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# GLACIAL GEOLOGY AND GROUNDWATER FLOW IN NORTHERN AND CENTRAL INDIANA

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## INTRODUCTION

Glaciologists in the past twenty years have made significant strides in understanding the patterns of deposition associated with glacial processes. These strides are not unlike the changes in geohydrology that we have witnessed in the same period in that they have been based on applying a new paradigm. In groundwater hydrology, quantitative modelling has allowed new predictions to be made about the response of complex systems to stress. In glaciology, a qualitative depositional systems model has allowed new predictions to be made about the continuity and variability of depositional units related to environments associated with glaciation. Ashley, *et al.* (1985) give five environments of deposition associated with glaciation: the subglacial, ice marginal, proglacial fluvial, proglacial lacustrine, and proglacial aeolian environments.

Deposits formed in these different environments also have different characteristics. Most importantly to geohydrologists, a certain predictability of sediment type and distribution is associated with each environment. This predictability allows hypotheses to be framed and tested. Geohydrologic tests of stratigraphic hypotheses can be performed, as well as conventional geologic tests such as coring and test drilling. For example, the interconnectedness of sands in a dominantly till setting is more easily evaluated by geohydrologic tests than by stratigraphic tests. The continuity of fine-grained deposits in a coarse setting, however, is probably more easily resolved using stratigraphic tests. The importance of understanding the depositional environments of glacial sediments is that it provides conceptual models for the spatial distribution and geometry of the various sediment bodies.

This paper presents four case studies from Indiana. These cases, however, do have analogues in the States adjacent to Indiana. The first two of these cases concern dominantly fine-grained deposits in four of the glacial environments. The final two are in dominantly coarse-grained deposits in the proglacial fluvial environment.

## PROGLACIAL LACUSTRINE WITH SUBGLACIAL AND ICE MARGINAL ENVIRONMENTS IN NEWTON AND JASPER COUNTIES

A droughty, sandy soil in Newton and Jasper Counties had supported scrub oak and cattle grazing before a corporate farm was developed to change the land to row-crop production. The row crops were irrigated with groundwater from bedrock. Bergeron (1981) studied the geohydrology of the area, and Figure 1 is taken from his report. The surficial deposits consist of aeolian sand (deposited initially in a proglacial aeolian environment) over sand and gravel (proglacial fluvial environment). These coarse sediments are underlain by till (subglacial and ice marginal environment) and lacustrine clays (proglacial lacustrine envi-

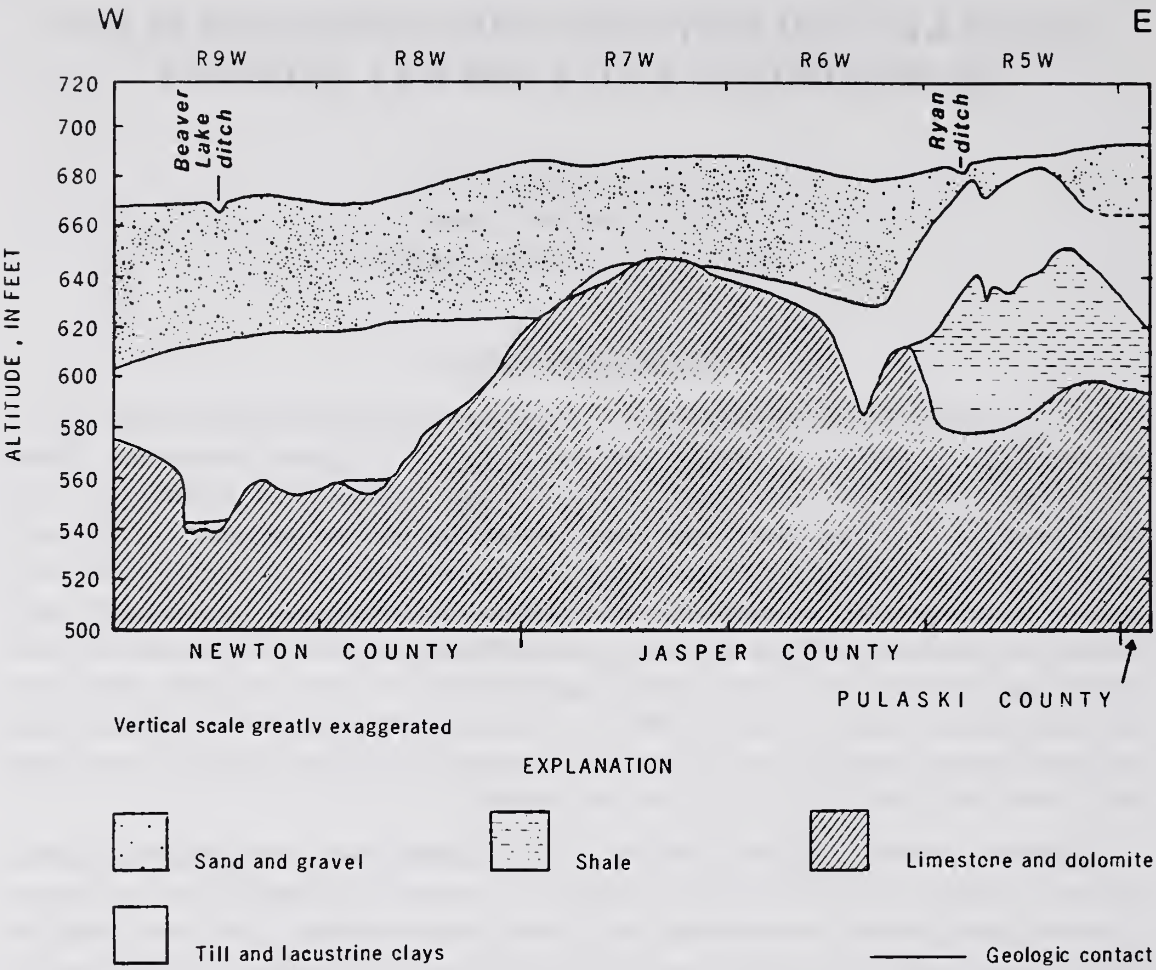


FIGURE 1. A west-to-east cross section from near the state line across Newton and Jasper Counties, Indiana (Modified from Bergeron, 1981, p. 12).

ronment) deposited on the bedrock. The bedrock is generally Silurian carbonate with fracture permeability, although there are some Devonian shales in places. Bergeron (1981) treated the till and lacustrine clays as a single semiconfining bed that allowed only vertical leakage between the overlying sands and the underlying bedrock aquifer. He assigned no storativity to this layer. In the ground-modellers lexicon, the till and lacustrine sediments were treated as a Tk layer.

Bergeron's (1981) model of the system was calibrated to a limited set of data gathered before irrigation began. The model predicted the response of the bedrock, the aquifer used for irrigation, reasonably well. The model, however, predicted declines in water levels in the surficial materials of several feet, after the irrigation pumpage started. Such declines in the surficial aquifer have not been observed to date (Basch and Funkhouser, 1985). The discrepancy between the observed and simulated responses is caused by the neglect of the storativity of the semiconfining materials. In the model, the recovery of the water levels in the bedrock aquifer was caused in part by leakage from the surficial aquifer through the semiconfining material.

As a result of the model's failure to predict accurately the changes in water levels in the surficial aquifer, a new study was begun with the focus being to investigate the storativity of the semiconfining beds. That study is still underway,

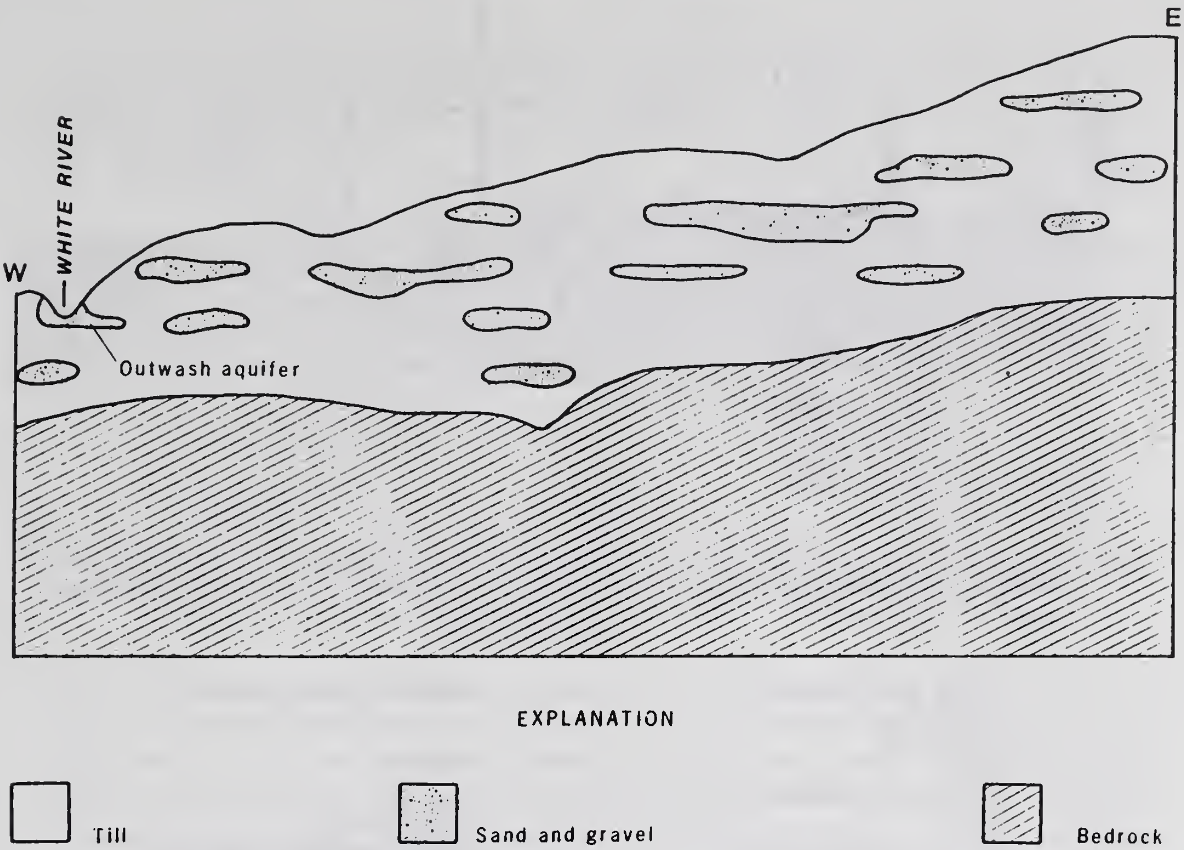


FIGURE 2. A west-to-east cross section across southern Delaware County, Indiana (Modified from Arihood and Lapham, 1982, p. 8).

but the importance of the distinction between the till and the lacustrine material is clear. While drillers commonly call the lacustrine material clay, it does contain a significant amount of silt and fine sand. But pity the poor geohydrologist trying to map the extent of till and lacustrine material on the basis of drillers logs. This interpretation is precisely the strength of new techniques in glacial stratigraphy. Using a limited set of gamma logs, the counsel of glacial stratigraphers, the predictive abilities of depositional-systems models in glacial terranes, and a knowledge of the hydraulic responses of materials in the field, the project personnel are taking the change in materials in the semiconfining beds explicitly into the model which is now being constructed.

It is too early to give out quantitative results. The project team, however, has decided that some recharge to the bedrock does come from storage in the semiconfining beds (Les Arihood, U.S. Geol. Surv., personnal communication, 1987). The long term question yet to be answered, of course, is what will happen when the stored water is used. If the water then will be derived ultimately from the overlying surficial materials, Bergeron's (1981) model predictions in the gross sense still will prove to be true.

## SUBGLACIAL AND ICE MARGINAL ENVIRONMENTS IN THE UPPER WHITE RIVER BASIN

The form, distribution, and interconnectedness of sands and gravels within till sequences is a difficult problem. Aquifers of this type commonly yield 10 to

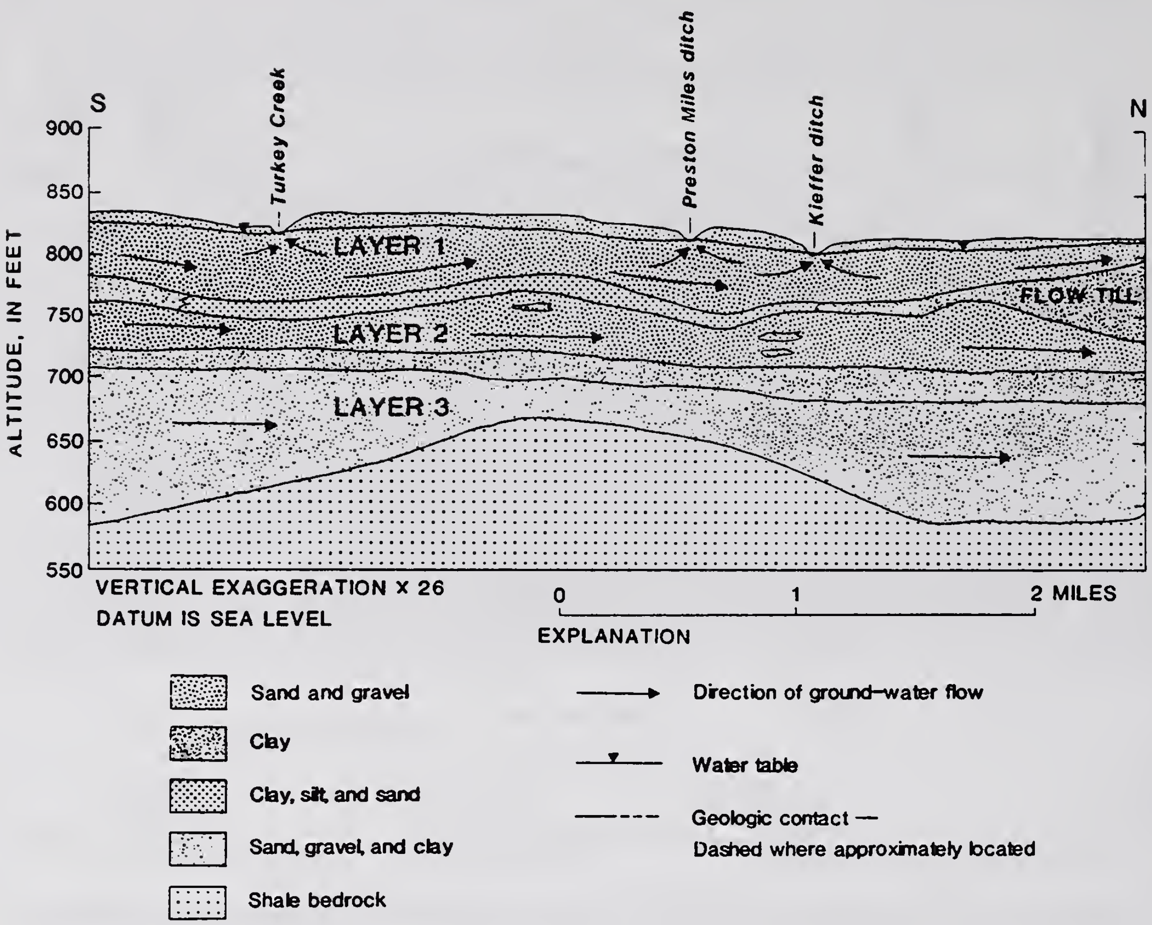


FIGURE 3. A south-to-north cross section across the border between Elkhart and Kosciusko Counties, Indiana (Modified from Lindgren, *et al.*, 1985, p. 12).

100 gallons per minute with exceptional wells yielding in excess of 400 (Banaszak, 1985). Arihood and Lapham (1982) studied this type of system in Delaware County, and Figure 2 is taken from their report. As can be seen, the sand as well as sand and gravel units were treated as basically isolated lenses of reasonably large extent. These units coalesce locally (Arihood and Lapham, 1982) to form more vertically extensive aquifers than are shown in Figure 2. Meyer, *et al.* (1975) were the first geohydrologists to work on this problem quantitatively in Marion County in Indiana. All workers are impressed with the difficulty and variability associated with these inter- and intratill aquifers.

In spite of the difficulties, reasonably accurate predictions of the quantity of water moving in these systems have been made. Additionally, in Marion County, the success of predicting the depth to and thickness of the first producing zone based on the maps of Meyer, *et al.* (1975) has been very good. The usefulness of similar maps by Arihood and Lapham (1982) has also been confirmed (Allen Samuelson, Ball State Univ., personal communication, 1986).

Understanding the interconnections of the sand and gravel aquifers becomes important for the planning and siting of potential sources of groundwater contamination in the relatively favorable surficial setting of till plains. As yet, no study to assess this potential on other than a site-specific basis is underway. The success of the relatively crude maps to predict the quantitative hydrology suggest

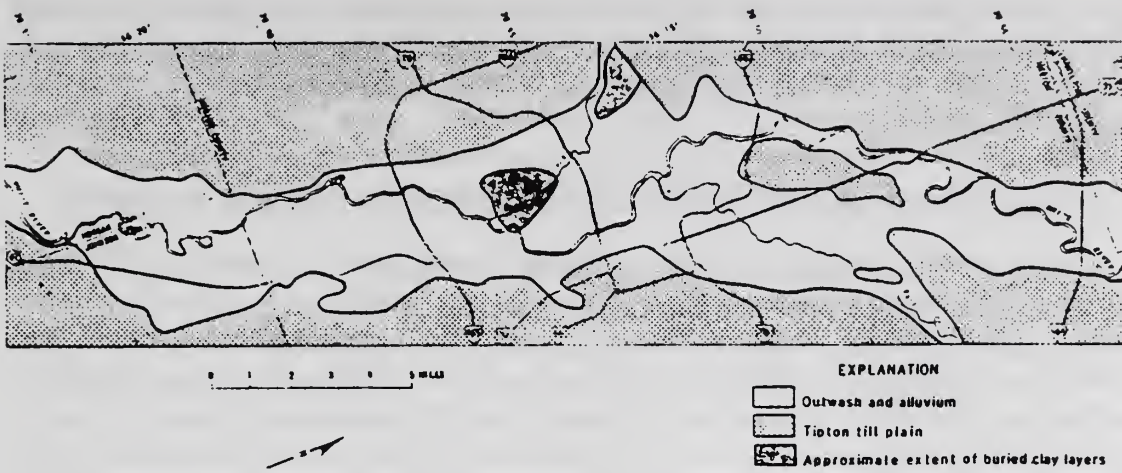


FIGURE 4. Outwash aquifer in Marion County, Indiana, showing the location of "buried clay layers" (Modified from Smith, 1983, pp. 12-13).

that the maps are reasonably accurate and are a good starting point. A study in which a geohydrologist and a glaciologist would interact has the most potential to produce an accurate understanding of the interconnectedness of these bodies on the scale of a county. In general, the glaciologist would provide the hypotheses for the geohydrologist to test quantitatively by the responses of the hydrologic system. The interplay should produce a new understanding of how to measure the interconnectedness and how to predict it.

## PROGLACIAL FLUVIAL ENVIRONMENT IN ELKHART AND KOSCIUSKO COUNTIES

The question of continuity of fine-grained deposits provides the opposite question to that considered above. Lindgren, *et al.* (1985) considered that question for an area in northeastern Indiana, and Figure 3 is from their report. Early efforts used drillers logs and some gamma logs to decipher stratigraphic relations. These logs and the general initial bias of the investigators led to the construction of a one-layer 2-dimensional flow model for the area under investigation. This model treated the clay as lenses and hydraulically considered the clay as reducing the transmissivity of a node proportional to its thickness in that node. The 2-dimensional model could not be calibrated.

After discussions with a glaciologist (Ned Bleuer, Indiana Geol. Surv., personal communication, 1983), changes were made in the geometry of the fine-grained deposits. The changes were based on the interpretation of the upper fine-grained unit as a flow till. The critical information was provided by the gamma logs, although, in retrospect, the hydraulic information also could have led to the same change in geometry. The change clearly required a 3-dimensional flow model. The 3-dimensional flow model calibrated readily with the new geometry and apparently is an accurate representation of the flow in the area.

Other geohydrologists may have the same bias, especially when considering the relative ease of constructing a single-layer, 2-dimensional flow model as opposed to a 3-dimensional, 3-layer model. Not all fine-grained deposits are flow tills, but it is intriguing to speculate on how many flow tills may have been assumed wrongly to be limited lenses. In this case, the input of a glaciologist was extremely important as were the availability of gamma logs. In the proglacial environment, rapid changes are expected. But sometimes these changes in sediment type may be laterally more extensive than their thickness would at first lead us to suspect.

## PROGLACIAL FLUVIAL ENVIRONMENT IN MARION COUNTY

Smith (1983), who constructed a digital model for the outwash of Marion County, also faced the problem of fine-grained material in coarse-grained outwash. Smith mapped four areas of significant "buried clay" on the basis of drillers' logs. These areas are shown in Figure 4. The area in the middle of Figure 4, near the confluence of White River and Eagle Creek, is being studied now (Bobay, in prep.). Above this area on the surface are a sewage treatment plant with attendant sludge lagoons, a large land-fill, a quarry and incline to an underground limestone mine, and several large industrial plants. With that potential for groundwater contamination, the nature of all the material below is important for defining flow paths, but even more so if there is significant fine-grained material.

The nature of the fine-grained material is not known now. Future study may include ground-penetrating radar, intensively filtered shallow seismic surveying, and more gamma logging. Hypotheses for the origin of the deposit include flow till, braided-channel deposits, and lacustrine deposits behind an ice dam near the mouth of present day Eagle Creek. One of these may be correct, but the correct hydrogeologic interpretation will require either a reasonable genetic hypothesis backed by present data supplemented with remotely sensed information or an extensive drilling program.

## CONCLUSIONS

Four studies in northern and central Indiana underscore that an understanding of glacial geology is the most important variable in defining ground-water flow. In spite of the lack of modern analogues, students of continental glacial deposits have broadened their understanding by using the depositional systems approach. Because of the systems' predictive power, prudent groundwater hydrologists, who work in continental glacial terranes, should master these current concepts and judiciously apply them.

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