BUREAU OF ECONOMIC GEOLOGY
The University of Texas
Austin 12, Texas

JOHN T. LONSDALE, Director

Report of Investigations—No. 38

Internal Structure of the Grand Saline Salt Dome, Van Zandt County, Texas

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ABSTRACT

Since 1947, the Morton Salt Company's Kleer mine in the Grand Saline salt dome has more than doubled in size. Balk's mapping of the salt structures in the pre-1947 workings showed that (1) the layers of salt near the southeastern border of the dome dip steeply southeast and south, presumably parallel with the dome border. Elsewhere the layers form intricate systems of folds. (2) The axes of all folds plunge nearly vertically. (3) Anhydrite and halite are elongated parallel to the nearest fold axis. (4) The absence of any fractures, faults, cross-cutting salt layers, foreign inclusions, and brine indicates an undisturbed evolution of the deformation structure in a nearly homogeneous, layered salt mass.

The present study includes the new workings and contains a composite map of Balk's study and this one. In addition to confirming Balk's conclusions, this study demonstrates that (1) the structure of this dome is not symmetrical; consequently, this dome probably rose as a series of spines. (2) Radical changes in strike of the trace of the axial planes at the mine levels occur along east-trending planes, which possibly represent zones of failure in the overburden. (3) Attenuation of folds is observed as the perimeter of the dome is approached. (4) Beds of giant salt crystals exhibit cleavage faces several feet on a side.

INTRODUCTION

General remarks.—Salt domes are fascinating structures. The sedimentary rocks peripheral to domes are being constantly investigated for commercial concentrations of oil, gas, and sulfur. However, the interiors of salt domes are accessible in only a few mines in the Texas-Louisiana region. Robert Balk (1949) during 1946–1947 studied the intricate pattern of shear folding exhibited in the walls and ceilings of the Morton Salt Company's Kleer mine in the Grand Saline dome, Van Zandt County, Texas. Since the time of his study the mine has nearly doubled in size. This paper summarizes the principal points of Balk's work and furnishes data on the new workings.

Why study the interiors of salt domes? Initially, this type of work is purely scientific in nature—it is a study of plastic deformation in a relatively homogeneous material. However, by studying such monomineralic rocks as salt, glacial ice, and marble, it is hoped that concepts will be developed that will increase knowledge of the more complex metamorphic rocks and lead to better understanding of how they have formed. Further, it may be possible to relate the internal structures of the salt structures found in the enclosing sediments and thus gain a fuller understanding of how domes form.

Location and description.—The town of Grand Saline, Texas, 60 miles east of Dallas, is located along the north rim of the Grand Saline salt dome (fig. 1). This dome is cylindrical with a diameter of about dome is cylindical with a diameter of about 8,000 feet and extends downward for 15,000 to 20,000 feet. The outer walls slope steeply outward at angles of 65 to 70 degrees, so that a more nearly correct descrip-

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tion of the shape of the salt mass would be that it is a frustum of a cone. The top of the dome is nearly flat, as shown by more than 20 wells which have reached salt at depths between 212 and 342 feet. Caprock is very thin, averaging 25 feet in thickness with a known range of 4 to 71 feet. The rocks cropping out around the dome (Wilcox) slope away radially from the dome at angles as high as 20 degrees (Balk, 1949, p. 1792). The surface expression of the dome is a topographic low, and the depression contains a saline lake, The Grand Saline, which was one of the sources of salt for the Confederacy.

Acknowledgments. — The main field work for this project (April 1957) was supported by the United States Atomic Energy Commission, Project AT-(11-1)-490, Reactor Fuel Waste Disposal Project, The University of Texas. Funds from the Geology Foundation, The University of Texas, covered costs of field work for the additional studies (October 1958) necessary for completion of the map. The drafting compilation was done by Mr. J. W. Macon and other draftsmen of the Bureau of Economic Geology. The writer wishes to thank the Morton Salt Company officials at the Kleer mine—C. R. Lesser, Plant Superintendent; M. R. Barker and R. Rucker, Mine Engineers (1957, 1958)—for their very generous cooperation during the entire study. For able assistance during the mapping the writer thanks W. T. Haenggi, E. L. Trice (1957), B. E. St. John, and T. E. Longgood, Jr. (1958). Longgood also critically edited the manuscript. The photographs were taken by D. E. Feray. Permission to republish Balk's

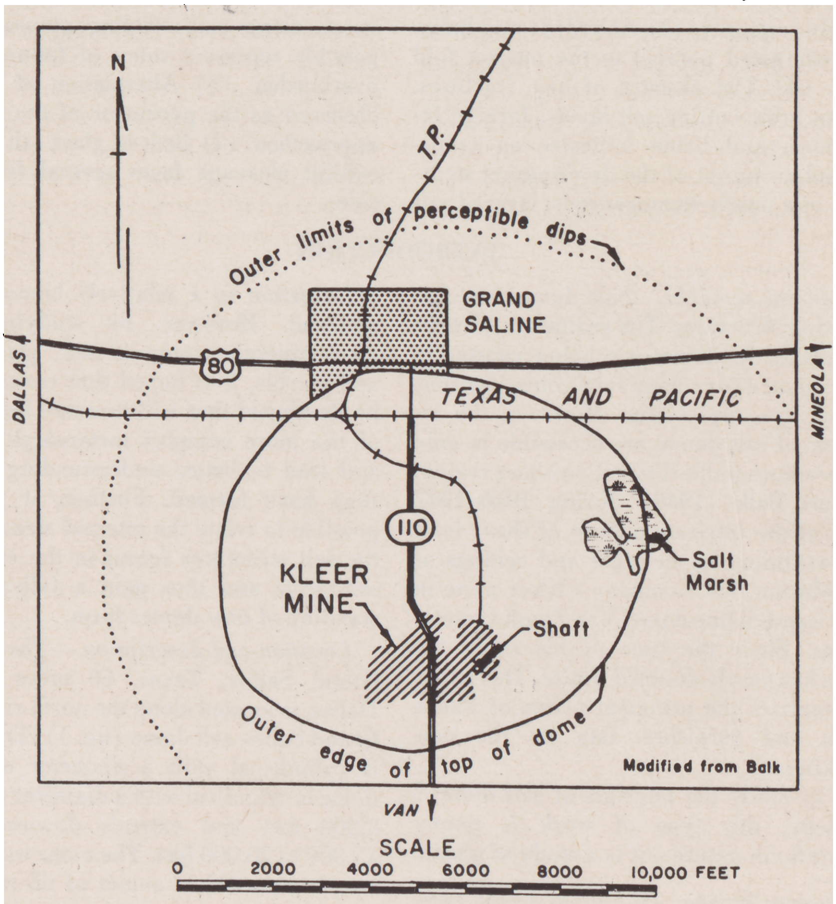

FIG. 1. Index map showing location of the Morton Salt Company's Kleer mine, Grand Saline salt dome.

map was granted by the American Association of Petroleum Geologists, Inc.

Morton Salt Company's Kleer mine.—This mine lies along the southern flank of the salt dome (fig. 1). The workings that were accessible to Balk cover an area of 1,800 feet in a north-south direction and 1,500 feet in an east-west direction (Pl. I). The southern limit of the mine workings is within a few hundred feet of the edge of the dome. These workings are floored at 700 feet below the ground surface (359 feet below sea level). Rooms approximately 60 feet wide and 85 to 130 feet high extend north, east, south, and west from the shaft with crosscuts and smaller tunnels connecting them. Nearly half the salt remains as support pillars.

The workings opened since Balk's mapping are almost entirely west of the older workings and are, at present, floored at 590 feet below ground surface. Room and pillar methods of mining are being used to develop this new area. As a result of these new workings, the accessible portion of the salt dome has been nearly doubled. The ceilings in the new rooms are at present between 20 and 25 feet high. Development is planned to proceed by lowering the floor, by increments of approximately 35 feet, in a series of benches until the total height of the rooms is on the order of 100 feet.

The accompanying map (Pl. I) attempts to join Balk's map of the old workings and the new mapping done in connection with this project. A perfect match was found to be impossible because of a difference in the base used in constructing the two maps. Balk apparently used the ideal mine plan; in the new map, the size and shape of the rooms and pillars were modified (using pace methods) to make the representation more nearly conform to the actual area mapped. This modified the scale and caused a mismatch. A slight gap is left to allow for error, but when the appropriate parts are superimposed the structures can be seen to continue without break. The apparent lack of banding in the new workings is the result of (1) less time spent in mapping the new workings, (2) the fact that the areas marked clear or faint would probably have been mapped by Balk as structureless salt, and (3) the fact that much of the new mine area contains purer salt than do the old workings.

General features.—Blocks of the salt are white to light gray crystalline aggregates of halite and minor anhydrite. Although most of the anhydrite grains are clear and colorless, their presence darkens the salt. Two analyses of the salt, reported by Balk, show that nearly 99 percent is sodium chloride; the remainder is nearly all anhydrite, with lesser amounts of gypsum, calcite, and sodium sulfate. Microscopic study by Balk demonstrated that only a minor amount of gypsum is present; he also observed two grains of dolomite(?).

The salt aggregate is composed of clear, colorless halite with no strain birefringence. Balk demonstrated an elongation of the salt crystals so that the vertical axis is 1.59 x either horizontal axis (average grain 5 by 5 by 9 mm). The anhydrite grains are also elongated upward. The orientation of salt crystals in single specimens and in related specimens along a fold and in comparable positions on several folds is now under investigation to determine if there is any correlation between shape and lattice orientation of the salt and the gross structure of the folds within the dome.

Balk also recognized crystals as much as 6 inches on a side which are always found within areas of what he termed compact salt (clear, massive salt with no observable anhydrite layers). In the new workings, on the other hand, there are areas of giant salt crystals (Pl. III, C; Pl. IV, A). Here light reflects from parallel cleavage planes over areas covering several square feet—some of these giant crystals are as much as 5 feet long and 3 feet wide (Pl. I, map coordinates S10–11, P3–04, M2-N4). Coarse salt with crystals showing cleavage faces up to 6 inches on a side are abundant in the southwestern portion of the new workings (Pl. I, D-G, 2–3). The giant crystal salt is restricted to a few very pure beds defined by enclosing parallel anhydrite layers. The very coarse salt in the southwest part of the mine may be in the same part of the stratigraphic section as the giant crystal salt, although precise correlation could not be accomplished across the mine. The largest coarse mass observed is 9 feet wide, 22 feet high, and more than 100 feet long (Pl. I, P3–04). Most of the mass is nearly optically continuous, although not a single crystal. These giant crystals generally have a cube edge upward (optimum orientation for translation gliding on the dodecahedral glide planes within the salt lattice). Some of the giant crystals break along dodecahedral glide planes or with conchoidal cleavage rather than along the familiar perfect cubic cleavage. A 300-pound single crystal was carved out of the giant crystal bed (Pl. I, S10) and is now on display at the main offices of the Morton Salt Company in Chicago.

Layers.—The most obvious feature of the salt is a layering caused by bands of salt containing concentrations of small (0.1-mm) anhydrite crystals (Pl. IV, B, C). These crystals are separate entities surrounded by the salt, and the fact that they absorb light more than the salt gives the layer a darker gray color. The darker the layer, the higher the concentration of anhydrite; the darkest bands containing as much as 15 percent anhydrite. These alternating bands of pure salt and anhydrite-rich salt are believed to be beds now deformed from their original horizontal depositional position. All interpretations of structure in salt are based on this belief.

Folds.—The layers have been strongly folded. The folds have been tipped on end by the upwelling of the salt into the dome so that the walls show only nearly vertical streaks and the contortions of the folds are best seen on the ceilings (Pl. II, D; Pl. IV, B; Pl. V). The map (Pl. I) shows the position of the anhydrite-rich beds and demonstrates their intricate folding. To the southwest the major folds become more attenuated and more compressed (Pl. I, J12–05). The new workings have exposed a systematic arrangement of folds whose axial planes trend in a southwesterly direction and approach parallelism near the southern edge of the dome a few hundred feet south of the southernmost workings.

The trace of the axial planes in the mine levels (fig. 1) changes strike radically along a relatively straight east-trending line (Pl. I, Ml–10) from a southwest to a northwest direction. This line may coincide with a former fracture in the overlying sediments which localized the upwelling of the salt. The fold trends at D3–5 (Pl. I) suggest another change in strike along an east-west line. (See also fig. 2.)

Toward the southwest, the zig-zag patterns along the axial portions of each fold are progressively more difficult to observe and appear to increase in amplitude. These patterns are shear folds caused by plastic failure of the salt in narrow closely spaced bands which are spaced about one-fourth to one-half inch apart. The shear folds have amplitudes that vary throughout the mine (Pl. II, C; Pl. III, A, B). In some places the amplitude is only a matter of inches; in others, the limbs of the Z-patterns extend for 5 or 10 feet before the bed turns back on itself. At M10 there are no visible shear folds and thus it appears that the salt has deformed by flowage, rather than along closely spaced slip bands.

Axial planes of all the shear folds are parallel to the axial planes of the main

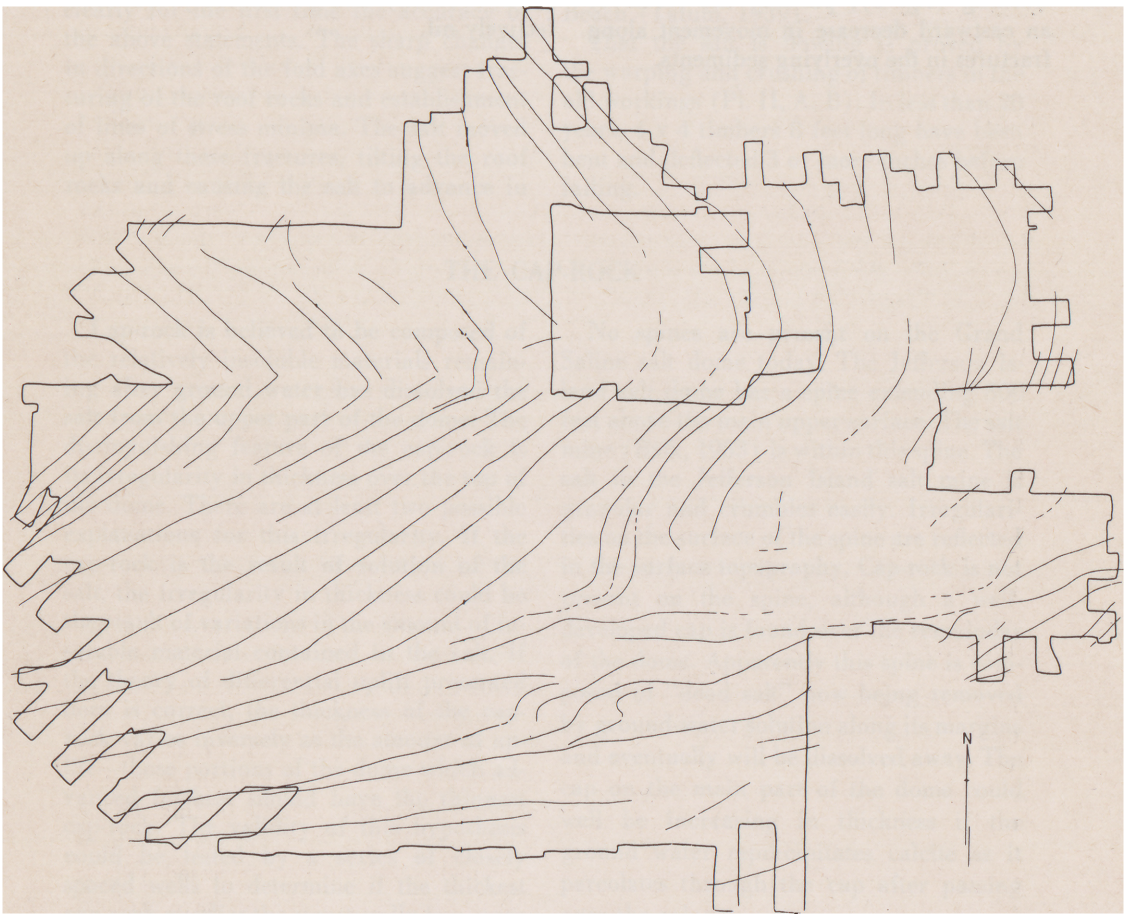

FIG. 2. Trace of axial planes of folds in the mine levels. Note the angular change in strike along an east-trending line, in the northwest part of the mine. Suggestions of other radical changes in strike along other east-trending lines are shown in the south-central and east-central parts of the mine. These lines may reflect fractures in the overburden which localized the upwelling of the salt mass.

folds no matter what changes in strike occur along the main folds (Pl. III, A).

A few closures can be found in the map area (Pl. I, F11, E12, E13, D14, 020). These represent either the highest part of an anticline or the trough of a syncline (Pl. II, D; Pl. VI). Usually it is impossible to determine which type of structure an individual closure is.

In the southern two-thirds of the map area all the major folds plunge steeply southwest (usually 70 or more degrees). In the northern third, the plunges are to the southeast except for the western segment which plunges northwest. The strike change is a smooth curve in the old workings and a sharp angular change in the new working (fig. 2), possibly the result of an eastward decrease in movement along fractures in the overlying sediments.

Negative structural features.—Balk has called attention to the absence of certain structural and mineralogical features in this mass. His observations were confirmed in this study and have an important bearing on interpretation of the origin of the dome:

(1) There are no fractures or faults within the mine.

(2) Layers do not cross each other.

(3) There is no minor gas present.

(4) No inclusions of wall rocks are present.

(5) Halite and anhydrite are the only common minerals.

(6) Porosity and permeability are effectively nil.

MODE OF UPLIFT

The fact that salt flows plastically under relatively small stress differences has been known for many years. Model studies show domes rising like a smooth bubble toward the surface. Balk (1949, p. 1815) said:

> The roof of a rising salt dome is not a smooth, trumpet-like surface, but more probably, a multitude of irregular salients, recesses, and sags, regardless of whether the roof yields by bending, or complex faulting. Each irregularity of the roof is likely to give rise to fields of greater or lesser shearing stresses, and thus should generate velocity differences between individual groups of salt layers.

The present mapping demonstrates clearly for the first time the accuracy of the above statements. The sharp changes in directions of the fold axes suggest fracturing of the roof rocks and establishment of lines of stress minima. The salt moved up along these fractures, tilting the roof rocks and causing the salt to advance in spines rather than as an entity. The attenuation of the folds suggests that the salt in the northeast part of the map area moved up farther than that in the southwest.

If the salt moved up as individual pencils or spines, then this would easily explain the inclusions of sedimentary materials found in the salt mass in such domes as Jefferson Island (Balk, 1953) and Bayou des Glaises (Woods, 1955) and in the cap-rock of other domes, for example, Raccoon Bend (McLellan, 1946), South Liberty (Morrison, 1929), McFaddin Beach (Tatum, 1939).

That the salt is flowing is proved by the warping and crushing of timbers in the old workings (Pl. II, A, B). In less than 20 years, 4 x 4 timbers 8 feet long have been bent and deflected 3 or more inches before failing.

THE CAP-ROCK

Cap-rock is believed to be composed of the relatively insoluble materials remaining after ground water has dissolved the salt from the upper part of the dome. The distinguishing feature of the cap-rock is its irregularity in thickness over the top of the dome. There are at least two possible explanations for this irregularity. If the cap-rock is the result of solution of the salt, the irregularity in thickness could be the result of variations in the amount of insoluble material contained in the salt. If the theory of differential uplift presented here is correct, the thickness of the cap-rock varies inversely as the amount of uplift—those portions of the dome which advanced farthest should have the thinnest cap-rock. The validity of this hypothesis could be tested by a series of closely spaced wells to determine if the thickest cap-rock overlies the structurally low areas of the dome.

No spines are present on the Grand Saline salt dome today. The Jefferson Island salt dome has a spine extending 800 feet above the main upper surface. The salt mine (Balk, 1953) is within this spine. The salt in the Jefferson Island salt mine is granular and crumbles easily. Irregularities on the surface of the spine are reflected in the surface topography. Cap-rock is not present on the spine, although a well-developed cap is found over the remainder of the dome. Apparently this spine is composed of "dead salt" now being removed by ground-water solution along its margins and eventually will be dissolved away. The cap on the main part of the dome could well be increasing in thickness if the ground water reprecipitates calcite as it percolates through the cap after passing over the spine.

SUMMARY

Grand Saline salt dome, which lies about 65 miles east of Dallas, Texas, is about 8,000 feet in diameter at the top and at least 15,000 feet high. Morton Salt Company's Kleer mine has, since 1947, more than doubled in size, total workings now being approximately 3,000 by 1,800 feet in plan, all lying in the southern quadrant of the dome. Some of Balk's (1949) principal conclusions, based on his study of the pre-1947 workings, are:

(1) Layers of salt near the southeastern border of the dome dip steeply southeast and south, presumably parallel with the dome border. Elsewhere the layers form intricate systems of folds.

(2) The axes of all folds plunge nearly vertically.

(3) Anhydrite and halite display a linear habit and are elongated parallel to the nearest fold axes.

(4) The absence of any fractures, faults, cross-cutting salt layers, foreign inclusions, and brine indicate an undisturbed evolution of the deformation structure in a nearly homogeneous, layered salt mass.

The present study has expanded the mapping to include the new workings. It confirms Balk's conclusions and, in addition, demonstrates the following:

(1) The structure of this dome is not radially symmetrical. Consequently, this dome probably rose as a series of spines.

(2) If the dome rose as spines, then the thickest cap-rock areas could be due to solution of (1) either nearby structurally high spines, or (2) salt rich in anhydrite, calcite, etc., or (3) both.

(3) Radical changes in attitude of the axial planes of folds occur along east-trending vertical planes. These planes possibly represent zones of failure (faults?) in the overburden.

(4) Attenuation of folds is observed as the perimeter of the dome is approached.

(5) Beds of giant salt crystals exhibit cleavage faces several feet on a side.

(6) Crushing of timbers in abandoned tunnels indicates a rate of plastic flowage into the tunnel on the order of 0.1 to 0.2 mm per year (at a depth of about 700 feet below the surface).

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REPORT OF INVESTIGATIONS
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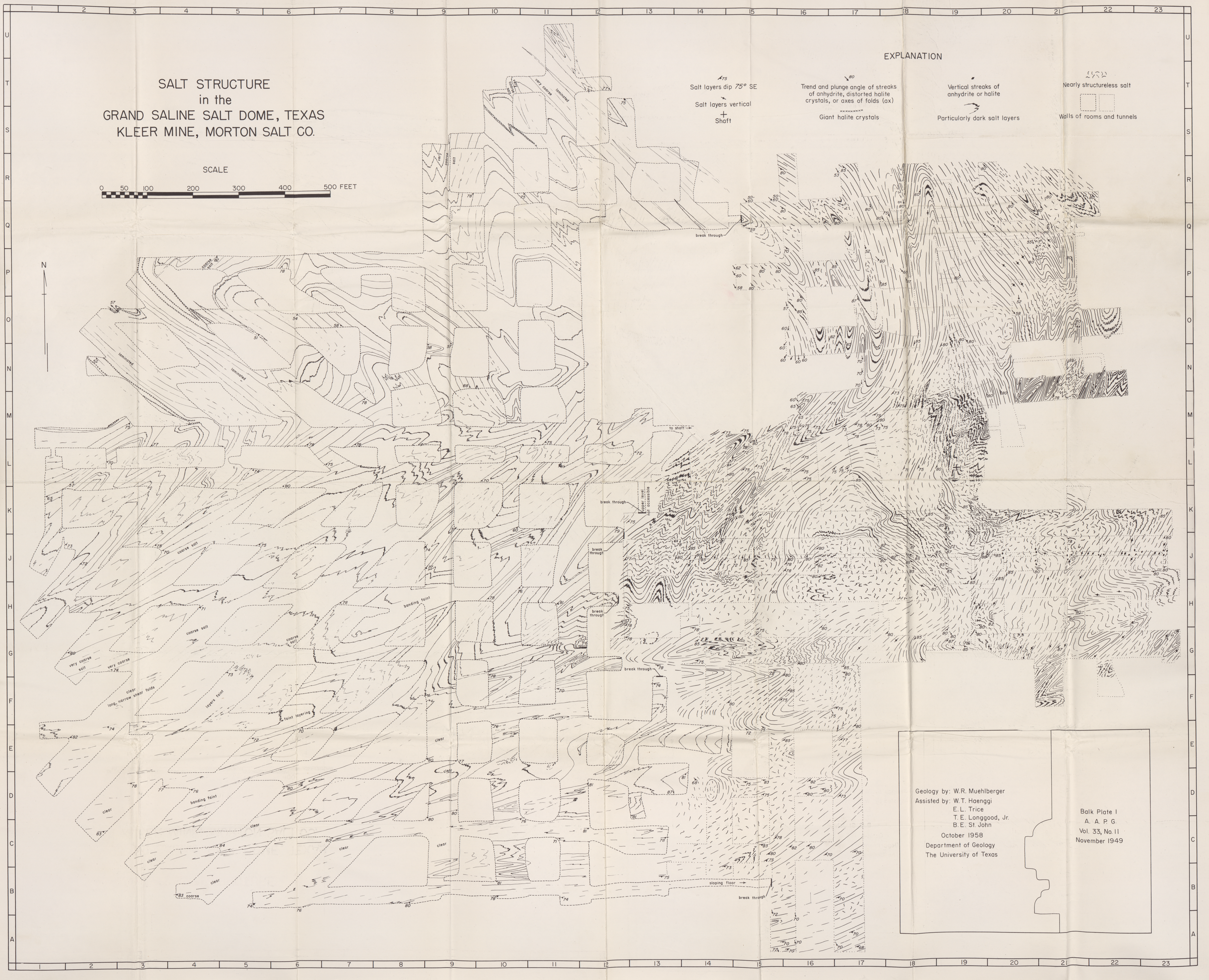
PLATE I



Plates II–VI

PLATE II

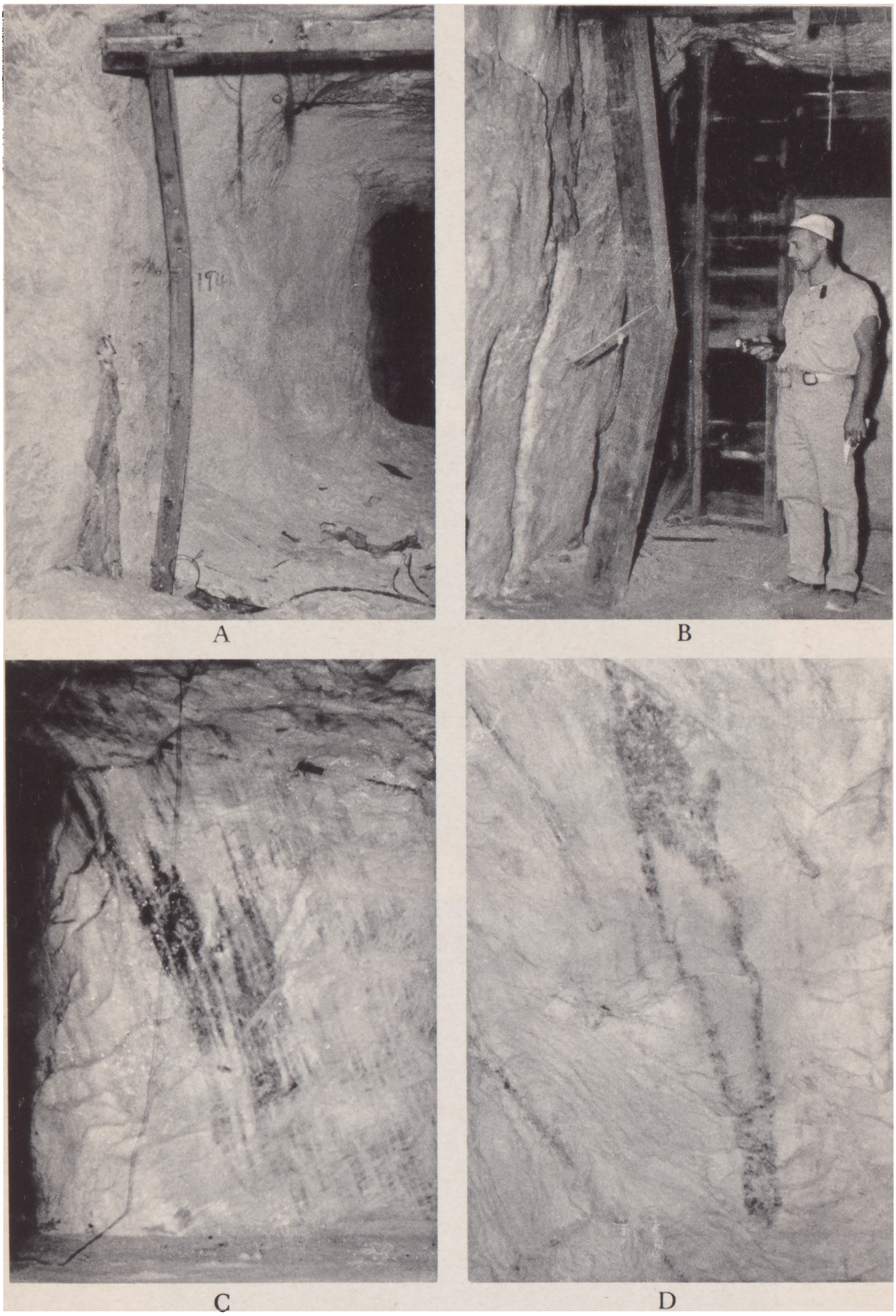
Evidence of plastic flow of salt, shear folds, and closed folds

A. Warped 4 x 4 timber support near H19. This timber is about 10 feet long and has been in place over ten years.

B. Buckled 8 x 8 timber support near J19. Notice 2 x 4 brace on crushed timber of wooden wall. Timbers have been in place at least ten years.

C. Intricate shear folding on wall at L9. Height of face about 25 feet. Individual salt crystals form the tiny light-reflecting areas.

D. Small closure exposed in ceiling at F11. Total length about 10 feet.



A B

C D

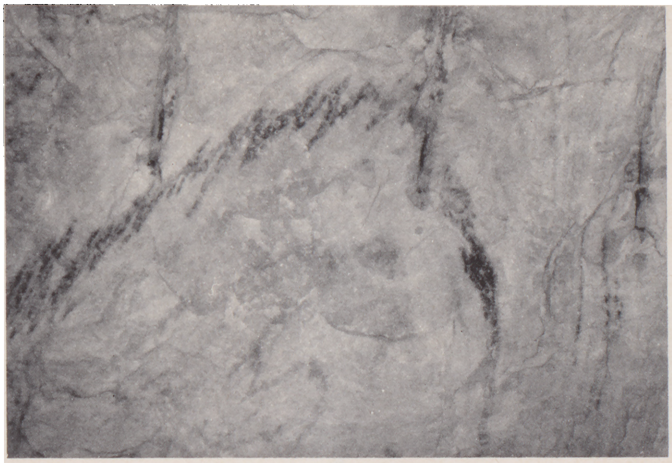
PLATE III

Shear folds and giant salt crystals

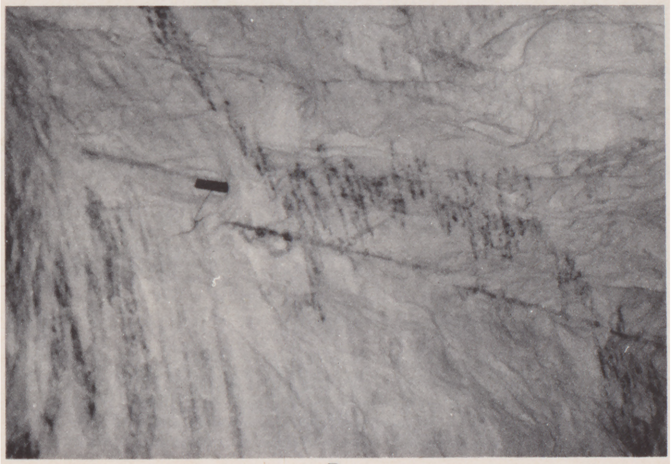
A. Shear folding in axial region of fold near M10. This shearing is always parallel to the axial plane of the fold.

B. Shear folding outlined by anhydrite-rich dark layer near G11.

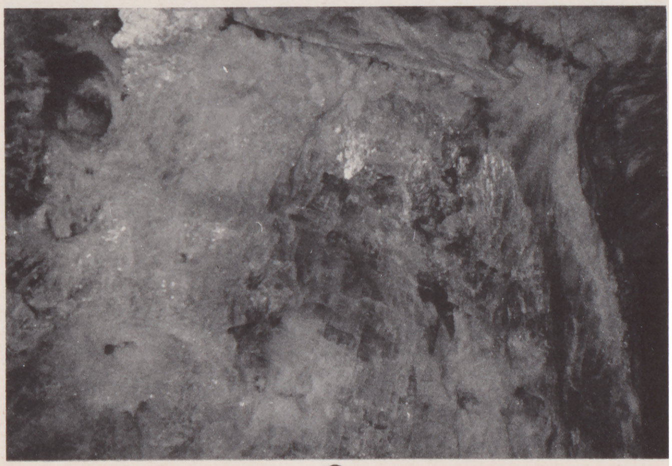
C. Giant salt crystals at S10. Drill hole near upper margin is about 6 feet long. Parallel traces of cleavage give estimate of size. Dark area in center is part of one crystal.



A



B



C

PLATE IV

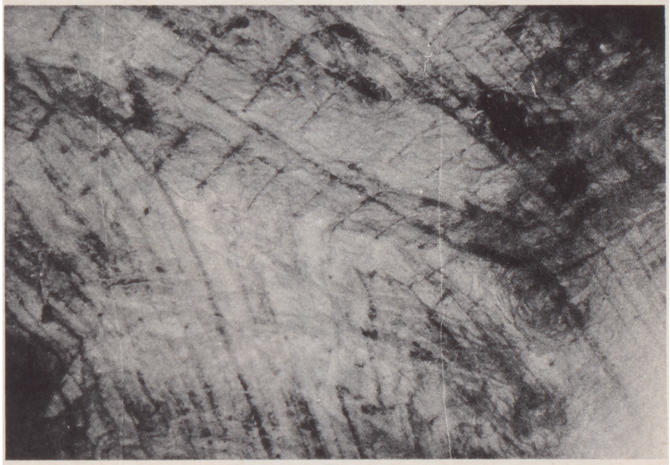
Giant salt crystals and salt structures

A. Giant salt crystals at S10. Central area of Plate III, C.

B. Northeast corner of room at L15. Shot holes are 6 to 8 feet long and mark the junction of the ceiling and the east wall. Notice fold axis extending diagonally downward across photograph from upper left corner.

C. West wall of room at L15. Tunnel in lower right is same as tunnel in lower left of photograph B. Nearly vertical banding caused by alternation of anhydrite-rich (dark) and anhydrite-poor salt.

A



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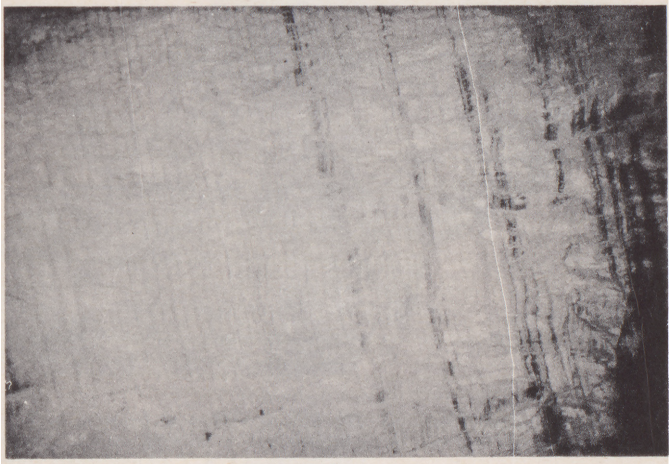
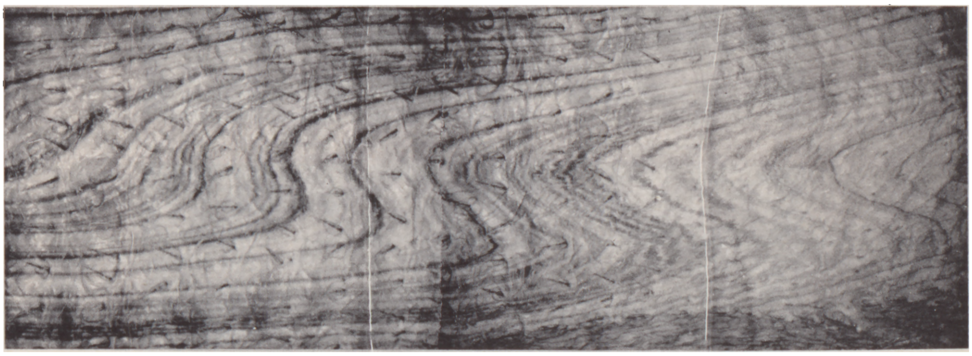


C



View of folds exposed in ceiling of room at PQR18 (Pl. I). Ceiling is nearly 130 feet above observer. Short straight lines are 8-foot drill blast holes. The changing shape of folds in the salt mine is excellently shown in this example.

Refolded closed fold exposed in ceiling at E13 (Pl. I). Axial plane cleavage shown by shear folds has been folded into an arc parallel to the elongation of the fold. Length of fold shown is about 35 feet. (Photomosaic assembled by T. E. Longgood, Jr.)

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