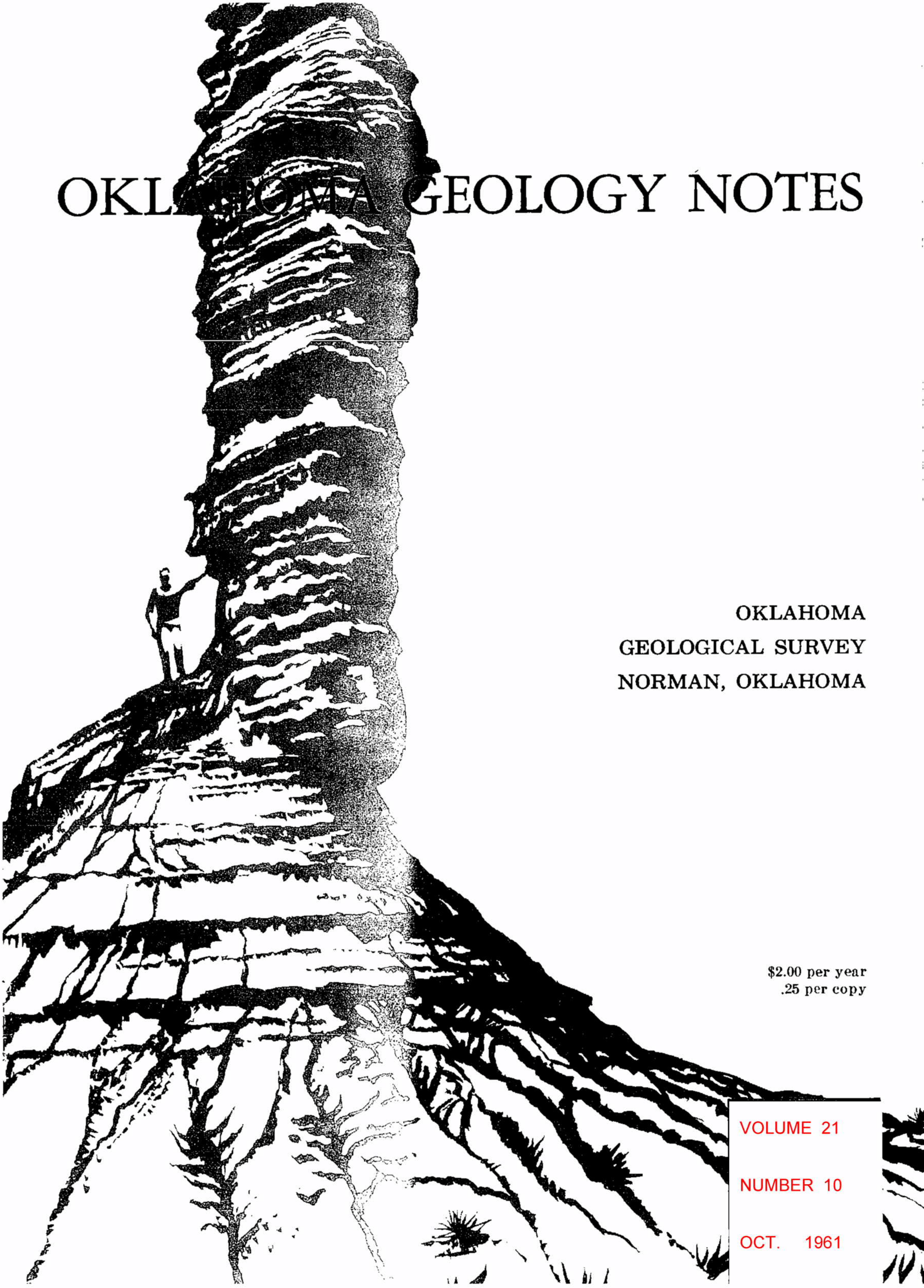
OKLAHOMA GEOLOGY NOTES



OKLAHOMA
GEOLOGICAL SURVEY
NORMAN, OKLAHOMA

$2.00 per year
.25 per copy

VOLUME 21

NUMBER 10

OCT. 1961

LPG Cavern in Wreford Limestone, Kay County, Oklahoma

Louise Jordan

In 1960, Continental Oil Company decided to construct a 300,000-barrel underground cavern for propane storage in its Ponca City refinery tank farm. Propane produced in excess of summer requirements would be put in storage instead of being used as a plant fuel and would allow the company to meet increased winter needs. Cost of the project, though more than $1,000,000, would be considerably less than tank storage on the surface.

It was decided that suitable storage could be found in limestone at a minimum depth of 350 feet in Continental's tank-farm area south of Ponca City. A site on the South Tank Farm in NE¼ sec. 4, T. 25 N., R. 2 E., was selected and hole 1 was cored from 44 to 449 feet. A lithologic log of the hole is shown at the right in figure 3. Five additional holes, spaced about 300 feet apart, as shown on figure 1, were drilled and cored. However, a limestone of sufficient thickness and continuity was not found below 350 feet. The Wreford Limestone, in which a suitable cavern could be mined, was present between 300 and 340 feet, a depth less than that recommended by Fenix and Scisson, Inc., of Tulsa, who construct most of the mined underground storage caverns for the

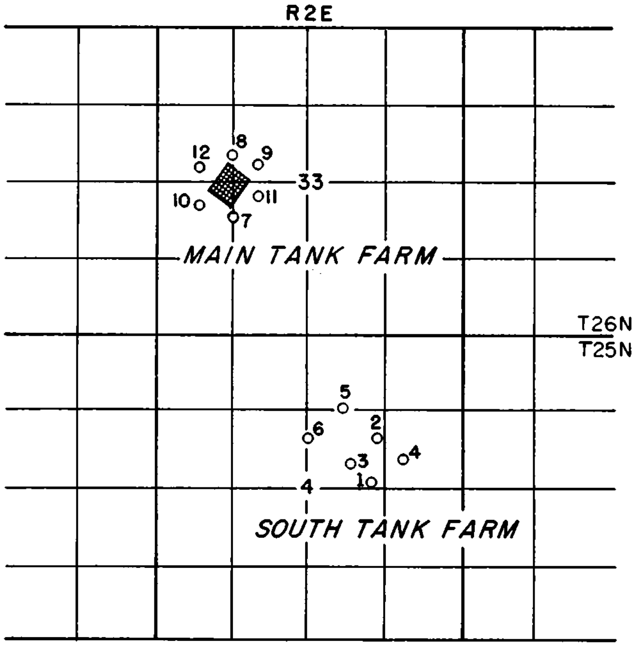


Figure 1. Location of core holes in Main and South Tank Farms showing position of underground cavern in relation to core holes.

petroleum industry in the United States. Also, an essentially impermeable layer of rock, about 33 feet thick, was required. This thickness would allow a maximum height of 25 feet for the cavern, and would leave 8 feet of limestone for the cavern roof. Laboratory tests indicated that the Wreford at places in this area had porosities averaging approximately 14.1 percent and permeabilities ranging as high as 30 millidarcys.

At the second site in the west-central portion of the Main Tank Farm (centering around C W½ sec. 33, T. 26 N., R. 2 E.) six additional holes (nos. 7-12) were drilled and cored (fig. 1). A composite log made from core holes 7, 9, and 12 (fig. 3) shows the stratigraphic section.

The most desirable stratum was the Wreford Limestone, encountered from 350 to 400 feet below the surface. The formation, averaging 36 feet in thickness, is essentially a light-gray limestone, containing interbeds of gray shale. One of the shale beds may be seen in figure 4

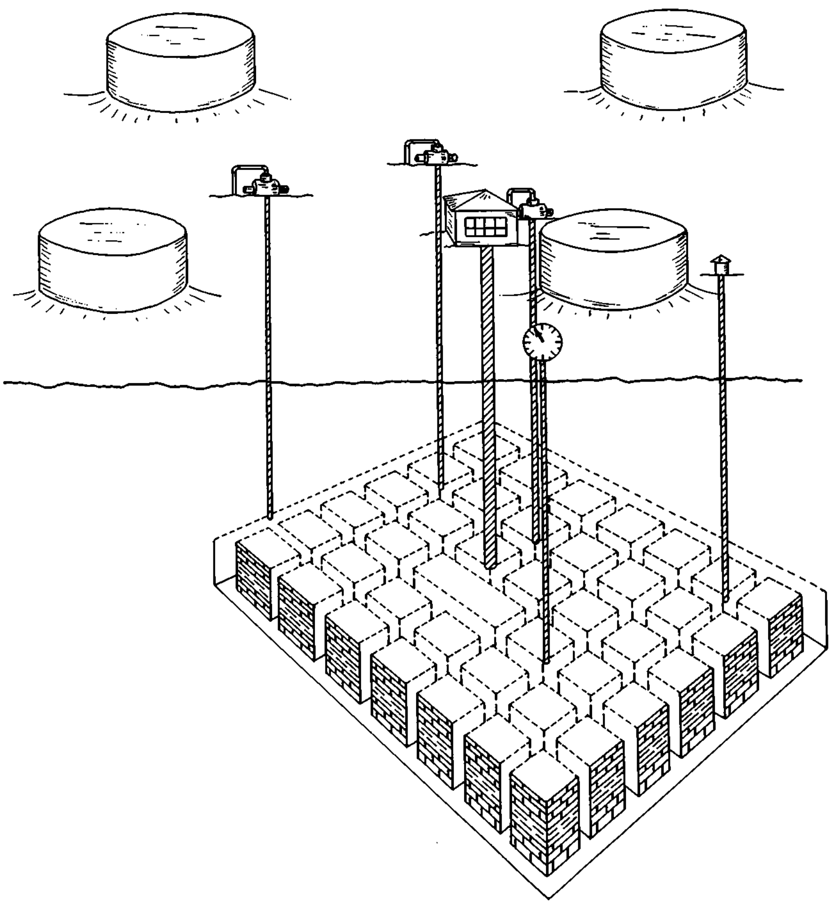


Figure 2. Diagram of the Continental Oil Company's underground storage cavern located near Ponca City, Kay County, Oklahoma, mined in Wreford Limestone.

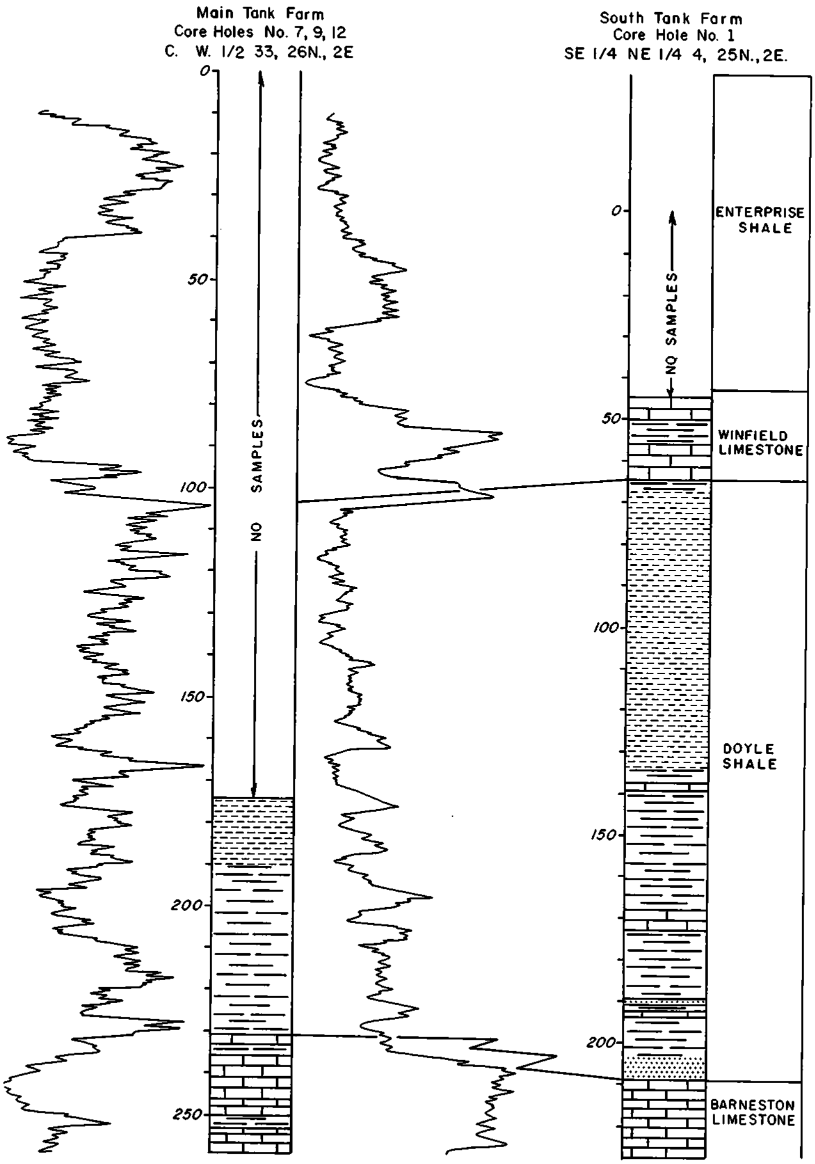
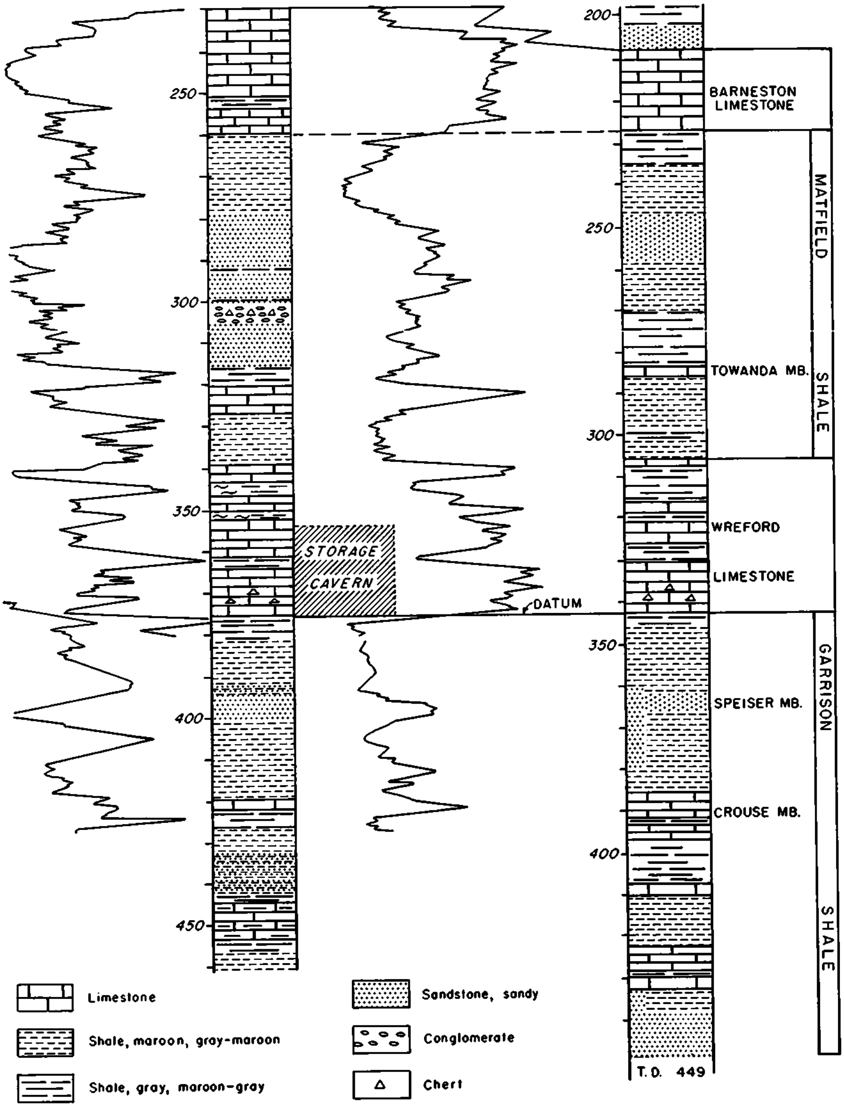


Figure 3. Composite log of Main Tank Farm (left) showing radiation log of core hole 9 to 380 feet with lithologic log of this hole from 300 to 380 feet;



the lithologic log of the section from 174 to 300 feet from core hole 7; and the radiation and lithologic logs of the section below 380 feet are from core hole 12; and lithologic log (right) of core hole 1 at South Tank Farm.

at head height of the man operating the bulldozer. In some of the core holes, beds of calcareous siltstone, less than 4 feet thick, are present in the upper 5 to 10 feet of the formation. The siltstone can be seen in the right wall of the tunnel in figure 5. Irregular areas of silicification occur in the lower 10 to 20 feet of the limestone section. The limestone contains abundant algae, *Osagia* sp., many of which are roughly fusiform in cross-section and at first glance might be mistaken for fusulinids. W. R. Cronoble (this number) describes the rock as a partially recrystallized algal biomicrudite and biomicrosparrudite. Representative rock samples had an average porosity of 11.6 percent and a maximum permeability of 4.1 millidarcys with the greater percentage of the tested material having less than 0.1 millidarcys.

The plan of the cavern is shown on figure 2. Depth to the floor, which consists of shale, is approximately 372 feet. The tunnels, each approximately 15 feet wide and 22 feet high, are spaced 50 feet apart. The cavern roof follows the bedding planes and therefore slopes 8 to 10 feet to the northwest. The highest elevation of the limestone stratum is at core hole 11 and lowest at core hole 12. The vent hole (fig. 2) is near the highest point and two pumps are in the lower part of the cavern so that the floor can be completely drained. Figure 4 shows the lower end of the shaft through which the equipment (dismantled, cut into

Figure 4. Photograph of underground operations with a view of the mine shaft in the background and showing 4-foot shale stratum in Wreford Limestone.
(Photograph courtesy of Continental Oil Co.)

Figure 5. Photograph showing calcareous siltstone in Wreford Limestone in tunnel of Continental Oil Company's underground storage cavern near Ponca City.
(Photograph courtesy of Continental Oil Company)

pieces if necessary, and reassembled on the mine floor) was lowered and the limestone was taken out by means of a large bucket. Another example of the type of equipment used in moving the rock to the main shaft is shown in figure 5.

Wreford Limestone, Kay County, Oklahoma

William R. Cronoble

The Wreford Limestone, basal formation of the Chase Group, Early Permian in age, was mined in sec. 33, T. 26 N., R. 2 E., Kay County, at a depth of 350 to 372 feet. The mined cavern will be used for storage of liquefied petroleum gas by the Continental Oil Company (Jordan, this number).

Megascopic description.—The rock is a medium-gray (N 5) fossiliferous limestone. Encrusting algae (*Osagia* sp.) occur as black, elliptical structures comprising approximately 20 percent of the rock. Little to no coarse terrigenous material is identifiable in hand specimens. Chemical components are predominantly sparry calcite, microspar, and micrite with minor percentages of chalcedony. *Osagia* sp. (from less than 1 mm to 4 mm in diameter), gastropods, bryozoans, pelecypods, and crinoid columnals are the more abundant skeletal materials. No sedimentary structures (such as bedding, etc.) were observed in the unit.

Microscopic description.—The rock is partly recrystallized algal biomicrudite and biomicrosparrudite. Approximately 65 percent of the sample is composed of skeletal material consisting of the encrusting algae, *Osagia* sp. (30 percent), with smaller percentages of fenestrate bryozoans (10 percent), pelecypods (5 percent), crinoid fragments and gastropods (2 percent each), and brachiopods and foraminifers (1 percent each) (pl. I, figs. 1-3). Traces of *Epimastopora* sp. (Dasycladaceae algae), ostracods, and encrusting bryozoans are also present. Both planispirally and helically coiled gastropods and biserial and planospiral foraminifers are present. Approximately 13 percent of the sample is composed of small, unidentifiable skeletal fragments (some smaller than 0.1 mm in diameter). Intraclasts constitute approximately 3 percent of the sample and are composed of skeletal-rich micritic material encrusted with *Osagia* sp. These intraclasts have an average diameter between 3 and 4 mm. No additional allochemical constituents occur in this sample.

Osagia sp. has encrusted skeletal nuclei of pelecypod, fenestrate bryozoan, and crinoid fragments. The skeletal fragments were abraded and fractured before encrustation by algal material (pl. I, figs. 4-6). Large unabraded fenestrate bryozoan fragments (more than 6 mm long) also occur in this unit (pl. I, figs. 1, 3); these larger fragments have not

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Explanation of Plate I

Figure 1. Algal-bryozoan biomicrosparrudite and biomicrudite; dark elliptical structures are algal encrustations (Osagia sp.) surrounding recrystallized skeletal fragments; lighter patches of matrix are microspar and sparry calcite; darker areas of matrix are micritic; large unabraded structure near center of photograph is a fenestrate bryozoan; much small skeletal material is scattered through matrix; crossed nicols; field diameter is 1.1 cm.

Figure 2. Osagia sp. common as dark encrustations around skeletal fragments; algae has encrusted bryozoan and mollusc fragments; lighter areas of matrix represent portions of the micrite matrix that have recrystallized to microspar and sparry calcite; crossed nicols; field diameter is 1.1 cm.

Figure 3. Encrusting algae common around recrystallized skeletal fragments (probably molluscan); in lower part of photograph, large semicircular structure is part of large recrystallized gastropod; interior of gastropod has been filled with skeletal debris (including several Osagia structures) and micrite matrix that has been partially recrystallized to microspar and sparry calcite; large unabraded bryozoan structure in upper left part of photograph; crossed nicols; field diameter is 1.1 cm.

Figure 4. Enlarged view of encrusting algae structure; algae has encrusted recrystallized skeletal fragment; blotchy appearance of matrix is caused by partial recrystallization of the micrite matrix to microspar and sparry calcite; small skeletal fragments are abundant; crossed nicols; field diameter is 4.0 mm.

Figure 5. Enlarged view of Osagia sp.; blotchy appearance of matrix is caused by recrystallization of micrite matrix to microspar and sparry calcite; micritic material adjacent to algal structures has not been recrystallized; in several areas a gradation from sparry calcite to microspar to micrite occurs, suggesting that the microspar and sparry calcite are the result of recrystallization of micrite; crossed nicols; field diameter is 4.0 mm.

Figure 6. Many of the algal structures still have rims of finer grained calcite surrounding them, although much of the matrix has been recrystallized to microspar and sparry calcite; finer grained calcite is commonly preserved in embayments in the algal structures; chalcedony replacement in left-central part of photograph; crossed nicols; field diameter is 4.0 mm.

Plate I

1

2

3

4

5

6

been encrusted by algae. Little to no pelecypod and crinoidal material occurs without algal encrustations.

The sample contains 9 percent insoluble material; after wet-sieving the residue on a 4.25 phi screen, 14 percent of the insoluble residue remained on the screen. Approximately 5 to 10 percent of the material remaining on the screen is composed of terrigenous particles, the remainder being composed of pyrite (2 percent), opal, and chalcedony. Much of the chalcedony and opal has replaced skeletal material as indicated by the preservation of organic structures. Approximately 1 percent of the sample is composed of terrigenous particles coarser than 4.25 phi in diameter. Most of the terrigenous material is extremely fine grained. Much of the coarser terrigenous material is concentrated in encrusting algae structures, probably having been trapped by the filamentous algae as it encrusted the skeletal nuclei.

Some slight lineation of the larger skeletal fragments (primarily algally encrusted material) is present. The allochemical constituents are poorly sorted; skeletal fragments greater than 1 cm in length are associated with abundant fragments less than 0.1 mm in diameter. Algally encrusted skeletal fragments and intraclasts are approximately the same size, and range from 3 to 4 mm in diameter.

Much of the original rock matrix (micrite) may have been recrystallized to microspar and finely crystalline sparry calcite (scattered areas of coarsely crystalline sparry calcite also occur) (pl. I, figs. 4-6). Approximately 15 percent of the matrix is micrite. Several areas in the sample show a gradation from microspar into micritic material (pl. I, fig. 5), suggesting that the micrite is recrystallizing to microspar. Much skeletal material has also been recrystallized to microspar and finely crystalline and coarsely crystalline sparry calcite. Some of the microspar may possibly be a primary precipitate and not the result of recrystallization. Chalcedony and opal replacements are present in some skeletal fragments, primarily in molluscan and crinoidal remains (pl. I, fig. 6). Algae and bryozoans have suffered little replacement.

Environmental interpretation—.The presence of fine-grained terrigenous material, micrite, and small skeletal fragments, and the poor sorting of skeletal material suggest an environment of relatively low energy. Fenestrate bryozoan, pelecypod, and crinoid fragments, and intraclasts were probably fragmented, abraded, and encrusted in an environment of relatively high energy and were then transported into and deposited in a low-energy environment. From just one sample, it is difficult to reconstruct the paleoenvironment during the deposition of the Wreford sequence. Because of the lack of abrasion of the encrusting algae structures, these encrustations could not have been transported a great distance. The algal encrustations completely surround nuclei, with oolitic-like structures (pl. I, figs. 4, 5), indicating that the nuclei were agitated sufficiently to permit algal encrustation on all sides. The association of coarser terrigenous material with the algal encrustations indicates that these structures developed in an environment of higher energy than that of the depositional environment to which they were transported. These algal structures may have developed in a high-energy environment immediately adjacent to the low-energy environment (similar to the environments in Florida Bay described by Ginsburg and Lowenstam, 1958) as the algal structures are unabraded and have undergone little transportation. Currents sufficiently strong to agitate nuclei 3 mm in diameter would have been competent enough to remove micritic material, fine-grained terrigenous material, and small skeletal fragments. Therefore, the algal developments were transported into an environment of relatively low energy.

Much of the micritic matrix and skeletal fragments were subsequently recrystallized to microspar and finely crystalline sparry calcite. Some skeletal material was also replaced by chalcedony and opal.

Reference Cited

Ginsburg, R. N., and Lowenstam, H. A., 1958, The influence of marine bottom communities on the depositional environment of sediments: Jour. Geology, vol. 66, p. 310-318.

Use of Stannic Chloride for Heavy-Liquid Flotation of Palynological Fossils

Phillip Davis

The use of stannic chloride in the concentration of palynological fossils by heavy-liquid flotation was discussed recently by Urban (1961). The instructions given by Urban for mixing a stock solution to the desired specific gravity dealt with only the anhydrous form of stannic chloride. Stannic chloride, however, readily combines with water to form a tri-hydrate ($SnCl_4 \cdot 3H_2O$), a tetra-hydrate ($SnCl_4 \cdot 4H_2O$), and a penta-hydrate ($SnCl_4 \cdot 5H_2O$). The penta-hydrate is sold commercially in the crystalline state, whereas anhydrous stannic chloride is available as a clear liquid. All experimental work with stannic chloride at the Oklahoma Geological Survey palynological laboratory has been with stock solutions mixed from the crystalline penta-hydrate.

The amounts of penta-hydrous stannic chloride necessary to make up 1,000 ml of solution of various specific gravities is presented in table I. Specifically, the amount of penta-hydrous stannic chloride required to prepare a solution of a particular specific gravity is 1.35 times greater than the amount of anhydrous stannic chloride needed for the same specific gravity. If tetra-hyrous or tri-hydrous stannic chloride is used, the amounts must be increased by 1.28 and 1.21 respectively.

Different halves of the same sample have been subjected to heavy-liquid separation, using both zinc chloride and stannic chloride. In each case, the separation of fossils with stannic chloride was more complete than with zinc chloride. The stannic chloride solution is less reactive, is much less viscous, and has proved to be easier to remove from the light fraction than has zinc chloride. The necessity of allowing the stock

TABLE I.—QUANTITIES OF PENTA-HYDROUS STANNIC CHLORIDE REQUIRED FOR 1,000 MILLILITERS OF SOLUTION OF VARIOUS SPECIFIC GRAVITIES

SPECIFIC GRAVITY	AMOUNT OF $SnCl_4$* (GRAMS)	AMOUNT OF $SnCl_4 \cdot 5H_2O$ (GRAMS)	PERCENT $SnCl_4$
1.23	320.6	432.8	26
1.25	351.4	474.4	28
1.27	383.4	517.6	30
1.33	468.0	631.8	35
1.40	561.2	757.6	40
1.47	663.8	896.1	45
1.55	777.5	1,049.6	50
1.64	904.2	1,220.7	55
1.74	1,045.0	1,410.7	60
1.85	1,203.0	1,624.1	65
1.97	1,380.0	1,863.0	70

*From Urban, 1961.

solution to cool to room temperature is also eliminated with the use of stannic chloride, since the reaction of the crystals with water is endothermic rather than exothermic as is true with zinc chloride.

Crystalline stannous chloride ($SnCl_2 \cdot 2H_2O$) has also proved superior to zinc chloride as a flotation agent although it has a greater tendency to form a precipitate with tap water than does stannic chloride. When mixing either stannic or stannous chloride solutions, care should be taken to use distilled water. Tap water available at the Oklahoma Geological Survey contains barium sulfate which will form a colloidal precipitate with stannous or stannic chloride. This precipitate inhibits the separation of fossils.

Reference Cited

Urban, J. B., 1961, Concentration of palynological fossils by heavy-liquid flotation: Okla. Geol. Survey, Okla. Geology Notes, vol. 21, p. 191-193, 2 tables.

New Thesis Added to O. U. Geology Library

The following Master of Science thesis was added to The University of Oklahoma Geology Library during the month of August, 1961:

Subsurface geology of Craig, Mayes, and eastern Nowata and Rogers Counties, Oklahoma, by Daniel McSpadden Strong.

INTERCONTINENTAL DETECTION OF UNDERGROUND NUCLEAR EXPLOSIONS IN OKLAHOMA

J. A. E. NORDEN

INTRODUCTION

The Advanced Research Projects Agency (ARPA) of the United States Government has established an important seismological observatory in the Wichita Mountains, near Lawton, Oklahoma. This observatory is now operated under the technical supervision of the Air Force Technical Applications Center (AFTAC) by The Geotechnical Corporation of Garland, Texas. The purpose of the observatory is to conduct a constant recording of the earth vibrations and to identify shock waves which could have been generated by nuclear explosions in remote areas. This work is a part of Project VELA Uniform, and was established according to the scientific and technological standards recommended in 1958 by the Conference of Experts to Study the Methods of Detecting Violations of a Possible Agreement on the Suspension of Nuclear Tests.

LOCATION AND DESCRIPTION OF OBSERVATORY

The Wichita Mountains Seismological Observatory has been reported on recently (1961) by M. G. Gudzin and J. H. Hamilton of the Geotechnical Corporation of Garland, Texas. This review of the seismological observatory is based on their article. Selective parts on instrumentation and technological operations are quoted directly from their report.

The site of the new observatory is in the foothills of the Wichita Mountains, about 15 miles northwest of Lawton, in southwestern Oklahoma. Oklahoma was selected as the site of this important seismological observatory because of the low seismic background and the existing underground constructional facilities. The site of the seismological observatory, chosen according to the recommendation of experts, has a nine square kilometer areal extent. Within this area, ten vaults, containing various types of seismometers, are arranged in a pattern. All seismometers were placed on the granitic bedrock of the area. The background noise level is approximately two millimicrons peak-to-peak (0.000,002 mm) at a period of one second. The spacing of seismometers in the array is approximately 2,000 ft.

Eight of the vaults are in two parallel lines trending in a northwest-southeast direction. Two additional vaults straddle the eight-vault pattern, their interconnection being perpendicular to the northwest-southeast trend of the parallel-line pattern.

The seismometers used are of four different designs:

1) The Benioff Vertical Seismometer is used in ten-element array and in three-component short-period seismograph. The instrument has an inertial mass of 100 kilograms. The free period of this seismometer is 1.0 seconds. This instrument is best suited for the detection of shorter period body waves. The term "body wave" means that these waves or,

more specifically, the dilatational P (Primus) and shear S (Secundus) pulses travel through the interior of the earth.

2) The Sprengnether Vertical Seismometer is used as a long-period seismograph for the detection of long-period surface waves. The inertial mass of the instrument is about 7.5 kilograms. The free period of the seismometer is 25 seconds. Long-period surface waves are known as the Gutenberg waves (named after B. Gutenberg), the long Rayleigh waves (named after Lord Rayleigh), and the long Love waves (named after A. E. H. Love).

3) The Melton Vertical Seismometer is used as the vertical component of the narrow-band seismograph. This narrow-band seismograph emphasizes the period range of 1 to 3 seconds and rejects the shorter period signals. This type of response may help in the study of shear waves. Inertial mass of the instrument is about 5 kilograms. The free period of the seismograph is 2.5 seconds.

4) The Press-Ewing Vertical Seismometer is used as the vertical component of the broad-band seismograph. The magnification of this broad-band seismograph is limited by the 5- to 8-second microseismic noise which is always present in the earth. For larger disturbances it responds equally well for several wave types and provides a recording of the complete disturbance on a single trace. This instrument has an inertial mass of about 7.5 kilograms. The free period of this seismograph is 12.5 seconds.

The seismic signals from the seismometers are amplified and transmitted to the recording center. The galvanometers in all recording systems are placed in a phototube amplifier. This enables higher magnification and more flexibility in recording. For instance, the Benioff vertical seismometer, when connected to its associated phototube amplifier, will resolve earth motions as small as one angstrom unit (0.000,000,1 mm) at a frequency of one cycle per second.

The light reflected from the galvanometer mirror falls on two photocells, and the optical system is designed so that, as the galvanometer deflects, the light varies in intensity but does not change its position on the photocells. This improves the linearity. The short-period and long-period phototube amplifiers have a dynamic range of over 70 decibels, and the short-period amplifier operates over a temperature range of from —60° F to +120° F. The thermal stability of the amplifier using the long-period galvanometer is not as good because the long-period galvanometer is more sensitive to temperature changes.

The output of the amplifiers, after passing through the data control unit, is recorded on 16 mm strip film and on magnetic tape. Trace, station, and date identification are printed on the film automatically at regular intervals. Precise time marks from a transistorized crystal-controlled timing system are placed on each record automatically in 5-minute intervals. The time is periodically checked against radio time signals received from Radio Station WWV in Washington, D. C. If the main power should fail, nickel-cadmium batteries can be used for emergency operation.

The magnetic tape speed is 0.3 inch per second, so that a 2,500-foot roll of tape will record for 24 hours. The record on 16-mm film is processed automatically by a Develocorder unit. Immediately after processing, the film is dried by a blower and then projected at $\times 10$ enlargement onto the viewing screen. In short-period recording, approximately 150 feet of film per day are required, and the film speed is 300 millimeters per minute as viewed on the recorder screen. For the long-period recording, approximately 30 feet of film per day are required, and the film speed is 60 millimeters per minute as viewed on the screen of the recorder.

Besides the magnetic tape and film recording units, helicorder units are also applied for monitoring and trouble-shooting. The chart speed of helicorder is 15 mm per minute. The recorders are of drum type, using heat-sensitive paper. As the drum rotates, the stylus leads along the axis of the drum, subscribing a helix similar to the way a lathe cuts a screw thread.

For the study of the films, a special viewer is used in which a rapid film transport mechanism allows any point on a 150-foot roll of film to be located in about 30 seconds. Magnification is $\times 20$. The time scale

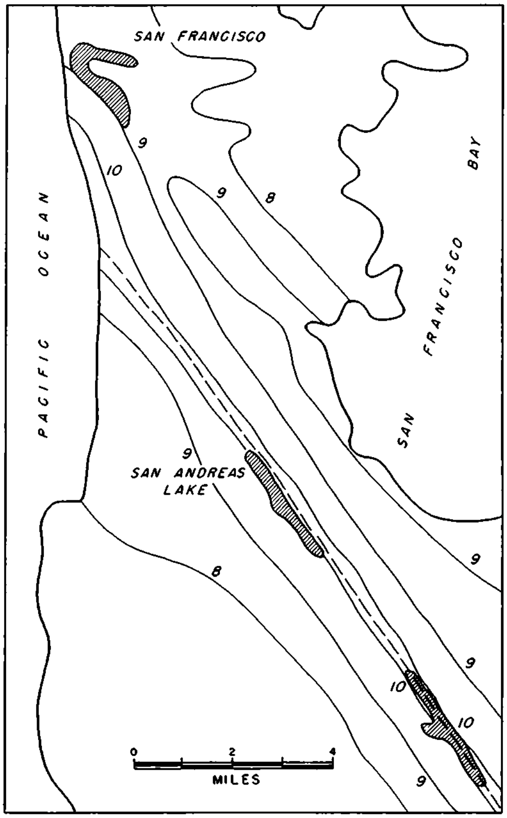

Figure 1. Isoseismal map of epicentral region, 1906 San Francisco earthquake.
(Redrawn from Lawson et al., 1908)

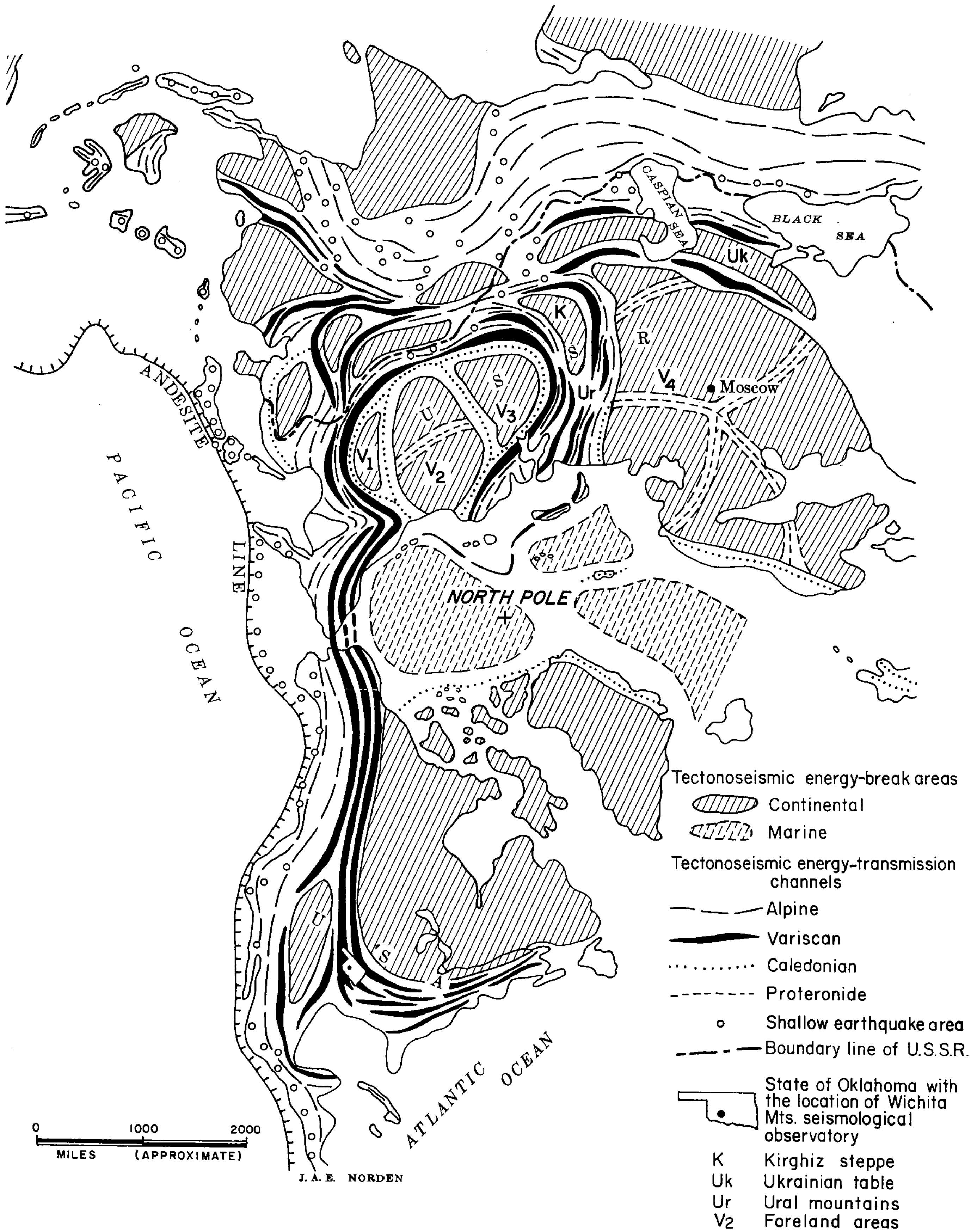

Figure 2. Schematic representation of intercontinental tectonoseismic energy-transmission channels between the United States and Soviet Russia.
(Oblique Mercator projection)

on the screen is 10 mm per second for the short-period recordings and 2 mm per second for the long-period recordings.

The Wichita Mountains Seismological Observatory is located at a convenient distance from Californian and Mexican earthquakes and should provide a significant contribution to the science of detecting and identifying underground nuclear explosions and earthquakes.

SEISMIC ENERGY TRANSMISSION IN GEOLOGICAL FORMATIONS

The problem of seismic-wave transmission is presented here in the light of the reference literature. Selected parts of reference literature were used and quoted in the text.

The transmission of the seismic energy depends on the type of rock and the weathering conditions of the formations. In general, the rule is that the greater the cohesional strength and solidity of a formation the weaker the seismic damaging energy on it (Sieberg, 1929).

Another rule in seismology is that cohesional strength and elasticity of the rocks generally show an increase with the age of the formations. Experimental tests have produced conclusive evidence to support this general rule.

It is known that seismic waves in crystalline formations, such as plutonic igneous rocks, metamorphic schists, and massive gneisses, as well as in thick-bedded crystalline limestones and dolomites, may pass through without significant increase in intensity; on the other hand, when formations are made of loose fragmental deposits, a considerable increase in the intensity of the shock waves may be noticed.

Perhaps one of the striking examples of this effect was reported at the Lisbon, Portugal, earthquake in 1755. This was one of the great earthquakes of historic time, killing about 55,000 out of a total population of 235,000. A part of the city, built on soft Tertiary strata, was almost completely destroyed; whereas the remainder, built on firm Mesozoic rocks, suffered less serious damage (Howell, 1959).

Kinetic energy is proportional to the square of velocity:

$$E = mv^2$$

where m is the mass of the moving object and v is the maximum velocity with which it moves.

If the motion is sinusoidal,

$$E = m\left(\frac{a}{2\pi f}\right)^2 = \frac{ma^2}{4\pi^2 f^2}$$

where a is the corresponding acceleration and f is the frequency. In case of greater damage on loose ground than on solid rock, there is more than just acceleration involved in causing damage. Perhaps the impact should be introduced here. The impact is equivalent to acceleration multiplied by the number of times applied. In explosions, there is usually a simple acceleration which is many times larger than all the others, so that impact and acceleration are about equal on firm ground.

On filled ground, however, where the rock stores some of the energy in resonance, there are commonly several successive cycles of motion of comparable amplitude, which would account for the greater intensity of damage (Howell, 1959).

The elasticity moduli of old crystalline masses is relatively high in comparison to other formations.

Young's modulus of some metamorphic and igneous rocks (Heiland, 1946):

Rock	*Young's modulus* $\times 10^{-11}$	*Investigators*
Quartzitic slate (Archean)	6.65	Adams & Gibson
Graywacke (Devonian)	7.6	Adams & Gibson
Tishomingo granite, Oklahoma	4.55 (lab)	Born & Harding
Gabbro	10.8	Adams & Williamson

One may think that the old crystalline masses and plutonic intrusives, due to their high elasticity moduli, are particularly favourable for transmission of seismic energy. Contrary to this, practical experience indicates that these formations rather act as barriers on which the seismic waves may suffer breaks (Sieberg, 1929). One may consider them as "seismic attenuators." Areas behind these "seismic attenuators" may fall in "seismic shadow," where the vibrations are limited to minimum level of microseismic effects.

Fault zones and fracture systems are generally known as weak lines of the earth's crust. When a shock wave of sufficient intensity falls on such fracture and fault systems, tectonic stresses here and there may suddenly resolve into a chain reaction of elastic strain-rebound displacements and could release new seismic energy which may increase the energy level of the causal transcurrent one. In this respect, fault dislocations to a certain extent may serve as "secondary foci" along the fracture belts.

The trends of fault and fracture systems may have essential influence on the transmission of the seismic energy. Fault systems best lead the seismic energy along their strikes. Isoseismic maps generally indicate this "tectonic lead." One outstanding example of such tectonoseismic relationship is shown by the isoseismic map of the epicentral region of the 1906 San Francisco earthquake (fig. 1). These tectonic lead lines represent tectonoseismic "energy-transmission channels."

In the records of underground explosions, the so-called Love waves and body-shear waves also are conspicuously weak. This is because the energy initiated by a radial pressure around the charge sends out a compressional pulse through the ground and produces relatively little shear (Howell, 1959). In contrast, earthquakes are characterized by the presence of strong shear waves and relatively weak compressional waves.

The problem of energy transmission is vitally important in the detection of remote explosions. When seismic energy is radiated from a source and encounters a seismic boundary, a part of the energy is reflected and a part transmitted into the new medium, causing a division of the original pulse. Within each medium there is absorption of energy from the pulse. The length of the seismic pulse, especially of surface waves, tends to increase, with a corresponding decrease in amplitude at any instant.

In general, absorption by the ground is an exponential function of distance, so that for any body wave,

$$E_{\Delta} = E_{b1}\Delta^{-2}e^{-\alpha\Delta}$$

where E_{Δ} is the energy in the waves at distance Δ , E_{b1} is the energy at unit distance, and α is the coefficient of absorption.

The solution for α at two Δ's:

$$\alpha = \frac{2}{\Delta_2 - \Delta_1} \ln \frac{A_{\Delta 1}\Delta_1}{A_{\Delta 2}\Delta_2} = \frac{1}{\Delta_2 - \Delta_1} \ln \frac{E_{\Delta 1}}{E_{\Delta 2}} \left(\frac{\Delta_1}{\Delta_2}\right)^2$$

where A is the amplitude and E is the energy in the waves at distance Δ . For observed earthquake body-wave pulses α is usually too small to measure. In near-surface layers α is larger, a typical value for body waves being as great as 0.062 per meter. For Pseudo-Rayleigh surface waves, the value of α is 0.017 per meter (Howell and Kaukonen, 1954).

Near the epicenter the body and surface waves often have nearly equal amplitudes, but at greater distances the surface waves become increasingly strong in comparison (Howell, 1959). The velocity of surface waves depends generally on frequency. This dependence of velocity on frequency is called dispersion. This means that high-frequency surface-wave vibrations travel at a velocity different from that of low-frequency vibrations. The coefficient of absorption for surface waves generally increases with frequency. The result of this is a rapid loss of high-frequency energy in seismic waves with distance from the source. Small explosions have a tendency to generate a greater percentage of high-frequency vibrations in the ground than do large explosions (Howell, 1959). Thus with large nuclear explosions, shock waves transmitted along tectonoseismic channels may have more favorable conditions of energy preservation in intercontinental passage. One may see the importance of the tectonoseismic transmission channels as lead lines along which more seismic energy is retained in distant transmission of shock waves.

INTERCONTINENTAL TECTONOSEISMIC ENERGY-TRANSMISSION CHANNELS BETWEEN NORTH AMERICA AND ASIA

Orogenic and cratogenic tectonic trends of the geological past (Kober, 1942), when plotted in oblique Mercator projection for North America and Asia, present an orientative picture of the possible tectonoseismic transmission channels between the two continents (fig. 2).

The map indicates that the seismological observatory in Oklahoma is located in the Variscan tectonoseismic channel line which runs along the inner belt of the Rocky Mountains and, through the Anadir peninsula, loops over to the Asiatic belt of U. S. S. R., where underground nuclear explosions may be expected.

This Variscan tectonoseismic channel is generally free from the earthquake disturbances of the younger Alpine orogen, which so fre-

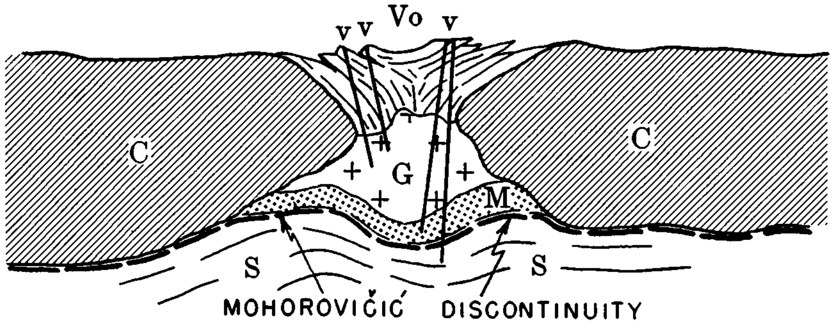

Figure 3. Schematic cross section of a Variscan tectonoseismic energy-transmission channel.
Vo—Variscan orogen
v—vulcanism
G—sialization, granitization
M—simatization, magma mixing
C—masses of cratonic tectonism (tectonoseismic energy-break areas)
S—sima

quently affect California and the west coast of the United States. The map shows in general the areas of shallow earthquake activity. Data plotted selectively were taken from the map of Gutenberg and Richter (1954).

Areas with cross shading on the map (fig. 2) represent those masses and blocks (including the "Zwischengebirge" of Kober, 1942) where rigid cratonic-type tectonism can be recognized. These masses are in great part crystalline rigid blocks. Their seismologic history indicates that they may be considered more or less as "seismic attenuators" in the transmission of the energy of seismic surface waves.

A schematic cross section of a Variscan tectonoseismic energy-transmission channel is shown in figure 3. This diagram was prepared after the concept of Kober (1942) to illustrate the character of a Variscan orogen. The diagram shows the possibility of "root" development underneath the orogen and the sialization (granitization) of the interior. Beneath the continental crust, the Mohorovičić seismic discontinuity is also indicated. Deep refractions along this discontinuity may travel with a speed in a range of 7.6 to 8.4 kilometers per second. Gutenberg (1952) reported that the first arrivals from explosions indicate a near-surface wave velocity of 5.9 to 6.5 kilometers per second. Rays penetrating to the Mohorovičić discontinuity may refract there and travel along it to be refracted back to the surface at more distant places.

Since tectonic fault zones and fracture systems are linear coherent elements along the trends of orogens, their influence on energy transmission in tectonoseismic channels is of great importance. These orogenic lead lines are locally penetrated by granitic core plutons ("Kern Plutonen"), which, when faulted, may contribute in a great deal to the increase of seismic energy transmission. The Wichita Mountains of Oklahoma may be considered as a core pluton. It is strongly faulted along a northwest-southeast trend. (Compare the elongate pattern of seismometers in the Wichita Mountains Seismological Observatory).

This core pluton is embedded in the channel of the Variscan seismic lead interconnecting the possible nuclear explosion sites of the U. S. S. R. with the Oklahoma "listening post."

The Asiatic part of the U. S. S. R., from the viewpoint of pattern of tectonoseismic channel lead, may be considered as one of the least isolated places of the world to use for concealed nuclear explosion tests with the hope that the shock waves will not be detected. The area is a perfect network of tectonoseismic channel leads of the Variscan, Caledonian, and Proteronide orogens. The intermediate foreland masses and the possible "Zwischengebirge" of the Kirghiz steppe, because of their fault systems, may act with less attenuation in the transmission of seismic energy. The strong fault systems in this tectonic environment rather offer a good lead toward the seismic energy transmission channels. The foreland masses V_1, V_2, V_3, and V_4 (fig. 2), because of their fault tectonics, are more like interconnecting linkages in the seismic energy transmission rather than blocking elements. In addition, the Proteronide channels in the foreland masses may act as seismic energy leads out from these areas. The Variscan tectonoseismic channels more or less may be regarded as a "main gathering system" along which the seismic energy may travel into the American continent.

Considering the limitations in selecting nuclear-testing explosion sites away from densely populated and important industrial areas, it is unlikely that any place in the Asiatic Soviet Union could serve as a concealed nuclear test site without being detected by shock waves spreading out from it. The seismological observatory in Oklahoma is like a geophysical "stethoscope" designed to feel the pulse of the main artery of this directional seismic lead system on the Variscan main line.

On the map (fig. 2) is indicated a part of the trend of the "Andesite Line" around the marginal belt of the Pacific Ocean. It is the limit of occurrence of andesites as they outline the Pacific area. The surface waves of earthquakes, traveling nearly parallel to the Andesite Line and striking it at large angles of incidence, are strongly attenuated, sometimes by as much as 90 percent, indicating that the line is a marked discontinuity in seismic wave velocity (Howell, 1959). Thus surface waves from Asia striking the Andesite Line at large angles of incidence would be attenuated to a considerable extent.

The "continental bridge" of the Variscan tectonoseismic lead could transmit seismic energy more favorably from the possible nuclear explosion sites in the U. S. S. R. to the Wichita Mountains Seismological Observatory of the United States than can the Pacific route of seismic arrival. On the other hand, the deep "roots" of the Alpine-type orogen of the West Coast of the United States could exert influence and a "baffling action" in the path of the trans-Pacific arrivals.

CONCLUSIONS

On the basis of earlier publication by M. G. Gudzin and J. H. Hamilton (1961) a general description of the Wichita Mountains Seismological Observatory of Oklahoma was presented. This observatory has great significance in the detection and identification of underground nuclear explosions at remote distances.

The problem of tectonoseismic energy transmission has been discussed and presented in the tectonoseismic framework of intercontinental tie between North America and Asia. The tectonoseismic channel of the Variscan orogen has an important tie with the Asiatic continent. This main artery of seismic energy transmission presents a favorable position for Oklahoma's seismological observatory in the detection of remote nuclear explosions.

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New Survey Publications

Circular 57, *Geology of northeastern Cherokee County, Oklahoma,* by John M. Starke, Jr., was issued on August 31, 1961. The book consists of 62 pages, 16 illustrations, and one plate, the latter being a colored geologic map of the area. The area of the report includes Rs. 21-23 E. of T. 19 N.; Tps. 17, 18 N. of R. 23 E.; and the east halves of Tps. 17, 18 N. of R. 22 E.

The book may be purchased from the Survey office $2.25, cloth bound, or $1.25, paper bound. The map, at the scale of 1½ inches to the mile, may be purchased separately for $1.00.

The *Index to geologic mapping in Oklahoma* is now in press and will be available shortly. The index consists of five maps on which are outlined the areas of 164 surface geologic maps, published, unpublished, and in progress, and the areas of 218 published and unpublished subsurface maps. Each map has a bibliographic index. The maps are:

Map I.	Surface mapping, 1901-1960, compiled by Carl C. Branson
Map II.	Subsurface mapping, 1940-1950, compiled by Louise Jordan
Map III.	Subsurface mapping, 1951-1956, compiled by Louise Jordan
Map IV.	Subsurface mapping, 1957-1958, compiled by Louise Jordan
Map V.	Subsurface mapping, 1959-1960, compiled by Louise Jordan

Salt in Wellington Formation, Grant County, Oklahoma

Louise Jordan

That salt exists in the Wellington Formation has been known ever since early oil tests were drilled in the northwestern part of the State. In the six northwestern counties of Oklahoma, Clifton (1926) showed salt in lithologic logs of wells drilled previous to 1926 below the "base of the red," which is the approximate top of the Wellington Formation. Northward in Kansas, salt has been mined by hydraulic and room-and-pillar methods for many years. At Hutchinson, Kansas, shafts have been driven some 600 feet to reach the top of salt beds; at Kanopolis to 800 feet; and at Lyons to 1,000 feet. At Hutchinson, the Carey salt mine, which has been in operation since 1923, is producing from a 7- to 12-foot layer of salt 645 feet below the surface (Swineford, 1955, p. 167). All these localities are near the eastern edge of salt deposits in Kansas in the Hutchinson Member of the Wellington Formation of Early Permian age (Taft, 1946, p. 241).

Based on information now available, the approximate eastern edge of the salt deposits in western Oklahoma is shown in figure 1. From the north boundary of the State southward to Caddo County, salt is found primarily in the Wellington Formation, although minor amounts are present in the Blaine Formation. In the southwestern part of the State, the salt occurs higher in the stratigraphic section, that is, above, below, and in the Blaine Formation (Jordan, 1959). In the northwestern part of the State, as well as in the Panhandle, considerable thicknesses of salt are found also just above and below the Cimarron Anhydrite, and in the Flowerpot Shale below the Blaine Formation as well as in the Wellington Formation (Jordan, 1960).

Early in 1961 an investigation was made of the subsurface salt deposits in the Wellington Formation near Medford, Oklahoma. It was found that information concerning the depth to and the thickness of salt beds in this area was limited. Electric logs of wildcat tests drilled in the area were examined. These unfocused resistivity logs were of the Parker Drilling No. 1 Schuermann (sec. 28, T. 27 N., R. 5 W.), Worley and Harrell No. 1 Dial-Knox (sec. 20, T. 27 N., R. 5 W.), and Smiley and Little Drilling Company No. 1 Biggs (sec. 8, T. 26 N., R. 5 W.)

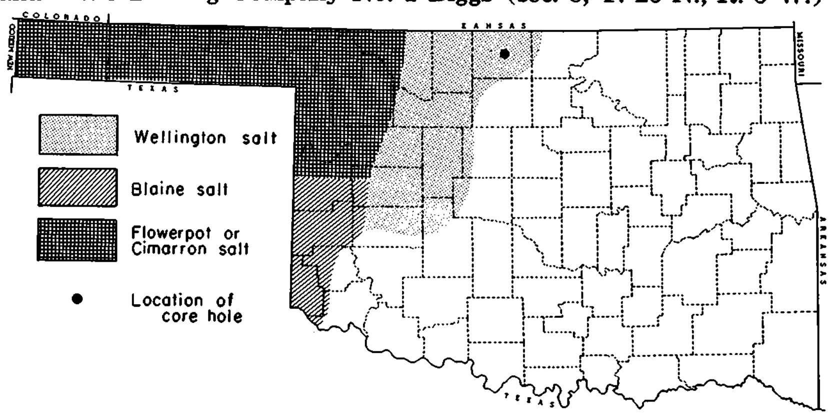

Figure 1. Map showing approximate areas of salt strata nearest the surface.

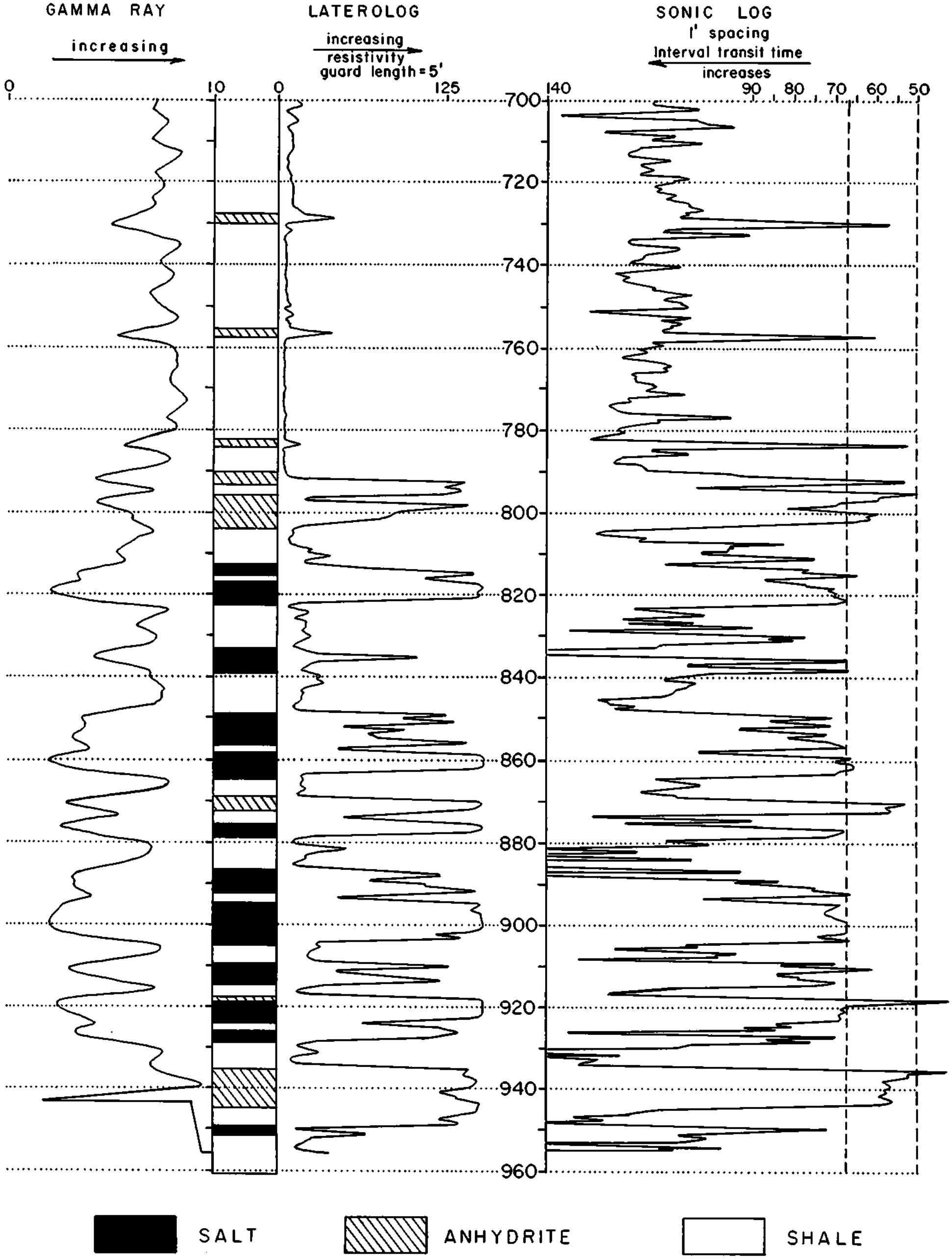

Figure 2. Gamma-ray-laterolog and sonic log surveys of test hole in sec. 32, T. 27 N., R. 5 W., Grant County, Oklahoma, showing salt section in the Wellington Formation.

wells. An educated guess was made that the salt might occur between the depths of approximately 840 to 960 feet below the surface at the site under investigation. The logs indicated that there might be a salt section approximately 40 feet thick between the depths of 920 and 960 feet below the surface.

To obtain specific information a test hole was drilled in SW cor. SW¼ SE¼ sec. 32, T. 27 N., R. 5 W., in Grant County. The hole was drilled with salt-brine mud. During drilling samples were taken continually and drilling speed was noted. On completion of drilling, a gamma ray-sonic-caliper and a laterolog survey were run in the hole. These curves and a lithologic log are shown on figure 2.

The total major salt section is from 812 to 928 feet, a thickness of 116 feet. The thickest collective section of salt is 42 feet thick and is from 886 to 928 feet below the surface. The 42-foot section contains 29 feet of salt or is 69 percent salt. The salt section contains four beds of shale, the thickest being five feet. The lithologic section shown in figure 2 was substantiated through the observation of drilling rates and the cuttings recovered during drilling.

The caliper log of the test showed little washing-out of salt because the hole was drilled with brine. Because the hole size did not change rapidly, there was little effect upon the sonic log (Tixier et al., 1959, p. 107). The gamma-ray and laterolog curves of the test hole do not differentiate anhydrite beds from salt beds with any certainty, but correlation of the sonic log with these curves makes a clear distinction. Typical sonic velocity for anhydrite is 20,000 feet per second, or an interval transit time of 50 microseconds per foot. The velocity value for rock salt is 15,000 feet per second, or an interval transit time of 66.7 microseconds per foot (Tixier et al., 1959, p. 108). Vertical dashed lines are shown on figure 2 at 50 and 66.7 microseconds per foot. At places the curve does not show these values and it is assumed that variable amounts of impurities of either shale or of the other evaporite are present.

In the test hole, the top of the Wellington Formation is placed tentatively at 265 feet and the base of the formation is estimated to be near 1,180 feet, by correlation with the laterolog survey of The Texas Company No. 1 Hula well (sec. 19, T. 27 N., R. 5 W.). The upper part of the Wellington from 265 to 790 feet consists essentially of gray and mottled red-brown shale with thin interbeds or inclusions of anhydrite or gypsum. The strata below the salt section from 950 to 1,180 feet are essentially anhydrite with gray shale interbeds.

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Shallow Halite Deposits in Northern Woodward and Southern Woods Counties, Oklahoma*

Porter E. Ward†

Halite in the Flowerpot Shale of Permian age has been found within about 30 feet of the land surface at the Big Salt Plain in northwestern Oklahoma (fig. 1). The salt plain is a widened segment of the Cimarron River flood plain lying between Woods and Woodward Counties. Brine from seeps and springs saturates the alluvium, the surface of which becomes salt encrusted during dry weather. The south side of the plain is bounded by cliffs that rise almost vertically for about 100 feet. The cliffs on the north side are not nearly so steep and are about half a mile from the plain. For the most part, the cliffs are capped by the Blaine Gypsum and underlain by the Flowerpot Shale. The unusual width of the flood plain may be due to collapse resulting from removal of underlying halite deposits.

During an investigation of the hydrology and geology of the salt plains, the U. S. Corps of Engineers drilled more than 50 test holes, 33 of which were core holes. Nineteen of the holes penetrated halite in the Flowerpot Shale at depths ranging from about 30 to 175 feet. The thickest salt-bearing zone penetrated by the test holes was 91 feet, and none of the holes passed through all the salt-bearing beds. The upper part of the 91-foot zone contains more shale than salt, but 80 percent or more of the lower 57 feet is salt. Most of the salt is bedded crystalline halite, but a minor amount occurs as a fibrous material filling vertical and near-vertical cracks in the shale. A considerable part of the halite is colorless, but much of it contains included shale and clay that impart an

*Publication authorized by the Director, U.S. Geological Survey.
†U.S. Geological Survey, Norman, Okla.

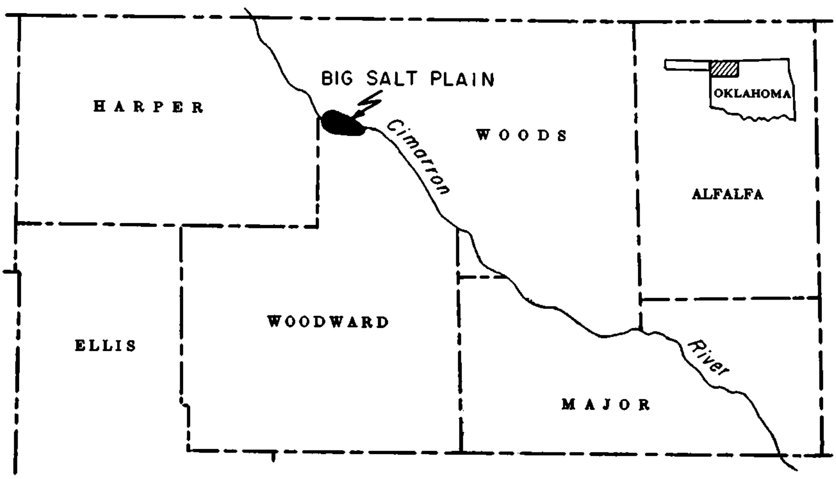

Figure 1. Index map showing location of the Big Salt Plain.

overall dull reddish-brown appearance. The shale beds of the Flowerpot are silty, gypsiferous, and blocky. Generally they are reddish brown but may be mottled or interbedded with greenish-gray beds. The formation is characterized by intersecting veins of colorless or orange-red selenite. Some gypsum occurs in the Flowerpot as thin impure beds, and some occurs as nodules.

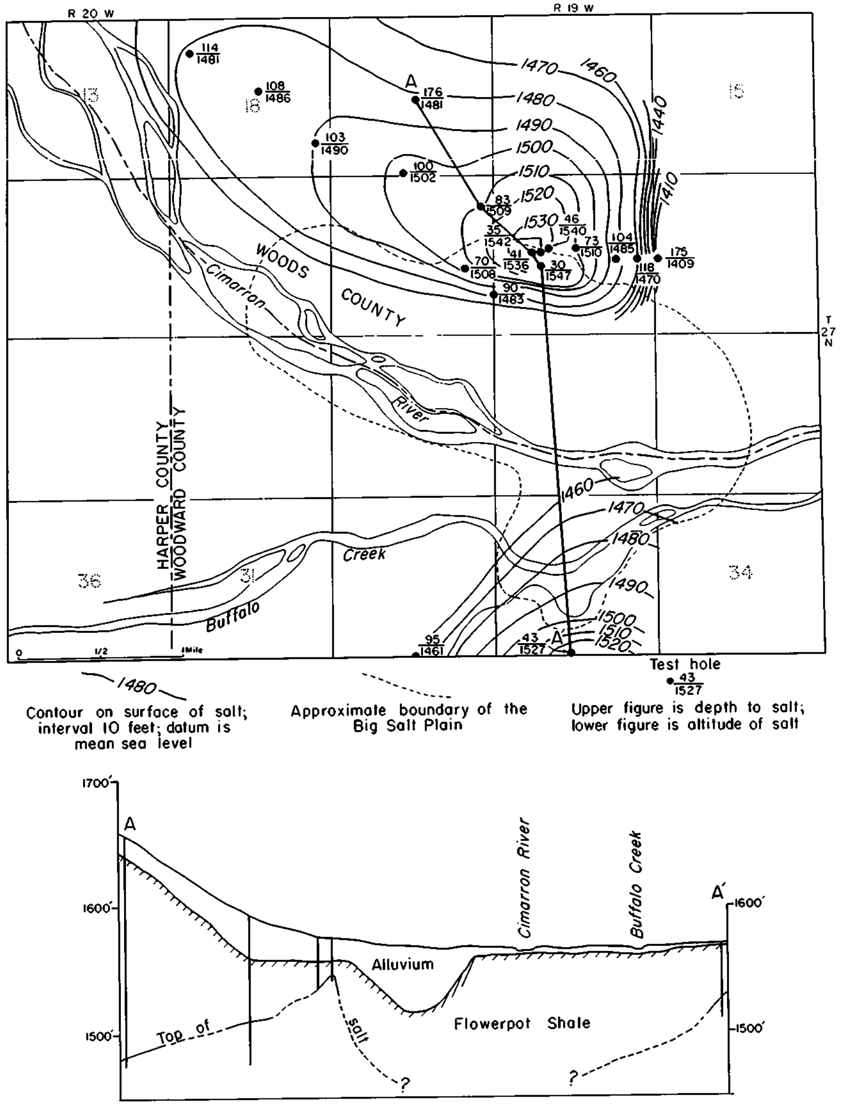

Figure 2. Map and generalized cross section of the Big Salt Plain area showing configuration of top of salt in the Flowerpot Shale.

Figure 2 is a map, based on test-hole data, showing the configuration of the top of the salt. One of the holes penetrated salt 29.7 feet below the surface of the flood plain. Alluvial sand and gravel was 19 feet thick, and the salt was only 10.7 feet below the top of the Flowerpot Shale. The salt is at relatively shallow depth on both sides of the river and appears to be deeper both upstream and downstream, but, because of the limited areal extent of drilling, this is uncertain. The river has cut a channel in the Flowerpot Shale to an altitude of about 1,518 feet above mean sea level. Less than 3,000 feet north of the channel, salt was found at an altitude of 1,547 feet, which is 29 feet above the bottom of the channel. The highest elevation at which salt was found on the south side of the river is 9 feet higher than the deepest part of the bedrock channel.

The Flowerpot Shale contains salt in many places in northwestern and southwestern Oklahoma, but the extreme shallowness of its occurrence at the Big Salt Plain is unique. The question of why ground water has not removed salt so near the surface has not been answered satisfactorily. If ground water moving into the vicinity became saturated with salt before reaching the plain, it could not, of course, dissolve the shallow salt beneath the plain. Cores show that some salt is being removed from beneath the plain. However, it is unlikely that all or even a large part of the salt carried into the Cimarron River in the area by ground water is derived from the small salt highs shown on the map. If it were, the salt would soon be removed because the amount dissolved is estimated by the U. S. Public Health Service to be about 2,600 tons per day, which is almost 1 acre-foot.

The shallow salt is apparently near the eastern depositional margin of the main body of salt in the Flowerpot Shale. The salt margin must retreat westward continually as salt is removed through solution, however, this marginal retreat apparently is extremely slow, perhaps because most of the salt is being dissolved not at the margin but west of it. This is indicated by the areas of very shallow salt at the present margin, which is thought to be near the original margin of deposition. Also, if all the salt being removed were from the margin, evidence of slumping would extend over a greater area.

In summary, it appears that ground water has not been able to remove all the shallow halite beneath the Big Salt Plain because the water becomes salt saturated before reaching the plain. In order to explain more clearly the removal of salt in the vicinity of the plain additional drilling and water sampling are needed, especially upstream and downstream from the locale of the present test holes.

Agmoblastus, A NEW PENNSYLVANIAN BLASTOID FROM OKLAHOMA

ROBERT O. FAY

The name *Agmoblastus* is here proposed for a fissiculate blastoid from the Hogshooter Limestone of Washington County, Oklahoma, with type species *Paracodaster dotti* Moore and Strimple, 1942. The original types are fragmentary and are supposed to be on deposit in the United States National Museum, Washington, D.C., but are missing. The present description is based upon observations of one complete specimen and about 57 radial plates, recently collected by Mr. Harrell L. Strimple and purchased for the collection of the School of Geology, The University of Oklahoma. The new genus may be characterized as a fissiculate blastoid, with 8 moderately well-exposed hydrospire fields, with 4-8 hydrospire slits in each field, one large U-shaped epideltoid with an elongate anal opening between it and the radial plates, possibly with a small atrophied hypodeltoid (missing), with 4 high, wide, arrow-shaped deltoid plates, ambulacra well away from oral opening, 3 large basal plates, and subcylindrical shape in side view. The genus belongs to the family Codasteridae Etheridge and Carpenter, 1886, and may be compared with *Angioblastus, Codaster, Paracodaster,* and *Sagittoblastus.* All have 8 hydrospire fields, with none on the anal side, and have one large epideltoid that is U-shaped, with short ambulacra restricted to the summit. The following short key will serve to distinguish the characters of these genera:

1. Hydrospire slits present only on deltoids .... *Paracodaster*
   Hydrospire slits present on radials and deltoids 2
2. Hydrospire fields wide .... *Codaster*
   Hydrospire fields moderately narrow to restricted 3
3. Hydrospire fields moderately narrow, with high, wide deltoids .... *Agmoblastus*
   Hydrospire fields restricted, with low deltoids 4
4. Deltoid narrow, ambulacra close to mouth .... *Angioblastus*
   Deltoids wide, ambulacra well away from mouth ... *Sagittoblastus*

The genus *Pterotoblastus* has restricted fields and wing-like radials and *Trionoblastus* has a superdeltoid and subdeltoid plate in place of an epideltoid plate on the adoral side of the anal opening; thus one can not confuse these genera with *Agmoblastus.*

Agmoblastus dotti (Moore and Strimple), 1942
Plate I, figures 1-4
Paracodaster dotti Moore and Strimple, 1942, p. 85-91, fig. 1.

The name is dervied from the Greek word *agmos,* meaning break, referring to the slits on the radial and deltoid plates, thus distinguishing this genus from *Paracodaster.* Theca subcylindrical, with flattened summit and rounded-flattened base, periphery below midheight, 8.5 mm long by 7 mm wide. Basalia wide, low, approximately 7 mm wide by 1.5

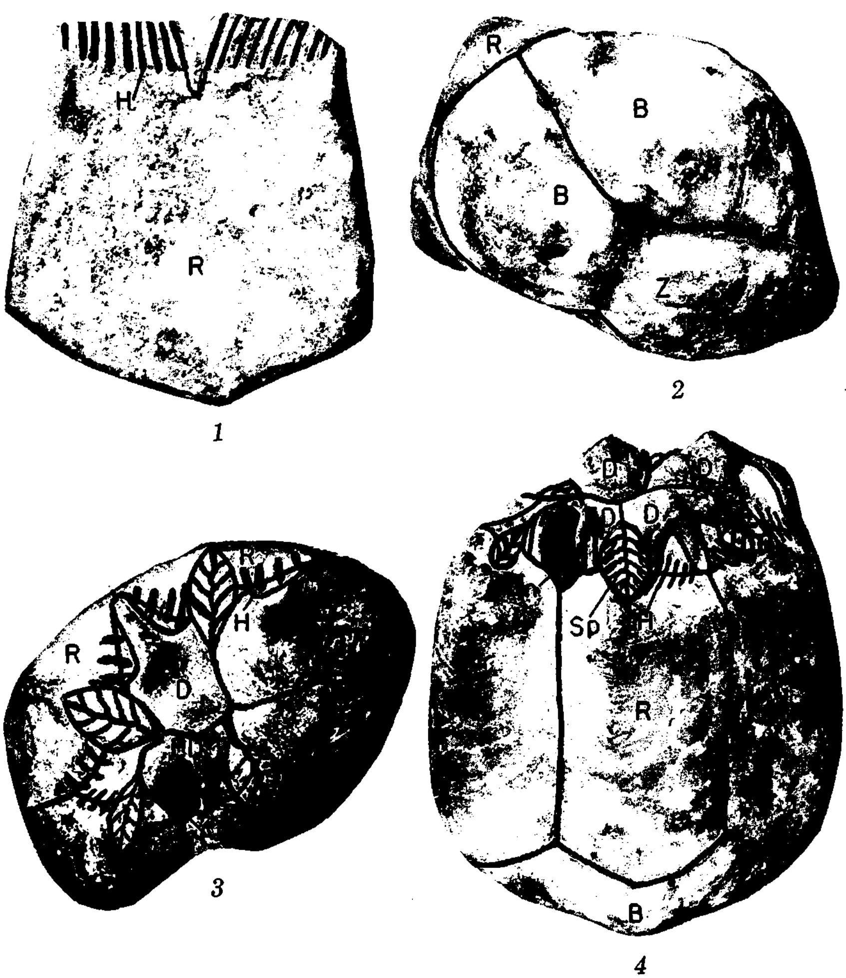

Plate I
Agmoblastus dotti (Moore and Strimple), 1942. Hogshooter Limestone, north of Ramona School, Washington County, Oklahoma.

Figure 1. Inner view of a radial plate, metatype OU 4311, x6.1

Figures 2-4. Aboral, oral, and (C) ambulacral views of a complete specimen, holotype OU 4310, x7.3

An—anal opening	H—hydrospire slits
B—basal plate	R—radial plate
D—deltoid plate	Sp—side plates
ED—epideltoid plate	Z—azygous basal plate

mm high, composed of 3 large normally disposed basals. Radials 5, pentagonal, about 4.5 mm long by 4.5 mm wide, with moderately narrow hydrospire fields extending to adjacent deltoid plates, except on anal side, where hydrospires are absent. The ventral surface of the radial plate is almost at right angles to the lateral surface, with short slits (4-8) on each side of an ambulacrum (except on anal side).

Deltoids 4, high, wide, strongly lobed, with rounded, restricted to moderately narrow hydrospire fields, each 2 mm long by 1.5 mm wide by 1 mm high. The oral opening is small and is surrounded by the deltoid lips and epideltoid lip. On the anal side the high, wide, U-shaped epideltoid adjoins adjacent deltoids and bounds the deep, elongate anal opening on the adoral side, resting laterally upon adjacent radial limbs. It is possible that a small, restricted hypodeltoid was present adjacent to the radial limbs, at the aboral end of the anal opening, but is now missing.

Ambulacra 5, subpetaloid, 1.5 mm long by 0.75 mm wide, with 5-6 side plates on each side of an ambulacrum, and a small outer side plate on the adoral-abmedial corner of each primary side plate. The brachiolar facet is on the outer side plate and associated side-plate handle. The ambulacra are restricted to the summit, well away from the oral opening, resting aborally upon adjacent radial limbs. The surfaces of the calyx plates are ornamented with fine growth lines, subparallel to the plate margins.

Occurrence.—Hogshooter Limestone, Missourian Series, Pennsylvanian System, west of railroad bridge, along creek north of Ramona School near C N½ sec. 28, T. 24 N., R. 13 E., Washington County, Oklahoma.

Types.—Lectotype (new holotype), OU 4310 (one complete specimen); metatypes, OU 4311, a figured radial plate (pl. I, fig. 1); OU 4312 (two fragmentary specimens); OU 4313 (about 57 fragments); School of Geology, The University of Oklahoma. The original syntypes are supposed to be on deposit in the U. S. National Museum but cannot be found.

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