The Use of Lineament and Fracture Trace Studies in Landfill Site Evaluation: What Information Does It Provide?

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Abstract

During the evaluation of a site for a proposed landfill location, several factors must be addressed to determine its suitability for refuse disposal. Of paramount importance is the impact that any leachate generated from the landfill will have on nearby groundwater quality. Recently, linear features observed on aerial photographs which may be indicative of subsurface geologic variations have been considered for providing supplemental information to that gathered from standard hydrogeologic field and office investigations. This paper addresses the meaning of these observed features in areas of thick unconsolidated deposits and their potential implications on the siting and design of landfills.

Introduction

To address the suitability of a site for landfilling, geologic and hydrogeologic field and office studies are typically undertaken to evaluate the continuity and distribution of subsurface materials, their physical and geochemical characteristics , the depth to the groundwater table and the direction and rate of groundwter flow, and the location of nearby active water supply wells. Because the siting and design of landfills are based on the concept of controlled containment of the refuse by a minimum thickness of low permeability materials, any hydrogeologic study undertaken is necessarily focused on the thickness, continuity and integrity of such materials beneath the site.

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Recently, studies of special aerial photographs have been considered for providing supplemental information to that gathered from the standard practice of drilling test bore holes, soil / rock sampling, field and laboratory testing, and installing monitoring wells. These studies have been used to assess if potential zones of high recharge or increased permeability are present across or beneath the site. Although not verified by any extensive research or field studies in areas with thick unconsolidated deposits, some studies in areas of shallow soil cover have shown a relationship between natural linear or curvilinear features observed on the photos known as lineaments or fracture traces, and the distribution and orientation of vertical bedrock fractures.

Several studies have indicated the presence of these linear features on aerial photographs of areas where bedrock is covered by several hundred feet of overlying unconsolidated soil deposits. The appearance of such features in these areas has prompted many questions. What do these features represent? Are they surficial drainage features? Do they represent the actual bedrock fracture patterns somehow mirrored through the great thicknesses of unconsolidated materials? Are they massive fracture zones of high permeability extending up from the fractured bedrock surface through the soil to the ground surface? Do they represent only preferential near surface recharge pathways? This paper addresses the question of the meaning of observed lineament and fracture traces in thick unconsolidated deposits and their potential implications on the siting and design of landfills.

Lineaments and Fracture Traces

Lineaments and fracture traces have been defined (Lattman, 1958) as natural linear and curvilinear features consisting of vegetative, topographic, soil-tone, and drainage alignments visible on aerial photographs and mosaics. In areas where bedrock is exposed at the surface, bedrock joints are included. By definition, lineaments are features which are observed on photographs to be 1 mile or more in length, whereas fracture traces are less than 1 mile. Although this definition implies a certain continuity throughout the length, Moore (1976) has indicated that the lineaments and fracture traces are actually made up of short, discontinous segments.

Several factors affect the interpretation or mapping of these features across the aerial photograph. These include film type, photographic scale, method of examination, length of viewing time per photograph, and the time of year in which the photograph is taken (Lattman, 1958; Trainer, 1967; Moore, 1976). Identical photographs of the same area interpreted by the same viewer at different times have been known to yield differences in the location and density of these mappings. It is for these reasons that the mapping of these features is still somewhat of an art rather than a well defined scientific technique that can be verified by objective measurements.

Application to Bedrock Water Availability

Studies (Hine, 1970; Moore, 1976) have shown a relationship between lineaments and fracture traces and the distribution of vertical bedrock fractures in areas of shallow soil cover. Water supply wells located on or very near vertical bedrock fractures mapped as lineaments and fracture traces have often yielded significantly greater quantities of water than wells located large distances from these features (Siddiqui, 1969; LaRiccia and Rauch, 1976).

Application to Unconsolidated Deposits

A study by Mollard (1957) concluded that lineaments and fracture trace patterns were generally independent of topography as well as the age, composition and depth of unconsolidated deposits over which they occur. The same study interpreted lineaments in areas where the bedrock was covered by more than 350 feet of unconsolidated materials. A more recent study performed by the United States Geologic Survey (Greeman, 1983) in Decatur County, Indiana, showed these interpreted linear features extending over areas covered by fine-grained glacial till as well as areas in which significant thicknesses of coarse-grained sand and gravel deposits are likely to be present. The highest density of mapped lineaments and fracture traces were found to correspond to the areas having the thickest accumulation of glacial drift. Mapped densities on the order of roughly 50 natural linear features per square mile at distances of approximately 500 feet apart or less have been observed in glacial terrain in Decatur and Jennings Counties, Indiana (Greeman, 1981,1983).

The Origin of Mapped Curvilinear Features

Perhaps the most unclear and highly disputed question regarding the existence of these lineaments and fracture traces is what do these features represent? In areas of shallow soil cover over jointed or fractured bedrock, there appears to be clear evidence to suggest that these mapped features tend to mirror the location and distribution of vertical bedrock joints. This has been verified at some rock outcrop locations and at quarry sites (Greeman, 1981, 1983). However, in areas of thick soil cover (i.e. several hundred feet), no clear evidence is available to suggest what these features may represent. Several explanations have been suggested for these features including describing them as:

1. **Massive fracture zones** of high permeability extending from the fractured bedrock up through the unconsolidated deposits to the ground surface. These fractures are thought to have been caused by the stresses induced in the soil when regional rebound of the bedrock strata occurred as the thick glacial ice melted.

2. **Zones of preferential recharge** connecting the fractured bedrock to the ground surface. The zones may or may not be of greater permeability than the surrounding soil. This explanation ignores any hydraulic effects of multiple aquifer systems above the bedrock, and assumes that recharge patterns remain constant through the soil thickness.

3. **Surface features** related to the final melting of the last ice sheet representing lineaments of the ice sheet (eg. crevasses,etc.) that may be marked by subtle near-surface variations in stratigraphy. This may include features such as buried melt channels containing more granular materials. Due to different soil texture and drainage characteristics, these zones may have become areas of preferential recharge to the near surface groundwater system, and would often be associated with surface drainage features. Higher moisture conditions in these zones, in addition to

possible higher degrees of weathering or leaching caused by accelerated flow, are most probably responsible for their appearance on aerial photographs.

4. **Surface drainage features** controlled primarily by topographic characteristics.

5. DEFECTS IN AERIAL PHOTOGRAPH

Although no definitive field studies have been performed to date to address the question of what these mapped lineament and fracture traces represent in areas of thick unconsolidated deposits, the available data tends to support the view that they represent subtle near-surface stratigraphic variations rather than zones of major fracturing or recharge from the bedrock surface up to the ground surface. Several key points support this conclusion:

1. These features have been mapped over areas of fine-grained soil and major granular deposits. The idea of major fractures extending through thick deposits of outwash sand and gravel appears remote.

2. For major fracture or "fault" zones to develop or propagate, there must be some magnitude of relative displacement between the adjacent sides of the fracturing. This phenomenon has not been documented for thick soil deposits overlying a bedrock surface undergoing regional rebound not seismically related.

3. No major fracture zones extending through several hundred feet of unconsolidated materials have been observed or field verified at any of the lineament or fracture trace locations. One attempt to locate a fractured zone at the reported location of a lineament near a proposed landfill site in 1984 was made with a trench excavation. Field observation yielded no indication of any evidence of major fracturing within the upper soil deposits.

4. The existence of multiple aquifer systems of varying regional distributions and hydraulic properties above the bedrock surface would strongly influence the prominent recharge patterns to any deep bedrock aquifer. For this reason, strictly vertical

recharge to the bedrock would appear highly unlikely.

5. The density of these features has been observed to vary with the thickness of unconsolidated deposits present (Greeman, 1983), rather than only bedrock type. This indicates that other factors which are more likely depositional in nature, would affect the location of these features.

Implications for Landfill Siting and Design

Over the last several years, there have been several instances in which those opposed to landfill development in Indiana have attempted to use lineament and fracture trace studies as a means of stopping landfills from being constructed. One specific case recently has suggested that an existing, closed landfill in central Indiana has begun to pollute deep aquifers only after a few years due to its location over a mapped lineament. Indeed, the explanation of what these lineaments and fracture traces represent directly effects the potential implications of these features on the evaluation of sites for waste disposal.

For example, those holding to a "major fracture" theory would suggest that a site placed over the mapping of one of these traces could potentially contaminate a multi-aquifer system separated by significant thicknesses of seemingly low permeability, fine-grained clayey soils. As shown in Fig. 1, leachate generated from the landfill could, depending on existing hydraulic gradients, pass vertically through the fractured zone down to the underlying aquifers in a period of time significantly less than if the fractured zone were not present. In addition, the ability of the fractured fine-grained soil to naturally attenuate the various levels of contaminants in the leachate would be severely compromised since flow would occur through the fractured pore space rather than through the soil matrix, where sorptive geochemical mechanisms are most intense.

To make a site suitable for refuse disposal assuming a "major fracture" hypothesis to be plausible, the fractured zone below the landfill would have to be mapped through the site in great detail prior to landfilling. Field locating these features from aerial photograph observations would be quite difficult since they do not have any surface

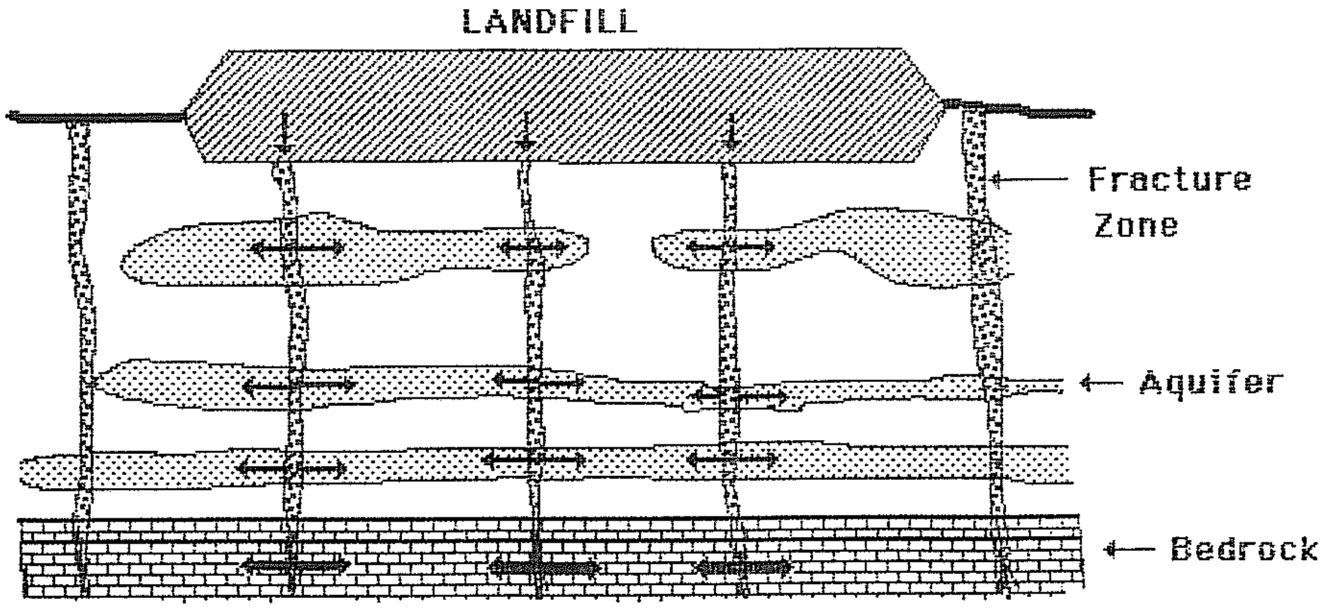

Fig. 1. Major Fracture Zone Hypothesis

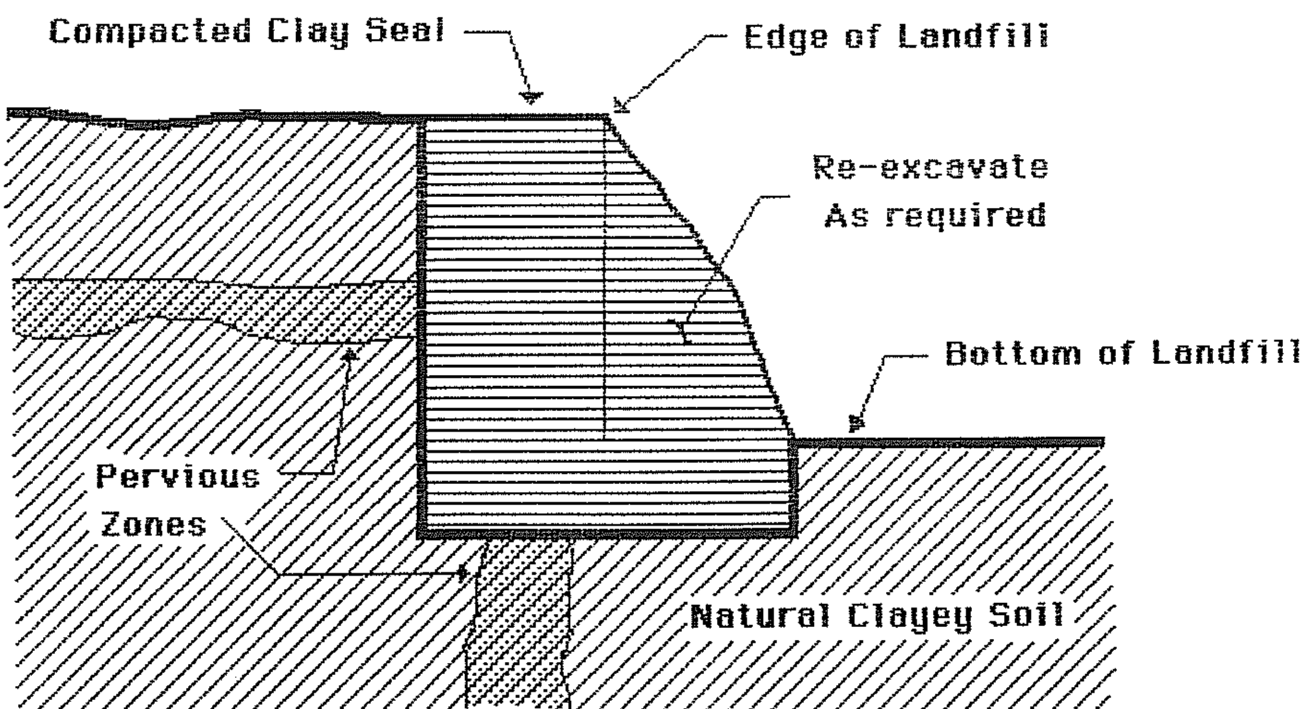

Fig. 2. Trench Sealing Techniques

expression to indicate there presence. Significant amounts of field sampling and testing may provide some indication of the general area location, but the exact delineation may remain questionable. If, assuming the fracture zone could be located, the upper portion of the zone adjacent to the base of the refuse would have to be overexcavated and sealed with a recompacted liner system of sufficient thickness to provide an appropriate hydraulic barrier with an acceptable attenuation capacity, as shown in Fig. 2. Although this may provide a safe engineered solution to potential leakage, the existance of such a zone beneath a proposed landfill site would most probably make it politically unsuitable. In addition, because of the observed density of these mapped features in typical glacial terrain, the number of politically suitable sites would be severely reduced.

If the explanation of the lineaments as being reflections of subtle near-surface variations in stratigraphy is correct, which appears likely from the existing available data, then the potential implications are much less severe. There would no longer be an explicit danger to deeper aquifer systems if sufficient thicknesses of fine-grained, low permeability glacial till were present below the bottom of the refuse. Of greater concern would be locating any shallow pervious zones that would potentially allow uncontrolled horizontal flow of leachate through the sides of the excavation trenches. Side sealing in a fashion similar to Fig 2. would be required to provide the appropriate hydraulic barrier to lateral leachate migration if such zones were disclosed during landfilling operations.

Conclusions

It is the author's opinion based on present available data that the presence of mapped lineament and fracture traces through a site does not indicate that the site is not suitable for refuse disposal. The presence of such features in areas of thick unconsolidated deposits most likely indicate areas where subtle near surface variations in stratigraphic or drainage characteristics may exist. Provided there is a sufficient thickness and continuity of low permeability soil present beneath the site, any variations in subtle near surface stratigraphy (eg. sand pockets or lenses) can be accounted for by appropriate sealing technques adjacent to the refuse disposal.

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