detailed procedure for preparing herbarium specimens is described in numerous books on plant taxonomy (Lawrence, 1951). The need for such a documentary collection is quickly apparent when one begins to work with closely allied species that require identification by specialists in those particular plant groups. The average palynologist is not a trained plant taxonomist, and he must rely upon help from others for plant identification; therefore a well-curated herbarium is essential. A common practice among some palynologists is to secure spores or pollen from specimens in herbaria. Unfortunately some collections, especially of tropical plants, are not correctly identified, and, if the palynologist is unaware of this fact, he will perpetuate errors.

Identification of documentary herbarium specimens from this country can be made with the various manuals and floras which now cover most of the plants of the United States. Works of this sort that apply helpfully to Oklahoma, where a study of modern pollen is underway, are listed in the selected bibliography at the end of this paper.

Immediately upon collection each spore- or pollen-bearing plant should be placed in a separate plastic bag along with an envelope containing an additional collection of the spores or pollen. The envelope should have a serial number and other collection data written upon it. The separate collections may be carried in a larger plastic bag or other container to the laboratory for preservation. It is important that the specimens be kept cool until processing. If possible the spore or pollen collections should be placed in vials of glacial acetic acid before the plants wilt. If this is not practical, then the envelopes and their contents must be quickly air dried for storage. Before spores or pollen are placed in glacial acetic acid for storage, or for the initial step in processing, the excessive leaves or floral parts should be removed. A convenient technique for quickly concentrating spores or pollen is to place several leaves or flowers in a beaker, cover them with a small amount of glacial acetic acid, and, with a large glass rod, crush and stir the material until spores or pollen can be seen floating in the liquid. Pour the liquid into a labeled vial and allow the particles to settle. Then carefully pour the liquid back into the beaker and recover more spores or pollen by repeating the schedule.

PROCESSING

Living spores and pollen contain protoplasm which must be removed in order to obtain the best material for cell-wall study and for comparison with fossils. Several techniques are available for removal of protoplasm, but the best appears to be the acetolysis process developed by Erdtman (1960). The modification outlined in figure 1 has been found successful and less dangerous. The process, however, should be

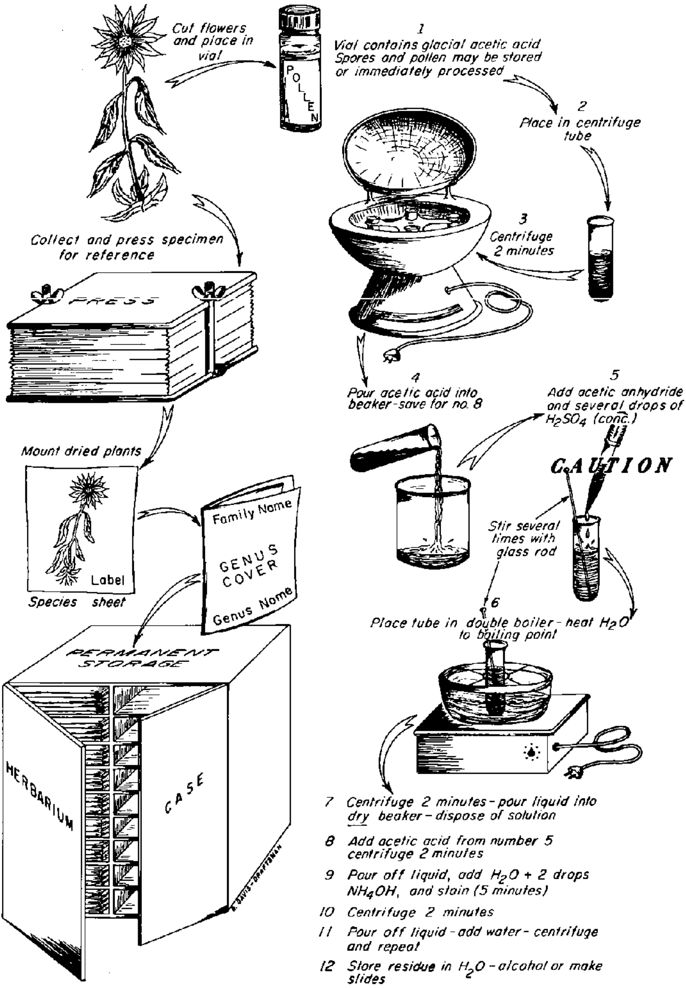


Figure 1. Schematic diagram showing procedure for sample preparation and curating of herbarium specimens for modern spore and pollen studies.

carried out in a fume hood, and the technician should wear a face mask and rubber gloves.

The technique outlined in figure 1 is satisfactory for the preparation of spores and pollen for most wall (exine) studies, but slight modification is necessary for the preparation of certain species. Specimens of some species require no staining, whereas those of others cannot be satisfactorily studied without it. The stains commonly used are Safranin O, Bismarck brown, Methyl blue, and Vert green. Many kinds of spores and pollen require chlorination to reveal the wall structure to best advantage. This process normally follows the acetolysis process (step 11 in fig. 1), and a small quantity from the sample is placed in a watch glass in which a small quantity of approximately 2-percent solution of sodium hypochlorite is added. The liquid is swirled in the watch glass and then placed under a microscope to determine the condition of the spores or pollen. If the walls become nearly transparent, enough water should be added to stop all reaction. If the cell walls do not become sufficiently transparent, additional sodium hypochlorite should be added until the desired reaction takes place; then water should be added and the reaction stopped. Some palynologists prefer to mount the acetolysized and chlorinated specimens separately on microscope slides, but others mix the two preparations and mount them together. The preparation of slides and the techniques of study will be discussed in part II of this paper.

Selected Bibliography

Coulter, J. M., 1891-1894, Botany of western Texas: U. S. Natl. Herbarium, Contr., vol. 2.

Erdtman, Gunnar, 1943, An introduction to pollen analysis: Waltham, Mass., Chronica Botanica Co., A New Series of Plant Science Books, vol. 12, 239 p., 28 pls.

__________ 1952, Pollen morphology and plant taxonomy. Angiosperms. (An introduction to palynology. I): Waltham, Mass., Chronica Botanica Co., 539 p. 261 figs.

__________ 1957, Pollen and spore morphology/plant taxonomy. Gymnospermae, Pteridophyta, Bryophyta: Stockholm, Almquist & Wiksell/ Gebers Förlag AB, 151 p., 5 pls., 265 figs.

__________ 1960, The acetolysis method. A revised description: Svensk Botanisk Tidskrift, vol. 54, p. 561-564.

Faegri, Knut, and Iversen, Johs., 1950, Text-book of modern pollen analysis: Copenhagen, Ejnar Munksgaard, 168 p., 9 pls.

Fernald, M. L., 1950, Gray's manual of botany, 8th ed.: New York, American Book Co., 1632 p.

Gleason, H. A., 1952, The new Britton and Brown illustrated flora: New York, New York Botanical Garden, 3 vols.

Goodman, G. J., 1958, Spring flora of central Oklahoma: Norman, Okla., Univ., Duplicating Service.

Harrington, H. D., 1954, Manual of the plants of Colorado: Denver, Sage Books, 666 p.

Hyde, H. A., and Adams, K. F., 1958, An atlas of airborne pollen grains: London, Macmillan & Co., Ltd., 112 p.

Lawrence, G. H. M., 1951, Taxonomy of vascular plants: New York, The Macmillan Co., 823 p., 322 figs.

Lundell, C. L., and others, 1942 and continuing, Flora of Texas: University Press in Dallas, Southern Methodist University. (Several parts published.)
New York Botanical Garden, 1905 and continuing, North American flora, descriptions of the wild plants of North America, including Greenland, the West Indies, and Central America: New York, New York Botanical Garden, 54 pts. (Many parts have been published.)
Rydberg, P. A., 1932, Flora of the prairies and plains of central North America [ed. by M. A. Howe]: New York, New York Botanical Garden, 969 p.
Shinners, L. H., 1958, Spring flora of the Dallas-Ft. Worth area, Texas: Dallas, Lloyd H. Shinners, 514 p.
Small, J. K., 1913, Flora of the southeastern United States, 2d ed.: New York, J. K. Small, 1934 p.
__________ 1933, Manual of the southeastern flora: New York, Science Press Printing Co., 1554 p.
Stemen, T. R., and **Meyers, W. S.**, 1937, Oklahoma flora: Oklahoma City, Harlow Publishing Co., 706 p.
Waterfall, U. T., 1962, Keys to the flora of Oklahoma, 2d ed.: Stillwater, Okla. State Univ., Research Foundation, 241 p.
Wodehouse, R. P., 1935, Pollen grains. Their structure, identification and significance in science and medicine: New York, McGraw-Hill Book Co., Inc., 574 p., 14 pls.
__________ 1945, Hayfever plants. Their appearance, distribution, time of flowering, and their role in hayfever, with special reference to North America: Waltham, Mass., Chronica Botanica Co., A New Series of Plant Science Books, vol. 15, 245 p., 73 figs.
Wooten, E. O., and **Standley, P. C.**, 1915, Flora of New Mexico: U. S. Natl. Herbarium, Contr., vol. 19.

Thickness Variation in Mazarn-Womble Shales of the Choctaw Anticlinorium, Oklahoma

William D. Pitt

Rocks lying between the Crystal Mountain Sandstone and the Bigfork Chert range widely in thickness within the area of the Choctaw anticlinorium (Honess, 1923; Pitt, 1955). Cross section B-B′ of plate I, Oklahoma Geological Survey Circular 34 (Pitt, 1955), shows a sequence only 350 feet thick in secs. 32, 33, T. 5 S., R. 24 E. ("short" section, fig. 1). The same sequence farther west, between secs. 27 and 18, T. 5 S., R. 23 E., is estimated to be 6,700 feet thick ("long" section, fig. 1). The Mazarn Shale in this unit is about 1,350 feet thick; the Blakely Sandstone, 150 feet thick; and the Womble Shale, 5,200 feet thick. These estimates are based upon strike and dip measurements made at 12 prominent outcrops along the dip section of this sequence

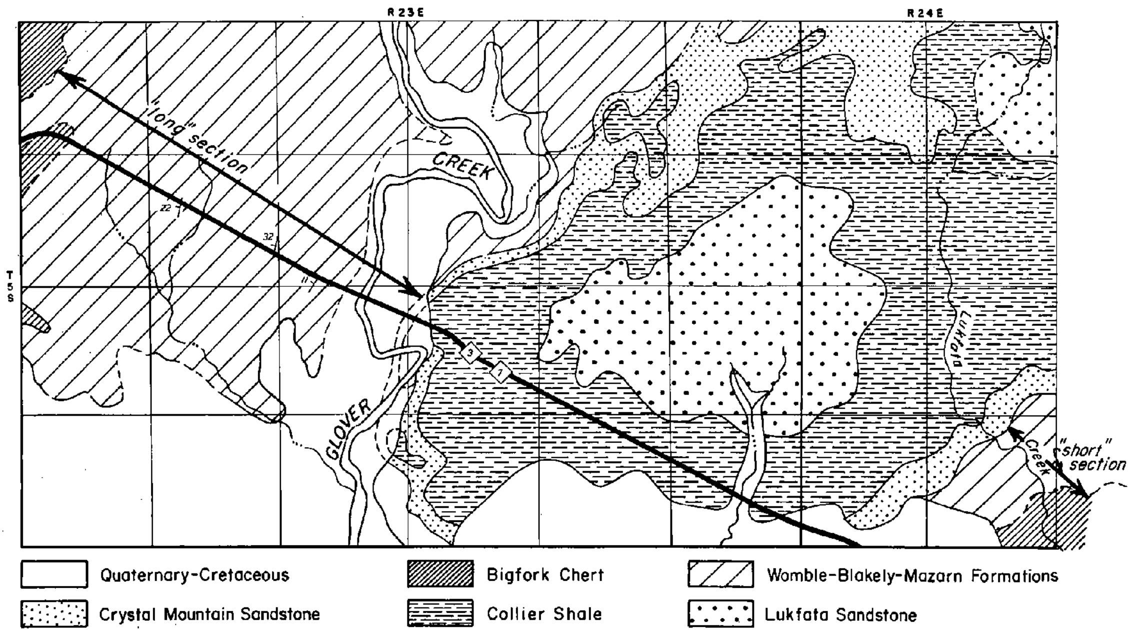


Figure 1. Generalized geologic map of part of the Choctaw anticlinorium showing the locations of the sections measured for estimation of thickness variation of the Mazarn-Womble sequence (modified from Honess, 1923, and Pitt, 1955).

in secs. 18, 19, 20, 21, T. 5 S., R. 23 E. (fig. 1). At these outcrops the beds generally dip northwestward at angles between 5 and 46 degrees, averaging 26 degrees northwestward. No isoclinal folding nor other evidence of repetition of section was found in this series of outcrops. It is noteworthy that if one estimates the thickness of the sequence between NW¼ sec. 27 and NW¼ sec. 18, T. 5 S., R. 23 E., by assuming an average dip of 26 degrees for the 3⅓-mile-wide outcrop band, a thickness of 7,900 feet is obtained.

The extreme variation in thickness may be explained by assuming that most of it results from the squeezing and flowage of the weak rocks, mostly shale, between the more resistant Crystal Mountain Sandstone and Bigfork Chert. Watson, who mapped part of the core area of Arkansas, stated that "the Womble Shale is a lubricant member in the Ouachita Mountains and bedding plane slippage in places obscures the true thickness" (Watson, 1959, p. 37). Possibly, also, some of the "abnormal" thickness of the sequence along the west flank of the Choctaw anticlinorium is the result of local isoclinal folding, as well as of faulting, slippage, or flowage. Finally, although this remarkable range in thickness is probably due primarily to tectonism, it may also be partly the result of differing rates of accumulation. The "depositional" lenticularity of the formations between the Crystal Mountain Sandstone and the Bigfork Chert is suggested by the apparent initial lenticularity of other formations within the Choctaw anticlinorium. The siliceous shales of the Choctaw anticlinorium, for example, show marked thickness variations. Spradlin (1959) pointed out that the Bigfork Chert in the Beavers Bend Park area in the southeastern part of the Choctaw anticlinorium shows "conspicuous variations in the width of its outcrop belt . . . variations not explicable by dip and topographic slope." He further noted that "there is wide variability in the stratigraphic position of the resistant ridge-making chert within the Womble-Bigfork-Polk Creek sequence" (1959, p. 21). Similarly, the Arkansas Novaculite shows marked thickness variation within the Choctaw anticlinorium, from 300 feet in the Beavers Bend Park area (SE¼ sec. 3, T. 5 S., R. 25 E.), where Spradlin measured it, to less than 100 feet in NE¼ sec. 14, T. 5 S., R. 22 E., along State Highways 3 and 7 (about 1½ miles northwest of the area shown on the west edge of fig. 1).

References Cited

Honess, C. W., 1923, Geology of the southern Ouachita Mountains of Oklahoma, Part I, Stratigraphy, structure, and physiographic history: Okla. Geol. Survey, Bull. 32, 278 p.

Pitt, W. D., 1955, Geology of the core of the Ouachita Mountains of Oklahoma: Okla. Geol. Survey, Circ. 34, 33 p.

Spradlin, C. B., 1959, Geology of the Beavers Bend State Park area, McCurtain, County, Oklahoma: Okla., Univ., unpublished Master of Science thesis.

Watson, John, 1959, Geology of the Bear Den Mountain area, Montgomery County, Arkansas: Okla., Univ., unpublished Master of Science thesis.

Nodoblastus, a New Upper Mississippian (Namurian) Blastoid from Russia

Robert O. Fay

The genus *Schizoblastus* has been reported to occur in rocks ranging in age from Middle Devonian to Permian, in Timor, Russia, New York, Missouri, Iowa, Ireland, and Canada. A study of specimens from these areas revealed that many species had to be referred to new genera or to other named genera. *Schizoblastus* itself is restricted to Middle Mississippian (Osagean) rocks of the Midcontinent region of North America.

The Russian blastoid *Schizoblastus librovitchi* Yakovlev, 1941, has not been restudied since the original description. In 1960, J. A. Arendt of the Paleontological Institute and Academy of SSSR kindly sent nine specimens of the above species to me for study. Examination of certain critical features showed that this species belongs to a new genus and that certain corrections must be made in the original description. For instance, rather than eight spiracles there are four paired spiracles; rather than two hydrospire folds on each side of an ambulacrum there is only one; a hydrospire plate is present and radials overlap deltoids, yet these features were not mentioned.

The presence of paired spiracles places this genus in the family Troosticrinidae Bather, 1899. The only genus of this family closely comparable with *Nodoblastus* is *Diploblastus*, which has two hydrospire folds on each side of an ambulacrum, two cryptodeltoids, and one pore between side plates, but has no hydrospire plate. *Nodoblastus* has no cryptodeltoids and has about two pores per side plate, thus being an advanced form that could have been derived from *Diploblastus* by fusion of cryptodeltoids with a superdeltoid to form an epideltoid, by reduction of two hydrospire folds to one, and by formation of a hydrospire plate with consequent increase in the number of hydrospire pores.

Genus *Nodoblastus* Fay, new genus

Type species—**Schizoblastus librovitchi** Yakovlev, 1941.

Generic diagnosis.—Bell-shaped to elliptical spiraculate blastoids with five paired spiracles or four paired spiracles plus anispiracle; anispiracle between a short epideltoid and long hypodeltoid; deltoids slightly longer than radials; radials overlapping deltoids; one hydro-

---

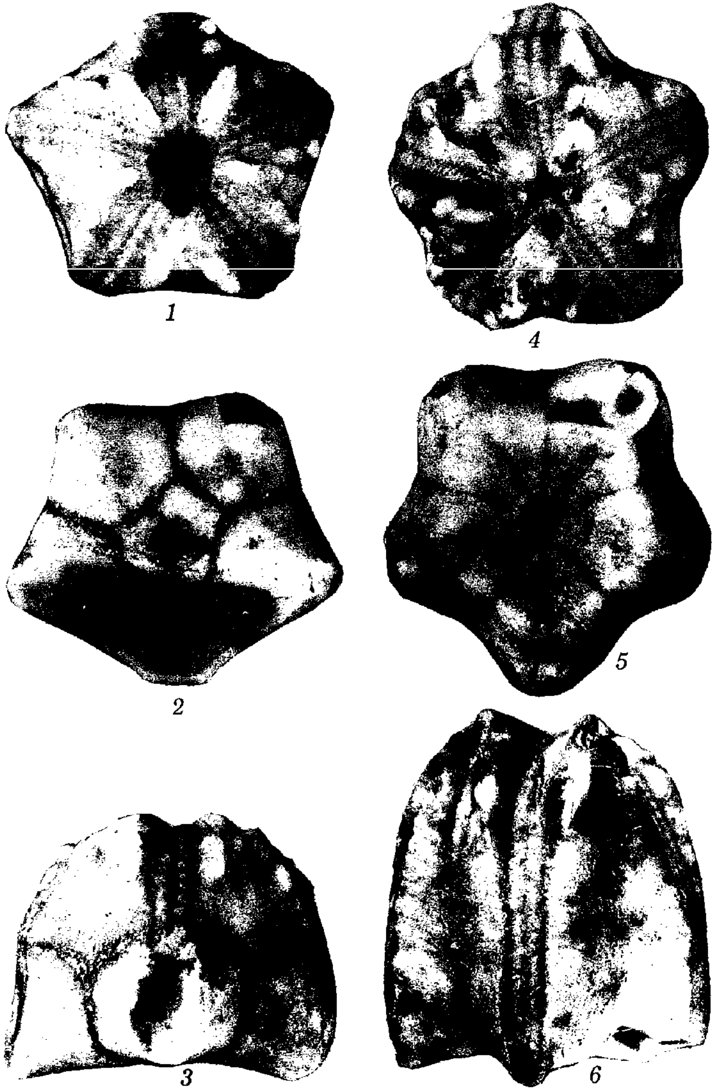
Explanation of Plate I

Nodoblastus librovitchi **(Yakovlev), 1941**

Figures 1-3. Oral, aboral, and "C" ambulacral views of plesiotype OU 5181, x5.5. Sutures marked with pencil.

Figures 4-6. Oral, aboral, and "D" ambulacral views of plesiotype OU 5186, x5.5.

Plate I



spire fold on each side of an ambulacrum; hydrospire plate present, with about twice as many pores as side plates; basalia small, in slight basal concavity; deltoids nodose, with medium-high deltoid crests.

Mississippian, Namurian, C_1^3, and Upper Visean, eastern side of Middle and Southern Ural Mountains, especially northern Kazakstan, Aktyubinsk Province, Russia.

Nodoblastus librovitchi (Yakovlev), 1941
Plates I-III

Schizoblastus librovitchi Yakovlev, 1941, p. 71-72, pl. 10, fig. 4.
Schizoblastus librovitchi Yakovlev, 1956, p. 89, pl. 20, fig. 4.

The description is mainly that of specimen OU 5181, supplemented by information on specimens OU 5182-5189.

Theca calcitic, 7.5 mm high by 9 mm wide, subpentagonal in top view, bell-shaped in side view, with slightly concave base (pl. I, figs. 1-3). Another specimen, OU 5186, is 10 mm high by 9.5 mm wide and is elliptical bell-shaped in side view (pl. I, figs. 4-6). The basalia is composed of three normally disposed basals, pentagonal in outline, and about 3.5 mm wide in slight basal concavity. The azygous basal is subquadrangular and the other two basals are elongate pentagonal. The stem is absent but a circular depression about 0.5 mm in diameter is present in the central face of the basalia. In specimen OU 5182, the basalia extended deeply within the theca, several millimeters above the level of the radial lips. The maximum width of the specimens is at the level of the radial lips or at 1 to 2 mm above the radial lips.

Radials five, each short, subpentagonal in oblique basal view, 4.5 mm long by 4 mm wide, curved at almost a right angle in the middle, with radial sinus 3.5 mm long by 1 mm wide. In side view the radial plate is almost subquadrangular to subpentagonal, 4 mm wide by 3.5 mm long, with radial sinus extending aborally beyond the basal plane into a prominent radial lip. At this lip the aboral part of the radial, or radial body, projects inward adaxially almost at

---

Explanation of Plate II

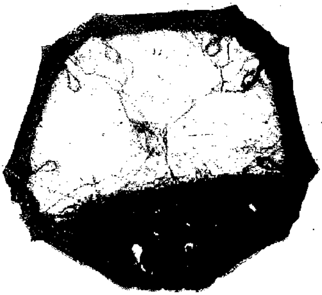
Nodoblastus librovitchi **(Yakovlev), 1941**

Figures 1-3. Aboral views of transverse thin section of plesiotype OU 5182. Figure 1 is oriented with "A" ambulacrum toward bottom and clearly shows one hydrospire fold on each side of an ambulacrum, x5.2. Figures 2 and 3 are enlarged views of "E" and "C" ambulacra, showing thick hydrospire plate next to the lancet, x15.0.

Figure 4. Oral view of polished cross section of plesiotype OU 5183, showing a stage of development of the spiracles near the summit, x5.9.

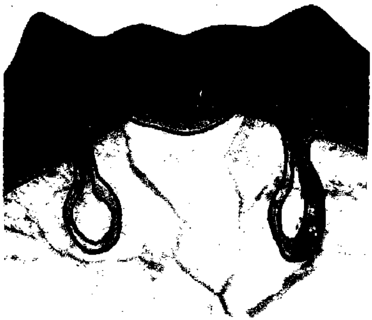
Figure 5. Oral view of polished cross section of plesiotype OU 5184, showing spiracular development about 1 mm below the summit, x9.3.

Plate II

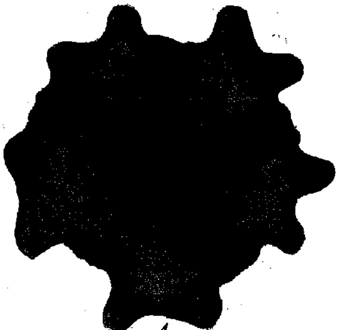


1

2



3



4

5

right angles to the radial limbs, being strongly pentagonal in basal view and 3.5 mm long by 4 mm wide. Radials overlap deltoids.

Deltoids four, lancet-shaped, each 4 mm long by 4 mm wide, with an angle of approximately 115 degrees at radiodeltoid suture with center at median aboral end of the deltoid. Each deltoid is pierced at the adoral end by a paired spiracle with a low medium septum. Where the septum is weathered, exposing the ends of the hydrospire canals, two spiracles appear to be present in place of one. In better preserved specimens, these spiracles appear partly to coalesce adorally into one spiracle, giving the appearance of a V-shaped spiracle, with a shallow adoral portion. A small subpentagonal deltoid lip is present adoral to and on either side of the spiracle, being about 0.5 mm wide by 0.5 mm long. On the anal side are two anal deltoid plates: the elongate lancet-shaped hypodeltoid adjacent to the radial limbs and the subpentagonal epideltoid adjacent to the mouth. The anispiracle, comprising the anal opening and the two coalesced adjacent spiracles, is between the epideltoid and hypodeltoid on the summit and is subelliptical. The oral opening is pentagonal, about 0.5 mm wide, surrounded by the four deltoid lips and epideltoid plate. The presence of four paired spiracles plus the anispiracle places this genus under the family Troosticrinidae Bather, 1899. The original description of the spiracles by Yakovlev (1941, p. 71) is here modified from four to eight; the anispiracle is as described by Yakovlev. Yakovlev figured a weathered specimen and stressed the separate nature of the eight spiracles, yet classified the species under *Schizoblastus*. *Schizoblastus* has 10 spiracles, with anus separate, so it is evident that the species belongs to another genus.

Ambulacra five, sublinear, each 9.5 mm long by 1.5 mm wide at deltoid crests to 1 mm wide at radiodeltoid suture. The lancet plate is exposed along the sides of the main food groove to about one-third the width of an ambulacrum, with about four or five cover-plate sockets per side plate. Each side plate is about 0.33 mm long by 0.33 mm wide, with a small subtriangular outer side plate resting on the bevelled adoral adlateral corner of each side plate. The side food grooves extend from the central region of each side plate, adjacent to the outer side plate, to the main food groove in an adoral direction, forming an angle

---

Explanation of Plate III

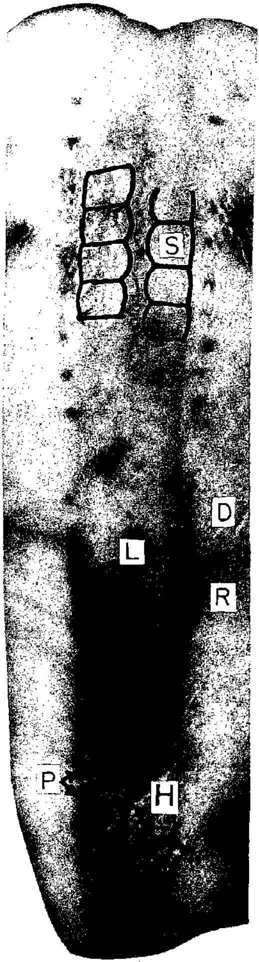
Nodoblastus librovitchi (Yakovlev), 1941

Figure 1. View of polished tangential section of "E" ambulacrum of plesiotype OU 5185, showing pores and hydrospire plates, x15.2.

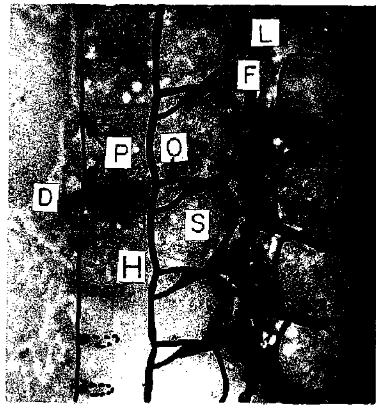
Figure 2. Enlarged view of an ambulacrum of pleisotype OU 5189, showing external view of ambulacral structures and hydrospire plate, x42.0.

Figure 3. Basal circlet of plesiotype OU 5185, x16.0.

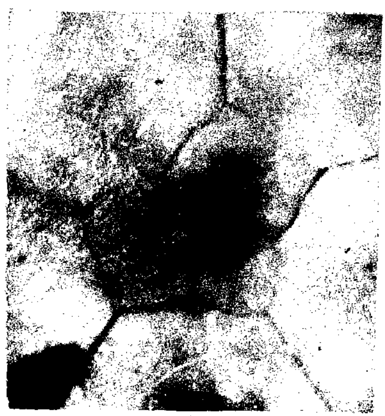
D - deltoid plate	O - outer side plate
F - main food groove	P - hydrospire pores
H - hydrospire plate	R - radial plate
L - lancet plate	S - side plate



1



2



3

of 150 degrees with the main food groove. About 24 side plates are in a 10-mm length of an ambulacrum. Hydrospire plate present, with about twice as many hydrospire pores as side plates, but pores randomly placed resulting in a gradual decrease in number adorally, with just a few on the deltoid plate. One hydrospire fold is present on each side of an ambulacrum. This differs from Yakovlev's (1941, p. 71) interpretation of two folds on each side of an ambulacrum; but repeated checking and examination of a thin section confirmed that only one fold is present. *Schizoblastus* has two folds; thus this species belongs to another genus.

The specimens are mostly weathered smooth, but faint traces of fine growth lines subparallel to plate margins are present. On the deltoid plates, large nodes about 1 mm wide and 0.5 to 1 mm high are present, especially along the adoral half of the deltoid margins, where two large nodes are present. The deltoid crests are about 1 mm high, thus adding to the nodose character of the summit, and hence the name *Nodoblastus*.

Types and occurrence.—Plesiotypes OU 5181-5189, in The University of Oklahoma paleontology collection, were donated by Dr. J. A. Arendt in 1960, from the Paleontological Institute and Academy of SSSR, Moscow, Russia. Upper Mississippian, Namurian Stage, C_1^3, from a limestone in Daibar Mountain, Zanchar Village, Aktyubinsk Province, northern Kazakstan, Russia. The principal plesiotype is OU 5181; OU 5182 is a thin section taken just above the radiodeltoid suture; OU 5183 is a polished transverse section of the summit; OU 5184 is similar to OU 5183, but deeper; OU 5185 is a polished tangential section of "E" ambulacrum; OU 5186-5188 are complete specimens; and OU 5189 is a fragment used to illustrate side-plate and food-groove structures. The Russian designation for the occurrence is "Nizhnekamennougolbnaya, Namyurskiy yarus, C_1^3, Izvestiyak, Khr. Daibar, Aul. Zanchar, Aktyubinskaya Obl., Sev. Kazakhstan, SSSR."

References Cited

Bather, F. A., 1899, A phylogenetic classification of the Pelmatozoa: British Assoc. Advancement Science, 68th Rept., p. 916-923.

Yakovlev, N. N., 1941, Klass Blastoidea, in Atlas rukovodyashchikh form iskopaemykh faun SSSR; tom IV, Nizhniy otdel kamennougol'noy sistemy: Leningrad, Komitet po delam geologii pri snk SSSR, VSEGEI, p. 70-72, pl. 10.

———— 1956, Morskie lilii i blastoidei kamennokugol'nykh i permskikh otlozhenii CCCP, chast' II: VSEGEI, Trudy, new series, vol. 11, p. 89, pl. 20.

Thickness of the Earth's Crust Below Nuclear Test Site GNOME, Southeastern New Mexico

John A. E. Norden

INTRODUCTION

Seismic observations in different parts of the world have disclosed that the number and total thickness of the surficial layers in the Earth seem to differ from place to place; however, beneath them all is a continuous major discontinuity which can be detected at each locality examined (Macelwane, 1936). Since the discovery of this major boundary by Andrija Mohorovičić in 1909 (Mohorovičić, 1910), it has been the object of extensive study (Hess, 1959). This seismic boundary, known as the Mohorovičić discontinuity (referred to in an abbreviated and unfortunately inelegant form as the "Moho"), is considered to be the marker of the bottom of the crust. Beyond about 100 km on the continents, Pn waves refracted through the deeper layer underlying the crust have velocities in the range of 7.6 to 8.4 km per sec, but at most places these first arrivals have a value of 8.1 ± 0.1 km per sec (Howell, 1959).

PURPOSE OF THIS SEISMIC STUDY

A recent publication on the GNOME underground nuclear explosion in southeastern New Mexico (Westhusing, 1963) presented a plot of observed travel times for the GNOME event (fig. 1). The location of GNOME ground zero was in the center of sec. 34, T. 23 S., R. 30 E., Eddy County, New Mexico. The 3-kiloton nuclear charge was placed 1,216 feet below the surface at the end of a 1,116-foot hooked and self-sealing tunnel in the Permian Salado Formation. On the day of detonation, December 10, 1961, 43 volunteer seismological teams participated in monitoring the GNOME event. The approximate locations of volunteer teams and their distances from ground zero are shown in figure 2.

The purpose of this seismic study was to examine the character of the slopes along the plot of travel times observed for the GNOME event and, with the velocities computed from the slopes, to determine the approximate depth of the Mohorovičić discontinuity below the GNOME test site. This determination is an approximation because the accuracy of the velocity values used is limited by the scale of the travel-time plot published by Westhusing (fig. 1).

SLOPE PLOT OF TRAVEL TIMES

The travel-time plot of the GNOME event (fig. 1) suggests a resolution for a three-slope problem. Slopes drawn through the points of the plot are shown in figure 3. In drawing these slopes some adjustment was necessary owing to scattering of the pattern at some distances (fig. 1). Velocities computed for the slopes are: P_0 = 5.15 km per sec, P_1 = 6.48 km per sec, and Pn = 8.10 km per sec. Velocity P_0 may be interpreted as the speed for the sedimentary series from the Ochoan of

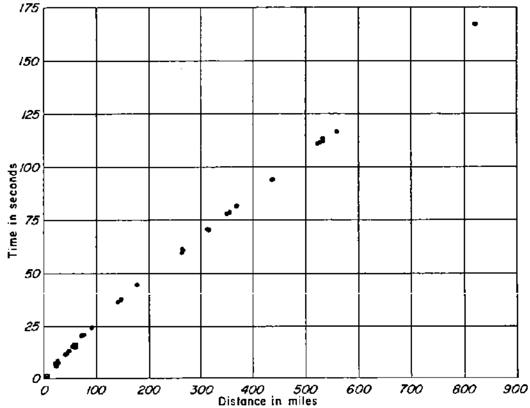


Figure 1. Observed travel times for the GNOME event.
(Redrafted from Westhusing, 1963, p. 33)

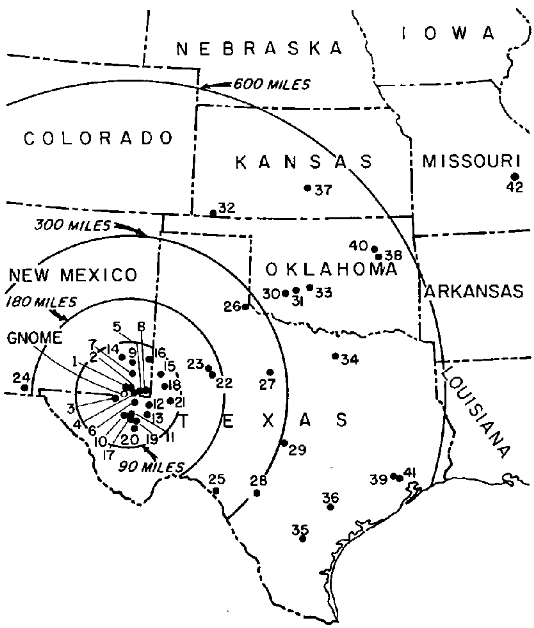


Figure 2. Approximate locations of GNOME ground zero (open circle) and 42 volunteer-team recording stations. Location of volunteer team 43 was outside map area in Maryland.
(Redrafted from Westhusing, 1963, p. 32)

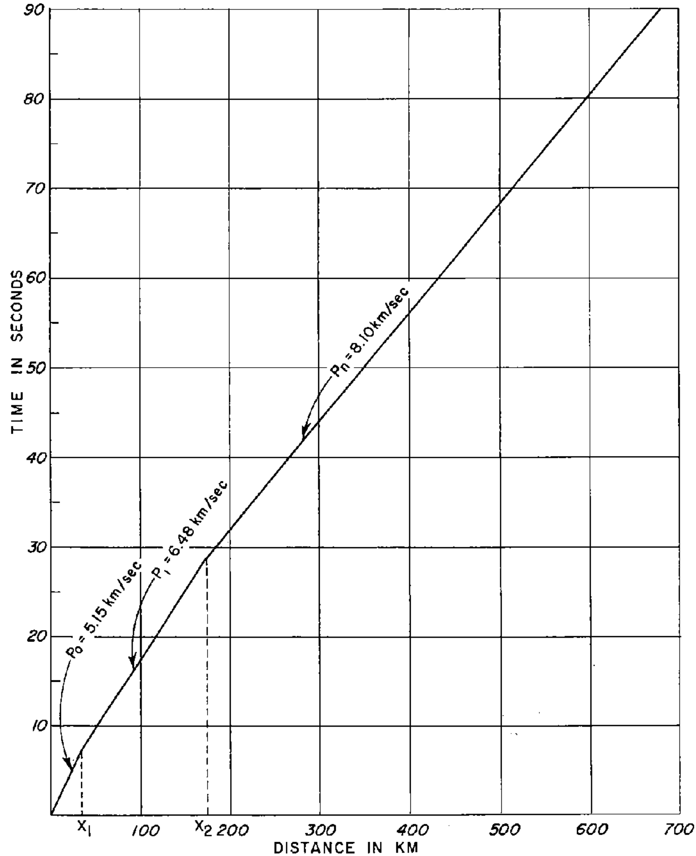


Figure 3. Slopes determined from travel-time plot of GNOME event. The slope of Pn velocity is shown only to a distance of 700 km from ground zero.

the Permian through deeper formations of the Paleozoic. Velocity P_1 is in the range of the speed of the P* wave of Conrad (Conrad, 1925). The slope of the P_1 velocity characterizes the "granitic" layer without indicating further differentiation within it. Continental blast studies (Woollard and others, 1955) carried out in the Atlantic Coastal Plain and Piedmont region, the Appalachian Mountains, the Shield area of Minnesota, the Colorado Plateau, the Basin and Range region, and the Coast Ranges (fig. 4) contributed a great deal of scientific support to the conclusion that the seismic method is rather limited with respect

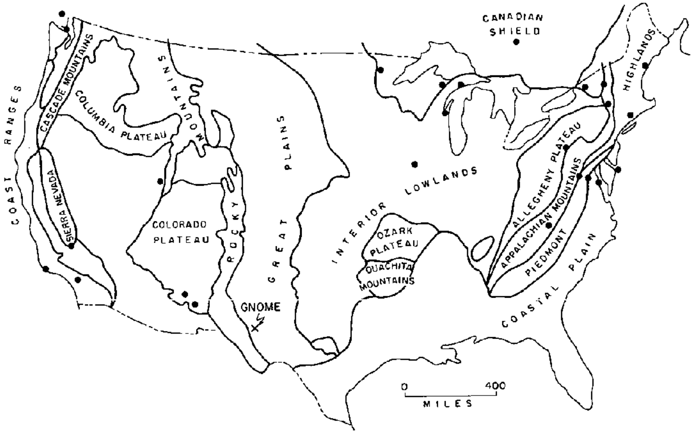


Figure 4. Locations of blast studies of crustal structure in North America. Cross indicates approximate location of GNOME ground zero.
(Redrafted from Woollard and others, 1955, p. 698)

to the resolution of finer details of crustal structure and that only the broader aspects may be inferred. The crust is an inhomogeneous entity, the wave velocity of which increases only slightly with depth. Velocity P_1, computed for the second slope of the travel-time plot of the GNOME event, does not show discriminating variation within the "granitic" layer. This is in agreement with the investigations made in other blast studies. The velocity Pn = 8.10 km per sec may be classified as the speed expected for the layer below the Mohorovičić discontinuity. The velocities for the Pn event in other blast studies (Woollard and others, 1955) were found to be in the range of 7.8 to 8.4 km per sec under the North American continent.

CALCULATION OF THE DEPTH OF THE MOHOROVIČIĆ DISCONTINUITY

With the velocities P_0, P_1, and Pn computed for the GNOME event and with the critical distances X_1 and X_2 read from the graph (fig. 3), the approximate depth to the top of the "granitic" layer and the depth to the Mohorovičić discontinuity can be determined. Critical distance X_1 was found to be about 37.2 km and the critical distance X_2 was about 173.5 km.

Depth (z_0) to the top of the "granitic" layer

$$z_0 = \frac{X_1}{2}\sqrt{\frac{P_1 - P_0}{P_1 + P_0}} \qquad (1)$$

With the use of equation (1), z_0 was computed to be 6.26 km below GNOME ground zero, or 5.59 km (approximately 18,410 ft) below sea level.

Depth (z_1) to the top of Mohorovičić discontinuity

$$Z_1 = (C)(Z_o) + \frac{X_2}{2}\sqrt{\frac{P_n - P_1}{P_n + P_1}} \qquad (2)$$

where

$$C = 1 - \frac{\frac{P_1}{P_o}\sqrt{\left(\frac{P_n}{P_o}\right)^2 - 1} - \frac{P_n}{P_o}\sqrt{\left(\frac{P_1}{P_o}\right)^2 - 1}}{\sqrt{\left(\frac{P_n}{P_o}\right)^2 - \left(\frac{P_1}{P_o}\right)^2}} \qquad (3)$$

With the use of equations (2) and (3) and substitution of the value for z_0, z_1 was computed to be 32.27 km below the sea level. The total offset for this depth relative to GNOME ground zero was computed to be about 43.85 km. This is approximately the distance of volunteer team 6 from ground zero. Thus for the offset range from the GNOME ground zero the thickness of the crust is approximately 32.93 km, or approximately —32.27 km subsea.

On the basis of the earlier blast studies (fig. 4), Woollard and others (1955) constructed a profile showing the variation of the depth of the Mohorovičić discontinuity beneath the North American continent (fig. 5). The Mohorovičić discontinuity on this profile is assumed to be at the top of the zone of high velocities, which range from 7.5 to 8.2 km per sec.

Figure 6, a diagram constructed on the basis of the earlier blast studies (Woollard and others, 1955), depicts the depth of the Mohorovičić discontinuity as a function of surface elevation. The corresponding data for the GNOME site (surface elevation, 0.667 km; elevation of discontinuity, —32.27 km) are indicated by a cross, and it can be seen that the point falls within the swarm of points representing continental data.

CONCLUSION

The travel-time plot of nuclear explosion GNOME in southeastern New Mexico as it was presented in a recent article, *Project GNOME volunteer seismological teams* (Westhusing, 1963), made possible the calculation of the approximate depth of the Mohorovičić discontinuity below the test area. Location of GNOME ground zero was C sec. 34, T. 23 S., R. 30 E., Eddy County, New Mexico. The 3-kiloton nuclear charge was placed 1,216 feet below the surface at the end of a 1,116-foot hooked and self-sealing tunnel. The nuclear charge was about 0.667 km above the sea level. The date of detonation was December 10, 1961.

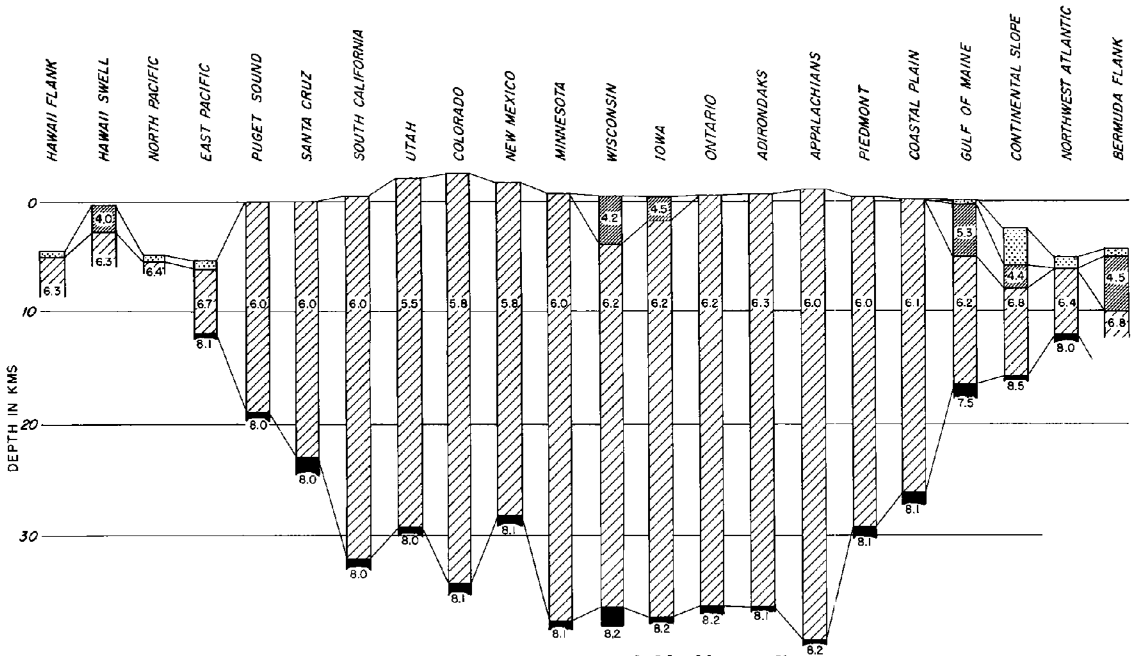


Figure 5. Crustal structure as revealed by blast studies.
(Redrafted from Woollard and others, 1955, p. 699)

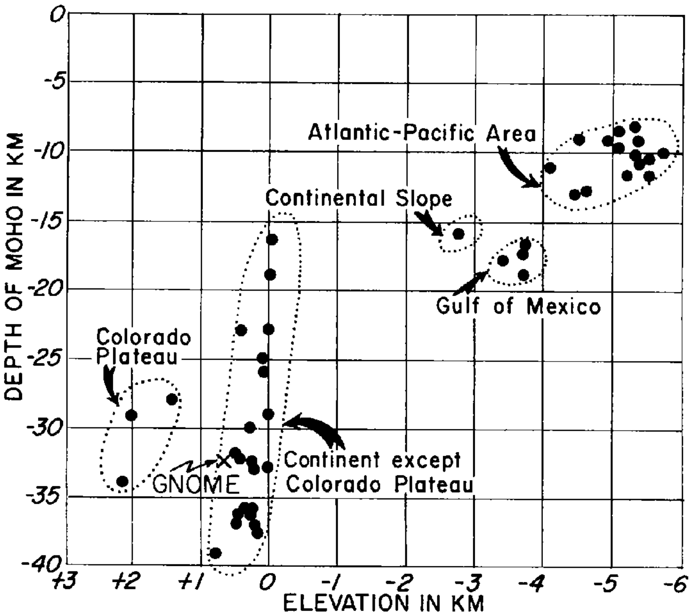


Figure 6. Depth of Mohorovičić discontinuity as a function of surface elevation. Cross is plot of data for GNOME ground zero.
(Modified from Woollard and others, 1955, p. 700)

Velocities computed on the basis of the travel-time plot are $P_0 = 5.15$ km per sec, $P_1 = 6.48$ km per sec, and Pn = 8.10 km per sec. Critical distance X_1 was about 37.2 km and X_2 was about 173.5 km. P_0 velocity characterizes the sedimentary series above the "granitic" layer; P_1 velocity is typical for the "granitic" layer; and Pn velocity is regarded as the speed of the normal condensation wave traveling immediately below the Mohorovičić discontinuity. Depth computed for the "granitic" layer was 5.59 km below sea level. The thickness of the crust below the level of GNOME ground zero for the total offset of about 43.85 km from GNOME ground zero was calculated to be about 32.93 km. Reducing this value to sea level datum gave the depth of the Mohorovičić discontinuity as about —32.27 km. This figure agrees closely with the results of earlier blast studies for the thickness of the Earth's crust in the North American continent.

References Cited

Conrad, V., 1925, Laufzeitkurven des Tauernbebens vom 28 November, 1923: Mitteilungen der Erdbeben-Kommission der Wiener Akademie der Wissenschaften, New Ser., no. 59.

Hess, H. H., 1959, The AMSOC hole to the Earth's mantle: Amer. Geophys. Union, Trans., vol. 40, p. 340-345.

Howell, B. F., Jr., 1959, Introduction to geophysics: New York, McGraw-Hill Book Co., Inc.

Macelwane, J. B., 1936, Part I, Geodynamics, in Macelwane, J. B., and Sohon, F. W., Introduction to theoretical seismology: New York, John Wiley & Sons, Inc.

Mohorovičić, Andrija, 1910, Das Beben vom 8.X.1909: Jahrbuch des meteorologischen Observatoriums, Jahrgang 9, 1909, Zagreb, 63 p.

Westhusing, Keith, 1963, Project GNOME volunteer seismological teams: Geophysics, vol. 28, p. 20-45.

Woollard, G. P., and others, 1955, Report of the special committee on the geophysical and geological study of continents, 1952-1954: Amer. Geophys. Union, Trans., vol. 36, p. 695-708.

New List of Available Publications Issued

The latest revision of the Oklahoma Geological Survey *List of Available Publications* was issued on July 1, 1963. The list includes only those Survey publications which are in print or are expected to be published before January 1964. These number:

65 Bulletins (7 in press or in preparation)
54 Circulars (1 in preparation)
20 Mineral Reports
12 Guide Books (1 in press)
21 Geological Maps and Charts
8 Director's Reports
2 Cooperative Reports

Numerous of the earlier publications of the Survey have been reduced in price, and the prices quoted for them in lists dated earlier than July 1, 1963, no longer apply. The list may be obtained free of charge from the Survey upon request.

OKLAHOMA GEOLOGY NOTES

Volume 23 July 1963 Number 7

In This Issue