UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

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MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: Eric S. Beckjord, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER, NO. 147, "MIRAMICHI EPICENTRAL AREA - IN SITU STRESS MEASUREMENTS"

The purpose of this memorandum is to transmit the results of in situ stress measurements conducted at the epicenter of the Miramichi earthquakes, New Brunswick, Canada (Figure 1). This research was performed by Ontario Hydro under a cooperative venture sponsored by the NRC and several Canadian federal and provincial agencies. The purpose of the work was to assess the tectonic cause of the seismicity at Miramichi. The results of this research are reported in full in the publications by McKay and Williams, 1985 and McKay, 1985.

Determination of the stress field is of relevance to the concept of tectonic provinces in Appendix A to 10 CFR Part 100. Changes in the direction and/or magnitude of the stress field could indicate that a tectonic boundary has been crossed and may indicate the need for reevaluation of the design basis earthquake at specific sites. The stress field also indicates which faults are favorably oriented for potential reactivation by the current stress field.

BACKGROUND

The Miramichi earthquakes of 1982 were among the most significant seismic events to occur in Eastern North America in several decades. There were two main shocks of magnitude 5.7 and 5.4 on January 9 and 11, 1982, respectively. The Miramichi earthquakes are important for several reasons (McKay and Williams, 1985):

(1) They were the largest earthquakes to occur in Eastern North America since the Cornwall-Massena earthquake of 1944.

(2) The main shocks were the first Eastern North American earthquakes of that size to be recorded on modern worldwide seismographic networks.

(3) The aftershock sequence was unusually long and complex. The records of these events yielded the most complete seismic record for any such event in Eastern North America up to that time.

To gain insights into the mechanism of seismicity at Miramichi, a seismic network was installed to monitor aftershocks. Also, detailed geologic mapping of the ground surface and excavated trenches, geodetic studies, and measurements of in situ stress were performed in the epicentral area of the earthquakes. As part of the detailed studies, an area of bedrock approximately 100 m x 50 m was

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exposed by excavating several meters of till. Pop-ups, rockbursts and other displacements occurred in the exposed rock surface shortly thereafter. These displacements (up to 10 cm), were measured by leveling techniques. Within 0 to 8 km of the cleaned bedrock surface, a total of 6 boreholes were drilled to an average depth of about 31 m. In situ stress measurements, using the United States Bureau of Mines borehole gauge, were conducted at several depths within the boreholes. Prior to the stress measurements, core samples of rock were retrieved from the boreholes for geologic identification and rock mechanics testing. Detailed geology of the epicentral area and the results of the rock testing are presented in McKay and Williams, 1985 and McKay, 1985.

TEST RESULTS

A. Stress Measurements

A total of 57 successful in situ stress measurements were made at the Miramichi site in the six boreholes drilled (McKay and Williams, 1985). The measurements show that both the magnitude and direction of the stress are highly variable. Figure 2 summarizes the results of the measured stress magnitudes. Both compressive and tensile stresses were measured. The compressive stresses were, in some cases, extremely high. Although highly variable, the average magnitude of the stresses is on the same order as that measured by Plumb et al., 1984a and 1984b in New York and New Hampshire, which seems to indicate that these stress magnitudes may be common in the New England/Maritime Canada areas. The mean measured direction of stress is about N55°E. This does not agree with data from the Bathurst mine, New Brunswick (McKay and Williams, 1985) where the measured stress direction, in a much deeper borehole (1km), was about N120°E or with northwesterly stress directions measured at Moodus (Rundle et al., 1986), but it is in rough agreement with the general direction of stress in the Northeastern United States and adjacent Canada which is eastnortheast to east.

Analysis of aftershock distributions and focal plane solutions for the Miramichi earthquakes (Wetmiller et al., 1984) indicate that the seismicity may be occurring along north-south striking thrust faults. The direction of stress from the focal plane studies is about N95°E as compared to N55°E from the stress measurements. Some investigators (e.g., Tullis, 1981 and Zoback et al., 1980) believe that inhomogeneities in the fault plane surfaces cause in situ stress directions to disagree with observed fault mechanisms. Other conditions cited include topography, glacial rebound, jointing patterns and weathering.

The hypocenters for the Miramichi earthquakes are believed to be as deep as 7 km below sea level. The deepest in situ stress measurement is only about 31 m. Although some investigators (e.g., Tullis, 1981 and Zoback et al., 1980) show some correlation between near-surface and deep stress measurements, shallow stress measurements may not be representative of stress at hypocentral depths.

B. Rock Deformations

After completion of the excavation in till and before the drilling program, pop-ups, rock bursts and other displacements occurred in the exposed bedrock at varying intervals. Leveling and re-leveling of the area indicated up to 10 cm of displacement. Although the reason for this deformation is not known, it is suggested that it could be related to stress release due to the excavation combined with solar heating of the exposed rock surface or possible second-order effects caused by seismicity at depth or both.

SUMMARY AND CONCLUSIONS

(1) There are high stresses in the plutonic bedrock at shallow depths in the Miramichi epicentral area. This is confirmed by the in situ stress measurements and by the observed pop-ups and rock bursts.

(2) The principal horizontal stress has a mean orientation of N55°E which is approximately in agreement with the general eastnortheast to east orientation of stresses in the Eastern United States and adjacent Canada.

(3) The measured stress orientation differs by about 40° from the direction of stress from focal plane studies (N95°E). It is suggested that inhomogeneities in the fault plane surfaces, and conditions of topography, glacial rebound, jointing patterns and weathering might cause the measured stress orientations to differ from those inferred from the focal plane solutions. It is also noted that the stress was measured near the surface (upper 30 m) compared to hypocentral depths of up to 7 km.

(4) Up to 10 cm of rock displacement due to pop-ups and rock bursts was measured. It is suggested that this could be related to either in situ stress release due to excavation and solar heating of the rock surface or to second order effects caused by seismicity at depth or both.

REGULATORY IMPLICATIONS

Since the Miramichi, New Brunswick earthquakes of 1982, RES has made an attempt to identify the tectonic source of this seismicity. The importance of identifying this source mechanism lies in the fact that the New Brunswick seismic events occurred in geologic terrain similar to the New England-Piedmont tectonic province and exceeded the previous largest historical earthquakes in this tectonic province by about half a unit of magnitude. The New England Piedmont tectonic province was designated by NRR staff in compliance with Appendix A to 10 CFR 100 for the case where earthquakes cannot be associated with tectonic structure.

It had been anticipated that in situ stress orientations measured from these tests, at shallow depths where faults and other structures can be seen, would be similar to those determined from the focal mechanisms of aftershocks at hypocentral depths and thus provide additional clues as to the nature of the earthquake source. The stress orientations from the near-surface tests were too variable to accomplish this. However, the tests confirm the presence of high in situ stresses in eastern North America and, in this case, within an area of high seismicity. We expect that these data along with the wealth of other geological and seismological information becoming available now will ultimately provide the basis for associating earthquakes with specific tectonic structures in eastern North America.

Further work in the Miramichi area, such as stress measurements at greater depth, or seismic reflection profiles to define subsurface structure is being considered by the NRC and Canadian agencies to resolve remaining questions.

Eric S. Beckjord, Director
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Enclosures:
1. Figures 1 and 2
2. List of References

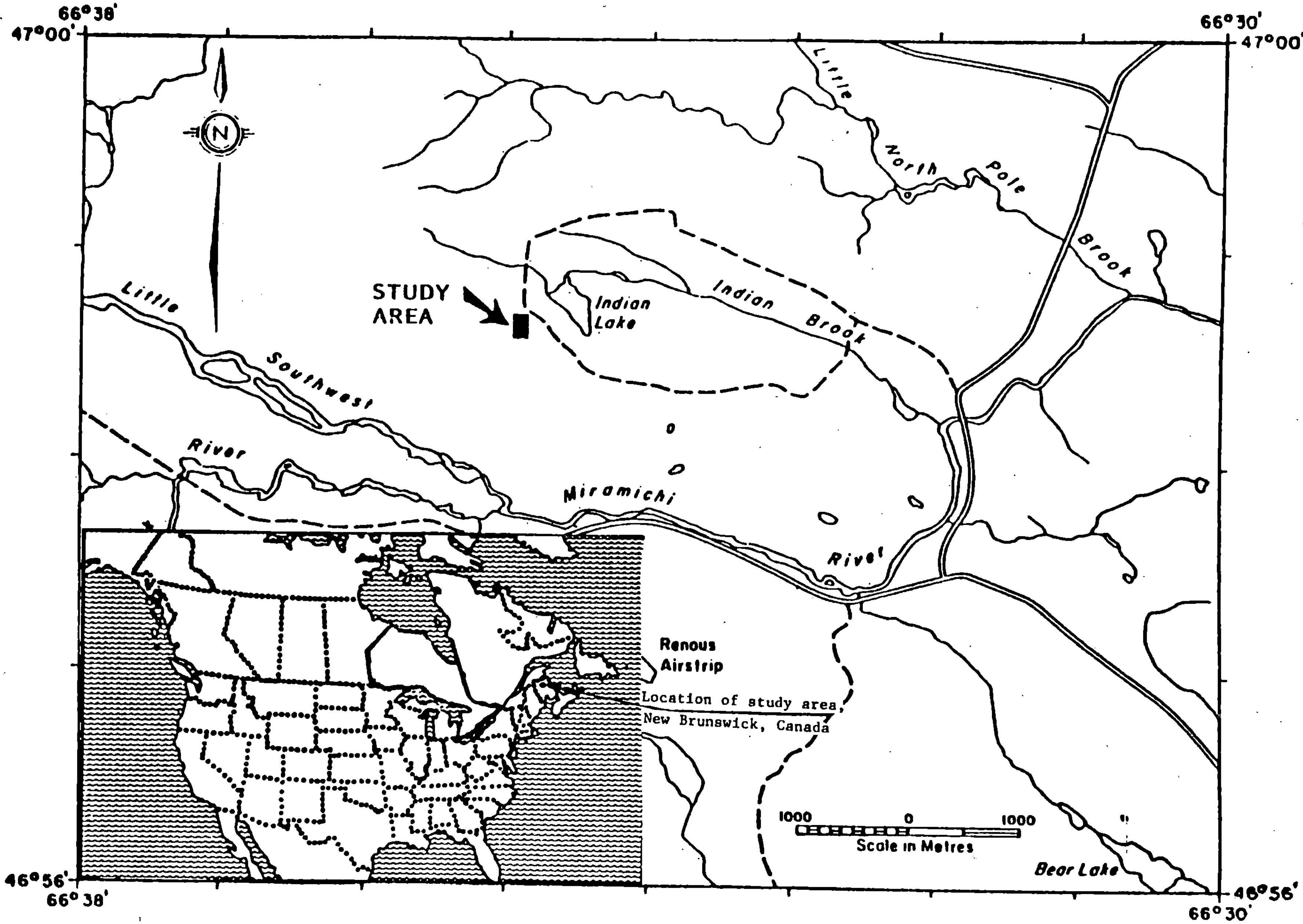

FIGURE 1 - LOCATION OF STUDY AREA

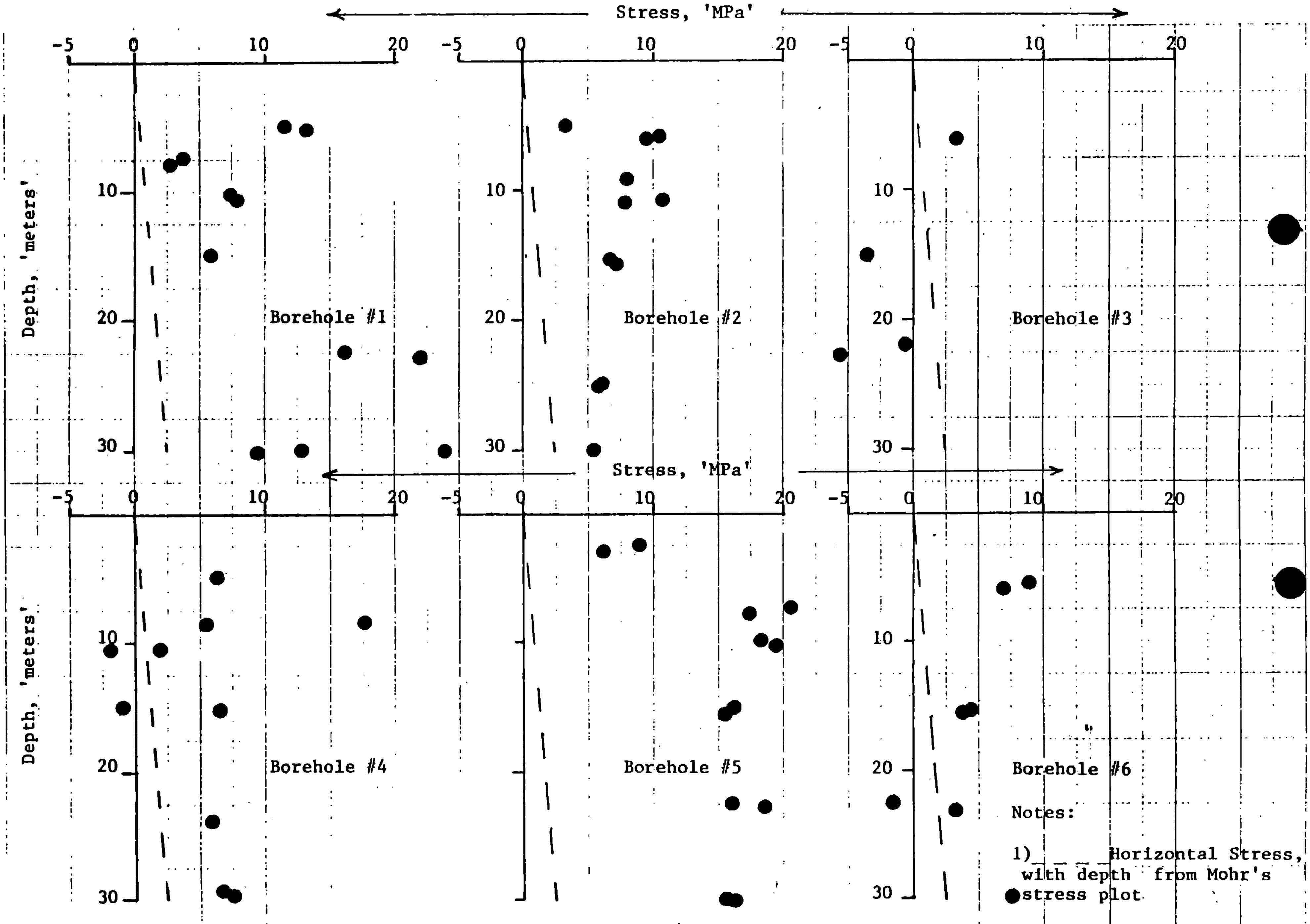

FIGURE 2 - INSITU MAXIMUM HORIZONTAL STRESS V/S DEPTH

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