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Some Factors Influencing Phreatic Cave Development in the Silurian Strata of Iowa

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The Silurian strata of eastern Iowa are characterized by solutional karst, expressed in part as caves. Most of the caves were developed within the phreatic zone although they generally are now hydrologically inactive. The formation of this karst was controlled by numerous factors. These include stratigraphically controlled variations in prekarst porosity, hydraulic conductivity, and clay content which affects solubility. These key factors are seen in both the *Cyclocrinites* Beds of the Hopkinton Dolomite and a portion of the Gower Fm., both of which contain a disproportionate number of caves.

In many shallow phreatic caves within the Silurian rocks passage morphology is controlled by the relationship between jointing and the hydraulic gradient. The alignment of these caves parallel to present-day ground-water flow lines indicates that they were probably developed after the present-day stream systems were in place. Therefore, the caves probably formed somewhere between the last glaciation in northeast Iowa (Pre-Illinoian) and the draining of the cave bearing strata.

INDEX DESCRIPTORS: Karst, Speleology, Caves, Silurian, Hydrology, Iowa caves.

SILURIAN KARST OF IOWA

The Silurian strata of eastern Iowa consists primarily of dolostones which attain a maximum thickness of 146 meters (480 feet) (Witzke, 1978). These rocks are characterized by solutional karst, which is expressed both as surface sinks and as caves whose entrances may occur in sinks but more commonly in valley walls. These caves may be up to approximately 300 meters (1000 ft.) in length (Hedges, 1974c; d). Although many are now within the vadose zone and thus no longer play an active role in the hydrologic system, most were formed under phreatic conditions. Bretz (1942) suggested that caves of shallow phreatic origin are usually linear in form, often with side passages. Picknett et al. (1976), suggested that this form is related to: 1) the increased solutional potential of descending ground water where it mixes with water in the saturated zone; and 2) the uppermost portion of the saturated zone, being the first locus of prolonged contact between the descending water of any given stratum. Solutional openings tend to develop at or near the top of the phreatic zone, resulting in relatively rapid ground water movement at this level. This further accentuates solution at the expense of deeper levels (Davis, 1960). In contrast, caves of deep phreatic origin tend to be irregular in shape (Bretz, 1942).

Although much descriptive material is available on caves in the Silurian strata of Iowa, primarily in publications of the Iowa Grotto and other caving organizations (Hedges, 1957-1963, 1967), little work on the genesis of these caves has been published. Hedges and Darland (1963) attempted to relate many caves to an assumed paleowater table, and Bounk (1978) discussed the origin of Dancehall Cave.

Studies relating these caves to the structure and stratigraphy of the Silurian strata are also lacking. An understanding of these relationships is critical to an overall understanding of karst genesis, and the movement of ground water in these strata. The purpose of this study was to investigate the relationship of Silurian caves with the structure and stratigraphy of these rocks. This was done by determining the stratigraphic position of a number of caves throughout the Silurian outcrop belt in Iowa. Then cave maps and morphology were compared with joint orientations in the vicinity and also with the local potentiometric surface in the Silurian aquifer.

FACTORS INFLUENCING CAVE FORMATION

Differential Susceptibility to Solution: The *Cyclocrinites* Beds

The *Cyclocrinites* Beds described by Johnson (1975) and Witzke (1978) are a unit of the Hopkinton Dolomite (Figure 1) characterized by the calcareous fossil green alga *Cyclocrinites dactioloides*. The *Cyclocrinites* Beds are identified in a core from Linn County (Sec. 16, T. 84N.,R. 7W.) occurring about 14-24 meters (45 to 75 ft.) above the base of the Hopkinton Formation. This unit is often vuggy (Figure 2) and is more permeable to ground-water flow than much of the Silurian section and thus under proper conditions is more susceptible to solution or karstification. For illustration, Figure 3 shows a suite of corehole geophysical logs from Linn County. The natural gamma log indicates a relative lack of argillaceous material while the gamma gamma log demonstrates high porosity and the neutron log shows a high water content in the *Cyclocrinites* Beds. This unit has been traced throughout the subsurface of Linn County (Bunker, 1977, personal communication; Wahl and Bunker, 1982) and is a major water bearing zone in eastern Iowa. Figure 4 shows the distribution of 23 caves or groups of caves for which reliable stratigraphic data are available. Eight of these (35%) are in the *Cyclocrinites* Beds, a high percentage considering that this unit averages only about 9 meters (30 ft.) in thickness or about 8% of a total Silurian sequence of approximately 120 meters.

Caves of shallow phreatic origin in the *Cyclocrinites* Beds include Indian Bluff (Figure 5), the upper level of Doll Cave (Hedges, et al., 1980, and personal communication 1974e) and Dancehall Cave (Figure 6). Also present are those of deep phreatic origin, such as Hunters (Figure 7), Worden's (Hedges, 1974a, b) and the lower level of Doll (Hedges, et al., and personal communication, 1974e).

The widespread geographic distribution of *Cyclocrinites* Beds caves, and the fact that caves of deep and shallow phreatic origin are found in these beds, suggests that the high percentage of caves located in this stratum result from original characteristics of the unit such as the high porosity, permeability, and paucity of argillaceous material. In the fossiliferous crinoid- and coral-rich facies, usually included in the Gower Formation, a similar situation exists. Five (22%) of the caves shown in Figure 4 occur in this relatively thin unit.

Joints and Ground-Water Flow

Shallow phreatic cave formation is influenced by the relationship between jointing, and preferred direction of ground-water flow is perpendicular to the water-table contours. Most carbonate strata have little intergranular porosity and secondary features such as fractures and joints serve as routes of ground-water flow. This implies that ground-water flow may not always occur at right angles to the water-table slope. Ground water will flow from joint to joint in a general downgradient direction (Figure 8). Cavern development will occur along those joints subparallel to the major flow lines. Ground water will utilize these joints and bedding planes that allow it to follow the highest pressure gradient downhead (Bogli, 1980).

This relationship can be seen at Sowards Cave (Silurian age Tete des Morts Formation) near West Union in Fayette County (Figure 9).

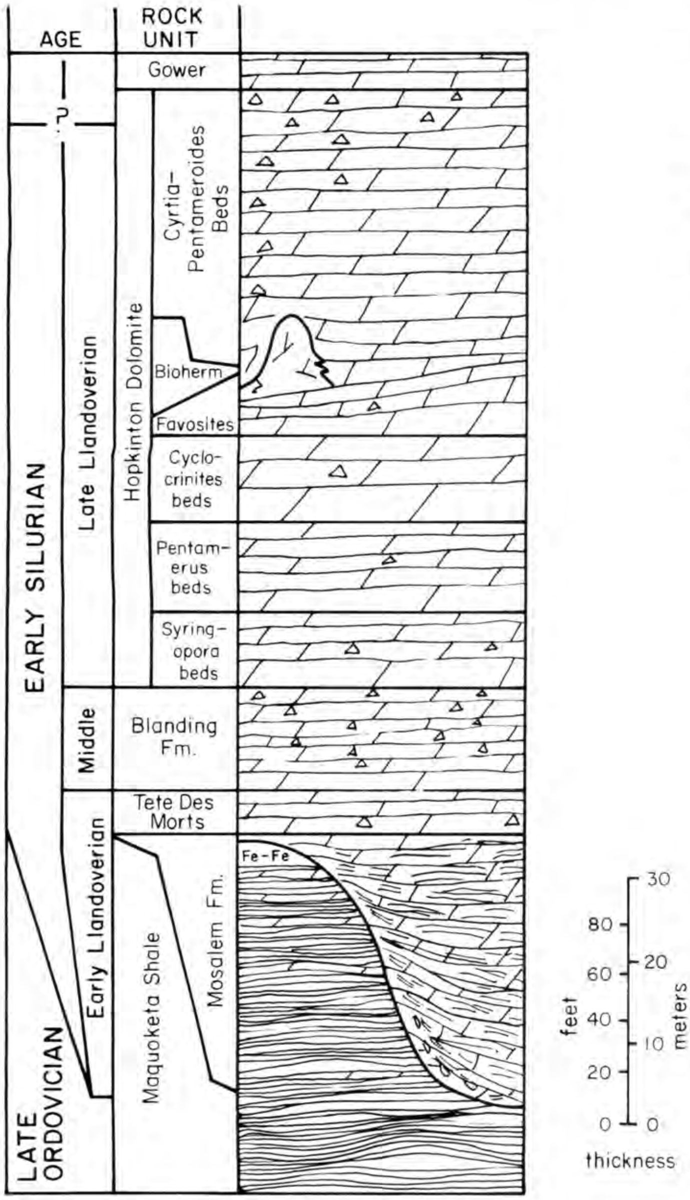

Figure 1. Generalized Silurian stratigraphic section of eastern Iowa (Witzke, 1978).

The main level of this cave follows two relatively inconspicuous joint trends. Together, these trends form a relatively direct route down gradient toward the Turkey River about 1.3 km (one mile) to the north. A number of more prominent joint trends at high angles to the preferred ground-water flow direction are utilized by the upper level (diagonal lines, Figure 9), but not the main level. The main level of this cave probably was formed by ground water flowing northward towards the Turkey River under hydrologic conditions very similar to those at present, although at or just below a higher water table. A third and lower level has been traced from its furthest accessible downstream point to the spring almost due north of that point (Barnett, 1968). Thus, the process of cave formation described above may presently be occurring in the lower level. The upper level, which displays more highly developed joint control, may have formed under other hydrologic conditions which utilized joints at higher angles.

Directional, joint controlled solution also occurs in the main passage of Dancehall Cave, located in Maquoketa Caves State Park, in Jackson County. Here, the joint trends followed facilitate a north to south ground-water flow (Figure 6 and 10). The numerically more prominent NE-E and NW-W joint trends are opposed to the water-table gradient and not generally apparent in the cave orientation.

A third example (Figures 5, 11) is Indian Bluff Cave. This cave also trends parallel to the present ground water table gradient, utilizing those joint trends which best facilitate flow. There is little or no solution along joints oriented in other directions. The overall pattern of this cave is controlled largely by two regional joint trends, one with a near E-W orientation, the other oriented approximately NE-SW. The controlling trends, although apparent in outcrop, are rarely seen as joints in the cave. They instead control the general trend of the passage. The details of passage morphology are influenced by other factors, including joints at other orientations. Davis (1960) noted in his studies of Appalachian caves that many caves ap-

Figure 2. Two inch diameter core of the *Cyclocrinites* Beds from Linn County (Sec. 16, T. 84N., R. 7W.) showing high porosity.

pear to be formed just below the water table, which they follow downhead toward major valleys.

The relationship between the present potentiometric surface and the orientation of shallow phreatic caves indicates that these caves originated in ground-water flow systems oriented similarly to those at present, although with a higher elevation water table. This suggests that these caves were formed after the last glaciation in this area, in the Pre-Illinoian (Hallberg, 1980) and development of drainage on the drift surface. Although landscape development on the Pre-Illinoian deposits has been complex, present day drainage has been evolving since at least Late Sangamon time, with extensive erosion in Wisconsinan time (Hallberg, 1979, personal communication). This brackets cave genesis somewhere between Late-Sangamon time and the lowering of the phreatic zone to a level below these caves. This is not meant to imply that all shallow phreatic caves in the Silurian of Iowa are of this age, as many are known for which the above realtionships have not been demonstrated

FURTHER STUDIES

Other questions concerning the karst in the Silurian strata of Iowa include: 1) what other factors control the karst distribution throughout the remainder of the Silurian section; 2) what petrographic attributes of the *Cyclocrinites* Beds make them especially susceptible to karst development; 3) is the joint/ground water relationship described here regionally widespread; 4) what are the *ages* of speleothems and clay fills found in many caves; 5) what is the relationship between ground-water movement through joint systems and the geometry of the deep phreatic caves; and 6) what is the relationship between shallow and deep phreatic karst?

CONCLUSIONS

Subsurface studies and cave distribution throughout the Silurian outcrop area of Iowa indicates the *Cyclocrinites* Beds of the Hopkinton Dolomite are major karst forming beds. These widespread solutional features are related to lithologic characteristics of these strata which include high porosity, high hydraulic conductivity and low clay content. Together these attributes make it especially susceptible to karstification. Passage directions in many shallow phreatic caves are a function of the relationship between the potentiometric surface and jointing. Solution commonly occurs along the joints which best facilitate downhead flow. The relationship between these caves and the present day potentiometric surface indicates that these caves were

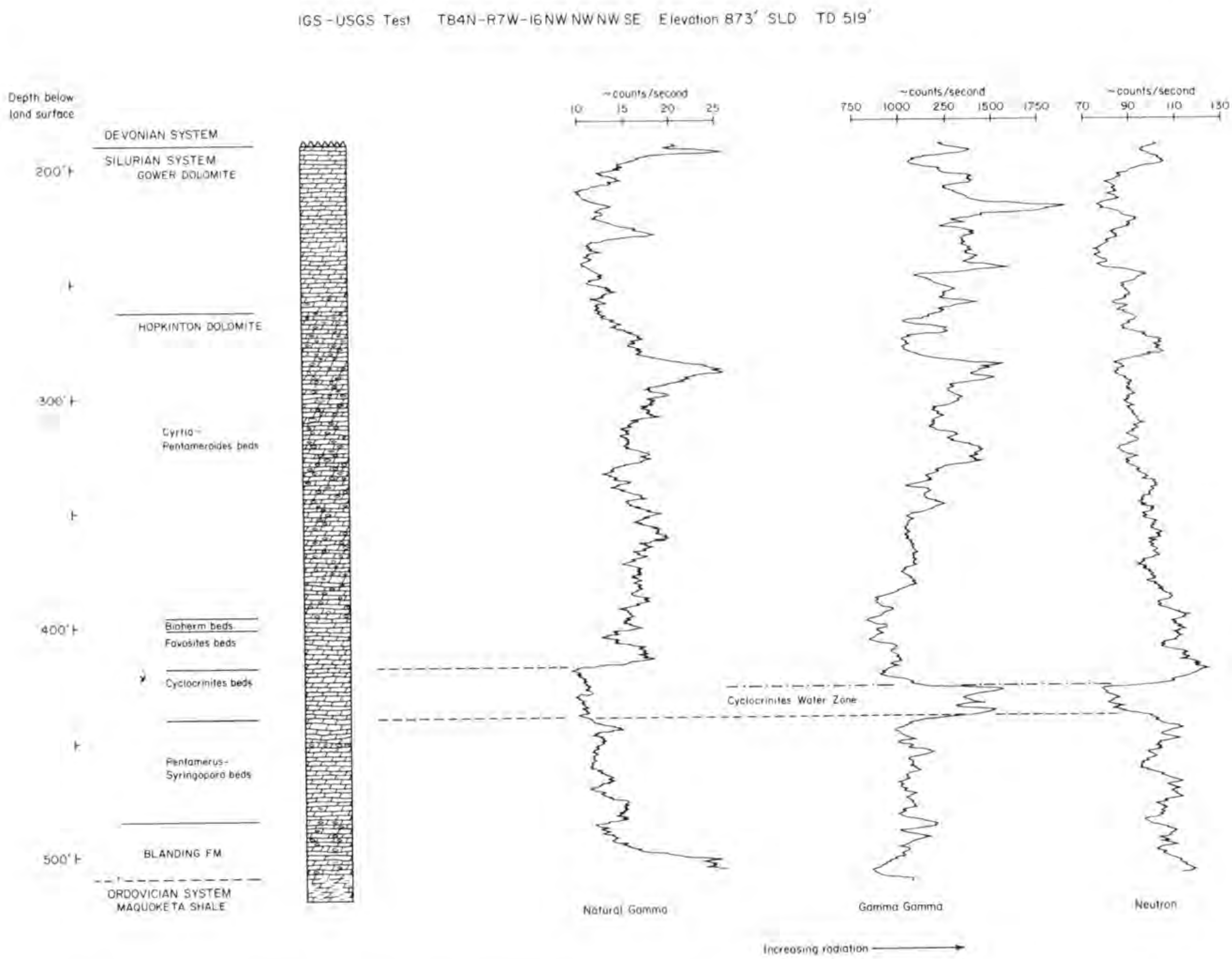

Figure 3. Lithologic log of a Silurian core from Linn County, Iowa with Natural Gamma, Gamma Gamma, and neutron logs (Bunker, 1979, personal communication).

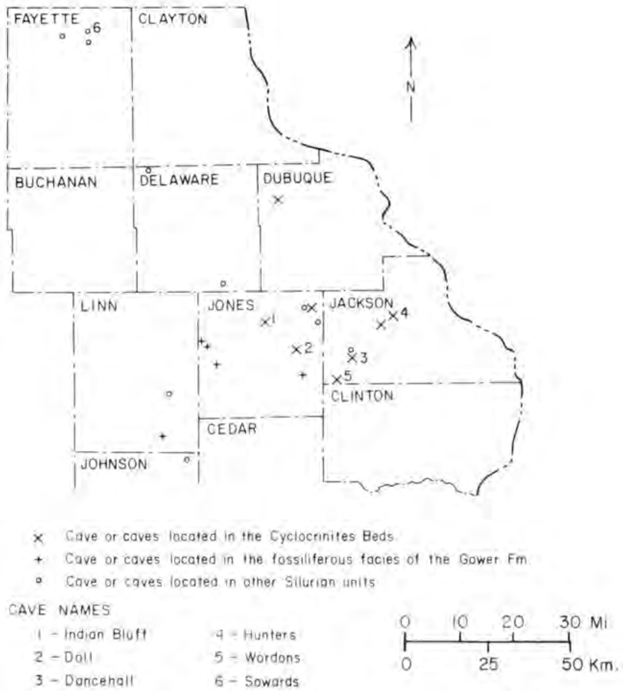

Figure 4. Map of east-central Iowa showing the distribution and stratigraphic position of selected caves.

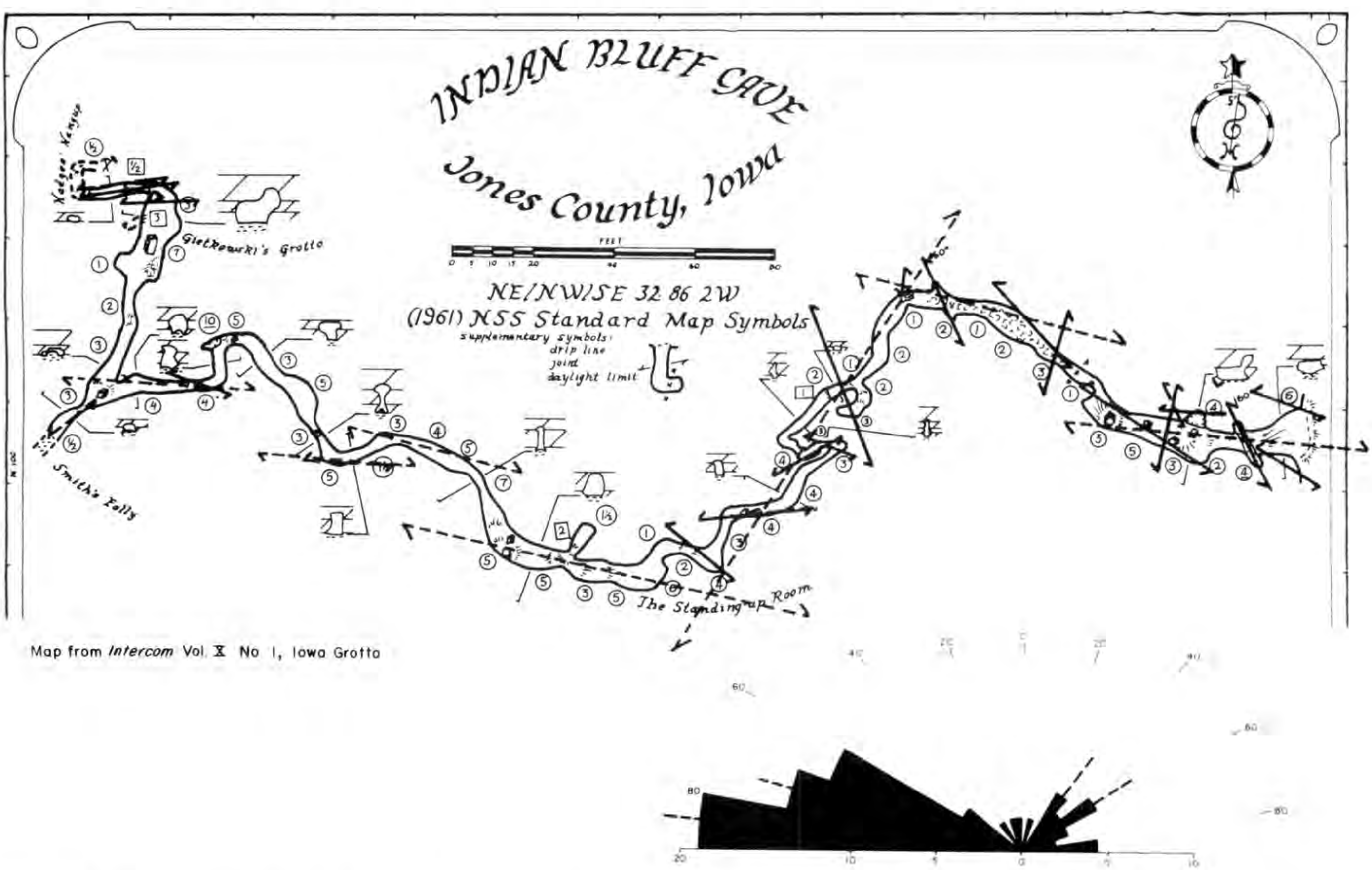

Figure 5. Map of Indian Bluff Cave (Hedges, 1974b), with cave joints shown as solid lines, and prominent surface joint trends (illustrated by the rose diagram), which control passage trends shown as dashed lines.

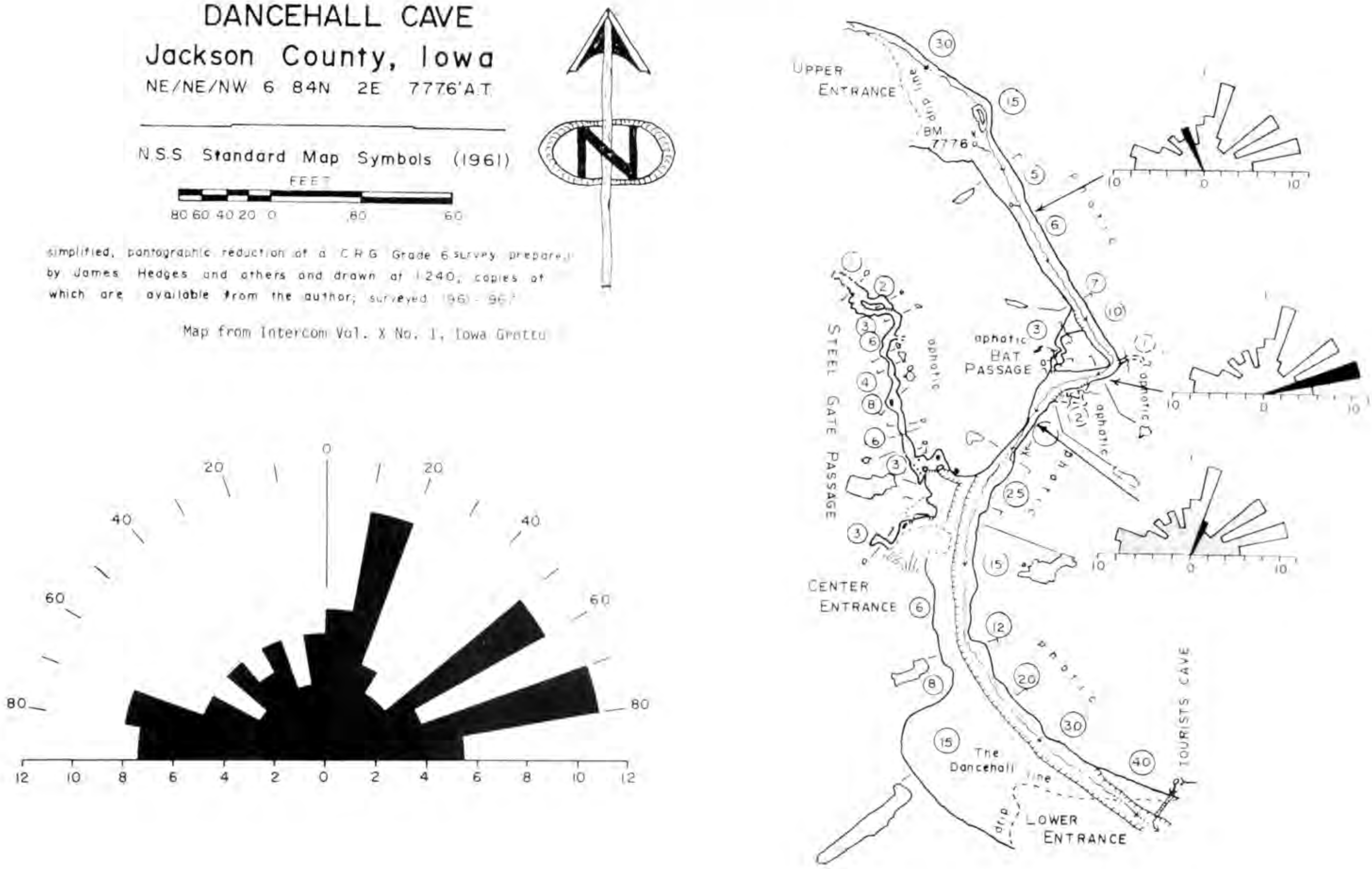

Figure 6. Map of Dancehall caves (Hedges, 1974c), showing the relationships of surface joint trends mapped nearby and cave passage direction.

most likely formed after the last glaciation in east-central and northeast Iowa.

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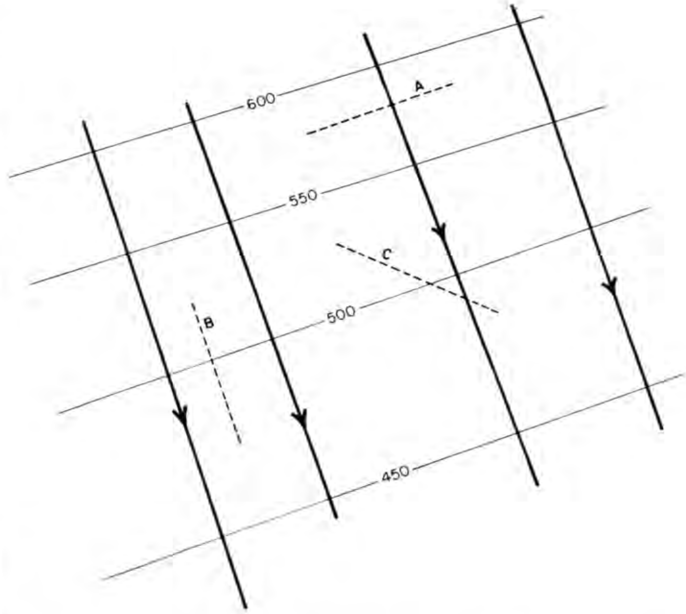
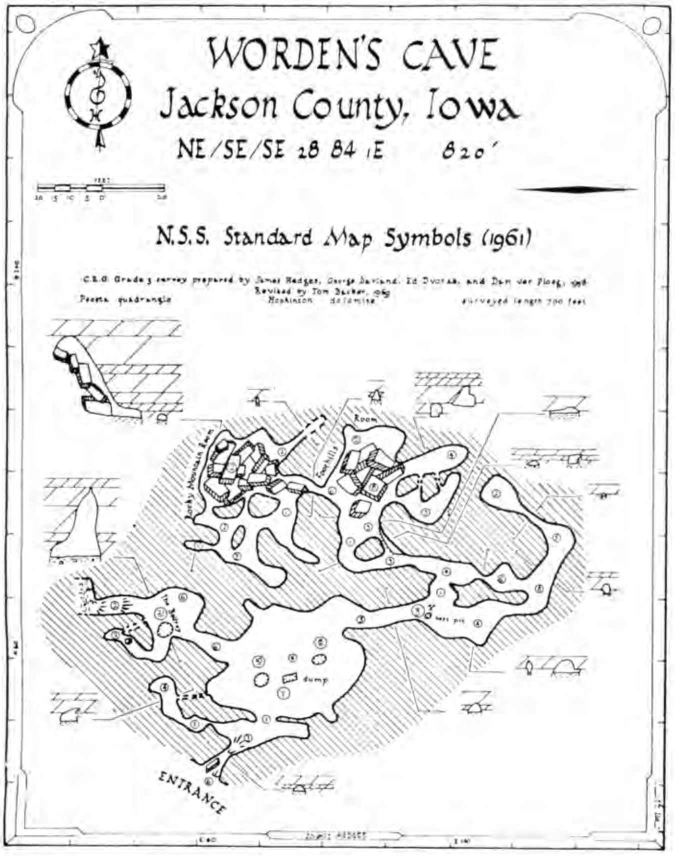


Figure 8. Diagram showing the relationship between the hydraulic gradient (lines with numbers indicating elevation above datum) and joints (dashed lines). Heavy lines indicate preferred ground-water flow, such as would occur in a hydraulically isotropic rock.
In a rock where major permeability occurs along joints, a joint in the orientation of joint A will carry little or no water unless it connects two joints with flows. Therefore water in this joint will become rapidly saturated with carbonate which will not be rapidly removed, thus little solution will occur.
A joint in the orientation of B will carry a high ground-water flow, constantly providing water unsaturated with carbonate allowing solution to occur relatively rapidly. Joint C is an intermediate example.



Map from Intercom Vol. X No. 1, Iowa Grotto

Figure 7. Map of Wordens Cave (Hedges, 1974a).

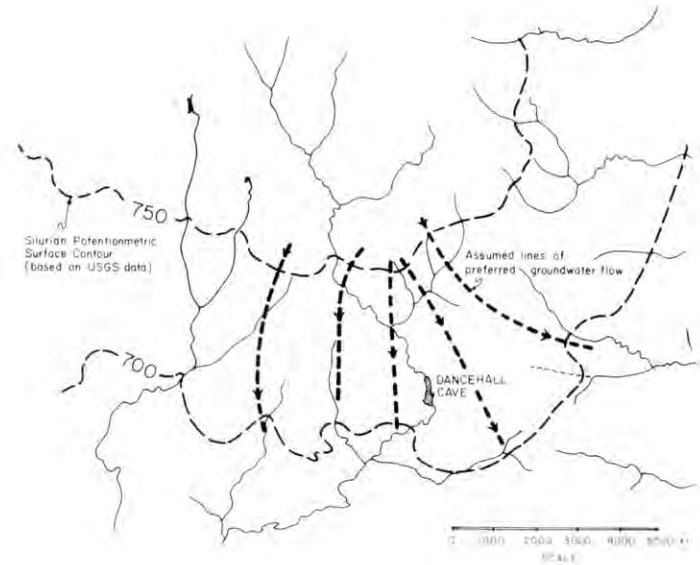


Figure 10. Map of the area around Dancehall Cave, showing the relationship between the cave and present day interpolated ground-water flow.

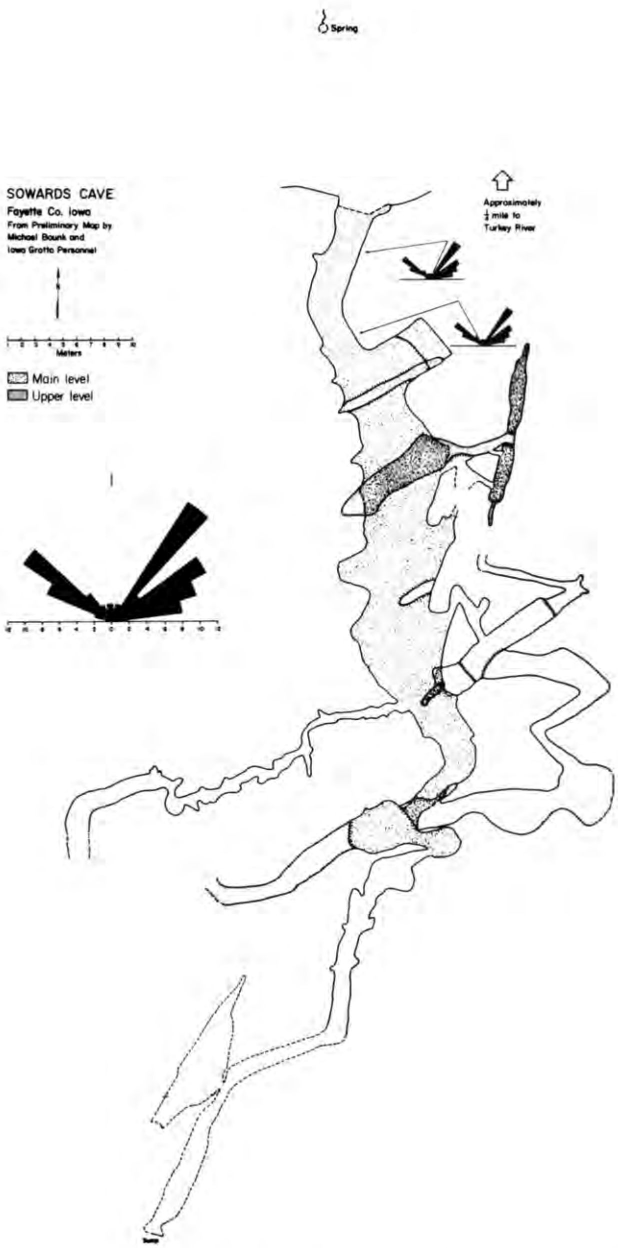


Figure 9. Map of Sowards Cave, showing the relationship between a rose diagram based on surface rock joints, ground-water gradient (downhead to the north) and cave morphology.

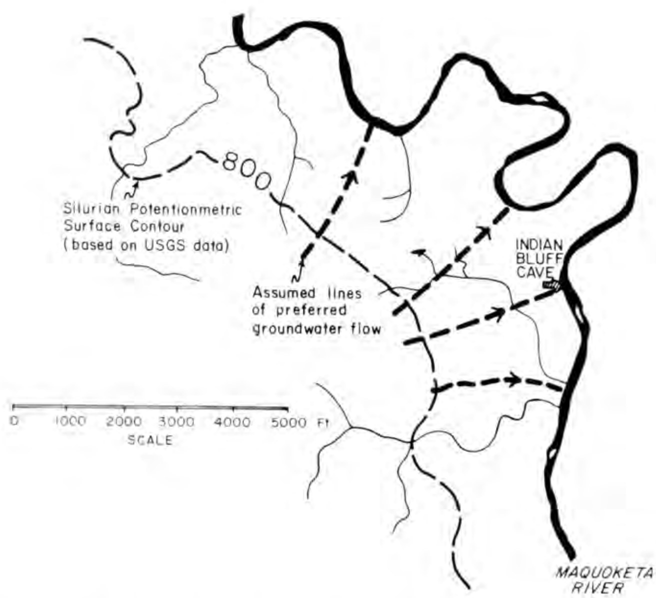


Figure 11. Map of the area around Indian Bluff Cave, showing the relationship between the cave and present day interpolated ground-water flow.