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PDR/LPDR

COALITION ON WEST VALLEY NUCLEAR WASTES
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June 8, 1992

TO: T. J. Rowland, DOE, West Valley demonstration Project
G. C. Comfort, NRC, West Valley Project Manager

FROM: Daryl Anderson, Coalition on West Valley Nuclear Wastes

SUBJECT: Enclosures

Ray Vaughan of the Coalition is away on vacation and asked me to send along the enclosed document for your review. As he mentioned in his letter of June 2 regarding the DOE request for rulemaking on TRU limits, we continue to look at unresolved site-characterization issues.

This document raises some important issues regarding the site. Naturally his "working draft" raises more questions than answers -- but these questions need substantive discussion.

Sincerely,

Daryl Anderson for,

Raymond Vaughan &
The Coalition

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REVIEW AND DISCUSSION OF VERTICAL FRACTURES REPORTED AT WV SITE: working draft

Raymond C. Vaughan
Coalition on West Valley Nuclear Wastes

135 East Main Street
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May 31, 1992

Three separate reports of vertical cracks or fractures (directly observed in 2 cases; inferred but disputed in one case) have been made by separate geologists, or geological teams, working at the Western New York Nuclear Service Center near West Valley, N.Y. We find that a good explanation of these fractures is lacking. None of the geologists has addressed the overall situation in a way that is sufficiently rigorous in terms of causality. We believe that all three reports must be considered together, and at least some new field work must be done, to reach an understanding of the exact nature, full extent, and underlying causes of these reported fractures. Any such understanding must be capable of generating defensible predictions of the evolution and future development of fractures of this type.

The critical importance of reaching such an understanding is due to the location of the reported fractures: all three lie within a circle of 1-km radius that also encompasses the NDA and SDA burial grounds of the Western New York Nuclear Service Center. Given their locations, such fractures may potentially act either as long-term pathways for migration of radionuclides or as planes of weakness that can accelerate geomorphic processes such as erosion.

This paper will review the three instances of reported fractures and will discuss several possible underlying causes. The discussion of possible causes will cover a spectrum of ideas (ranging from ideas that are supported by empirical evidence to other ideas that are relatively speculative and unsupported), the purpose being to promote further discussion and investigation. We do not claim at the present time to understand the origin, behavior, or full extent of the reported fractures, but we reiterate our belief that any defensible characterization of the Western New York Nuclear Service Center must include a thorough understanding of such fractures.

The word "fracture" will be used interchangeably with "crack" in this paper.

Case no. 1: Fractures in till reported by Dana, Fakundiny et al. in research trenches located 200 m from the SDA burial trenches:

In this case, the fractures were observed ca. 1976 in the three research trenches dug in the same glacial till (Lavery

Till) that contains the SDA and NDA burial grounds. The fractures were observed in the till itself and were found to occur as two sets of fractures with those in each set being aligned parallel to one another and extending vertically downward as much as 15 m below the surface. In reporting the fractures, Dana, Fakundiny et al. noted that the two sets of parallel fractures tended to match the orientation of joints observed in nearby bedrock. An informal description of these fractures by Fakundiny (1989) is attached. Detailed description and discussion can be found in Dana, Fakundiny et al. (1979). See also the review by Fakundiny (1985, pp. 126-132).

Case no. 2: Fractures reported by Belcher in an exposed clay face on the west side of Buttermilk Creek; apparently also observed by Fakundiny:

In this case, fractures in clay were observed in 1970 in or near an area where mass wasting or slumping is known to occur, about 2500 ft upstream from the railroad bridge that crosses Buttermilk Creek. Belcher (1970) noted two sets of essentially parallel fractures and suggested the possibility of an alignment that matched the orientation of joints in nearby bedrock—yet he rejected this possibility because (among other reasons) he found a misalignment of about 45° between the bedrock joints and the "pseudo-joints" in the clay. Except for this apparent misalignment, Belcher's description of the two parallel sets of fractures is reminiscent of the sets of fractures observed in the Lavery Till by Dana, Fakundiny et al. The fractures observed by Belcher were in a layer of clay that lies beneath the Lavery Till (apparently the varved clay at the base of the lacustrine unit), located immediately downhill from, and only about 250 m from, the research trenches of Dana, Fakundiny, et al. Belcher discusses several possible causes of the fractures, including dessication, landslide movement, and faulting, yet he rejects each of these possibilities and concludes that the cause "cannot be attributed to ordinary known processes." Belcher considers the fractures to be tension cracks and expresses the firm opinion that they are "of recent origin." His full description is attached.

Other geologists, particularly Fakundiny, would apparently regard Belcher's observation of two sets of parallel fractures in the varved clay as commonplace. See Dana, Fakundiny et al. (1979, pp. 19-20) and Fakundiny (1985, p. 127). In the latter work, Fakundiny states that "Fractures in undisturbed material...can be classed as open, closed, or incipient.... Incipient cracks are recognized where the till does not display fractures until it is stressed in new excavations and cracks, consequently forming systematically oriented sets unrelated to the exposure's geometry. This latter type is common within the varved clay section of the Kent till below the burial till." In part, this statement by Fakundiny fits Belcher's observations, for it seems probable that the open cracks observed in the clay bank by Belcher had been incipient cracks until they were stressed, and thereby opened up, by local slumping or mass wasting. However, as discussed below, there are unresolved questions about the genesis of parallel sets of fractures in either clay or till.

Case no. 3: Possible deep vertical fracture in shale east of Buttermilk Creek, inferred by de Laguna; disputed by Sun and Mongan:

Between 1969 and 1971, a series of six shale-fracturing tests was conducted on the east side of Buttermilk Creek on the Western New York Nuclear Service Center property. High-pressure injections of either water or grout were made at depths between 150 m and 450 m. The tests were intended to induce horizontal fractures in the shale bedrock, the purpose being to evaluate shale-fracturing as a disposal method for radioactive liquids and slurries. One way the results were monitored was a precise measurement of changes in the ground surface elevation at the top of the injection well. The injections typically produced very small surface uplifts, ranging up to about 1 cm.

The third such injection, made in August of 1970 with 90,600 gallons of radioactively-tagged [^{95}Zr-^{95}Nb] water at an injection depth of 374 m [1226 ft], did not produce uplift at the surface; instead, it caused the surface to subside about 0.3 cm. It was believed that "most of [the] injection fluid went into open joints" in the rock (Sun and Mongan 1974, p. 80; also pp. 41-42 for background data on joints). The fourth injection, made in May of 1971 with 98,700 gallons of radioactively-tagged water at a depth of 308 m [1010 ft], produced results that led Sun and Mongan (1974, p. 85) to conclude that the injected water had entered "two different fracture systems" in the rock during that particular injection.

Further measurements made one week after the fourth injection showed an unexpected peak of radioactivity (from the tagged water) in one of the monitoring wells that had been drilled near the injection well. This unexpected peak of radioactivity led one of the researchers (de Laguna) to conclude that the fourth injection "had fractured vertically downward from 1,010 ft to 1,395 ft, and then had turned horizontal and had moved out of the east." He went on to say that "a vertical fracture had been predicted for the injection at 1,010 ft, but that it should fracture downward was a complete surprise. Presumably, the liquid injection found and followed a joint, but no joints were believed present in the shale with a vertical height of 375 ft." (de Laguna 1972/73, quoted in Sun and Mongan 1974, pp. 89-90)

Sun and Mongan (1974, pp. 90-93) disagree with de Laguna's hypothesis of a 375-foot vertical fracture in the rock; they blame a flaw in the monitoring well for the anomalous peak of radioactivity. However, Sun and Mongan are properly cautious with their language; they criticize de Laguna's hypothesis with words like "hard to believe", "hard to imagine", "no reason to believe", and "unlikely"--but they are unable to disprove his hypothesis. They temper their own "possible interpretation" with words like "presumably" and "probably."

Given the importance of the issue, and given the unexplained fractures observed in the nearby clay by Belcher, and in the nearby till by Dana, Fakundiny, et al., the question of a 375-ft vertical fracture in the shale must be considered unresolved.

Scope of the problem:

In two of the three cases described above, the existence of the fractures is not at issue. The reported fractures are relatively well-documented in the reports already cited. It is not clear to what extent the primary data (including photos and individual measurements of fracture orientations) have survived.

In the third case described above, it is not clear whether a deep vertical fracture in the shale exists or not.

The problem, therefore, is 1) to find a defensible causal explanation of the origin of the fractures described in the first two cases, regardless of the outcome of the third case; 2) to conduct tests to show the presence or absence of the hypothetical vertical fracture described in the third case; and 3) to ensure, in the event that the deep fracture of the third case is found to be real, that a defensible causal explanation can be found that covers all three cases.

Part 2 of the problem as defined above would involve field tests capable of detecting subsurface fractures. While we are not experts in geology, we would suggest techniques such as horizontal or oblique core-sampling, well-logging, and various other types of signal-reflection or signal-refraction imaging.

Part 1 of the problem as defined above may be considered a non-problem by some experts. If so, we disagree. We find it to be a very real problem that must be addressed and resolved before the Western New York Nuclear Service Center site can be said to be characterized. In the rest of this section we will discuss this question, i.e., whether a defensible causal explanation must be found for the first two cases of reported fractures, or, alternatively, whether a sufficient explanation already exists for those fractures.

Based on our reading of Dana, Fakundiny et al. (1979) and Fakundiny (1985), it appears that Fakundiny may consider the fractures of the first two cases to be sufficently explained by the idea that these fractures are inherited from the regional pattern of bedrock jointing. We would disagree with any such assertion.

We do not disagree with the general idea that fractures in till and clay may mimic, or be inherited from, the joints in underlying bedrock. This is a plausible idea that is supported by a growing body of evidence. But we reject this as a sufficient explanation for the Western New York Nuclear Service Center fractures on two grounds, one being the site-specific discrepancies that will be discussed below, the other being that the "explanation" of inheritance from the regional joint pattern is not a sufficent explanation. Specifically, the "explanation" of inheritance from the regional joint pattern lacks a causal mechanism. It is therefore incapable of explaining how and when such fractures in till and clay were formed, and likewise incapable of predicting whether and how such fractures will continue to develop, grow, and evolve in the future.

(Even though we support the general idea, it should be noted that the idea that fractures in till and clay may be inherited from joints in underlying bedrock is relatively new and not fully established as part of the geologic curriculum. We note the cautious language that Fakundiny and others have used to describe it. Fakundiny, Myers et al. (1978, p. 139) call it a "curious phenomenon" and cite four earlier references to it in the literature, the earliest being a study of stratigraphy and structure in the Batavia area by a professor of geology at Alfred University (Sutton 1951). Dana, Fakundiny et al. (1979, p. 41) continue to refer to the idea with cautious language; they cite Fakundiny, Myers et al. (1978) in support of their assertion that the "idea of glacial tills inheriting the joint patterns of the underlying bedrock is not new" and they proceed to say that the idea "has not been challenged, to our knowledge, in the literature.")

As an additional example of glacial tills inheriting the joint patterns of the underlying bedrock, we note that the same phenomenon has been observed near Smithville, Ontario, where remedial work is being conducted at a PCB-contaminated site (McIelwain et al. 1991).

Belcher (1970; copy attached) is a clear advocate of the general idea that glacial tills tend to inherit joint and fracture patterns of underlying bedrock. As he states on p. 1 of his report, "Adequate research in the past has proven that joints, fractures and faults project themselves upward through overlying glacial drift. The drift tends to mask joint patterns, leaving only the more significant lineaments as obvious structural features. The thickness of the drift has an effect although shallow drift, ranging between two and four feet, will carry the influence of extremely minor fractures to the surface providing there is sufficient lineal continuity for the eye to separate it from random occurrences. The mechanism of the projection is not well understood."

Belcher's statement about the problem of transmitting joint patterns up through <u>thick</u> <u>layers</u> of glacially deposited material brings us to the major site-specific discrepancy at the Western New York Nuclear Service Center. The attached cross-section of the relevant portion of the Buttermilk Creek valley shows the problem: The fractures observed in till and clay are more than 100 meters [more than 300 feet] above the bedrock floor of the valley. It is difficult to believe, especially in the absence of either a clear-cut example or a well-understood mechanism, that relatively minor bedrock joints can project themselves upward through such a thickness of multi-layered glacial deposits.

One of the points that Fakundiny has discussed in print (see Dana, Fakundiny et al. 1979, pp. 40 and 49-60; also Fakundiny 1985, p. 129) seems relevant here. He notes that studies of the engineering properties of the moist [Lavery] till have shown that its plasticity will not allow open fractures to be maintained below a depth of 15 m. At some greater depth, we presume the till will no longer accommodate incipient fractures; this apparently needs to be determined experimentally. In any case, the plasticity of the till at depth seems to add to the weight of argument against the idea that joint patterns in bedrock can be transmitted through a thickness of more than 100 m of till and other glacial deposits.

Fakundiny and others have shown a very interesting correspondence among fracture patterns in the Lavery till, bedrock joint patterns, linear topographic features or lineaments, and the "trellis"-like orientation of creeks in the vicinity of the Western New York Nuclear Service Center (see Dana, Fakundiny et al. 1979, pp. 41-44; Fakundiny 1985, p. 129). In the latter work, Fakundiny states that he finds this correspondence "close enough to support the hypothesis that fractures in the upper few meters of till are pervasive throughout Buttermilk Creek valley and also a have [sic; apparently means 'have a similar'] orientation throughout the valley." If this is intended as a <u>scientifically</u> <u>sufficient</u> <u>explanation</u> of the fractures observed in the upper few meters of till, we disagree, as already noted. The correspondence in orientations is clearly interesting but must be regarded as a starting-point, not a conclusion, in understanding the origin and future behavior of the fractures observed in till and clay.

It should also be noted that Belcher (1970, p. 4) did <u>not</u> find a good correspondence between the bedrock joint orientations and the fracture orientations he observed in the clay bank at the Western New York Nuclear Service Center. The 45° discrepancy he found between the fractures in clay and the bedrock joint orientations was one of the reasons he rejected bedrock jointing as a cause of the fractures he observed in clay. Measurement of orientations was clearly a professional specialty of his, so it seems unlikely that the discrepancy can be attributed to carelessness or error. Unfortunately, Belcher's report does not contain numerical data from his orientation measurements.

In summary, we find that the fractures observed in till and clay lack a scientifically valid explanation. The questions of <u>how</u> and <u>when</u> they were formed remain unanswered, and, consequently, their future behavior remains unpredictable—especially if they are of recent origin. The idea that they are "inherited" from minor joint patterns in the underlying bedrock seems untenable, given the thickness of the intervening glacial deposits.

In the following sections we will present several hypotheses for the origin of the fractures observed in till and clay. In presenting these hypotheses, our purpose is to promote further discussion and investigation. The first hypothesis is based on the obvious idea that a sufficient magnitude of unevenness or shifting in the underlying bedrock can be transmitted upward through thick glacial deposits, even if minor joint patterns cannot. The next two hypotheses are based on the obvious idea that near-surface fractures can be induced in a material of limited plasticity by stretching it: either stretching it radially outward in a single plane, or stretching it by placing it on the convex side of a stack of incompressible materials that are being forced to bend. In either case, the deeper layers of clay and till would undergo plastic flow as they were stretched, but the upper layers would be placed under tension without the benefit of the hydraulic pressures that accompany plastic flow in the deeper layers. The predictable result in either case, upon reaching a quantifiable yield point, would be the formation of near-surface fractures—incipient fractures at first, eventually developing into open fractures as the stretching continued.

In general terms, we believe these hypotheses are capable of explaining the observed fractures. Whether any one of them fits the entire body of evidence remains to be seen.

Hypothesis no. 1: Fracture formation is an ongoing process driven by faulting in the vicinity of the Western New York Nuclear Service Center:

We believe it is accurate to say that very little is known about faults in the bedrock in the vicinity of the Western New York Nuclear Service Center. Reports of faults seem to come and go, with no concerted effort to prove or disprove their existence or extent. One example would be the fault observed in the gorge of Cattaraugus Creek (Zoar Valley) that was a factor in the mid-1970s decision not to reopen the reprocessing plant at the Western New York Nuclear Service Center. A second example appears to be the fault, fracture, or uplifted bedrock which, according to Belcher (1970, p. 3), passes through the northern portion of the Western New York Nuclear Service Center (crossing Buttermilk Creek 500 ft northeast of the railroad bridge) and also passes through four creeks further west, from Connoisarauley Creek to the South Branch of Cattaraugus Creek.

A third example is the Attica branch of the Clarendon-Linden fault. Fakundiny, Myers et al. (1978, esp. pp. 123 and 134-37) trace this southwest-trending Attica branch fault as far south as Varysburg; they apparently do so with a high degree of confidence, based on VIBROSEIS profiling and on the work of Van Tyne. They apparently have an absence of evidence (rather than evidence of absence) for the possible southwestward continuation of this branch fault past Varysburg. If the straight line of the branch fault is projected southwestward, however, it passes roughly 10 km <u>east</u> of the Western New York Nuclear Service Center. Belcher (1970, pp. 2 and 5), using different criteria, reaches a different conclusion. Although his terminology is confusing, he concludes that any continuation of the Attica branch fault "passes well to the <u>west</u> of the Nuclear Service Center." (emphasis added) See also Dames & Moore (1970, pp. A-6 to A-8 and Plates A-5, A-6a, and A-6b). The lack of consistency in these expert opinions and the apparent lack of scientific curiosity about what happens to the Attica branch fault southwest of Varysburg do not inspire confidence.

Given the lack of reliable information about faulting in the immediate neighborhood of the Western New York Nuclear Service Center, we propose as a hypothesis that one or more freely slipping but very slow-moving faults either crosses or runs parallel to the valley of Buttermilk Creek in the vicinity of the NDA and SDA burial grounds. We propose this as a hypothesis to explain the observed fractures in till and clay and (if it exists) the deep vertical fracture in the shale east of Buttermilk Creek. As part of this hypothesis, we suggest the possibility that such a fault or faults may exist only in the lower strata that are exposed in valleys such as the Buttermilk Creek valley; at least some of the hills encountered by such a fault may be detached from the lower strata on one or the other side of the fault, and would therefore not show signs of faulting.

(We are not experts in geology but note that the concept of a detached hill is depicted, albeit in a different context, by Fakundiny, Myers et al. (1978, pp. 169-70). We believe that the concept fits the hypothesis we are suggesting here: a very slow motion along a fault, either strike-slip or dip-slip, which is observable mainly in the deeper valleys.)

<u>Hypothesis no. 2: Fracture formation is an ongoing process driven by downslope creep of soil units</u>:

Fakundiny (1985, p. 133) mentions creep in the context of surface layers "a few centimeters thick that move a few centimeters per year." Given 1) the plasticity of the till at depth, 2) the uncommonly thick layer of till at the Western New York Nuclear Sevice Center site, and 3) the high gravitational gradient due to high topographic relief at the site, we suggest that entire soil units may be undergoing a very slow downslope creep. If so, the process may possibly be augmented by the twice-daily "kneading" of tidal forces. The Lavery Till, for example, could be creeping downhill at an almost-undetectable rate, either into the Buttermilk Creek valley or toward the Cattaraugus Creek valley or both. If occurring, such creep would involve a very slow rate of plastic flow (and consequent spreading-out) at depth, while the upper 15 m would be unable to match the smooth plastic flow properties and would therefore start to develop cracks.

<u>Hypothesis no. 3: Fracture formation is an ongoing process driven by differential glacial rebound</u>:

Fakundiny, Myers et al. (1978, p. 127) mention the crystalline basement rock anomaly (determined from gravitational and magenetic field surveys) that follows the southern boundary of the Cattaraugus Creek watershed, and they state that "basement rock types may have greatly influenced local post-glacial rebound rates." We raise the question of whether the <u>differential</u> rebound implied by these statements is complete, or, alternatively, whether the relaxation or adjustment process at this geophysical divide (i.e., the southern edge of the Cattaraugus Creek basin) is still ongoing at a very slow rate. A very slow hinge-type movement which continued to drive the southern edge of the Cattaraugus Creek basin upward would put the surface under tension and would tend to produce fractures (at least incipient fractures) in the general vicinity of the "hinge." We suggest this as a hypothesis that could explain the observed fractures in clay and till at the Western New York Nuclear Service Center.

<u>Hypothesis no. 4: Fracture formation was induced relatively suddenly by the earliest (and deepest) shale-fracturing tests done at the site in 1969</u>:

Deep injections of pressurized fluid are believed to have caused seismic activity at Dale, N.Y., and Painesville, Ohio. We suggest as a hypothesis that the 1969 injections at the Western New York Nuclear Service Center produced unusual non-seismic effects, possibly including effects described in the first two hypotheses listed above. If there was (is) an existing fault near the injection well, the injections may have caused, or temporarily increased, movement along the fault. If the fluid injected into the well found its way into the interface between the bedrock valley of Buttermilk Creek and the glacially deposited till, it may have caused, or temporarily augmented, downslope creep of the till. In general, we note that deep injections of pressurized fluid may cause unexpected distortion or stress relief.

<u>Conclusion</u>

Much remains to be determined about the fractures reported at the Western New York Nuclear Service Center before the site can be properly characterized. At least some geologic field work must be done to prove or disprove the existence of the deep fracture in shale on the east side of Buttermilk Creek. Field work also appears necessary to reach a firm conclusion on the origin of the various types of fractures observed.

<u>References</u>

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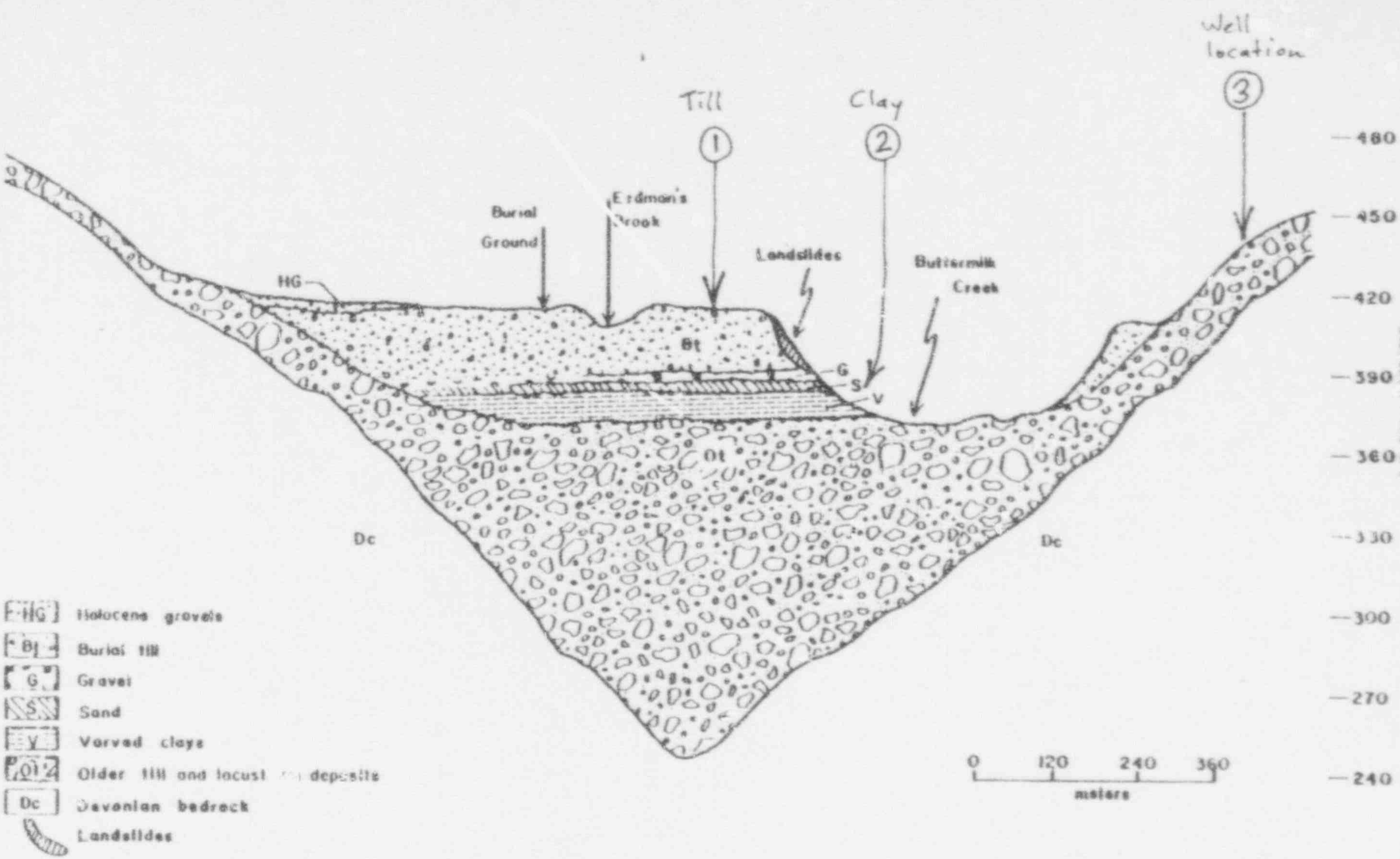
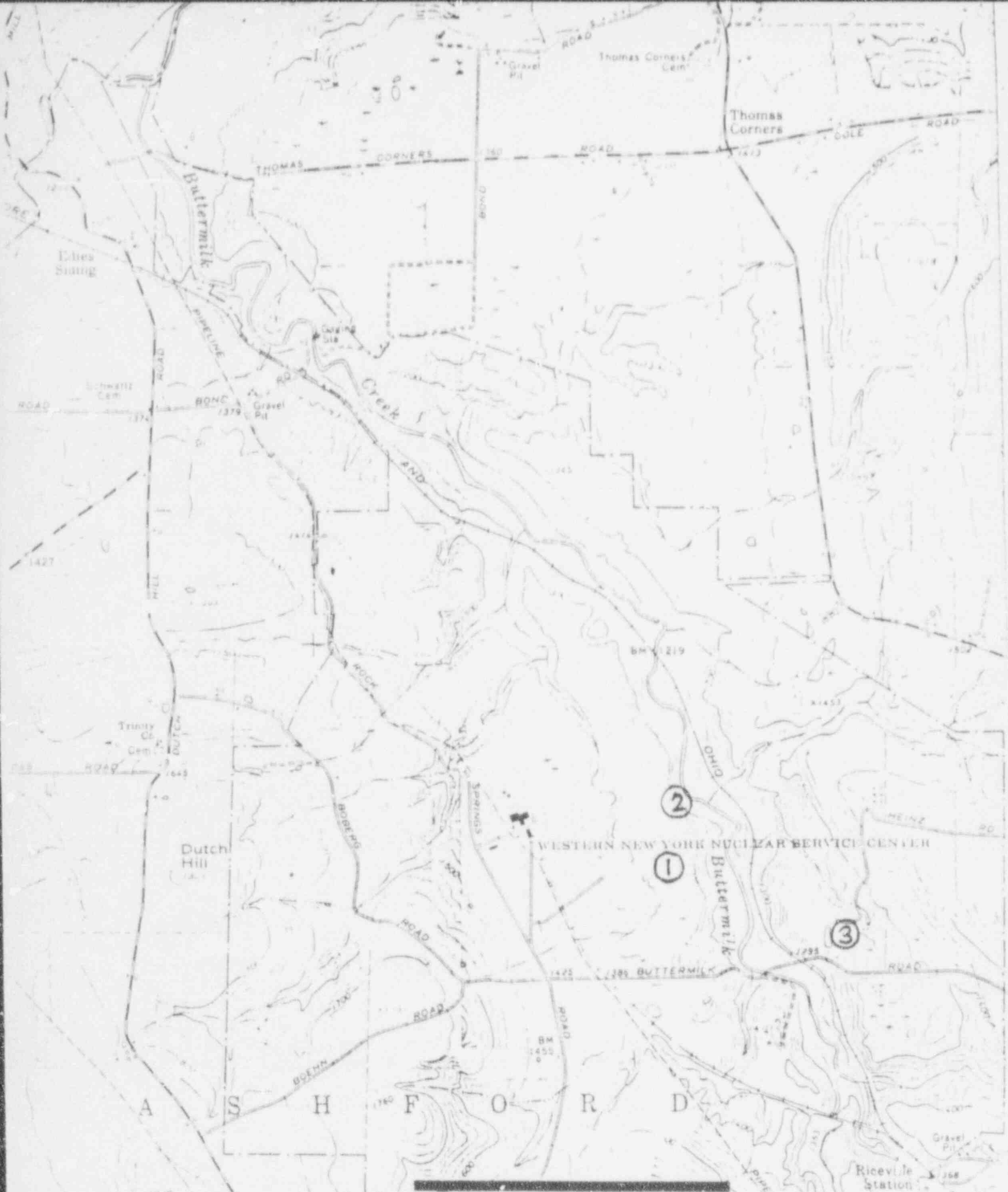


Figure 5. Generalized east-west cross section of glacial deposits at the Western New York Nuclear Service Center.

From Dana, Fakundiny et al. (1979). Note the vertical exaggeration.
Numbers in circles show the approximate locations of the three reported cases of fractures.



Portion of USGS topographic map, Ashford Hollow quadrangle.

Numbers in circles show the approximate locations of the three reported cases of fractures.

Transcription of part of the presentation that Robert Fakundiny (New York State Geologist) made to the New York State Low-Level Radioactive Waste Siting Commission on November 16, 1989. Transcription by Raymond C. Vaughan, November 26, 1991.

Fakundiny was showing slides during his presentation and was discussing a test trench that had been dug at the West Valley site, roughly 200 meters east of the existing radioactive-waste disposal trenches of the State-Licensed Burial Ground. Just prior to the part transcribed here he had been talking about the question of whether water could enter or leave the waste-burial trenches, through either the sand lenses or the cracks that have been observed in the silty till (Lavery Till) in which the test trench and waste-burial trenches are located. After characterizing the sand lenses as discontinuous (and hence incapable of allowing any substantial flow of water), he proceeded as follows:

"Well, that leaves the cracks. Now here we have a close-up of the cracks with a pencil sticking in it right here. This crack is not perpendicular to the wall, by the way; this crack is going right in, and the camera is focused right on the plane of the crack. This pencil, which you can only see the end of, is sticking in the crack, so it's actually at an angle like this. We also noticed other cracks orthogonal, or essentially at right angles, to that—like this. When the material was exposed to the air and would start to dry out, blocks would fall out of the walls that had these ortho—these rhombic forms to them—so they were falling out as diamond-shaped blocks, if you're looking down on top of them. Certainly not the kind of thing you would expect from just the slumping of clay into the trenches. We measured the kinds of cracks you find in the bedrock in the region around here—and we measured these cracks, and we found that they were identical, that they were lined up—so somehow, these are what we call joints that have been inherited in the clay. Now the question was, if they're exposed in the weathered area, how far do they go down through the trench, because certainly here they would act as an avenue for water to enter from the surface; it would come down this crack and possibly get into a trench. Now remember, this is in the weathered horizon here.

"Now we're looking at the trench—this is Al Randall and Dave Prudic from the U.S. Geological Survey—they're down into the good moist till, and the cracks that we saw start to die out. This up here is the bottom of the weathered section, and you can see down here that there are actually no cracks exposed in this particular part of the trench, but we did notice cracks—of some kind of nature of crack—down to about 15 meters; that was the lowest we could go. In the weathered area we found chemical changes in the cracks that would indicate that water had gone through them—they were either oxidation features or reduction features, both—so we found the kinds of classical evidence that you see for water moving through cracks. So in the upper part it's very possible that local—nearby precipitation from the top surface—could go down a crack and migrate sideways into a trench, possibly—but certainly cracks would not be a way for water to get out of the bottom of the trenches, because there were none exposed there...."

DONALD J. BELCHER & ASSOCIATES

Incorporated

CABLE: FOTOANALYST

SITE ANALYSIS
EXPLORATION & DEVELOPMENT
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June 19, 1970

LETTER REPORT

TO: Dames and Moore
100 Church Street
New York, New York 10007

FROM: Donald J. Belcher, President
Donald J. Belcher & Associates, Inc.

RE: Western New York Nuclear Service Center
Regional and Local Structural Patterns and Their Evaluation

The initial investigation was undertaken as an analysis of aerial photographs of the region between Batavia, New York and the vicinity of the site of the Western New York Nuclear Service Center.

This analysis identified bedrock control of surface and near-surface features. These take the form of abnormal lineaments on the surface of the glacial drift covering bedrock, control of drainage lines other than by local jointing, gullying and color patterns directly associated with the above, and by sheared rock faces not attributable to glacial action.

Adequate research in the past has proven that joints, fractures and faults project themselves upward through overlying glacial drift. The drift tends to mask joint patterns, leaving only the more significant lineaments as obvious structural features. The thickness of the drift has an effect although shallow drift, ranging between two and four feet, will carry the influence of extremely minor fractures to the surface providing there is sufficient lineal continuity for the eye to separate it from random occurrences. The mechanism of the projection is not well understood.

Where drainage lines are concerned, erosion has exposed bedrock influences -- not always bedrock -- and the stream courses are influenced by jointing as well as by fractures. Jointing provides a micro-control, while controls that persist reasonably for a mile or more are considered as lineaments generated by fractures in the bedrock.

Faults are generally distinguished by the obvious effects of offsets. Lacking such evidence, the term "fracture" is applied.

THE CLARENDON FAULT

As a part of this investigation, consideration was given to the possible extension of this fault into the area of concern.

Aerial photography of the entire region was used and a detailed analysis made on the basis described above.

Based on this compilation, a regional map was prepared on a 1:250,000 scale base with supporting aerial photographs annotated to identify the features considered to be significant to this investigation.

It is of particular importance to recognize that this work is conducted on individual photographs without particular knowledge of the relationship of the individual photograph to the region. This largely insures that the results are not biased in favor of or against a correlation that may or may not appear when the photographs are assembled into a mosaic.

The results of the regional mapping when compiled suggests that some extension of the fault may occur. The regional map has been annotated to associate two widely separated fracture traces as a possible projection of the Clarendon fault. One, in the Attica Quadrangle related to Tonawanda Creek (Photo No. 1534/011) and the second, in the Ashford Hollow Quadrangle (Photo No. 1592/1872). To make this association: it is obvious that these two fractures have an unique orientation, approximately that of the Clarendon fault, but it is necessary to assume that an offset to the west exists immediately south of Batavia. This offset is in the order of two miles and is considered to be too abrupt for this region. Certain aspects of Tonawanda Creek in this (South Batavia) quadrangle suggest that the control by this offset exists immediately south of the Lehigh Valley Railroad track (Photo No. 1601/1606) but the area is covered by outwash and alluvium to an extent that renders this problematical. Strong control of the channel of Tonawanda Creek is reasserted in a NNE - SSW direction at Alexander, approximately one-half mile south of the US 20 bridge.

If such a continuation of the principal fault does exist, its ultimate extension passes well to the west of the Nuclear Service Center.

LOCAL FRACTURE PATTERNS.

Cattaragus Creek from a point near Gowanda to Arcade, a distance of approximately 30 miles, exhibits evidence of very strong structural control. North of the creek the fracture pattern is sparse and oriented generally NNE.

Cattaraugus Creek and the fracture pattern south of this demarcation assume a northeasterly trend. These appear to be more closely related to the structural trends in the Pennsylvania sediments that produce oil and gas south and east of the site.

Several fracture patterns pass through the site and these were investigated in the field. Photo Nos. 1574/1037, 1038 and 1039 illustrate their trend and position in relation the Nuclear Service Center.

The most northerly of these trends NE-SW and passes through the northern portion of the site. The most dramatic aspect of this fracture is its influence on the course of Buttermilk Creek, for it is at this point that this north-flowing stream converts from a meandering "uncontrolled" channel to a rigidly controlled channel flowing, apparently, on a lower gradient. This suggests strong structural control and may result from either normal faulting or an encounter with an upfolded bedrock. Inasmuch as this same characteristic is repeated on-trend in the courses of Connoisarauley Creek and three others to the west, including the south branch of Cattaraugus Creek, it is considered to be a general bedrock high.

The point at which this fracture crosses Buttermilk Creek lies downstream and 500 feet northeast of the Baltimore & Ohio bridge. A landslide of recent date that has occurred in the deep valley filling obscures any significant outcrops and further investigation was not within the scope of this study.

Three thousand feet upstream, on a trend that passes through the southern portion of the site, Buttermilk Creek has undercut and exposed a fresh face that consists of glacial till, some stratified drift and a fifteen-foot exposure of a dense clay in which are encased erratics of one to three-inch dimension. This deposit is evidently of early glacial origin and its thickness unknown, since it extends below stream level.

The exposed clay section clearly retains an open, psuedo-joint pattern. Within a horizontal distance of 80-100 feet, vertical cracks are evident. These extend from below water level upward for varying distances with the central crack apparently extending, at least its influence, into the stratified drift. The central crack was open as much as 1/8 - inch to 3/16 inch and was clean and free of infiltered extraneous material. This crack, along with several others, extends into the bank and intersects other "joints" at approximated right angles.

The spacing of the cracks is roughly regular, with intervals of two to three feet being typical. This association of vertical cracks terminated abruptly within fifty feet on each side of the central crack. On the northern (downstream) flank, the last two cracks dip at an angle of 45° toward the northeast.

The close association of this unusual grouping with the regional fracture pattern merited some further consideration.

1. Typical dessication cracks were noted as bearing no resemblance to the anomalous cracks.

2. Landslide movement was considered and discarded because of the lack of any resemblance to cracking related to that type of failure.

3. The reflection of joints in the underlying bedrock was considered as a cause since it is known that joints do project their influence through glacial till and other unconsolidated materials.

Accordingly, the joint pattern in local outcrops was observed to consist of two sets with a consistent strike in each. The strike of the psuedo-joints in the clay were determined to be at variance by approximately 45°. This disparity, the unknown depth to bedrock, the fact that no movement was evident and that these appear to be tension cracks seemed to eliminate this possibility.

4. Faulting was discarded because of the clear absence of movement and the recent date indicated by the clean surfaces of the cracks.

5. The only similar pattern familiar to the writer is the major pattern of fractures related to unconsolidated sediments draped over piercement structures (salt domes) and domes on the buried bedrock surface. These are found in areas that enclose hundreds of acres, whereas the Buttermilk feature is confined to less than one acre. Further, these are long-term processes, whereas the cracks observed are of recent origin.

The conclusion can be expressed that this assemblage of micro-fractures in these clays is of recent origin, the cause of which cannot be attributed to ordinary known processes.

In summary, the analysis and study conducted to evaluate local and regional structural patterns reveals a reasonably standard occurrence of fractures common in the sedimentary bedrocks of New York State.

The Clarendon fault, if it does in fact project below Batavia, passes to the west of the site under consideration.

With the single exception noted in the glacial clays, there was no evidence found to indicate post-Pliestocene movement associated with the observed fractures.

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