Effects of Solution of Bedrock Salt in the Earth's Crust

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ABSTRACT

Solution of rock salt lying near the surface by percolating water in recent times has resulted in surface brines, salt caves, and collapse features. Examples of surface brines are salt springs, saline rivers, and salt lakes, such as Great Salt Lake and the Dead Sea. Surface collapse along the leached eastern boundary of the Kansas salt basin is still taking place.

In past geologic time there were similar solution phenomena, and collapsing resulted in great accumulations of breccia. Perhaps the most spectacular, and certainly the most accessible, example of this is the Mackinac breccia exposed in the Mackinac Straits region of Michigan. Here indurated collapse breccia has been eroded into prominent spines and stacks.

The cause of the collapse was the leaching of Salina salt on the north basin rim in early Devonian time. The collapsing involved hundreds of feet of stratigraphic section and covered many square miles. Non-indurated breccia and megabreccia, produced by the let-down and tilting of great slabs of rock, are of greater quantitative importance than the indurated breccia.

INTRODUCTION

Salt of oceanic origin can occur above sea level in at least four ways: (1) by uplift (relative) of marine sediments containing rock salt beds; (2) by upward intrusion of salt masses ("salt domes") under pressure; (3) through transport by wind; and (4) in solution in connate water in uplifted sediments. In this discussion we are concerned primarily with rock salt, and what happens when it comes into contact with undersaturated water. Surface brines are one result, and caves and cave roof collapse are another.

BRINE SPRINGS

Brine springs were known and exploited in prehistoric times. Some are the result of the draining out from rocks elevated above sea level of the connate water originally deposited concurrently with the sediment. Others, however, are due to contact of circulating ground water with bedrock salt which has lost its protective cover by erosion. Many of the early salt domes discovered in the Gulf Coast region were found by the presence of salt springs at the surface. A line of salt springs with chloride concentrations ranging from 20,000 ppm to more than 200,000 ppm in northwestern Texas and western Oklahoma occupies the outcrop belt of salt-bearing middle and upper Permian rocks. It has been concluded that the eastern margin of the Permian salt in this area is a leached boundary. (1) Many other examples of salt springs due to the solution of shallow rock salt bodies could be cited.

BRINE STREAMS

In humid regions salt, due to its high solubility, does not crop out, but the truncated edge may lie at a shallow depth hidden by a veneer of soil, alluvium or other mantle rock. Rivers crossing such hidden salt edges become contaminated by the salt or by the overlying saturated ground waters. A good example of this is the Arkansas River in south-central Kansas which immediately to the east of Hutchinson crosses the solution truncated edge of the westward dipping Permian salt measures. As it does so, its chlorinity content becomes increased many fold.

Elevation above drainage will permit meteoric water to flush saline connate water out of the containing rocks and into the surface drainage. However, the period of time during which this type of brine enrichment of surface water takes place is probably a short one.

BRINE LAKES

This discussion will be confined to interior lakes which are not residual bodies of cut-off sea water. The drainage basin of many salt lakes contain known deposits of rock salt of original oceanic origin, and it is the thesis here that the solution of the bed rock salt resulted in the saline lake water. Great Salt Lake in Utah has to the south salt beds close enough to the surface so that they can be exploited by strip mining. Eardley (2) has stated his belief that these salt deposits "which crop out extensively in Sanpete Valley within the Great Salt Lake drainage area" have contributed to the salinity of Great Salt Lake. The deepest part of Death Valley is floored by a salt crust and here again to the south within the drainage basin are the Avawatz Mountains with bedded salt deposits (Figure 1). The southern end of the Dead Sea is notable for a salt-cored ridge, Jebel Usdum, rising 821 feet above the sea and extending for a distance of seven miles (Figure 2) which contains an enormous volume of rock salt. (3) Every rain which falls on this salt must result in more sodium and chlorine ions entering the sea at the mountain foot. Mrs. Lot, incidentally, is an erosional spire on the top of the ridge. Bedded salt deposits occur elsewhere in the Dead Sea drainage basin as well.

Salt lakes may also receive sodium chloride from connate waters flushed from the sedimentary rocks lying above drainage in the basin. However, a point to remember is that the time during which connate waters drain from their original habitat, and the time that it takes surface and ground waters to leach a salt body lying above drainage are both relatively short. Furthermore, the volume of brine moving lakeward even during the salt enrichment phase is highly variable, depending upon rainfall and water table levels within the watershed. Therefore, salt lake age and other conclusions drawn from analyses of currently entering waters are highly suspect. Without doubt many salt lakes, including Great Salt Lake and the Dead Sea, received the greater part of their sodium and chlorine ions and at a much higher rate, before man and his test tubes arrived on the scene.

OTHER THEORIES OF BRINE ORIGIN

Abundant evidence exists that sodium and chlorine ions can be carried by the atmosphere as well as by running water. These elements are washed out of the air by rain in humid areas, and are deposited by dry fall out where precipitation is less abundant (13). In either case the ions which reach the surface are subject to pick up by rain wash and running water, so contribute to the salinity of streams and lakes. The original source for this salt also is the ocean. It gets into the atmosphere in at least two ways: (1) directly from the ocean through the evaporation of spray; and (2) wind pick up of salt precipitated on playa floors. Salt of the first type is of course most abundant in coastal areas, but nonetheless it can travel many miles inland. Playa salt is oceanic salt that has been recycled at least once. The same arid conditions that bring about its precipitation also make it vulnerable to wind transportation. Strong winds sweeping across desert floors cannot only pick up this salt and carry it long distances, but they can also transport it uphill and over divides into basins lying at higher elevations, which is something that running water cannot do.

The classic hypothesis of salt lake and playa origin is that the sodium ions are the result of rock weathering (especially soda feldspar) whereas the chlorine comes from both rocks and volcanic emanations. But chlorine is a rare element in the primary minerals of the earth's crust

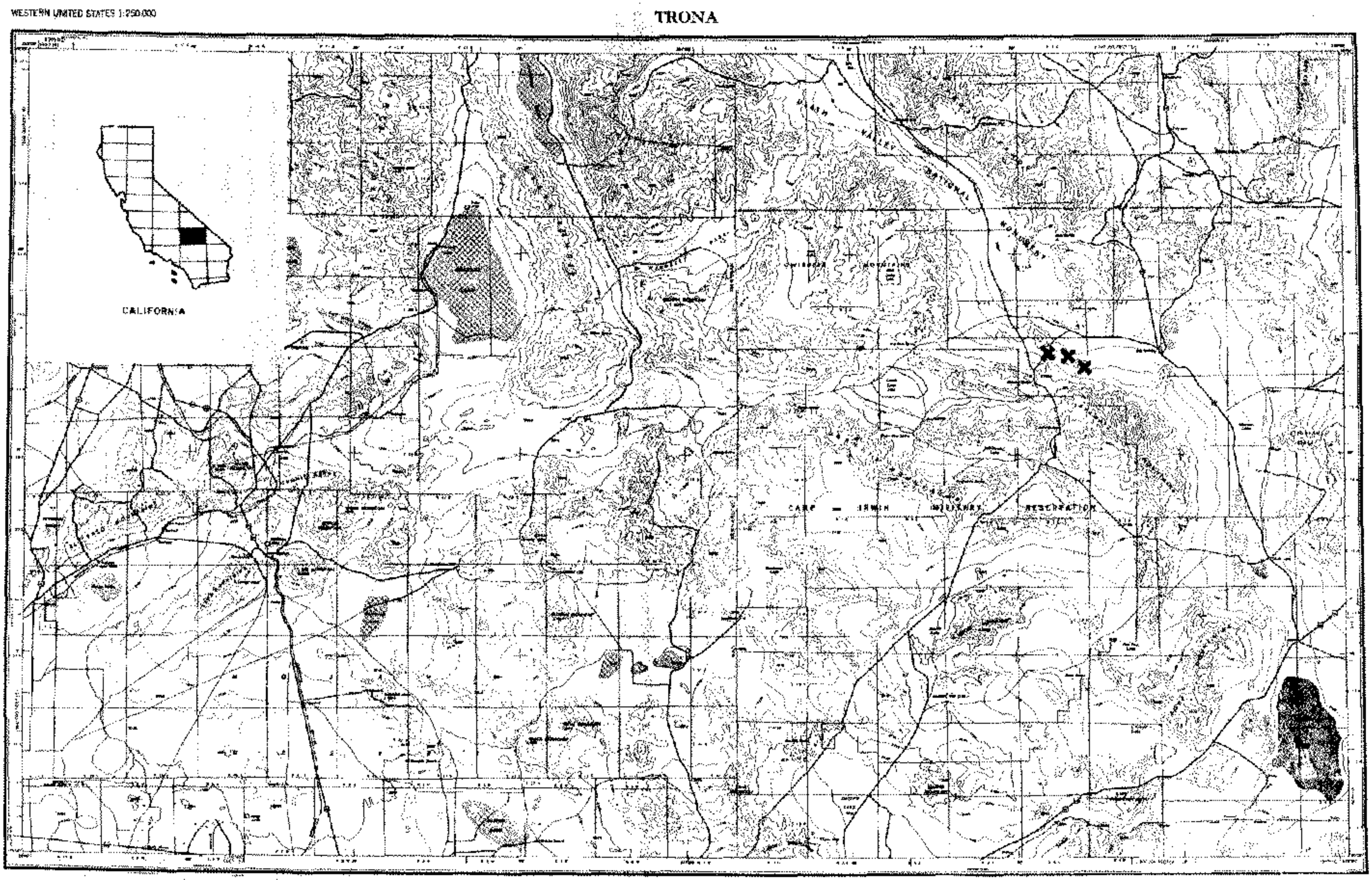

Figure 1. Location of bedrock salt deposits on Death Valley drainage basin. U.S. Geol. Survey, Trona quadrangle.

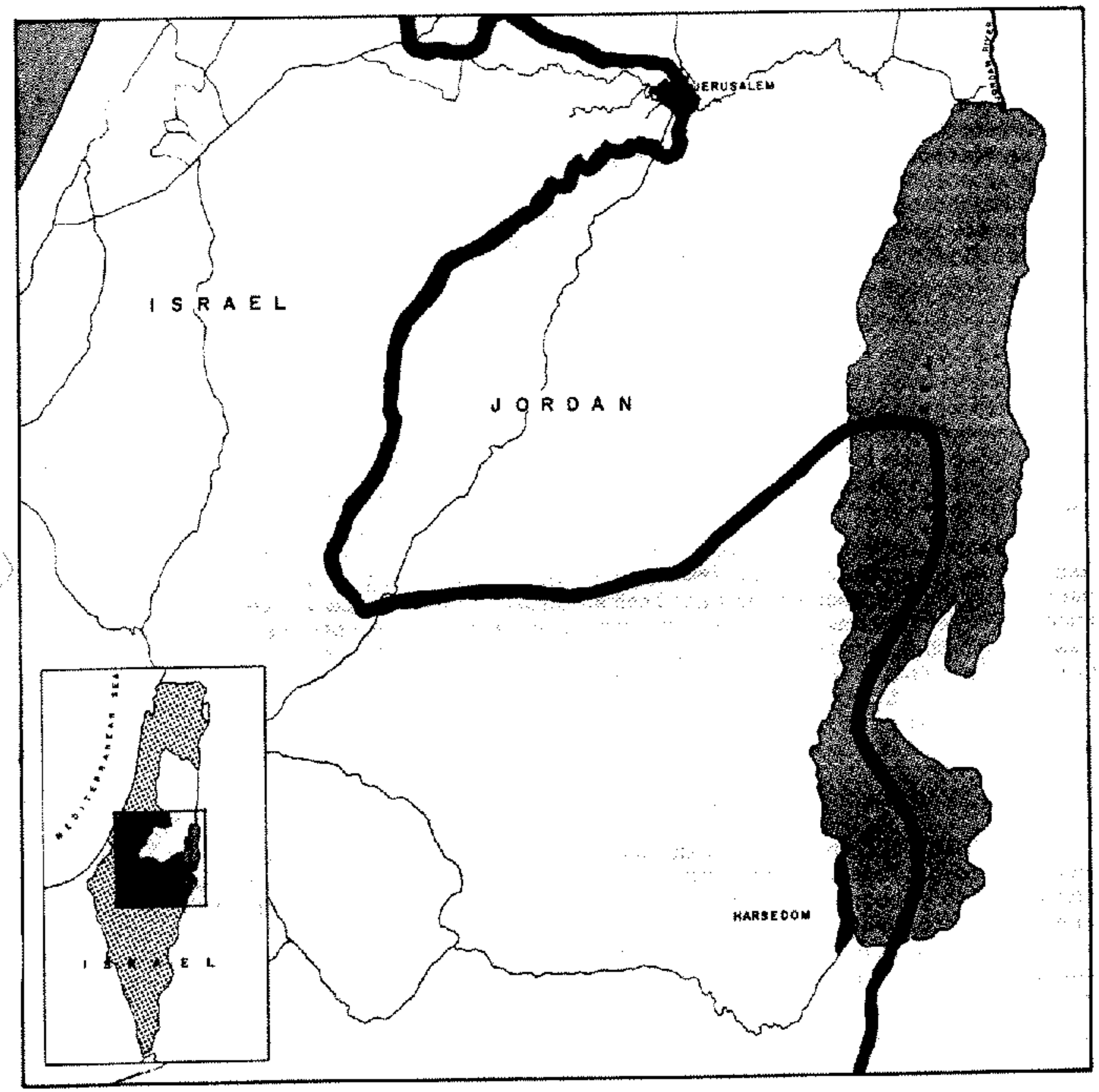

Figure 2. Harsedom, a ridge of outcropping salt on the shore of Dead Sea.

(the common apatite is the fluorapatite) and it is by no means abundant in volcanic gases which in turn are highly erratic in both time and space. Therefore the classic hypothesis fails because of the volumetric inadequacy of available chlorine. Furthermore, if the sodium and chlorine ions in the ocean came largely from feldspathic rocks and volcanic gases, there should be approximately as much potassium as sodium, and fluorine as chlorine, in sea water. It should be noted that the classic hypothesis was developed before world wide drilling of sedimentary basins in the search for oil resulted in the discovery of rock salt in such quantities that it can now be considered to be a fairly common sedimentary rock. Without doubt there still remains many salt deposits to be discovered in the future.

SALT CAVES

Because of the solubility of salt, one would expect caves to be abundant, especially where salt body lies above the water table and therefore comes into contact with under-saturated migrating waters. However, the same extreme solubility also is responsible for the fact that in most areas the salt has been dissolved to such depths that salt caverns are not visited by man in the same way as are limestone caverns. Numerous drilled wells around the rim of the Salina salt basin in Michigan and Ontario, and in other areas, where the structure brings the rock salt close to the surface, have penetrated small caves in the salt measures (4).

SURFACE COLLAPSE

In many areas the solution of underlying rock salt has been accompanied by collapsing which has created depressions at the surface. The Hutchinson, Kansas, topographic sheet shows a line of swamps and lakes extending north across west-central McPherson County (Figure 3). This zone of depressions lies along the truncated edge of the Permian salt and is without doubt due to the leaching of the underlying salt with subsequent collapse. Depressions have been formed in historic time.

Similar collapsing has been observed in other areas of shallow rock salt. Ward (1) in addition to noting the presence of salt springs in northwestern Texas and Oklahoma, also points out that the solution of subsurface salt has been accompanied by "solution and collapse features of the surface along the eastern margin of the salt." Other writers (5, 6) have pointed out collapse features resulting from the leaching of gypsum and anhydrite in the Permian rocks of the Texas and New Mexico area. Harrison (7) mentions collapsed beds associated with each of the salt plugs in the Colorado-Utah salt dome province. Collapse features, including surface depressions, are well known in the Gulf Coast salt dome area (8) and in the early days led to the discovery of several of these salt intrusions.

ANCIENT COLLAPSE BRECCIAS

The collapse of the roof overlying salt caverns, with resultant tumbling downward of the overlying rock into a jack straw arrangement of angular blocks with finer material filling the interstices, is by no means confined to the present erosion cycle. In geologic time, at least as far back as the Silurian, similar conditions existed and widespread collapsing occurred. The rock which results from the compaction and cementation of the collapse debris is known as breccia, and it is by these breccia deposits that we are able to recognize geologically ancient collapsing.

The Mackinac breccia of the Mackinac Straits region in Michigan is probably the most spectacular, and certainly the most accessible, example of large scale collapse into caverns dissolved in salt in North America. The detailed description of this occurrence (4) which includes a discussion of previous contributions to collapse and subsidence, is no longer in print. A condensation of parts of the original publication appeared in a fairly recent guidebook of the Michigan Basin Geological Society (9).

Differential erosion of indurated breccia has produced prominent rock spires on both St. Ignace Peninsula and Mackinac Island in the Mackinac Straits area. Examples include

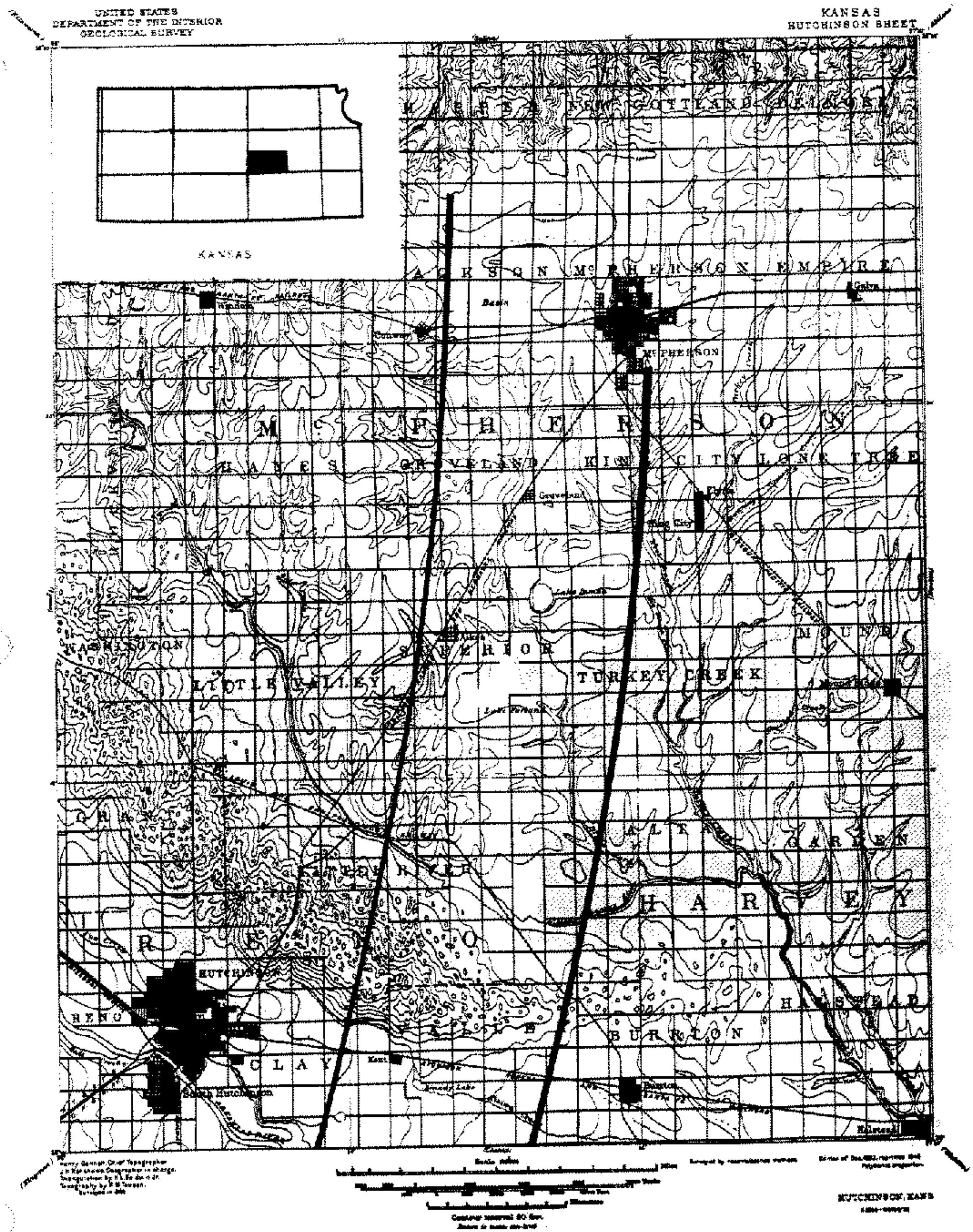

Figure 3. Belt of depressions overlying truncated eastern edge of Permian salt in central Kansas. U.S. Geol. Survey, Hutchinson quadrangle.

Castle Rock and St. Anthony's Rock (Figure 4) on the mainland, and Sugarloaf and Arch Rock on Mackinac Island. However, the volume of indurated breccia is very much less than the volume of unindurated breccia, which underlies many square miles, with depths up to 700 feet. In addition, there are occurrences of megabreccia where blocks of sedimentary rock with horizontal dimensions ranging from a few feet to hundreds of feet have been dropped and tilted so the strata now dip from 6° to 25°. A fault bounding one such megabreccia block can be seen in a cut on U.S. Highway 2 west of St. Ignace.

The breccia fragments range in size from powder to rock slabs over 20 feet in maximum dimension. Stratification can be seen in the larger fragments, with dips from horizontal to vertical. There is no relationship between the orientation of adjacent fragments.

Limestone and dolomite (Figure 5) are the main rock types in the breccia, but chert and shale are also present. The fragments can be correlated by fossils and lithology with the

Figure 4. St. Anthony's Rock, St. Ignace, Michigan.

Figure 5. Dolomite fragments on the Mackinac breccia.

stratigraphic column for this area (Figure 6). Formations represented are the Pointe aux Chenes (Salina) and St. Ignace (Bass Island) of the upper Silurian, and the Bois Blanc and Detroit River of the lower Devonian. The overlying Dundee rocks are not disturbed.

Obviously these breccia aggregates, consisting as they do of intermixed rocks from a stratigraphic section hundreds of feet in thickness and millions of years apart in age, were

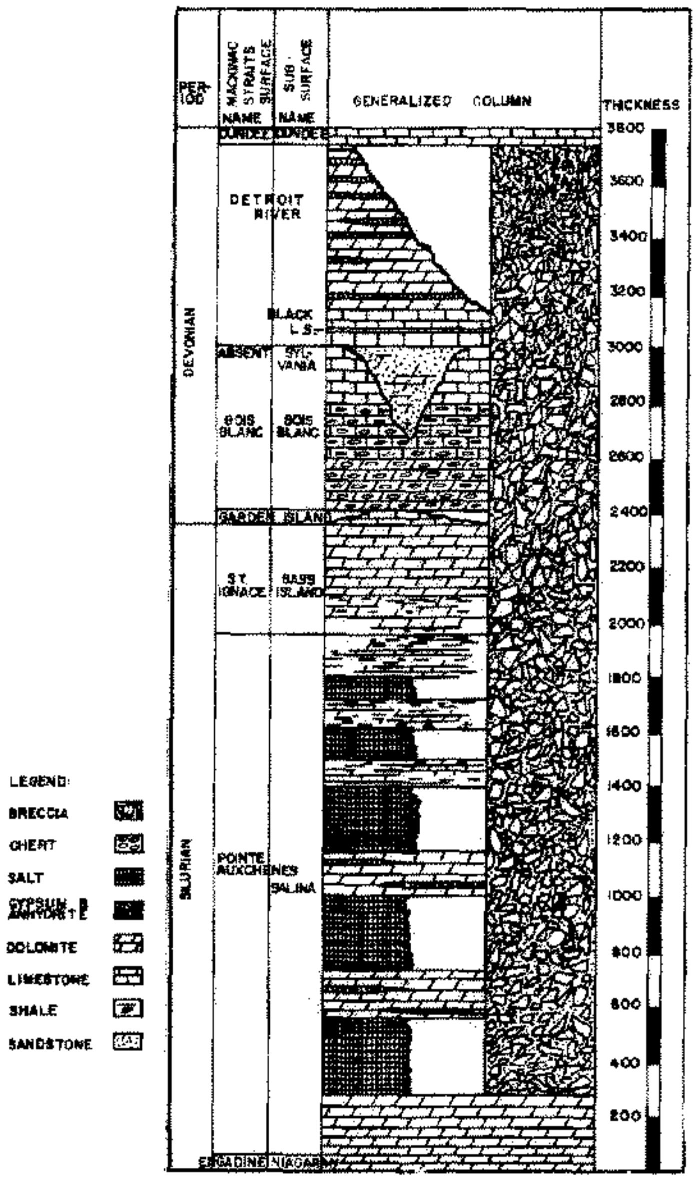

Figure 6. Stratigraphic column, Mackinac Straits region, Michigan.

formed by extensive collapse. The clue to this is the isopach map of the Salina salt (Figure 7) which has a thickness interval of 100 feet. The north end of the salt deposit has an exceptionally blunt edge, thinning from 1200 feet to zero in a short distance. This is a leached rather than a natural (depositional) edge. The original salt boundary was an unknown distance north of the present boundary; the Salina rocks have been truncated by erosion north of St. Ignace.

The postulated sequence of events in the Mackinac Straits area follows:

1. Submergence of Niagaran rocks and deposition of several hundreds of feet of Salina shale, dolomite, salt and gypsum.
2. Subsequent deposition of the Bass Island dolomited, cherts, and limestones, and the Detroit River dolomites and limestones.
3. Emergence and solution by percolating ground waters of great quantities of salt around the rim of the Salina basin (this activity could also have taken place during earlier post-salt emergences). A vast series of caves and caverns were formed.

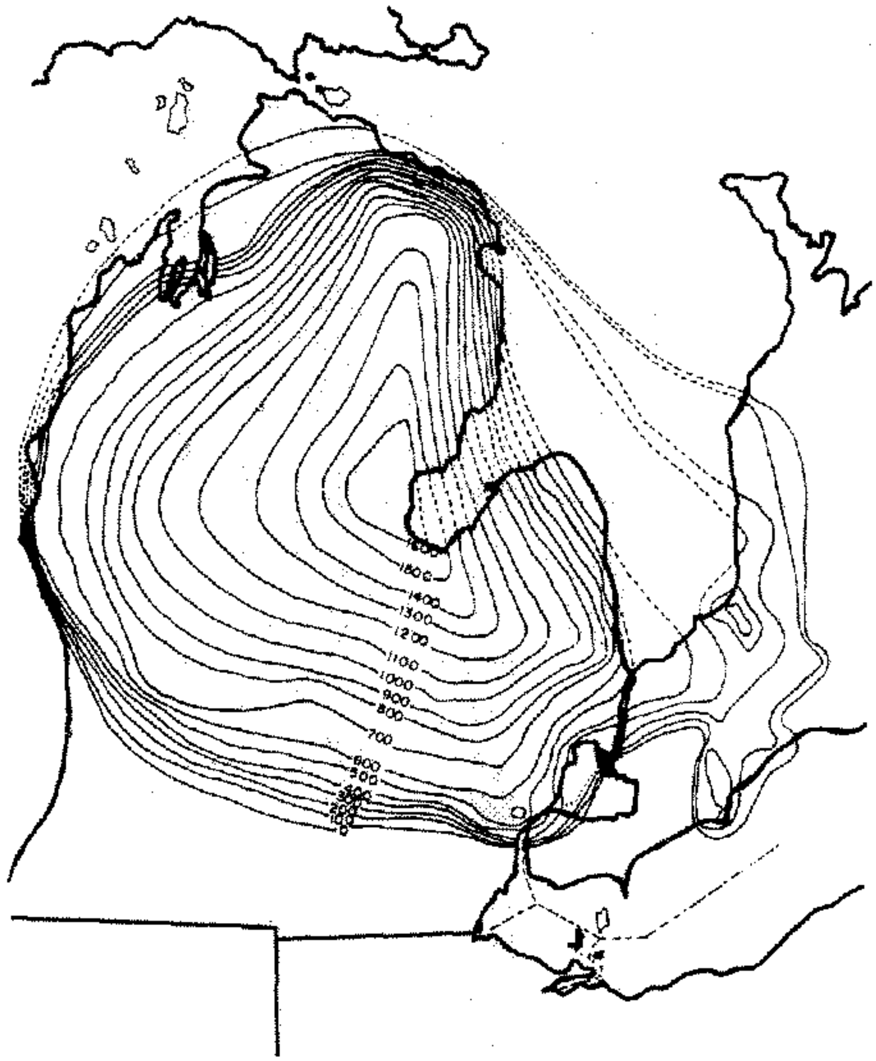

Figure 7. Isopach map showing aggregate thickness of Salina salt layers in southern peninsula of Michigan. Interval: 100 feet.

4. Collapse, no doubt taking place over a long period of time, of the cavern roofs. One type of collapse was local and sudden, producing the transformational breccia previously described. The other type was on a more regional scale; failure of cavern roofs in this instance let down great blocks of strata, producing megabreccia.
5. Cementation by ground waters circulating through the sink holes of some of the collapse debris, producing indurated breccia.
6. Peneplanation followed by submergence and the deposition of the Dundee and younger formations.
7. The eventual arrival of the present cycle of erosion. Differential erosion resulted in isolating the indurated breccia masses by removing much of the surrounding non-indurated breccia. Wave erosion along the shores of the glacial and present Great Lakes carved some of the cemented breccia into stacks.

The southern edge of the Saline salt is also a leached boundary, and collapse effects can be seen in Monroe County in southeastern Michigan and on the Bass Islands in western Lake Erie. In both of these areas the Bass Island dolomites, which once overlay the salt measures, are brecciated as in the Mackinac Straits, but not on such grand scale. To the northeast, in southwestern Ontario, local leaching of Salina salt produced subsidence, also in the later Silurian and early Devonian (10).

The only other North American locality known to me where probable collapsing has created great breccia masses is at Bear Rock at the junction of Great Bear and MacKenzie Rivers at Fort Norman in the Northwest Territories, Canada (11). Smaller scale evaporite solution and collapse in the Mississippian rocks of southwestern Montana have been described (12) recently.

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