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The Scotch Grove Strath in Maquoketa River Valley, Iowa

James Hedges

George W. Darland Jr.

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JAMES HEDGES and GEORGE W. DARLAND, JR.

Abstract. Maquoketa river, located in the Dissected Till plains of east-central Iowa, was established consequent on the Nebraskan and Kansan drift sheets and superposed across preglacial bedrock valleys eroded into the exhumed pre-Desmoinesian backslope of the Niagara cuesta.

Where deeply entrenched into bedrock uplands, except in the Richland Highlands, modern Maquoketa river is bordered by rock terraces, which bevel structure. The presence of a series of shallow-phreatic caves 20 to 60 feet below the terraces, which transects structure, shows that the terraces are erosional, not structural, features.

Caves related to the strath contain evidence of a time of aeration followed by complete re-submergence and filling with fluvial and lacustrine sediments. Because Maquoketa River valley has been neither aggraded nor dammed up to the level of the caves since Kansan time, the caves and, therefore, the strath are believed to be of Aftonian age.

The Scotch Grove strath is topographically equivalent to and at Savanna, Illinois appears to merge with the Central Illinois peneplane and with Baselevel No. 3 of the Freeport Baselevel Section, but inability to find a definitive criterion common to all three regions prevents their unequivocal correlation.

REGIONAL PHYSIOGRAPHY

Geography

Location. Maquoketa River valley is eroded along the strike of the backslope of the Niagara cuesta in the Dissected Till Plains of east-central Iowa. It includes 1,897 square miles in southeastern Fayette, central Delaware, northern Jones, Jackson, and portions of adjacent counties.

Topography. Highest elevations in the valley occur on the north rim, which lies along the drift-mantled crest of the Niagara cuesta at 1,200 to 1,260 feet AT. The south rim is lower toward the southeast, being at about 850 feet near the Mississippi River. The valley floor lies at about 590 feet at the mouth. A late-youthful to mature erosional topography, more or less mantled with Iowan drift in the west and with Peorian loess in the east, prevails. Local relief rarely exceeds 300 feet.

Climate. At present, Maquoketa River valley is a region of Savanna morphogenetic type (Peltier, 1950). Its average annual temperature is 47.9°F, ranging from a January average of 21°F to a July average of 75°F, and its annual precipitation averages some 33 inches, of which 70 per cent occurs in the spring and summer months (H. G. Hershey, 1955). There are an average of 90 freezes and thaws each year (Visher, 1945), while the

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surface of the ground is sufficiently frozen to prevent ready absorption of rainfall for about 4.5 months each year. Previous interglacial intervals are believed to have been perhaps 5°F warmer and somewhat more moist that the present (Flint, 1957).

Paleozoic Stratigraphy and Structure

Silurian dolomites of Alexandrian and Niagaran ages are the uppermost indurated rocks underlying 98 per cent of Maquoketa River valley. The formations represented, and their average thicknesses in this area, are the Edgewood (40 feet), Kankakee (50 feet), Hopkinton (125 feet), and Gower (60 feet). Inliers of Maquoketa shale (Ordovician) and outliers of Desmoinesian sandstone (Pennsylvanian) about equally share the remaining area (Calvin, 1895, 1897; Calvin and Bain, 1899; Savage, 1905; Scobey, 1938; Tester, 1937; Tuttle and Northup, 1955).

All Paleozoic rocks dip toward the southwest at about 14 feet per mile. Superimposed on this regional homocline are a few low anticlines which plunge southwestward across the valley. The largest is the Savanna anticline, located in the southeastern part of the valley. Its amplitude is slightly more than 100 feet and its width is about 15 miles (Hackett and Bergstrom, 1956; Howell, 1935; Savage, 1905).

The areal geology of Maquoketa River valley is shown in figure 1.

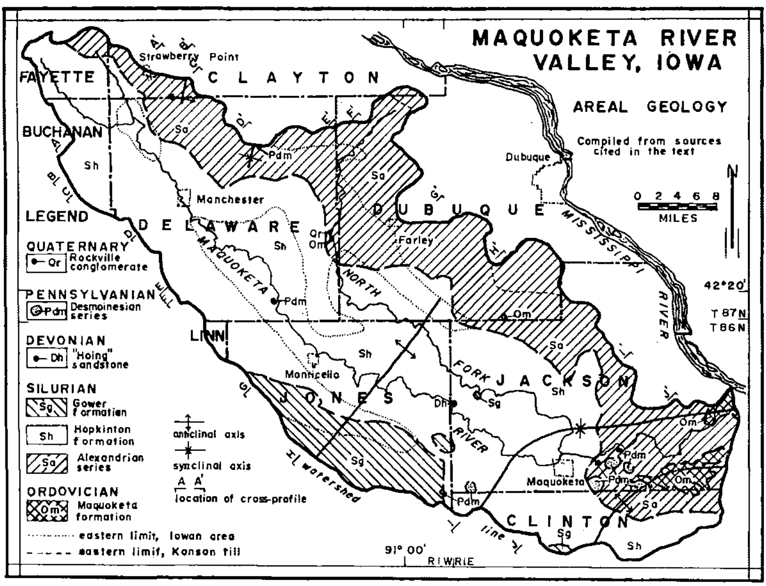

Figure 1 Areal geology map of Maquoketa River valley, Iowa.

The Pleistocene

Preglacial topography. The dominant feature of the preglacial bedrock surface of the area now drained by Maquoketa river is the exhumed pre-Desmoinesian backslope of the Niagara cuesta. This surface, marked by scattered Desmoinesian outliers in Jackson and Delaware counties, bevels gently across the Silurian strata and crosses onto Maquoketa shale where the shale is exposed at the crest of the Savanna anticline. Deep, narrow valleys are entrenched below this surface near Monticello, Center Junction, Nashville, and Elwood, but the preglacial valley system has not been mapped in detail (Norton and others, 1911). Local preglacial relief amounted to perhaps 400 feet along the major valleys. The floors of the deepest valleys lie over 100 feet below the level of the Havanna strath at Clinton (Horberg, 1946), but direct evidence of its presence in the Maquoketa valley is lacking. The highest bedrock elevations along the north rim may represent the Dodgeville peneplane (Bates, 1939; Trowbridge, 1921).

Glacial modifications. Nebraskan ice overspread all of Maquoketa River valley and its drift sheet completely obliterated the preglacial drainage system, except in the area north and east of North Fork river, where few buried valleys are known to exist.

Kansan ice overspread all of the valley except two small areas south of Dubuque (Tri-State, 1948), but the only important permanent stream dislocation which seems to have resulted was the superposition of Maquoketa river across the Richland Highlands south of Strawberry Point.

Iowan ice invaded the western part of the valley, where its drift sheet mantles the older erosional topography (Alden and Leighton, 1915). East of the Iowan drift margin, Peorian loess caps the ridges and forms dune-like accumulations on the valley slopes (Kay and Apfel, 1929).

Present thicknesses of the Pleistocene deposits rarely exceed 150 feet except where they overlie preglacial valleys. Bedrock outcrops are common along most of the larger streams.

A schematic block diagram showing relationships among structure, stratigraphy, and topography in Maquoketa River valley is shown in figure 2.

The Strath

Evidence

Topography. The Scotch Grove strath consists of a pair of discontinuous rock terraces which lie 60 to 80 feet below the general upland level along Maquoketa river. They are as much as one-half mile wide and represent a level at which the river reached grade and began widening its valley at some time in the past.

Projected topographic profiles, compiled from U. S. Geological Survey 30′ series quadrangles surveyed 1889-1904, were drawn at one-mile intervals along Maquoketa River valley. Representative examples are shown in Fig. 3. The strath is first seen at 1,100 feet AT near Joy Spring, southwest of Strawberry Point (No. 1). No strath can be identified in the Richland High-

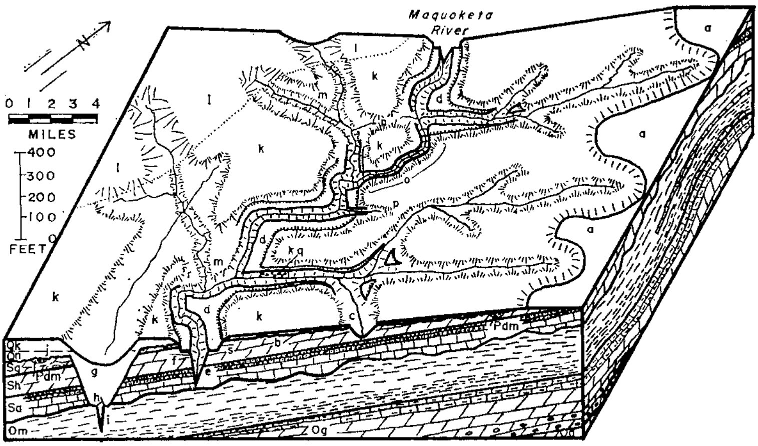

Figure 2 Schematic block diagram (isometric projection) showing relationships among structure, stratigraphy, and topography in Maquoketa River valley, Iowa. (a) Dodgeville peneplane; (b) exhumed pre-Desmoinesian surface; (c) resurrected preglacial valley; (d) Scotch Grove strath; (e) Aftonian valley; (f) Aftonian shallow-phreatic cave; (g) partly-exhumed preglacial valley; (h) Havanna strath (projected from Clinton); (i) "deep-stage" preglacial valley; (j) buried Nebraskan gumbotil plain; (k) Kansan gumbotil plain; (l) Iowan area; (m) Iowan terrace; (n) partly-exhumed Aftonian valley; (o) Yarmouthian valley; (p) drift-blocked and beheaded preglacial valley; (q) Rockville conglomerate; (r) drift-filled continuation of valley (c) to valley (g); (s) Yarmouthian shallow-phreatic cave.

lands (No. 2). A sag valley continuing eastward through Campton to Dundee where the modern river loops northward through the Highlands may represent the course of the river at the time that the strath was developed. The strath re-appears below Forestville at 1,040 feet (No. 3), but is absent around Manchester where the river crosses a buried valley (No. 4). The strath can be identified at most points in the Delhi Plateau (Nos. 5 and 6) at elevations declining from 980 feet near Delhi to 940 feet near Hopkinton, but is absent around Monticello where the river crosses another buried valley (No. 7). With local exceptions, the strath can be identified the remaining distance to Mississippi river (Nos. 8, 9, and 10). It lies at 800 feet near Maquoketa and at 750 feet near the Mississippi.

The gradients of both strath and river are 2.4 feet per mile in the lowest 25 miles of the valley. Their vertical separation is 160 feet at the mouth of the river but, due to the higher gradient of the modern than of the ancient river, it is only 40 feet at Joy Spring.

The strath lies at varying elevations within the Hopkinton dolomite, and below the town of Maquoketa, crosses onto Kankakee dolomite upturned along the north flank of the Savanna anticline. However, because the Savanna anticline was bevelled during pre-Desmoinesian erosian, and because the altitude and slope of the strath are roughly accordant with the altitude and slope of the exhumed pre-Desmoinesian surface, one might rea-

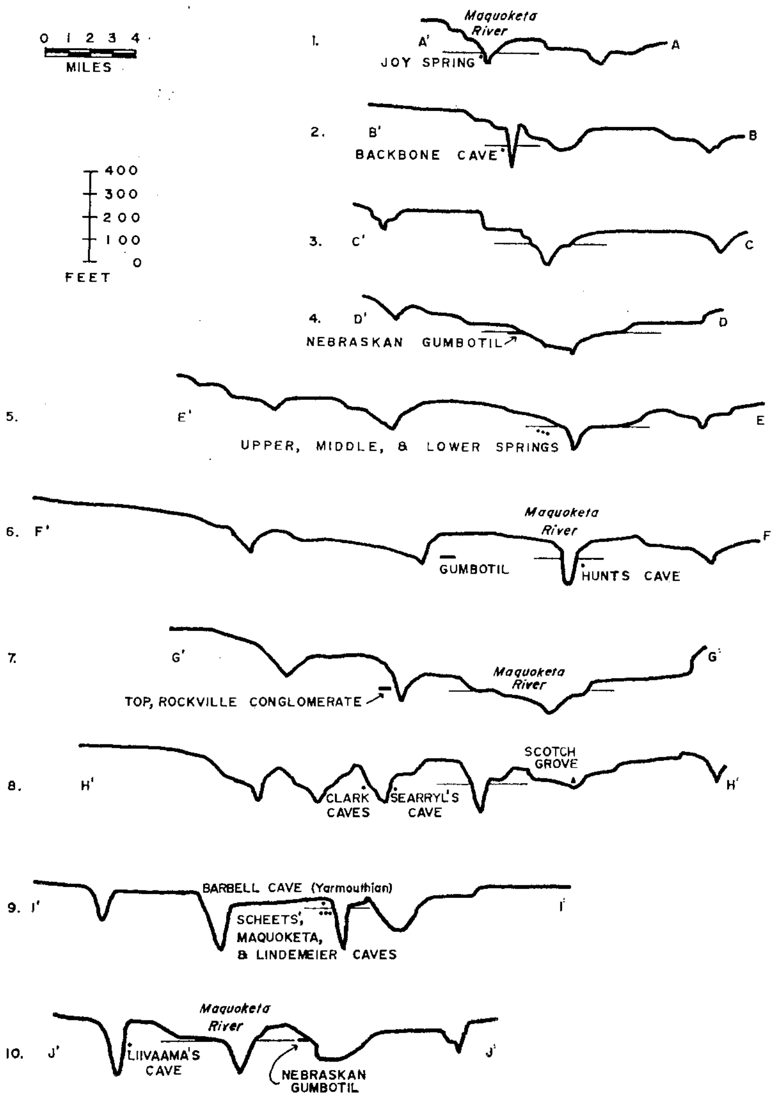

Figure 3 Representative topographic profiles of Maquoketa River valley, Iowa, looking downstream. For locations of profiles, refer to marginal letters in Fig. 1.

sonably object that the "strath" just described is a structural terrace developed at the contact of the unconsolodated Pleistocene materials on the Silurian dolomites. That the strath is a cyclic erosional surface of Pleistocene age and not a structural terrace will be demonstrated in the following sections.

Caves. Recent field studies, among which may be mentioned those by Davies (1960) in this country, by Sweeting (1950, 1960) in England and Australia, in Belgium by Ek (1961), in

Czechoslovakia by Droppa (1961), and in the USSR by Soloviev (1961), as well as theoretical (Rhoades and Sinacori, 1941) and experimental (Kaye, 1957; Ewers, 1963) studies, have substantiated the earlier views of Swinnerton (1932) that many limestone caves were developed at or slightly below the level of the water-table during periods of water-table stability coinciding with periods of graded condition in surface streams. The passages of caves of this type lie at, or slightly below, the levels of Pleistocene terraces and other former base-levels of erosion indicated in the present landscape. These "shallow-phreatic" caves can be recognized independently of their proximity to terraces because their passages (a) slope toward valleys, (b) in a branching pattern become more numerous but of smaller dimensions with increasing distance from the valley to which they are tributary, and (c) contain or show signs of once having contained free-surface streams draining ground-water from beneath upland areas to the adjacent valleys of perennial streams.

Most caves in Maquoketa River valley are of this type and, excepting a few which lie close beneath the former level of negligible erosion represented by the Kansan gumbotil (Kay, 1916) and which are of Yarmouthian age, all those along Maquoketa river which are of this type lie 20 to 60 feet below the Scotch Grove strath (see figure 3, No. 9). We interpret this association as evidence favoring a cyclic, rather than a structural, origin for the strath.

Age

Topographic relationships. That Maquoketa river is in a post-Nebraskan course is shown by its superposition indiscriminately across buried bedrock valleys. Because there are Iowan terrace remnants in the Maquoketa gorge through the Richland Highlands (Alden and Leighton, 1915) and because the Iowan glacier does not seem to have caused the permanent dislocation of any large stream in the valley, the superposition of Maquoketa river across the Richland Highlands cannot have occurred more recently than the Yarmouthian. Because the Richland Highlands segment of the valley is not bordered by a strath, it cannot be of the same age as is the remainder of the valley. The strath lies not less than 50 feet below the level of negligible erosion represented by the Kansan gumbotil, therefore it could not have been developed during Yarmouthian time. Maquoketa River valley has been neither aggraded nor flooded up to the level of the strath at any post-Yarmouthian time, the Illinoian (Flint, 1931), Iowan (Alden and Leighton, 1915), and Tazewell (Shaffer, 1954) levels falling short both of the strath and of its related caves. The Richland Highlands segment of Maquoketa River valley must consequently be of Buchanan age, the remainder of the valley and the strath bordering it of Aftonian age, and the buried bedrock valleys of preglacial age.

The distribution of the shallow-phreatic caves shows that the strath was developed along Maquoketa river in its modern course, except in the Richland Highlands. Caves along small streams in resurrected preglacial valleys north of North Fork river are no larger than are caves along small streams in Aftonian valleys superposed across buried preglacial valleys south of Maquoketa river, and all of these caves are much smaller than caves along the lower courses of Maquoketa and North Fork rivers. If the strath and the caves related to it were of preglacial age and Maquoketa river were hap-hazardly sprawled across them, this close positive correlation between cave size and stream size should not obtain.[1]

Stratigraphic relationships. It is interesting to note that the strath in Delaware county lies at the same elevation as the only recorded outcrops (Kay and Apfel, 1929) and well records (Iowa Geological Survey, unpublished data) of Nebraskan gumbotil, and at the same elevation as the top of the Rockville conglomerate (Tuttle and Northup, 1955) in Maquoketa River valley. While there are too few data available to permit confidence that these relationships may not be coincidental, they would seem to indicate the contemporaneous development during Aftonian base-levelling of four different kinds of features: (1) where streams were superposed from the Nebraskan drift plain across bedrock highs, they developed broad bedrock valleys now represented by the strath, (2) where drift in interstream areas extended below the level of the streams and was thus preserved from erosion, chemical weathering of the drift produced Nebraskan gumbotil, (3) where outwash sands and gravels lay in resurrected preglacial valleys below the level of the Aftonian streams, they were locally cemented into Rockville-type conglomerate, and (4) beneath bedrock areas bordering the streams, solution by ground-water developed shallow-phreatic caves.

Cave sediments. The sequence of sediments typically found within caves related to the Scotch Grove strath indicates an Aftonian age for the caves, complementary to the Aftonian age previously deduced for the strath.

Combining the partial sections exposed in Searryls Cave (located on the right bank of North Fork river at the east line of Jones county) and in the Maquoketa caves (located in and

[1] This association of largest caves with largest streams is in apparent contradiction to Davies (1960), who found that the largest caves in the Potomac River basin are mainly confined to headwater areas—are located along the smallest streams. However, the findings of Turyshev (1961) in the Ufa Plateau of Russia are similar to ours.

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near Maquoketa Caves State Park, Jackson county), the following sequence is made out:

5. sub-aqueously deposited calcite; also, sub-aerially deposited calcite and aragonite; also, (at entrances) talus
4a. —unconformity—
4. lacustrine silts and clays; also, sub-aqueously deposited calcite
3. fluvial sands and silts
2. sub-aerially deposited calcite
1. breakdown

These units are believed to represent: (1) partial collapse of the roof-rock due to loss of buoyant support when late-Aftonian entrenchment of Maquoketa river lowered the watertable, thus initially draining the cave (White and White, 1963); (2) sub-aerial deposition of speleothems during this late-Aftonian vadose stage; (3) aggradation of the cave streams consequent on aggradation of Maquoketa river with pro-Kansan outwash; (4) deposition of varved silt and of clay in caves now completely flooded due to the blocking of their mouths by Kansan debris; also, deposition on the cave ceilings of dog-tooth spar from $CaCO_3$-saturated water filling the caves; (4a) erosion of the preceding units by cave streams rejuvenated by post-Kansan re-entrenchment of Maquoketa river; (5) deposition of calcite crystals in travertine pools formed in erosion trenches (4a) as Maquoketa river quickly removed Kansan debris from its valley and lowered the water-table below the level of the caves — thus causing the cave streams to dry up; also, renewed deposition of sub-aerial calcite and aragonite speleothems; also, accumulation of talus dams across the mouths of the caves due to the attenuation of the volume of the cave streams below that required to keep the incident debris cleared away.

Because in all Maquoketa River valley caves, irrespective of their ages, there is present only one areally extensive breakdown, that breakdown being always confined stratigraphically to a position above the deposits of the first phreatic stage in the history of the cave and below the deposits of the first vadose stage, it is not believed that the breakdown units in these caves were caused by the passage above them of the glaciers, or by other recurrent events such as glacial-interglacial climatic changes. Because Maquoketa River valley has been neither aggraded nor flooded up to the level of the caves at any post-Yarmouthian time, the fluvial sands and silts and the overlying lacustrine deposits cannot be of post-Yarmouthian age. In view of these considerations, and in view of the above-described positive correlation between the sizes of the caves and the sizes of post-Nebraskan streams, it is believed that the interpretation given above of the typical sedimentary sequence in caves related to the Scotch Grove strath is that which is most compatible with the physiographic history of the surrounding region.

"Post-Kansan Erosion". The rock-bound gorges of the Maquoketa were at first believed to be of preglacial age (Calvin, 1895), due to their appearance of long-continued erosion. Later, Leighton (1917) assigned to them a post-Kansan age on the ground that the gorges appear to be unglaciated. Proposing an Aftonian age for the gorges entails explaining the absence of glacial characters within them and, in addition, the mechanism by which they were re-occupied following retreat of the Kansan ice.

The gorges of the Maquoketa might have been preserved from the Kansan glacier, either by filling with proglacial outwash, or by entombment in ice in the manner suggested by Wilson (1896) with respect to the rock gorges of the Iowan area. If ice-entombment did occur, the lingering of this ice beneath the ground-moraine and retreatal outwash for a time after the retreat of the glacier, melting later and producing depressions in the drift plain along the courses of the gorges, would have facilitated re-occupation of the Aftonian gorges by Yarmouthian streams. The preglacial rock valleys being relatively wider and straighter than the Aftonian, any ice formed in them prior to the arrival of the Nebraskan glacier would have been more likely to have been displaced and the valleys completely filled with drift, not to be re-occupied by Aftonian streams. On the other hand, if the observed accordance in elevation of the Nebraskan gumbotil with the strath is not coincidental, that is to say if the three gumbotil plains developed on the three pre-Wisconsin drifts should represent interglacial base-levels of erosian, it is difficult to understand how Maquoketa river could have re-occupied its winding bedrock valley during post-Kansan re-entrenchment without being superposed across spurs, for the Kansan gumbotil plain lies at or above the elevation of the bedrock throughout the area south and west of North Fork river.

Correlation

Topography. The strath is topographically equivalent to surfaces in Illinois described by Horberg (1946) from analysis of bedrock topography as the Central Illinois peneplain and by O. H. Hershey (1896) from visual examination of modern topography as No. 3 of the Freeport Baselevel Section. Both of these surfaces are developed along preglacial valleys and were assigned preglacial ages. Their relationships with Pleistocene stratigraphy were not stated, but they could have been formed at the level of drift fills in the preglacial valleys during Aftonian time and need not antedate development of lower areas of the bedrock topography, as Horberg and Hershey apparently assumed.

Horberg places the Central Illinois peneplain at 700 at 750 feet AT near Savanna, Illinois. Hershey places Baselevel No. 3 at 800 feet at Savanna. The Scotch Grove strath lies at 750 feet at the mouth of Maquoketa river, ten miles above Savanna. Horberg began his "Lancaster peneplane" at 800 feet near Savanna. However, in view of the gross methods employed and, particularly, of the questionable reality of a Lancaster, or sub-summit, peneplane (Bates, 1939), these discrepancies are not believed to be significant. Nor are the much lower gradients of the Central Illinois and No. 3 surfaces a valid objection to the correlation with them of the strath. Other things being equal, the much larger size of Mississippi river relative to Maquoketa river would enable it to develop a much lower gradient.

Stratigraphy. It was noted that the Scotch Grove strath, the Nebraskan gumbotil, and the Rockville conglomerate in Maquoketa River valley all occur at equivalent elevations. A partial examination of the literature on the Pleistocene geology of Iowa and Illinois has disclosed no references to Nebraskan gumbotil occurring at elevations above that of the Central Illinois peneplaine, or above the level at which the Scotch Grove strath will probably be found to occur in the other river valleys of northeastern Iowa, although Nebraskan drift is occasionally found to lie higher than the strath, or the Rockville conglomerate, or the shallow-phreatic caves, in modern interstream areas. The Olin occurrence of Rockville conglomerate (Tuttle and Northup, 1955) and Nebraskan gumbotil penetrated by wells near Anamosa (Iowa Geological Survey, unpublished data) occur at elevations equivalent to those of caves of uncertain age in the gorge of the Wapsipinicon at Anamosa. The Pine Creek conglomerate (Udden, 1898), which bears a gross resemblance to the Rockville, is equivalent in elevation to the Central Illinois peneplain on the Illinois side of Mississippi river.

While these few scattered locations are not definitive, neither are they antagonistic to the proposed correlation of the Scotch Grove with the Central Illinois, nor to the suggested relationship of strath, gumbotil, and conglomerate.

Caves. At the present time, no caves in northern Illinois are known to be related either to the Central Illinois peneplain or to Baselevel No. 3. This avenue of correlation remains to be explored.

Conclusions. None of the several available methods of correlation — visual examination, analysis of modern topography, analysis of bedrock topography, relationships with Pleistocene deposits, caves — is applicable to all three areas. For this reason, the correlation of the Scotch Grove, Central Illinois, and No. 3 surfaces must remain tentative. It is thought, however, that such a correlation is indicated by a preponderance of the evidence at hand.

Origin of the name, "Scotch Grove Strath". Although the strath along Maquoketa river would normally be defined as an extension of the Central Illinois peneplane, the different age which we derive for the strath indicates the desirability of giving it a name having the connotation of Aftonian age. We find a precedent for this in the use of "Hennepin cut-off" in reference to buried preglacial Princeton valley between Fulton and Hennepin, Illinois, when origin marginal to the Kansan ice is implied. In the absence of any settlements built upon the strath and of any local geographic name attached to it, we have named it for the village of Scotch Grove, which stands on the drift plain adjacent to the strath in central Jones county.

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Preliminary Investigation of Thermokarst Development on the North Slope, Alaska[1]

GARY S. ANDERSON[1] AND KEITH M. HUSSEY[2]

The North Slope of Alaska is extensively featured by a characteristic form of morphology designated "thermokarst". Briefly, thermokarst is a term applied to a "karst-like" topography formed in permafrost regions that have had extensive thaw. Aerial photographs of the North Slope reveal many thaw features that have forms analogous to karst areas.

GENERAL DISCUSSION AND LITERATURE REVIEW

Since the phenomenon of thermokarst has not been extensively studied and a majority of people without experience in the Arctic or Subarctic are not acquainted with the term, it seems warranted to summarize some of the problems associated with limitations imposed by definition of the term and the classification of thermokarst features; and also to discuss the developmental features and the work that has been done in the field to date. The term thermokast was proposed by M. M. Ermoleav in 1932 (Mukhin, N. L., 1960) as ". . . a form of relief having a certain similarity to karst formation but resulting from the action of heat." At the time of Mukhin's work (1960) he consid-

[1] Formerly, Iowa State University, Ames, Iowa, now University of Alaska, College, Alaska.
[2] Iowa State University, Ames, Iowa.