Click Here to Return to Main Index

The Field Investigation of Bedrock in the Explosive Ordinance Disposal Range Brunswick Naval Air Station

January 22, 2003

1.0 Background

At the request of the U.S. Environmental Protection Agency (USEPA), Gannet Fleming (GF) performed a field investigation of bedrock outcrops in the Explosive Ordinance Disposal (EOD) range of Brunswick Naval Air Station on December 2, 2002. Gannett Fleming gratefully acknowledges the assistance of Dr. Arthur Hussey, Professor Emeritus, Bowdon College; and that of Tony Williams, Environmental Manager for Brunswick Naval Air Station, in this investigation.

The objective of the field investigation was to observe bedrock structure, composition, morphology, and fracturing in order to guide the proposed geophysical investigation of bedrock near Site 11. Such observations may contribute to our knowledge of the bedrock at Site 11 by providing:

- Characteristic orientations, widths and depths of significant bedrock depressions, necessary to structure the geophysical investigation appropriately.

- Insight into which of 9 proposed lineaments may be physically real, fracture-related bedrock depressions.

- Characteristic morphology and fracturing of bedrock rises, suggesting mechanisms by which groundwater of conduct of overburden layers may interact with bedrock.

The EOD range proved an excellent choice for this investigation since the area has minimal overburden, is largely cleared of woods, and has abundant bedrock outcrops.

This document presents key findings of the 2002 bedrock investigation, and summarizes ramifications for the proposed 2003 geophysical investigation. Further field investigation with Dr. Hussey's assistance is planned for spring 2003, prior to updating the 2003 workplan. A more detailed report covering all non-geophysical field investigations into bedrock will be released in the late spring.

2.0 Regional Bedrock

The Eastern Plume at Naval Air Station, Brunswick resides over the Cape Elizabeth Formation (CE). This formation is characterized as thinly-bedded gray schist, composed primarily of quartz-plagioclase-biotite-muscovite, and characteristically interbedded with thin beds of quartzite schist. It exhibits differential weathering and erosional features which result from rock layering and lithologic variability. Bedding planes and schistosity (a cleavable planar layering in the rock) of the formation characteristically strike to the NNE, and dip steeply to the SE.

3.0 Key Findings
In all, 80 bedrock features (bedding, schistosity, jointing, and other layering) have been observed in the rocks of the Brunswick vicinity to date. Key findings are presented in the sections below.

3.1 Size and Orientation of Major Linear Bedrock Depressions
Significant linear bedrock depressions were found, oriented NNE and NE. These depressions range in size from 50-130 feet in width and 5-20 ft. in-depth.

3.2 Steep West-Facing Bedrock Slopes
Most NNE oriented bedrock rises in the EOD range have steep western slopes. Eastern slopes are predominantly gentle, although exceptions do exist. The steeper western slopes of bedrock rises can consist of a series of small (4-5 feet) terraced outcrops (Figure 1), or larger individual cliffs (15-18 feet or more above overburden) (Figure 2). Some of these slopes are associated with significant pegmatite sills. The largest of the pegmatite sills is approximately 10 to 12 feet wide, 600 ft. long and ranges in height 4 to 8 feet above the EOD pond (Figure 3).

3.3 Site 11 Bedrock Peak
Considerable evidence now suggests that the bedrock peak at Site 11 is in fact a NNE oriented ridge with a steeper western face. Such a feature may or may not include a pegmatite sill.

3.4 Pegmatite/Meta-Volcanic Rock near CL-1
A major pegmatite outcrop resides within 400 ft of the 8+ mile lineament, CL-1 (Figure 4). (CL-1 is the primary NNE lineament with the most consistent supporting evidence over its 8+ mile length. It extends to the North in the deepest part of the bedrock trough between EW-5A and MW-305.) This West-facing pegmatite cliff has far more micro-aperture fracturing than other EOD outcrops. Furthermore, a meta-volcanic chlorite schist was discovered at the base of this outcrop. Such rock is uncommon in the area, although not unheard of. The local geologic/hydrogeologic significance of these features is unknown at this time.

3.5 Schistosity and Fracturing
Schistosity and jointing (fracturing) are the most significant of the observed bedrock features for conceptualizing possible bedrock/overburden groundwater interactions. The variations of these characteristics by rock type are presented in Figure 5.

3.5.1 Cape Elizabeth Schistosity
Figure 5A depicts the schistosity of the Cape Elizabeth Formation. This rose/pole diagram reveals a strict NNE orientation, steeply dipping to the ESE. (Note that pole plots are somewhat non-intuitive. A fracture dip to the ESE appears as a point in the WNW quadrant of the compass.) Consequently, West-facing slopes of Cape Elizabeth rock that are sufficiently steep and high enough to rise above the Presumpscot clay may make good hydraulic contact with overburden formations. This observation applies both

to the Site 11 bedrock peak, and to the (West-facing) East wall of the NNE bedrock trough, especially between EW-5A and MW-305.

3.5.2 Cape Elizabeth Joints

Figure 5B depicts 32 joints observed in the Cape Elizabeth Formation. These joints are most frequently oriented WNW, dipping steeply to the SSW or NNE. If steep, near vertical fractures such as these exist at the Site 11 bedrock peak, they could provide overburden flow entry into or through the peak/NNE ridge. A cluster of sub-horizontal sheeting joints can be seen as well in the pole plot.

3.5.3 Pegmatite Joints

Figure 5C depicts 14 joints observed in the pegmatite structures. As volcanic intrusions, these rocks have very different fracturing patterns than the meta-sedimentary Cape Elizabeth Formation. 13 of these joints are steeply dipping. Roughly a third of the joints are oriented NW or NNW, commonly dipping to the SW. The remainder of the joints cover a wide variety of NE and ENE orientations, dipping both to NW and SSE. Consequently, if the Site 11 bedrock peak is a NNE ridge encompassing a pegmatite sill, the sill may serve to impede horizontal and vertical groundwater flow more than a wholly CE ridge might. However, this is not definitive.

3.5.4 All Bedrock Features

Figure 5D depicts the strike and dip of all 80 bedrock observations. Bedding planes combine with Cape Elizabeth schistosity to create a predominant NNE strike orientation in this diagram. The major WNW rose-petals are comprised primarily of Cape Elizabeth joints. The orientation-influence of the pegmatite is largely lost when looking at this combined perspective. Regarding dip angles, very few features were observed in interval 15-65 degrees.

3.6 Fracture Correlation of Lineaments

Of the lineaments delineated in the vicinity of Site 11 for the workplan, those oriented NNE and WNW correlate well to observed Cape Elizabeth Formation schistosity and joints. Consequently, 7 of 9 lineaments near Site 11 can be considered fracture-correlated (Figures 5 and 6). In addition, a small set of EOD fractures does correlate to N50E, suggesting a possible physical reality for the two NE oriented lineaments; However, further fieldwork is required to demonstrate this. There was no significant fracture correlation to the NW in the CE, suggesting that NW lineaments such as the Mere Brook valley linear (not depicted) may not be fracture-related.

3.7 Bedrock Hydraulic Conductivity

Given the consistent, steeply dipping fractures noted both in CE and pegmatite outcrops, it is likely that many bedrock areas will register greater vertical than horizontal hydraulic conductivity. Exceptions to this would include flow directly along fracture zone strikes or areas of horizontal sheeting. In overburden, the vertical hydraulic conductivity is often an order of magnitude or more less than horizontal conductivity.

4.0 Ramifications for the Geophysical Investigation
These observations suggest several modifcations that could be made to the proposed geophysical investigation.

- Greater effort could be focused on investigating ***both*** eastern and western slopes of the Site 11 bedrock peak, especially to seek out steep West-facing slopes.
- Overburden stratigraphy at Site 11 could be determined to the extent possible, especially in areas of steep western slope.
- The possibility of a pegmatite sill and contact joints could be evaluated at Site 11.
- The possibility of cross-peak/ridge fractures could be evaluated
- The possibility of steep West-facing slopes, pegmatite sills, and fracture zones in the deepest part of the bedrock trough near EW-5A and MW-305 should be evaluated.

These suggestions will be incorporated into the investigations as funding permits.

5.0 Further Fieldwork
As mentioned earlier, further fieldwork is planned in conjunction with Dr. Hussey to:

- Capture the fracturing of East-facing slopes (since such bedrock slopes are known to directly contact sand at Site 11).
- Further examine rock composition and fracturing near CL-1, to evaluate the possible hydrogeologic significance of this lineament.
- Ensure that sample density is sufficient to capture both regional and local fracturing (e.g. to further evaluate fracture correlation to NE and NW lineaments).
- Further evaluate the characteristic extent of steep NNE slopes to determine the most cost-effective spacing between parallel cross-ridge seismic/resistivity lines to reasonably detect such features.

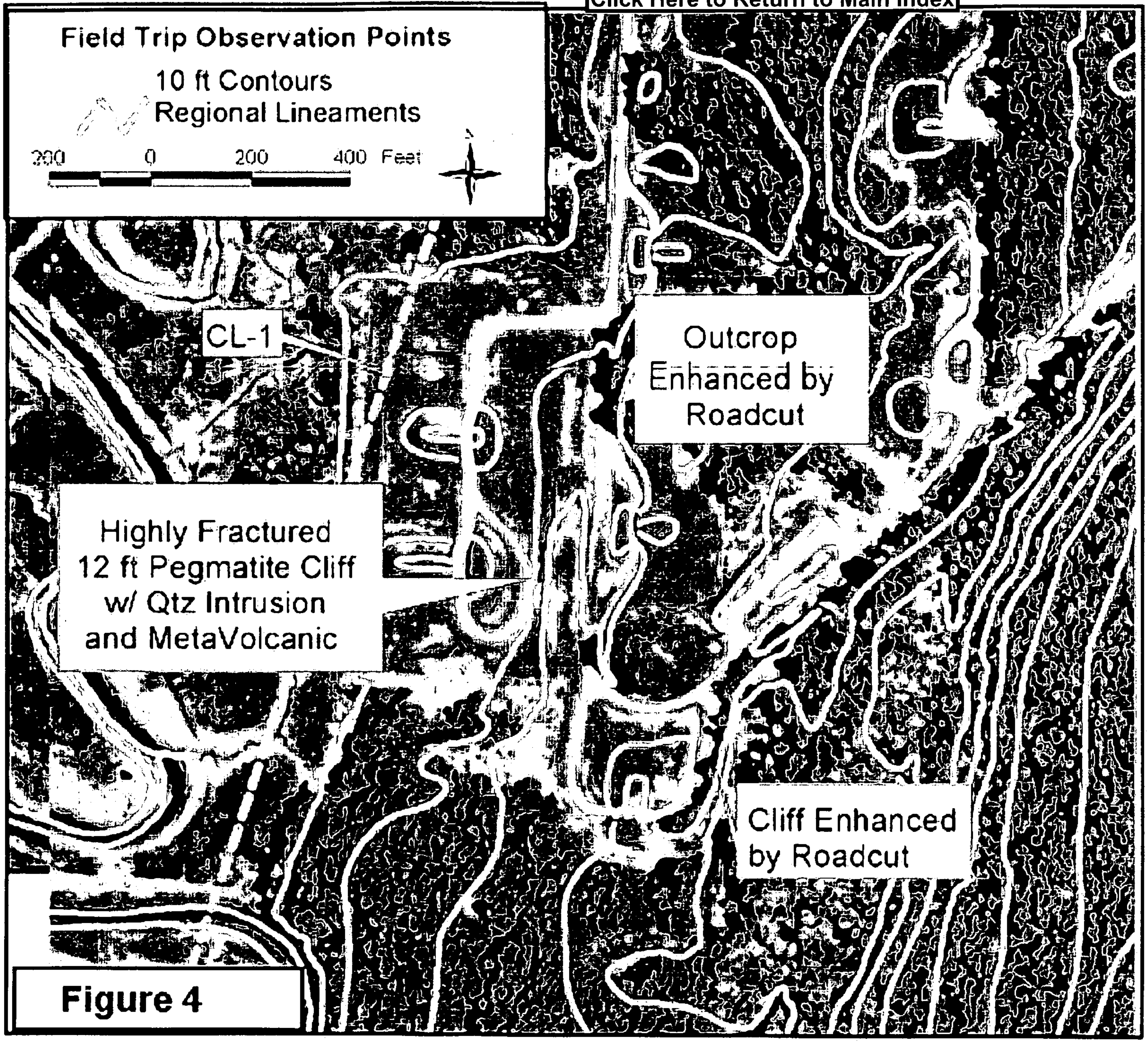
Click Here to Return to Main Index

Click Here to Return to Main Index

Figure 2

Figure 3

Click Here to Return to Main Index



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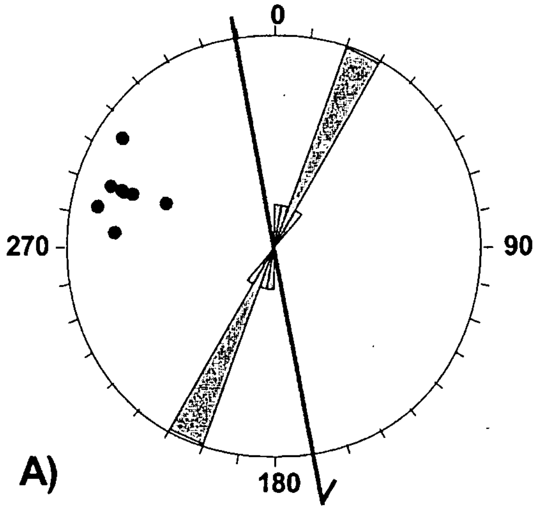
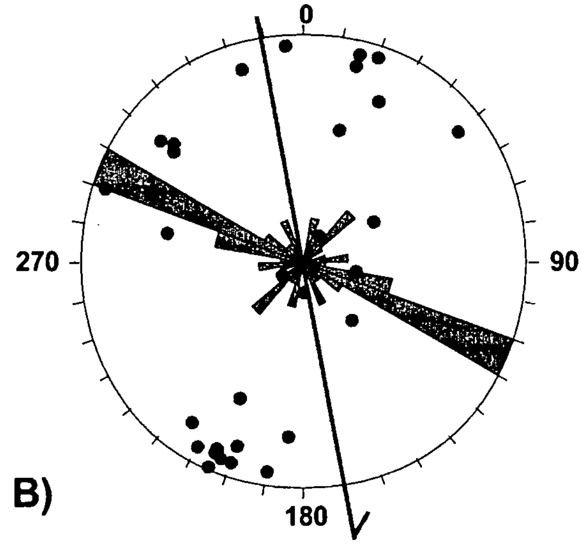
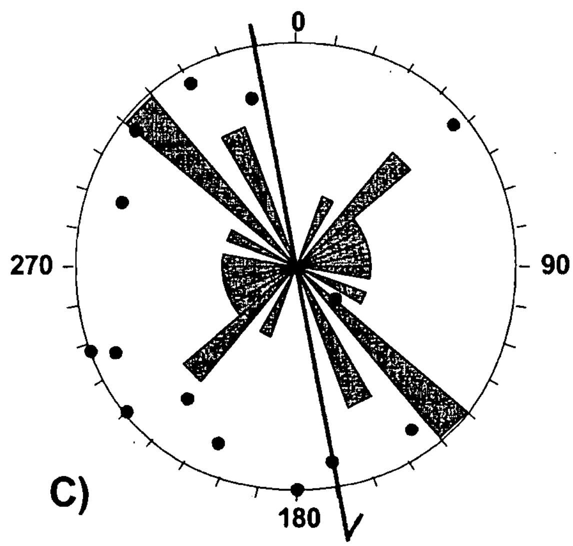
Figures 5A, 5B, 5C, and 5D
Bedrock Features in the Brunswick Area



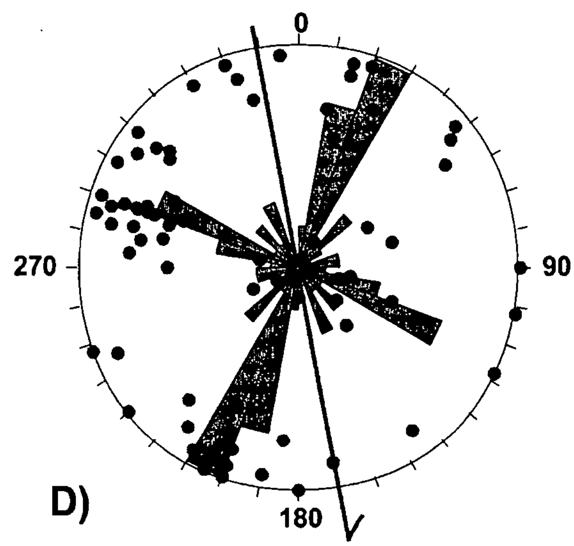
Rose - Cape Elizabeth (CE) Schistosity Strikes n= 8
- Pole Plot - Dips of CE Schistosities
- Approx. Direction of Glacial Flow



Rose - CE Joint Strikes n= 32
- Pole Plot - Dips of CE Joints
- Approx. Direction of Glacial Flow



Rose - Pegmatite Joint Strikes n= 14
- Pole Plot - Dips of Pegmatite Joints
- Approx. Direction of Glacial Flow



Rose - Strikes of All Bedrock Features (includes bedding, etc.) n= 80
- Pole Plot - Dips of All Bedrock Features
- Approx. Direction of Glacial Flow

Rose Diagram: A relative frequency histogram. The size of each rose petal indicates the relative frequency of strikes within the given 10 degree bin, in proportion to the frequency of the bin having the greatest number of strikes.

Pole Plot Explanation: Each red point represents the intersection point between a lower hemisphere of the compass and a perpendicular pole projecting from the joint plane at the compass center. Therefore, features oriented NNE (as in 1A) and steeply dipping to the ESE have points plotting close to the compass circle-edge in the WNW.

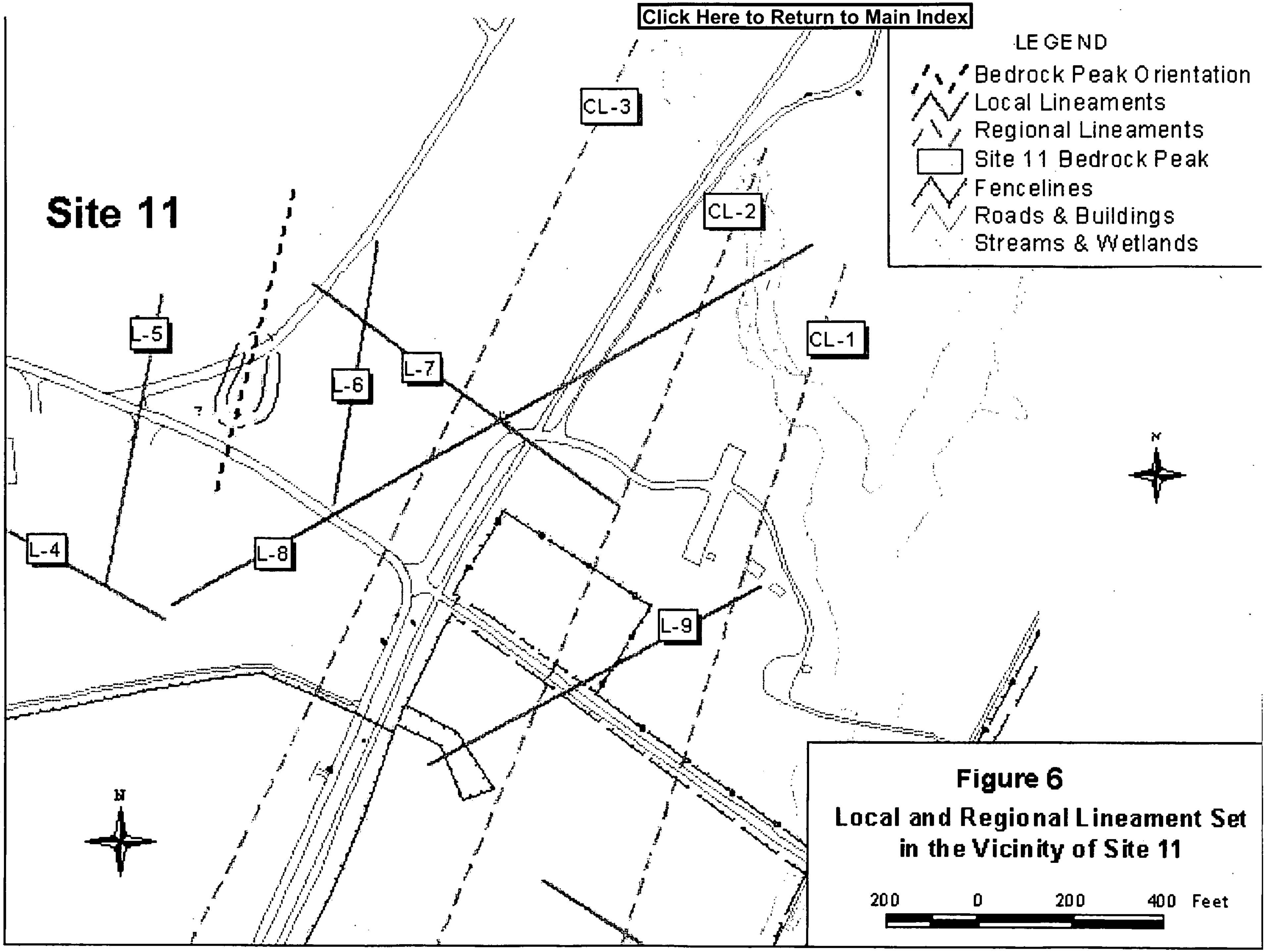


Figure 6

Local and Regional Lineament Set in the Vicinity of Site 11

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