The uraniferous matinenda formation, Elliot Lake, Ontario: a braided river model.

Etienne Alexandre. Lantos
University of Windsor

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LA THÈSE A ÉTÉ MICROFILMÉE TELLE QUE NOUS L'AVONS REÇUE
THE URANIFEROUS MATINENDA FORMATION,
ELLiot LAKE, ONTARIO:
A BRAIDED RIVER MODEL

by

Etienne Alexandre Lantos

A thesis
submitted to the Faculty of Graduate Studies
through the Department of Geology in Partial Fulfillment
of the requirements for the Degree of Master of Science at The University of Windsor

Windsor, Ontario, Canada

1979
ABSTRACT

The Denison Mines Limited property is about 10 miles NNE of Elliot Lake, northern Ontario. The ore zone is a uraniferous, oligomictic quartz-pebble conglomerate, located in the Matinenda Formation (Huronian) which rests unconformably on Archean basement. The coarser contents in the Matinenda sequence seem to be confined to linear, palaeotopographic depressions of the sub-Huronian surface. This relationship is also reflected in the uniformity of current direction given by cross-bedding and fabric in the Matinenda sub-arkoses and conglomerates and the Mississagi quartzites. Although the rocks are folded in a west-plunging syncline and form a succession 2.28 billion years old, they have been subjected to very little metamorphism and a minimum of deformation. Thus sedimentary rock types and structures are preserved in a relatively unaltered state.

Vertical variations in lithofacies such as upward fining, channels grading upward into small scale cross-bedding, and lateral interfingering of various rock types in the ore zone indicate that the conglomerate was deposited by a braided river system. The uranium minerals, uraninite and brannerite, are found predominantly in the conglomerate. Higher grade ore tends to occur in coarser, more tightly packed conglomerates. As part of a braided river system these conglomerates would form as bar and lag deposits of limited lateral extent, interfingering with finer-grained
side channel deposits. This being the case, examination of mine headings for lateral variations in grain size and sedimentary structures may prove useful in searching for higher grade ore. Since the conglomerates form in laterally limited environments, the ore "reefs" are diachronous units comprising coalescing conglomerate pods, not synchronous laterally extensive beds.
ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my thesis advisor, Dr. Mary W. Davis, a friend, for her tireless help and guidance, above and beyond the call of duty, including trips to Elliot Lake, where this thesis was born.

I would also like to thank Denison Mines Ltd. for hiring me and giving me the opportunity to work underground, for providing map plans, sections and reports, and for shipping sample material to me. Thanks especially go to Chief Mine Geologist, Mr. Russ Gunning, for his guidance and patience, and for agreeing to act as my external examiner. Thanks also for any help from Al MacEachern, Bob Jorgenson, George Howard, Dennis Walsh and Don Bouffard, all mine geologists. Thanks to Chief Mine Geologist Doug Sprague for allowing me to go underground at Rio Algom Mines Ltd.

I am very grateful to Dr. R.K. Jull for allowing me to use his dark room facilities. Thanks also to my co-advisor Dr. Frank Simpson.

Last, but by no means least, thanks to my dear wife Julie, who translated my thesis into proper English and without whom this thesis would never have been written.
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INTRODUCTION

The study area is located about 10 miles NNE of the town of Elliot Lake, northern Ontario. The Denison Mines Limited property is situated on the west bank of Quirke Lake in Township 150; nine miles north along highway 108 from the city limits of Elliot Lake, a paved road extends eastward to the mine site (Fig. 1).

Denison Mines Limited (formerly Consolidated Denison Mines Limited) came into being in 1953 and went into uranium production three years later.

The ore, present in an oligomictic quartz-pebble conglomerate of Huronian age, occurs near the base of the Matinenda Formation. The latter rests unconformably on a basement of Archean greenstone.

The author was employed by Denison Mines Limited during the summer of 1976, and over a period of four months studied the lithology and sedimentology in the active mining area. Factors limiting the area of study included: availability of clean air, safety of the mine headings, availability of water (to wash the walls) and the amount of mining activity. Distances between sampling stations were thus tightly controlled by mining practice.

The aim of this project was to study the sedimentology
of the ore-bearing rocks and suggest a method of using it as an exploration tool. Many ideas have been advanced by previous authors on the depositional history of this area. Extensive work has been done by Pienaar (1963), Roscoe (1968), Robertson (1968) and others, many of whom suggested the fluviatile origin of the Matinenda Formation. Pienaar (1963) goes into further detail concerning the depositional environment, including the suggestion that:

"...oligomictic gravels would be deposited on the bottoms of wide stream channels as gravel bars or lag gravels."

However, detailed outcrop scale studies required to confirm or disprove these suggestions have not been carried out until the present study.

Collection of data at the mine was carried out both above and below ground. Time spent underground was used collecting samples, drawing geological sections and taking black-and-white photographs. About twenty geological sections were constructed to determine if any lithofacies variation was present. Photographs were used to provide a record of small scale structures. (Photographic methods for use underground are described in Appendix II.) From the numerous samples collected (approximately 50 hand samples) a lithologic classification was developed. Non-confidential information acquired from Denison Mines files was used to complement the data collected underground. Due to company policy confidential ore grade data was not available for.
publication.

The Matinenda Formation does not comprise a very complex sequence of rock types; when first presented with the lithology of the mine the apparent monotony of the rock type was noted. However, with increased familiarity, subtle variations became apparent which are significant in determining the depositional environment.

Before any attempt could be made to interpret these variations, it was important to consider the influence of metamorphism on the original texture of these sediments. In spite of the great age of these sediments, $2,288\pm 87$ million years old (Fairbairn, et al, 1969), they have been subjected to only low grade metamorphism. Pienaar (1963) mentions that the oligomictic conglomerates contain mineral assemblages (chlorite and stilpnomelane) diagnostic of the lowest grade of hydrothermal metamorphism. The relative absence of chlorite in the ore zone itself (Trudell, 1977) suggests that they have been affected by a very mild metamorphism, if at all, and that any alteration that is present is the result of diagenetic processes such as overburden pressures, cementation, and degradation of feldspars, and these were insufficient to alter markedly the primary fabric and sedimentary structure of the sediments (thin section descriptions in Appendix I).
Therefore, assuming that the depositional character of these sediments is largely unaltered, it should be possible to determine the type of environment in which they were deposited by comparison with modern-day analogs.

The study was restricted to a depositional interpretation of the Matinenda ore zone, based upon lithologies, sedimentary structures and facies relationships observable in this rock unit. No attempt was made to compare the Denison Mine's conglomerates with other deposits.
REGIONAL GEOLOGY

Stratigraphy

Regional Stratigraphy

Since the mid-18th century, when the Blind River area was first explored, the stratigraphic nomenclature has gone through many changes. The rocks now named the Matinenda Formation were first recognized as a white quartzite of Early Huronian age, by Logan in 1863, later they were referred to as the Mississagi quartzite in the Bruce Series by Collins in 1914 and 1925. Roscoe (1957) first used the present terminology, calling it the Matinenda Formation in the Elliot Group (Robinson, 1968).

The nomenclature used here (Table 1) is that published by the Federal-Provincial Committee on the Stratigraphy of the North Shore of Lake Huron.

Local Stratigraphy and Structure

The local stratigraphy of the Denison Mines property (Fig. 2) was determined by surface drilling and the sinking of No. 1 and No. 2 shafts. This idealized section shows the two main conglomerate horizons. The lower horizon comprises the A and B reefs (now being mined). The upper zone, zone A, approximately 10 to 14 feet thick, is composed of layers of two or three conglomeratic bands, the lowermost of which is usually coarser grained. The conglomeratic
layers are separated by quartzite beds (6 inches to 2 feet thick). Denison geologists label these Q1, Q2, etc. Zone B, normally 8 to 12 feet thick, is usually more homogeneous and coarser grained, and often fines upwards. It is sometimes found lying directly on the basement rocks (as at Quirke Mine) or more often on a relatively thick pile of metaarkoses. Zones (or reefs) A and B are nearly always separated by what Denison geologists name IQ (Interbedded Quartzite). This zone is composed of bedded and cross-bedded metaarkoses. The thickness of this zone is highly variable, ranging from a few inches to over 10 or more feet towards the southeast end of the mine. This zone was found by the author to also be located above "reef" A and below "reef" B. Furthermore, numerous zones called reef A had the attributes of reef B and vice versa. This led the author to the conclusion that the "layer cake" model does not apply in this case.

The upper horizon is composed of three lenticular layers of uraniferous conglomerates (D, E and F reefs). The average dip of these horizons is approximately 15° south. Numerous normal and thrust faults transect the ore zones; individual displacement ranges up to and over 150 feet. The sequence is seen cut by a diabase dyke (Nippissing Diabase). The dyke's
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Figure 1. Location map of Jenison Mines property. (Geologic map after Pienaar, 1963. Inset map from Robertson, 1976)
distributed throughout the base of the Quirke Syncline were probably intruded at one time into a congruent set of fractures. The intrusion of diabase bodies is associated with localized silicification, carbonatization, chloritization, albitization and dissemination of sulphide mineralization (Robertson 1968).

**Subdivision of the Matinenda Formation**

The Members present in the Matinenda Formation are described below. On the northern limb of the Quirke Syncline only the uppermost part of the Stinson Member is present. The Manfred Member is present in its entirety. The ore conglomerates (A and B reefs) occur in the Manfred Member. The Ryan Member can be found only in the south limb of the syncline:

- Manfred Member
- Stinson Member
- Ryan Member

**Matinenda Formation**

- Manfred Member: poorly sorted subarkose
- Stinson Member: better sorted subarkose
- Ryan Member: poorly sorted subarkose

**Importance of Basement Topography**

Hart et al., (1955) speak of irregularities on the pre-Huronian surface. With this in mind, an attempt was made to construct a paleotopographic profile across the Denison Mine Ltd. property. This has been achieved using drill-hole data, and Pienaar's (1963) isopach map of the Matinenda Formation,
Figure 2. Local stratigraphy of Denison Mines Ltd. (From Denison Mines' files.)
using the upper surface of this Formation as a datum line. This method eliminates any structural effects, such as faulting, but scarcity of drill-hole data to the basement leads to some imprecision.

While it was already known that the thickest conglomerate beds were to be found in the deepest topographic depressions (Hart et al., 1955), Figure 3 shows the relationship between the higher grade ore and the deeper paleo-valleys; Profiles DC and FE transect the most productive area of the mine. The range of current directions (N139°E to N158°E) determined by Pienaar (1963), from cross-bed measurements, also correspond to the general NW-SE direction of this linear depression. This suggests a strong basement topographic control on depositional processes within the environment, or on the presence of the environment, in which the Matinenda was formed.
Figure 3a. Isopach map of the Matinenda Formation (after Pienaar 1963), profile A-B, longitudinal section showing basement topography using top of the Matinenda as datum. Vertical exaggeration X35.
Figure 3b. Isopach map of the Matinenda Formation (after Pienaar 1963), profiles D-C and F-E showing basement topography using top of the Matinenda as datum. Vertical exaggeration X35.
PREVIOUS WORK

Intensive geological research followed the discovery of uranium in the Blind River - Elliot Lake area. In 1954, both the Geological Survey of Canada and the Ontario Department of Mines initiated studies within the area. The Ontario Department of Mines assumed responsibility for regional mapping, and the Geological Survey of Canada investigated the ores and their origin (Robertson, 1968).

Mining company geologists and consultants were the first to publish descriptions of the ore deposits. Joubin, (1954) described the uranium deposits of the Algoma District. Hart et al., (1955) described the uranium deposits of the Quirke Lake trough. Much early research was also undertaken at universities and by private companies. Notable among these was Pienaar's (1963) published work on the stratigraphy, petrology and genesis of the Elliot Lake Group.

Interest dropped in the early 1960's due to the fall in the uranium market and subsequent closing of most of the mines. It was not until exploration interests picked up in the late 1960's (with increased demand for uranium as an energy source), that Robertson's (1968) report on the geology of Township 149 and Township 150 was published, as was Roscoe's (1968) comprehensive treatment of the uraniferous conglomerates, (although both produced preliminary reports in 1957). A
summary of the various views on the depositional environment of the oligomictic quartz-pebble conglomerate may be found in Table 2.
<table>
<thead>
<tr>
<th>Author</th>
<th>Major contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hart et al. (1955)</td>
<td>Discovered that major orebodies lie largely within pronounced depressions on the pre-Huronian surface. The thickest beds of conglomerate occur in the lowest parts of the depressions. Depressions were caused by differential erosion of the Archean surface.</td>
</tr>
<tr>
<td>McDowell (1957)</td>
<td>Conducted exhaustive study of primary current structures. Discovered current directions are from NW to SE. Suggested a fluvial origin.</td>
</tr>
<tr>
<td>Davidson (1957, 1959)</td>
<td>Concluded that the Matinenda was deposited by river processes and later reworked as beach gravels.</td>
</tr>
<tr>
<td>Pienaar (1963)</td>
<td>Carried out detailed study of cross-beds. Paleocurrent direction N139E to N158E. Suggested that both arenites and conglomerates deposited by same paleo-stream system, and exposed to winnowing and reworking under shallow water lacustrine conditions.</td>
</tr>
<tr>
<td>Roscoe (1968)</td>
<td>Postulated a fluvial origin on the basis of current directions.</td>
</tr>
</tbody>
</table>

Table 2  Summary of major sedimentological studies on the ore conglomerate at Elliot Lake, Ontario. Summary comments only on depositional history.
LITHOLOGY

Until now previous authors (such as Pienaar, (1963), and Roscoe, (1968)) have only forwarded a general classification for the rock types found within the Matinenda Formation (conglomerate, grit, quartzite, etc.). However, lithologies are more variable than this.

On the basis of observations of collected hand samples, and of rocks in situ in mine headings, six lithologic categories were established. The characteristics of these six lithologies are summarized and illustrated in Table 3.

The ore zone at Denison Mines Ltd. comprises four major types of conglomerate, each differently packed, or with different modal clast sizes.

In addition to these conglomerates, a few of the beds inside the A and B zone are composed of coarse-grained (1.0 - 5.0 mm) subarkosic sandstone (classification from Dott, (1964)). This is designated Lithology 5. Furthermore, a more complex lithology, consisting of interbedded subarkose and conglomerate, is found to act as a single unit. This is called Lithology 6. On average there is a one-to-one ratio between the thickness of the conglomeratic layers and the subarkosic layers (photo, page , both the coarse and fine grained beds average 3 inches in thickness). The conglomerates occur as superimposed lenticular bodies, 2 to 5 feet in length, within the subarkose. These lenses average 2 to 3 inches in thickness reaching a
maximum of 12 inches. These conglomerates nearly always show erosional upper and lower surfaces. It is not uncommon to find upward coarsening within the coarser fractions of Lithology 6, a phenomenon not present in the other lithologies. This lithology is therefore quite distinctive from any normal interbedding of Lithologies 1 and 5.

All rock types are generally poorly sorted and grain to grain contact occurs only within Lithology 1, all other conglomerates are matrix supported. The term matrix used here refers to the fine sand fraction rather than the small pebble fraction.

Thin-section descriptions of the conglomerates are detailed in Appendix I. The quartz pebbles appear to be of fairly high-grade metamorphic origin owing to their granoblastic polygonal form. The smaller quartz grains (in the matrix) may be of igneous origin (Trudell, 1977). Pyrite and heavy minerals (monazite and rutile) show a tendency to be concentrated around the bigger quartz pebbles. Pyrite grains are found in two distinct forms; one rounded, and clearly detrital (Theis 1973), the other euhedral, showing rimming and apparent growth zoning perhaps diagenetic in origin (Stanton, 1972), but more probably related to mobilization and crystallization (Theis 1973 and Roscoe 1969).
Pebbles casually identified as chert were often found by the author to be quartz pebbles filled with small black inclusions of an unknown origin (Fig. 4). Alternate high and low concentrations of "inclusions" give the dark pebble a laminated appearance. Although dark brown or black chert pebbles are commonly referred to in the literature (Minter 1976, Theis 1973), the clasts studied are probably derived from metamorphosed sandstones or siltstones. No radioactivity is recorded from these pebbles. X-Ray Fluorescent studies performed by Dr. Peter Petö, University of Windsor, found a complete lack of uranium in these pebbles, quartz alone was present. "However, there is a liberal scattering of chert pebbles in the conglomerate bands of the lower reef with a few much smaller chert pebbles more widely scattered in the upper reef. The chert pebbles are angular to subangular while the black quartz pebbles are usually well rounded". (R. Gunning, personal communication).

The sub-arkoses have been petrographically studied by Pienaar (1963) and Trudell (1977). Whilst concluding that quartz grains are commonly first cycle, sub-angular to sub-rounded, and that the plagioclase is usually highly altered to sericite, they also record the virtual absence of any cementing material or authigenic overgrowths. Pienaar (1963) suggested that this was indicative of the impermeable nature of the sediment, and that the absence of second cycle quartz indicated a first cycle plutonic source for the detritus.
Figure 4  Thin-section of black, laminated pebble, showing spherical inclusion trails.
<table>
<thead>
<tr>
<th>Lithology</th>
<th>Name</th>
<th>Pebble Roundness</th>
<th>Pebble Shape</th>
<th>Rock Colour*</th>
<th>% Pebi</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>well-packed conglomerate</td>
<td>rounded</td>
<td>mainly prolate</td>
<td>medium gray (N5)</td>
<td>70-75</td>
</tr>
<tr>
<td>#2</td>
<td>moderately well-packed conglomerate</td>
<td>subrounded to rounded</td>
<td>equant</td>
<td>medium gray (N5)</td>
<td>50-70</td>
</tr>
<tr>
<td>#3</td>
<td>loosely packed conglomerate</td>
<td>subangular to subrounded</td>
<td>oblate to equant</td>
<td>moderate yellow green (10Y 7/4)</td>
<td>25-50</td>
</tr>
<tr>
<td>#4</td>
<td>pebbly subarkose</td>
<td>subangular to subrounded</td>
<td>oblate to equant</td>
<td>light olive (10Y 5/4)</td>
<td>1-25</td>
</tr>
<tr>
<td>#5</td>
<td>subarkose</td>
<td>subangular to subrounded</td>
<td>--</td>
<td>light olive (10Y 5/4)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>#6</td>
<td>interbedded subarkose and conglomerate</td>
<td>subrounded to rounded</td>
<td>equant</td>
<td>(10Y 5/4) and (NS)</td>
<td>20-70</td>
</tr>
</tbody>
</table>

*Rock colours after Rock Colour Chart, G.S.A.*

Table 3. Summary of lithologies found at Denison Mines.
<table>
<thead>
<tr>
<th>Pebbles</th>
<th>% Sandy Matrix</th>
<th>Grain size Range</th>
<th>Pebble Packing Proximity Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>70-75</td>
<td>25-30</td>
<td>20-75 mm</td>
<td>25-50%</td>
</tr>
<tr>
<td>50-70</td>
<td>30-50</td>
<td>10-50 mm</td>
<td>10-25%</td>
</tr>
<tr>
<td>25-50</td>
<td>50-75</td>
<td>5-50 mm</td>
<td>1-10%</td>
</tr>
<tr>
<td>1-25</td>
<td>75-99</td>
<td>5-50 mm</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>1</td>
<td>&gt; 99</td>
<td>1-5 mm</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>20-70</td>
<td>50-75</td>
<td>2-50 mm</td>
<td>10-50%</td>
</tr>
</tbody>
</table>

Note: Ruler in pictures is in 1/10 of a foot.
SEDIMENTARY STRUCTURES

Paleocurrent directions within the Matinenda Formation have been extremely well documented by McDowell (1957) and Pienaar (1963) among others, and it was felt to be largely unnecessary to repeat this study. Their data, therefore, was accepted as an integral part of this study on sedimentary structures.

Where photographs of such structures were not available geological sections were drawn.

Some sedimentary structures (cross-beds etc.) are enhanced by concentrations of pyrite along discrete planes, i.e. bedding surfaces. The pyrite, apparently of detrital origin, has important significance for an understanding of the genesis of the ore and will be discussed further in the section on economic geology.

Interstratal Structures (see Table 4)

Each lithology tends to have a characteristic bed thickness which varies little throughout the mine. Bed thicknesses for various lithologies are outlined in Table 4. Figure 5 shows the relative uniformity of bed thicknesses.

Except for Lithology 2, all rock types exhibit erosional features on their upper or lower surfaces. Lithology 2 often lies gradationally over Lithology 1 as part of an upward fining sequence.
Interfingering of various lithologies is conspicuous throughout the mine, and although sometimes camouflaged by the irregularity of the heading walls, it is usually very easy to recognize. Lithology 1 (well packed conglomerate) and Lithology 6 (interbedded unit) are nearly always laterally continuous. Lithologies 2, 3, 4 and 5 are often very discontinuous (fig. 6). The subarkose (Lithology 5) is, most often present as lenses of various thickness and length. Figure 7 shows a thickly laminated subarkose pinching out into a well-packed conglomerate.

Gradational lateral variations in lithology were found to occur where no interfingering existed. Thus the tracing of a certain bed for any distance greater than five feet was often difficult. Lateral variation is most prominent in Lithologies 3 (loosely packed conglomerate) and 4 (pebbly subarkose) (fig. 8).

Figure 8 Gradational lateral transition between Lithologies 3 and 4.
<table>
<thead>
<tr>
<th>Lithology</th>
<th>Bed thickness in cm</th>
<th>Type of Bedding contacts</th>
<th>Lateral Continuity</th>
<th>Channeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>over 100</td>
<td>erosional upper surface</td>
<td>continuous</td>
<td>fills in deep narrow channels</td>
</tr>
<tr>
<td>2</td>
<td>30 - 100</td>
<td>gradational above Lithology 1. Erosional over all others</td>
<td>discontinuous (fig. 6)</td>
<td>intermediate channel fill</td>
</tr>
<tr>
<td>3</td>
<td>30 - 100</td>
<td>Erosional over all lithologies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10 - 100</td>
<td>- erosional lens channel fill</td>
<td>discontinuous (fig. 6)</td>
<td>intermediate channel fill</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>laterally gradational (fig. 7)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3 - 10</td>
<td>- erosional lens channel fill</td>
<td>discontinuous lenses (fig. 7)</td>
<td>fills wide shallow channels</td>
</tr>
<tr>
<td>6</td>
<td>30 - 100</td>
<td>- erosional gradational lower surface</td>
<td>continuous</td>
<td>rarely found filling channels of any sort</td>
</tr>
</tbody>
</table>

Table 4  Some Interstratal and Intrastatal Structures.
Intrastratal Structures

Channeling
Channels are erosional features common in fluvial environments (Blatt et al., 1972). A number of channel features are present in the mine which vary greatly in relative depth and width; some may be so shallow as to be almost unrecognizable as a channel. They may be classified as three main types as shown below.

Deep and narrow 5 - 15 ft. wide 6-8 ft. deep
Wide and shallow 15 - 40 ft. wide 4-6 ft. deep
Very wide and shallow over 40 ft. wide 2-4 ft. deep

Lithology 5 (subarkose) is usually the rock type found to fill in, and thus define, wide shallow channels. Lithology 1 (well-packed conglomerate) is the major rock type filling in the deeper and narrower channels. Lithologies 2, 3 and 4 (conglomerates and pebbly subarkose) (Fig. 9) make up the intermediate channel fill. Lithology 6 (interbedded unit) is rarely (if ever) found filling channels of any sort.

Cross-Stratification

Pienaar (1963) measured most of the cross-bedding within the Matinenda Formation underground. He only was able to recognize cross-bedding where concentrations of pyrite occurred. He concluded that paleocurrent directions, derived from cross-beds, were of the same general direction throughout
the deposition of the 3,000 feet of sediment, from the base of the Matinenda Formation to the overlying Mississagi Formation. This is indicative of the persistence of the paleoslope throughout the life of the depositional environment.

Cross-bedded conglomerates are only clearly visible under ideal conditions, such as clean walls, good illumination, abundant pyrite and when the sediment is well sorted.

Only one type of cross-bedding was encountered in the mine, the trough cross-bed. The mechanism of formation is mainly through the filling in of channels and irregularities on the stream bottom.

The size of the sediment filling in the channels varies considerably. Figure 10 shows trough cross-bedded subarkose (Lithology 5) filling in a scoured subarkose. Figure 11 shows a channel cut into a loosely packed conglomerate (Lithology 3), later filled in by a well-packed conglomerate (Lithology 2).

Two different scales of trough cross-bedding were encountered in the mine. Figure 19 illustrates both. Lithology 5 (subarkose) fills in a relatively shallow channel and the cross-bedding is of a small scale. Adjoining this, are large scale cross-beds with relatively shallow inclination. They were probably formed by accretion of sediments on a bar (Blatt, et al., 1972). Whilst it was fairly easy to recognize cross-bedding in Lithologies 2, 5 and 6, it was virtually impossible to identify it in Lithologies 1, 3 and 4, with any degree of certainty. Thus it became largely invalid to define any relationship between lithology and cross-bedding.
Upward Fining

As mentioned earlier, Lithology 1 (well-packed conglomerate) is often very thick (approximately 6 to 8 feet). The quartz pebbles near the base sometimes reach 10 to 13 cm in diameter, and diminish in size gradually, to about 1.5 to 2.0 cm in diameter near the top of the bed (Fig. 12). This upward-fining sequence within the conglomerate is conspicuous throughout the mine; it is also found within Lithologies 2, 3 and 4, although occurrences are relatively rare and poorly exposed.

Figure 12  Coarse well-packed conglomerate grading upwards into a finer grained, moderately well-packed conglomerate.
<table>
<thead>
<tr>
<th>Lithology</th>
<th>Average Bed Thickness in cm</th>
<th>Maximum Grain Size in cm</th>
<th>Velocity of water for transport* m/sec</th>
<th>Sorting</th>
<th>Flow Regime</th>
<th>Depositional Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>8</td>
<td>1.5</td>
<td>Good</td>
<td>Very high energy</td>
<td>Very high flow of water to deposit only coarse sediments. Some finer particles trapped. Heavy minerals may have similar flow regime.</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>5</td>
<td>1</td>
<td>Moderate</td>
<td>High energy</td>
<td>High flow of water. Some fine sediments trapped.</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>5</td>
<td>1</td>
<td>Bad</td>
<td>Moderate to high energy</td>
<td>Moderate flow of water. Coarser sand may deposit.</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>5</td>
<td>1</td>
<td>No</td>
<td>Moderate energy</td>
<td>Moderate flow of water. Low supply of coarse sediments. Deposition of subarkose.</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>0.5</td>
<td>0.5</td>
<td>Moderate</td>
<td>Low to moderate energy</td>
<td>Low to moderate flow of water. Deposition of subarkose only.</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
<td>5</td>
<td>1</td>
<td>Moderate</td>
<td>Variable</td>
<td>Alternating environment of 2 and 5 above.</td>
</tr>
</tbody>
</table>

Table 5 Summary of conditions to deposit the six lithologies.

* from Verhoogen, et al, 1970
From Section E-19A

Figure 5. Fairly uniform bed thicknesses of various lithologies.
Near Section E-3

Figure 6. Interfingering of various lithologies.
Figure 7. Lens of thickly laminated sub-arkose pinching out into a well packed conglomerate.
Figure 9. Horizontally bedded vertical sequence cut by two channels. Channel on right filled by a moderately well-packed conglomerate (Lithology 2) and overlain by subarkose (Lithology 5). Channel on left is filled by a pebbly subarkose (Lithology 4).
Figure 10. Trough cross-bedding in subarkose.
Figure 11. Channel cut into a loosely packed conglomerate (Lithology 3) filled by a well-packed conglomerate (Lithology 2) exhibiting trough cross-bedding.
LEGEND FOR FIGURES
5 to 21

interfingering

trough cross-bedding

erosional bedding contact

gradational bedding contact

bedding contact

fining upwards

coarsening upwards

lens

pebble band

Figure 13. Legend for figures 5 to 21.
LEGEND

1. well-packed conglomerate

2. moderately well-packed conglomerate

3. loosely-packed conglomerate

4. pebbly subarkose

5. subarkose

6. interbedded subarkose with well-packed conglomerate (interbedded unit)

Figure 14. Legend for all other drafted figures.
trough cross-bedding

low angle trough cross-bedding

pebble beds

interfingering

fault plane and relative movement

scouring

bedding contact

gradational bedding contact

gradational lateral variation in lithology

lens

fining-upwards

coarsening-upwards

Figure 14. (Cont'd)
FACIES VARIATION AND DEPOSITIONAL INTERPRETATION

Eynon and Walker (1974) studied bar growth in a Pleistocene braided river, recording photographically numerous vertical sections through the river deposits. The five facies they recognized are given below.

1. Bar core facies: Basal gravel, often with sand wedges, very coarse (approximately 10 cm), upward fining.

2. Bar stoss facies: Tabular units of cross-bedded, coarse and pebbly sand, coarsening upward.

3. Bar front facies: Almost entirely coarse grained gravels, with large scale cross-beds.

4. Bar top facies: Undulatory bedded gravels (channeling or crude horizontal stratification, imbrication of clasts.

5. Shallow braided facies:
   a) Lower part: cross-bedded gravels resting on erosional contact.
   b) Upper part: sands and gravels resting gradationally upon lower cross-bedded gravels, or upon bar top.

This is summarized diagramatically in Figure 15.

A comparison was made between the braided river sections of Eynon and Walker (1974) and those sections recorded in the Matinenda Formation at Denison Mines Ltd.
Figure 15. Cross-section through a modern braided river, Eynon and Walker, (1974).
Section E-18 is very similar to that of Eynon and Walker (1974) (Fig. 16 & 17). Figure 16 shows a coarse, well-packed conglomerate which fines upward, and is cut by numerous sand lenses. This is closely comparable with Figure 16, where a coarse, well-packed conglomerate (Lithology 1) grades upward into a finer grained, moderately well-packed conglomerate (Lithology 2) with interfingerings of Lithology 5 (subarkose). The reworked zone of Figure 17 closely resembles the cross-bedded subarkose with occasional pebbles (Lithology 4). In both cases this is overlain by a regularly cross-bedded, loosely packed conglomerate (Lithology 3, which represents the bar top facies. (The shallow braided facies is usually represented by the interbedded subarkose with conglomerate (Lithology 6); however, in Figure 16 it is Lithology 5 (subarkose) which is present.)
Figure 16. Section E-18 from Denison mines.

Figure 17. Bar top facies, Eynon and Walker, (1974)
Section E-10 (Fig. 18) can be compared with the side channel facies of Eynon and Walker (1974) (Fig. 15). An upward fining core, comprising Lithologies 1 and 2 (well-packed conglomerates), interfingers with the interbedded subarkose and conglomerate (Lithology 6), and is overlain by the shallow braided facies, here represented by Lithology 6.
Section E-7 (Fig. 19) is designated as bar front, by comparison with Figure 20. Lithologies 1, 2 and 4 (conglomerates and pebbly subarkose) comprise the bar core with an upward-fining conglomerate overlain by the shallow braided deposit of Lithology 6 (interbedded unit) with numerous trough cross-beds. An erosional contact separates the bar core from the bar front facies. A well cross-bedded subarkose starts the channel fill, later filled by alternating well and loosely packed conglomerates (Lithology 2 and 3). This is then overlain by the bar top (Lithology 3, loosely-packed conglomerate) and shallow braided facies (Lithology 6). Bar front deposits differ from the bar core in that they comprise medium size beds of loosely-packed conglomerates, rather than the very thick beds of better-packed conglomerate found in the core.

Mine geologists have interpreted this feature as a low angle fault; however the author is not in agreement with this.
Figure 19. Section E-7 from Denison Mines.

Figure 20. Bar front facies, Eynon and Walker (1974)
Of all the sections studied, the closest comparison is found between Section E-2 (Fig. 21) and Figure 22, which illustrates a bar core facies, overlain by a shallow braided facies. In both cases a basal conglomerate, with an upper erosional surface, underlies the bar core (an upward-fining, coarse conglomeratic deposit (Lithology 1), containing numerous sand lenses (Lithology 5). This is then overlain by a reworked sandy wedge, correlating with Lithology 4 (subarkose with occasional pebbles). The bar top conglomerate of Eynon and Walker (1974) is reminiscent of Lithology 3 (loosely-packed conglomerate). Finally, the sequence is completed by the shallow braided stream facies (Lithology 6), in an identical manner to that seen in the photograph taken by Eynon and Walker (1974).

The occurrence of numerous channel fill deposits within the conglomeratic beds is of additional interest. Leopold and Wolman (1957) suggested a possible mechanism for their deposition (Fig. 23). During a period of high water flow, a braided river bar is cut by an active zone of sediment transport (A in Fig. 23); this channel is later filled in by sediment whose size depends on the energy of the water and availability of sediments (Table 5). Such scours would fill with sand size sediment (B in Fig. 23)
Figure 2.1, Section E-2 from Denison Mines.

Figure 2.2, Bar core facies, Eynon and Walker (1974).
during the falling river stage (or perhaps during later floods which weren't so severe), however, it was usually recorded that the bottom of such sand filled scours were lined with reworked pebbles. Water of a higher energy would result in the deposition of coarser and more numerous pebbles within the scour (C in Fig. 23) (Middleton, 1972).

Figure 23. A possible mechanism for creation of channel fill deposits within a braided bar (after Leopold and Wolman, 1957).
VERTICAL LITHOLOGIC VARIATIONS

Vertical lithologic variations have been considered from two main points of view; firstly a comparative study, and secondly, a statistical analysis.

The vertical sequences of rock types do not show any immediately obvious pattern of repetition or cyclicity, and it was therefore necessary to find a way to identify those lithologies which tend to occur together.

With the braided river interpretation in mind, the vertical sequences recorded at the mine were compared with those of Williams and Rust (1969). They enumerated a series of facies, from analysis of a braided river, based on grain size (Table 6).

A very close resemblance can be seen between Facies D and Lithology 5 (subarkose), between Facies F and Lithology 6 (interbedded unit) and Facies G and Lithologies 1, 2 and 3 (conglomerates). Silt and clay horizons were not found within the ore zone. The lack of fine grained material (silts and clays) within this braided river system may perhaps be explained by the fact that there was no vegetation (grasses, trees, etc.) during the lower Huronian, to stabilize such material. In what must have been a very high energy environment, any such material which may have
been deposited (i.e. from overspill) would have been immediately washed away with any change in the main channel course.

Williams and Rust (1969) record two types of vertical facies relationships: firstly a simple relationship with no erosional contacts, and secondly a complex relationship with many erosional contacts. An attempt has been made to correlate these results with those recorded at the mine. Little correlation exists with the simple model; the only example is where a subarkose overlies a well-packed conglomerate with an erosional base. However, a close similarity can be seen where there are many erosional contacts, and the finer material has been eroded away (Table 7). This may indicate a highly active fluvial environment, where only the coarsest material is deposited, with some fine material trapped between the grains.

Note that Lithology 4 is not compared with any of the facies encountered by Williams and Rust. The author believes that Lithology 4 (pebbly subarkose) corresponds with Eynon and Walker's reworked facies but found no other evidence to support this fact.
<table>
<thead>
<tr>
<th>Facies</th>
<th>Williams and Rust</th>
<th>Denison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facies A</td>
<td>Laminated silt and clay</td>
<td>Not present</td>
</tr>
<tr>
<td>Facies B</td>
<td>Banded sands and silty clay</td>
<td>Not present</td>
</tr>
<tr>
<td>Facies C₁</td>
<td>Banded sands and silts</td>
<td>Not present</td>
</tr>
<tr>
<td>Facies C₂</td>
<td>Silty</td>
<td>Not present</td>
</tr>
<tr>
<td>Facies D</td>
<td>Sand with small and large scale cross-beds</td>
<td>Lithology 5 subarkoses</td>
</tr>
<tr>
<td>Facies E</td>
<td>Wind transported sand</td>
<td>?</td>
</tr>
<tr>
<td>Facies F</td>
<td>Complex association of gravel and sand. Vertical and lateral changes are apparent over inches and feet, occurring in thin impersistent units</td>
<td>Lithology 6 interbedded subarkoses and conglomerates</td>
</tr>
<tr>
<td>Facies G</td>
<td>Mostly gravels with occasional thin impersistent layers of sand</td>
<td>Lithologies 1, 2 and 3 conglomerates</td>
</tr>
</tbody>
</table>

Table 6: Comparison of lithologies between Williams and Rust (1969) and Denison Mines Ltd.
<table>
<thead>
<tr>
<th>Williams' and Rust</th>
<th>Denison Mines</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>1 (2,3)</td>
<td>Channel fill separated by shallow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>braided facies</td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>Channel fill separated by shallow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>braided facies</td>
</tr>
<tr>
<td>G</td>
<td>1 (2,3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Channel fill separated by shallow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>braided and reworked facies</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>1 (2,3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Channel fill separated by reworked</td>
</tr>
<tr>
<td></td>
<td></td>
<td>facies</td>
</tr>
<tr>
<td>G</td>
<td>1 (2,3)</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>1 (2,3)</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Comparison of complex relationships of a braided river facies (Williams and Rust (1969) with sections recorded at the mine.)
A second approach to the study of this variation is the modified chi-square method used by Walker (Harms et al., 1975) and Krumbein (Krumbein, 1967), and is an attempt to apply statistical analysis to a set of data, although the final interpretation must necessarily be subjective.

The aim of this analysis is to determine whether vertical transitions from one lithology to another occur randomly, or whether the occurrence of one lithology somewhat predetermines the lithology which overlies it. This analysis assumes a Markov process statistical model for sediment deposition, which is to say that the probability of one event (lithology) occurring depends only upon the event (lithology) which immediately precedes it. If lithologic transitions are non-random, i.e. if some transitions are preferred over others, then a flow chart of these transitions can illustrate the basic patterns or cycles of depositional succession.

This method is generally used where a long, continuous vertical section is available, and certain repetitive patterns may indeed be deduced from outcrop observations. However, it is equally applicable to composite vertical sections constructed from isolated outcrops, or to isolated outcrops whose precise stratigraphic relationships are unknown (as in the present study), since the raw data considered are lithologic transitions and not lithologic successions. The method is particularly valuable in the present case, due
the limited vertical exposure; some quantitive record of lithologic transitions is required to "see" the overall pattern of vertical succession operative in these rocks. The main objection to such a matrix is that it does not show the nature of the transitions (gradational, sharp, channelled, etc.), but in the conglomerate units of the Matinenda where sharp and channelled contacts predominate this is not a serious objection.

A record was made of actual transitions known to occur within the twenty or so geological sections taken from the mine (Appendix III). Transitions were recorded along vertical profiles spaced ten feet apart laterally across the sections. Since observability of these sections was controlled by a number of factors (many of them non-geological, such as access to water for washing walls), it was assumed that the sections represented a random sample of the ore zone. The location of the sections are reasonably well-scattered throughout a large area and not biased into one small area (refer to plan view, p. 92), are oriented geographically in a variety of directions, and are of sufficiently similar wall area so that the overall results are not biased by the results of one or two sites. Combining data from many profiles in a number of sections in this way provides a substantial
data base upon which to characterize the lithologic nature of a limited stratigraphic interval. The spaced-profile observation method eliminated any bias which might be introduced due to varying lengths of sections. Recording of vertical profiles began at the start of each cross-section, but due to editing of the drafted sections in Appendix III, many have been shortened at each end.

A tally matrix, showing the observed number of times any one lithology passes upward into any other, is shown in Figure 24. Internal transitions from one lithology to the same lithology (e.g. from "5" to "5" on Fig. 10) were not recorded in the tally matrix. This accounts for the zero values for the diagonal elements in Fig. 24. While it is possible to record such transitions in units that have internal variation from bottom to top, it is not possible to do so for units without internal variation. Inclusion of only those such recognizable transitions would bias the matrix. Thus it is realized that there may be diastems within any unit as the result of channel cutting which will not appear to have statistical significance. Only changes from one lithology to another will appear significant.
<table>
<thead>
<tr>
<th>Lith.</th>
<th>1</th>
<th>2</th>
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<th>4</th>
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<tr>
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<td>19</td>
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<td>9</td>
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<tr>
<td>5</td>
<td>12</td>
<td>43</td>
<td>12</td>
<td>6</td>
<td>0</td>
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<td>90</td>
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<tr>
<td>6</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>3</td>
<td>13</td>
<td>0</td>
<td>38</td>
</tr>
<tr>
<td>Total</td>
<td>43</td>
<td>133</td>
<td>38</td>
<td>55</td>
<td>76</td>
<td>53</td>
<td>448</td>
</tr>
</tbody>
</table>

Figure 24. Matrix showing number of times any one rock type (row) passes upward into any other (column). Compiled from transitions found in mine sections. Total number of observed transitions was 448. The number of transitions from each section was as follows:

- E-1 17
- E-2 16
- E-3 14
- E-4 13
- E-5 34
- E-6 33
- E-7 19
- E-8 17
- E-9 50
- E-10 33
E-11 16
E-12 19
E-13 19
E-14 13
E-15 34
E-16 36
E-17 17
E-18 14
E-19 34

This matrix, however, does not provide a clear representation of important relationships, and must be transformed into a new matrix, where possible random effects have been negated, and non-random effects enhanced. This is achieved by constructing an intermediate matrix of predicted or expected random transitions, by cross-multiplying the row and column totals of Figure 24, and dividing each new entry by the total number of facies transitions (Fig. 24).
<table>
<thead>
<tr>
<th>Lith</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.2</td>
<td>26.0</td>
<td>7.4</td>
<td>10.7</td>
<td>24.5</td>
<td>10.3</td>
</tr>
<tr>
<td>2</td>
<td>12.1</td>
<td>38.6</td>
<td>10.9</td>
<td>15.8</td>
<td>36.3</td>
<td>15.3</td>
</tr>
<tr>
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<td>4.3</td>
<td>13.8</td>
<td>3.9</td>
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<td>12.9</td>
<td>5.4</td>
</tr>
<tr>
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<td>5.4</td>
<td>17.3</td>
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<td>7.1</td>
<td>16.3</td>
<td>6.9</td>
</tr>
<tr>
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<td>8.4</td>
<td>26.9</td>
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<td>11.1</td>
<td>25.3</td>
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</tr>
<tr>
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<td>3.6</td>
<td>11.4</td>
<td>3.2</td>
<td>4.7</td>
<td>10.7</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Figure 25  Expected values for matrix given in Figure 24.

This new expected value matrix is then subtracted from the initial observed value matrix (Fig. 24) and figure 25 is created. If the chi-square matrix is created using the formula:

\[
\frac{(\text{Observed} - \text{Expected})^2}{\text{Expected}}
\]

the total chi-square value for the data array is 230.3. This far exceeds the chi-square value of 52.62 required for a 25 degree of freedom table at the 0.1% significance level. Because the diagonal elements were not recorded, the "expected values" in the chi-square matrix for the diagonals are essentially meaningless. Therefore it could be argued that they should be omitted from the total chi-square value. If they are omitted then this value becomes 143 which still greatly exceeds the 0.1% significance level. Thus the pattern of vertical lithologic succession is distinctly non-random. To interpret this non-random pattern, we can consider the observed-minus-expected difference matrix, Figure 26.
<table>
<thead>
<tr>
<th>Lith.</th>
<th>1</th>
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<th>4</th>
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<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-8.2</td>
<td><strong>16.0</strong></td>
<td>-6.4</td>
<td>2.3</td>
<td>-2.5</td>
<td>-1.3</td>
</tr>
<tr>
<td>2</td>
<td>-12.1</td>
<td>-38.6</td>
<td>3.1</td>
<td>-1.8</td>
<td><strong>34.7</strong></td>
<td>1.7</td>
</tr>
<tr>
<td>3</td>
<td>-3.3</td>
<td>0.2</td>
<td>-3.9</td>
<td>1.4</td>
<td>-6.0</td>
<td><strong>4.6</strong></td>
</tr>
<tr>
<td>4</td>
<td><strong>14.4</strong></td>
<td>6.7</td>
<td><strong>4.1</strong></td>
<td>-7.1</td>
<td>-12.3</td>
<td>-4.9</td>
</tr>
<tr>
<td>5</td>
<td>4.4</td>
<td><strong>16.1</strong></td>
<td>4.4</td>
<td>-5.1</td>
<td>-25.3</td>
<td><strong>7.6</strong></td>
</tr>
<tr>
<td>6</td>
<td>7.6</td>
<td>1.4</td>
<td>-1.2</td>
<td>-1.7</td>
<td>3.7</td>
<td>-4.5</td>
</tr>
</tbody>
</table>

**Figure 26** Frequency matrix showing amount over and below (-) the random number of times any one rock type passes upward into any other. Cut-off point is 4.0 (chosen subjectively and underlined).

This matrix now shows more common transitions as positive numbers and less common transitions as negative numbers. As before the diagonal elements are essentially meaningless. Numerous cut-off points were experimented on; a cut-off of 5.0 or over eliminated too many obvious transitions, and a cut-off below 4.0 made the facies relationship diagram too complicated. Therefore a cut-off value or relative transition probability value of 4.0 was taken as the most useful choice in this case. High positive values (above 4.0) are now isolated, being of most importance to the facies model. From these values a lithology relationship diagram is then constructed (Fig. 27).
Figure 27

Facies relationship diagram showing only those transitions that occur more commonly than random. Diagram is derived from data in Figure 26, and only shows transitions whose observed - minus - predicted transition frequencies exceed 4.0. Dotted arrows show transition frequencies in the range 4.0 to 5.0; dashed arrows, 5.0 to 10.0; solid arrows, transition frequencies over 10. Four facies associations have been interpreted and circled on the diagram. Interpretation is based on geological sections from the mine, and the models of Eynon and Walker (1974) and Cant and Walker (1976).
The #1, 2 and 5 rock type association is present in the bar core facies developed by Eynon and Walker (1974). A coarse-grained, well-packed conglomerate (Lithology 1) grades upward into a finer-grained, moderately well-packed conglomerate (Lithology 2), often containing numerous lenses of subarkose (Lithology 5). This combination is overlain by a reworked facies made up of a pebbly subarkose (Lithology 4), interfingered or overlain by the bar top facies composed of loosely-packed conglomerate (Lithology 3). All this is finally overlain by the shallow braided facies with interbedded subarkoses and moderately well-packed conglomerate (Lithology 6).

Current Directions

There is a general agreement among geologists working in the Quirke Syncline about the uniformity of paleocurrent directions. Piennar (1963) used rose diagrams to illustrate the consistent paleocurrent directions (N139°E to N158°E) preserved by cross-bedding and pebble orientation within the Matinenda and Mississagi Formations (Fig. 28). The long axes of pebbles lie perpendicular to the paleocurrent direction, indicating that the pebbles rolled on the river bed (Harms et al., 1975 Rust, 1972b). The consistency of the trend, despite the wide (19°) scattering, is characteristic of a braided river deposit (Blatt et al, 1972).
Not only are the paleocurrent directions fairly consistent, but also the conglomeratic unit is confined to a narrow band approximately 2 miles wide suggesting a strong basement topographic control; the ore conglomerate was deposited into a paleovalley (Fig. 3).
A DEPOSITIONAL MODEL FOR THE MATINENDA FORMATION

A Summary

Before speculating on the possible depositional environment represented by the Matinenda Formation, a short summary of the important features recorded from the mine is presented, and a review of the various possibilities for depositional environments is given.

The facts concerning the Matinenda Formation, as we know them now, are summarized below.

1. The deposition is confined to a deep linear depression within the Archean basement.
2. The sequence thickens from N.W. to S.E.
3. The average pebble size decrease from N.W. to S.E.
4. Paleocurrents are unimodal and trend uniformly S.E.
5. The lateral facies variations are comparable with those recorded by Eynon and Walker (1974).
6. The vertical facies variations are comparable with those recorded by Williams and Rust (1969).
7. Sedimentary structures include trough cross-bedding, channeling, lensing and fining upward sequences.
8. Rocks are poorly sorted.
9. Quartz pebbles are large (maximum size 3-4 cm.) and well-rounded.
10. The conglomerate matrix is composed of granitic material (quartz and feldspars); the pebbles are often metamorphic in origin.

11. The smallest grain size (non-opaque) represented is sand size (1 mm).

12. The pebbles show signs of rolling on the river bed (long axis perpendicular to flow).

Sedimentary environments which normally have conglomeratic components

1. Alluvial Fan

Features found in fans are: poor sorting, angular fragments (from mud and debris flow), a general thinning away from the source area and long axis of pebbles are parallel to flow directions (Bull, 1972).

Although the Matinenda within the mine is rather poorly sorted, it is composed essentially of large and well-rounded pebbles. The majority of the facts listed earlier are from in-mine observations, but some apply to the Matinenda as a whole, such as the sequence thickens from N.W. to S.E., i.e., thickens away from the postulated source area. The pebbles' long axes are perpendicular to current directions. Also Pienaar (1963) noted: "Matinenda... is well stratified and thickens away from the source area, features not characteristic of alluvial fan accumulations."
2. **Beach**

Beach sands show bimodal cross-bedding directions, are much better sorted and contain less matrix. Conglomerates are much thinner and do not fine upwards. (Harms et al., 1975).

The paleocurrents found in the Matinenda Formation are unimodal and trend uniformly S.E. It is relatively poorly sorted, the sediment contains up to 99% matrix (Table 3). The conglomerate in the mine is relatively thick, sometimes measuring up to 6 to 8 ft., and upward fining is ubiquitous.

3. **Submarine Fan**

Sediments in submarine fans show larger amounts of finer sediments and sedimentary structures are of the turbidite type (reverse grading, convolute-bedding, etc.).

The smallest grain size (non-opaque) in the Matinenda within the mine is sand size ($\sim 0.25$ mm). No reverse grading nor convolute bedding is present in the sediments of the mine.

4. **Glaciofluvial**

Glacial environments show a wider range in grain size (boulders to clay) and very poor sorting (Rust, 1975). Conglomerates are usually polymictic.

The rocks in the mine are poorly sorted but the maximum size of the pebbles is 3 to 4 cm and the minimum size is 1 mm. Conglomerate is strongly oligomictic.
5. **Meandering River**

A typical meandering river section starts with a channel floor conglomerate zone, overlain by large and small-scale trough cross-stratified sandstone, followed by interbedded mudstones and siltstones, and a scoured surface followed by massive sandstone containing angular mud clasts (Allen, 1970). Blatt et al. also mention that paleocurrents derived from cross-beds in braided river deposits show relatively low variances as compared with those from meandering rivers.

The sedimentary structures found within the Matinenda Formation in the mine do not correspond with this model, and the absence of fine grained material also argues against a meandering river origin.

6. **Reworked Fluvial**

There is a possibility that the upper parts of the Matinenda Formation in the mine have been reworked by marine processes, but the observations were limited to mined out areas and this environment was not observed.

**Braided Rivers - A Possible Depositional Environment**

From the features observed, and the data collected at the mine, and by comparison with the work of Eynon and Walker (1974), Williams and Rust (1969), Walker (Harms et al., 1975) and others, it would seem that the oligomictic quartz-pebble conglomerate was deposited by a braided river, confined within the linear basement depression.
The sedimentary structures and the nature of the clasts all point to a high energy, fluvial environment. (Middleton, 1965); (Blatt et al., 1972); (Pettijohn, 1957) and others.

Cant and Walker (1975) and Eynon and Walker (1974) compared meandering with braided river environments, and their results suggest the latter is found here. For instance, coarse material is more commonly found in the braided river environment (Blatt et al.; 1972). Similarly, interfingered or well-packed conglomerate with subarkoses is of common occurrence in a braided river system (Williams and Rust, 1969). Furthermore, cross-beded conglomerates are often found in the uppermost layer of a braided river system (Eynon and Walker, 1974).

**Stratigraphic Implications**

Supposing that this sequence of sediment was deposited in a braided river environment, then a comparative area can be examined (Fig. 29). Figure 29, Norman Wells is a map of reworked glacial debris, not a virgin depositional system, and is used here only to demonstrate the morphology (plan view) of a braided river.
Figure 29. Plan view of a braided river (from Canada Map, Norman Wells 96E), Mackenzie River, N.W.T.

Sections which can be postulated at points A through E (After Eynon and Walker, 1974, and Williams and Rust, 1969) will show comparable lateral variations to those recorded at various locations throughout the mine (Fig. 30).

Figure 30. Hypothetical cross-sections which might be found at points A through E.
Furthermore if the cyclic shifting of the main channel through time is then postulated, we may envision a vertical sequence recording both deposition and erosion (Fig. 31). The combined vertical and horizontal facies relationships shows us a complex interfingering of facies both along (parallel to flow) and across (perpendicular to flow) a braided river channel. This compares with the facies relationship diagram in Figure 27.

Figure 31. Hypothetical section showing cyclic shifting of main channel deposits through time.

The Matinenda formation in the mine is represented mainly by the conglomeratic fraction. In order to isolate this facies in our model a block diagram (Fig. 32) shows the relative position of the coarse and fine grained well-packed conglomerates in the braided river model. The block diagram.
shows clearly the diachronous nature of the conglomerate.

Figure 32. Block diagram showing diachronous nature of the conglomerate ore zones. Time-lines are horizontal.

Figure 32 may be compared to Figure 33 (an actual cross-section of the mine, constructed in an attempt to highlight larger scale sedimentological features. The section shows
the impersistent nature of the conglomeratic zones (reefs),
as even on a large scale they can still be seen to inter-
finger with the subarkoses. Furthermore, these conglomeratic
sheets are repeated many times through the vertical sequence,
reflecting the build up of the sedimentary-pile. Although
this actual section does not exactly run perpendicular to
the paleocurrent direction (the section runs N-S whilst flow
was NW-SE), they both show the same "stepping up" feature.

This observation is of interest because it demonstrates
that the so-called ore reefs are not laterally persistent
beds, and that the overall mine plan is not confined within
a single, instant-in-time, stratigraphic interval.
Figure 33. North-South cross-section through the mine (exact position unknown), showing the diachronous nature of the A and B ore zones (from Denison Mines' files). D, E and F zones are 100 to 200 feet higher (stratigraphically). C zone is present at Quirke Mine.
Paleogeography and Paleoclimate

It has already been shown that this river's source probably lay to the NW; the New Quirke Mine property lies therefore, "upstream" of Denison Mines Ltd. The author observed that granite fragments were also never found at Denison, but commonly encountered at New Quirke, this examination of the lithologies at the New Quirke Mine supports the "upstream" nature of the rocks at this mine. Thin section study of samples taken from Denison Mines Ltd. (Appendix I) suggests a dual source; the quartz and feldspars of the matrix is of local, igneous origin (Trudell, 1977), whilst the large, well-rounded quartz pebbles obviously originate from a more distant source (Pettijohn, 1975), probably metamorphic. A large area of metaquartzite, older than the Matinenda formation, lies approximately 200 miles to the NW of Elliot Lake, and might be considered as a possible source for these quartzite pebbles. Uranium and pyrite were deposited as Aphebian palaeoplacers, accumulated mainly in detrital heavy minerals under anoxic atmosphere. The ozyatmoverion occurred approximately 2200 million years ago (McMillan, 1977), after the deposition of the conglomerate near the base of the Matinenda formation.

Pre-Huronian erosion and lower Huronian deposition possibly occurred under reducing atmospheric conditions and it is probable that much of the deposition took place in a cold climate (Robertson, 1968).
ECONOMIC GEOLOGY

Various theories for the origin of the uranium have been postulated since the discovery of this deposit. The three major theories are the epigenetic, the syngenetic and the remobilized syngenetic theories. Davidson, (1965), Derry, (1960), and many others advanced the epigenetic theory. They believe that hydrothermal solutions travelled along faults and dykes, and were deposited in the porous and permeable conglomerate. But unless faults and dykes actually cut the conglomerates, flow of solutions to them through the sands would be limited, and, in fact, the sands themselves should be somewhat mineralized.

Adams and Weaver, (1958), Roscoe, (1968) and others advanced the syngenetic theory. They believe in the theory that both uraninite and brannerite are known to occur as detrital minerals, but that it is unlikely that much uraninite survives present-day weathering; they would have been more likely to have survived under non-oxidizing conditions that appear to have prevailed during early Archean weathering. High ferrous/ferric ratios, rarity of limestones and scarcity of hematite all point toward an anoxic atmosphere in pre-Gowganda time.

Some of the pyrite and uranium minerals are present as euhedral minerals; for this reason Robertson, (1968) and many others believe that some of the metallic minerals were remobilized by diagenetic processes. This however can support both the syngenetic and the remobilized theory.
From examination of the relevant lithologies it would seem that the pyrite is detrital. It is generally proportional in size to the quartz pebbles, and could be expected to behave similarly under certain hydraulic conditions. Close examination identifies euhedral pyrite within the slightly recrystallized subarkose (Appendix I). Theis, (1976) also noted a similar correlation between the uranium bearing minerals and pebble grain size, and this would seem to suggest that both the pyrite and the uranium minerals (uraninite and brannerite) are of placer origin. Based on previous studies by different authors mentioned above and observations of the Denison Mines' ore body, the author supports the modified placer origin of the uranium and the pyrite.

The depositional model presented in this thesis should provide a powerful exploration tool. Theis (1976) shows that the highest grade ore is found within the coarser, better packed conglomerate. Using this theory and using the model presented in this thesis, it should be possible to devise a system for pinpointing the higher grade ore. As demonstrated earlier, it is possible to trace the lateral extent of these bar deposits (Fig. 31). Although it is difficult to predict where another bar will be located, owing to the erratic nature of the main river channel, identification of bar edge deposits (loosely packed conglomerate and pebbly subarkose, Lithology 3 and 4) can help in locating previously undiscovered bars.
Consideration of the sedimentology of the deposit may also help in following the highest grade ore within the bar core (coarse and finer well-packed conglomerates, Lithology 1 and 2), rather than straying into the economically poorer side-channel deposits.

The exploration flow-chart (fig. 34) shows all the possible ways to get to and from the ore zone (Lithologies 1, 2 and 6). All lateral and vertical (perpendicular to bedding) variations recorded in the mine are included.

Figure 35 shows five different ways mining may head out of an ore zone. Two of the pathways lead to other ore pockets; the other three, lead away from the ore or even out of the braided river system itself (defined as "out" in Figure 34 and 35). Whilst numerous other mining pathways are possible, only the five illustrated in Figure 35 are significant. All pathways are illustrated heading out from a bar core for the sake of consistency.

The first example starts from a typical braided river bar (this includes fine grained sediment interfingered with the bar conglomerate). Lithology 4 (pebbly sandstone) is then encountered laterally, which itself extends laterally into a loosely packed conglomerate (Lithology 3). As mining continues laterally or vertically (perpendicular to bedding plane), Lithology 6 is intercepted. This shallow braided facies may or may not be mineralized. From this
Figure 34. Exploration Flow-chart for use within the Denison Mine’s ore zone. Flow-chart depicts lithologies likely to be encountered while drilling in one direction. Flow-chart operates in either direction.
Figure 35: Five possible mining pathways showing vertical and lateral transitions. For legend see figure 34.
point on mining may advance vertically to reach another braided bar.

The second and third pathways start in the same fashion but have different conclusions. In both cases a barren subarkose is encountered moving laterally or vertically from the bar core. Continuing perpendicular to bedding (vertically) the shallow braided facies (Lithology 6) will be reached. Further mining may encounter barren ground above this unit, or, of lesser probability, reach a new mineralized bar.

The last two pathways represent cases of isolated braided bars, i.e., bars separated by distances making mining uneconomical. The fourth pathway exemplifies a typical isolated braided bar overlain by great thicknesses of subarkose. The last pathway is the typical lateral variation away from an isolated braided bar, where the conglomerate becomes less and less packed as the braided river system is left.

Scale has been purposefully omitted from the exploration flow-charts as more work is needed before quantifying the theory presented in this thesis.

The size of the braided bars and the relative distances between them depends on the site of deposition within the braided river system (Eynon and Walker, 1974). Near the head of the braided river, near Quirke Mine and the N.W. corner of Denison Mine, the braided bars are numerous, and tend to be large and coarse grained (p. 63). Thus, the
first two pathways of figure 35 may be repeated at numerous intervals before leaving the braided river system. Downstream, however, the distances between individual bars increase (laterally and vertically, p. 63), resulting in the configuration shown by the last three pathways. In this region the vertical continuation of mining may prove uneconomical, while lateral variations may still be pursued.

Owing to the erratic nature of any rivers' courses, maintaining a tight control over these ore bodies would involve a great amount of drilling, although not necessarily more than the amount being drilled at present. Differences in density between braided bars and the surrounding subarkose and the probable differences in conductivity, porosity, and permeability may warrant the use of certain geophysical tools to aid in the search for these ore-bearing bars.

As confidential ore-grade values were not available for publishing further testing of the theory presented in this thesis was not possible. It would, however, make an excellent project for the future.
CONCLUSIONS

Six main lithofacies have been identified in the rocks exposed by mining at Denison Mines Ltd: a coarse grained moderately well-packed conglomerate; a medium grained moderately well-packed conglomerate; a loosely packed conglomerate; a pebbly subarkose; a subarkose; and an interbedded well-packed conglomerate and subarkose acting as one unit.

Various environments are characterized by vertical and lateral transitions of the rock types mentioned above: a bar core facies, characterized by a coarse grained, upward fining basal gravel; a bar front facies with coarse grained gravels and large scale trough cross-beds; a bar top facies composed of undulatory bedded gravels (channeling) or crude horizontal stratification, imbrication of clasts; and finally the shallow braided facies made up of cross-bedded gravels resting on an erosional contact overlain by sands and gravels resting gradationally upon lower cross-bedded gravels or upon the bar top.

These same environments are also characterized by vertical transitions of the above mentioned lithofacies: a coarse conglomerate fining upward and containing sand lenses, typical of the bar core facies of a braided river; this being overlain by a bar top lithofacies, the loosely packed conglomerate; overlain by the shallow braided lithofacies composed of interbedded medium grained moderately well-packed conglomerate and
sandstone; finally a reworked facies characterized by a pebbly sandstone scarcely encountered in the Matinenda formation of the mine.

Study of these lithofacies, supported by a statistical treatise, and study of the primary sedimentary structures, indicate that these sediments were deposited by a braided river.

The ore bearing conglomerate is thus deposited as bar and lag deposits, interfingerling with lower grade, finer-grained side channel deposits. The uranium and pyrite is believed to be deposited at the time of sedimentation and later slightly remobilized by diagenetic processes.

Careful examination of mine headings and drill core for lateral variations in grain size and sedimentary structures, using the exploration flow-chart as an exploration tool, may prove useful in searching for a higher grade ore conglomerate.
APPENDIX I

Thin section descriptions

EL-1

Section through black pebble, 6 cm in diameter. The pebble has a finely laminated appearance, and is composed of granoblastic quartz. The pebble is clearly of metamorphic origin. Its pre-metamorphic origin is uncertain, though a siltstone may be possible.

Laminae are composed of alternating bands rich in "spherical" trails of sub-microscopic opaques (or holes) and cleaner quartz. They appear to have been formed by the migration of these minerals (?) from a central point (Figure 4.)
This quartz pebble is clearly of metamorphic origin (granoblastic polygonal quartz). There is a tendency for pyrite and monazite to concentrate around the bigger quartz pebble.

**Composition of the matrix:**

Point counting along traverse, shown above (250 counts)

<table>
<thead>
<tr>
<th>Composition</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>quartz</td>
<td>141</td>
<td>56.4%</td>
</tr>
<tr>
<td>feldspar</td>
<td>79</td>
<td>31.6%</td>
</tr>
<tr>
<td>pyrite</td>
<td>25</td>
<td>10.0%</td>
</tr>
<tr>
<td>monazite</td>
<td>5</td>
<td>2.0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>250</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

**Size**

Average size of pyrite: 0.5 to 1 mm
Average size of quartz: 0.5 to 2 mm
Average size of monazite: 0.5 to 0.7 mm
Composition of the matrix (250 counts).

<table>
<thead>
<tr>
<th>Composition</th>
<th>Counts</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>quartz</td>
<td>155</td>
<td>62.0%</td>
</tr>
<tr>
<td>feldspar</td>
<td>80</td>
<td>32.0%</td>
</tr>
<tr>
<td>pyrite</td>
<td>15</td>
<td>6.0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>250</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

Size

Average size of quartz is 2 mm

Point count inside darker pebble

<table>
<thead>
<tr>
<th>Composition</th>
<th>Counts</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>quartz</td>
<td>160</td>
<td>80.0%</td>
</tr>
<tr>
<td>pyrite</td>
<td>40</td>
<td>20.0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>200</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

Most pyrite grains are located at multiple grain boundaries. Quartz is equigranular (approximately 0.02 mm).
EL-4 (subarkose, Lithology 5)

Composition (whole rock)

<table>
<thead>
<tr>
<th>Composition</th>
<th>Counts</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>quartz</td>
<td>169</td>
<td>68.0%</td>
</tr>
<tr>
<td>feldspar</td>
<td>74</td>
<td>20.0%</td>
</tr>
<tr>
<td>pyrite</td>
<td>5</td>
<td>2.0%</td>
</tr>
<tr>
<td>monazite</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>rutile</td>
<td>trace</td>
<td>trace</td>
</tr>
</tbody>
</table>

Total 250 100.0%

Size
Average quartz size: 2.0 to 4.0 mm

Shape
Quartz: well rounded to very well rounded
Monazite: very well rounded
Pyrite: subrounded to euhedral (cubic)
EL-3  (fine-grained conglomerate, Lithology 2).

Composition (whole rock)

<table>
<thead>
<tr>
<th>Composition</th>
<th>Counts</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>quartz</td>
<td>196</td>
<td>78.5%</td>
</tr>
<tr>
<td>feldspar</td>
<td>43</td>
<td>17.6%</td>
</tr>
<tr>
<td>pyrite</td>
<td>10</td>
<td>4.0%</td>
</tr>
<tr>
<td>monazite</td>
<td>1</td>
<td>0.5%</td>
</tr>
<tr>
<td>Total</td>
<td>250</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Size

Quartz pebbles, long diameter: 4.0 to 15 mm
APPENDIX II

PHOTOGRAPHY

Apart from the battery operated light on the miner's helmet, there is no illumination at all in a quiet mine heading. To be able to take reasonably sharp pictures one must have a good camera, preferably a Single Lens Reflex, a sturdy tripod, an electronic flash and a very fast film (ASA 400 is quite sufficient). To outline details of grain size the picture should be taken 2 to 2½ feet away from the wall; the wall should be wet to enhance contrast. A single operator is sufficient: with camera set on tripod, and the object clearly in focus (using head lamp), shutter speed is set at "B" and diaphragm set according to the electronic flash information. The headlamp is switched off, and while everything is absolutely dark, the shutter release is pressed open. The flash is aimed at 45° to the wall. Leaving the shutter open, the flash is aimed again on the other side at 45°. The shutter is then released.

The 45° angle prevents too much reflection because of the wet surface, and gives a high relief to flat objects. The author found that even with a high quality electronic flash, the picture would be of poor quality if taken from ten feet or more away. Furthermore, the further the camera is from the object the more flashes are needed.
Section Drawing

Where photography was difficult, and for very long geologic sections (50 to 150 ft.) drawing on square lined paper was necessary. The wall is pre-measured (using spray paint) in sections of 5 feet in length and each of these sections is drawn from the floor to about 10 feet in height. Washing the walls was necessary (making it practically impossible to work if water was not available) as blasting causes sand to deposit on the walls obscuring detail.
APPENDIX III

Geological sections drawn from the mine (slightly shortened for presentation here) and their location in the mine.
Plan view of Denison Mines' active mining level (1977) and location of geological cross-sections.
Section E-3
Heading 28311 South-Wall
Wall strike N70E
Section E-4 North Wall
Heading 283° 10' North Wall Strike 89° 0' E
Section E-9 (D)
Heading 26211 North Wall
Wall strike N150E
Section E-9 (A)
Heading 26986 South Wall
Wall strike N110°E
Section E-13 (A)
Heading 26050 South Wall
Wall strike N00°E

5 ft.
Section E-14
Heading 26206 South Wall
Wall strike N100°E
REFERENCES


DAVIDSON, C.F. 1959. Further observations on uraniferous conglomerates, a discussion. Econ. Geol., vol. 54, pp. 1316-1320.


VITA AUCTORIS

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