Investigation of Solution Collapse Breccia in Mature Salt Cavities

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ABSTRACT

Man-made and natural-occurring solution collapse breccia, the result of salt cavity roof failure and insoluble ledge collapse, has been investigated at WYANDOTTE CHEMICALS CORPORATION's Michigan underground storage, waste disposal and solution mining operations. Wireline caliper, gamma ray/neutron and sonar logs show the progression of insoluble ledge collapse, debris accumulation on lower insoluble ledges, and the beginnings of cavity filling by rubble during development of an underground LPG storage facility in the "B" salt of the Michigan Salina. A television survey of a hole drilled through the rubble of a mature salt cavity intended for subsurface waste disposal revealed bulking by "sidewalk" size slabs of rubble and very little open hole. Comparison is made with outcrops of breccia found in the Mackinac Straits area which is thought to have a similar mode of origin.

A solution collapse structure, whose origin is believed to be contemporaneous with the deposition of the "B" and "C" units of the Michigan Salina, occupying an area of approximately 40 acres, has been investigated. Core samples and wireline logs from wells located in this structure show removal of approximately 200 feet of salt from Unit B of the Salina group. Bulking by collapsed insoluble ledges in the "B" salt section and approximately 50 feet of overlying Unit C roof rock, plus a thickened undisturbed Unit C dolomitic shale-anhydrite section account for the volume of salt removed. A structure map on top of Unit C shows little or no evidence of the underlying solution collapse feature, thus dating this event.

It is thought that within reasonable limits, bulking will stabilize a salt cavity and thus serve to protect the overlying section from destructive subsidence. Additional work is required to determine the relationship between salt extraction, cavity bulking and subsidence. This will serve to define the limits of safe extraction for salt well systems.

INTRODUCTION

The occurrence of solution collapse breccia is not an uncommon phenomenon; published observations of this breccia type appear throughout the literature. However, inasmuch as geologic processes operate within the expanse of geologic time, these reports are for the most part "after-the-fact" reconstructions of the solution collapse brecciation process. At Wyandotte Chemicals Corporation, in our underground storage, disposal and solution mining operations, we have provided the conditions necessary to create a man-made solution collapse breccia in the layered salt of the Salina group in Michigan. In this study, we will present some observations on the brecciation process, comparing man-made breccia with outcrops of solution collapse breccia on Mackinac Island and with a natural-occurring breccia found in our brine field on Grosse Ile, Michigan.

ACKNOWLEDGEMENTS

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MAN-MADE BRECCIA

A series of wireline surveys made in connection with the development of an LPG storage cavity in the B unit of the Salina group is shown in Figure 1. At the far left is a portion of a gamma ray/neutron log. Excursions to the right represent salt layers, and to the left, shale-bearing dolomite and anhydrite-bearing dolomite. In the middle of Figure 1 are three 36 inch caliper logs, the first of which was run after removing about 440,000 cubic feet of salt and the last run four months later after having removed an additional 160,000 cubic feet. Solution of the salt was accomplished by tubing injection through a series of nozzles set at 1284 feet, with a nitrogen pad used to prevent roof scalping.

The caliper log, within the range of its arm expansion, delineates zones of solution, collapse and debris accumulation. The first caliper log shows three ledges at 1138, 1157 and 1186 feet; salt and insoluble rock between these ledges appear to be washed out. The second caliper log run one week later shows the ledge at 1138 feet to be still in place . . . probably the result of nitrogen padding, and the ledge at 1157 feet to have collapsed, with debris accumulating on the ledge at 1186 feet interpreted by observing the ledge to have moved up hole. A portion of a sonar survey (vertical and horizontal scales are equal) run on the following day is shown at the far right of Figure 1. It agrees favorably with the second caliper log in that it reflects cavity and ledges. The sonar survey, because of its greater range, shows that the collapse at 1138 feet extends some 17 feet out from the cavity's center, whereas the caliper could not show collapse beyond the range of its 36 inch arms. However, where the second caliper log shows the beginnings of solution between the ledges at 1186 and 1193 feet, the sonar survey shows none. This serves to delineate the lower end of the sonar sensitivity range and that the caliper log may depict incipient ledge undermining to better advantage. The third caliper log shows the ledge at 1138 feet is in place, but collapse of the ledges at 1186 feet and 1193 feet has occurred with debris accumulating on the ledge at 1220 feet. The third caliper log also picks up rubble in areas which were shown to be open hole in the second caliper log. Insofar as the nozzles were set at 1284 feet, we assume that below this depth to the bottom of the salt are open hole and rubble filled cavity. As more salt is dissolved out, we would expect the cavity to fill with rubble. That this does indeed happen was borne out in a waste disposal project initiated in 1966.

Two disposal wells were drilled through the Salina Unit B in an attempt to locate large brine filled cavities into which could be disposed a 6% solids-bearing lime waste slurry. Wellsites were located in an abandoned brine field which had been in operation for more than 50 years. However, neither well showed the expected sizeable cavity. Instead, the 200 foot thick Unit B was found to contain only rubble-filled cavity and broken formation. The only sizeable open hole observed was in the 30 foot thick salt-bearing Unit D. Here, two cavities were found separated by a four foot thick dolomite ledge. A television survey was run in an attempt to evaluate the character of the rubble. The survey permitted an examination in a straight down view of the floor of one cavity in Unit D as illustrated in Figure 2. In this figure, we are looking down into a cavity into which is suspended a television camera which "sees" its boom extension and light source. The rock cavings appear to be large angular blocks, resembling slabs of broken sidewalk.

COMPARISON WITH MACKINAC BRECCIA

The angular blocks of cavity debris are similar in appearance and probably too in origin to some of the solution collapse breccia found in Michigan's Mackinac Straits region. Geographically located at the northern end of the Lower Peninsula, the Mackinac Straits are geologically located at the rim of the Michigan basin. As reported by K.K. Landes (1945), the Mackinac breccia is caused by the dropping of rock fragments into cavities formed by the solution of the Salina salt. (In this region, Pointe aux Chenes formation is the equivalent surface term for the Salina.) Ground water is theorized as the agent of solution. The Mackinac breccia differs most from that of the man-made breccia at Wyandotte in that portions of the Mackinac breccia contain blocks from overlying formations. The Wyandotte man-made breccia is intra-formational containing blocks only of the Salina Group. Within the Salina itself, there is no evidence to suggest that Unit C extensively fragmented and dropped into Unit B, or that Unit E has largely filled the cavity of Unit D. This difference between the two breccia types is probably only a reflection of solution intensity and not mode of origin.

In terms of cementation, the Mackinac breccia can be classified as being either uncemented porous, uncemented—composed of dolomite fragments imbedded in a shale matrix, and indurated with a calcium carbonate cement. A study of the

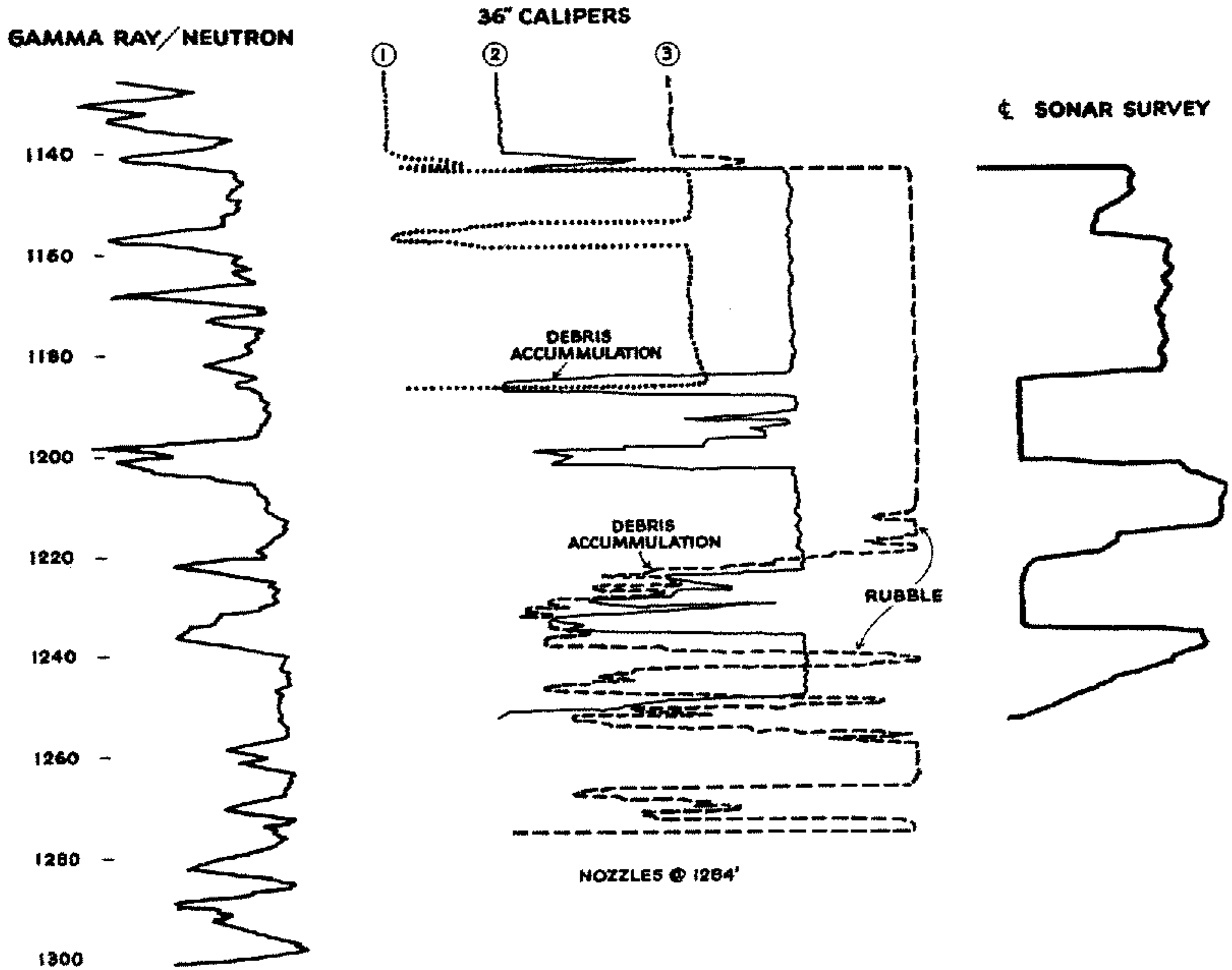

Figure 1. Progression of solution, insoluble ledge collapse and debris accumulation in a cavity being developed for underground LPG storage as shown by wire line surveys.

Figure 2. Straight down view of rubble on cavity floor as shown by television survey.

Wyandotte man-made breccia cementation is found in an unpublished report of Carl A. Bays & Associates to the Wyandotte Chemicals Corporation. Bays discusses the composition of fine grained cavity debris samples recovered with a cable-tool core barrel as being of three types:

> (1) Platy soft white gypsum with gray, fine-grained subrounded dolomite cemented by fine-grained gypsum; (2) small to inch-large fragments of dark and light gray dolomite with a gray shaly mud binder, cemented with soft platy gypsum; and (3) coarsely crystalline transparent euhedral gypsum intermixed with a gray shaly mud. Because solution is confined to the Salina, and the Salina at Wyandotte contains no calcium carbonate, we would not expect to find a calcium carbonate cement. In the Mackinac breccia, ground water contains dissolved calcium carbonate and it accounts for the cement found in the rubble.

It is felt that within reasonable limits, bulking of a cavity with debris serves to protect the overlying section from destructive subsidence. Beyond a certain point, however, the continued removal of salt will result in an interformational breccia, such as found in portions of the Mackinac breccia where blocks of the Bois Blanc Formation are found in cavities dissolved in the Salina. Additional work is required to determine the relationship between salt extraction, cavity bulking and subsidence.

SOLUTION COLLAPSE STRUCTURE FOUND ON GROSSE ILE

A solution collapse structure, thought to be older than the Salina Unit D, involving the "B" and "C" units of the Michigan Salina has been investigated. Within a 40 acre area "B" salt thins from about 190 feet to less than 20 feet and the thickness of the overlying insoluble unit (Unit C plus "B" rubble) increases from 140 to more than 290 feet. A structure map on the base of Unit B (Fig. 3) shows a slight dip to the north and little structural relief. A structure map on the top of the "B" salt (Fig. 4) shows the salt to be deeply sculptured by solution, thought to have occurred during "B" and "C" time. Within the area shown by our data points, we can see one distinct channel; others probably lie outside of the area covered. This channel has its "head" in the down dip direction implying, in this area, subterranean updip solution. A structure map on the top of Unit C (Fig. 5) shows little relief, the deeply sculptured "B" salt being filled in by the time that Unit D was deposited, thus dating this event as being contemporaneous with Units B and C, but older than Unit D. A core taken in the middle of the solution feature shows intense brecciation for a distance 90 feet above the salt top. Figure 6 shows an example of the breccia. The groundmass varies, but in Figure 6 it is largely a shale-bearing dolomite with sub-angular to subrounded fragments of dolomite and anhydrite. Some of the dolomite fragments are pitted or are wafer-like where interbedded salt has been leached out. These fragments are probably remnants of insoluble stringers which are common in Unit B. Fifty feet of this breccia is clearly Unit C, the remainder being jumbled Unit B rubble. The fifty feet of Unit C has retained its gamma ray/neutron identity and is readily traced throughout the solution structure, its thickness being constant. Brecciation stops in a ten foot thick breccia bed in Unit C. Above this bed is a thickened Unit C (shaly-dolomite with minor anhydrite) section.

Cross bedding and cut-and-fill structures are found indicating a shallow water depositional environment. A structure map on top of the uppermost brecciated anhydrite mirrors Figure 4, top of the "B" salt. This infers that intensive solution did not begin until the uppermost breccia anhydrite bed was deposited.

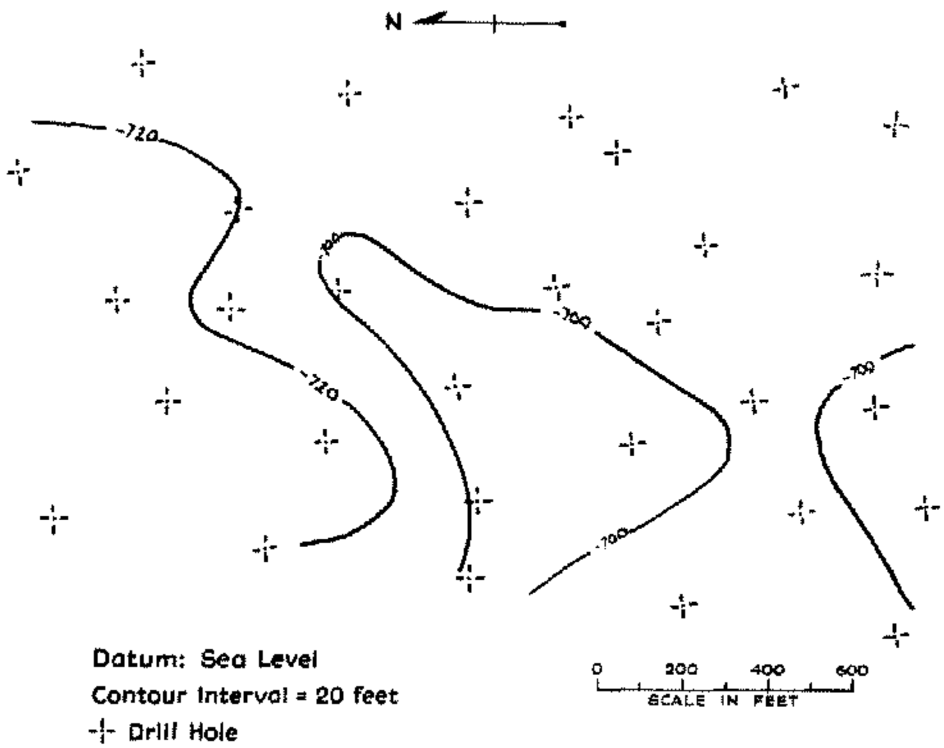

Figure 3. Structure map on base of Salina Unit B showing little structural relief and a slight· northerly dip.

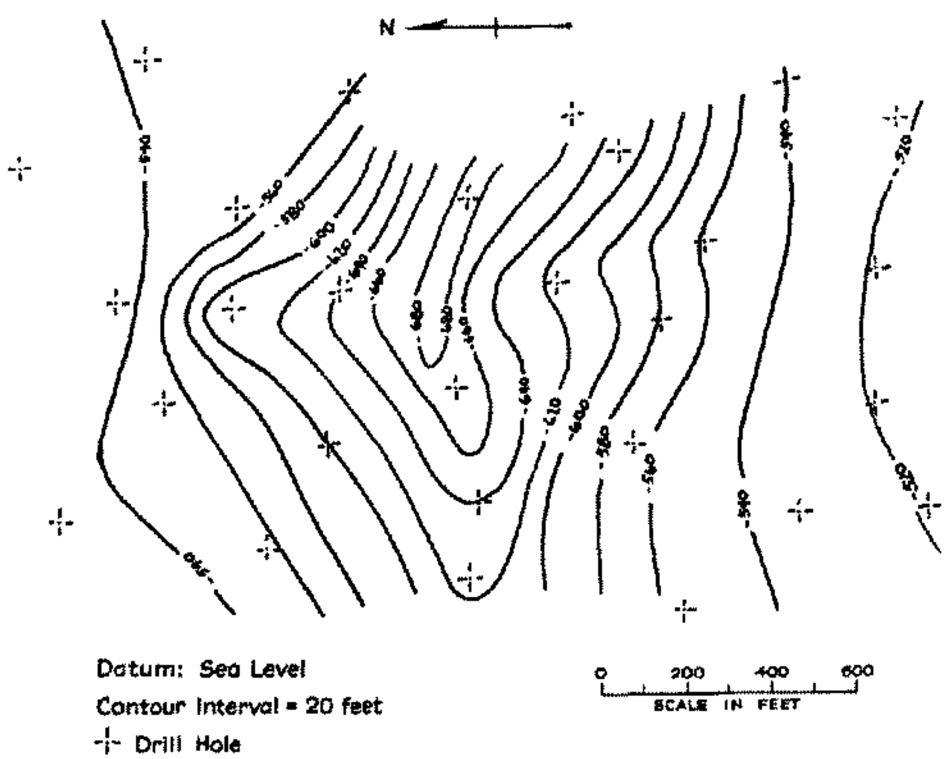

Figure 4. Structure map on top of Salina Unit B salt showing solution structure.

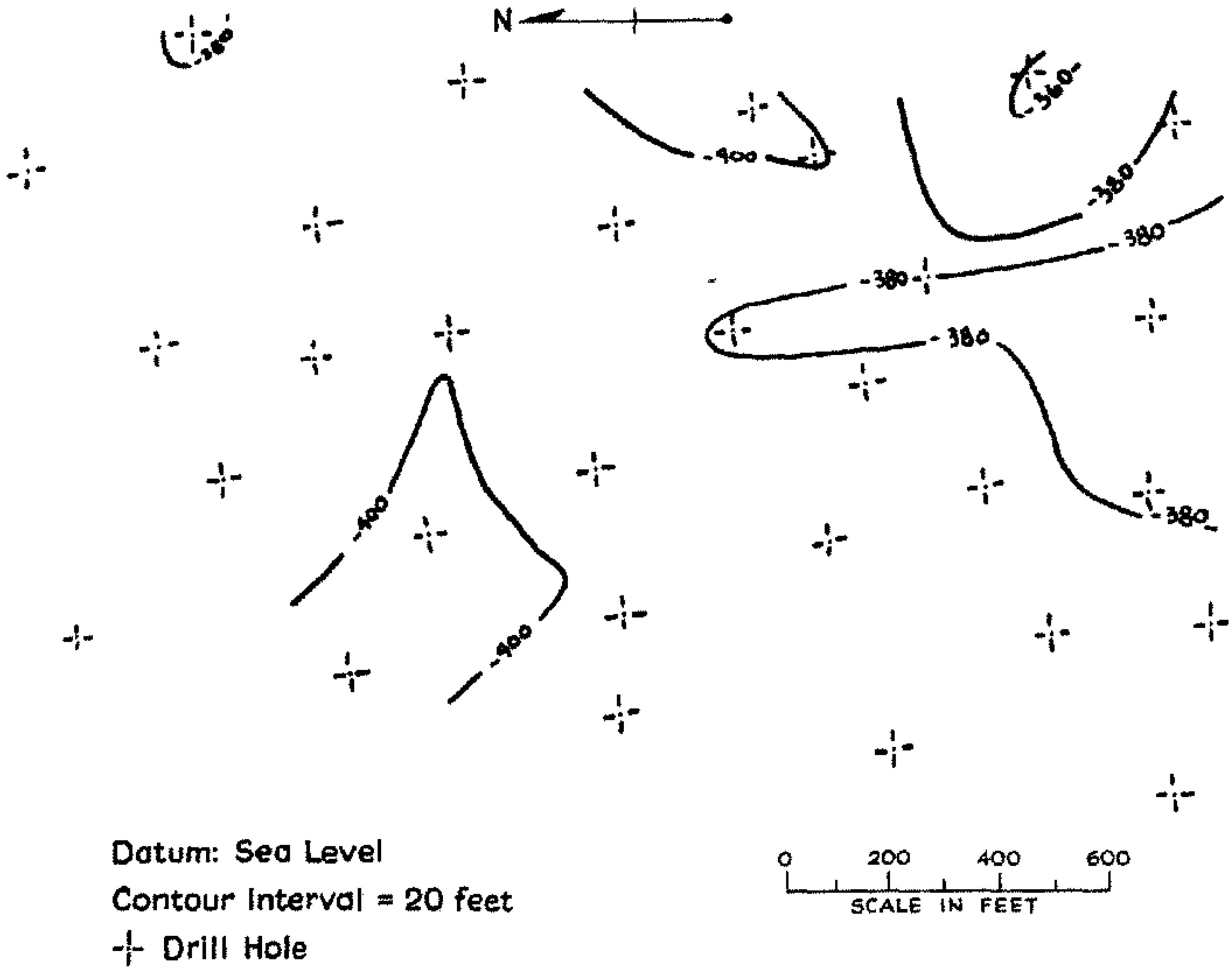

Figure 5. Structure map on top of Salina Unit C showing little structural relief, dating "B" salt solution structure as being older than Unit D.

SUMMARY

In this report, some of the processes that cause solution collapse breccia have been presented. The progression of insoluble ledge collapse and debris accumulation within a man-made cavity have been demonstrated. It has been shown that a cavity can be filled with rubble, impeding the onset of destructive subsidence, and comparisons have been with the natural-occurring Mackinac breccia where continued solution led to the dropping of blocks of overlying formations into cavities developed within the Salina Group. A natural-occurring solution feature has also been discussed, in which salt solution was compensated for not by dropping of latter deposited blocks, but by cavity rubble and a compensating increase in thickness of the overlying sedimentary unit.

REFERENCES

Landes, K.K., Ehlers, G.M. & Stanley, G.M., 1945, Geology of the Mackinac Straits region. Michigan Geol. Surv. Publ. 44, Geol. Series 37, 204 p.

Figure 6. Example of solution collapse breccia as shown by core cut in drill hole located in the center of solution structure.