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C P 1046
Ottawa, Canada
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INFO-0343

ca9111008

NEOTECTONIC INVESTIGATIONS IN SOUTHERN ONTARIO: PRINCE EDWARD COUNTY - PHASE I

by

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original contains color illustrations

A research report prepared for the
Atomic Energy Control Board
Ottawa, Canada

Project No. 3.131.1

March 1989

MAGNEC
AMNEC
MULTI-AGENCY GROUP FOR NEOTECTONICS IN EASTERN CANADA
L'ASSOCIATION MULTIPARTITE POUR LA NÉOTECTONIQUE DANS L'EST CANADIEN
CONTRIBUTION 89-02

Canada

Research report

NEOTECTONIC INVESTIGATIONS IN SOUTHERN ONTARIO : PRINCE EDWARD COUNTY, PHASE I

ABSTRACT

This report summarizes the preliminary results of geological and geophysical investigations of possible neotectonic features in Prince Edward County, southern Ontario, made by the Ontario Geological Survey during 1988. Low magnitude seismic events indicative of contemporary stress relief occurred during 1987-88 near Salmon Point and Consecon (M 2.2). These events were located proximal to a major regional fault system crossing Lake Ontario and consisting of the Clarendon-Linden Fault System in New York State and the Salmon River-Picton fault systems in Ontario.

Detailed observations were made of regional jointing orientations (predominantly 060° and 125°), erosion of surficial deposits adjacent to open fractures, a local fault displacement (post-glacially), dome structures located at Point Petre, and dissolution/karst terrains in the eastern part of the study area.

Excavations of four pop-up structures indicate that three are "classical" pop-ups and one is atypical in structure. Level transects were conducted across complex structures in the eastern part of the study area.

Detailed refraction seismic and resistivity surveys were conducted on pop-up and fault features. Preliminary results indicate that the Picton Fault is a complex zone of fractures with differing bedrock on each side. The central zone of the "East Duck Pond" pop-up is fractured and may contain variable amounts of water.

Overturned and upright folds in the Consecon Quarry located outside of the primary research area were documented and found to be trending in a west-northwest to northwest direction. This fold orientation is compatible both with a glacial shove origin and with the present stress field orientations. Although glacial shove can produce overturned folds, it cannot form upright folds. A regional, tectonic deformation oriented northeasterly is therefore suggested as the causative mechanism.

RÉSUMÉ

Le présent rapport résume les résultats préliminaires des recherches géologiques et géophysiques que la Commission géologique de l'Ontario a effectuées, en 1988, sur l'existence possible d'éléments néotectoniques dans le comté Prince Edward, au sud de l'Ontario. Des événements sismiques de faible magnitude, indicateurs de la libération des contraintes contemporaines, ont eu lieu en 1987 et 1988 près de Salmon Point et de Consecon (M 2,2). Ces événements étaient situés près d'une faille régionale importante qui traverse le lac Ontario et comprend le système de failles Clarendon-Linden dans l'État de New York et les systèmes de failles Salmon River et Picton, en Ontario.

Des observations détaillées ont été faites de l'orientation des fissures régionales (060° et 125° en grande partie), de l'érosion des dépôts superficiels adjacents aux fractures ouvertes, du rejet post-glaciaire local d'une faille, des dômes à Point Petre, de même que des terrains de dissolution et de karst dans l'est de la région étudiée.

Des excavations dans quatre surrections ont permis d'indiquer que trois étaient de type «classique» et que la quatrième était de structure atypique. Des coupes transversales de structures complexes ont été exécutées dans l'est de la région étudiée.

Des relevés de réfraction des séismes et de la résistivité ont été effectuées sur des éléments de surrections et de failles. Les premiers résultats indiquent que la faille Picton est une zone complexe de fractures dont la roche-mère diffère d'un côté à l'autre. La zone centrale de la surrection "East Duck Pond" est fracturée et pourrait contenir des quantités variables d'eau.

Des plis renversés et droits dans la carrière Consecon, située à l'extérieur de la région principale à l'étude, ont été documentés et s'orientent dans les directions ouest-nord-ouest et nord-ouest. Cette orientation des plis est conforme à la poussée glaciaire et à la direction des champs actuels de contrainte. Bien que la poussée glaciaire puisse produire des plis renversés, elle ne peut provoquer de plis droits. Une déformation tectonique régionale orientée vers le nord-est est donc suggérée comme cause.

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1.0 INTRODUCTION

1.1 INTRODUCTION

Detailed mapping of structural features in the southern part of Prince Edward County was initiated in 1987 by the Ontario Geological Survey. The work of the Ontario Geological Survey is complementary to studies in the Charlevoix region of Quebec and the Miramichi region of New Brunswick being conducted by other member agencies of the Multi-Agency Group for Neotectonics in Eastern Canada (MAGNEC).

Investigations by the Ontario Geological Survey have centred on the field identification of geological features which may indicate neotectonic activity, particularly features that have clearly occurred since deglaciation (approximately 12 000 years ago in the Prince Edward County area). This information, which is indicative of geologically recent structural instability, will be submitted for consideration in revisions to the National Building Code scheduled for 1992. In the Paleozoic bedrock these features include faults, stress relief features (pop-ups), domes and off-set strata along adjacent bedding planes.

Activities of the 1988 field season were concentrated in the southern part of Prince Edward County. In addition to detailed field mapping, activities included detailed geophysical surveys over selected structural features. A number of informal names for both geographic locations and geological structures have been used throughout the report and are indicated by quotation marks.

1.1 LOCATION

Prince Edward County is an irregularly shaped peninsula which extends into the eastern part of Lake Ontario (Figure 1). The study area is located in the southern part of the county, in Athol and South Marysburgh Townships (Figure 2). It encompasses approximately 100 square kilometres bounded by the Lake Ontario shoreline and Latitude 43°56' N, Longitude 77°03' W and Longitude 77°12' W. The area was chosen for study because it is transected by part of a major fault, it is considered an area of little or no seismicity, the Quaternary deposits are relatively thin enabling bedrock features to be seen in plan view, recent and historic aerial photographs are available for the region, and the area is easily accessed.

FIGURE 1

LOCATION OF PRINCE EDWARD COUNTY SOUTHERN ONTARIO

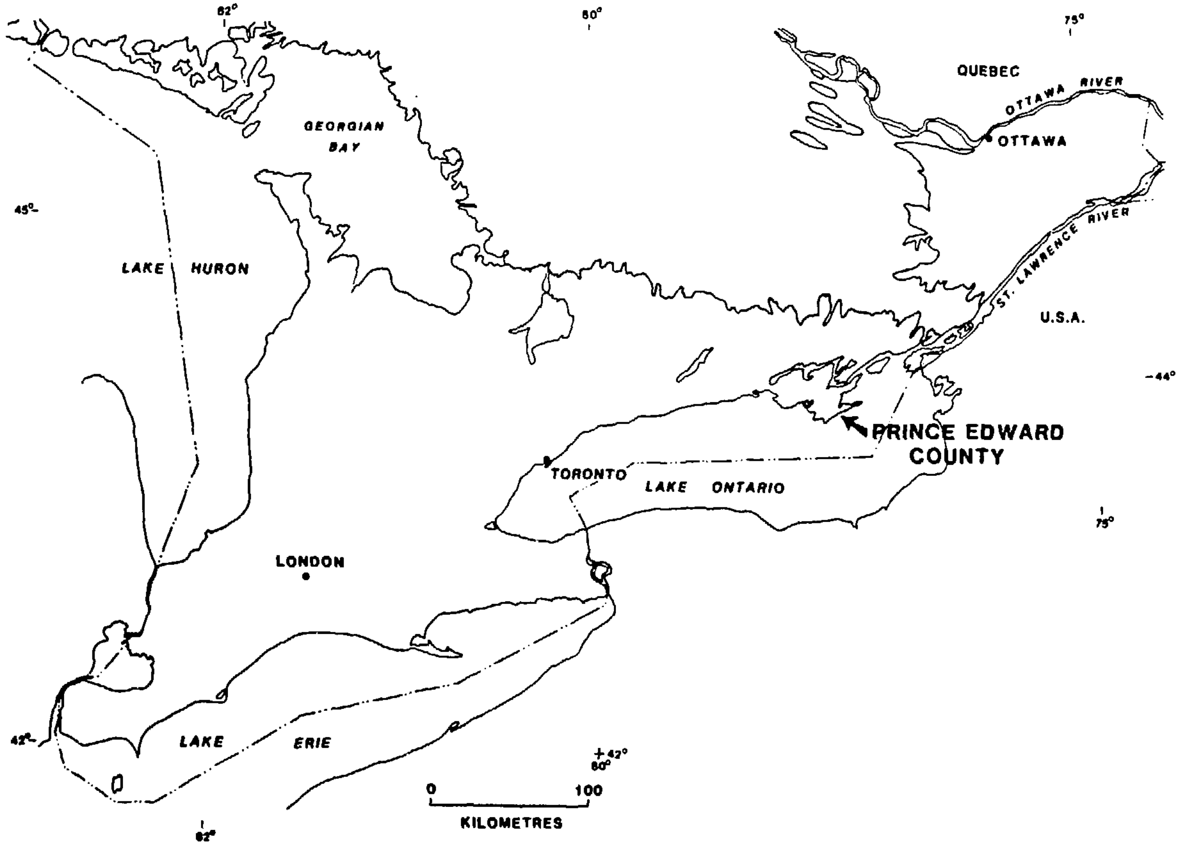
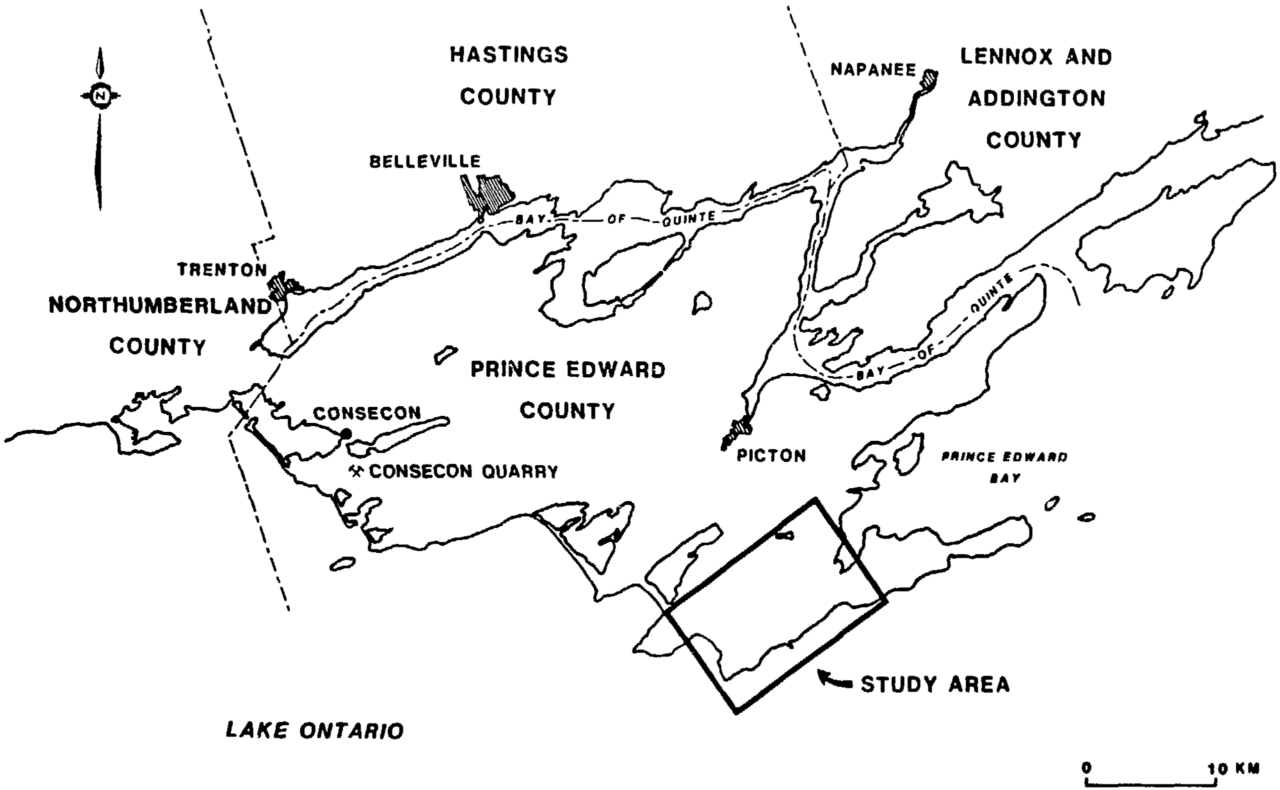


FIGURE 2

LOCATION OF PRINCE EDWARD COUNTY STUDY AREAS



1.3 PREVIOUS WORK IN STUDY AREA

The bedrock geology of Prince Edward County was mapped on a reconnaissance scale by Liberty (1961), Carson (1980,1981,1982) and again by Williams (1984). The Quaternary geology was mapped by Leyland (1982,1983,1984). The mapping, due to its reconnaissance nature, did not reveal many of the features and structures present in the Quaternary deposits and in the bedrock of the study area.

The best exposures of the Paleozoic bedrock occur along the shoreline of Lake Ontario. A stereographic examination of aerial photographs of the shoreline regions of Prince Edward County was conducted by Creasy (1976) who identified a number of structural features. These include folds, domes and faults.

In 1987, mapping of the study area was undertaken to examine and identify features of both the Quaternary deposits and the Paleozoic strata observed on 1:10,000 false-colour infrared aerial photographs of the area (Figure 3), as well as previously mapped or identified structures (Liberty 1961, Creasy 1976). The Quaternary deposits were examined by Gorrell (1988), and the Paleozoic bedrock structures were examined by McFall. The results of these preliminary investigations indicated the need for additional, more detailed work on a number of the structures in order to assess their characteristics and possible origin.

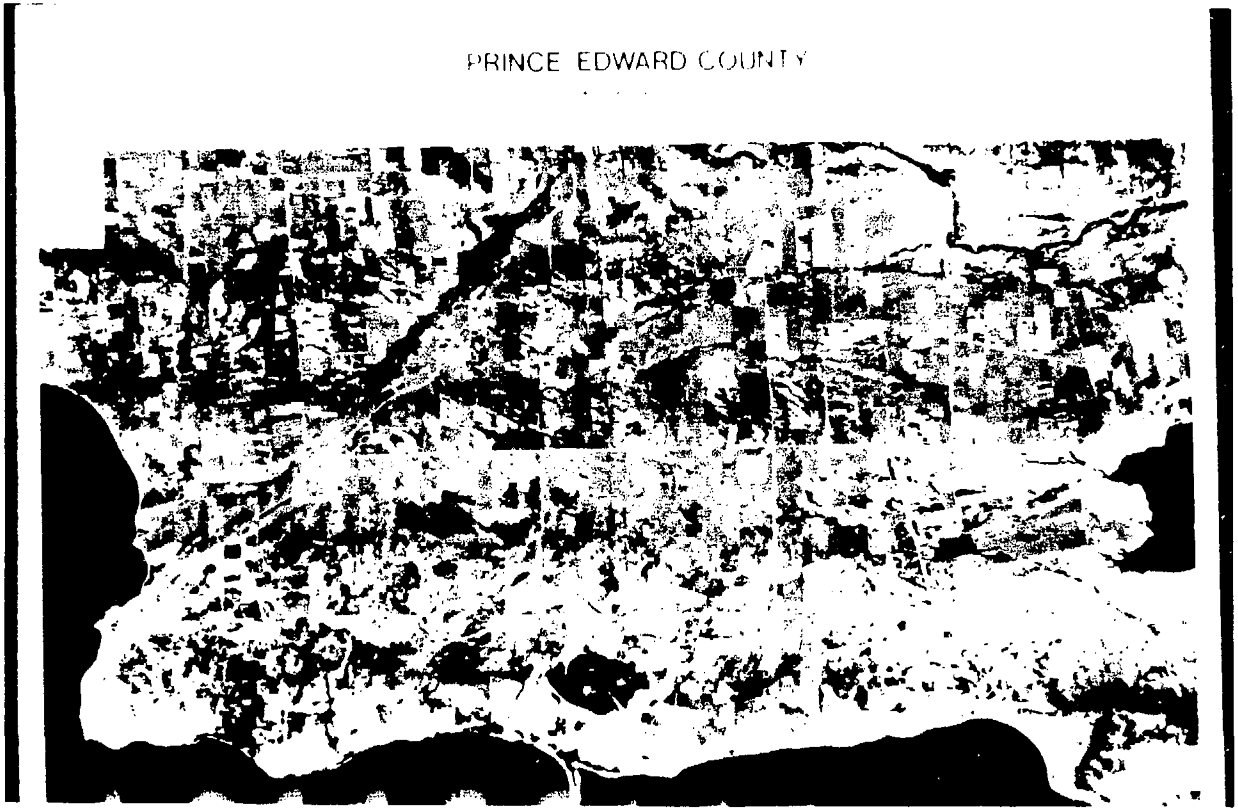


Figure 3: Mosaic of 1:10,000 False-colour Infrared Air Photographs of Prince Edward County Study Area. Mosaic and air photographs courtesy of Ontario Centre for Remote Sensing.

In the spring of 1988, two boreholes were drilled into the largest pop-up in the study area (UTM 4859360mN 332120mE). These boreholes were targeted to test the subsurface configuration of the structure, the possibility of a central fault, the stratigraphy, and to obtain samples for residual stress testing. The first borehole was drilled to a depth of 59.5 metres with complete recovery of core. The second borehole was abandoned at 3.9 metres due to a breakdown of the drilling equipment.

1.4 BEDROCK GEOLOGY

The study area is underlain by rocks of Ordovician age that rest unconformably upon the Precambrian basement (Figure 4) and are overlain by a thin veneer of Quaternary and recent deposits. The total thickness of the Paleozoic succession in the Belleville area, about 40 kilometres to the north (see Figure 2), amounts to 210 metres (Carson, 1961a); although it is probably somewhat more in the study area due to its downdip location. On a regional scale, these strata dip very gently at 1 to 3 degrees toward the south.

The Lindsay Formation forms much of the bedrock surface and consists of thin to thick beds of limestone with irregular shaly partings which impart a nodular texture. The Verulam Formation, which underlies the Lindsay Formation, consists of interbedded limestones and shale and exposure is limited primarily to a few outcrops in the eastern part of the study area.

FIGURE 4

GENERALIZED BEDROCK STRATIGRAPHY PRINCE EDWARD COUNTY

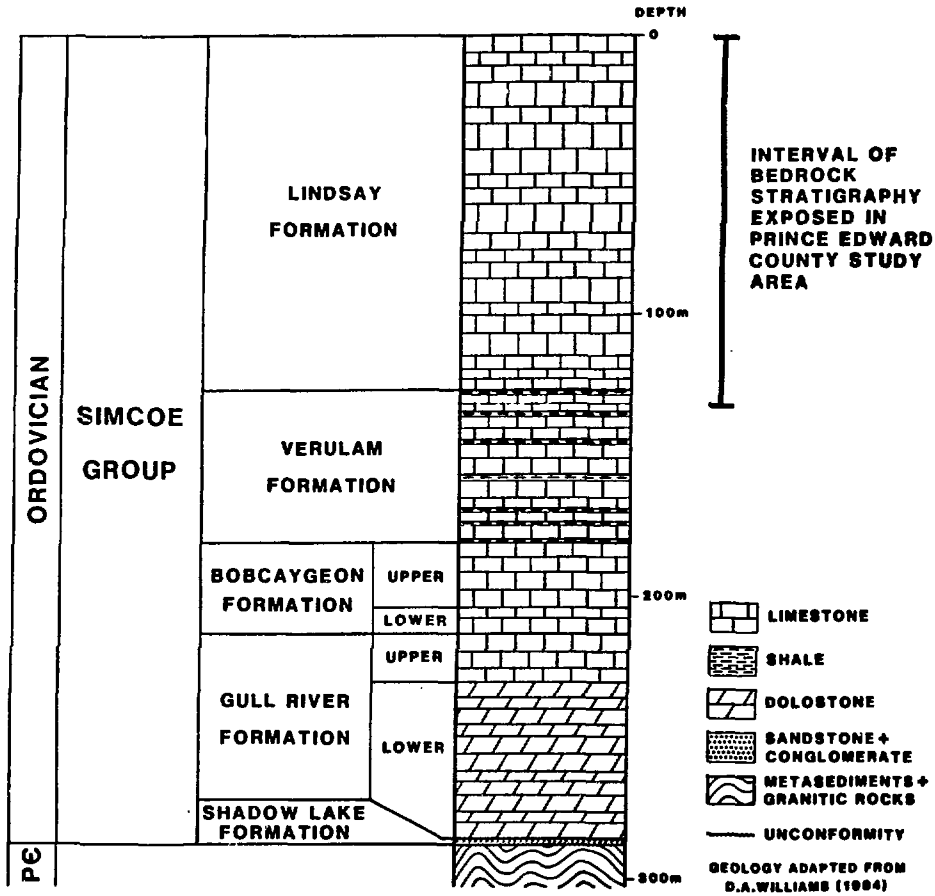
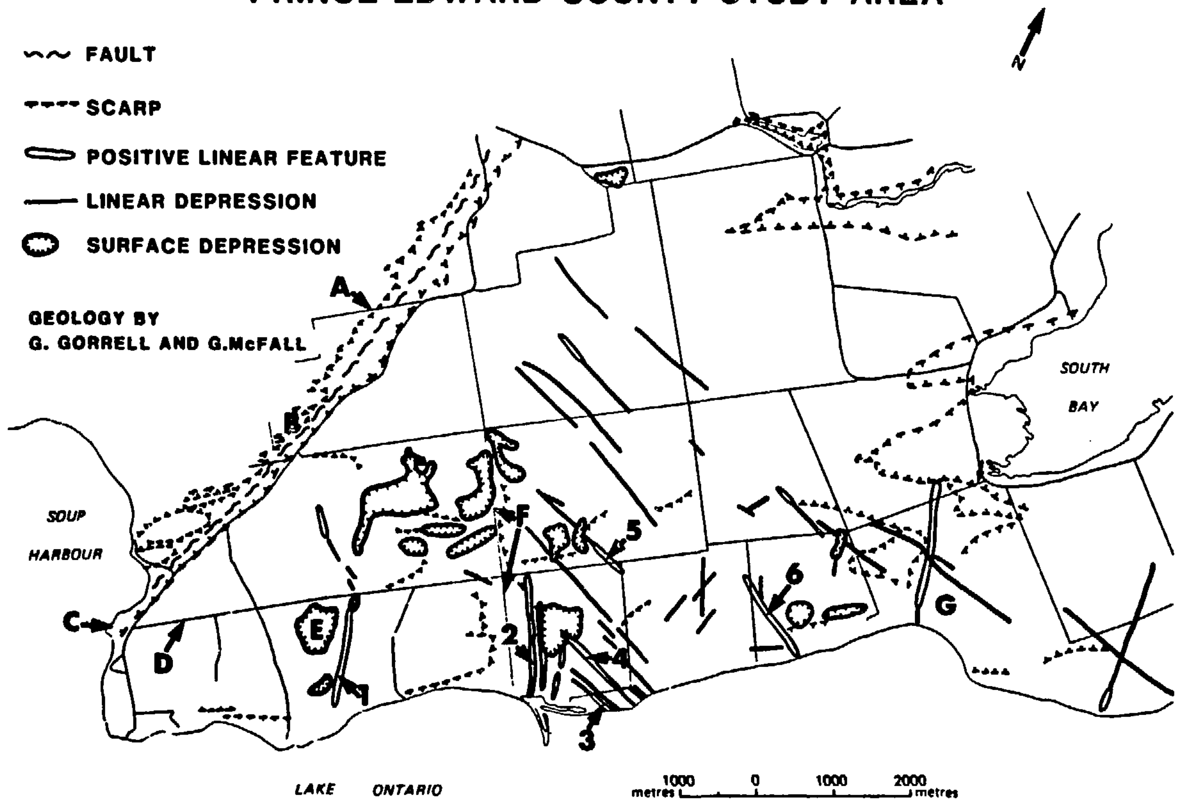


FIGURE 5

DISTRIBUTION OF BEDROCK FEATURES, PRINCE EDWARD COUNTY STUDY AREA



GEOGRAPHIC LOCATIONS

- A Scott's School Road
- B Creasy's Farm
- C Point Petre picnic area
- D "Conservation" road
- E "West Duck Pond"
- F Lighthall Crossroad
- G Murphys' pasture

BEDROCK FEATURES

1. "Apple Tree" pop-up
2. "Gull Pond" pop-up
3. "Lakeshore" pop-up
4. "East Duck Pond" pop-up
5. "Corner" pop-up
6. "Three Sheep" pop-up

The western part of the study area is cut by the eastern arm of the Picton Fault which strikes northeasterly (Figure 5). On a local scale, deformations of the bedrock have been observed in the form of domes, pop-ups and faults that may be related to high horizontal stresses within the region (White et al 1974).

1.5 ACKNOWLEDGEMENTS

Partial funding for this project was provided by the Atomic Energy Control Board and support was provided by Ontario Hydro who made available their geophysical equipment and the Ontario Centre for Remote Sensing, Ministry of Natural Resources who supplied aerial photographs for the project. The study was aided by the availability of recent information on earthquake epicentres for the Prince Edward County region provided by J. Drysdale, Geological Survey of Canada, and information and support by members of the Multi-Agency Group for Neotectonics in Eastern Canada is greatly appreciated.

2.0 **REGIONAL FRAMEWORK**

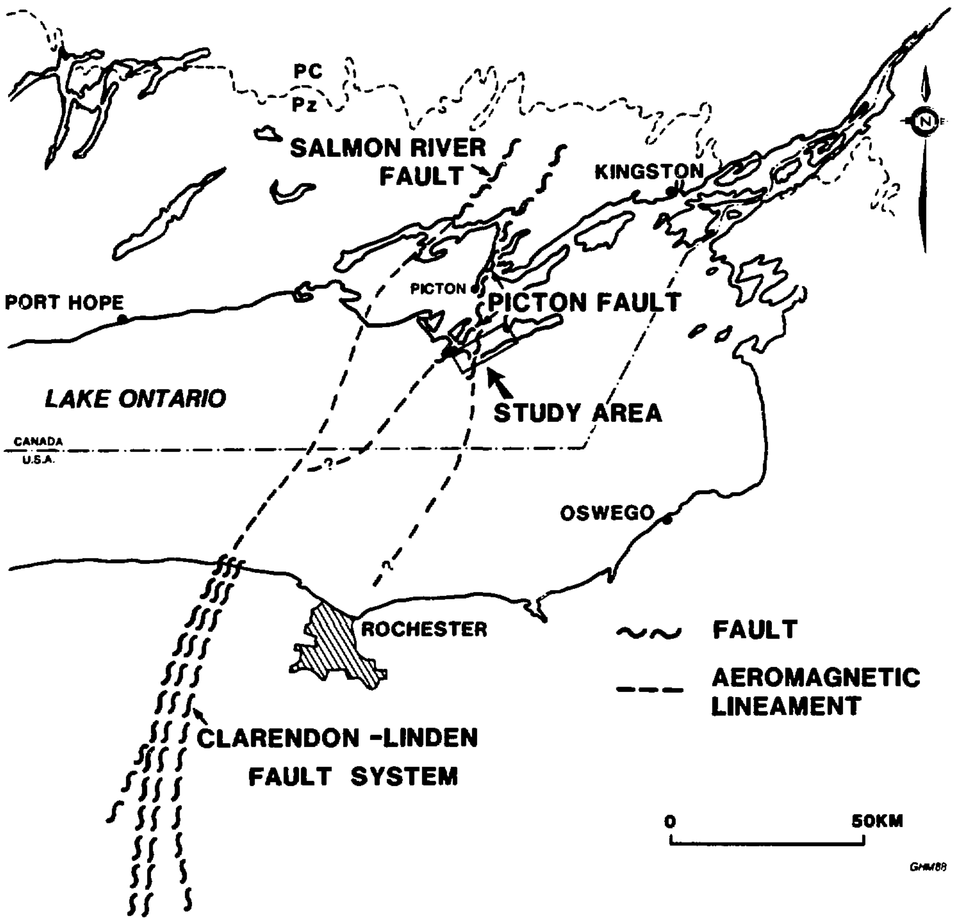
2.1 STRUCTURAL SETTING

Part of the regional framework of the Prince Edward County and eastern Lake Ontario region can be defined by known faults. These are: the Salmon River Fault (Carson 1981a) and the Picton Fault system (Liberty 1961) (see Figure 6). The Clarendon-Linden Fault system in western New York State has been documented as passing northeastward into Lake Ontario, trending towards Prince Edward County (Fakundiny et al 1978).

A total-field aeromagnetic map of eastern Lake Ontario (GSC 1987) (Figure 7) reflects changes in the magnetic characteristics of the Precambrian basement rocks. Prominent geophysical lineaments identified on this map coincide with bathymetric anomalies along a northeasterly trending line which connects the Clarendon-Linden fault to the Salmon River Fault and to the western arm of the Picton Fault system (Figure 6). A second, parallel geophysical lineament begins near Rochester New York, crosses Lake Ontario in a northeasterly direction, and connects with the eastern arm of the Picton Fault which crosses the western part of the study area. This second lineament was also identified by Hutchison et al (1988).

FIGURE 6

REGIONAL STRUCTURAL SETTING EASTERN LAKE ONTARIO



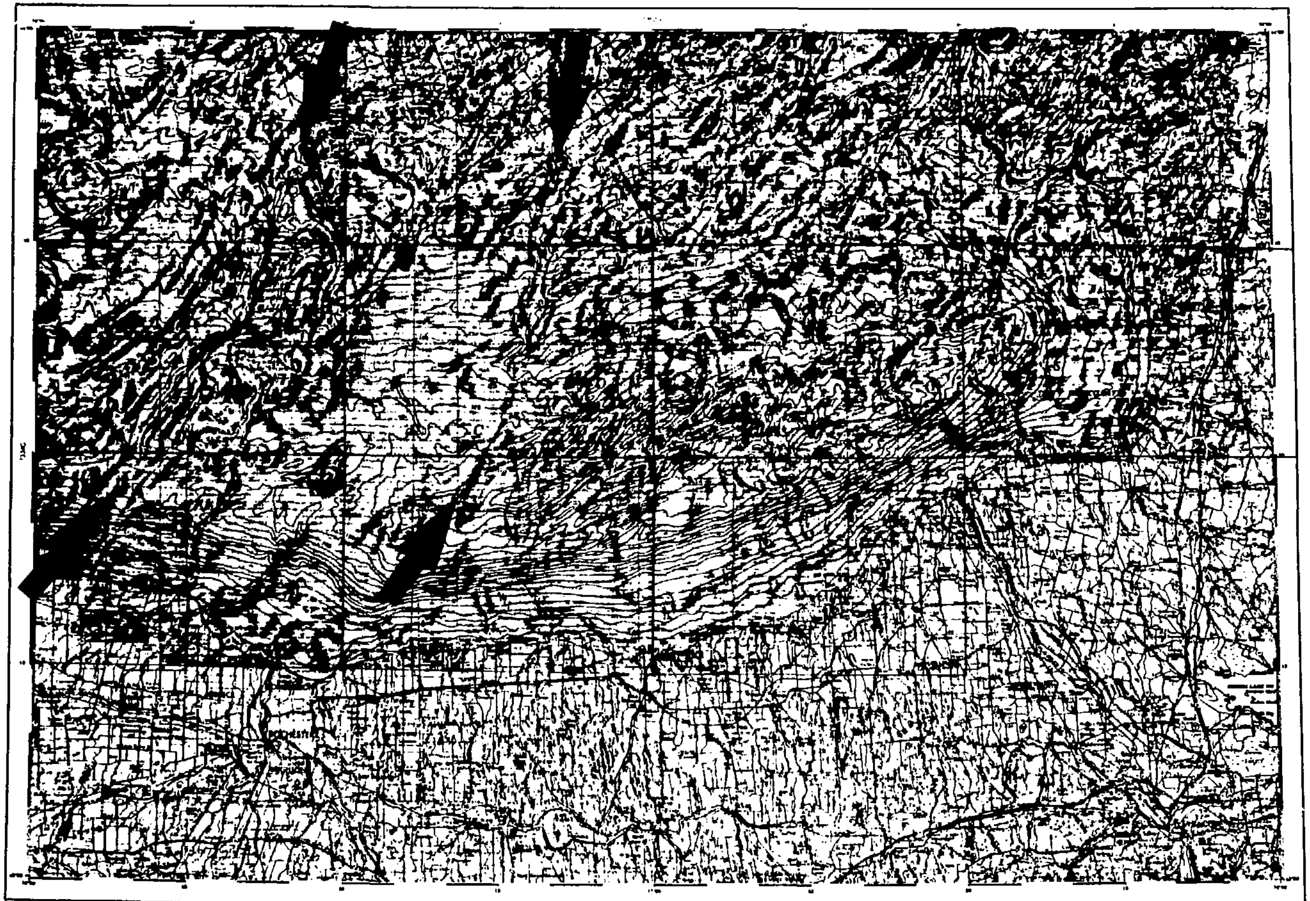


FIGURE 7: Total-Field Aeromagnetic Map of Eastern Lake Ontario (GSC Map 7333G). Arrows denote magnetic lineaments described in the text.

The faults have been mapped at surface, have bathymetric expressions and coincide with magnetic lineaments in the basement. This indicates that they cut through both the Paleozoic and Precambrian rocks and are continuous from western New York State to north of Prince Edward County. The distinctive differences in magnetic signatures across the faults implies an origin within the Precambrian basement and upward attenuation through the Paleozoic succession to the surface.

2.2 SEISMICITY

Although Prince Edward County area is generally considered to be aseismic, two low magnitude earthquakes were reported within the county during 1987-88 (Figure 8).

The first earthquake was not recorded by the seismograph network and was felt only in the Salmon Point area. It occurred during the winter, approximately around Christmas time.

The second earthquake was recorded by the Geological Survey of Canada Seismic Network. It occurred at 6:22 AM (local time) on September 9, 1988. The epicentre was located at 43.989 Latitude and 77.403 Longitude (the Consecon area) and had a magnitude of 2.2 at 10.3 kilometres depth.

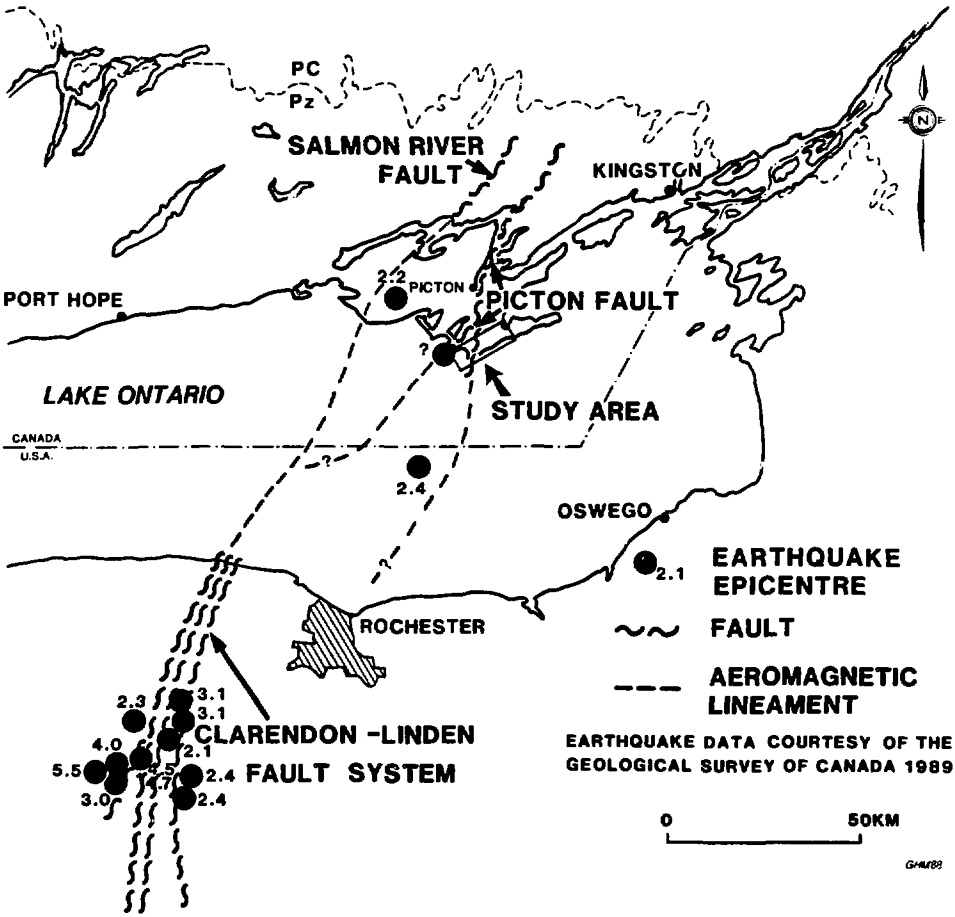
An earlier earthquake was reported south of Prince Edward County in Lake Ontario. This earthquake was originally catalogued as occurring on March 13, 1979 at 43.56 Latitude 76.60 Longitude with a magnitude of 1.9 and an estimated depth of 18 kilometres (Seismological Service of Canada, Provisional Catalogue 1979, Jan-March). This event was subsequently re-evaluated and relocated to 43.59 Latitude and 77.330 Longitude with a magnitude of 2.4 at 18 kilometres depth.

2.3 DISCUSSION

All three earthquakes appear to be related to the regional faults of eastern Lake Ontario (Figure 8). The 1979 earthquake epicentre in the original report was located on a northwest trending line of earthquake epicentres extending from Oswego, New York, to Prince Edward County. It has now been relocated by seismologists from the Geological Survey of Canada so that it is near the eastern extension of the Picton Fault. The 1987/88, unrecorded earthquake occurred near Salmon Point which is the western arm of the Picton Fault. The 1988 2.2 magnitude earthquake occurred in the vicinity of the Consecon Quarry which is situated near the extension of the Salmon River Fault. On May 1, 1988, a 2.1 magnitude earthquake located on the Clarendon-Linden Fault (42.947 Latitude and 78.115 Longitude) in western New York State was recorded by the Canada Seismic Network. Numerous other earthquakes, some in excess of magnitude 5.0, have also been reported on or close to the Clarendon-Linden Fault System. This suggests that the regional fault system (Clarendon-Linden/Salmon River/Picton) may be seismically active both in New York State and in Prince Edward County.

FIGURE 8

EARTHQUAKE EPICENTRES AND REGIONAL STRUCTURAL SETTING EASTERN LAKE ONTARIO



3.0 DETAILED FIELD MAPPING

3.1 INTRODUCTION

During the 1988 field season, a variety of activities was conducted with respect to field mapping. Much of the work was directed towards further examination and delineation of structural features such as faults, pop-ups, open fractures and possible fold structures.

The best exposures of the Paleozoic bedrock occur along the Lake Ontario shoreline. Detailed observations of the bedding attitudes and fractures along the shore line were made during the 1987 and 1988 field seasons. Man-made exposures, such as abandoned pits or quarries, excavated cattle ponds, road-cuts and bulldozer-cleared bedrock outcrops were also examined in detail.

3.2 JOINTS

Joints are readily observable along the shoreline (Figure 9) and in road-cuts and excavations. These were not always "tight" with sides touching, but range in width from a few millimetres to over 30 centimetres (discussed under Open Crevices). Sporadic calcite infillings were observed, and weathered edges were most

Figure 9: Joints in Bedrock Exposure on Lake Front, Prince Edward County Study Area.

often observed at exposures along the lake front. In vertical outcrop, the joints were commonly observed to be vertical to sub-vertical, although this was not the case in the Point Petre area where dips of up to 78 degrees were observed. Multiplex joints (Fakundiny 1978), which are narrow zones of multiple fractures, were observed in one location.

Joints could also be identified in other ways, particularly open joints. Water and soil trapped in the open or weathered joints provided favourable growing places for vegetation. In areas of very thin, or no soil cover, joints were marked by lines of thriving weeds and grasses (Figure 10). During the very dry summer of 1988, green stripes were observed in the open fields in orientations similar to observed joint directions (Figure 11). These were probably due to the retention of moisture in the joints and/or slightly thicker soils in the vicinity of the joints. Careful observations of a grain field near the Lighthall Crossroad noted that some plants were taller, and riper than others and that these tall plants occurred in lines across the field. These lines were oriented similar to the joint directions (060^{0} and 125^{0}). This observation was confirmed in discussions with a local farmer who indicated that one very prominent "mature plant" line was collinear with a small open crevice.

Preliminary results of the joint data gathered along the lake front within the study area are presented in Figure 12. They illustrate that the dominant joint directions are northeast

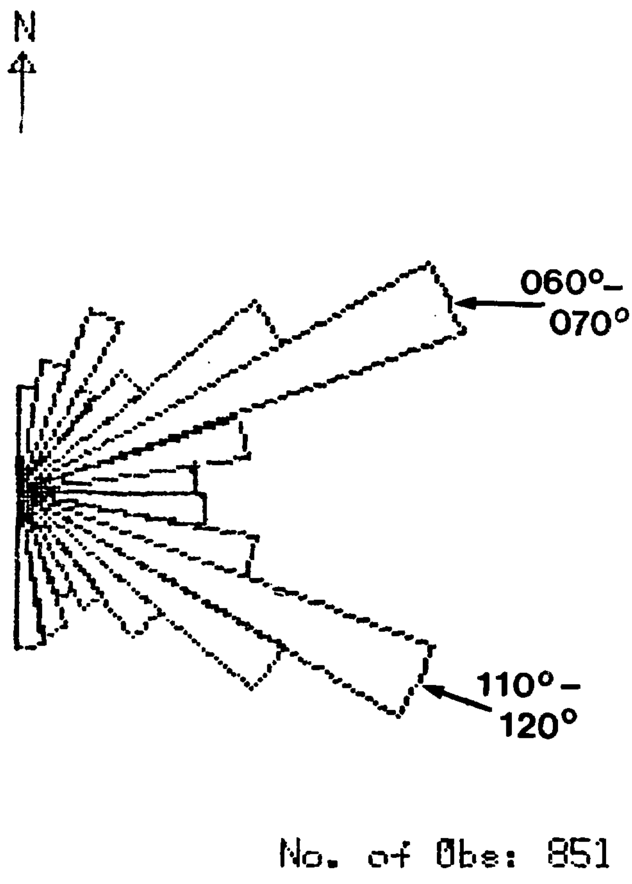
Figure 10: Foliage Enhanced Joints in Bulldozed Area, Prince Edward County Study Area.

Figure 11: Joints Marked by "Green Stripes" in Grass Covered Field, Prince Edward County Study Area (photograph courtesy of J. Franklin Associates, Orangeville).

FIGURE 12

ROSE DIAGRAM OF JOINTS MEASURED ON LAKE FRONT EXPOSURES, PRINCE EDWARD COUNTY STUDY AREA

PRELIMINARY RESULTS



1. Sector lengths are calculated based on the square root of the frequencies.

2. 10 degree sectors.

and east-southeast.$^{\circ}$ The most common joint orientations are 060 and 125°, although 020°, 090° , 115°, and 170° are also observed.

3.3 OPEN FRACTURES

During the 1987 field investigations, open fractures were observed to occur throughout the study area. A preferred orientation for the open fractures is not immediately apparent but they do reflect the main joint orientations (060° and 125°) of the region. Of particular interest was a swarm of nine open fractures that occurs at the back of an abandoned beach located in a field to the west of the Lighthall Crossroad and just north of the "Conservation" road (UTM 4861500mN 337900mE). Eight of these fractures are oriented 125°. The surface material is being removed or "flushed" down the open fractures by the surface waters. Observations made in the fall of 1987 and the summer of 1988 indicate an apparent increase in size of a large bowl shaped depression where material has been eroded from the abandoned beach deposit over one of the open fractures (Figure 13). The active mechanism of erosion was observed during a heavy rain storm in October (1988) when large quantities of surface runoff were observed pouring down the bedrock openings.

In addition to the open fractures observed at the back of the beach, linear surface depressions and open fractures were discovered in front of the beach ridge. It is, therefore, possible that open fractures occur under the beach deposit and

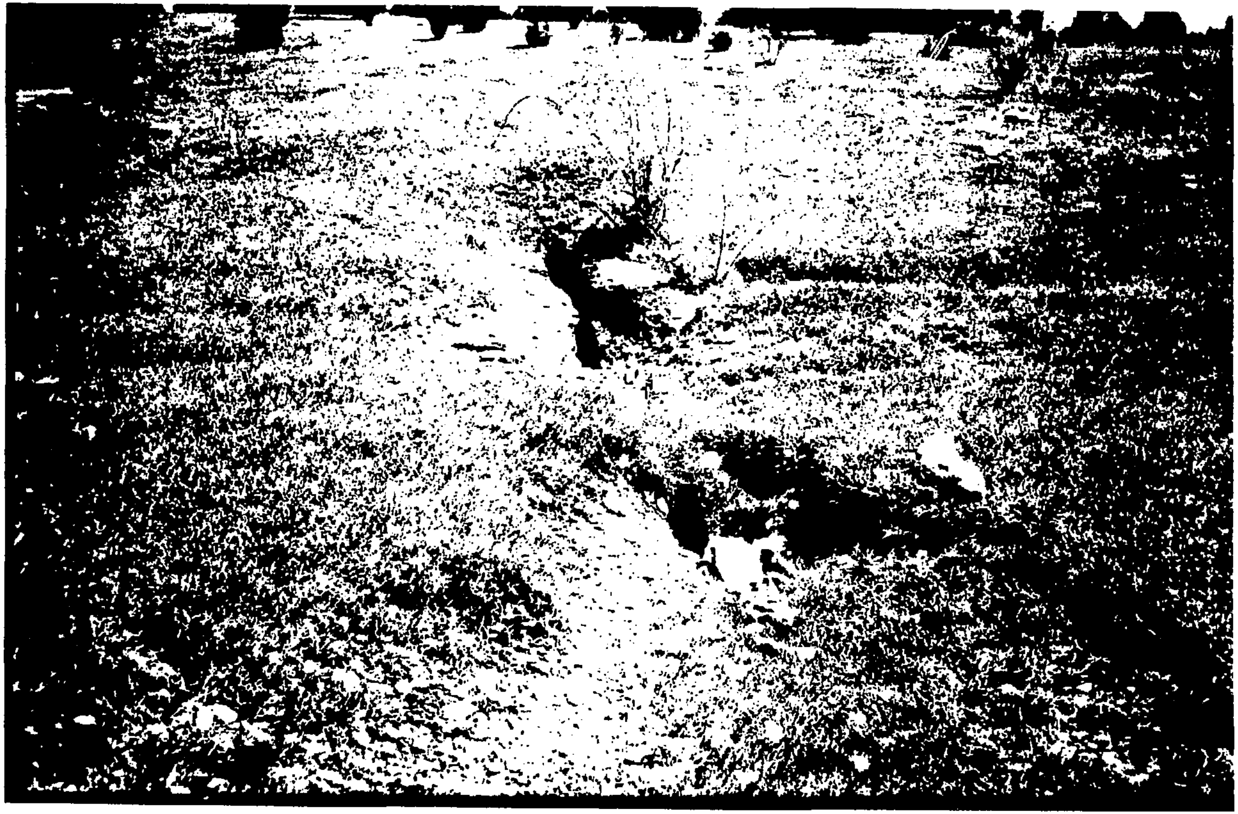


Figure 13: Open Fractures, Prince Edward County Study Area.

that with time, the removal of the overlying beach material will be accomplished. Perhaps this is a recent analogue to what has been observed at other locations along beach ridges where the material is missing across an identifiable lineament. Of interest is the fact that erosion is happening in this particular area now, and not when other beach gaps, which are now inactive, were formed. It is difficult to determine how and when the joints were opened. In some locations, the openings are interpreted as having occurred prior to glaciation as large Precambrian boulders were observed wedged into the openings, probably by overriding ice (Gorrell, 1988). Some open crevices may have been widened by dissolution of the limestone walls. These are most common in areas exhibiting other dissolution features such as rounding and incising of the limestone surfaces and sink holes. Still other open crevices exhibit relatively fresh surfaces with little or no apparent evidence of dissolution and some, like those at the abandoned beach, appear to have opened or been rejuvenated more recently.

The exact mechanisim for initial opening or rejuvenation of the open crevices is unknown, however it is possible that more than one mechanisim may have been responsible. Tension due to glacial unloading might possibly be responsible for openings preferring the northwest orientation, but their apparent concentration in one area and parallelism with the pop-ups (compressional features) brings this interpretation into question. Preferential weathering, or plucking by glacial ice sheets, of the highly fractured multiplex joints could also produce open crevices as would dissolution of the limestone by large volumes of water at the base of the ice sheet, by glacial lakes which covered the region, or by post-glacial rivers and water courses. Alternatively, if the multiplex joints observed in the study area are interpreted as small shear zones, then opening and/or rejuvenation of northwest trending joints may be related to stresses associated with seismicity along the "Oswego" earthquake epicentre trend which intersects the study area from the southeast. At least two prominent northwest trending linear depressions, which appear to be open crevaces, extend along strike from pop-up structures that appear to have formed along older faults (see Figure 5). This suggests that some of the open crevaces may be related to rejuvenation and/or weathering of pre-existing faults. Although it is probable that tectonic stresses are responsible for the opening the fractures, equally convincing arguments can be made to support the other mechanisms mentioned above. It is also possible that several mechanisms have been operational in the evolution of the open crevices. However, there is presently no conclusive evidence to support any proposed mechanism and therefore additional work on this problem is indicated.

3.4 FAULTS

The eastern arm of the Picton Fault crosses the western part of the study area (Figure 5) about a kilometre north of Point Petre. On land, the fault occupies a broad valley which trends 020° and is infilled with glacio-fluvial and post-glacial fluvial sediments. Due to these thick deposits, the fault is nowhere exposed.

A small fault was observed just south of the West Duck Pond ("West Duck Pond" fault) (UTM 4857900mN 328820mE) where a glacially polished and striated surface occurs at a level 30 to 40 centimetres below an adjacent, unpolished limestone surface (Figure 14). A number of explanations have been postulated (eg. faulting, differential weathering, Gorrell, 1989) for this occurrence. Excavation across this feature revealed an irregular fracture which contained blebs of weathered calcite. More importantly, the polished surface and striations (oriented 260°) appeared to dip downward and terminate against the fracture zone (oriented 125°). The simplest explanation for the observed relationships is faulting which resulted in the downward movement of the polished surface block relative to the unpolished surface block. This in turn implies a possible post-glacial age for that motion.

Alternatively, the downward movement of the block may not necessarily be due to tectonic stress and two other mechanisms

Figure 14: "West Duck Pond" Fault, Prince Edward County Study Area. Glacially polished block surface on left, unpolished block surface on right.

are suggested here and by Gorrell (1988) for this apparent relationship. The first entails the subsurface dissolution of the limestone beds adjacent to the fracture on the polished block side and subsequent tilting of the overlying block. The possibility of karst collapse would be supported if a circular depression, which can be seen on early aerial photographs, immediately to the north of the fault is a sinkhole. Verification of the presence of a sinkhole cannot be made as the area is now flooded by a man-made wetland. The second mechanisim requires that the ice sheet, which polished and striated the one block, abruptly rise to a higher level over the unpolished block at the exact location of the fracture. As none of the proposed mechanisms can be proved or disproved, it is doubtful that the cause of this relationship can be resolved on the basis of the presently available data.

Bedrock outcrops along the shoreline were carefully examined for the presence of calcite filled fractures. These commonly occurred where lineaments, which are possibly topographic expressions of faults, were identified on the aerial photographs. Commonly the calcite vein was irregular with "S" or "Z" shaped lenses suggestive of either left or right lateral movement of the adjacent limestone blocks. In other cases, where the aerial photograph lineaments proved to be related to the erosional edge of a more resistant bedding plane, no calcite infillings were observed.

3.6 POP-UPS

In previous years, nine positive linear features were identified as possible pop-ups; five of these were confirmed by bedrock observations and measurements. These are, east to west: "Three Sheep" Pop-up, "Corner" Pop-up, "East Duck Pond" Pop-up, "Lakeshore" Pop-up, and "Gull Pond" Pop-up.

During the 1988 field season, four structures were hand excavated to observe the covering deposits, the surface of the flanking bedrock and the axial zone (Figure 15). Observations of the exposed bedrock are listed in Table 1.

The "East Duck Pond" pop-up, which occurs as a long grass covered ridge (Figure 16), is the highest pop-up structure within the study area. Excavation across the pop-up exposed the typical inverted "V" configuration of the bedrock and a narrow axial zone that is infilled with highly weathered calcite "sand" and veins of euhedral calcite.

The bedrock forming the "Lakeshore" pop-up is exposed on the lake shore (Figure 17). It also exhibits the inverted "V" configuration and the axis is infilled gouge-like, limestone material which is cut by a vein of sheared calcite. Calcite was also observed attatched to the axial faces of the upturned bedrock. The presence of the gouge indicates that the pop-up formed along a fault, perhaps breaking along the attatched calcite material.

FIGURE 15

LOCATION OF EXCAVATIONS, PRINCE EDWARD COUNTY STUDY AREA

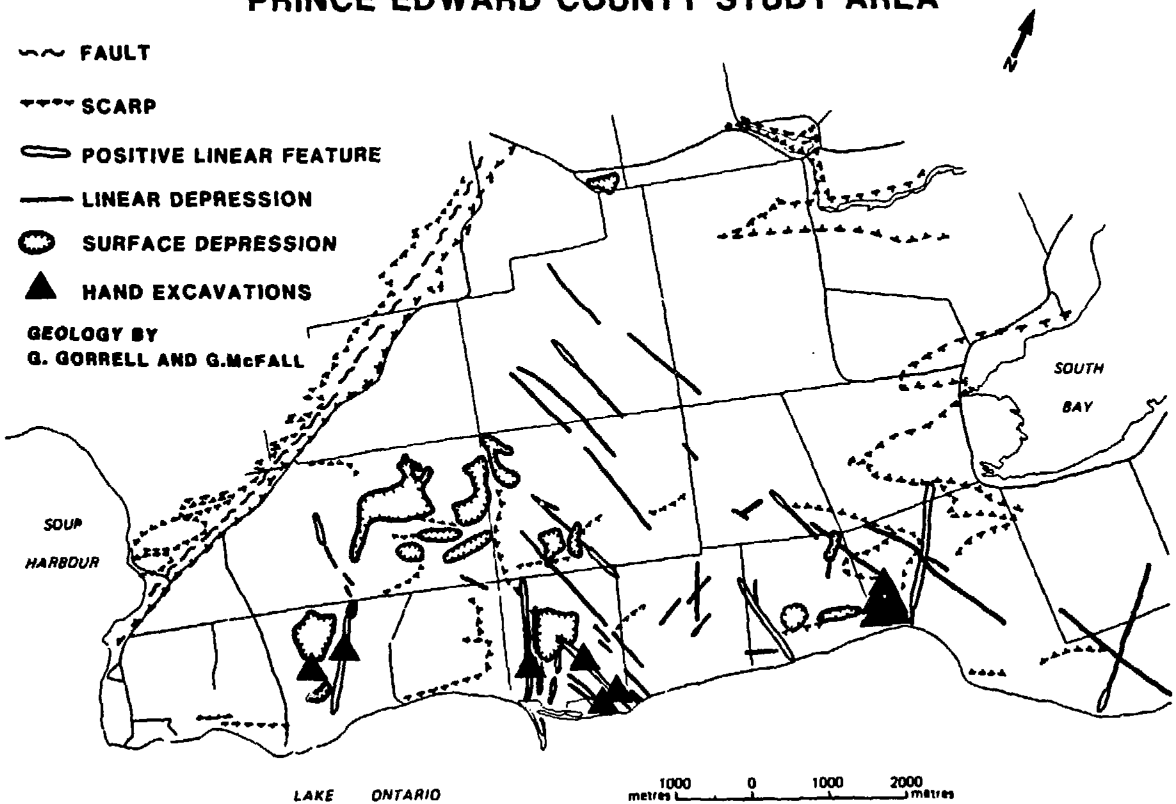


TABLE 1

EXCAVATED POP-UPS IN PRINCE EDWARD COUNTY

INFORMAL NAME	GENERAL ATTRIBUTES				EXCAVATION				
	TREND	LENGTH (M)	WIDTH (M)	HEIGHT (M)	UTM CO-ORD	AXIAL TREND	FLANK ATTITUDES: WEST FLANK	FLANK ATTITUDES: EAST FLANK	AXIAL ZONE
East Duck Pond	110°	1050	1.8	13.8	4859400N 332100E	112°	090°/13°S	095°/12°NE	weathered calcite
					4859250N 332450E	110°	116°/4.5°SW	107°/31°NE	calcite vein
Lakeshore	110°	280[1] 30+[2]	0.7	8.3	4858900N 332330E	104°	107°/17°SW	116°/11°NE	gouge and sheared calcite vein
Gull Pond	155°	1500	1.5	26	4859160N 331290E	none	154°/4°SW	unable to measure	none observed
Apple Tree	154°	1130	0.5	6.5	4858200N 329150E	170°	166°/12°SW	143°/7°NE	"limestone sand" (gouge?), sub-horizontal slickensides

1 on land
2 offshore extension observed from land

Figure 16: "East Duck Pond" Pop-up, Prince Edward County Study Area.

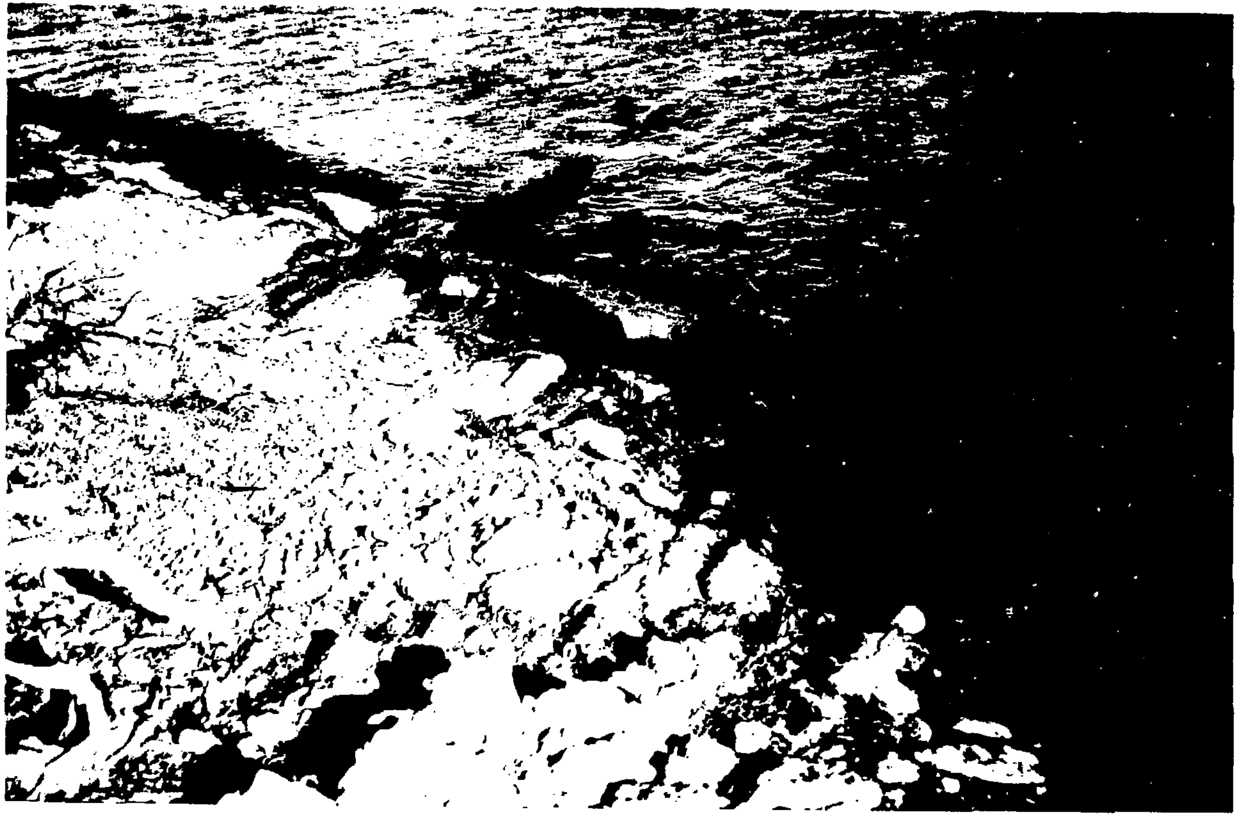


Figure 17: "Lakeshore" Pop-up, Prince Edward County Study Area.

Although the "Apple Tree" pop-up does display the more classical inverted "V" shape bedrock configuration, the axial zone of the pop-up is quite singular. The axis consists of a 1.7 metre wide opening between the bedrock flanks that is infilled with pale grey, moderately sorted, angular, partly consolidated "sandy" material composed primarily of limestone with no Precambrian fragments and no calcite, either in veins or lenses, present. The axial zone was excavated to a depth of 1 metre with no apparent change in the composition of the infilling "sand", although it became somewhat more consolidated, and only a slight reduction in the width of the zone. Due to the absence of Precambrian fragments, it is unlikely that the "sandy" material is a till, although it may be a very locally derived till composed of eroded limestone only. The material is not dissimilar to the gouge observed in the axial zone of the "Lakeshore" pop-up. As sub-horizontal slickensides were observed on the planar bedrock surface that forms the west wall inside the axial zone, it is likely that the "sandy" material represents a gouge. The presence of the slickensided surface also indicates that a fault, on which strike-slip motion had occurred, formed the locus for the formation of the pop-up.

The "Gull Pond" pop-up differs from other bedrock structures in the study area in its orientation and apparent structure. Where exposed, the "Gull Pond" pop-up does not exhibit the inverted "V" shaped bedrock configuration with axial fracture observed in other pop-ups within the area. In outcrop and where excavated, the "Gull Pond" pop-up has no apparent axial fracture and appears similar to a monoclinal roll. This does not however preclude the possibility of it being a pop-up.

Where available, the infilling materials of the pop-up axes were sampled for later evaluation. In all cases, no evidence of glacial scouring or polish was observed on the bedding planes that form the pop-up flanks.

Systematic sampling was also undertaken of the deposits on both sides and over the structures to determine the nature of the covering material, its thickness, its continuity across the features, and to test for possible offset of material across the features. Examination of these samples has not yet commenced.

3.6 COMPLEX STRUCTURES

A series of fold-like patterns, possibly related to the bedrock, were observed on air photographs of the southeastern part of the study area centred around UTM 4862000mN 335000mE. These may represent possible folds or domal structures. Three lines were hand levelled across these features, two northwest-southeast which were tied into the lake level and a perpendicular cross-line. Where available, bedding plane attitudes were measured and five 1.5 metre square holes were dug through the surficial deposits to measure additional bedding attitudes (see Figure 17). These data were found to be of poor quality due to the rubbly nature of the weathered bedrock surface and the results at this time are inconclusive.

Numerous traverses were also made across unusual criss-crossing features observed on the air photographs to the east of the fold-like structures in the Murphys' pasture (UTM 4861000mN to 4863500mN, 335000mE to 337500mE). Detailed examinations of the surface deposits, depth to bedrock and intervals of levelled transects were also conducted. This is a very complex area; the bedrock having been modified both by Quaternary processes and human activities.

3.7 DISCUSSION

A number of difficulties was encountered when attempting to map the bedrock features. Many of the difficulties are due to the nodular nature of the bedrock which yields irregular bedding plane surfaces that reduce the accuracy of attitude measurements (Figure 18). It is therefore difficult to define the original bedrock surface and bedding planes for measurement in areas of nodular limestone beds. The limestone is also subject to dissolution processes. In many structures, such as the open crevices, it is difficult to ascertain whether the feature is the result of a) dissolution only or b) both dissolution and neotectonic stress. If the latter, the amount of contribution by each process is unknown.

Figure 18: Bedrock Outcrop Showing Weathering Characteristics of Lindsay Formation, Prince Edward County Study Area.

Neither the Picton Fault nor the pop-up structures are oriented along the predominant joint orientations of 060^{0} and 125^{0}. They both, however, do trend northeast and northwest and are aligned with the less common joint directions (ie. 115^{0}) This may indicate that stresses forming the bedrock features were different to those that formed the dominant joint system; differences perhaps being in magnitude, orientation, duration and origin. Additional work is required to determine if the less common joint directions are localized, and whether they occur proximal to the bedrock structures.

It is interesting to note that many of the long linear depressions and the pop-ups occur orthogonal to the Picton Fault. This may indicate a possible relationship between these features.

In evaluating the jointing, faulting and other bedrock features, consideration must be made of the regional and local stress regimes both now and historically. The contribution to *the regional and local stress regimes is made by the underlying* Precambrian rock is not known. The Ordovician strata were deposited on an irregular and knobby Precambrian surface (Liberty 1961). Subsequent faulting may also have brought the Precambrian into juxtaposition with the Ordovician strata. Stress testing conducted at the Darlington Nuclear Generating Station Site indicate that there is about a 45 degree shift of stress direction from north-northeast in the Precambrian rocks and Lower Ordovician Gull River Formation to east-northeast for the remaining overlying Paleozoic Simcoe Group (Haimson and Lee 1980). This would lead one to question the degree to which stresses in the underlying Precambrian rock influence the local stress regime.

4.0 GEOPHYSICAL SURVEYS

4.1 INTRODUCTION

Many of the bedrock structural features scattered throughout the study area are partially blanketed by Quaternary and recent deposits making direct observation difficult. Several obscured structural features were examined by refraction seismic and resistivity exploration techniques. Using the two techniques over the same profiles and evaluating their results in conjunction with observed geological information decreases the potential ambiguities and aids in a better interpretation of the subsurface material represented.

Two areas and five individual structural features, including two faults and three pop-ups, were examined. In addition, two of the structural features were examined in detail: the extension of the Picton Fault and the "East Duck Pond" pop-up. More detailed information regarding the geophysical studies of the Prince Edward County study area will be made available as an Ontario Geological Survey Open File Report (Allam and McFall, in preparation).

Geophysical investigations of open joints and subsurface cavities cannot be successfully accomplished with either seismic or resistivity techniques.

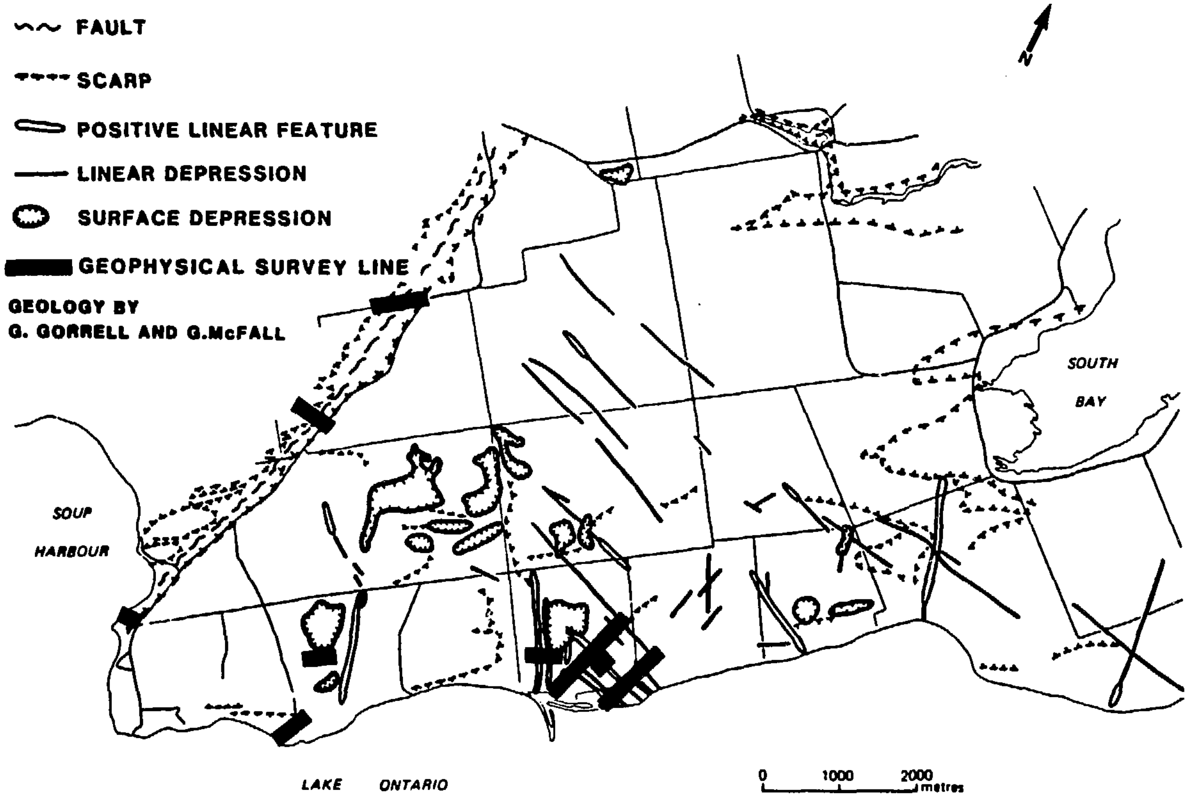
4.2 SEISMIC REFRACTION SURVEYS

Shallow seismic refraction method was applied at the study area to determine the vibrational characteristics of the different underground layers, the depths of the layer interfaces and their structural configuration. A Geometrics/Nimbus ES-125 single channel enhancement seismograph was loaned to the researchers from the Aggregate Assessment Office of the Ontario Geological Survey for a period of four weeks. A Geometics/Nimbus ES-1210 twelve channel enhancement seismograph was loaned to the project by Ontario Hydro for a period of eight weeks. A 10 pound sledge hammer and strike plate were used as a seismic energy source. Additional equipment and materials were rented or purchased from Exploranium G.S. Limited, Bolton, Ontario.

A total of ninety seven seismic lines were conducted at ten geophysical investigation sites (Figure 19); five sites to test stress relief features and five sites to test recognized or possible faults. The geophone arrays for each site were designed according to the nature and scale of the geological feature being examined. Several seismic spreads were made at the site of the previous year's drilling programme so that the seismic layers and velocities could be correlated with the subsurface geological information for the area. As a more accurate assessment of the seismic survey results can be made by combining them with the

FIGURE 19

LOCATION OF GEOPHYSICAL SURVEYS, PRINCE EDWARD COUNTY STUDY AREA



results from the resistivity surveys, preliminary results of the seismic surveys are described in section 4.6, Preliminary Results and Discussion, on page 44.

4.3 RESISTIVITY EXPLORATION SURVEYS

A locally made resistivity measurement unit, consisting of a milliammeter and millivoltmeter, was rented from the Department of Earth Sciences, University of Waterloo, for a period of ten weeks. In this study, resistivity measurements were conducted using the Schlumberger electrode configuration. Resistivity profiles consisting of seventy eight Vertical Electric Sounding (VES) stations were located along seismic profiles at eight of the investigation sites. Resistivity profiling was not required as the lateral variations could be obtained by relating the successive stations at the same site. Preliminary results of the resistivity surveys are described in conjunction with the seismic survey results in section 4.6.

4.4 LOCAL INVESTIGATIONS

Local seismic investigations were conducted in two areas; one on the lake front near the extension of the Lighthall Crossroad (see Figure 5) that consisted of one long profile (UTM 4856750mN 328790mE to 4857040mN 328890mE), and the other in the area south of the "East Duck Pond" that consisted of two seismic profiles (UTM 4858700mN 331750mE to 4860900mN 332300E, and UTM 4558800mN 332220mE to 4860000mN to 332700mE)(Figure 19). Both areas were examined to determine the nature of the prominent lineaments observed on aerial photographs and the possible presence of faults. Interpretation of the results of these surveys is presently unavailable as the processing of the raw data has not been completed.

4.5 DETAILED INVESTIGATIONS

Detailed seismic and resistivity studies were conducted on four features: the Picton Fault, the "West Duck Pond" fault, the "Lakeshore" pop-up, the "Gull Pond" pop-up, and the "East Duck Pond" pop-up (Figure 19). The Picton Fault was examined by profiles that crossed the structure in three locations: Scott's School Road (UTM 48625500mN 327850nE), Creasy's Farm (UTM 4860700mN 327450mE), and the Point Petre picnic area (UTM 4857450mN 326300mE). The "West Duck Pond" fault was crossed by three short profiles. The "East Duck Pond" pop-up was also crossed by three profiles: the first located to the north near the retaining berm of the artificial pond (UTM 4859400mN 332100mE), the second located at the drillhole site (UTM 4859360mN 332120mE), and the third near the lower cross road (UTM 4859250mN 332450mE). The "Lakeshore" pop-up and "Gull Pond" pop-up were each crossed by only one detailed profile (UTM 4858900mN 332330mE, and UTM 4859100mN 331300mE).

4.6 PRELIMINARY RESULTS AND DISCUSSION

4.6.1 Picton Fault

Three profiles for seismic and resistivity investigations were selected to cross the Picton Fault. These profiles are, from north to south: Scott's School Road, Creasy's Farm, and the Point Petre Picnic area (Figure 19).

Preliminary results from Scott's School Road profile indicate an irregular distribution of the third and fourth velocity layers (see Appendix A). A "graben-like" feature in the central area of the profile has a lower seismic velocity and higher conductivity than the laterally equivalent or adjacent rock.

A possible interpretation of these characteristics is that this is a zone of fractured rock with a high water content. This in turn suggests that the main part of the fault is a zone rather than a large, single fracture. Collinear breaks in the seismic velocity interfaces indicate the possible presence of auxiliary faults. Indicative, but not definitive, of tectonic movement of these faults is the apparent offset of the velocity layers, particularly the layer interpreted as weathered bedrock. Stepping of the bedrock surface at the faults suggests the of possibility of neotectonic movement occurring on these structures after the erosion of the valley. The irregular surface could, however, be the result of erosion.

It is interesting to note that the seismic characteristics of the solid rock on the west side of the fault differs from those characteristics of the solid rock on the east side of the fault. This difference reflects and confirms the presence of a vertical offset proposed by Liberty (1961) who mapped each side of the fault as a different member (informal members A and B) of the Lindsay Formation.

In order to test the amount of vertical displacement on the Picton Fault, deeper penetration of the bedrock is required. This could be accomplished by increasing the strength of the seismic energy source, for example a weight drop or explosive source. This could test for a possible offset of the Lindsay/Verulam contact only. As the Verulam Formation has a lower velocity than the Lindsay Formation, it will interfere with the refracted energy, thus any attempts to penetrate below this formation will require the employment of down-hole refraction seismic methods.

4.6.2 "East Duck Pond" Pop-up

The largest stress relief feature (pop-up) in the study area was also geophysically studied in detail. Three seismic profiles were located across the feature: one to the north by the retaining berm of the artificial pond, the second located at the drillhole site where the pop-up has its maximum elevation, and the third located to the south near the lower cross road (Figure 19).

Preliminary results of the seismic profile of the drillhole site indicate a very complex arrangement of velocity layers relative to highly conductive layers identified by the resistivity studies (see Appendix A). The centre of the profile, below the pop-up structure, is a "V" shaped zone of lower velocity which may represent a zone of weathered or fractured limestone along the axis. The zone may extend deeper than shown, but this could not be determined due to the shortness on the seismic spreads and the relatively small energy produced by a sledge hammer/strike-plate source.

Resistivity measurements yielded the presence of a highly conductive layer that is thickest in the middle of the profile; the lower boundary penetrates the upper part of the second velocity layer. The lower part of the second layer and the central part of the third and fourth velocity layers also have higher conductivities than the adjacent areas. This may be due to the presence of joints and fractures in the central zone that are fully saturated with water near the surface and less saturated at depth. The zone of low conductivity is coincident with the higher velocity seismic layer and as such may represent the more rigid bedrock.

The distribution of seismic and conductive characteristics of the bedrock described above indicate the presence of a central zone within the pop-up. This zone may contain fractures that formed as a result of compressional forces responsible for the formation of the pop-up. The presence and/or circulation of surface or groundwater through these fractures may have enhanced the weathered nature of the central zone. Comparison of the geophysical results to the core retrieved from the drillhole will aid in the interpretation of the geophysical results.

5.0 CONSECON QUARRY

5.1 INTRODUCTION

Consecon Quarry is located near the town of Consecon in western Prince Edward County, about 13 kilometres south-southeast of Trenton (Figure 2). The bedrock exposed by the quarry operations is the Lindsay Formation. At this location, it consists of nodular, generally thinly bedded limestone. The strata dip gently (at about 5 degrees) towards the north-northwest (344 ^{0}). Superimposed on this is a non-continuous array of folds (Figure 20).

5.2 DESCRIPTION OF STRUCTURES

Folds observed in the quarry walls are all geometrically concentric, or parallel, and display west-northwest to northwest trending axes. Many of the folds are asymmetrical, overturned to the southwest and are separated from the underlying strata by decollement or detachment surfaces. Upright folds are also present, at least one of which is chevron-like and is succeeded upward by an asymmetrical fold. Dips on the limbs of the folds vary from 19 to 64 degrees (see Table 2). The fold hinges are not curvilinear but are defined by fracture bounded, unbent

TABLE 2

DATA ON FOLDS IN THE CONSECON QUARRY, PRINCE EDWARD COUNTY

Fold #	Bedding Orientations	Fold Axes[2]
1	285°-27°	
	255°-19°	
	292°-19°	300°-09°
	285°-32°	
	115°-55°	
	140°-46°	
	132°-37°	
	125°-64°	
2	150°-50°	
	154°-55°	
	305°-32°	318°-05°
	295°-36°	
	308°-31°	
3	150°-47°	
	142°-49°	
	136°-46°	
	130°-55°	
	140°-53°	307°-18°
	292°-55°	
	290°-50°	
	295°-55°	
	297°-56°	
	300°-60°	
4	150°-47°	
	142°-49°	
	136°-46°	
	321°-32°	144°-05°
	341°-25°	
	344°-19°	
	325°-19°	
5	293°-40°	
	297°-31°	303°-06°
	149°-38°	

[2]Beta axes as determined from equal area net, lower hemisphere plots. (see Appendix B).

segments of rock that exhibit differing amounts of rigid body rotation (Figure 20). This form of brittle deformation implies that at the time of deformation the strain rate was rapid or that the rocks were close to the earth's surface.

The quarry is active and limestone strata have periodically been removed. Initial observations of the quarry walls in 1984 and at subsequent intervals during the removal of material from the quarry wall has resulted in the exposure of a series of discontinuous, but similarly oriented, folds (Figure 21). This in turn suggests that although the folds are geometrically parallel and thin-skinned, they do not persist for great distances along the axial trace and are non-penetrative on the scale of the quarry.

5.3 DISCUSSION

The overturned, west-northwest to northwest trending folds can be achieved by layer parallel, simple shearing that results in the movement of the upper layers relative to the underlying layers. To form overturned, west-northwest to northwest trending folds, the upper layers must move in a southwest direction.

Two mechanisms can be suggested to achieve this configuration; glacial flow to the southwest or tectonically derived crustal stresses. Glacial flow in the region of the quarry is oriented in a west-northwest direction, as are striations measured in the Prince Edward County study area (293°

Figure 20: Deformation in Consecon Quarry Exposed in 1988, Prince Edward County.

Figure 21: Deformation in Consecon Quarry Exposed in 1984, Prince Edward County (photograph courtesy of J.R. Bowlby, Ontario Hydro).

and 255^{0}) (Gorrell 1989, in press), and as such would not be capable of producing northwest trending axis of folds. To the north of Prince Edward County, a drumlin field exhibits a north-northeast to northeast alignment and shapes indicative of southwesterly ice flow. It is questionable whether this ice sheet extended into the Consecon area. No indicators of southwest ice flow have been observed in the immediate Consecon area and, if the deformation represents an earlier flow, it is unlikely that the folds would have survived the effects of the later, northwest trending glaciation. Also glacial flow could not explain the presence of the upright folds.

Pure shear caused by tectonically induced compressive stresses however can produce both upright and overturned folds. As reported earlier, pop-ups in the study area occur in the northwest orientation indicating relief of stresses oriented southwest-northeast. Similar orientations of stress relief features occur in the Roblindale Quarry at Roblin, Ontario, approximately 60 kilometres north of the Consecon Quarry (McKay 1987, McKay and Williams 1989). Other stress relief structures have been observed throughout southern Ontario (White et al, 1974) and stress orientation data for southern Ontario (Lo 1978, Lee 1981) support the presence of a regional stress regime oriented southwest-northeast. The orientation of the folds in the Consecon Quarry is consistent with the present day stress orientation and therefore they were probably formed by a stress field with a similar orientation. The age of the folds, however, is not known.

6.0 SUMMARY OF PHASE I

A variety of activities were conducted in the Prince Edward County study area by the Ontario Geological Survey in 1988. These focused on the detailed examination of bedrock structures in the area, such as faults and pop-ups, in order to determine their subsurface characteristics and to evaluate the possible age of formation or last movement of the features. The activities included: detailed mapping of bedrock structures, geophysical investigations using refraction seismic and resistivity techniques, excavation of features where feasible, systematic soil sampling, and detailed surveying.

Two earthquakes have been felt in the region; the first occurring in the winter was unrecorded, the second occurring in September 1988 was measured at a magnitude of 2.2 and was located near Consecon. These and earlier earthquakes in the region were located proximal to regional fault systems indicating that present-day stress relief is occurring.

Detailed mapping and observations of the bedrock structures in the Prince Edward County study area were conducted. Removal of surficial deposits down open joints was observed to have continued from previous observations. The presence of calcite filled veins which exhibit lateral offset of the adjacent bedrock blocks identify the existence of small scale faulting in the study area. Excavation of a fracture in the zone between glacially polished and unpolished bedrock surfaces suggests the occurrence of post-glacial (neotectonic) movement on a local fault. A number of complex structures occurring in the eastern part of the study area were found to be the product of modification by both natural processes and man's activities. Evidence of the dissolution of the bedrock and karst features were also observed in this area; elsewhere the contribution of bedrock dissolution is less obvious. Changes of bedding attitude and joint orientation were measured along the shoreline at Point Petre to confirm the presence of a local dome structure. Four pop-ups were excavated to expose the flanks and axis and to observe the nature of the Quaternary cover across the features. The axis of two features were clearly defined by opposing dips of bedrock layers, gaping of the bedrock, and the presence of calcite veins. Where excavated, the "Gull Pond" Structure appeared more like a monoclinal fold with no central axis or calcite-filled, central fracture.

Geophysical investigations were conducted on a number of features on the study area. These include: three profiles across the Picton Fault, three detailed profiles across the "East Duck Pond" pop-up, and detailed profiles across the "Lakeshore" pop-up, the "Gull Pond" Structure and the "West Duck Pond" fault. The open fractures could not be successfully investigated with the geophysical equipment available.

A series of overturned and upright folds were examined in the Consecon Quarry. The bedding attitudes and direction of the overturned fold indicate a southwest oriented mechanism for formation. The orientation of the local and regional evidence of glacial movement does not support a "glacial shove" origin for these folds however, the orientations of stress relief features both on a local and regional scale are similar indicating a possible tectonic origin for these folds.

Primary indicators of possible neotectonic movement within the study areas are the preserved surface expression of pop-ups and the occurrence of earthquake activity within the region. Interpretations have been made for post-glacial movement on the local fault by the "West Duck Pond" and for apparently recently opened fractures as indicated by the ongoing removal of surface deposits. Alternative mechanisms may have produced these latter two phenomrna and therefore they are not conclusive evidence for or against neotectonic movement. With further study, these problems may be resolved.

7.0 RECOMMENDATIONS FOR PHASE II

A number of activities for future work, either as a continuation of the present programme or resulting from the authors' evaluation to date, are proposed below.

By the summer (1989), both airborne "C" band and "X" band SLAR and thermal imagery will have been flown by the Canadian Centre for Remote Sensing, Energy, Mines and Resources Canada, and the United States Geological Survey respectively, for the study area for which ground observations will be required.

The Survey will continue detailed geophysical investigations of bedrock structures within the study area, including: pop-ups, faults and the complex fold-like structures in the east. Consideration should be given to deeper exploration of the Picton Fault in order to determine the amount to throw. This would require a more powerful seismic energy source such as a weight drop. Consideration should also be given to using other geophysical techniques such as electromagnetic, VLF, and gravimeter measurements.

As the best exposures of the Paleozoic bedrock within the study area occur along the Lake Ontario shoreline, side scan sonar and sub-bottom profile surveys will be conducted in June 1989 by McQuest Marine Research and Development in the offshore region. This will provide additional information on the distribution of pop-ups, faults, and joints as well as testing for domal structures, possible folds, erosion features, and dissolution features/karst features.

Contingent on the availability of funds, a drilling and stress testing programme would add significantly to the understanding of stress regime in the area. This should include at least one (and preferably more) boreholes drilled to the basement augmented by four or five shallow boreholes to intersect the Verulam/Bobcaygeon Formation contact, which is distinctly marked by a change in lithology, as opposed to the Lindsay/Verulam Formation, which is a gradational contact and therefore is poorly marked. These boreholes would directly supply stratigraphic and structural information and could be used for down-hole geophysics, overcoring and hydrofracture stress testing, and possibly groundwater investigations. A number of sites for surface stress testing (using strain gages) could be identified to precede and supplement borehole stress tests.

As recent low level seismicity has been recorded both in the region and along the Clarendon-Linden Fault, the following activities should also be undertaken. Portable seismic monitoring stations installed along the two arms of the Picton Fault and in the Consecon region adjacent to the extension of the Salmon River/Clarendon-Linden Fault could provide valuable monitoring data on the occurrence of seismicity on the Canadian end of that regional fault. Microseismic monitoring of local structures, or localized areas of regional structures, to record microearthquakes that occur as a result of adjustments of stresses would yield information on the behaviour of the rock in response to the stresses. The network would be situated to monitor primarily the Picton Fault but other possible neotectonic features, such as the pop-ups, could also be targeted.

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APPENDIX A

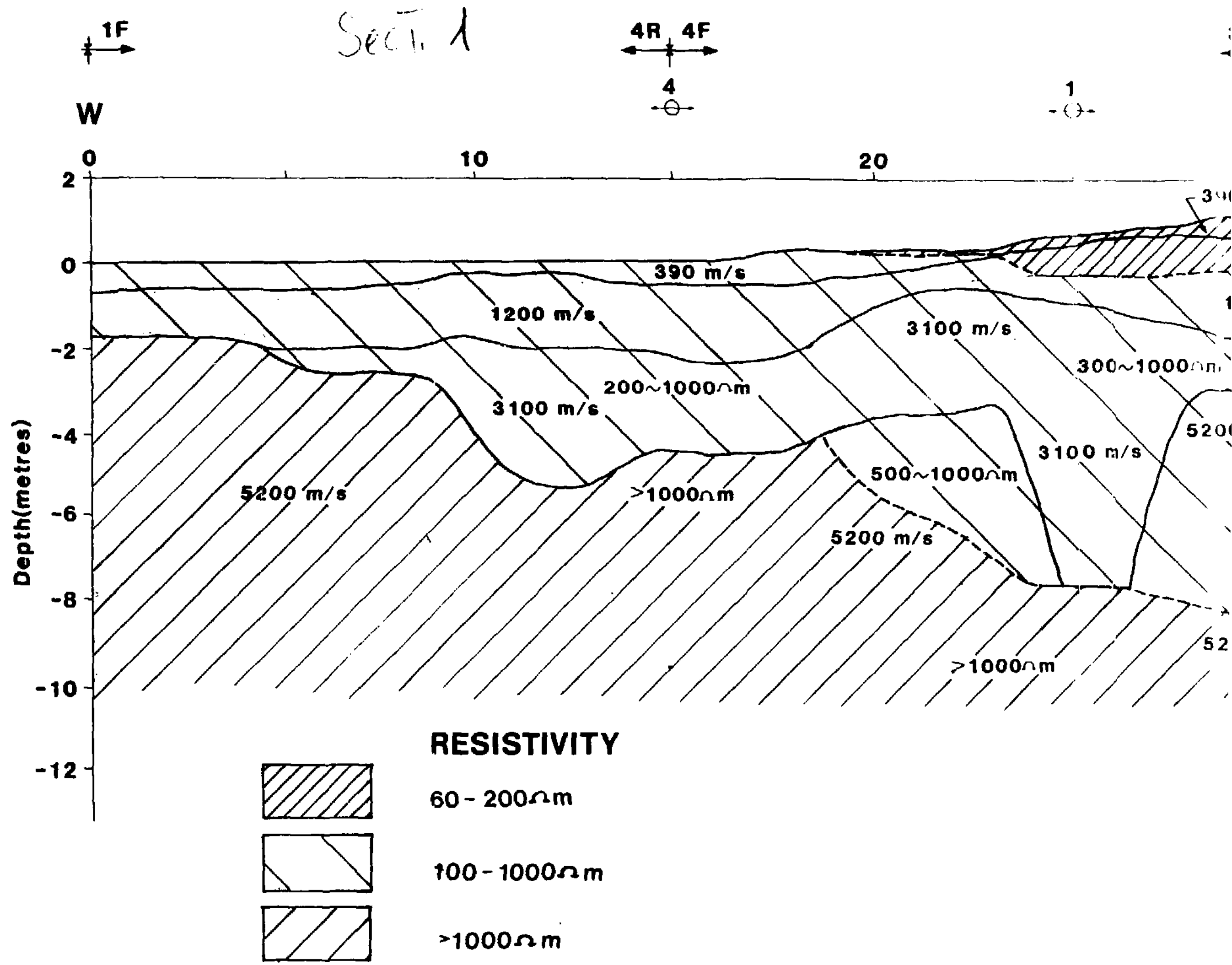
GEOPHYSICAL SURVEY - PRELIMINARY RESULTS

PICTON FAULT: Scott's School Road Profile

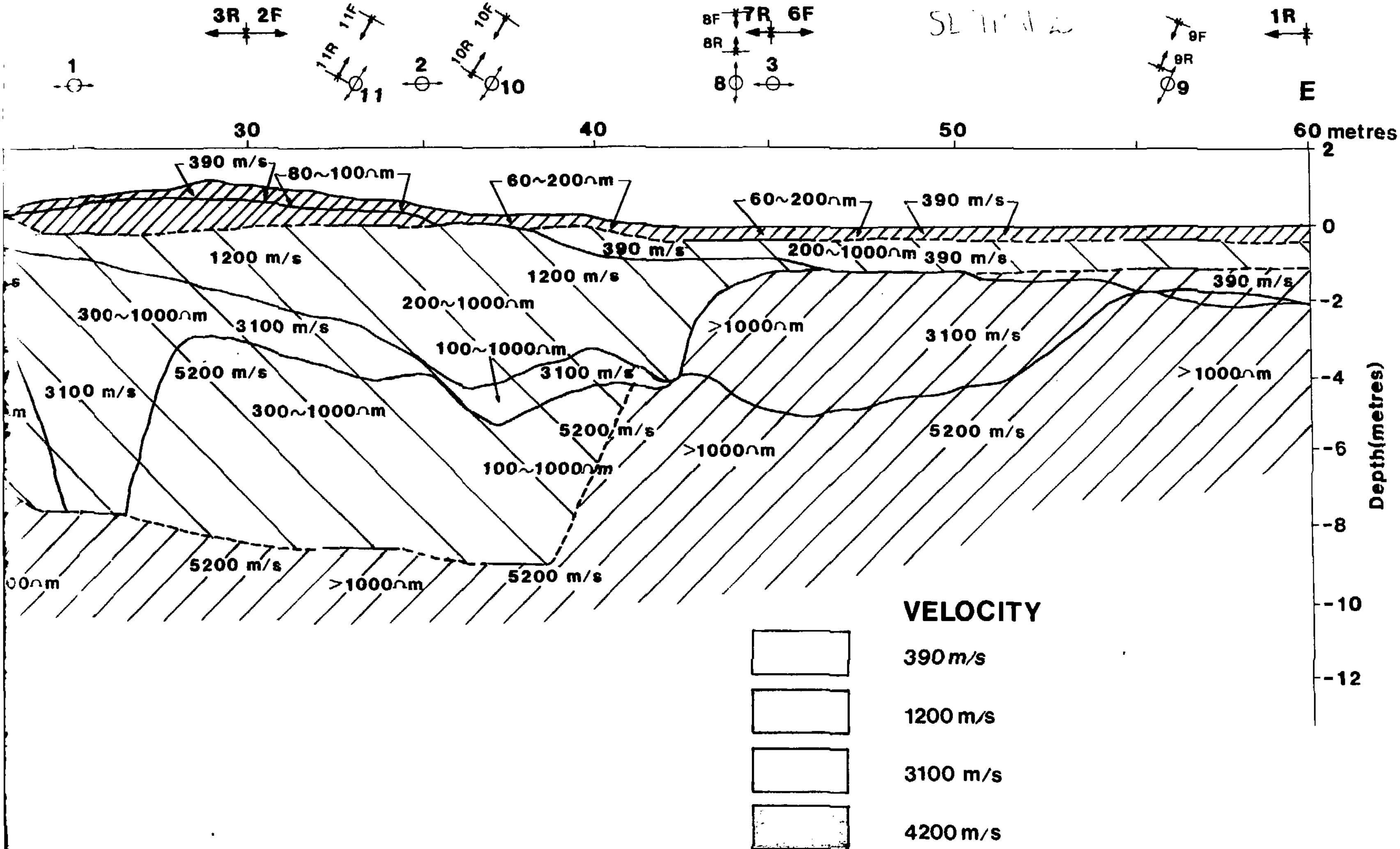
"EAST DUCK POND" POP-UP: Drillhole Location Profile

DRILL-HOLE P

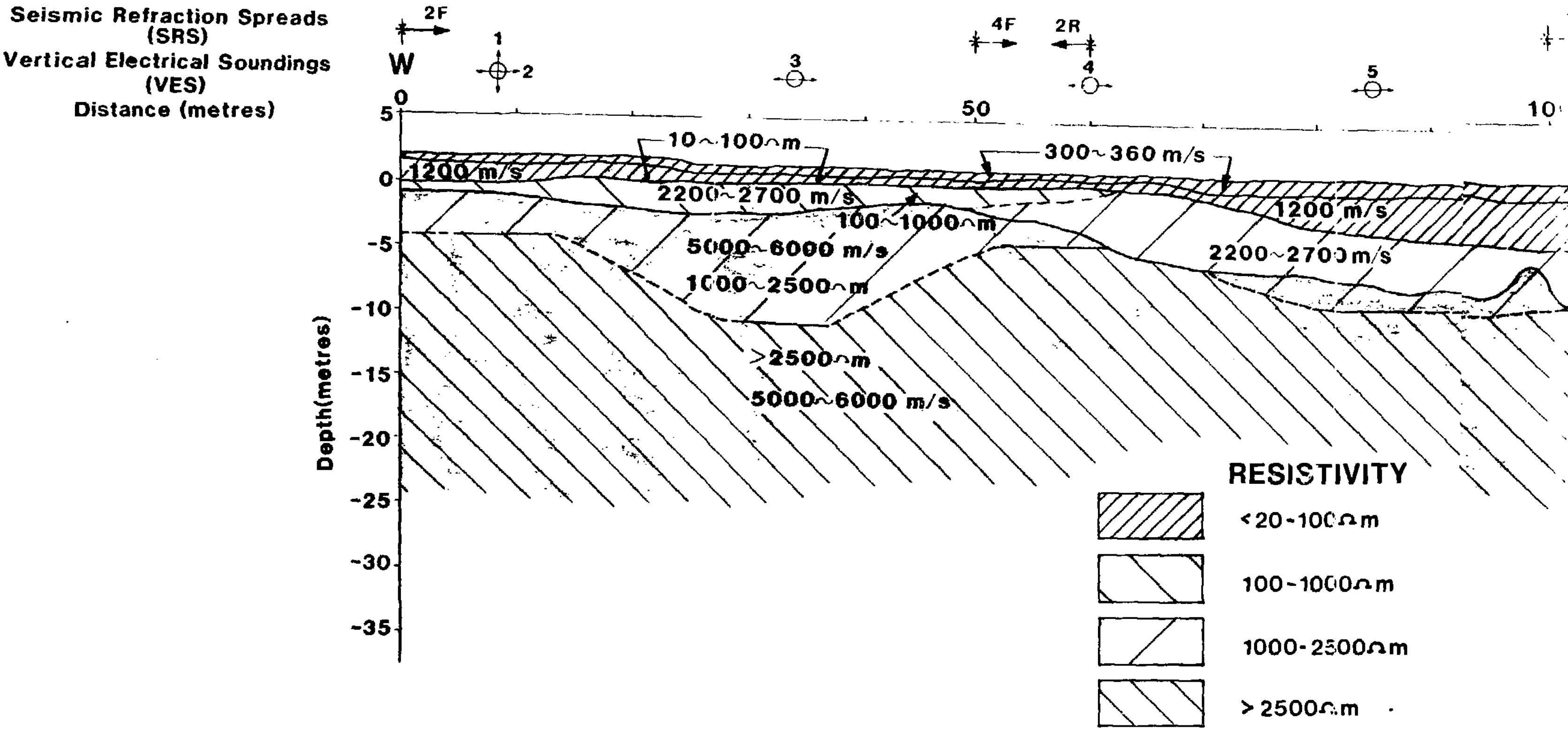
Seismic Refraction Spreads (SRS)
Vertical Electrical Soundings (VES)
Distance(metres)

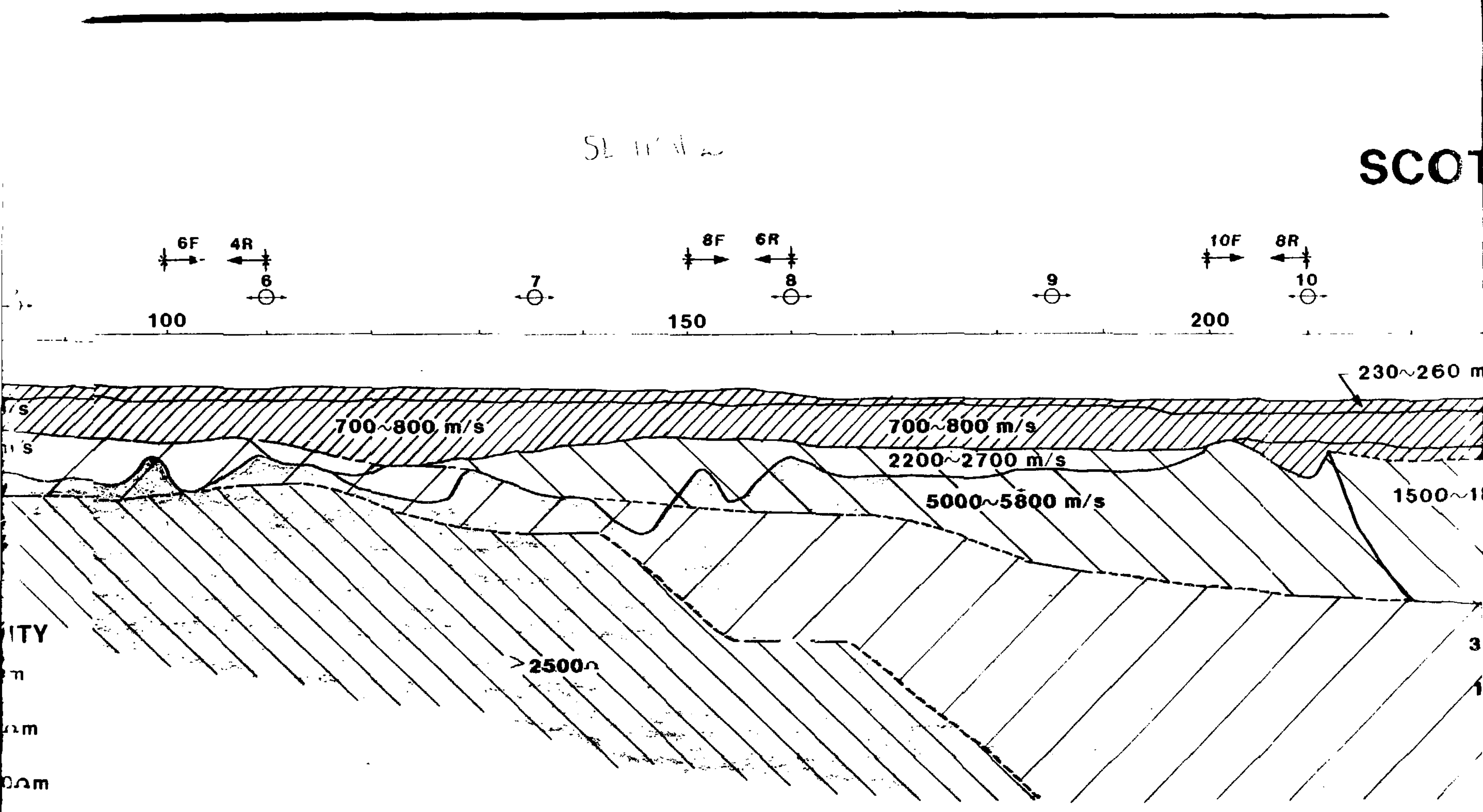


..L-HOLE POP-UP SITE (09)



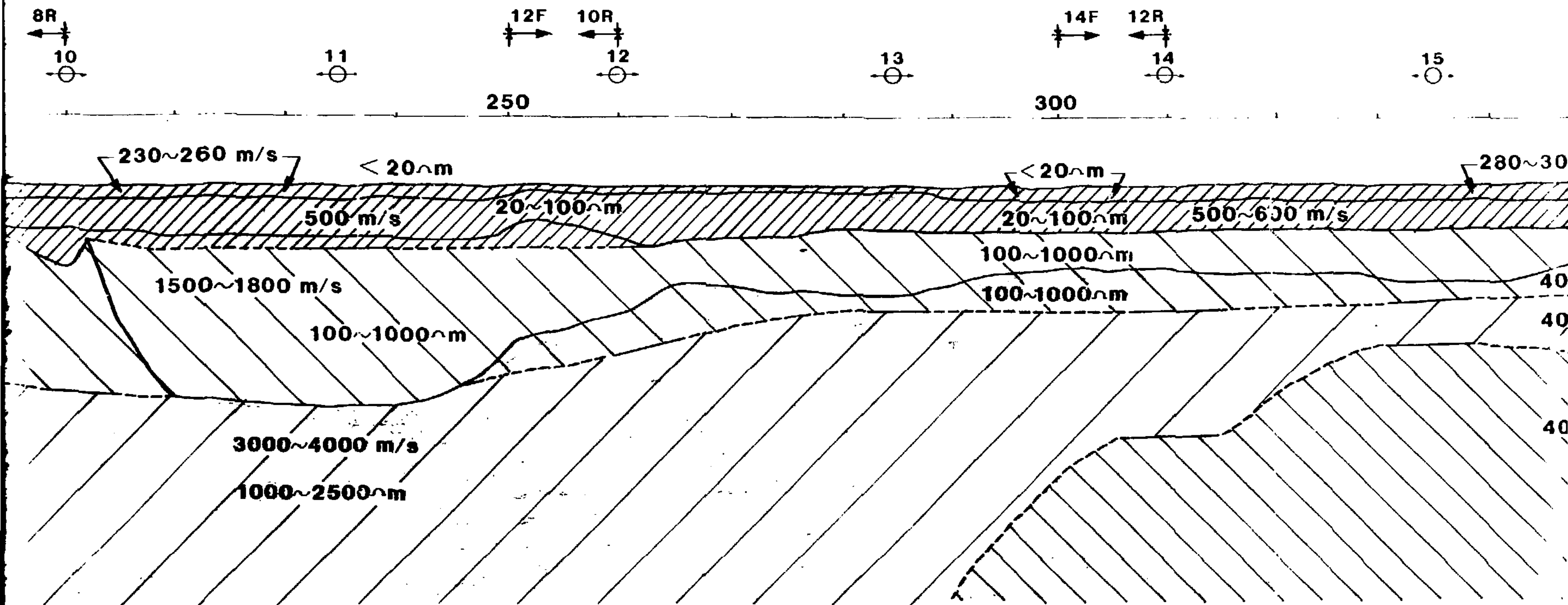
Sect. 1


Seismic Refraction Spreads
(SRS)
Vertical Electrical Soundings
(VES)
Distance (metres)
Depth(metres)
W
2F
4F
2R
1
2
3
4
5
0
50
5
0
-5
-10
-15
-20
-25
-30
-35
10~100Ωm
300~360 m/s
1200 m/s
2200~2700 m/s
100~1000Ωm
5000~6000 m/s
1000~2500Ωm
1200 m/s
2200~2700 m/s
>2500Ωm
5000~6000 m/s
RESISTIVITY
<20-100Ωm
100-1000Ωm
1000-2500Ωm
>2500Ωm

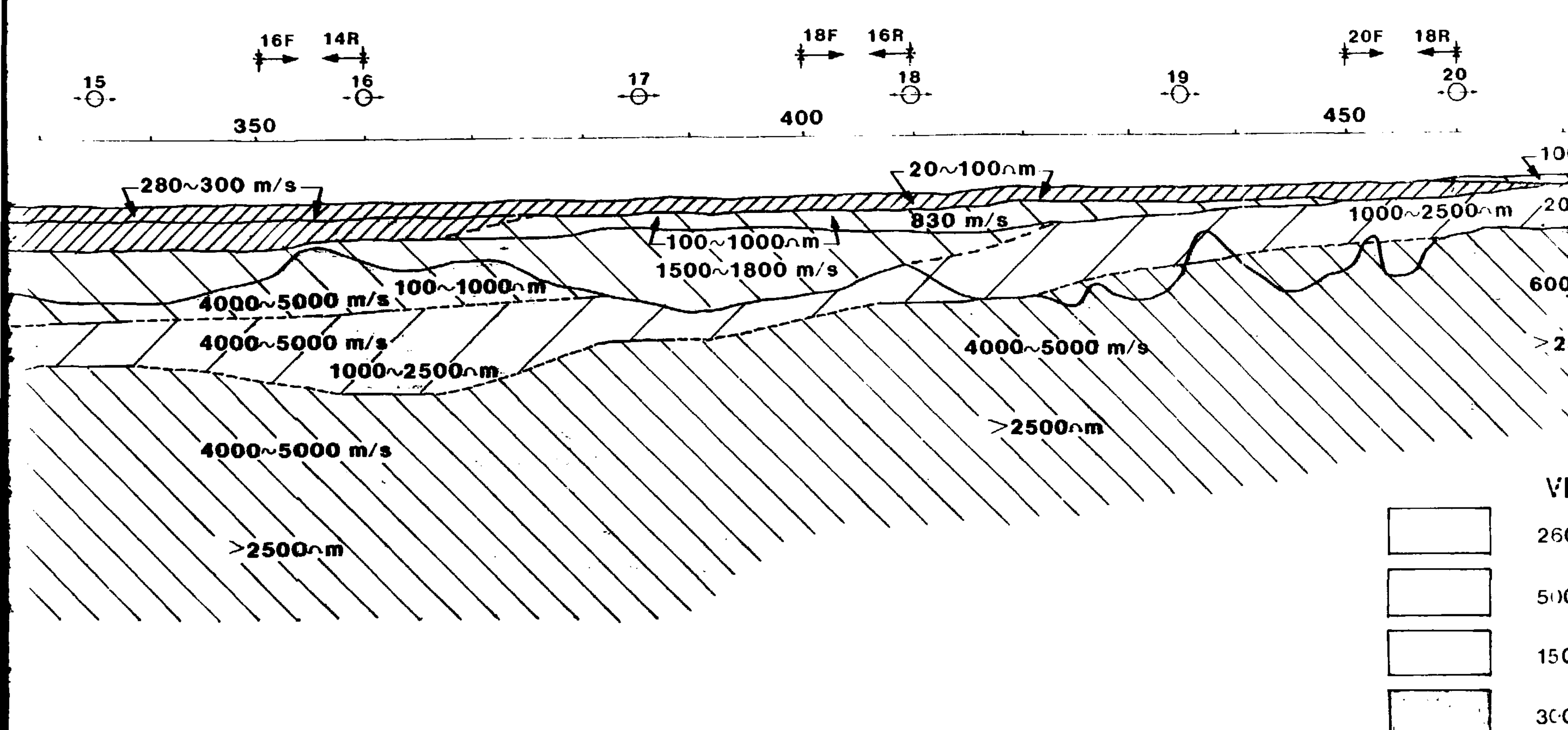

SCOT
6F
4R
8F
6R
10F
8R
6
7
8
9
10
100
150
200
230~260 m
700~800 m/s
700~800 m/s
2200~2700 m/s
5000~5800 m/s
1500~1
>2500Ω
ITY

SECTION 3

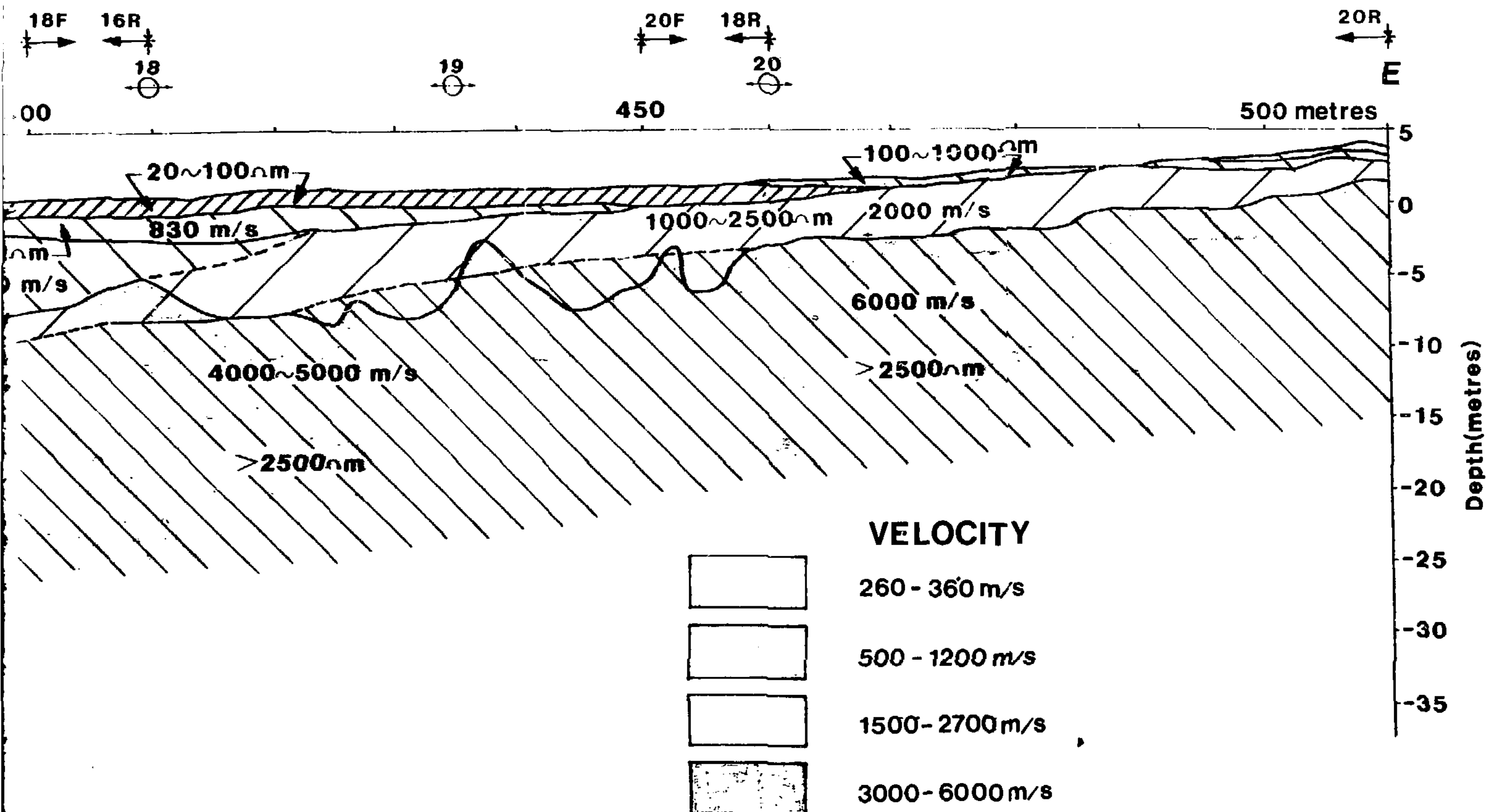
SCOTT`S SCHOOL ROAD SITE



SECTION 4


15
16F
14R
16
17
18F
16R
18
19
20F
18R
20
350
400
450
280~300 m/s
20~100∩m
830 m/s
100~1000∩m
1500~1800 m/s
1000~2500∩m
4000~5000 m/s
100~1000∩m
4000~5000 m/s
1000~2500∩m
4000~5000 m/s
>2500∩m
4000~5000 m/s
>2500∩m

SECTION 5

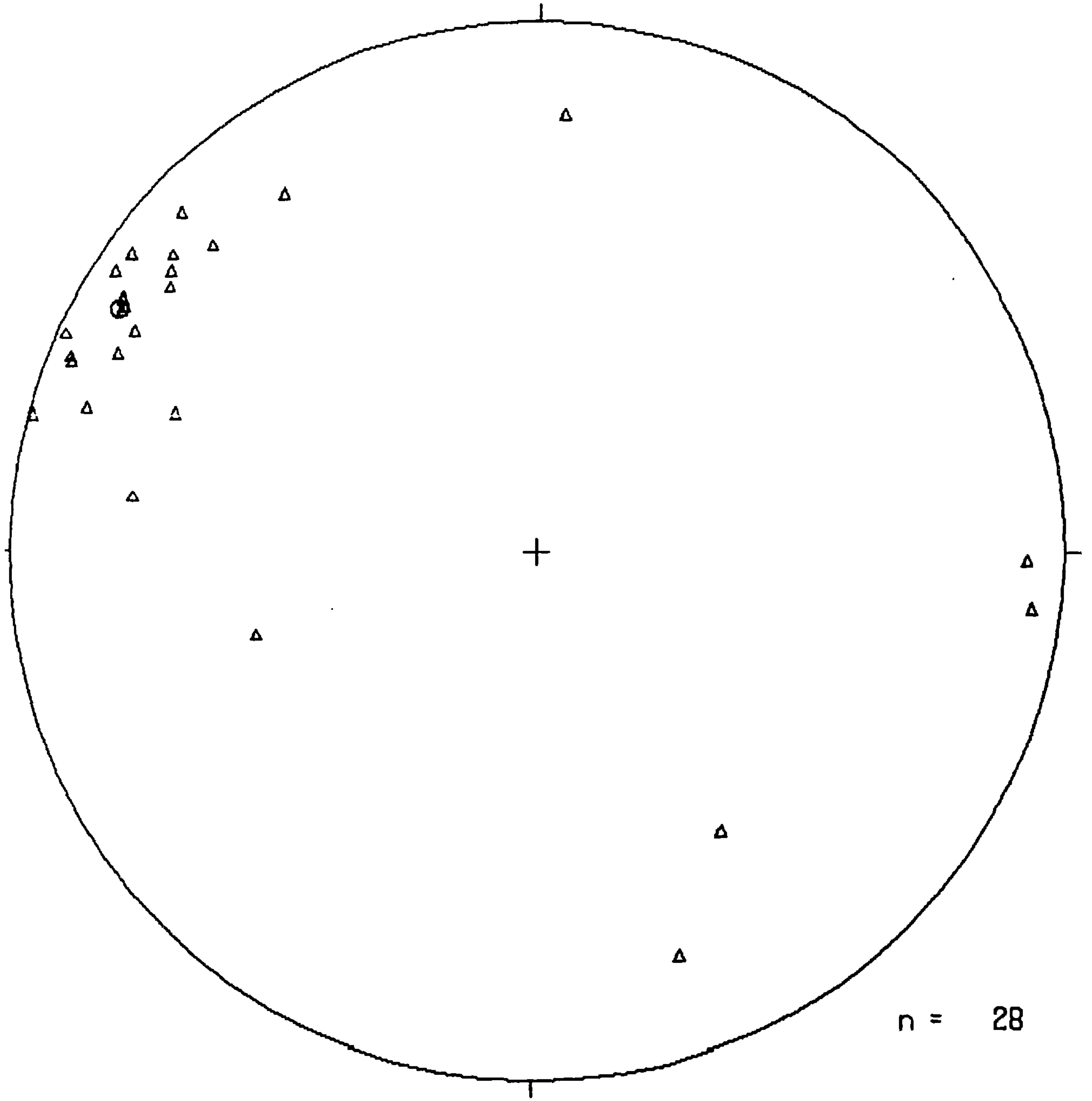


18F
16R
18
19
20F
18R
20
20R
E
00
450
500 metres
20~100Ωm
100~1000Ωm
830 m/s
1000~2500Ωm
2000 m/s
Ωm
m/s
6000 m/s
4000~5000 m/s
>2500Ωm
>2500Ωm
5
0
-5
-10
-15
-20
-25
-30
-35
Depth(metres)
VELOCITY
260 - 360 m/s
500 - 1200 m/s
1500- 2700 m/s
3000- 6000 m/s

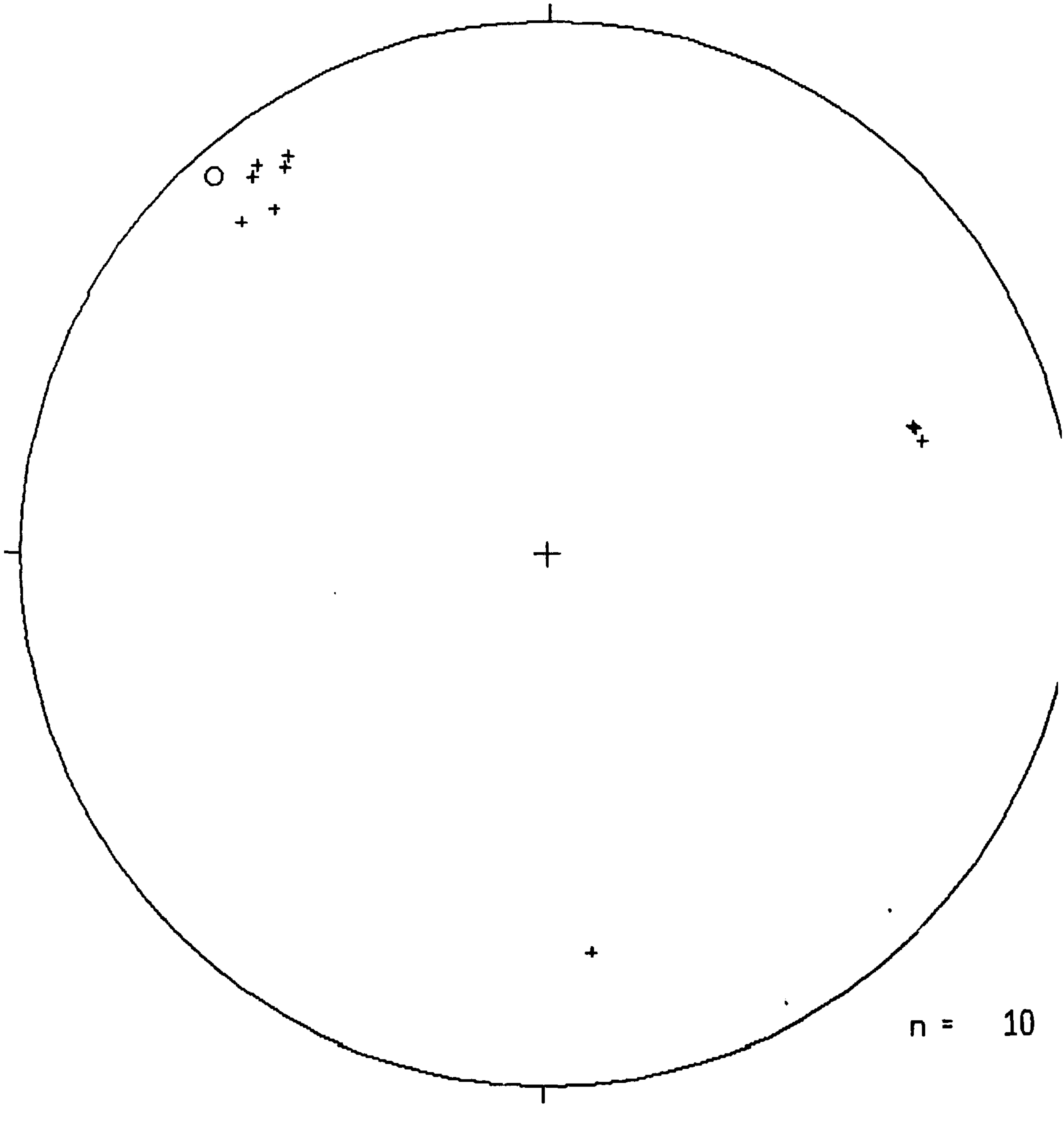
APPENDIX B

BETA PLOTS FOR FOLDS IN CONSECON QUARRY

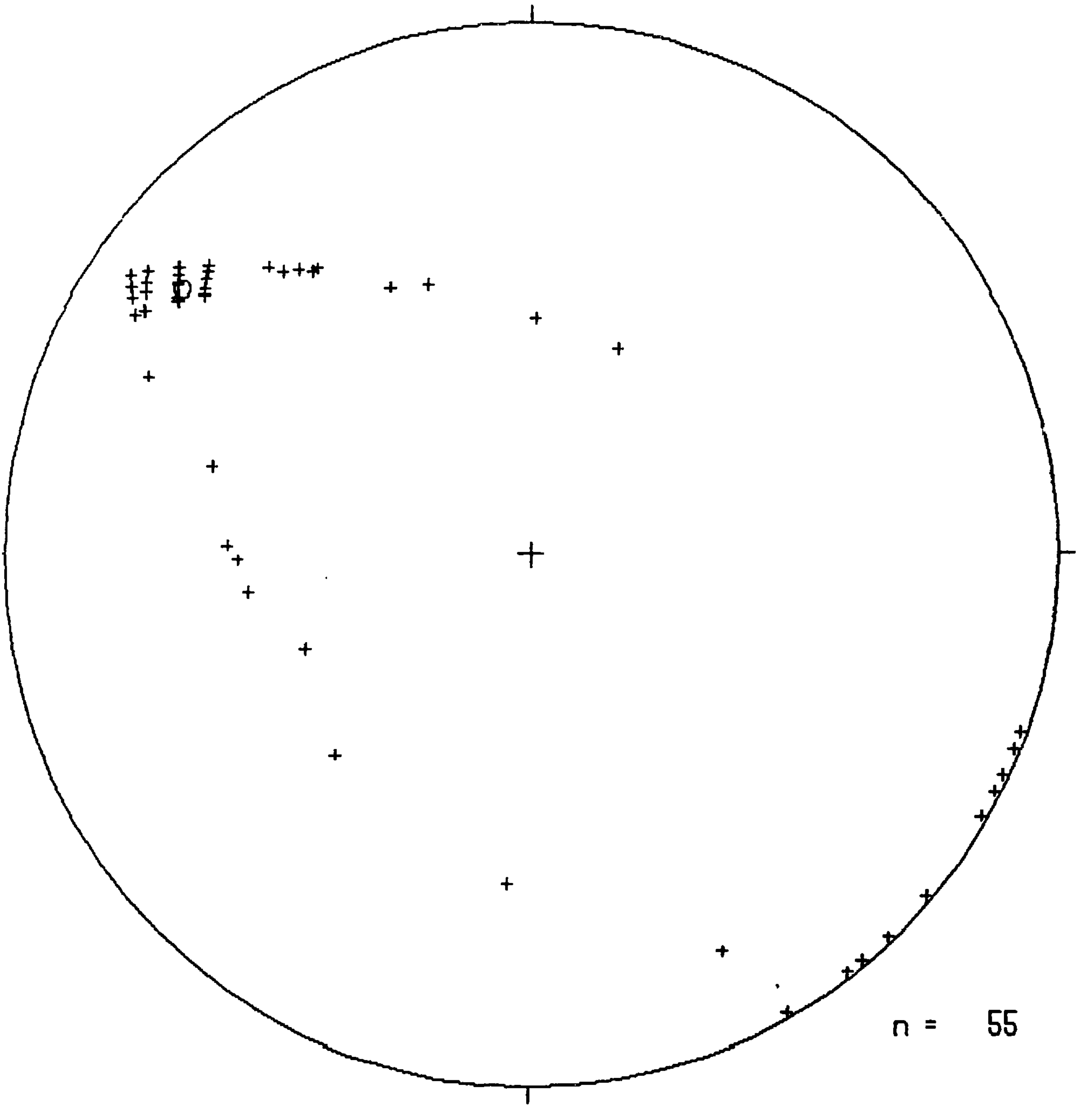
Beta Plot of Fold # 1-Consecon Quarry



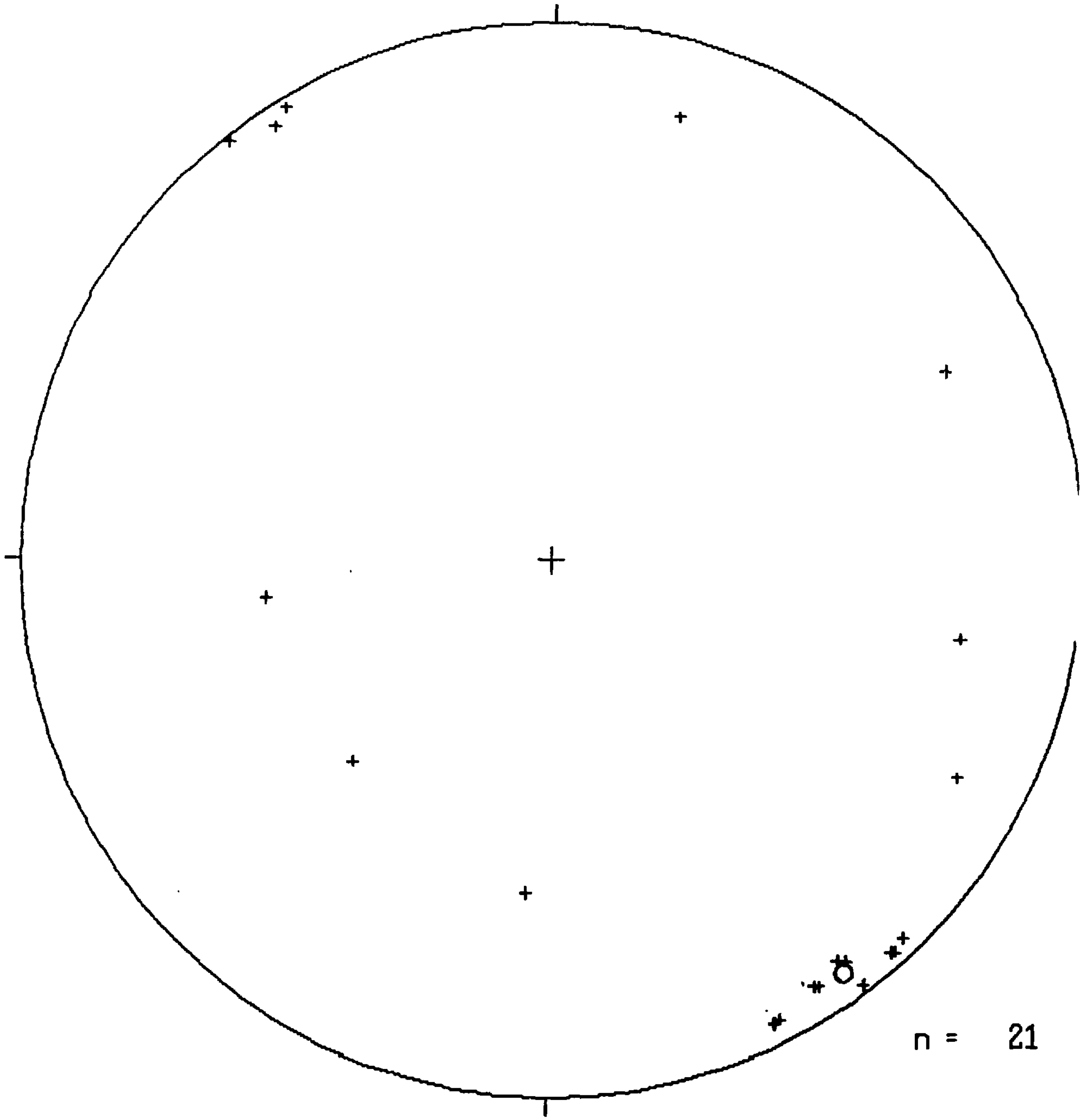
Beta Plot of Fold # 2-Consecon Quarry



Beta Plot of Fold # 3-Consecon Quarry



Beta Plot of Fold # 4-Consecon Quarry



Beta Plot of Fold # 5-Consecon Quarry