The Use of Test Pits to Investigate Subsurface Fracturing and Glacial Stratigraphy in Tills and Other Unconsolidated Materials[1]

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Abstract. **Joints and fractures, common in Ohio glacial tills, often influence shallow ground water flow paths and rates. Environmental site investigations in glacial till and lacustrine sediments should include determination of the glacial stratigraphy and evaluation of the presence, extent, and density of subsurface fractures. The test pit is one approach to directly assess fracturing and stratigraphy. The design and construction of deep test pits is examined in this research report, which includes an extensive literature review and case studies from three test pit sites in Ohio. A generic design is recommended that may be used for 1-meter, 2-meter, 3-meter, or 4-meter deep test pits. Scaled drawings are included.**

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INTRODUCTION

Joints and fractures are common in Ohio's unconsolidated subsurface materials, including glacial tills and lake plain sediments (White 1982). These features can extend from the soil structural units into the lower geologic strata, acting as conduits for ground water and contaminant flow from shallow to deep systems (Kirkaldie 1988; Kirkaldie and Talbot 1992). Older glacial deposits such as Illinoian tills typically have higher hydraulic conductivities than younger deposits such as Wisconsinan tills. This is due to greater fracturing and greater leaching of soluble minerals from the matrix. The depositional environment also has implications on extent of fracturing. Lodgement tills typically have more shear stress fracture networks than ablation tills or glaciolacustrine tills which typically exhibit polygonal desiccation fracturing. Characterizations based on primary porosity will often provide erroneous conclusions if the secondary porosity is controlling ground water flow due to fractures, joints, and other macropores.

Therefore, environmental investigations of sites containing fine-grained unconsolidated materials should use methods that are designed to determine the local stratigraphy and to check for the presence and extent of fracturing on a site-specific basis. Knowledge of the stratigraphy including depositional and post-depositional history can greatly aid in predicting the hydraulic properties of a site, as demonstrated by Melvin and others (1992) and Simpkins and Bradbury (1992). One site investigation method that is cost-effective and relatively easy to implement is the use of test pits. Such pits also allow the investigator to identify other hydraulically conductive pathways such as sand lenses and paleosols. These features are common along the ice margins where there were repeated minor glacial advances and retreats.

Shallow test pits are commonly cited in the soils literature. The USDA's Soil Survey Manual (Soil Survey Division Staff 1993) describes such pits for the detailed study of soil pedons, and recommends that the pit expose a vertical face approximately 1.0 m in width and usually 2.0 m or less in depth. The USDA manual also recommends that horizontal sections of each soil layer be excavated to expose structural units and patterns.

Deeper pits have been used by researchers in Denmark (Klint and Fredericia 1998; McKay and others 1999) and Canada (McKay and others 1993; McKay and Fredericia 1995) to study geologic materials underlying the soil layers. In one case, freshly excavated benches in an active landfill were used to map the geology and fracturing to depths of up to 18 m (McKay and Fredericia 1995). Test pits have also been used in the United Kingdom to characterize potential landfill sites. Gray (1996) reported excavating 26 test pits, each 2.0 to 5.0 m deep, into fissured glacial till in Norfolk, England. Croxford (1996) reported using 57 test pits laid out in a grid pattern across a site in Scotland that was composed of peat, boulder clay (till), and fractured flagstone bedrock. Remedial investigators of coal gasification sites in northeast England included the excavation and sampling of numerous test pits up to 4.5 m deep stating that "considerable benefit is gained from the use of trial pits which are relatively cheap to carry out and provide the investigator with an excellent visual appraisal of the site" (Forth and Beaumont 1996).

Test pit investigations are often superior to mapping of natural exposures, that is, stream cuts or pre-existing excavations such as road cuts and quarries. The advantages of using a test pit include the flexibility of choosing the location and depth of the excavation, and that the test pit provides a fresh exposure. A fresh exposure is helpful to avoid the confounding effects of weathering, erosion, oxidation, and vegetation.

MATERIALS AND METHODS

The methodology begins with clearly defining the objectives of the field investigation before designing the test pit and fracture mapping procedures. For example, at a site where there is a very thick sequence of clay-rich glacial deposits (20-40 m or more), the primary

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concern may be lateral migration of water and contaminants towards nearby streams, ditches, or agricultural drainage tiles. In this situation, investigators may be primarily interested in sand lenses at any depth and fractures in the shallower weathered and oxidized zone. At a site where the clay-rich deposits are relatively thin (<10 m) and/or overlie a prolific aquifer, the main concern will likely be downward flow and contaminant migration. In this case, investigators will be interested in identifying the presence of deep, possibly widely spaced, fractures. This situation would favor the excavation of not one, but several test pits, each with limited mapping of the weathered zone and more intensive mapping of the deeper benches. The number of pits, focus of the field analysis, and the extensiveness of the mapping effort will be dependent upon the overall goals of the investigation and available resources.

Test Pit Design

Two important factors in test pit design are depth and location. Criteria for test pit location must include accessibility, suitability for construction, and most importantly, safety. Accessibility plays a key role in allowing people (for example, site managers, regulators, researchers) and equipment (for example, lab equipment, heavy machinery) to efficiently utilize the pit. Suitability for construction is the practical aspect of excavation constraints, including space for pit and subsequent overburden, location of utilities, and consideration of ground and surface waters. Typically, an ideal site will be in an open area free of utilities, and positioned so as not to have an associated drainage area directly upgradient. Designers also want to avoid areas of known drainage tiles. If possible, the excavation should be planned for the dry summer months, because the water table is normally lower and upper soil layers will be dryer and thus more stable.

The decision of design depth must be made before laying out a pit and developing a plan for overburden placement. The decision should be based on the depth needed to reach the materials that are to be evaluated (for example, the future bottom of a pond, waste lagoon, or landfill), and upon any other site-specific limitations. Initial assessments can be made using a small truck-mounted coring rig or hand auger. This is particularly useful to determine the depth to the water table and whether a pump will be needed to keep the pit dry.

The final depth should be reached by benching or stair-stepping of the pit walls. The authors' design recommendation for a 4.0-m deep pit (Fig. 1) can also be followed for a shallower pit by sequentially eliminating the shallower benches from the design. Each bench should be cut 1.0-m deep and 1.0- to 2.0-m wide. This allows site investigators to trace fractures and joints to depth in a 3-dimensional view while meeting excavation safety requirements. Some soils will not safely support the benching method and may require additional measures such as shoring, sheeting, or bracing (Brown and others 1995). However, these measures will obscure any fractures that might be visible on those faces.

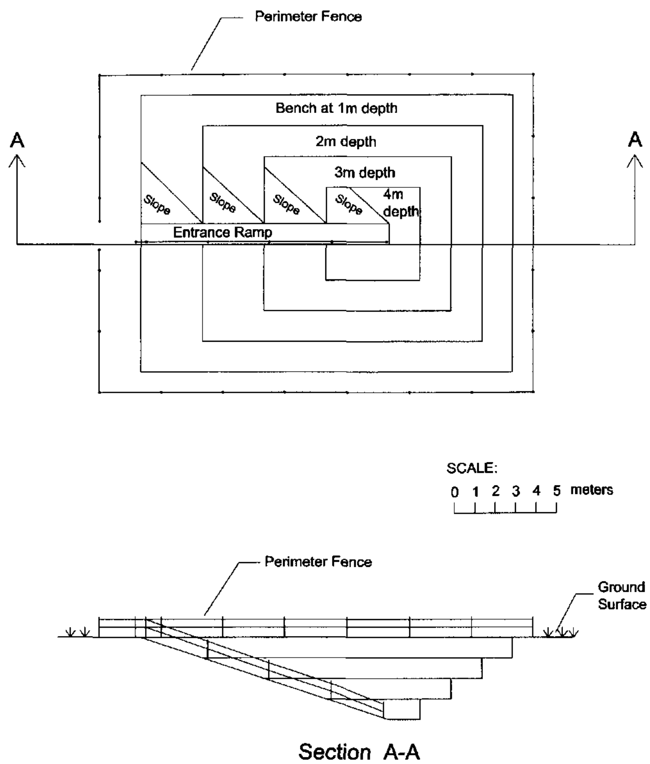

FIGURE 1. Recommended test pit design which can be used for pits up to 4.0 m deep.

To provide protection for the pit if it is to be left open for several days or more, plan to cover the pit surfaces with tarps and/or plastic to prevent desiccation.

Excavation Safety

Any pit can present physical dangers such as difficult entry and exit; slip, trip, and fall hazards; and the possibility of cave-ins which could trap and suffocate workers. In contaminated sites, chemical hazards may also cause low lying areas, such as a pit, to collect high density gases and vapors. Pit safety in Ohio is regulated under the Ohio Administrative Code (OAC) chapter 4121:1-3-13 and 4121:1-5-26, and Ohio Revised Code (ORC) chapter 3781:25-32, and the US Department of Labor, Occupational Safety and Health Administration (OSHA) excavation safety requirements which are found in the US Code of Federal Regulations 29 CFR 1926.650 -1926. 652, Subpart P of the Safety and Health Regulations for Construction. Copies of these regulations can be obtained from the US Government Printing Office or via the internet. Web addresses for OAS, ORC, and CFR are listed in the literature cited section. These regulations apply to any trench or excavation over 1.22 m (4 ft) in depth. Workers cannot enter such excavations unless adequate protection from cave-ins has been provided, the excavation has been examined by a competent person for indications of potential cave-ins, and the competent person authorizes entry into the excavation. A competent person is defined as one who is capable of identifying existing or predictable hazards and has the authority to take prompt corrective measures to eliminate them. Such a person is legally liable for the safety of those who enter the pit. In some jurisdictions, test pit design and construction may have to be approved and supervised by a registered professional engineer, professional geologist, or professional soil scientist.

The types of adequate excavation protection are sloping, benching, shielding, shoring, and sheeting of the sidewalls, as specified in 29 CFR 1926.652(b) and (c). The slope ratios for sloping and benching are dependent upon the soil classification as defined in Appendix A to Subpart P. For example in fractured cohesive clay loam (a Type B soil), a multiple bench system may be used for excavations 6.1 m (20 ft) deep or less, consisting of 1.22 m (4.0 ft) benches with a 1:1 slope ratio (Appendix B).

In any pit, workers must be protected from loose soil or objects falling off the face of the excavation; all equipment and materials must be kept at least 0.61 m (2.0 ft) from the edge of the excavation; and workers shall not enter an excavation in which there is accumulated or accumulating water unless adequate precautions are taken. Likewise, workers shall not work on the faces of benched excavations at levels above other employees unless adequate precautions are taken (29 CFR 1926.652(f)). With litigation so prominent, it is important to fence around the perimeter of the pit to avoid accidents by humans and animals.

Test Pit Construction

The first step in any site excavation is to notify the respective utility protection service for your state. In Ohio, notify the Ohio Utility Protection Service (OUPS) by phone at 1-800-362-2762. It may also be necessary to contact individual utilities that do not subscribe to the OUPS system. This will set in motion the mark-out process, whereby all underground utilities are marked, if any exist. Nonetheless, care should be exercised during excavation in case some utilities went unmarked. The pit designer may also want to notify the utility locator services early in the design phase to aid in siting a pit around known utilities.

Next, select the appropriately sized excavation equipment; a rubber tire backhoe may be adequate for a small pit, whereas a large track excavator is required for deep pits. It is important to keep in mind that as the pit gets deeper, the pit also widens at least 1 to 2 times the depth. The excavator must have the reach capacity to place overburden safely away from the pit. Typical machine ratings would dictate that a 10-ton rubber tire backhoe be used for 1.0- to 2.0-m deep pits, and a 20-ton track excavator be used for 2.0- to 4.0-m deep pits.

The first dig will be a small test pit to expose underlying soil conditions. This preliminary pit is not intended for human access, and therefore may have vertical walls. The test pit will confirm that the larger pit is going to expose the material intended and determine if perched water table conditions exist or if granular layers, which have a tendency to form hazardous "slump" failures, are present. After examining the preliminary pit, immediately backfill to avoid any potential hazards associated with this excavation.

Once the site location is fine-tuned, lay out the overall length and width of the designed pit. Topsoil should be stripped and stockpiled separately. Then begin cutting the first 1.0-m bench, working down to deeper benches in a sequential manner. Care by the machine operator should be taken to preserve the faces of each bench. Overburden should be piled as far away as possible from the edge of the pit. Large clods and rocks should be removed from the top of the pit edge, as they may unpredictably roll into the pit.

Some additional materials needed for pit construction include perimeter safety fence, fence posts, caution tape, rope, and possibly a water pump. Safety fence is needed to secure the pit, and rope makes a nice handrail for the pit's access ramp.

Field Modifications and Test Pit Finishing Operations

After the excavation has been finished, the field crew needs to flatten and clean off the benches using picks and hand shovels. To improve accessibility, build ramps and steps. Excavation in fine-grained materials usually leaves extensive smearing of the sidewalls and benches. This smearing obliterates all surface expressions of fractures, compromising the usefulness of freshly excavated pits for site assessment purposes. Therefore, remove smeared materials from faces and benches using trowels, whisk brushes, and pocket knives. Place all removed materials into buckets and carry these out of the pit. This prevents the trampling of side wall materials onto the faces of the bench floors. Locate and mark bench floor fractures early to prevent them from being destroyed during the pit finishing operation. Likewise, it is essential to rapidly mark the fractures as they are uncovered and before the soils dry potentially causing new desiccation fractures to develop. This process may require several days and/or a team of personnel to complete. During this time, remove any ponded water that may have accumulated in the bottom of the pit with a portable contractor's pump. In some seasons and on some landscape positions, it may be necessary to have a pump running nearly full time to lower the water table in the pit. If needed, use palettes to stabilize wet or soft areas.

Fracture Mapping and Pit Closure

In a test pit, a variety of fractures can typically be observed including 1) fractures with visible staining, coatings, halos, striations, or in-filling, and 2) fractures without such visible staining or in-filling (Fig. 2). The first photo shows a regular network of stained oxidized fractures approximately 1.0 m on center as revealed during the excavation and preparation of the Madison County test pit. The second photo is of open unstained fractures in pre-Illinoian till located in Batavia, OH. Those fractures of the first type (Fig. 2a) are open to flow at present or were some time in the past. However, they are not necessarily open at present, since stress conditions may have changed or fractures may become so in-filled with silts and clays that they are no more conductive than the surrounding matrix. In a series of large-scale column vertical dye infiltration experiments in Denmark's fractured tills, Jørgensen and Baumann (1998) observed that at depths of 0.0-4.0 m, 96% to 99%

of ground water movement occurred through the visible stained fractures, whereas at greater depths the stained fractures were less hydraulically active. This suggests that the presence of oxidized or in-filled fractures are useful indicators of the likelihood of fracture flow but are not, in themselves, definitive. Hydraulically conductive unstained fractures (Fig. 2b) can penetrate many meters below the visibly weathered and oxidized zone, as demonstrated by field measurements of hydraulic conductivity, depth of tritium penetration, and depth of

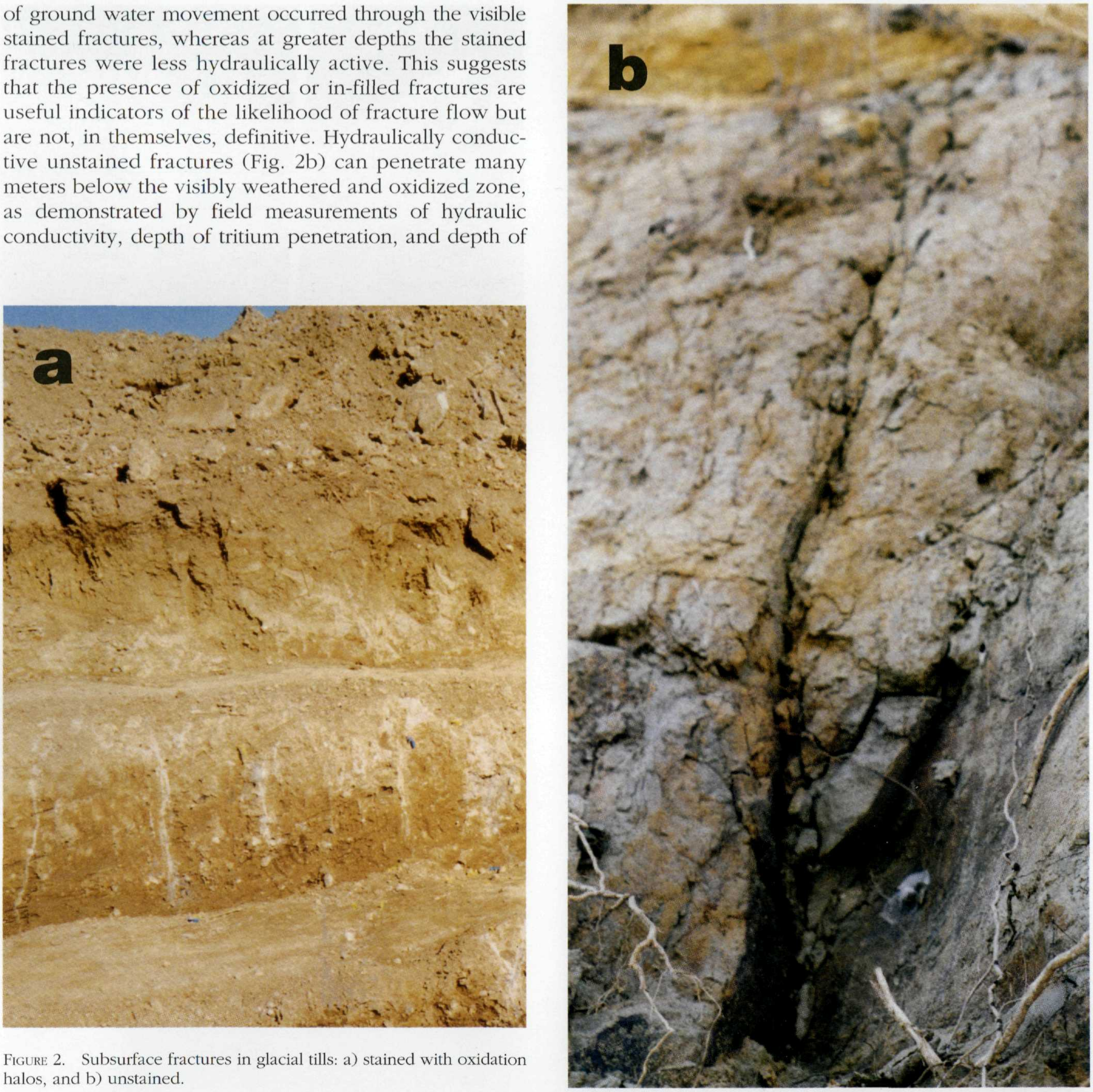

FIGURE 2. Subsurface fractures in glacial tills: a) stained with oxidation halos, and b) unstained.

large seasonal fluctuations of hydraulic head (Ruland and others 1991; McKay and Fredericia 1995). Unstained fractures can be very important but it can often be difficult to distinguish pre-excavation fractures from those caused by stress relief during excavation or desiccation after excavation. McKay and Fredericia (1995) recommend procedures for minimizing later misinterpretation of post-excavation desiccation fractures, including beginning mapping immediately after excavation, quickly marking all fractures with nails or paint. They also developed a classification system for describing types of unstained fractures.

Before disturbing the cleared faces of the excavation, photo document each face. Immediately highlight the fractures using string, tape, ribbon, and/or spray paint to label features of interest. These can be held in place with 16d 3.5-in common nails or their equivalent which can be driven into the bench sidewalls and floors with a geologist's soft-rock or brick hammer. The hammer's wide chisel end is also useful for the hand finishing process. Separate the different soil and till zones, marking the boundaries between layers.

There are two common approaches to fracture mapping: line mapping and area mapping. During line mapping, investigators lay out a horizontal or vertical painted line or string along a bench or wall of the pit. All fractures intersecting this line are then measured and described in detail. These descriptions include orientation, length, width, and fracture coating. Line mapping introduces a bias towards fractures that occur at a large angle (that is, nearly perpendicular) to the fracture wall, and under-represents fractures that are parallel or nearly parallel to the wall. To overcome this bias, mapping should be carried out on at least two bench walls at right angles to each another.

During area mapping, investigators cover the benches and/or sidewalls with large sheets or rolls of acetate or Mylar® polyester film and use colored permanent marker pens to trace the fractures and other macropores onto the plastic sheeting. All of the fractures within that area are mapped and described. When performed on a bench floor, this method is particularly useful for characterizing vertical fractures.

There are several published characterization protocols which describe analysis techniques for exposed fractures, including measurements of fracture order, position, size, shape, orientation, surface texture, halo, fracture coatings, mineral alteration, and precipitation (McKay and Fredericia 1995; Klint and Fredericia 1998; McKay and others 1999). This allows computation of parameters such as fracture spacing (mean perpendicular distance between adjacent fractures), fracture intensity (number of fractures per meter), fracture trace frequency, fracture density, and fracture aperture. In addition, orientation can be plotted as a rose diagram or stereographic projection.

After all observations, measurements, and photo documentation are completed, backfill the pit, replace the topsoil, and revegetate the site. If you plan to exhume and re-examine the pit after backfilling, use a geotextile membrane to line the pit prior to backfilling (Darmody and Bicki 1989).

RESULTS

Three Ohio test pit investigations are described. Sample results from these excavations are briefly shown, with the emphasis upon the various methodologies used in pit design and construction. More detailed information on the specific findings at each of these three sites have been presented elsewhere, and are so referenced.

Richland County Test Pit

As part of a proposed landfill permit application, a hydrogeologic investigation of glacial till was performed at a Richland County, OH, site. The study included the construction of six small test pits (Hull and Associates 1993). These backhoe pits were excavated to a depth of approximately 2.0 m, and each pit covered a 6.0 m by 5.0 m area (Fig. 3). The front face of each pit had two benches approximately 2.0 m wide by 2.0 m long by 1.0 m deep. The rear sides were sloped at a 1:1 ratio to provide an access ramp. The procedures followed were those specified by USDA (Huffman 1992). Field observations included fracture spacing and orientation, moisture content, presence/absence of free water, plasticity, and thickness, color, texture, and grain size distribution of each stratigraphic unit (Table 1). Results of the observations were discussed at The Ohio Academy of Science Symposium (Weatherington-Rice and Angle 1994).

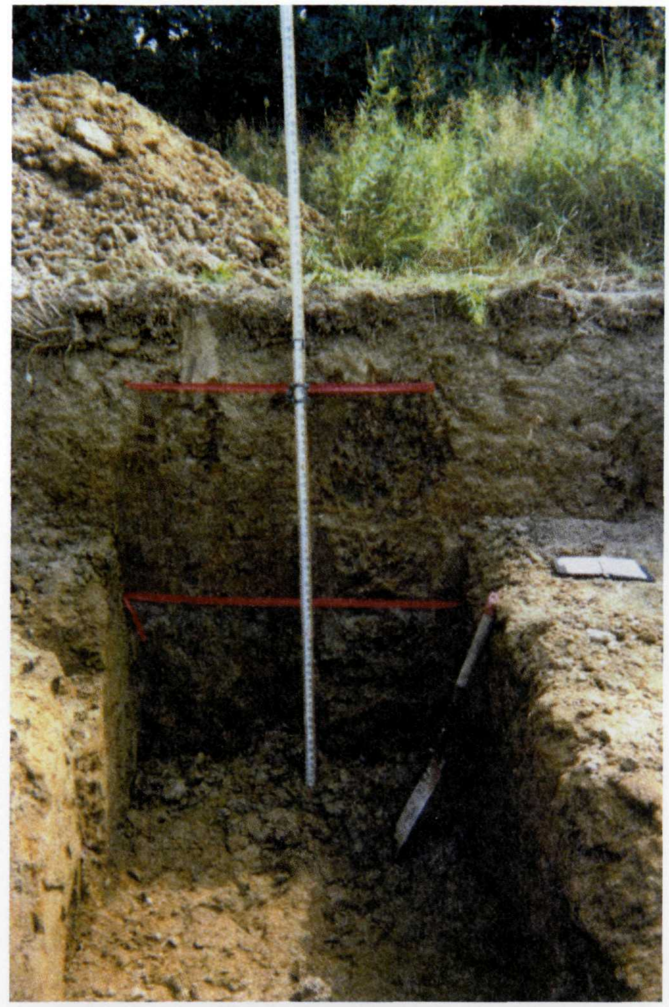

FIGURE 3. Richland County test pit.

Clark County Test Pit

A small test pit was constructed in 1997 to document site conditions for a proposed landfill near Tremont City, OH. The dimensions of the pit were 3.7 m wide

TABLE 1

Stratigraphic unit description from one of the Richland County test pits.

Unit	Thickness (cm)	Description*
1	35	Soil horizons A and B: light brown clayey silty loam, dry, blocky, friable.
2	71	Brown mottled gray silty clay, little sand, trace of gravel, very hard, damp to moist, slightly plastic, 5 to 10 cm fracture spacing.
3	102	Dark brown silty sandy clay, moist, plastic, very stiff, fracture spacing 25 to 30 cm

*modified from Hull and Associates 1993.

by 6.0 m long by 3.7 m deep. The test pit included multiple 1.0 m high benches (Fig. 4). The finishing operation using archaeological techniques was performed by 5 investigators working approximately one day after the excavation was accomplished. Site investigators measured fracture spacing, length, depth, continuity, and aperture. Samples were also collected for description and analyses of grain size and clay mineralogy. The till was observed to contain two types of fracturing: stress fractures striking N50E and N45W and polygonal desiccation fractures (Weatherington-Rice 1998). Data from this field study were used in constructing a 3-D geographic information system (GIS) which provided active visualization of the proposed landfill in relation to the aquifers, sand seams, springs, seeps, terrain, and the test pit features (Catalano and others 1998).

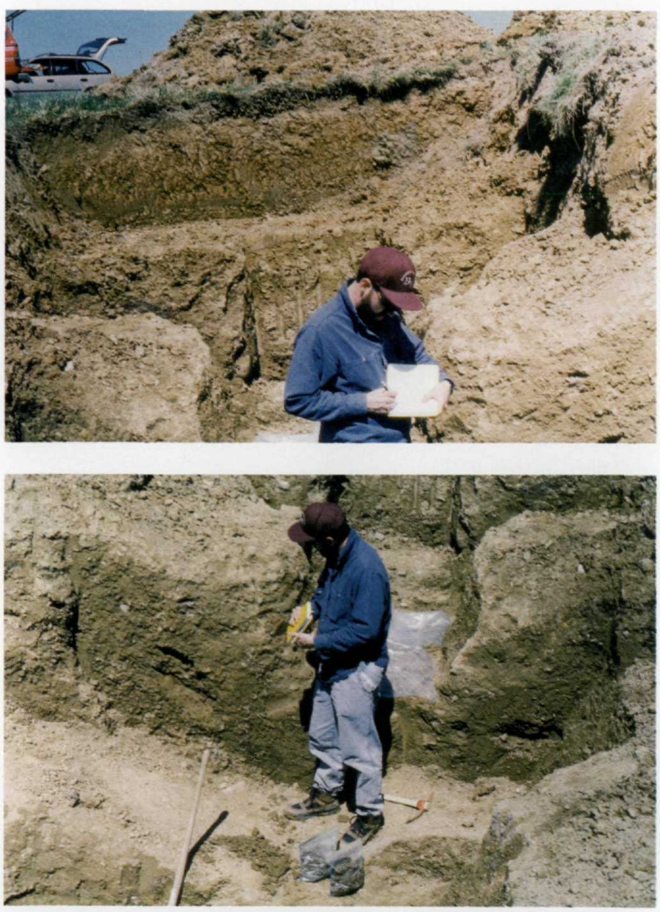

FIGURE 4. Clark County test pit.

Madison County Test Pit

A large test pit was constructed at The Ohio State University's Molly Caren Agricultural Center near London, OH. The pit was constructed in conjunction with The Ohio Academy of Science field workshop on joints and fractures in glacial till which was held 28 August 1997 (Christy and Weatherington-Rice 2000). The dimensions of the pit were 10 m wide by 25 m long by 3.7 m deep. The test pit included four 1.0 m high benches on two sides in a tiered configuration and ramps on each end to facilitate access for the 175 workshop participants (Fig. 5). The finishing operation using archaeological techniques took approximately two days after the excavation was accomplished, and involved up to 15 workers at a time. *In situ* measurements of the saturated hydraulic conductivity were made in small boreholes intersecting fractures and in similar boreholes positioned in the till matrix. Percent of total volume affected by fracturing was assessed. Analyses of particle size distribution, clay mineralogy, calcite, dolomite, and iron content were conducted on material collected from both the fracture faces and the matrix. In depth discussion of the results is presented by Fausey and others (2000).

FIGURE 5. Madison County field workshop test pit.

DISCUSSION

Test pits provide a method to assess fracturing through direct visual observation. Some have asserted that they have never seen fractures in years of experience with excavating tills, but it is critical to understand that the investigator cannot simply look at a freshly bulldozed site. In fine-grained clayey materials, the earthmoving equipment will often leave smeared faces and fractures may not be visible. Therefore, specific procedures such as those described in this paper must be followed to allow the fractures to be uncovered and measured.

Test pits are a relatively inexpensive investigative tool, especially for hydrogeologically complex sites. Often, several pits can be installed for the cost of one soil boring. In addition, site characterizations based on soil borings often miss fractures and zones of saturation; either the borehole does not happen to extend through the fracture or the geologist fails to adequately examine the sample. On large sites, multiple pits placed in geomorphically and topographically diverse locations (for example, uplands, depressions) are recommended.

There are scale issues to address in designing test pits. Soil boring evaluation often exposes small-scale fractures that appear to be discontinuous. In fact, they may be part of an intricate, large-scale fracture system, connected to fractures with much larger apertures. This system of small-scale fractures (conduits) connected to larger-scale fractures at increased spacings is analogous to river systems where many rivulets feed small tributaries, which in turn feed larger streams that ultimately flow to regional rivers. From one step to the next, the number of tributaries or feeder streams decreases as the size of the tributaries and the spacing between them increases. Klint and Fredericia (1998) recommend excavating an exposure 50 times the mean spacing of the fracture system to provide statistically valid data.

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