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MINERAL RESOURCE SURVEY
**Circular No. 48**

The information contained in this circular was gathered by a unit of the WPA Geological Investigation Project, sponsored by The University of Texas, Bureau of Economic Geology. The purpose of this survey is to assemble information concerning the mineral resources of Texas and make it available to the public. It is hoped that this information will be a contribution to the industrialization of the State. The following report gives the results of work done in Houston County by Work Project Nos. 17743 and 18508 from April 7, 1941, to March 3, 1942.

# AN OCCURRENCE OF BENTONITE IN HOUSTON COUNTY, TEXAS*

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## *INTRODUCTION*

Bentonite was discovered in Houston County in 1940 by a staff member of the Bureau of Economic Geology.[1] On correlation of the sections in which the bentonite was exposed, namely, at Hurricane Bayou and Alabama Ferry, it was found that though these localities were some 20 miles apart, the two sections wee almost identical. This led to the obvious conclusion that the shale member containing the bentonite was continuous throughout the intervening area. Therefore, it was the work of this project to trace this shale member with its accompanying bentonite beds by means of outcrops, auger holes, and excavations. Surveys were made of the sites that encountered or exposed the bentonite, and the results were plotted on base maps made from aerial photographs.

## *BENTONITE*

*Historical sketch.*[2] — Bentonite was first described in 1897, although the Geological Survey of Canada reported that it had been used prior to that time at the Hudson's Bay Posts for washing blankets. The first commercial shipments were made in 1888 by William Taylor, of Rock Creek, Wyoming, after whom the mineral was called "taylorite." However, when it was found that this was a preoccupied name for another mineral substance, the clay was renamed "bentonite" from its occurrence in the Fort Benton shale of the Rock Creek district. Since 1888, production has steadily grown until in 1938 some 200,000 short tons valued at nearly $2,000,000 was produced by eight states, of which California and Wyoming were the largest producers, the others being Arizona, Mississippi, Oklahoma, South Dakota, Texas, and Utah.

*Definition and origin.* — Bentonite has been defined by Ross and Shannon[3] as being "a rock composed essentially of crystalline clay-like mineral formed by devitrification and the accompanying chemical alteration of a glassy igneous material, usually tuff or volcanic ash; and it often contains various proportions of accessory crystal grains that were originally phenocrysts in the volcanic glass." Thus, most bentonite is a decomposition or alteration product of igneous rocks with the majority of the deposits resulting from the formation of crystalline minerals and partial decomposition of volcanic glass (ash). Sometimes volcanic lavas are changed to bentonite, but in the ordinary deposit the volcanic ash has been partially altered by water which in turn has combined with the ash and has partially leached out the alkalies. It is likely that some of the alteration is accompanied by corrosive gases which accompanied the ash expelled from the volcano.[4]

*Composition.* — Bentonite is essentially a complex hydrous aluminum silicate usually containing from 5 to 10 percent of alkalies or alkaline earth oxides. Alkali bentonites are those containing oxides of calcium and magnesium. The chief minerals in this complex silicate are the clay minerals montmorillonite and beidellite. The former has strong base exchange properties, and it is now generally believed that the position that the alkali and alkaline earth oxides occupy in the crystal structure and the amount present largely explain variations in properties of the different bentonites.

*General characteristics.* — Most bentonite deposits contain an admixture of sandy particles and mica. Pulverized bentonite is fine grained and usually light colored, ranging from white to dark green, but it may be pink, brown, blue, or even black. Unlike most clays, bentonite is generally easily fusible at a comparatively low heat, and on firing, the color is usually white, buff, or brown. When freshly cut, it commonly presents a waxy or tallow-like luster which may become dull or powdery on drying. The waxy varieties may be cut into thin translucent shavings. The fracture is roughly conchoidal, but it may be platy or shale-like, or it may have no distinct fracture.

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*Assistance in the preparation of these materials was furnished by the personnel of Work Projects Administration Official Projects Nos. 665-66-3-233, 165-1-66-695, and 265-1-66-214.

[1]Stenzel, H. B., New zone in Cook Mountain formation, the *Crassatella texalta* Harris — *Turritella cortezi* Bowles zone: Bull. Amer. Assoc. Petrol. Geol., vol. 24, pp. 1663-1675, 1940.

[2]Lang, W. B., and others, Clay investigations in the Southern States, 1934-35: U.S. Geol. Survey Bull. 901, p. 4, 1940.

[3]Ross, C. S., and Shannon, E. V., The minerals of bentonite and related clays and their physical properties: Jour. Amer. Ceramic Soc., vol. 9, pp. 77-79, 1926.

[4]Sellards, E. H., Mineral production in Texas, *in* The Geology of Texas, Vol. II, Structural and Economic Geology: Univ. Texas Bull. 3401, p. 295, 1934 (1935).

Most bentonites exhibit a marked plasticity, and some have an unusual absorbent ability. In fact, the most distinctive feature of bentonite is its strong affinity for water. Certain bentonites absorb 5 times their weight, or as much as 15 times their volume of water. This results in an increase in volume of the bentonite itself and in the formation of a slippery, plastic, gelatinous mass that is very soft and bears a close resemblance to liquid soap. When powdered bentonite particles are agitated in water, those of some varieties remain in suspension indefinitely, and even salt will not coagulate them. The suspended particles of other varieties soon settle out.[5]

*Uses.* — Two general types of bentonite are known — the true or northern bentonites first discovered in the Black Hills area of Wyoming and South Dakota and the southern or so-called meta-bentonites found mostly in Texas and California. The meta-bentonites show markedly less swelling in water than the northern type and are used chiefly in preparing oil-well drilling fluids and in purifying fats and waxes. Nearly one-half of the 1936 production of bentonite was used in the preparation of drilling muds. The bentonite helps support heavier constituents of the mud, such as barite and iron oxides. The next most important use is in the filtering and the decolorizing of oils. Thus, "activated bentonite" is bentonite that has been treated with sulfuric acid, a treatment giving it properties similar to those of fullers earth and making it satisfactory for use in the refining of oil. Bentonite has other important uses such as rejuvenation of molding sand in foundries, sealing of dams, and making water-bearing sands impervious. Minor uses are as a de-inker of newspapers, as a filler in soap and paper, as a water softener, in soap and detergents, sprays and insecticides, in cosmetics, polishes, adhesives, ceramic glazes, absorbents.[6]

## *METHODS OF FIELD WORK*

Field work was directed to tracing out the belt of bentonite between the known outcrops at Hurricane Bayou and Alabama Ferry. Outcrops of the bentonite were sought on the sides of hills, in stream valleys, gullies, railroad and highway cuts, and at other places. Detailed prospecting was done by boring test holes. These were made with a 3-inch post-hole auger, a bit consisting of two vertical, curved blades cupped together at the bottom to form a basket and provide cutting edges. Two men are needed to operate the drill. The equipment consisted of 4½-foot lengths of ¾-inch heavy iron pipe and couplings, a 3-inch post-auger bit, a "T" handle, and pipe wrenches. The handle was removed and length of pipe or drill stem added with every 4½ feet of depth. This method proved particularly effective for depths of less than 25 feet; for greater depths the method did not prove satisfactory in the area worked.

Auger holes and outcrops were carefully logged and surveyed by the plane-table method, with the data being plotted on base maps. Whenever possible a spacing pattern of 100 yards between holes was adhered to.

Numerous samples were taken at intervals throughout the survey to determine vertical and lateral variations in quality. Care was taken to obtain clean, fresh samples. Each sample was put immediately into an air-tight jar.

## *STRATIGRAPHY OF THE AREA*[7]

The area investigated is in the Gulf Coastal Plain Eocene where detailed stratigraphic correlations are most difficult because of the similar composition of the beds and the lack of good exposures. However, the horizon containing the bentonite is an exception, for the bentonite could be traced, bed for bed, over a distance of some 20 miles. The member in which the bentonite is found is the Landrum shale of the Cook Mountain (Crockett) formation. The east Texas Cook Mountain has been divided into four members which are defined by their composition. These members are:

Mount Tabor shale
Spiller sand
Landrum shale
Wheelock marl

These beds dip gently to the south-southeast, which is the normal attitude of beds in this part of the Gulf Coastal Plain. Thus, in the normal sequence the oldest beds crop out in the northwest corner of the county and the youngest in the southeast corner. The rate of dip of these beds is slight — approximately 70 feet per mile, an angle of only 0° 46'. The average width of outcrop for each unit of the Cook Mountain formation in Houston County is 1 mile; the average thickness approaches 100 feet.

The basal member of the Cook Mountain, the Wheelock marl, lies disconformably on Stone City beds. This member is made up chiefly of gray, calcareous, fossiliferous, glauconitic marine shales; throughout the county it produces a slight cuesta. The Wheelock contains subordinate limestone layers and concretions; it changes by transition and interfingering into the overlying Landrum shale.

For the purposes of this survey, the Landrum is divided into an upper and lower part. The lower consists of black-brown, unctrous, sparingly glauconitic shales of brackish water or lagoonal origin. Subordinate lentile of glauconite and of calcareous, glauconitic marine shales are interbedded in this part of the Landrum. It is in one of these lentils, the so-called Hurricane marine lentil, that are found the persistent bentonite beds which are the object of this study. The upper part of the Landrum member is nonmarine, less unctuous, less plastic, and more silty than the lower, resulting in a speckled light brown color.

The next higher member is the Spiller sand which consists of gray or brown sands with some lignitic partings. This sand is more resistant than the underlying Landrum shale and is easily recognized, because it supports a pronounced cuesta and is flanked by two shale members.

The top member of the Cook Mountain formation is the Mount Tabor shale which consists of brown, unctuous, calcareous shales of brackish water origin. Subordinate beds of glauconitic marls and black impure limestones, both richly fossiliferous, are included in this member. All the beds above the Mount Tabor are nonmarine and are in the Yegua formation.

[5]Davis, C. W., and Vacher, H. C., Bentonite: its properties, mining, preparation, and utilization: U.S. Bur. Mines Tech. Paper 609, pp. 12-13, 1940.

[6]Tarr, W. A., Introductory Economic Geology, McGray-Hill Book Company, Inc., New York, N.Y., p. 586, 1938. *See also* Chelf, Carl, Bleaching Clay deposits in Gonzales County, Texas, Bur. Econ. Geol., Min. Res. Survey Circ. No. 43, May 1942.

[7]Stenzel, H. B., *op. cit.*

## *BENTONITES OF THE HURRICANE LENTIL*

*The Hurricane lentil.* — The bentonite with which this paper is concerned occurs in a marine lentil of the lower Landrum member of the Cook Mountain formation. Stenzel[8] proposed that this lentil be known as the Hurricane lentil since he found it exposed in the Landrum shale at three separate localities in Houston and Leon counties. This member is easily traceable and retains a constant composition over long distances (See fig. 1 and the accompanying detailed descriptions of sections at Hurricane Bayou and Alabama Ferry.) Thus, the Hurricane lentil with its characteristic bentonite beds offers an excellent horizon for detailed structural definition in this region.

Two layers of bentonite are contained in the lentil: an upper layer 1.0 to 4.0 feet thick and a lower layer 0.3 to 0.6 of a foot thick. They are separated by about 11 feet, stratigraphically, of shale and prominent clay-ironstone ledges. Wherever found these ledges occupy similar stratigraphic positions and are of a more or less constant character. In all sections the uppermost ledge is composed of three concretionary layers, this being an excellent field check.

The faunal content of the lentil also offers valuable field checks. Immediately below the lower bentonite, the small pelecypod *Plicatula* forms a distinct bed which is present in all sections. The gastropod *Turritella cortezi* Bowles and the pelecypod *Crassatella texalta* Harris occur in the lentil at most localities. These fossils are most important checks in that they are not found in the remainder of the Cook Mountain formation. Thus, in the field the Hurricane lentil can be identified by the following:

Bentonite (two beds, separated by a constant stratigraphic interval)
Clay-ironstone ledges
*Plicatula* bed
Zone of *Crassatella texalta* Harris and *Turritella cortezi* Bowles

In many places gypsum crystals are quite common in this lentil. The crystals are usually tabular with their size varying up to 0.5 of a foot. The gypsum is usually associated with a light yellow encrusting iron mineral, probably copiapite. Both of these minerals are secondary and are probably due to the weathering of the Landrum shales.

Shales of this lentil are red brown, sparingly fossiliferous, somewhat calcareous, even textured, and regularly bedded. The shale underlying the lower bentonite is almost always gray, glauconitic, and often includes fossil corals, while the shale above the upper layer of bentonite is usually red brown and often gypsiferous.

*Scope of investigation.* — As previously mentioned, the belt of bentonite between Hurricane Bayou and Alabama Ferry was drilled, logged, and mapped in detail. Some ninety outcrops, mostly of the upper bentonite, were located and 254 auger holes drilled and logged. Logs of typical holes are given at the end of this paper.

Because of the constant character of the lower bentonite, this bed was used as the key horizon for mapping, although it was reached only a few times with the drill due to its depth and the overlying concretionary layers. It had been found that in both Houston and Leon counties the stratigraphic interval between the upper and lower bentonites remained relatively constant. Therefore, when the base of the upper bentonite was reached, the hole was regarded as completed.

The elevation of the lower bentonite was then computed by subtracting the constant stratigraphic interval, 11.2 feet, from the elevation of the base of the upper bentonite.

Samples of the upper bentonite from likely looking localities were sent to the Bureau of Economic Geology. Also complete faunal assemblages collected from five localities were added to the collections of the Bureau of Economic Geology.

*General character of the bentonites.* — The upper bentonite averages 3.5 feet thick, is usually fine grained, and in many instances carries an admixture of sand particles. The color ranges from almost white to sulfur yellow to dark blue green. However, at most localities it is a dark olive green. On wetting, the color becomes darker. Freshly cut exposures are waxy or soapy in texture and may be cut into thin translucent shavings. The bed is usually very difficult to penetrate with the drill, and the deeper it lies, the harder it drills. The bentonite is relatively non-plastic and has only moderate absorption ability. It is of the non-swelling or meta-bentonite type. A small lump of the bentonite placed in 100 cm of water, after standing over night broke down into small fragments but did not diffuse or swell. When dry, it appears dull and powdery and becomes very hard and brittle. It exhibits definite conchoidal fracture, and jointing is commmon to the bed.

The lower bentonite averages 0.4 of a foot thick. It usually is purer than the upper and differs in color, a dull gray, and thickness; otherwise, it is very much like the upper. It does not vary widely either vertically or laterally, as does the upper, but remains constant in character. Because of the thicknes of overburden and the thinness of the layer, the lower bentonite was considered economically unfavorable, and throughout the survey most of the attention was directed toward the upper layer of bentonite and its commercial possibilities.

An outcrop of the upper bentonite is unique and striking. It is almost always barren, because bentonite is not conducive to the growth of vegetation. Due to the peculiar properties of the bentonite, an outcrop presents a crinkled coral-like appearance. Because of weathering the color is usually a faded yellow green. The surface is fluffy or peculiarly granular when dry. When rain falls, the outcrop becomes exceedingly slippery, like grease or liquid soap; when the ground dries, the bentonite shrinks and cracks extensively, but as the moisture only affects the upper 1 or 2 feet, the cracks are limited to the same depth.

*Theory of origin.* — It seems well established that the original substance of true bentonites was volcanic ash which under favorable conditions may have been transported several hundred miles from the point or points of ejection before coming to rest. This is shown by the wide distribution of the Ordovician bentonite, which is known to extend from Birmingham, Alabama, northward to the Georgian Bay region, a distance of about 900 miles, and approximately equal distance east and west.[9] The bentonites of the Hurricane lentil in Houston County are Tertiary in age, being found in the Crockett formation of the Caliborne group, which is middle Eocene.

[8] *Op. cit.*, p. 1669.

[9] Lang, W. B., and others, Clay investigations in the Southern States, 1934-35: U.S. Geol. Survey Bull. 901, p. 11, 1940.

Such favorable conditions for the long transportation of finely divided ashy materials may have well existed in Tertiary time since evidences of volcanic activity during that period have been reported from several states, notably Alabama, Louisiana, Texas, and Arkansas. Arkansas would seem to be the most favorable location for the Tertiary volcanoes that gave rise to the ash falls which resulted in the formation of the east Texas bentonite.[10]

The agents of transportation were either the wind or water or both; because of the character of the marine lentil in which the bentonite occurs, the probably site of ash deposition was in the shallow relatively undisturbed waters of a lagoon. This is borne out by the fact that the lower Landrum shales are apparently lagoonal, for they contain considerable amount of disseminated lime, have some obviously marine fossils, overlie with an imperceptible transition the marine Wheelock marl, and contain some truly marine layers.[11]

The two layers of bentonite are relatively pure in character, and it is probable that the ash was quickly submerged and then went through the normal process of changing to bentonite. Because of the different grades of bentonite that are found both laterally and vertically in the belt, it must be assumed that natural leaching played an important part in the formation of the bentonites. Thus the physical and chemical environment of the clay-forming materials was most effective in the development of the ultimate product.

## *ECONOMIC CONSIDERATIONS*

*Factors to be considered.* — A careful investigation of the commercial possibilities of a deposit of bentonite should be made before investing heavily in its production. Such a study should include the following: the possibility of marketing the product; the price obtainable; cost of mining, treating, and transportation to the market; the amount available in the deposit; the nature of the crude bentonite; its suitability for the consumer's requirements. Most consumers desire a homogeneous product which is in sufficient quantity to yield a uniform supply for years. Deposits of this type are not common. It must be remembered that most crude bentonites contain impurities, such as sand, gypsum, and carbonaceous matter, which must be removed at considerable expense. Purified bentonite from different levels and different parts of the same deposit may have different properties, such as variation in color, colloid content, and east of hydration.

The present supply of bentonite is large enough for normal demand. Several companies with trained staffs and years of experience in the production and marketing of bentonite products are successfully operating today. Many of the special processes of sizing, purification, and chemical treatment of bentonite are covered by United States and foreign patents.[12]

All these factors should be carefully considered and weighed by prospectors and others who are interested in the commercial production of bentonite from the Hurricane lentil.

*The evaluation of a bentonite.* — Standard testing methods and specifications for the commerical evaluation of a bentonite have not been extensively developed or generally accepted. Specific uses demand specific products. However, in general, the commercial importance of a bentonite may depend on various elements of its physical condition, such as marked adsorption, absorption, or coalescence; on its effect on emulsions, suspensions, and surface tension; on its chemical reaction; or on a combination of all these factors.

The chemical composition of a bentonite appears to have little to do with its utility, except in a few instances. Therefore, the chemical analysis of a bentonite is ordinarily of little value in the evaluation of a bentonite intended for commercial use. The only means of determining the value is to make a practical test to learn if the product will serve a particular purpose.

*Effect of soil creep.* — In Houston County the unconsolidated Coastal Plain deposits slump or creep down the slopes of ravines and valleys. At places this overlapping mantle of material may extend a vertical distance of 100 feet or more below the base of the formation from which it is derived. This mantle ranges from 1 foot to 10 to 20 feet in thickness depending on the material, slope, length of period of accumulation, and other factors. It not only seriously interferes with prospecting operations, for it effectively conceals outcrops, but it would certainly interfere with the mining of bentonite, because in the long run the mining costs of a deposit which has a large amount of soil creep would destroy the profits.

*Commercial possibilities of the bentonites of the Hurricane lentil.* — The chemical and physical properties of the bentonite from various parts of the upper layer are still in the process of being investigated by the Bureau of Economic Geology. The upper layer is the only one that offers any hope of commercial production, since the lower layer averages only about 0.5 of a foot in thickness and always carries a large amount of overburden, being some 11 feet below the upper bentonite in the section.

Two deposits in the Hurricane lentil of Houston County could possibly be worked profitably. One deposit (*see* fig. 2) is located on the Palestine highway, (U.S. Highway 287), 0.8 of a mile northwet of the town of Crockett, county seat of Houton County. It is only 0.3 of a mile from a main line of the Southern Pacific (T.&N.O.) Railroad. The deposit covers about 320 acres and has an overburden of about 5 feet of unconsolidated material. The upper bentonite is hard, yellow olive green, and averages 3 feet in thickness. It is rather pure, being free from gritty inclusions.

The second deposit crosses State Highway 7, the Lock and Dam road, at a point approximately 10 miles southwest of Crockett (*see* fig. 3). Good exposures of the upper bentonite occur on both sides of the highway, the workable dimensions being about 1.5 miles long and 0.7 of a mile wide. The bentonite exposed here is of good grade, very hard, dark green in color, and has relatively small overburden, 3 to 5 feet. The upper layer averages about 3.5 feet in thickness. This deposit is easily accessible since it is crisscrossed by a network of roads.

Logs of the charcteristic drill holes accompany this report.

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[10]Crider, A. F., Volcanic ash in northern Louisiana: Bull. Amer. Assoc. Petrol. Geol., vol. 8, pp. 524-525, 1924.

[11]Stenzel, H. B., The geology of Leon County, Texas: Univ. Texas Pub. 3818, p. 137, 1938 (1939).

[12]Davis, C. W., and Vacher, H. C., *op. cit.*, p. 39.

*Mining and production.* — At both of these deposits simple ;mining methods could be employed. The deposits could easily be worked by the usual stripping methods. The overburden could be removed by scrapers and tractors, supplemented with power shovels on beds that are deeply covered. Small scrapers could be used to insure removal of the remaining foreign material that results from the contamination with overburden. The bentonite ledge could then be broken up by pick and shovel and loaded directly into truck for transportation to Crockett where it could be shipped by rail to Houston or some other point at which milling and treating plants are located.

### *SUMMARY*

In Houston County the Hurricane lentil of the Landrum member of the Cook Mountain formation contains two layers of bentonite, one of which has commercial possibilities. Both layers are continuous from Hurricane Bayou to Alabama Ferry, an airline distance of some 20 miles. Two likely areas for the production of bentonite from the Hurricane lentil are described.

### *ACKNOWLEDGMENTS*

The writer would like to take this opportunity to express his appreciation to the landowners in Houston County and to the crew whose industry and interest made this survey possible. Special thanks are due to H. B. Stenzel, geologist with the Bureau of Economic Geology, whose help and advice were invaluable both in the carrying out of the survey and in the preparation of this paper. Thanks are also due to E. H. Sellards, Director of the Bureau of Economic Geology, William N. McAnulty, State Supervisor of the Mineralogical Survey, and to Robert C. Redfield and Glen L. Evans, geologists with the Bureau of Economic Geology.

*Description of Two Sections of the Hurricane Lentil*
*Exposed in Houston County, Texas.*[13]

*Section 1. Alabama Ferry, Houston County, Texas. Left bank of Trinity River about 0.2 to 0.5 mile downstream from the abandoned Alabama Ferry, about 7.5 miles west-southwest of Porter Springs; Bureau of Economic Geology locality No. 113-T-9.*

| | *Thickness Feet* |
|---|---|
| t. Brown shale, similar to bed *q* but more weathered | 2.5 |
| s. Brown shale with four light-colored silty shale beds | 3.8 |
| r. Clay-ironstone concretions, hard, yellow-brown | 0.3 |
| q. Brown shale, thin bedded, gypsiferous | 7.1 |
| o. Bentonite, bright gren when weathered, black-green when fresh, waxy, with many desiccation cracks; this bed forms broad, flat bench at low-water stage on south end of exposure | 3.6 |
| n. Glauconite marl, as bed *l* | 0.8 |
| m. Clay-ironstone bench, hard, brown, glauconitic, fossiliferous in two layers | 0.9 |
| l. Glauconite marl, gray-green, massive, fossiliferous | 1.9 |
| k. Marl, as bed *i* | 0.8 |
| j. Silt beds | 0.8 |
| i. Marl, gray-blue to gray-green, poor in glauconite and fossils | 4.5 |
| h. Bentonite, gray-blue when fresh, bright green when weathered, waxy with many slippage planes | 0.4 |
| g. Glauconite marl, gray-green, soft, richly fossiliferous, abounds in *Plicatula* | 0.8 |
| f. Limestone, hard, gray-green, glauconitic, fossiliferous | 0.3 |
| e. Clay-ironstone bench, hard, brown, richly glauconitic, fossiliferous, similar to bed *c* | 0.9 |
| d. Glauconite marl, similar to bed *b*; contains *Crassatella texalta* Harris and *Turritella cortezi* Bowles | 1.5 |
| c. Clay-ironstone bench, hard, brown, fossiliferous, glauconitic | 0.4 |
| b. Glauconite marl, dark green, fossiliferous, broken coal branches common | 1.2 |
| *DISCONFORMITY* | |
| a. Shale, black to black-gray, non-fossiliferous, non-glauconitic | 2.0 |

*Section 2. Hurricane Bayou, Houston County, Texas. Bed of creek from bridge on Crockett-Rusk County road (Mail Route 1), 3.35 miles northeast of Crockett; Bureau of Economic Geology locality No. 113-T-2.*

| | *Thickness Feet* |
|---|---|
| n. Brown shale, badly weathered to red-brown clay soil | — |
| m. Bentonite, dark green, waxy, conchoidally fracturing, pure, with numerous desiccation cracks | 3.3 |
| l. Marl, slate-gray, thin-bedded, poor in fossils and glauconite | 0.5 |
| k. Clay-ironstone concretions in Marl, 3 layers, hard, yellow, brown, or purple; marl is dark green and rich in glauconite and fossils | 3.2 |
| j. Marl, same as bed *h* | 0.8 |
| i. Silt lentils, light gray-yellow, well-bedded, muscovitic, lacking fossils and glauconite | 0.4 |
| h. Marl, light gray to light greenish-brown, thin-bedded, unctuous, slightly glauconitic and fossiliferous | 6.0 |
| g. Bentonite, dark green-black, with numerous slippage planes and irregular pockets of fossils and glauconite | 0.3 |
| f. Marl, dark green, richly fossiliferous and glauconitic, particularly rich in *Plicatulas; Crassatella texalta* Harris also occurs | 1.5 |

[13]Stenzel, H. B., New zone in Cook Mountain formation, the *Crassatella texalta* Harris — *Turritella cortezi* Bowles zone: Bull. Amer. Assoc. Petrol. Geol., vol. 24, pp. 1674-1675, 1940.

| | Thickness Feet |
|---|---|
| e. Clay-ironstone bed; this bed forms flat creek bottom at north end of lower meander | — |
| d. Clay-ironstone, hard, yellow-brown, glauconitic, calcareous | 0.8 |
| c. Marl, weathered, glauconitic, but not indurated | 0.8 |
| b. Limestone, hard, brown, weathered, impure, smooth-topped | 0.5 |
| a. Marl, same as bed *c* | 0.5 |

*LOGS OF TEST HOLES*

Logs of several characteristic holes are given below, the location of the holes being shown on figure 2. Asterisks indicate beds containing bentonite.

| | Depth in feet From | To |
|---|---|---|
| *Hole No. 18:* | | |
| Clay, brown, sandy | 0.0 | 1.7 |
| Clay, gray, clay-ironstone fragments at bottom | 1.7 | 3.0 |
| Clay, red and gray, mottled | 3.0 | 5.2 |
| Clay, red | 5.2 | 6.3 |
| Clay, light red and gray | 6.3 | 7.3 |
| Clay, brown, mottled | 7.3 | 8.0 |
| Clay, dark gray and brown, sandy | 8.0 | 14.0 |
| Clay, orange and brown, sandy | 14.0 | 15.3 |
| Clay, gray and yellow, sandy | 15.3 | 20.5 |
| Clay-ironstone gravel | 20.5 | 22.5 |
| *Bentonite, yellow-green (upper) | 22.5 | 23.2 |
| Glauconite, brown and green, fossiliferous | 23.2 | 24.8 |
| Glauconite, green | 24.8 | 26.0 |
| *Hole No. 40:* | | |
| Gray sand soil | 0.0 | 1.0 |
| Clay, red and gray, mottled | 1.0 | 4.7 |
| *Bentonite, yellow-green (upper) | 4.7 | 7.4 |
| Shale, gray and brown, plastic | 7.4 | 8.0 |
| Marl, brown and gray, fossiliferous, glauconitic | 8.0 | 9.5 |
| *Hole No. 35:* | | |
| Gray-brown sand soil | 0.0 | 0.5 |
| Clay, red | 0.5 | 4.1 |
| Shale, gray-brown, probably bentonitic | 4.1 | 5.0 |
| *Bentonite, light olive green (upper) | 5.0 | 7.9 |
| Marl, gray and brown, calcareous, fossiliferous, glauconitic; some ironstone | 7.9 | 10.7 |
| Shale, gray, gypsiferous, fossiliferous | 10.7 | 11.5 |
| *Hole No. 32:* | | |
| Clay, red and gray, mottled, sandy | 0.0 | 2.5 |
| *Bentonite, light olive-green, weathered at top, rust-yellow at bottom (upper) | 2.5 | 4.6 |
| Shale, medium gray and brown, fossiliferous, calcareous | 4.6 | 6.5 |
| *Hole No. 36:* | | |
| Soil, gray-brown, sandy | 0.0 | 2.5 |
| Clay, reddish-orange, mottled, sandy | 1.2 | 3.4 |
| Clay, yellowish brown | 3.4 | 4.0 |
| *Bentonite, olive-green (upper); upper 0.5 feet weathered and impure | 4.0 | 6.0 |
| Shale, gray | 6.0 | 6.9 |
| Marl, glauconitic, brown, calcareous, fossiliferous | 6.9 | 8.7 |
| *Hole No. 38:* | | |
| Shale, weathered brown | 0.0 | 0.7 |
| Shale, light chocolate-brown with ironstone stains and a few tiny clay-ironstone fragments | 0.7 | 1.7 |
| Shale, light chocolate-brown with a little copiapite | 1.7 | 5.7 |
| Shale, light brown, gypsiferous | 5.7 | 7.5 |
| Shale, gray-brown, glauconitic | 7.5 | 7.7 |
| Marl, olive-drab, glauconitic, bentonitic (?) | 7.7 | 8.7 |
| *Bentonite, greenish-brown, impure (upper) | 8.7 | 9.7 |
| *Bentonite, yellow-green (upper) | 9.7 | 11.7 |
| Shale, gray, calcareous, plastic | 12.1 | 12.7 |
| Marl, dark, green, fossiliferous, glauconitic | 12.7 | 14.2 |

| | Depth in feet From | To |
|---|---|---|
| *Hole No. 57:* | | |
| Soil, gray, sandy | 0.0 | 0.7 |
| Sand, orange, clayey | 0.7 | 1.0 |
| Clay, light red and gray, mottled, sandy | 1.0 | 3.9 |
| Clay, orange and gray, mottled, sandy | 3.9 | 9.5 |
| Light brown shale with interbedded light gray to yellow silts | 4.5 | 6.0 |
| Above grading into medium to dark brown shales with copiapite and yellow silts | 6.0 | 17.0 |
| Above grading into black shales with a few thin-shelled fossils | 17.0 | 26.0 |
| Marl, black, with a few thin-shelled fossils | 26.0 | 31.8 |
| *Bentonite, dark gray (upper) | 31.8 | 34.5 |
| Glauconite, dark greenish-gray, fossiliferous | 34.5 | 38.8 |

Following are logs of several characteristic drill holes, the location of which is shown on figure 3. Asterisks indicate beds containing bentonite.

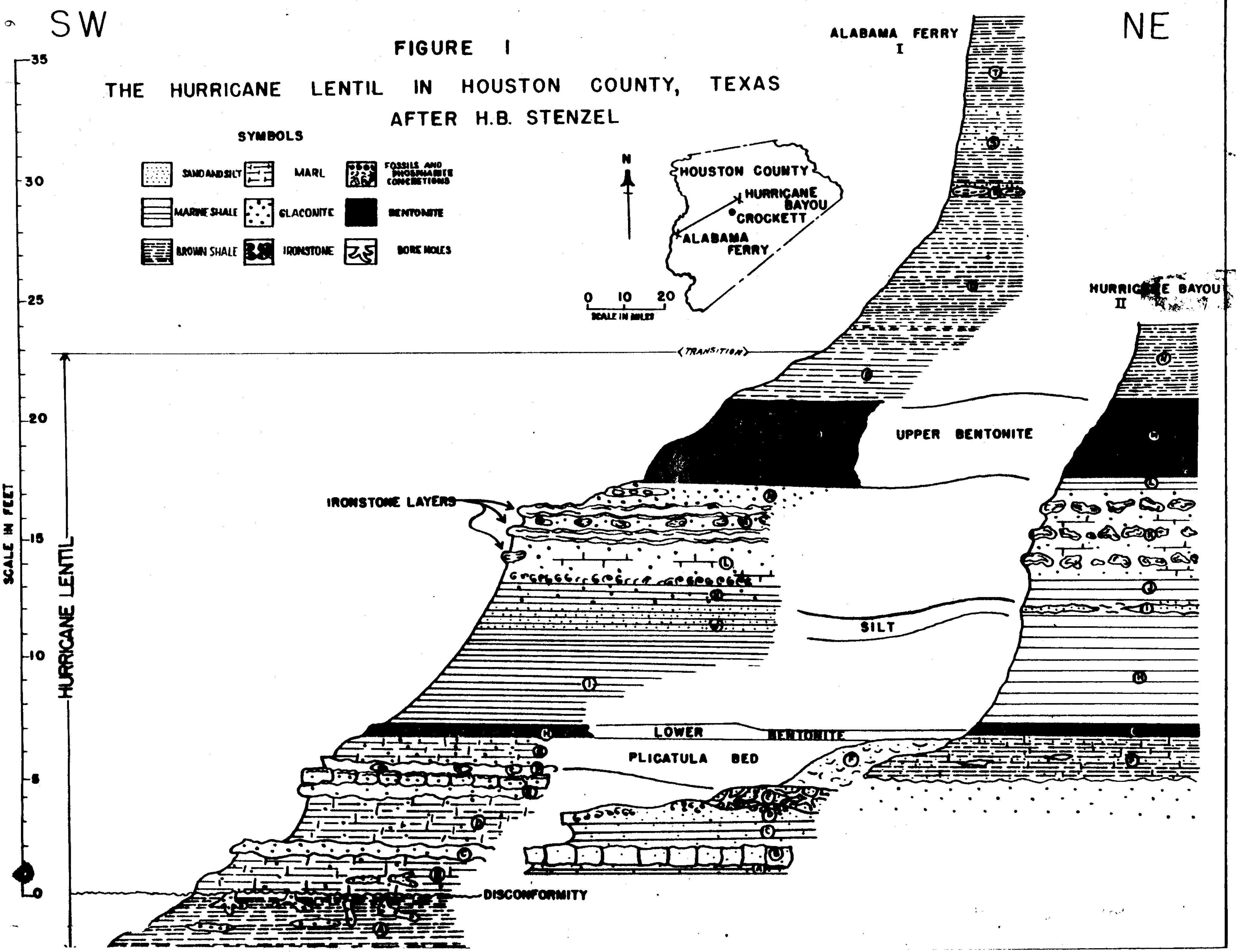
| | Depth in feet From | To |
|---|---|---|
| *Hole No. 173:* | | |
| Top soil, brown, sandy | 0.0 | 1.0 |
| Clay, red-gray, plastic | 1.0 | 4.0 |
| Shale, gray-orange | 4.0 | 16.0 |
| Clay, red-yellow, bentonitic | 16.0 | 17.7 |
| *Bentonite, dark green, hard (upper) | 17.7 | 19.3 |
| Shale, gray | 19.3 | 20.3 |
| *Hole No. 176:* | | |
| Fine tan soil | 0.0 | 3.0 |
| Red gumbo | 3.0 | 6.0 |
| Shale, gray, orange | 6.0 | 13.0 |
| Shale, gray | 13.0 | 15.3 |
| Clay, gray-green, bentonitic | 15.3 | 17.5 |
| *Bentonite, dark yellow-green, hard (upper) | 17.5 | 19.3 |
| Shale, gray, bentonitic | 19.3 | 20.0 |
| *Hole No. 181:* | | |
| Sand, brown | 0.0 | 1.0 |
| Clay, red | 1.0 | 4.5 |
| Gumbo, red-gray | 4.5 | 14.4 |
| Shale, yellow-gray | 14.4 | 18.3 |
| Clay, yellow-brown, bentonitic | 18.3 | 19.3 |
| *Bentonite, dark yellow-green, hard (upper) | 19.3 | 21.8 |
| Shale, yellow-gray, bentonitic | 21.8 | 22.3 |
| *Hole No. 182:* | | |
| Sand, brown | 0.0 | 1.0 |
| Clay, red | 1.0 | 4.0 |
| Gumbo, dark gray | 4.0 | 6.0 |
| Shale, gray | 6.0 | 8.5 |
| Shale, yellow-gray | 8.5 | 10.0 |
| Clay, yellow-red, bentonitic | 10.0 | 10.5 |
| *Bentonite, hard, dark green (upper) | 10.5 | 12.3 |
| Shale, gray, bentonitic | 12.3 | 13.0 |
| *Hole No. 184:* | | |
| Clay, red | 0.0 | 4.0 |
| Shale, gray-yellow | 4.0 | 5.5 |
| Shale, brown, bentonitic | 5.5 | 6.2 |
| *Bentonite, hard, dark green (upper) | 6.2 | 7.8 |
| Shale, yellow-gray, bentonitic | 7.8 | 8.5 |
| *Hole No. 188:* | | |
| Clay, red | 0.0 | 3.5 |
| Shale, gray | 3.5 | 7.3 |
| Shale, yellow-green, bentonitic | 7.3 | 9.0 |
| *Bentonite, dark yellow-green, hard (upper) | 9.0 | 10.0 |
| Shale, yellow-green, bentonitic | 10.0 | 10.7 |

| | Depth in feet From | To |
|---|---|---|
| *Hole No. 190:* | | |
| Gumbo, dark gray | 0.0 | 3.8 |
| Shale, gray | 3.8 | 5.0 |
| Shale, yellow, bentonitic | 5.0 | 6.0 |
| *Bentonite, yellow-green, hard (upper) | 6.0 | 7.3 |
| Shale, gray, bentonitic | 7.3 | 8.0 |
| *Hole No. 192:* | | |
| Gumbo, red-gray | 0.0 | 5.5 |
| Shale, gray | 5.5 | 9.0 |
| Shale, red-gray | 9.0 | 10.5 |
| *Bentonite, yellow-green (upper) | 10.5 | 11.6 |
| Shale, gray, bentonitic | 11.6 | 12.0 |

FIGURE I

THE HURRICANE LENTIL IN HOUSTON COUNTY, TEXAS

AFTER H.B. STENZEL



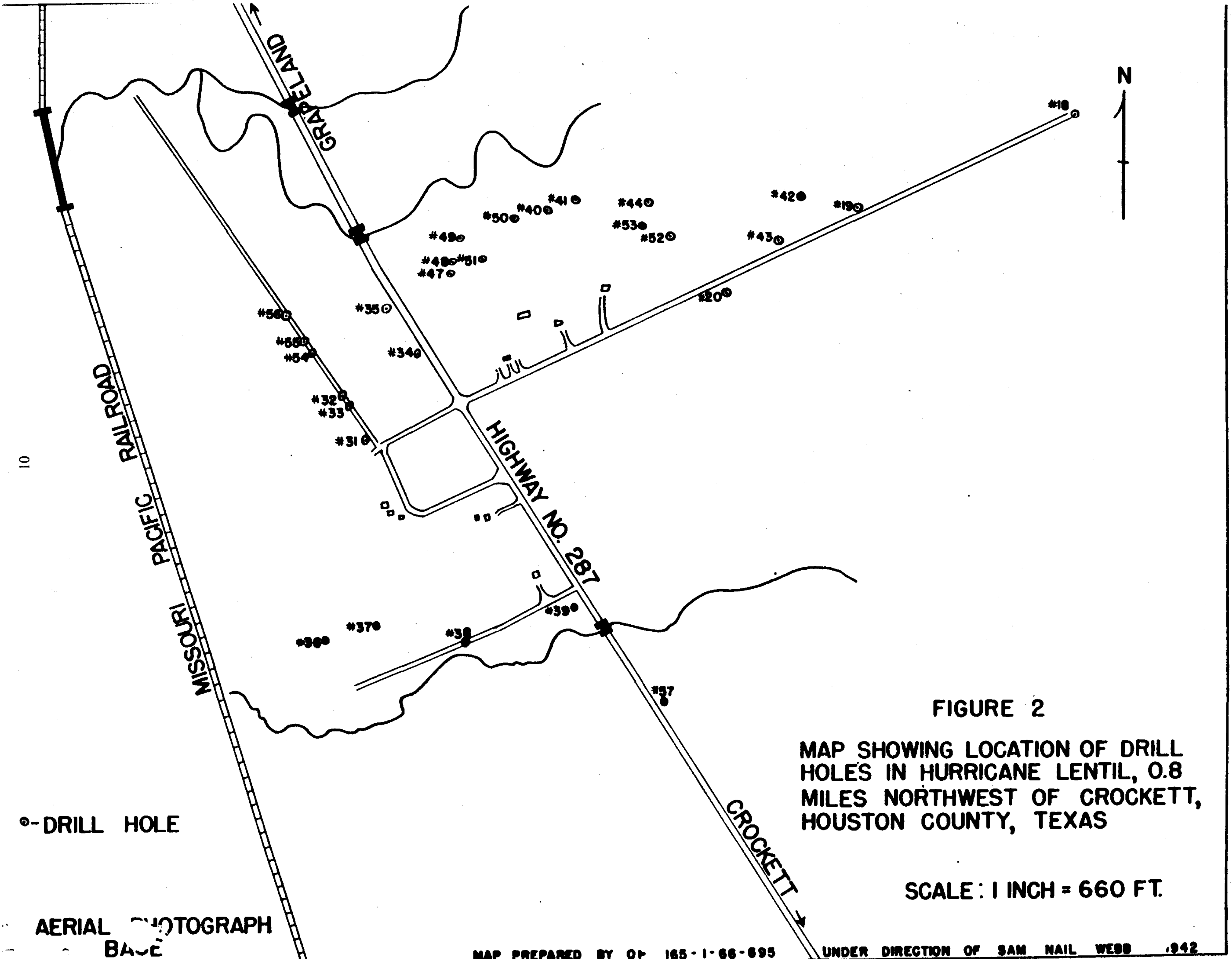



FIGURE 2

MAP SHOWING LOCATION OF DRILL HOLES IN HURRICANE LENTIL, 0.8 MILES NORTHWEST OF CROCKETT, HOUSTON COUNTY, TEXAS

SCALE: 1 INCH = 660 FT.

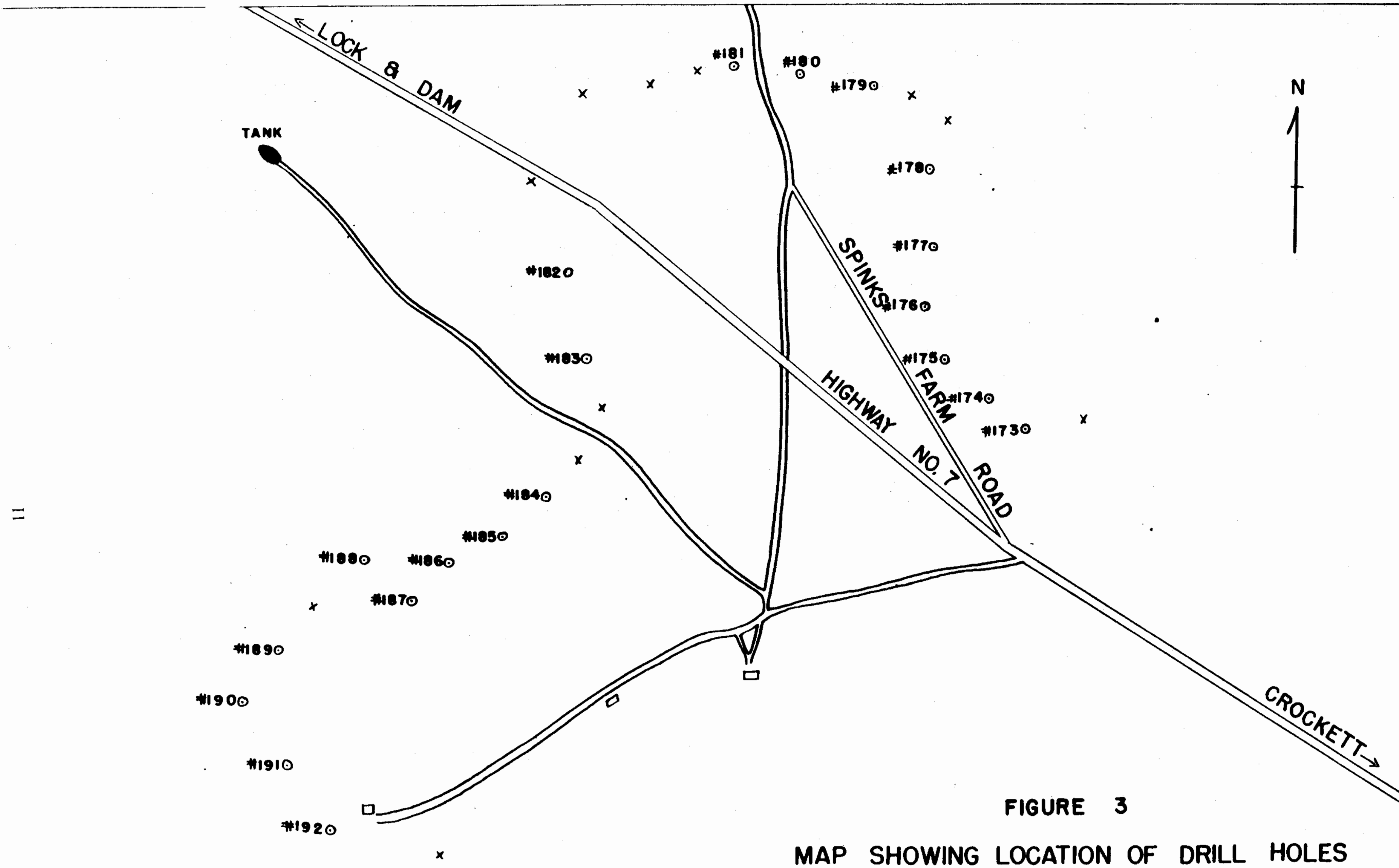



**FIGURE 3**

**MAP SHOWING LOCATION OF DRILL HOLES AND OUTCROPS IN HURRICANE LENTIL, 10 MILES SOUTHWEST OF CROCKETT, HOUSTON COUNTY, TEXAS**

⊙-DRILL HOLE
x-OUTCROP

SCALE: 1 INCH = 660 FT.

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AERIAL HOTOGRAPH BASE