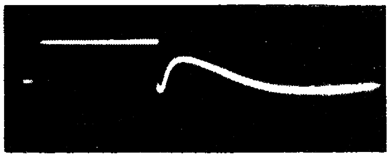

Fig. 1. Oscilloscope trace of response to tap stimulus.

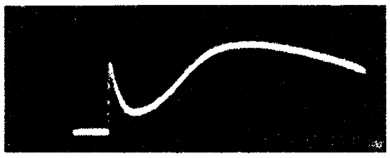

Fig. 2. Oscilloscope trace of response to electric stimulus.

disappears on repetition and when the plasmodium is killed. In addition, there is apparently an upper limit as the intensity of the blow is increased. The magnitude of the response may reach as high as 75 millivolts. There is good but not conclusive evidence that the magnitude of the response to a given strength of stimulus is significantly related to the vigor of the plasmodium. It can be demonstrated that this stimulus response is propagated along the thread.

In order to obtain a full picture of this response, the sweep speed of the oscilloscope was reduced to 2 seconds per inch by connecting a high capacitance across the sawtooth terminal and ground. Since the parameters of this response can be defined with considerable accuracy, it would seem that such a preparation makes an ideal test specimen for the assay of the effect of a variety of chemical agents on the activities of the protoplasm.

The attempt to stimulate the plasmodium electrically is fraught with many difficulties. The physical state of the environment of the plasmodium, which is determined in part by the electrolyte solution, the dimensions and placements of the electrodes, and the resistance and distributed capacity of the whole system in the absence of the plasmodium, produces pictures that are similar to a biological response. However, an electric response can be obtained, as is evidenced by Figure 2. Taken under the same conditions of calibration as the tap stimulus, the response shows qualitatively the same characteristics. Again the magnitude of the response would seem to be in some measure related to the vitality of the protoplasm, since a vigorous thread of rapidly streaming protoplasm gives a higher response than a thin thread with somewhat sluggish flow. Very rarely is the magnitude of the response anything like that following a tap stimulus.

The conditions necessary to produce an electric response to an electric stimulus seem quite different from those reported by Tasaki and Kamiya (*2*). The technique used in this study showed no evidence of a millisecond response, no matter what the voltage or current employed. Instead, it was found that a stimulus of at least 0.1-second duration seemed to be required. With such a duration, a response was obtained with a stimulus of 800 microamperes at 1.5 volts. Increasing the strength of the stimulus to 1 milliampere at 4.5 volts produced a graded response. Occasionally, this could be carried into higher levels. However, if the electric stimulus was increased very much, either the response failed completely, possibly because of a shock effect, or else it was obscured by the stimulus artifact.

The difficulty in getting a consistent response from the familiar electric set-up is the result of the simple fact that the protoplasmic thread is not a nerve fiber. A slime mold is capable of transmitting a stimulus just as is all living matter, but it differs from other tissues. For example, an excellent action potential of *Dionaea* was obtained by Stuhlman and Darden (*3*) with a maximum of 130 millivolts.

Tauc (*4*) attempted to find an action potential in *Physarum* but obtained only a spontaneous drop in the resting potential that was possibly owing to the formation of a membrane over the electrode.

The plasmodium of a slime mold is in reality "tissue" in the sense that it is an aggregation of centers of activity that are "cells" without walls. In short, it is not a homogeneous mass even though it is a continuous sheet of flowing protoplasm. Moreover, it moves—toward food, for example—as an integral whole and must therefore possess some means for transmitting stimuli from one point to another (*5*).

We may conclude, then, that a strand of one of the most primitive forms of life yields an action potential, both when it is stimulated electrically and when it is stimulated mechanically.

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References and Notes

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5 July 1955

Regional Crossbedding and Petrology as Source Area Indicators

Basal Pennsylvanian sediments (Caseyville, Mansfield, Babylon sandstones, and equivalents) of the Eastern Interior Basin (Fig. 1) are separated by 500 to 1200 miles from possible source areas such as the Canadian shield and inferred Paleozoic uplands to the east. This geographic separation, together with mineralogic maturity and lithologic uniformity of the sandstones, makes it difficult if not impossible to determine source areas from regional variation of gross lithology. This is especially true because appreciable extrapolation beyond present basin limits is required. Our solution to this problem involves regional measurement of crossbedding and regional sedimentary petrology to determine the location and composition of probable source areas.

In order to have fullest confidence in our conclusions, it was necessary to study basal Pennsylvanian sandstones of the Michigan Basin (Parma sandstone) and portions of the Appalachian Basin (Sharon and Lee sandstones) in addition to the sandstones of the Eastern Interior Basin. Inclusion of these areas led to more definitive conclusions about Eastern Interior Basin sediment sources and provided the essential key to a sediment source interpretation of the basal Pennsylvanian of much of the northeastern part of the United States.

More than 950 measurements of crossbedding in 340 outcrops were obtained from more than 1000 miles of linear basal Pennsylvanian outcrop in the North Central States. Statistical analysis (hierarchical case of the analysis of variance) provided measures of reliability for average directions of sediment transport and also segregated total variability of crossbedding direction into small scale (within an outcrop), intermediate scale (within a 6- or 12-mile interval), and large scale (between 6- or 12-mile intervals along the outcrop belt). The order of variability within an outcrop is much less than it is within an intervals and within an interval it is greater than it is between intervals along the outcrop belt.

Regionally, crossbedding direction is very uniform. Crossbedding points south-southwest in all areas studied except in western Illinois, where it points southeast. The crossbedding is interpreted as accurately reflecting sediment transport on the regional slope from the source area toward the area of greatest subsidence and crustal instability (Ouachita trough). Excluding western Illinois, a general southwestward tilt of the craton in the North Central States is implied.

Because of the orthoquartzitic char-

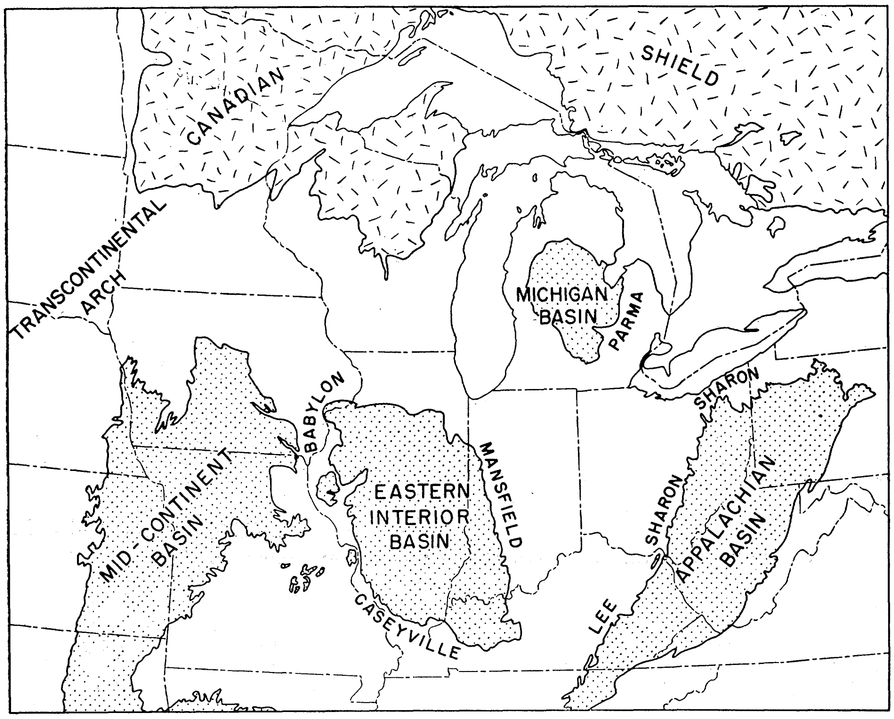

Fig. 1. Index map showing general structural framework of area and basal Pennsylvanian formations studied.

acter of these sands, relative abundance of the quartz varieties and tourmaline roundness provided the best basis for determination of regional mineral associations. Measurements of these two parameters, together with modal mineralogy, analyses, were obtained from 79 samples. Statistical analysis (the analysis of dispersion, a form of multivariate analysis) was used to test for significant differences between mineral associations. In western Illinois, where crossbedding indicates a southeastward transport direction, feldspar is very low (less than 1 percent), metamorphic quartz varieties are low, and tourmaline roundness is high. The high roundness of these sands implies a long history of abrasion. Their mature mineralogy indicates a similar conclusion.

Hence, the basal Pennsylvanian sands of western Illinois were derived from preexisting sediments with a long transport history. In contrast, the basal Pennsylvanian sediments of other parts of the North Central States, which all have a general south-southwestward flow pattern, have somewhat more feldspar (1 to 5 percent), more metamorphic quartz, and low tourmaline roundness; they are also characterized by metamorphic quartz pebble conglomerates. This implies a source area dominantly composed of preexisting sediments only one or two cycles removed from their parent crystalline rocks. In each case, contrasts in transport direction coincide with detrital mineralogic contrasts.

Based on this crossbedding and petrologic evidence, most of the northeastern part of the United States, including the Michigan Basin, the northwestern portions of the Appalachian Basin, and most of the Eastern Interior Basin, had a common source in the northeastern United States and/or in the southeasternmost parts of the Canadian shield. The western Illinois part of the Eastern Interior Basin, farther in the interior of the continent, had a minor source to the northwest, the Transcontinental arch.

This study (*1*) shows the value of field mapping of appropriate directional sedimentary structures (in this case, crossbedding; in other cases, flow marks, slump structures, and so forth) as a rapid and easy method of assessing source area location. Sedimentary petrology leading to knowledge of regional mineral associations not only permits inferences concerning composition but, further, provides a valuable internal check on the degree to which the directional sedimentary structures truly reflect the regional slope. Knowledge of regional mineral associations is especially necessary in clean marine shelf sandstones where relationships of sediment transport direction to the regional slope are not completely understood.

Basal Pennsylvanian sediments, a relatively thin stratigraphic interval, show a very widespread areal uniformity in sediment transport direction. Over smaller areas, it has been shown that similar uniformity of transport direction exists through many hundreds of feet of both shallow shelf and geosynclinal deposition (*2–4*, and others). Thus, it appears that in many cases of both cratonic and geosynclinal sedimentation, large sedimentary volumes have had relatively uniform transport directions. Such uniformity appears to be especially characteristic of stable shelves and geosynclines in the preorogenic stages of development. Distribution of structural elements and magnitude of differential activity between them control this uniformity.

The combined knowledge of directional sedimentary structures and petrology thus provide on a regional scale a sensitive and rapid assessment of the ultimate objectives of a provenance study—regional tectonics and paleogeology. Additional provenance studies using the methods employed here will probably be the most accurate and rapid way available for reconstruction of the structural development of the continents.

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1. This article is published with the permission of the chief, Illinois Geological Survey. A complete report of this investigation will be published in *J. Geol.*
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Necessity is not the mother of invention; knowledge and experiment are its parents. This is clearly seen in the case of many industrial discoveries; high-speed cutting tools were not a necessity which preceded, but an application which followed, the discovery of the properties of tungsten chromium-iron alloys; so, too, the use of titanium in arc lamps and of vanadium in steel were sequels to the industrial preparation of these metals, and not discoveries made by sheer force of necessity.—W. R. WHITNEY.