Glacial geology mapping in Berrien County, Michigan: Resolving the third dimension for increasing the accuracy of resource assessment

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In Michigan, 92% of the state's glacial geology remains unmapped at a scale useful for resource planning, which we consider a scale of at least 1:50,000. Virtually every hydrogeologic report, environmental assessment, and remedial investigation contains a section on the geologic setting of the site being studied. For most of Michigan, this means the glacial geology of the site. The only map available for the entire state is the “Quaternary Geology of Michigan”, published by the Geological Survey Division in 1982. This map, at a scale of 1:500,000, was never meant to be used for detailed investigations. In the absence of anything better, it is commonly used as a guide to the stratigraphy that can be expected for site investigations. At scales typically around 1:1,200, these sites are barely a pinprick on the state map. It should come as no surprise when the state map doesn’t correlate well with the site map. Michigan has a reputation for plentiful water resources. According to the National Ground Water Association, Michigan has more water wells that any other state (about 1.2 million). About half of these wells are in glacial aquifers, and the majority of bedrock aquifers are recharged through glacial materials. Yet, these deposits have not been adequately mapped at a scale that enables planners to predict where the water-bearing formations exist, let alone estimate their potential for water production. Without this information it is not possible to determine safe yields for these formations or to delineate sole-source aquifers, let alone perform the source-water assessments currently required by the EPA.

The fact is that glacial sediments dominate the geology of Michigan. There are many ways this fact affects our daily lives. Soil fertility, erosion potential, runoff/infiltration, load-bearing capacity and suitability for construction materials all depend on the sediments that glaciers left behind. Regarding hydrogeologic impacts for instance:

- All of our ground water for drinking and irrigation either filters through or is stored within glacial deposits.
- Strategies for environmental cleanup must take into account the glacial stratigraphy for cost-effective planning.
- Source-water assessments should be done considering aquifers as glacial-hydrostratigraphic units.

Mapping Pleistocene deposits has the advantage that, due to their recent deposition, they retain much of the original topography. Hence, morphology has played a role in the development of glacial theory. This has been a bane as well, since one of the problems plaguing glacial geology is our historic legacy of using morphology as a proxy for sedimentology. Leverrett and Taylor (1915) described the internal characteristics of the glacial deposits of Michigan and Indiana only in the few areas where such data was available. Out of necessity, they relied on morphology to make conclusions about landform genesis. Based on his literature survey, Flint (1957) defined moraine as “an accumulation of drift having a constructional topographic expression … independent of the surface underneath it, and having been built by the direct action of the ice.” The use of a largely topographic classification led Leverrett and Taylor (1915) and many others to misclassify as moraines landforms we now know to be fluvial deposits.

Jahns’ (1941 and 1953) mapping efforts in Massachusetts led him to recognize that glacial landforms appeared associated together in a genetic series. Jahns called these associations of features
“sequences” (Jahns, 1941, p. 1910), in the sense that landforms could be traced from sub-glacial to sub-aerial ice-contact to proglacial types. Ice-front positions were determined by mapping the locations of “…ice-contact meltwater deposits, such as eskers or ice-channels fillings, kames, kame terraces [and] kame plains…” (Koteff, 1974, p. 122). The terminology choice of “sequence” by Jahns (1941, p. 1910) was “unfortunate” (Koteff, 1974, p. 122), due to the extant use of the word in a time-transgressive manner. Jahns intent was to use the term to mean deposits being formed contemporaneously. Koteff and Pessl (1981) subsequently renamed the term “morphosequence” (as a combination of morphologic and sequence) both to eliminate the confusion with the time connotation and to add the geomorphology component of the mapping technique. Morphosequence analysis is not just a morphologic examination of topography. It must also include the distribution of texture and sedimentary structures and reconstruct the grade and base level relationships of the entire depositional sequence.

Koteff’s (1974) own fieldwork as well as a review of his colleagues’ mapping led him to recognize eight morphosequence types:

A. Fluvial ice-contact sequence
B. Fluvial non-ice-contact sequence
C. Lacustrine ice-contact sequence
D. Fluvial-lacustrine ice-contact sequence
E. Fluvial-lacustrine non-ice-contact sequence
F. Lacustrine-fluvial ice-contact sequence
G. End moraine and associated outwash
H. Glaciomarine

As can be deduced from the nomenclature, the key features of the idealized sequences (Figure 1) are whether it begins in contact with the ice and the existence and distribution of fluvial and lacustrine units. Of lesser importance are moraines and coastal influences. Jahns (1941) suggested that drawing profiles of outwash plains at a vertical exaggeration of 20x would readily illustrate the form of the sequences and show the position of former ice margins (Figure 2). These can then aid in restoring the collapsed outwash plain to its original form.

Koteff (1974) and Koteff and Pessl (1981) believed that basal shearing was responsible for sediment transfer from ice entrainment to the fluvial system. Gustafson and Boothroyd (1987) showed this to be incorrect, that the main source of water and sediment transfer from the glacier is from subglacial drainage. This does not alter the utility of the morphosequence concept.

The Valparaiso morainic system in eastern Berrien County, southwestern Michigan, is a 10-18 km-wide continuous belt of collapsed glacial landforms. Previously, the composition of the moraine belt was inferred to be of unsorted materials, including coarse- to fine-textured tills, and some stratified deposits. The moraine boundary was defined primarily on classical geomorphic evidence of relative high elevation, "kettled" or "swell & sag" topography, presence of boulders at the surface, steep ice-contact face, etc. Recent geologic mapping using more than 25,000 water-well and engineering boring records, airborne and down-hole geophysical data, and test drilling has revealed the three-dimensional deltaic structure of deposits composing the Valparaiso morainic system in eastern Berrien County, southwestern Michigan (Figure 2). The deposits include over 50 glaciodeltaic morphosequences, mostly ice-marginal deltas that are graded to proglacial Lakes Madron and Dowagiac. Correlating the elevations of the heads of deltas and the fluvial/lacustrine interface allowed us to group glaciodeltaic morphosequences by outlet/proglacial lake level and therefore, infer the location of nine ice margins at various stages during construction of the Valparaiso Moraine. The resulting geologic map shows shingled deposits from a highly undulating ice margin, rather than the single, linear margin shown on older maps.

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Each delta grades from ice-contact landforms underlain by coarse-grained facies at its head to non-collapsed landforms underlain distally by fine-grained facies. Proximal deltaic deposits are coarse grained, locally containing boulders and lenses of poorly sorted flowtill with zones of collapsed bedding along ice-contact slopes. A gravel-pit exposure extended by a drill hole in the middle of our characteristic delta on Rangeline Road, showed, from top to bottom: 20 ft glaciofluvial sand and gravel; 15 ft deltaic foreset sand, silt, and gravel, dipping 10° SSE; 30 ft pebbly sand; 35 ft coarse to medium sand; 26 ft medium to very fine sand and silt at the base; overlying 5.5 ft of gray silty (Saugatuck?) till. Comparable proximal and distal sections are derived from water-well data in this deposit. Predictive vertical sections down gradient and across the gradient show the 3-D distribution of sedimentary facies within this deposit, based in part on other deep exposures in Michigan, and in modern glacial environments at the Bering Glacier, Alaska. This example demonstrates the relationship between sedimentary and hydrogeologic facies, which requires reliable subsurface data, and a modern understanding of glacial lake levels and ice-marginal processes that distribute the facies in repetitive and predictable motifs.

Figure 1. Morphosequence classification
Figure 2. Early 20th Century glacial depositional model vs. model developed by recent mapping.