PRESIDENTIAL ADDRESS

PROBLEMS OF INTERPRETING THE BEDROCK SURFACE OF ILLINOIS

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One of the traditions of the Illinois State Academy of Science is that the retiring president discuss some topic of scientific research, or education, in which he has a personal interest. This tradition seems worthy of perpetuation, at least as a means of emphasizing the objectives of the Academy, and it is my sincere hope that those of you who are outside of my own area of research will find something of interest in these comments.

As my contribution to this succession of discussions, I wish to consider briefly some of the problems that one encounters in any attempt to interpret historically the development of the topography on the bedrock of Illinois. Over much of Illinois, the bedrock surface is obscured by glacial, alluvial, and eolian deposits that range up to several hundred feet in thickness, and for the most part, therefore, it is a buried topography with which we are concerned. As a somewhat naive graduate student, I first became involved in the interpretation of this bedrock surface in 1937 when, with the aid of the Illinois State Geological Survey, I undertook a study of the history of the abandoned valley of the Ancient Mississippi River (Frye, 1938). Since that time, I have had only intermittent opportunities to continue work on this problem, but others have contributed significant data and interpretations and I have continued to be interested in considering the regional implications of these data in the solution of the problem of reconstructing the history of this bedrock surface.

Illinois occupies a unique position in the drainage history of the vast interior of the North American continent. The southern tip of the state includes the northern limit of the Mississippi Embayment along which the Tertiary marine invasion penetrated most deeply into the continental interior. Forming the boundaries of our state are the Mississippi, Ohio, and Wabash Rivers — and the mouth of the Missouri River is at our western border. The gulfward outlet for part of the evolving glacial Great Lakes was by way of the Illinois River valley, which extends diagonally across the state. In other words, Illinois has been a focal point for the streams that sculptured the bedrock topography of the continental interior and, thus, our area may be critical to the interpretation of the regional erosional history of much of the Mississippi River basin.

The shape of the bedrock surface

over most of Illinois, masked by its mantle of glacial deposits, has been described by Horberg (1946, 1950), and the erosional history of the unglaciated "driftless area," which includes the northwestern corner of Illinois, has been analyzed by Trowbridge (1921). In many parts of Illinois, the relief on the eroded bedrock surface is greater than that of the present topographic surface because the deep valleys that were cut into the bedrock are invariably filled, at least partly, with Pleistocene deposits, whereas bedrock extends, in general, to the highest points of the present topography. Nevertheless, the shape of the bedrock surface is generally similar to that of the present surface in that it is characterized by relatively broad and flat tabular uplands that are notched by sharply incised valleys.

These tabular uplands are not all at an accordant or consistent level, but within the uplands there are several "preferred" elevations that have been considered to be the product of the partial destruction of former, relatively flat surfaces that had been developed by several distinct cycles of erosion (Trowbridge, 1921, 1959; Horberg, 1946, 1950; Leighton, Ekblaw, and Horberg, 1948). It is generally agreed that the erosional incision that produced the deep bedrock valleys took place after the last cycle of planation, or "peneplanation," that developed these extensive upland plains. There is marked disagreement, however, concerning the age and the sequence of events that produced the erosional trenching below these upland surfaces and thus gave rise to the systems of major valleys — both past and present. At one extreme in the range of historical interpretations is the conclusion that the topography of the bedrock surface, including the excavation of the deepest bedrock valleys, had developed to essentially its present form during the Tertiary Period (that is, prior to the first episode of continental glaciation), and that during the Pleistocene (or glacial) Period the erosional history of Illinois consisted of little more than the burial of a former landscape. At the other extreme of interpretation is the view (Frye, 1938) that the deepest erosion of the bedrock valleys did not take place until after the advance of the Kansan glaciers, which concludes, therefore, that this event took place at a point in time nearly halfway through the glacial age.

It is true that we are dealing with differences of interpretation based on inadequate and incomplete data, many of which are themselves subject to differences in interpretation. When we consider the means that may be used to resolve such a marked difference of opinion, it appears that there are three general approaches that may be helpful. These are, first, the comparison, or analogy, of the relationships as we see them in Illinois with other parts of the Mississippi drainage system where the physical events, including the erosional history, have been independently dated. We may use a second approach to the problem by determination of the ages of the deposits that rest upon the various elements of the bedrock surface in Illinois and then use these dates as limiting points in the development of the surfaces on which the deposits rest.

And third, we may use the genetic implications of the shape and character of the surface itself as a guide to the erosional history. Let us briefly examine these several lines of evidence.

In using the first approach to our problem, when we search for regions within the present Mississippi River drainage basin with which to establish analogies with dated sequences of events, we are confronted with the fact that a well established late Tertiary and early Pleistocene chronology does not exist in the eastern or northern parts of the basin. When we look southward toward the Gulf, we find that the Tertiary chronology is based on the marine sequence and that the nonmarine Pleistocene deposits are largely correlated with events in our own region. It appears that the most profitable direction to look for a meaningful analogy is toward the west and southwest, because in that part of the basin we find a nonmarine stratigraphic sequence extending throughout the late Tertiary and Pleistocene that has been correlated by vertebrate and invertebrate fossils, as well as by physical stratigraphy. The type areas of the two earliest episodes of Pleistocene continental glaciation occur in the Missouri basin (Frye and Leonard, 1952) and these early glacial stages have been integrated with the stratigraphic sequence in the Great Plains, which serves to place them with relation to a well dated sequence of late Miocene and Pliocene strata (Frye, Leonard, and Swineford, 1956; Frye and Leonard, 1959). Toward the southwest, beyond the direct influence of continental glaciers, the deposits and terraces in the Red River basin (Frye and Leonard, 1963) have also been integrated with the Great Plains' chronology. As the Red River and the Missouri-Kansas River system are major tributaries to the Mississippi, their erosional histories should be pertinent to our problems in Illinois. These two basins present distinctly different bases of comparison as the Missouri-Kansas Valley was directly invaded by continental glaciers, whereas the Red River basin was beyond the reach of continental glaciation and its history therefore reflects only the regional climatic changes and structural events. The evidence from these western tributary basins (Frye and Leonard, 1952, 1963) strongly indicates (1) that the late Tertiary drainage lines were at relatively high levels and were associated with surfaces comparable to our tabular uplands; (2) that marked valley incision took place during the Nebraskan; and (3) that the Kansan glacial stage witnessed the final establishment and much of the deep trenching of major valleys in the positions they now occupy. It is true, particularly in the southwest, that valley dissection during the Illinoian and Wisconsinan generally exceeded the depth of the Kansan valley floors and locally produced drainage changes. but otherwise did not profoundly modify the bedrock topography. It appears that our first approach supports the interpretation of a young age for the deep bedrock valleys, but this cannot be considered conclusive evidence until the terraces have been traced from these areas into the Illinois region.

When we consider our second approach to the problem by the dating of deposits that lie upon and above the bedrock surface in Illinois, we discover that this method becomes progressively more precise as we approach the Recent in age (Leverett, 1899; Frye and Willman, 1960; Willman, Glass and Frye, 1963). Some unconsolidated deposits on bedrock (e.g., in Adams and Pike Counties) may be as old as Cretaceous and thus define in a present upland the position of a surface that developed prior to the Tertiary. Many deposits of chert gravels in upland situations in southern and western Illinois have been called "Lafayette type" and have been assigned a Tertiary age by many workers. On the basis of these age assignments it generally has been held that the bedrock upland surfaces were all developed prior to the end of Tertiary time, and further, that the supposed absence of Pleistocene water-laid deposits on these uplands implies that the trenching of the deep valleys also took place before the end of Tertiary time. Although it is probable that ages from Cretaceous through Tertiary are represented by some of the upland gravels in Illinois, many, if not most of these deposits have not as yet been dated with certainty. Some of the upland gravel deposits, as exemplified by exposures in southern Calhoun County, contain pink quartzite boulders more than two feet in diameter, and exceedingly sparse cobbles of igneous rock; such deposits are most reasonably explained as the product of glacial transport — probably by the Nebraskan. As these deposits of probable Nebraskan age occur on tabular divides above deep bedrock valleys their presence casts doubt on the existence of the deep valleys at the time of their deposition.

In Illinois we find that confirmed localities of Nebraskan glacial till are so rare as to have minor value to the solution of this problem. However, there are a few water-laid gravel deposits for which a Nebraskan age is fairly well established, for example north of Banner in Peoria County. The position of these deposits suggests that by Nebraskan time the major valleys were incised below the bedrock tabular uplands, but probably were well above the position of the present flood plains of the major valleys.

Since neither Tertiary deposits nor Nebraskan glacial till serve to define with certainty the age of the deep bedrock valleys in Illinois it appears that the relation of Kansan till (that is, the second major glacial episode) to the bedrock surface may be critical to our problem. As the position of the Ancient Mississippi Valley has been described (Horberg, 1950; Frye, Glass and Willman, 1962) as leaving the present Mississippi above Moline and trending east south-east to the bend of the Illinois River in Bureau County, and approximately along the Illinois Valley to the Mississippi near Alton, it would appear that there should be ample opportunity to relate Kansan till to this major valley trench. Unfortunately, however, the Kansan glaciers from the west fell just short of reaching this valley and it is not known whether or not the Kansan glaciers that invaded Illinois from the northeast reached this far to the west (Willman, Glass and Frye, 1963). Such a geographic pattern deprives us of the possibility of relating the stratigraphy of tills of Kansan age to the trench of the Ancient Mississippi Valley. Also, this same geographic pattern causes one to speculate as to the possibility that these glacial fronts may have been the barriers that served to establish the course of this major stream. Definitive use of this approach must await refined subsurface studies in east-central Illinois of correlations of the several till sheets and the relation of these tills to the bedrock valleys of eastern tributaries to the Ancient Mississippi River.

In spite of the uncertainties in the use of this method of establishing Tertiary and early Pleistocene dates for bedrock sculpture, when we reach Illinoian time the stratigraphy of the deposits overlying the bedrock shows us conclusively that the major bedrock valleys had been cut into their deep channels before the advance of the Illinoian glacier. The Ancient Mississippi River, which had temporarily been diverted to a western course by the advancing Illinoian glacier, returned to its former course, reflected in the topography of the till plain surface by sags over the deep erosional valleys, after the withdrawal of the last of these pulsating glaciers. This ancient course, although it was roughly parallel to the position of the present Illinois Valley, was somewhat east of it in Putnam, Marshall, Woodford, and McLean Counties, and it joined the trench of the present Illinois Valley by way of the lower Sangamon Valley in southwestern Mason County. The major stream was not forced into the present position of the Mississippi River until the first advance of the Woodfordian glaciers during the later part of Wisconsinan time. The Mississippi was subsequently prevented from returning to the ancestral course by the presence of prominent end moraines across the position of the buried bedrock valley in Bureau County.

Now let us turn to our third approach to the problem, by consideration of the genetic implications of the shape or form of the bedrock surface itself. Trowbridge (1921) utilized this approach in his detailed analysis of the several accordant levels within the divide areas in the unglaciated region of the upper Mississippi Valley "Driftless Area," and Horberg (1946, 1950), by use of extensive subsurface data, has analyzed the planated surfaces below the drift in Illinois. Studies that have been made of the upland bedrock topography, both where it is buried by glacial deposits and in the unglaciated region, have mostly reached the conclusion that several cycles of regional erosion occurred before the event of major dissection that produced the deep bedrock valley trenches. If several distinct cycles of erosion did in fact occur, each of them must have progressed to an advanced stage to have produced the broad flat areas that are ascribed to them. It is not our purpose here to attempt to determine if these seemingly accordant levels are the result of multiple cycles of peneplanation caused by sudden marked changes in base level, or if they were produced by one continuing episode of erosion and therefore are the reflection of differences in the erosional resistance of various bedrock units, or, perhaps, if they may even represent successive pediplains. It is sufficient for our purposes to agree with the overwhelming weight of evidence that the upland surfaces had been developed by the end of Tertiary time and that during Pleistocene time they were modified only locally by glacial erosion. Therefore, we are again brought back to the problem of the interpretation of the deep bedrock valleys cut below these upland surfaces. When we consider these bedrock valleys from the viewpoint of their morphology we find that we have both regional data (Horberg, 1950) and local details that are not compatible with an erosional development expectable under conditions of structural stability and uniform base level control over an extended period of time.

The local details of morphology, although suggestive, are far from conclusive in the solution of our problem. The significant features of the local topography include precipitous valley bluffs suggestive of youthful canyon cutting, both at the surface and buried beneath the Pleistocene fill; sharply faceted spurs, particularly along the lower part of Illinois Valley; tributaries whose bedrock floors have oversteepened gradients adjacent to the master valley; and a drainage pattern that certainly is not reminiscent of a long established and well adjusted drainage system.

The outstanding regional morphologic anomaly of the major valleys is the gradient of the bedrock floor of Ancient Mississippi Valley. For a distance of about 350 miles south of the northern border of Illinois the floor of this bedrock valley, as contoured by Horberg (1950), declines less than 50 feet in altitude, which indicates the equivalent of a uniform gradient, if it is in fact uniform, of less than 1/7 of a foot per mile. Such a gradient is clearly inconsistent with the shape and pattern of this erosional valley. Furthermore, we are confronted with the necessity of explaining this anomalous gradient across a region where the structure of the bedrock gives us no helpful clues.

A reasonable explanation of gradients in these bedrock valleys may be furnished by the concept of temporary warping of the crust produced by the loading and unloading of glacial ice during the Pleistocene. Such a concept has been suggested as the explanation of the anomalous gradient of the bedrock valley floor of an abandoned drainage way through which Kansan outwash discharged in central Kansas (Frye and Leonard, 1952, p. 190). Although no direct measure of crustal depression by earlier glaciers is possible, it has been estimated that the last maximum of the Wisconsinan glacier depressed the crust more than 2000 feet in central Canada (Farrand and Gajda, 1962, p. 10). Unless we assume that the rocks of the crust are without strength there must have been a complementary "forebulge" surrounding this depressed area. Such an isostatic "forebulge" might be compared to the low ridge that rises around a pebble dropped on the surface of a pool of partly congealed tar. Furthermore, if we relate the central isostatic depression and peripheral elevation to a simple lever, a positive movement at the crest of the "forebulge" of more than 200 feet seems reasonable.

In order to gain a better quantitative view of the crustal situation, L. D. McGinnis, geophysicist with our Survey, has calculated volumes of crustal material that would be involved if we assume a symmetrical ice mass comparable in maximum dimensions to the Wisconsinan and with the amount of central depression assigned to this last glaciation. He suggests that the total volume of rock displaced to accommodate such a depression beneath this idealized ice cap amounts to about 2.6×10^5 cubic miles. This volume would have to move into the "forebulge" area unless the earth behaved like a liquid, which it doesn't. If this volume were moved into a 400 mile wide ring around the generalized "circle" of the ice cap the peripheral ring would be raised in elevation about 420 feet. If this volume were moved into an 800 mile wide ring, the ring would be raised roughly 160 feet.

If we project these relations backward in time it is apparent that both Illinoian and Kansan glaciers were more extensive, at least in Illinois, than were the Wisconsinan glaciers and therefore it is safe to assume that the isostatic movement of the surface was as great or greater than these approximations during the Kansan and Illinoian glacial episodes, and that they may have equaled this amount during the Nebraskan.

Another factor that is pertinent to our analysis of the effect of isostasy on valley development is the timing of the causes and effects. Rebound after glacial unloading is known to lag by some thousands of years before the crust approaches a return to equilibrium (Farrand and Gajda, 1962) and it is reasonable to assume that the subsidence of the peripheral bulge must also lag behind the removal of its cause. Also, the speed with which glaciers are know to have advanced and retreated (Frye and Willman, 1960) suggests that isostatic crustal movement lagged behind the causative event. These time relations lead to the conclusion that when continental glaciers were advancing rapidly they were riding up onto the back side of their own induced "forebulge", and that when they were retreating rapidly a topographic depression generally occurred between the margin of the glacier and the back-slope of the peripheral swell or forebulge.

When we consider the locations, shapes and gradients of the deep bedrock valleys of the Illinois region in light of the foregoing it appears that many of the apparent anomalies may be explained by valley incision below a temporarily up-warped surface during and immediately following episodes of continental glaciation, and that the present gradients of the bedrock floors of the deep filled valleys are quite different from the stream gradients that existed while these sharply incised valleys were being cut.

If a stream were forced across the position of a forebulge by the physical presence of glacier fronts it seems certain that the large volumes of water known to have been present during episodes of glaciation — and therefore flowing down these abnormally steep gradients — would have produced rapid incision of valleys characterized by a youthful morphology. Thus, positions of major drainage lines would have become fixed before the complete dissipation of the glaciers and before isostatic readjustment could have been far advanced. As the interval of rapid and deep valley cutting must have been followed by the subsidence of the forebulge area and the resultant flattening, or even reversal of the gradients in segments of the major valleys, the final result would be overdeepened valleys cut in bedrock and subsequently partly filled by alluvial deposits. Indeed, this is the situation as we find it in Illinois. It is interesting to note that the long segment of essentially no gradient in the bedrock valley of the Ancient Mississippi is within a region that should have been strongly influenced by forebulges of both the Kansan and the Illinoian glaciers, and that might also have been similarly influenced by the Nebraskan glacier. Consideration of this approach to the general problem of genetic interpretation of the bedrock surface of Illinois may prove to be a fruitful field for detailed research in the future.

In this brief review it has not been my intention to attempt definitive answers to the many questions involved in the interpretation of the history of the development of the bedrock surface of Illinois, but rather to point out some of the problems as they appear to me and to suggest some of the possible lines of attack on these problems. If by so doing I have helped to stimulate new thought and activity, I will have been successful.

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