BULLETIN 83

STRATIGRAPHY, PETROLOGY, AND GENESIS OF THE ELLIOT GROUP, BLIND RIVER, ONTARIO, INCLUDING THE URANIFEROUS CONGLOMERATE

P. J. Pienaar

1963

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By

P. J. Pienaar

DEPARTMENT OF
MINES AND TECHNICAL SURVEYS
CANADA

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PREFACE

The discovery of important uranium-bearing conglomerates in Blind River area led to the beginning (in 1954 by the Geological Survey of Canada) of a detailed study of the deposits and their geological relationships. One phase of this study was assigned to the author, under the supervision of S.M. Roscoe, and was written up as a doctorate thesis. The present report, which is extracted from the thesis, deals with the stratigraphy, sedimentary petrology, facies changes, origin, and depositional features of the strata containing the ores and the overlying strata. It supplements reports being prepared by Roscoe.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, December 15, 1960

Bulletin 83—Die Stratigraphie, Petrographie und Entstehungsgeschichte der Elliot-Lake-Gruppe Blind River (Ontario) mit Einschluß des uranhaltigen Konglomerats. Von P. J. Piehaar

Bericht über eine eingehende Untersuchung der Stratigraphie, der Sedimentpetrographie, der faziellen Wechsel, der Entstehung und der Ablagerungsverhältnisse des uranhaltigen Konglomerats.

Бюллетень 83 — Стратиграфия, петрология и генезис группы озера Иллиот, Слепая река, Онтарио, включая ураниеносный конгломерат. Автор: П. Дж. Пиенаар.

Отчет о подробном исследовании стратиграфии, осадочной петрологии, смены фаций. генезисе, и особенностях отложений ураниеносного конгломерата.

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STRATIGRAPHY, PETROGRAPHY, AND GENESIS OF THE ELLIOT GROUP, BLIND RIVER AREA, ONTARIO

Abstract

The Elliot Group, previously considered to be part of the Mississagi Formation, includes the lowermost Huronian sedimentary rocks in the Quirke Lake syncline, Blind River area, Ontario, and contains the uranium deposits.

The group consists of a lower formation (Matinenda), and an upper formation (Nordic). On the south limb of the syncline, the Matinenda Formation is subdivided into a lower and an upper member.

A southeastwardly direction of detrital transport is inferred from the crossbedding and gravel fabric and agrees closely with isopachal trends and the general direction of size diminution.

The lower Matinenda Member consists mainly of subarkoses and pyritic, uraniferous, oligomictic conglomerates. Rocks of the member appear to be normal sediments of fluvial origin. Distribution and thickness are related to base configuration, and several separate trough-like accumulations are present. Ore conglomerates are confined to the thick 'valley-filled' accumulations. The ore zones are comprised of interlacing multiple lenticular sedimentary units with uranium and thorium preferentially concentrated in well-packed conglomerate units. There is no apparent relationship between ore and secondary structures or alterations.

The lower member was locally eroded prior to deposition of the upper member which was laid down by swift southeasterly flowing streams that debouched coarse gravels in wide scour channels and deposited sands marginal to these channels. The sediments were extensively winnowed in shallow water, probably near a shoreline. Transgression of the shoreline and re-working of the detritus led to formation of fine-grained equigranular quartzite at the top of the upper member.

Silts and argillite of the Nordic Formation were deposited following a northerly advance of the shoreline and the submergence of the area along the south limb of the syncline.

Résumé

Le groupe Elliot, qu'on attribuait autrefois à la formation Mississagi, comprend les roches sédimentaires huroniennes les plus anciennes du synclinal du lac Quirke, dans la région de Blind River, en Ontario, et contient les gisements d'uranium.

Le groupe se divise en une formation inférieure (Matinenda) et une formation supérieure (Nordic). Sur le flanc sud du synclinal, la formation Matinenda se subdivise en un niveau inférieur et un niveau supérieur.

On suppose que les matériaux ont été transportés à l'état détritique et suivant une direction sud-est à en juger par la stratification entrecroisée et la disposition des éléments clastiques des conglomérats; ce qui est assez conforme aux lignes isopaques et à la direction générale suivant laquelle les dimensions des éléments clastiques diminuent.

Le niveau inférieur de la formation Matinenda se compose principalement de roches subarkosiques et de conglomérats pyritiques, uranifères et oligométiques. Les roches de ce niveau semblent être des sédiments normaux

d'origine fluviale. Leur répartition et leur épaisseur se rattachent à la configuration de la surface de base, et il s'y trouve plusieurs masses distinctes en forme de bassin allongé. Les conglomérats contenant du minerai se limitent aux épaisses accumulations qui se sont formées dans des vallées. Les unités sédimentaires de forme lenticulaire qui constituent les amas de minerai sont multiples et entrelacés. L'uranium et le thorium s'y trouvent concentrés de préférence dans les bancs conglomératiques bien tassés. Il n'y a pas de relation apparente entre le minerai et les structures secondaires ou les altérations.

En certains endroits, le niveau inférieur a été érodé avant la mise en place du niveau supérieur, ce dernier résultant de cours d'eau rapides, coulant vers le sud-est, qui ont abandonné des graviers grossiers dans de larges canaux d'affouillement et déposé des sables en bordure des parois des canaux. Les sédiments ont été vannés à profusion en eau peu profonde, probablement à proximité de la ligne du rivage. La transgression de la ligne du rivage et le triage répété des matériaux détritiques ont abouti à la formation de quartzite à grain uniformément fin au sommet du niveau supérieur.

Les siltstones et l'argilite de la formation Nordic se sont déposés à la suite du déplacement vers le nord de la ligne du rivage et de la submersion de la région le long du flanc sud du synclinal.

Chapter I

INTRODUCTION

In 1953, uraniferous conglomerates were discovered in the lowermost formation of the Huronian System along the north shore of Lake Huron, 12 miles east of the town of Blind River. This stimulated widespread exploration and led to the development, 25 miles northeast of Blind River, of the largest uranium mining camp in Canada.

The Blind River uranium deposits are confined to the Huronian sedimentary rocks, which have been weakly metamorphosed and folded into a broad east-west trending syncline and anticline (*see* Fig. 1). Both the syncline and the anticline plunge gently towards the west. Except for the Pronto deposit along the south flank of the anticline, all the uranium deposits occur in the syncline, known as the Quirke Lake syncline, which lies north of the anticline. The study of the Huronian stratigraphy has been limited to six townships, 149, 150, 143, 144, 137, 138, all on the syncline.

Numerous diamond drill holes and mine openings in the Quirke Lake syncline afforded an excellent opportunity to study Huronian stratigraphy in detail. In addition, well-preserved crossbedding provides a means of studying the direction of detrital transport.

Previous Work

The recognition in 1847 of Huronian sedimentary formations north of Lake Huron is credited to Logan and Murray. During the following 60 years numerous geologists investigated and discussed the Huronian and pre-Huronian rocks. The reports of these authors have been well documented by Collins (1925)[1].

The most comprehensive data on the Huronian stratigraphy in the Blind River area are contained in a memoir published by Collins in 1925. His accurate location of the critical Huronian formations on the Blind River map-sheet played a most important part in the discovery of the uranium field.

Abraham (1953) described the geology near the Pronto Uranium Mine; Joubin (1954, 1955), Hart and Harper (1955), Young (1955), Robertson (1955), Holmes (1956 and 1958), and Pountney (1956) described features of general interest and local geology. Traill (1954) and Arnold (1954) documented the results of preliminary mineralogical investigations. A preliminary isopach map of the lowermost Huronian formation in the Quirke-Elliot Lake area was published by Roscoe (1956). A preliminary map of townships 149 and 150 by Abraham (1957) was issued by the Ontario Department of Mines. Robertson has continued mapping townships in the area since 1956.

[1] Names and/or dates in parentheses are those of references cited in the Bibliography.

The directional sedimentary structures in the lower Huronian formation in the Blind River and Bruce mines area were investigated by McDowell (1957). During the 1957 Commonwealth Mining and Metallurgical Congress, a brochure on the regional geology in the Blind River area was compiled by the mine geologists.

A preliminary account of the subsurface geology and mineralogy of the Quirke Lake-Elliot Lake area was published by Roscoe (1957a). Roscoe also proposed a revised nomenclature for the Huronian stratigraphy in the Quirke Lake syncline.

Field work on which this report is based was done during the field seasons of 1955, 1956, and 1957.

Acknowledgments

Assistance from mining and exploration organizations in the Blind River area greatly facilitated the field study.

R. Weber (1955), D. Rogers and R. M. Maclaughlin (1956), and C. R. Hudson (1957) ably assisted in the field work.

The author is greatly indebted to Dr. J. E. Hawley under whose invaluable guidance the thesis was written, to Dr. L. G. Berry who identified X-ray powder patterns, and to Drs. J. W. Ambrose, J. Usher and R. H. H. Lemon for their helpful discussions and criticisms.

Mr. G. MacDonald did the chemical and spectrographic analyses and Mr. F. Dunphy the X-ray spectrochemical analyses. Appreciation is expressed to Professor T. V. Lord and members of the Metallurgical Department, Queen's University for helpful advice and uranium analyses.

Chapter II

GENERAL GEOLOGY

The pre-Huronian basement in the Quirke Lake syncline consists of metavolcanic and metasedimentary rocks that have been invaded by granites and related rock types. Intense folding and metamorphism, and prolonged erosion of these pre-Huronian rocks preceded the deposition of the Huronian sedimentary pile. The contact between the Huronian and pre-Huronian rocks is a major unconformity, but is commonly masked by residual deposits formed prior to the deposition of Huronian rocks.

The Huronian sedimentary rocks belong to the subarkose[1], greywacke, argillite, and limestone suites, intercalated with various types of conglomerates. Some of the formations increase in thickness and vary lithologically towards the south and east. These rocks have been moderately metamorphosed and folded into a broad syncline which plunges gently towards the west. Dips range from 5 to 65 degrees but average roughly 20 degrees. Sedimentary rocks attain a maximum thickness of approximately 5,000 feet in the central part of the syncline. Dykes and sill-like bodies of diabase and lamprophyre invaded the Huronian and pre-Huronian rocks. Steeply dipping reverse and normal faults, as well as gently dipping thrust faults, traverse the Huronian rocks in the syncline.

Classification of Huronian Sedimentary Rocks

Collins (1925) divided the Huronian rocks into a lower Bruce Series, and an upper Cobalt Series which he believed to rest unconformably on the Bruce Series. A tabulation of Collins' classification is given in Table I.

In recent years a wealth of detailed information on the Huronian stratigraphy was obtained from drill-holes and mine openings in the Quirke Lake syncline. Such data clearly indicated the need for revision of the stratigraphic terminology, especially in the lowermost Mississagi Formation. The radioactive conglomerates in this formation made it imperative that diagnostic sedimentary units within the formation should be recognized and defined. Thus, Roscoe (1957a) has proposed the tentative new system of nomenclature that is followed in this presentation.

A slightly modified version of Roscoe's tentative classification is shown in Table II, and is compared with that of Collins in Table III. Essential changes in the terminology are the redefinition of the base of the Mississagi Formation, introduction of new formational names for units below the redefined Mississagi Formation, and the introduction of new group terms.

[1] Subarkose is a term used synonymously with feldspathic quartzite.

Table I

Collins' Classification of Huronian Formations

Series	Formation	Lithology
Cobalt	Upper white quartzite and cherty quartzite	Mainly quartzite and minor limestone
	Banded cherty quartzite	Fine-grained quartzite, chert, and minor limestone
	Lorrain	Quartzite and jasper conglomerate
	Gowganda	Boulder conglomerate, greywacke, and impure quartzite
	Unconformity	
Bruce	Serpent	Quartzite
	Espanola	Espanola Limestone Espanola Greywacke Bruce Limestone
	Bruce Conglomerate	Boulder conglomerate
	Mississagi	Quartzite, argillite, and conglomerate

The main reason for the introduction of new group terms is the cyclic repetition throughout the syncline of polymictic boulder conglomerates[1], overlain by fine-grained sedimentary rocks, overlain in turn by coarse-grained clastic rocks. This feature, and the knife-sharp contacts of the boulder conglomerates with other sedimentary rocks, clearly suggest natural boundaries, and thus warrant genetic subdivisions (Roscoe, 1957b).

In this presentation the Matinenda Formation along the south limb of the syncline is tentatively subdivided into two members, an upper and lower. This division is desirable because of the sharp contact between the members and their lithological dissimilarities. Based on lithological similarities, rocks in the north limb have been correlated with the lower member. Neither stratigraphic nor time equivalence can be conclusively demonstrated.

Roscoe's tentative classification has not been generally adopted in the Blind River area, although most of the stratigraphic units he mentioned are recognized and named informally. Common practice in this area is to subdivide the Mississagi Formation, as defined by Collins, into three divisions: upper, middle, and lower. These subdivisions have been elevated to formational rank, but their exact limits have not been formally defined. Some authors, as McDowell (1957) and in the

[1] Conglomerates containing a mixture of different types of rock fragments.

brochure (1957), include the Nordic Formation in the middle Mississagi whereas Abraham (1957) tentatively suggested that the polymictic boulder conglomerate be defined as the base of this formation. Whatever system of nomenclature is followed, the recognition of the argillite-greywacke suite below the polymictic boulder conglomerate at the base of the Whiskey Formation is of utmost importance, especially in areas where the Matinenda Formation may be absent. In such circumstances the underlying argillite and greywacke might be interpreted erroneously as of pre-Huronian age.

If the Huronian rocks in the Quirke Lake syncline are defined as the type section, as was suggested by Roscoe (1957a) and Thomson (1957), a genetic classification is desirable. Any classification that tends to group genetically different sedimentary units will only reduce the value of the type section.

Pre-Huronian Rocks

The oldest rocks in the Quirke Lake syncline area consist predominantly of metavolcanic rocks, metasediments, and meta-gabbro. Age relationships between the various members of this assemblage are uncertain, but evidence from drill-cores suggests that the metavolcanic and metasedimentary rocks are interbedded. These rocks have been intensely metamorphosed, folded, and intruded by granite and related rock types. Prolonged erosion has removed most of the metavolcanic and metasedimentary rocks and only infolded remnants are found in the pre-Huronian basement.

Distribution and Topography

The vast area of pre-Huronian rocks surrounding the Quirke Lake syncline are composed mainly of granites and allied rock types.

Remnants of metavolcanic rocks and meta-gabbro occur along the north rim of the syncline, north of the inlet to Quirke Lake, and north and west of Quirke mine (*see* Fig. 1). A broad belt of metavolcanic and metasedimentary rocks occurs along the south rim of the syncline and extends from south of Nordic mine to the nose of the syncline at Whiskey Lake.

The northwesterly extension of this broad belt of metavolcanic rocks under the cover of the Huronian rocks has been confirmed by drill-holes in the syncline. The north edge of this metavolcanic belt extends in a northwesterly direction from Whiskey Lake, to the east end of Teasdale Lake. The south edge of the belt has a similar trend northwest from Nordic mine. Thus a belt of pre-Huronian metavolcanic and metasedimentary rocks underlies most of the syncline.

The broad belt of metavolcanic rocks is flanked by granite and in some places invaded by tongue-like bodies of granite. Granite however underlies most of the Huronian rocks around Elliot Lake and the area to the southeast, and extends northeast to a small lake 1,500 feet west of Stanleigh mine. Another large irregular granite mass underlies Huronian rocks in the northeast part of Quirke Lake. This granite underlies the northeastern part of Quirke Lake, east of Panel mine and northeast of Can Met mine, as well as Teasdale Lake. Several small granite

Table II

Table of Formations, Quirke Lake Syncline

		Group	Formation	Member	Thicknesses in the syncline: North Limb	Thicknesses in the syncline: South Limb	Lithology
CENOZOIC	Recent						Swamp deposits
	Pleistocene						Sand, gravel, clay, and glacial deposits
		Unconformity					
	KEWEENAWAN?	Diabase and lamprophyre intrusions					
	Unconformity						
		Cobalt[2]	Gowganda		Up to +2,100′	Up to 1,200′	Polymictic[1] boulder conglomerate, argillite, siltstone, greywacke, arkose, and quartzite
		Local unconformity					
			Serpent		350′–900′	0–700′	Feldspathic quartzite, subgreywacke, greywacke-polymictic boulder conglomerate
			Espanola	Espanola Limestone	400′–600′	0–550′	Siltstone—limestone; minor greywacke
				Espanola Greywacke			Greywacke, calcareous greywacke, siltstone, and intraformational conglomerates

PRECAMBRIAN	HURONIAN	Quirke		Bruce Limestone	100′–200′	80′–140′	Limestone and minor siltstone
			Bruce Conglomerate	—	50′–370′	15′–200′	Polymictic boulder conglomerate
		Hough[2]	Mississagi[2]	—	600′–1,300′	1,300′–1,750′	Feldspathic quartzite, subgreywacke, and minor greywacke
			Whiskey	—	100′–500′	500′–800′	Interbedded greywacke, argillite and siltstone. Polymictic boulder conglomerate at the base
		Elliot	Nordic		Absent	0′–280′	Interbedded argillite, greywacke, subgreywacke, siltstone, and minor feldspathic quartzite
			Matinenda	Upper member		0′–440′	Feldspathic quartzite, fine-grained, quartzite and polymictic boulder conglomerate
				Lower member	0′–350′	0′–720′	Subarkose, grit, fine-grained quartzite, radioactive oligomictic conglomerates and quasi-basal conglomerates
		Disconformity					
		Residual deposits					
		Unconformity					
	PRE-HURONIAN	Intrusive granites and allied rocks Acidic and basic metavolcanic rocks, meta-gabbro, greywacke, quartzite, argillite, polymictic boulder conglomerate					

[1]Paraconglomerates or mudstone conglomerates.

[2]This table incorporates some changes in the tentative classification initially proposed by Roscoe (1957) and used by Pienaar (1958); it represents proposals that have been approved by the Committee on Stratigraphic Nomenclature (Roscoe, 1959, per. com.). These changes include: use of Cobalt Group instead of Dunlop Group; Hough Group instead of Mississagi Group; and Mississagi Formation instead of Ten Mile Formation.

Table III

A Comparison of Huronian Nomenclature

Nomenclature of Collins		Nomenclature of Roscoe	
Series	Formation	Group	Formation
Cobalt	Gowganda	Cobalt[1]	Gowganda
Unconformity			
Bruce	Serpent	Quirke	Serpent
	Espanola		Espanola
	Bruce		Bruce
	Mississagi	Hough[1]	Mississagi[1]
			Whiskey
		Elliot	Nordic
			Matinenda

[1]See footnote, Table II.

embayments are also found in the metavolcanic belt between the inlet to Quirke Lake and Quirke mine. The outline of these granite masses is inferred from drill-hole data.

It is possible to deduce from diamond drill hole data that the surface upon which the Huronian rocks were deposited was not planar but had considerable local relief and that the most pronounced pre-Huronian topographic features were valleys along the northeast and southwest contacts of the metavolcanic belt with granite.

One of the valley-like structures extends from north of Stanleigh mine in a southeasterly direction to Nordic mine. Between Lake Nordic and Nordic mines the valley is poorly defined, due to the paucity of bore-hole data. Maximum relief is about 250 feet. Another much more poorly outlined valley-like structure occurs at Quirke Lake in the northern part of the syncline. This structure trends southeast from east of Quirke mine towards Stanrock mine. There are also indications of a topographical high between Stanrock and Can Met mines, as well as southeast of these properties. Pre-Huronian relief is difficult to estimate in this area, but appears to attain a maximum of 200 feet at Panel mine.

These valley-like structures are described later in more detail. Their distribution suggests that they were formed by the differential erosion of the granite and metavolcanic rocks. Some other Pre-Huronian valleys, however, bear no relation to the contacts between metavolcanic and granitic rocks. Such valleys are found northeast of Pecors Lake, northwest of Whiskey Lake, and south of Stintson Lake.

Deposition of the lowermost Huronian formation lithostratigraphic units was affected by these valley-like structures. It is shown in later chapters that the trend of these valleys corresponds closely with that of the isopachs of the lower Matinenda member, as well as the mean azimuth of crossbedding. This feature is further substantiated by the obvious alignment of mining properties parallel with the trend of the valleys, especially those along the border of the metavolcanic belt.

This phenomenon is easily explained. The main conglomerate beds, including ore-bearing beds, are in the lowermost 200 feet of the lower Matinenda member. These rocks, which represent the initial phase of sedimentation of the lower Matinenda member, were thus deposited most abundantly in valleys, and the producing mines are aligned along the two principal pre-Huronian valleys.

Metavolcanic and Metasedimentary Rocks

Metavolcanic rocks are the most common pre-Huronian rock-type intersected in drill-holes in the syncline. They are mainly andesitic in composition, but interbedded acidic rocks, probably lavas, have been observed in a few drill-holes.

The andesite is dark greyish green, fine-grained schistose lava with brecciated flow tops and amygdaloidal zones. Pillow lavas were observed in outcrops. The andesitic lavas consist mainly of chlorite, highly altered feldspar, epidote, quartz, white mica, calcite, and black iron oxide. The highly altered feldspar laths, up to 0.8 mm long, are approximately basic andesine, An_{40} in composition. Round and ellipsoidal amygdules, up to 20 mm across, are composed of quartz, calcite, and chlorite.

A pale grey, fine-grained, banded acidic lava, probably a rhyolite, was observed by Collins (1925) half a mile north of the inlet to Quirke Lake. Robertson (per. com.) also observed rhyolites in the pre-Huronian basement in the southern part of township 143. A dark green, coarse-grained amphibolitic metagabbro was encountered in a few drill-holes at Quirke Lake. A breccia containing angular fragments, up to 10 inches across, of basic and acidic volcanic rock with minor quartz was observed in a drill-hole on the north shore of Pecors Lake. The angular aggregate is cemented by fine-grained chloritic material, and may be a pyroclastic agglomerate interbedded with the lavas.

Pre-Huronian metasediments consist of many rock types. The most common metasediment encountered in drill-core varies from a dark grey, fine-grained, sericite schist to a green chlorite schist. These rocks were intersected in drill-holes around Stintson Lake and southwest of Nordic Lake, and are colloquially known as 'argillites'. They are composed of fine-grained, white mica, chlorite, and minor quartz, and may be argillites or tuffaceous sediments. However, in some places it is doubtful whether these rock types are of pre-Huronian age as they may represent residual deposits of the underlying lavas. Commonly the short drill-core sections provide inconclusive data.

A dark grey, medium-grained[1] greywacke is common in the pre-Huronian sedimentary assemblage, particularly in bore-holes around Stintson and Horne Lakes. This greywacke exhibits a typical, disrupted framework structure, and consists mainly of rock fragments, quartz, minor plagioclase, pyrite, and pyrrhotite grains in a matrix of white mica, chlorite, and silt-sized quartz grains. The matrix constitutes approximately 40 per cent of the total volume of the rock. Rock fragments, mainly lava and chert, appear to be more abundant than in the Huronian greywackes. The angularity of the grains, the poorly sorted nature of the greywacke, and the presence of unstable constituents, clearly indicate a 'poured in' type of deposition.

In the Can Met shafts and in drill-holes southwest of Stintson Lake, a polymictic boulder conglomerate was observed in the pre-Huronian sequence. It consists of cobbles and boulders of grey granitic rocks and volcanic rocks in a greywacke matrix.

Lean, cherty iron-formations are found in the pre-Huronian basement in the southern part of townships 143 and 138, and Collins (1925) reported remnants north of Quirke Lake. In addition, a light grey, fine-grained orthoquartzite was observed in the pre-Huronian assemblage south of Stintson and Pecors Lakes (Robertson, per. com.).

Data on the structure of the pre-Huronian assemblage are extremely scanty. Contacts, bedding, and banding, where recognizable, strike westerly and northwesterly (Roscoe, 1957a), and dips range from 45° to 75°S, NE, and N. The contact between the intrusive granite and metavolcanic rocks is commonly obscured by metasomatic assimilation.

Granitic Rocks

Most of the samples studied were selected from granitic masses occurring along the north rim of the syncline, and up to 30 miles northwest of Quirke mine (*see* Fig. 1). They were studied primarily to compare them with granitic cobbles from the Huronian polymictic boulder conglomerates.

The pre-Huronian granitic rocks are mainly hypidiomorphic and leucocratic, and vary from medium-grained to coarse-grained to porphyritic. Some gneissic

[1]A modified version of the Wentworth-Udden geometric size classification will be followed in this presentation. This has been reviewed by Pettijohn (1957a), Williams, Turner, and Gilbert (1954) and Krumbein and Sloss (1953). A quantitative definition of each grade size is as follows:

	Name of Particles	*Diameter of Particles (mm)*
Gravel	Boulders	256
	Cobbles	256 - 64
	Pebbles	64 - 16
	Small pebbles	16 - 4
Sand	Very coarse	4 - 1
	Coarse	1 - 0.5
	Medium	0.5 -0.25
	Fine	0.25-0.05
Silt		0.05-0.01
Clay		0.01

types are also present. The suite of granitic rocks investigated consisted of medium-grained, pink granite; reddish, coarse-grained to porphyritic quartz monzonites; and grey, medium-grained to porphyritic granodiorites. Modal analyses of these rocks are shown in Table IV.

The plagioclase of these granitic rocks is mainly oligoclase, ranging from An_{11} to An_{28}. It has been extensively altered to white mica. Microcline, considerably less altered than the plagioclase, is present in all the samples, but no orthoclase was recognized. Some feldspar phenocrysts are up to 20 mm across. Both patch and string perthites are common, except in one sample. The quartz grains, completely free of inclusions, are only slightly strained and exhibit myrmekitic intergrowth with oligoclase.

Most mafic minerals have been completely altered to chlorite, but partly altered biotite has been observed in two samples. Calcite occurs as an alteration product of the oligoclase, as well as in veinlets. Although epidote is essentially an alteration product of the basic oligoclase, evidence from one sample suggests a later introduction.

Table IV

Modal Analyses of Pre-Huronian Granitic Rocks (volume per cent)

	RF-44	55-54	RF-330	RF-339	RF-715	RF-1074
Quartz	29	30	17	12	32	27
Plagioclase[1]	43	35	25	52	24	32
and						
White mica	An_{12-14}	An_{10-12}	An_{18-20}	An_{26-28}	An_{10-12}	An_{16-18}
Microcline	21	23	33	13	29	32
Perthite	—	8	19	10	10	6
Chlorite	5	2	4	8	2	2
Biotite	—	—	—	1	—	P
Calcite	P	P	P	P	2	P
Epidote	—	—	1	2	—	P
Zircon	P	—	P	P	P	P
Apatite	P	P	P	P	P	P
Black iron oxides	P	P	P	P	P	P
Sphene	—	—	—	—	—	P
Allanite	—	—	—	P	—	—
Muscovite	—	—	—	—	P	—
Monazite	—	—	P	—	—	—
Pyrite	—	—	—	—	P	P

P—Designates minor quantities.
[1]Plagioclase extensively altered to white mica.
Results adjusted to the nearest one per cent.

Accessory minerals include black iron oxides, apatite, zircon, pyrite and, rarely, sphene, allanite, and monazite.

These granitic rocks were also chemically analyzed, and the results are tabulated in Table V. Both quantitative and qualitative spectrographic analyses of the trace elements are shown in Table VI.

Although the silica content may differ by as much as 10 per cent, this suite of pre-Huronian granitic rocks belongs to the clan of silica-rich rocks. They also vary from essentially potash-rich with a low lime content, to soda-rich rocks with a higher lime content. However, these variations are common in any differentiated batholith.

The alumina content of the pre-Huronian granitic rocks corresponds with the average of 15.66 per cent given by Nockolds (1954) for 137 granodiorites. The somewhat higher alumina content of RF-339 may be attributed to extensive alteration of the plagioclase to white mica. The rubidium content of these rocks ranges from 50 ppm to 360 ppm, but averages 159 ppm. This average agrees with the average rubidium content of 170 ppm reported by Horstman (1957) for 66 granitic rocks. However, the K:Rb ratios are not constant and vary from 149 to 640. This may be a significant feature, but the number of analyses is too small to draw any conclusions. The remaining elements show no diagnostic variation.

Table VI clearly shows the strikingly low trace element content of the pre-Huronian granitic rocks. Of the elements detected, only chromium varies from less than 9 ppm to 51 ppm. This variation, however, has no significant affiliations and the chromium is probably present in the chlorite and the micas. Lead is probably present in the potassium minerals. Vanadium, silver, copper, nickel, cobalt, tin, boron, beryllium, and molybdenum are either absent or present in insignificant amounts.

Table V

Chemical Analyses of Pre-Huronian Granitic Rocks (per cent)

	RF-44	55-54	RF-330	RF-339	RF-715	RF-1074	A-1
SiO_2	71.72	74.61	69.58	64.35	72.72	69.87	70.14
Al_2O_3	15.07	14.80	16.00	17.47	14.50	15.30	15.66
Fe_2O_3	1.24	0.79	1.23	2.84	1.76	1.40	0.77
FeO	1.18	0.40	0.56	2.15	0.35	0.45	2.14
MgO	0.85	0.19	0.31	1.66	0.16	0.22	1.08
CaO	0.63	0.78	1.06	3.10	0.88	0.88	2.40
Na_2O	4.41	4.15	3.45	5.25	2.93	4.18	4.20
K_2O	3.20	3.98	6.79	2.00	5.10	5.40	2.08
$H_2O(110°)$	0.12	0.16	0.20	0.02	0.03	0.12	0.05
$H_2O(900°)$	0.98	0.49	0.41	1.015	0.90	0.59	0.81
TiO_2	0.29	0.15	0.12	0.78	0.11	0.18	0.24
ZrO_2	0.0086	0.0082	0.0086	0.0074	0.0071	0.0132	0.0033
MnO	0.020	0.010	0.011	0.08	0.01	0.0048	0.06
SrO	0.0062	0.005	0.014	0.028	0.005	0.0095	0.015
Rb_2O	0.0050	0.021	0.015	0.0094	0.036	0.0135	0.0105
Total	99.73	100.54	99.76	100.75	99.60	98.63	99.66

Carbon dioxide not determined
Analyses by G. MacDonald, Miller Research Laboratory, Queen's University, except A-1 from J. R. Robertson (per. com.).

Table VI

Spectrographic Analyses of Trace Elements in Pre-Huronian Granitic Rocks

A. Quantitative

	RF-44	55-54	RF-330*1	RF-339*2	RF-715	RF-1074	A-1
Cr %	0.0020	0.0051	0.0022	0.0035	<0.0009	<0.0009	0.0021
V %	0.0023	<0.0015	<0.0015	0.0019	<0.0015	<0.0015	<0.0015
Ni %	<0.0007	<0.0007	<0.0007	0.0008	0.0028	<0.0007	<0.0007
Co %	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Cu %	0.0006	0.0006	0.0003	0.0007	0.0003	0.0003	0.0006

*1 La:Sr 0.46.   *2 La:Sr 0.44

B. Qualitative

	RF-44	55-54	RF-330	RF-339	RF-715	RF-1074
Pb	FTr	S	S	S	W	M
Sn	ND	ND	ND	Tr	ND	ND
V	M	FTr	Tr	VS	FTr	FTr
Cu	S	S	M	VS	M	M
Ag	ND	FTr	ND	FTr	FTr	ND
Ni	Tr	ND	ND	S	ND	ND
Co	Tr	ND	ND	M	ND	ND
Cr	W	ND	ND	VS	ND	FTr

Elements not detected: B, Be, Mo
ND—not detected   W—weak   VS—very strong
FTr—faint trace   M—medium
Tr—trace   S—strong
Analyses by G. MacDonald, Miller Research Laboratory, Queen's University.

The detection of lanthanum in samples numbers RF-330 and RF-339 is most interesting. Lanthanum commonly occurs in zircon, apatite, allanite, and monazite. As the above-mentioned samples contain these accessory minerals in greater abundance than the other samples, the presence of lanthanum can be related to the presence of these minerals.

Although detailed field work is lacking, cursory examinations of the pre-Huronian granitic masses revealed no evidence that these rocks may be granitized sediments. Thin section studies also indicate the absence of poikilitic and replacement textures commonly observed in granitized sediments.

Geochemically, these pre-Huronian granitic rocks behave as normal igneous rocks, except for the low trace element content. If these rocks were metasomatized sediments, a larger array of trace elements may be expected. It seems more likely that the pre-Huronian granitic rocks belong to a normal igneous clan of a particular geochemical province, characterized by a low trace element composition.

It is also interesting to note that these granitic rocks are more radioactive than the normal acid igneous rocks. The average uranium and thorium contents of 27 pre-Huronian granitic rocks are 0.0011 and 0.0027 per cent respectively (Roscoe and Steacy, 1958). This is somewhat higher than the average of 0.0004 per cent uranium and 0.0013 per cent thorium given by Vinagradov (1954) for granitic rocks.

Residual Deposits on the Pre-Huronian Surface

As previously stated, the contact between pre-Huronian and Huronian rocks is marked by a transition zone of residual deposits or paleosol. This paleosol has been described by Collins (1925), Roscoe (1957a), and McDowell (1957), and represents the weathering products resting on the pre-Huronian surface prior to the deposition of the Huronian sediments.

The paleosol varies in thickness from a few inches to 50 feet and also changes with the character of the underlying basement rock. In the field the paleosol is more readily recognized on a granitic terrain, where it also attains a maximum thickness. Commonly a granite grades upward into a whitish rock that retains a granitic texture but is characterized by the lack of mafic constituents. Close to the Huronian contact the whitish rock grades into a greenish sericitic rock with a perceptible clastic texture. In contrast to the slightly altered plagioclase of the granite, plagioclase in the lower part of the paleosol is extensively replaced by white mica. In the upper part of the paleosol the plagioclase is virtually replaced completely by white mica. Microcline, a more stable mineral, is only partly replaced by white mica in the upper part of the paleosol. The final product, a coarse-grained, greenish sericitic rock, exhibits a typical disrupted framework texture; angular microcline and quartz grains floating in a sea of white mica. The white mica may have been an original clay mineral that recrystallized during metamorphism (Roscoe, 1957a) and/or hydrothermal activity. The paleosol passes upward into stratified Huronian sedimentary rocks.

The residuum overlying the metavolcanic rocks is much thinner than the granitic paleosol and in places it is unrecognizable. A dark green, fine-grained massive 'argillite', mainly composed of chlorite and white mica, is, however, present in many places. As stated before, it is often difficult, especially in drill-core, to tell whether this rock is actually a paleosol or a pre-Huronian metasediment.

The original granite and the paleosol were chemically analyzed, and the results are shown in Table VII. The compositional changes between these two rocks are graphically plotted on the 'straight-line' diagram of Leith and Mead (1915) (*see* Fig. 2). A 'straight-line' diagram is constructed by dividing the percentage of each constituent in the granite by its percentage in the paleosol, and multiplying the quotients by 100.

It is evident from Figure 2 that silica, magnesia, potash, and zirconium remain nearly constant. The near constancy of these four oxides may be used as a basis from which to compare the relative gains and losses of the other oxides. All constituents to the left of these four oxides show relative gains, whereas those

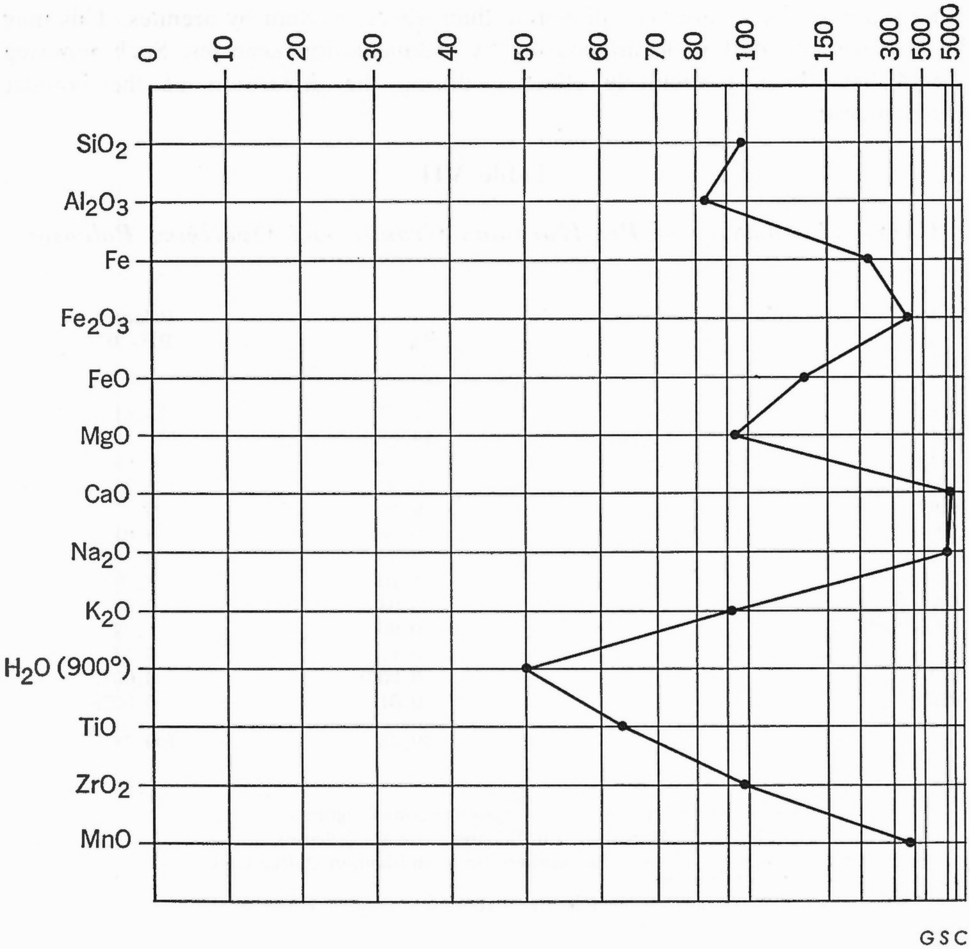

FIGURE 2. Differences in composition of granite and derived paleosol.

falling to the right represent relative losses. Thus, soda, lime, manganese, total iron, ferrous iron, and ferric iron were lost, and water, titanium, and alumina were gained.

The relative losses of mobile oxides, such as lime, soda, and manganese, may be attributed to weathering processes during the formation of the paleosol. However, the loss of total iron is peculiar and may imply weathering of the granite under reducing conditions.

It is generally recognized that in weathering alumina may remain reasonably constant. In this event, silica, magnesia, potash, and zirconium would all have suffered a slight loss relative to alumina. The slight loss of magnesia and potash, if any, is, however, not unusual in weathering of granitic igneous rocks.

The paleosol is overlain by arenites and basal conglomerates of the Matinenda Formation and, in some localities, by the boulder conglomerate of the Whiskey Formation. The paleosol varies considerably in thickness and appears to be thinner where overlain by boulder conglomerate than where overlain by arenites. This may be attributed in part to local scouring by sedimentation agencies. Such scouring would have been particularly effective during the deposition of the boulder conglomerate.

Table VII

Chemical Analyses of Pre-Huronian Granite and Overlying Paleosol

	Granite RF–715	Paleosol RF–707
SiO_2	72.72	74.61
Al_2O_3	14.50	17.30
Fe_2O_3	1.76	0.62
FeO	0.35	0.25
MgO	0.16	0.17
CaO	0.88	0.019
Na_2O	2.93	0.16
K_2O	5.10	5.59
H_2O (110°)	0.03	0.09
H_2O (900°)	0.90	1.78
TiO_2	0.11	0.17
ZrO_2	0.0071	0.0072
MnO	0.01	0.0029
Total	99.46	100.78

RF—715 41 feet below the Huronian—pre-Huronian contact, granite.
RF—707 1 foot below the Huronian—pre-Huronian contact, paleosol.
Both samples from a bore-hole on the northern tip of an island in Quirke Lake, northeast of Can Met mine.
Analyses by G. MacDonald, Miller Research Laboratory, Queen's University.

Huronian Sedimentary Rocks

Elliot Group

This group (*see* Table II) comprises all formations that unconformably overlie the pre-Huronian rocks and underlie the polymictic boulder conglomerates at the base of the argillite-greywacke suite. It is subdivided into two formations: a lower, Matinenda, and an upper, Nordic. The group has been the subject of special study and is discussed in Chapter III.

Hough Group

This group by definition includes all sedimentary units between the base of the polymictic boulder conglomerate, which underlies the main argillite-greywacke suite, and the base of the Bruce boulder conglomerate. The Hough Group is subdivided into a lower Whiskey Formation, and an upper Mississagi Formation. The Whiskey Formation consists of a basal polymictic boulder conglomerate and interbedded argillite, siltstone, and greywacke, and the Mississagi Formation (redefined) is essentially composed of arenites. The contact between the two is gradational.

In the Quirke Lake syncline, the Hough Group thickens from 650 feet at Quirke mine in the north, to 2,400 feet in the southern part, north of Elliot and Flying Goose Lakes. It is present throughout the Huronian sequence in the syncline.

Whiskey Formation

This formation increases in thickness at an average rate of 100 feet per mile, from 100 feet at Quirke mine in the north to 750 feet near Stintson Lake in the south.

The Whiskey Formation can be subdivided into two members: the polymictic boulder conglomerate at the base, and the argillite, siltstone, and greywacke member.

Polymictic Boulder Conglomerate

This unstratified boulder conglomerate, a most reliable horizon marker in the lower Huronian sequence, occurs at the base of the Whiskey Formation throughout the syncline. It has been traced west for 30 miles, and from descriptions by Collins (1925) it appears to be much more widespread.

In places in the northern part of the syncline this conglomerate overlies the Matinenda Formation, whereas in other places it rests directly on the pre-Huronian basement (*see* Fig. 3). Isolated remnants are found on the pre-Huronian granite slopes north of Quirke Lake. In the southern part of the syncline it commonly overlies the Nordic Formation, but in some places it rests on the Matinenda Formation. The transgression of this conglomerate across lower Huronian lithological units was first described by Roscoe (1957a). The boulder conglomerate is characterized by unusually sharp contacts.

Although the thickness of this boulder conglomerate ranges from 6 inches to 230 feet, it is commonly between 20 and 50 feet. It attains a maximum thickness northwest of Stintson Lake, where conglomeratic layers are interbedded with beds of greywacke, siltstone, and subgreywacke. It is strikingly thinner in the Consolidated Denison and Quirke mines area, where it overlies the thickest succession of the Matinenda Formation (Roscoe, 1957a). South of Whiskey Lake this conglomerate is only 6 to 12 inches thick, and is actually a coarse-grained pebbly greywacke.

The Whiskey boulder conglomerate is composed of a heterogeneous assemblage of boulders up to several feet across, cobbles, and pebbles randomly dispersed in a greywacke-siltstone matrix. These rudaceous components are mainly rounded, and consist of pink and grey granitic rocks, quartz, chert, metavolcanic rocks and rarely, quartzite. Percentages of each pebble-type vary from place to place. However, where the conglomerate is thin most pebbles are quartz, rarely granite or other varieties. Texturally, it is an ill-sorted, loosely packed conglomerate and in some places actually a conglomeratic greywacke.

The matrix of the conglomerate is mainly a dark grey, medium- to fine-grained, poorly sorted greywacke. In the upper part of the conglomerate the matrix is commonly a siltstone. Subrounded to subangular sand- and silt-sized clastic grains consist of quartz, plagioclase, rock and chloritic fragments, microcline, minor chert and muscovite, suspended in an aggregate or matrix[1] of fine white mica and chlorite. Disseminated pyrite is abundant, but black iron oxides are rare. This conglomerate is also slightly radioactive, and the autoradiographs examined indicate that monazite and zircon are the radioactive minerals.

In thin sections examined, pronounced hydrothermal effects are conspicuously absent. Only later calcite veinlets were observed, cutting across pebbles as well as matrix. The contacts between pebbles and matrix are sharp and completely devoid of replacement embayments. The plagioclase feldspar in the granite pebbles is more altered than that in the conglomerate matrix. This would suggest that the pebbles suffered a certain amount of alteration prior to deposition. In all the Huronian sedimentary rocks cataclastic effects predominate over any other changes, except recrystallization. Quartz grains show undulatory extinction and there is abundant evidence for dynamic crushing. These effects are attributed to folding and faulting.

The significance of this boulder conglomerate was recognized by Roscoe (1957b), and forms the basis for his revision of the lower Huronian stratigraphy. McDowell (1957), however, challenged the reliability of the boulder conglomerate as a marker horizon and a reference plane for stratigraphic classification. He suggested that its areal extent is unknown and it merely represents a time-rock unit. It is difficult to reconcile these objections with the present data. As previously stated, this conglomerate is remarkably widespread and no evidence was found in drill-core to suggest that it occurs at different stratigraphic levels. Furthermore, its presence throughout the syncline represents the initial phase of a sedimentation that covered the entire syncline. All the earlier Huronian sedimentary members were restricted to local areas. The above-mentioned features must have genetic connotations that warrant use of the conglomerate for stratigraphic subdivision.

The origin of the boulder conglomerate at the base of the Whiskey Formation is unusual and uncertain. It is characteristic of the blanket type of polymictic conglomerates occurring in cyclic repetition throughout the Huronian sequence. These conglomerates are also noted for their sharp contacts with associated subarkoses, argillites, and greywackes. Furthermore, they have distinctive textural and lithological features that serve to differentiate them from oligomictic and other conglomerates in the sequence. These features are: the disrupted framework structure, an excess of matrix over gravel material, and the polymictic assemblage of stable and unstable components. All these features seem to imply changes in the competency of the transporting agents and environmental conditions. The environment

[1] Interstitial materials less than 0.02 mm in diameter in rudites and arenites are classified as *matrix* in this report. Such material is characterized by fine-grained white mica but also contains silt-sized and clay-sized clastic particles and chlorite flakes. The various matrix materials are not distinguished in this report. Presumably the fine-grained, white mica was derived from material originally deposited, or diagenetically formed in the sediment, as clay minerals.

was probably characterized by the domination of mechanical over chemical weathering, mass transportation of debris, and rapid deposition.

The Whiskey boulder conglomerate, as well as other similar rocks in the Huronian sequence, can be classified as the paraconglomerates or mudstone conglomerates of Pettijohn (1957a). They are commonly deposited by subaqueous turbidity flows or slides. They are also similar to conglomerates described by Blissenbach (1954), deposited by sheet floods under alluvial fan conditions. In addition to these similarities, a tillite origin was tentatively suggested by McDowell (1957). His arguments for a glacial origin are based on the texture and variable thickness of the conglomerate.

Thus, this type of conglomerate may be deposited under a variety of geological conditions and appears to confirm a statement by Twenhofel (1947) that conglomerates have no significant depositional environments. However, the conglomerates described by Pettijohn (1957a) and Blissenbach (1954) were deposited under conditions of strong relief, reflecting an active tectonic setting.

A sudden change from rather stable conditions to an active tectonic setting is probably the only basic requirement for the deposition of the Whiskey conglomerate. It is suggested that this conglomerate was deposited by mudflows following a sudden uplift of the source area. Mechanical disintegration exceeded the chemical weathering and the unsorted debris was deposited as a blanket over the Huronian sediments and part of the pre-Huronian basement. However, the fact that this polymictic conglomerate is normally very thin and changes to a quartz-pebble conglomerate where it overlies thick accumulations of Matinenda sediments needs further explanation. Presumably the thick Matinenda sediments extended above the base-level of deposition, and the mudflows dumped their debris mainly along the flanks of the bar-like structures. Later, minor reworking spread a thin veneer of quartz pebbles over the bar-like accumulations. According to Pettijohn (1957a), gradation from this type of polymictic conglomerate to a normal conglomerate, is common.

Although no conclusive arguments can be advanced against a glacial hypothesis, certain lithological peculiarities must be explained before this hypothesis can be accepted. In the first place, the overlying argillites are completely free of ice-rafted erratics, which are a common feature of glacial deposition. Secondly, the cyclic repetition of this conglomerate, followed by fine-grained sediments, which in turn grade into coarse-grained clastic rocks, is difficult to explain under erratic glacial deposition. This type of rhythmic deposition is more easily explained by tectonic control.

Argillite-Greywacke Member

This member thickens at an average rate of 90 feet per mile, from less than 100 feet at Quirke mine in the north, to 720 feet at Stintson Lake in the south. The lower contact is commonly very sharp, but the upper contact is gradational.

This member is composed of interbedded argillite, siltstone, greywacke, and minor feldspathic quartzite. In the southern part of the syncline, the lowermost part of this unit consists mainly of argillite and minor siltstone, which grade upward into a thick central greywacke section with thin siltstone beds and minor subgreywacke and feldspathic quartzite. The upper part consists mainly of greywacke and thin siltstone beds and commonly exhibits ripple-marks. In the northern part of the syncline, this member is characterized by a lower laminated argillite section and an upper part of mainly greywacke and thin siltstone beds. Ripple-marks and mud-cracks were observed near the base of the argillite member along the north shore of Quirke Lake.

The argillite is commonly a dark grey, fine-grained rock that may be finely laminated or massive. The laminations range from less than 1 to 5 mm thick and are commonly distorted, faulted, and folded on a micro-scale. The micro-structures clearly indicate the incompetency of this unit during folding, but some are undoubtedly due to soft sediment slumping.

In thin sections the argillite is seen to consist of a fine-grained aggregate of white mica and chlorite with scattered silt-sized particles of quartz, untwinned feldspar, and chlorite fragments. Minor constituents are mainly pyrrhotite, tourmaline, iron oxides and, rarely, pyrite. Unzoned tourmaline, up to 0.1 mm long, is probably an authigenic product.

The siltstone is a grey, even-grained rock, mostly interbedded with argillite and greywacke. It is a very well sorted sediment, containing silt-sized grains of quartz, chlorite fragments, and feldspar, embedded in a fine white mica matrix. Pyrrhotite and pyrite, up to 1 mm across, occur as disseminated blebs and stringers.

A dark grey, medium-grained greywacke (*see* Fig. 4) is the most common arenite in this unit. It commonly shows graded bedding, cross-laminations, and ripple-marks. The greywacke shows typical disrupted framework texture and contains sand- and silt-sized particles of quartz, plagioclase (An_{8-32}), microcline, orthoclase, and rock fragments. Rock fragments, altered to chlorite, constitute 6 per cent of the volume of the rock. Zircon, biotite, calcite, epidote, pyrite, and black iron oxides are present in minor quantities, generally less than 1 per cent. The matrix is mainly composed of fine white mica and minor chlorite. Plagioclase feldspar dominates over potash feldspar, and the average ratio of soda:potash feldspar is four. This rock is rather exceptionally well sorted for a greywacke, the average sorting index[1] being 40, denoting a fairly high degree of sorting.

The greywacke grades into a medium-grained, grey subgreywacke containing less feldspar and matrix material. Feldspathic quartzite is a better sorted rock (sorting index of 24) composed of quartz, plagioclase, microcline, and minor rock fragments embedded in a fine white mica matrix. Rock fragments form only

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[1] A rough method for estimating the degree of sorting in an arenite was described by Pettijohn (1957a) and McDowell (1957). This sorting index is the number of times the diameter of the largest grain exceeds that of the smallest. Such a sorting index is divided into the following classes:

8 times or less	—good sorting
8 to 64 times	—fair sorting
64 to 128 times	—poor sorting
greater than 128 times	—very poor sorting

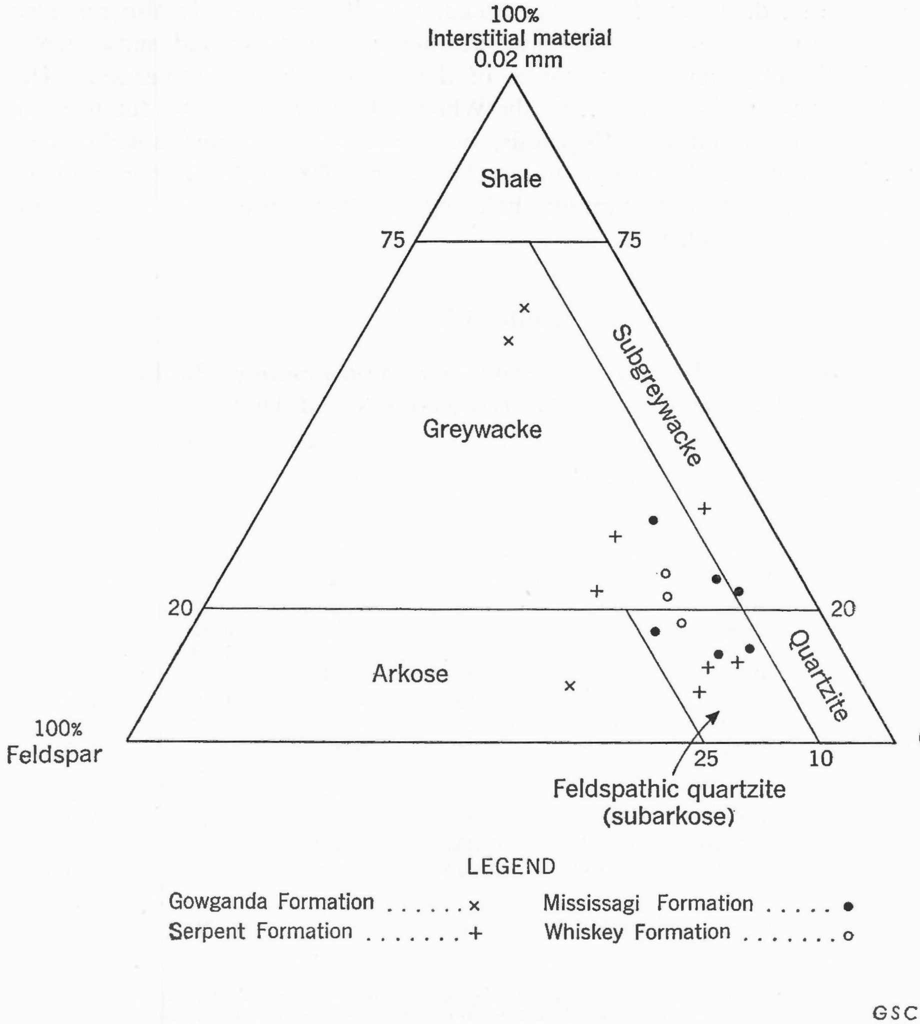

FIGURE 4. Mineralogical classification of Huronian arenites (*after Krumbein and Sloss*, 1953).

2 per cent of the rock, and the amount of matrix is less than in the greywacke. It was probably formed by extensive winnowing of either the subgreywacke or the greywacke in local areas.

Analyses of an argillite and a greywacke from the Whiskey Formation (Table VIII, 55-2) compare favourably with the average analyses of shales and greywackes (Table VIII, A and B).

The alumina, potash, and ferrous iron of the Whiskey argillite are considerably higher than those for the average shale, whereas the soda, lime, and ferric iron are lower. The higher alumina content may be due to the finer grained texture of this lutite, or it may have been augmented by residual clays and bauxitic material. The low content of soda and lime suggests derivation from a highly weathered source where residual clays had accumulated. Potash was probably also removed from the detritus under such intensive weathering conditions and subsequently restored in the clay mineral complexes of the argillite during authigenesis. The high potash content of the lutite from the Whiskey Formation may be due to more effective restoration during authigenesis, but some potash is undoubtedly fixed in the minor untwinned feldspar grains. The higher ferrous-ferric iron ratio of this argillite than that of the average shale suggests that it was deposited under a more reducing environment.

Table VIII

Chemical Analyses of Huronian Sedimentary Rocks and the Average for Greywackes and Shales

Sample	55–2	PH–4	55–92	55–27	A	B
SiO_2	58.77	70.12	86.79	90.58	58.10	64.70
Al_2O_3	22.50	15.90	6.00	5.00	15.40	14.80
Fe_2O_3	0.00	1.81	0.74	0.06	4.02	1.50
FeO	5.60	3.50	—	0.40	2.45	3.90
MgO	2.13	1.99	0.12	0.12	2.44	2.20
CaO	0.10	0.66	0.065	0.053	3.11	3.10
Na_2O	0.28	4.15	0.13	1.95	1.30	3.10
K_2O	6.60	Tr*	4.59	1.23	3.24	1.90
H_2O(100°)	0.11	0.11	0.04	0.03	5.00	0.70
H_2O(900°)	3.72	1.72	1.30	0.30		2.40
TiO_2	0.81	0.71	0.090	0.11	0.65	0.50
ZrO_2	0.0080	0.066	0.0048	0.0049	—	—
MnO	0.060	0.050	0.0020	0.0016	—	0.10
Total	100.69	100.79	99.88	99.84	96.71	98.9

55–2 Argillite, Whiskey Formation. Location: Bore-hole from Consolidated Denison mine.
PH–4 Greywacke, Whiskey Formation. Location: Bore-hole 1,500 feet west of Stanleigh mine.
55–92 Feldspathic quartzite, Mississagi Formation. Location: Bore-hole from Can Met mine.
55–27 Feldspathic quartzite, Serpent Formation. Location: Bore-hole from Consolidated Denison mine.
A Average analyses of 78 post-Precambrian shales, Pettijohn (1957a).
B Average analyses of 27 greywackes, Pettijohn (1957a).
*Tr <0.5 per cent.
Analyses by G. MacDonald, Miller Research Laboratory, Queen's University.

Nanz (1953) noticed that younger shales contain less alumina, ferrous iron, total iron, and potash than Precambrian slates, and attributed this to differences between Precambrian and later environments. The more reducing environment inferred from the ferrous-ferric iron ratio seems to support Nanz' suggestion. It is possible, however, that this argillite merely belongs to a hybrid type of lutite which has an unusually high alumina content.

The chemical composition of the Whiskey greywacke differs from that of the average greywacke by having a higher soda and silica content and lower potash content. The high silica is probably the result of more winnowing of the component materials than the average greywacke as is suggested by the sorting index. Greywackes are mostly 'poured in' type sediments, characterized by poor chemical weathering and the survival of soda. This explains the higher soda content, but does not account for the low potash content. An average soda:potash feldspar ratio of four was observed in thin sections, which confirms the low potash content of the analyzed greywacke. It all seems to indicate that the greywacke was derived from a potash-poor terrain.

The trace elements of arenites and lutites were determined with the hope of finding recognizable differences in minor element contents of these rocks from the various formations. Trace elements were determined by both qualitative and quantitative spectrographic means. In Figure 5 trace elements in rocks from the Whiskey Formation are graphically compared with those from the Nordic Formation. In Table IX, trace elements of Huronian lutites and arenites are compared with those of Pennsylvanian and low-grade Devonian shales.

Table IX

Trace Elements (in ppm) of Huronian Sedimentary Rocks and Pennsylvanian and Devonian Shales

Element	55–2	RF–573	PH–4	RF–574	A	B	C	D	E
Rb	299	253	—	—	122	199	233	—	250–700?
Cr	160	185	117	87	62	110	67	116	100–400?
V	192	255	82	35	35	43	45	99	50–300
Ni	105	92	46	78	21	26	51	76	20–100?
Co	10	53	10	42	TL	TL	TL	16	10–50
Cu	49	59	135	88	78	78	74	17	30–150
B	—	—	—	—	34	104	109	—	—

TL Low concentration
55–2 Argillite from Whiskey Formation
RF–573 Argillite from Nordic Formation
PH–4 Greywacke from Whiskey Formation
RF–574 Subgreywacke from Nordic Formation
A Average analyses of eleven Pennsylvanian freshwater shales from Pennsylvania, Degens, *et al.* (1957).
B Average analyses of eleven Pennsylvanian brackish-water shales from Pennsylvania, Degens, *et al.* (1957).
C Average analyses of eleven Pennsylvanian marine shales from Pennsylvania, Degens, *et al.* (1957).
D Mean analyses of nine low-grade metamorphosed Devonian shales from New Hampshire, Shaw (1954).
E Amounts of trace elements in shales, Krauskopf (1955).
Rb determined by X-ray means
Analyses by G. MacDonald and F. Dunphy, Miller Research Laboratory, Queen's University.

Argillite from the Whiskey and Nordic Formations contains similar amounts of trace elements, except for minor variations in Rb, V, Co, Ag, and Mo contents. Very little is known about the geochemical behaviour of Ag and Mo during sedimentary processes and they may have been introduced from a later extraneous source. Lead commonly substitutes for potassium in silicate minerals, but may also go into solution and become trapped in clay minerals by adsorption. Gallium generally follows alumina in sedimentary rocks. Boron is undoubtedly fixed in the tourmaline in the argillites.

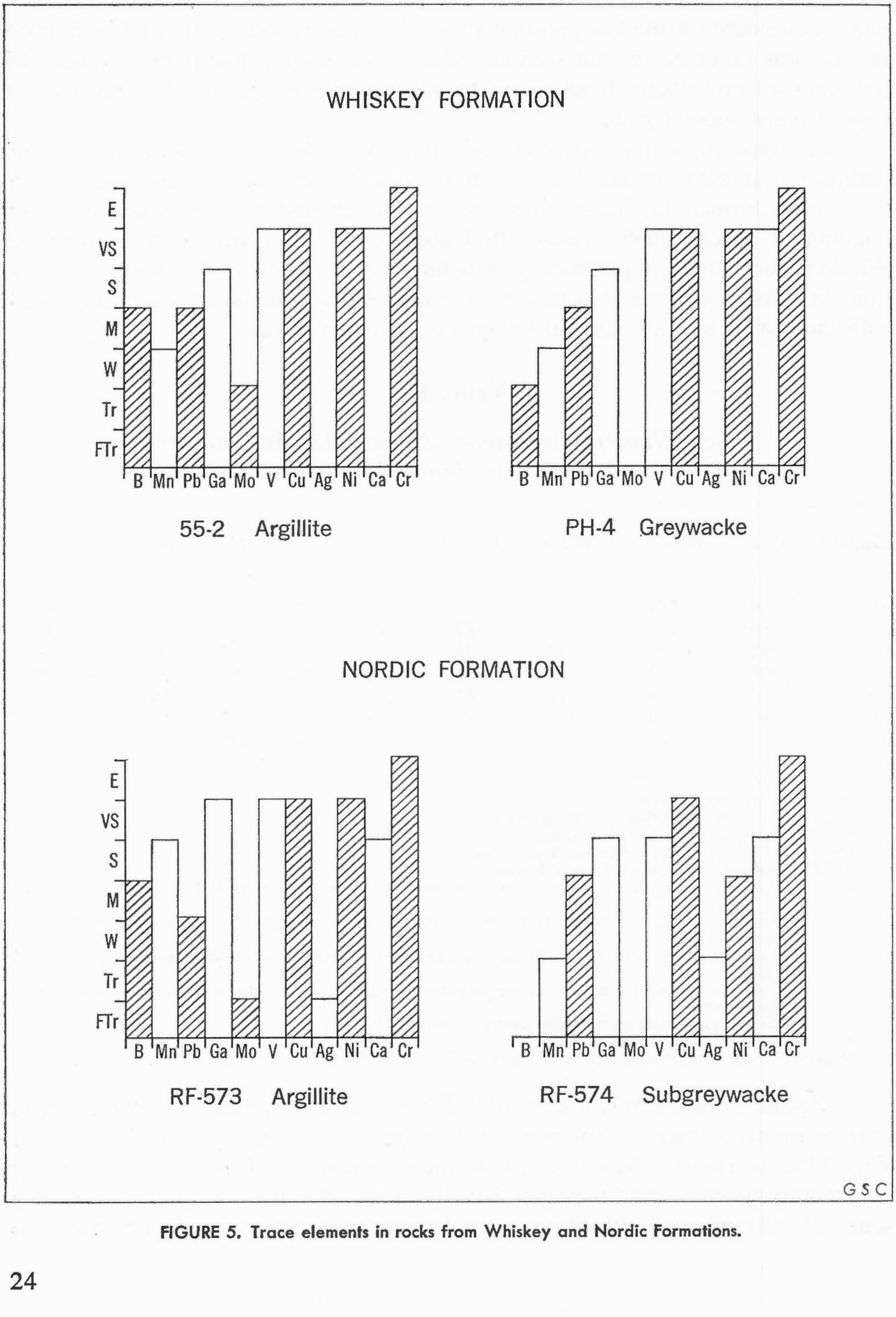

FIGURE 5. Trace elements in rocks from Whiskey and Nordic Formations.

The Huronian argillites have larger amounts of Cr, V, and Ni than both the Pennsylvanian and Devonian shales. However, concentrations of these elements are still lower than the maximum reported by Krauskopf (1955). Cobalt is only present in appreciable amounts in sample RF-573, where it exceeds the maximum concentration reported in shales. It is possible that Co may have been augmented by hydrothermal introduction. Copper in the argillites is lower than in the Pennsylvanian shales, but higher than in the Devonian shales.

The mode of occurrence of these elements in the argillites is uncertain. They may be concealed in the layered structures of the micaceous and chloritic minerals or trapped in the minerals by adsorption, Shaw (1954) and Rankama and Sahama (1950). However, some of these elements, especially Ni, Co, and Cu, were probably augmented by hydrothermal solutions or lateral secretions. It is important to note the wide range in the abundance of these elements in lutites. This may be due to the depositional environment as shown by Degens, *et al.* (1957), or to variations in the amount of mechanically derived silts in the lutites; some lutites contain more silt and hence less clay minerals than others.

Rubidium in the Huronian argillites is slightly higher than it is in the Pennsylvanian marine shales, but much lower than the maximum reported by Krauskopf (1955). As in igneous rocks, rubidium in sedimentary rocks follows potassium closely, and Horstman (1957) stated that marine shales have K:Rb ratios similar to that of average igneous rocks. The K:Rb ratios of samples 55-2 and RF-573 are 182 and 202 respectively. This is slightly lower than the 270 for the average igneous rocks reported by Horstman (1957), but is well within the range of variation.

The greywacke of the Whiskey Formation (PH-4) has the same trace elements as the lutites, except that Mo and Ag are absent. However, the amounts of these elements are lower in the greywacke than in the argillites (*see* Table IX and Fig. 5). Boron is also present in the greywacke, but no tourmaline was observed in the sections examined. No data are available on the concentrations of trace elements in greywackes. Trace element concentrations in sandstone were reported by Krauskopf (1955), but the term sandstone includes many kinds of arenites that differ in composition and conditions of deposition. Such data have therefore little value in comparing different types of arenites.

The subgreywacke (RF-574) from the Nordic Formation has a lower concentration of trace elements than the greywacke (PH-4), except for Ni, Co, Ag, and Mo. These elements were probably introduced from an extraneous source. Both the greywacke and subgreywacke contain more trace elements than the other Huronian subarkoses and quartzites (*see* Table XIX).

It is interesting to note that the amount of trace elements decreases progressively from the lutite, to the greywacke-subgreywacke clan, to the subarkose-quartzite clan. The percentage of matrix materials in these rocks, mainly composed of fine micaceous minerals, also decreases in the same order. Thus, there seems to be a direct correlation between trace element concentrations and the percentage of fine micaceous matrix material. This may be because trace elements in sedimentary rocks are mainly concealed in the structures of micaceous minerals, and the abundance of such minerals controls the concentrations of trace elements.

Origin of the Argillites

The difference between marine and freshwater shales has always been a controversial issue, but such a distinction is often essential for palæogeographic reconstruction. Marine shales generally have more potash and magnesia than freshwater shales (Pettijohn, 1957a). Both the Huronian argillites are potash-rich, but they also contain anomalously high alumina, which is characteristic of hybrid lutites. The origin of hybrid lutites is uncertain and it is doubtful whether the potash content of these argillites is sufficient to identify the environment of deposition.

Recently, Degens, *et al.* (1957) tentatively suggested another method of distinguishing between marine and freshwater shales. They found that Pennsylvanian marine shales contain more B and Rb than freshwater shales (*see* Table IX) and less gallium. The Huronian argillites have an abnormally high Rb content even for marine shales, and also contain B and Ga. Although the amount of B and Ga is not known, the high Rb content favours a marine origin for these argillites.

On the other hand, although Degens and associates recognize the greater content of Rb in marine shales, they do not quote the potash content. In most lutites rubidium is fairly closely linked with potassium (Horstman, 1957). Some lutites, especially those formed by abrasion, contain more soda and less potash than others (Pettijohn, 1957a). Thus, if Rb follows K in lutites, the lower Rb content of the Pennsylvanian freshwater shales may be due to a lower potash content. Unless, therefore, the potash content of the shales is known, the diagnostic value of Rb is questionable.

It must be concluded, therefore, that the chemical evidence for the origin of these argillites is contradictory and inconclusive.

Collins (1925) suggested that the argillite of the Whiskey Formation was deposited in freshwater rather than in the sea. His evidence is mainly based on the fine laminations of the argillite. A deep-water marine, or a very large lake environment was postulated by McDowell (1957). The presence of mud-cracks, which are not usually preserved in a marine environment, is significant evidence for a non-marine origin. Mud-cracks also suggest periodic subaerial exposures and the ripple-marks favour some deposition above the wave base-level.

From the evidence of the sedimentary structures, in the absence of fossils, it is believed that the lutites of the Whiskey Formation were deposited in a freshwater rather than in a marine environment.

Sedimentary History

Following the tectonic setting that led to the deposition of the boulder conglomerate at the base of the Whiskey Formation, the entire area was submerged, presumably in a body of freshwater. Regolithic clay products from a northerly source were deposited in tranquil waters and silts during periods of turbulence. Regression of the strand line accompanied by subaerial exposures resulted in the formation of mud-cracks. Ripple-marks were formed by wave action in the shallow water close to the strand line. Deposition of the lutites was probably accomplished under stable tectonic conditions.

This stable tectonic setting was interrupted by an uplift, and chemically immature sediments were poured into the depositional site to accumulate as greywacke. Winnowing of the greywacke debris by depositional agencies resulted in the formation of siltstone and subgreywacke beds. In local areas extensive winnowing led to the formation of feldspathic quartzite. Intermittent periods of rapid deposition followed by winnowing resulted in the formation of an interbedded assemblage of greywacke, subgreywacke, and siltstone. Sedimentation of the upper part of this formation was probably accomplished under shallow water or deltaic conditions which favoured the accumulation of ripple-marks and cross-laminated greywacke and siltstones.

The cessation of this type of sedimentation was not abrupt, but there was a gradual shift to an environment characterized by the deposition of crossbedded, coarse-grained subarkoses. McDowell (1957) suggested that this change was accomplished by an advancing deltaic flood plain.

Mississagi Formation

This formation consists essentially of coarse- to medium-grained arenites, and thickens rapidly towards the south and southeast. It varies in thickness from 600 feet at Quirke mine in the north to 1,750 feet in the south and southeasterly parts of the syncline. The thickest intersections were in drill-holes north of Hough Lake and northeast of Elliot Lake. The feldspathic quartzites of the Mississagi Formation are similar to those of the Matinenda Formation, but are commonly finer grained, better sorted, better bedded, and in most places noticeably less feldspathic.

In the northern part of the syncline, the Mississagi Formation is roughly divisible into three units: A lower unit, 200 to 300 feet thick, consisting of a greenish, coarse-grained, feldspathic quartzite with minor thin siltstone beds; a central unit, 200 to 500 feet thick, composed mainly of grey, medium-grained subgreywacke, minor feldspathic quartzite, and thin greywacke beds; an upper unit, 200 to 500 feet thick, consisting mainly of a light grey, medium-grained feldspathic quartzite and thin siltstone beds.

This sequence is less distinct in the southern part of the syncline. There greenish, coarse-grained, feldspathic quartzite, approximately 200 feet thick, is recognizable near the base of the Mississagi Formation, but the remainder of the sequence is predominantly a light grey, medium-grained, feldspathic quartzite interbedded with subgreywacke and siltstone.

In the Quirke Lake area some pyritic, oligomictic conglomerates, 3 to 12 inches thick, are present in the upper and lower units. These conglomerates contain subrounded quartz, chert, and minor feldspar pebbles ranging from 5 to 20 mm in diameter, in a matrix with abundant interstitial pyrite. They are markedly radioactive. Similar rudites are present in the lower unit of the Mississagi Formation along the south limb of the syncline, but most of these are only feebly radioactive. In addition, single layers of pebbles of quartz and black chert, up to 40 mm in diameter, occur in the upper and middle units.

The Mississagi Formation displays excellent crossbedding. Planar and trough crossbedding predominate; simple crossbedding is rare. The direction of detrital transport inferred from the crossbedding directions is to the southeast, which corresponds to the direction of maximum thickening of the formation (*see* Fig. 20). Ripple-marks are present, and a single stylolite was observed.

Petrographic Description

The modal analyses of the arenites from the Mississagi Formation are shown graphically in Figure 4.

Feldspathic Quartzite

The medium- to coarse-grained feldspathic quartzites consist of subrounded to subangular, sand-sized grains of quartz, microcline, and plagioclase (An_{10-25}) embedded in a fine white mica matrix. Minor constituents include calcite, chert, orthoclase, muscovite, chlorite, zircon, black iron oxides, and, rarely, epidote, and apatite. The average potash feldspar:soda feldspar ratio is approximately 2. Disseminated pyrite is commonly present, but some occurs as seams parallel with the crossbedding. Abundant cataclastic effects are shown by the undulatory extinction of quartz grains and fragments of muscovite partly wrapped around clastic grains. Sorting indices range from 25 to 60. The lower coarse-grained feldspathic quartzite member has a large sorting index, as well as a higher feldspar and matrix content than the medium-grained upper feldspathic quartzite member.

A common feature of the arenites, especially those with abundant matrix, is the serrated edges of clastic grains. This serrated appearance of quartz grain boundaries is produced by fine white mica projecting into the grains. Sedimentary petrologists attribute this rather common feature in sandstones to the reaction of intrastratal solutions on clastic grains during diagenesis. Diagenetic effects are difficult to separate from metamorphic effects, however, and it is possible (perhaps probable) that this incipient replacement is due to mineralogical reconstitution under low-grade metamorphic conditions.

Subgreywacke

This uneven grained arenite contains subangular to subrounded sand and silt-sized grains of quartz, microcline, plagioclase, and chlorite-bearing rock fragments in a fine white mica matrix. Rock fragments constitute 3 per cent of the total rock, and the average potash feldspar:soda feldspar ratio is 1.5. Minor amounts of pyrite, muscovite, and black iron oxides with a leucoxene coating are also present. The sorting index is approximately 50, implying a fairly well sorted subgreywacke.

Greywacke

The greywacke shows only a faint disrupted framework structure, but the grain size is strikingly uneven and it has an average sorting index of 76. The greywacke is a dark, medium-grained arenite. It consists of angular to subangular sand- and silt-sized particles of quartz, plagioclase, microcline, chert, and chloritic rock fragments in a matrix of fine white mica and chlorite. Rock fragments form about 8 per cent. Pyrite, biotite, sphene, muscovite, epidote, and zircon occur in minor quantities. Equal amounts of plagioclase and potash feldspar are present, which is unusual as the feldspar of most greywackes is mainly plagioclase. Some veinlets of white mica and pyrite were observed cutting across clastic grains.

Siltstone

This greenish, uneven grained sedimentary rock varies from 1 inch to 12 inches in thickness. It consists of angular sand-sized grains of quartz and feldspar scattered through silt-sized particles of the same composition. The matrix is mainly fine white mica. The siltstone is probably an accumulation of fine winnowed products.

Chemical Composition

A sample from the upper medium-grained feldspathic quartzite of the Mississagi Formation was analyzed and the results are shown in Table VIII.

The analysis is typical of a sandstone with a low mobile oxide content and a high silica content. The high Al_2O_3:Na_2O ratio and low lime content indicate the chemical maturity of this feldspathic quartzite. This implies extensive chemical weathering of the parent detritus. The high potash content is, however, difficult to explain, especially as petrographic studies show an average potash feldspar:soda feldspar ratio of 2. Normally a potash-rich sedimentary rock indicates a certain amount of chemical maturity with the removal of the more mobile oxides lime and soda, but it may also imply a potash-rich source.

In general, the feldspathic quartzite of the Mississagi Formation contains more silica than those of the lower Matinenda member, but less than those of the Serpent Formation and fine-grained Huronian quartzites.

Environment of Deposition

The coarse-grained subarkoses, greywackes, and subgreywackes of the Mississagi Formation have a sorting index greater than 50, matrix content exceeding

15 per cent, and are texturally immature[1], evidently they were deposited rapidly and exposed to but little winnowing action. The medium-grained subarkoses are texturally submature subjected to more pronounced winnowing during transportation and deposition.

In the northern part of the syncline the bulk of the formation consists of texturally immature arenites with texturally submature arenites abundant only in the upper part. In the southern part of the syncline texturally immature arenites predominate only in the lower 200 feet of the formation; the remainder and bulk of the formation is characterized by texturally submature, medium-grained feldspathic quartzite.

The detritus of the Mississagi Formation was derived from a northwesterly source and deposited under conditions typical of a near-shore or deltaic environment as postulated by McDowell (1957). However, conditions of deposition must have varied. The initial deposition of the coarse-grained feldspathic quartzite, without much winnowing, was followed by increased tectonic activity and the supply of poorly weathered debris. In the northern part of the syncline this debris accumulated rapidly as greywacke and subgreywacke, whereas in the southern part the debris was washed by depositional agencies resulting in the deposition of quartzite and subgreywacke. The final stage of sedimentation was characterized by a more stable tectonic setting and the accumulation of winnowed feldspathic quartzite, probably under conditions of an advancing strand line.

Quirke Group

The Quirke Group includes all the sedimentary formations from the base of the Bruce Conglomerate, which underlies a limestone unit, to the base of a thick polymictic boulder conglomerate overlying a feldspathic quartzite formation. The lower contact is sharp, but the upper is gradational.

This group contains a diagnostic suite of sedimentary rocks, recognizable in many parts of the north shore of Lake Huron. Its thickness in the Quirke Lake

[1] In recent years the concept of maturity has emerged from the study of sedimentary rocks. The maturity of a sediment was described by Plumley (1948) as the approach to a most inert end state through chemical and physical processes. Folk (1951) introduced textural maturity to describe the effects of physical processes on a sediment. Textural maturity of a rock is expressed by its clay content, sorting index, and roundness of clastic grains. Four classes of textural maturity, namely, immature, submature, mature, and supermature, were proposed by Folk (1951). Only the immature and submature classes are of any importance in the Huronian arenites. An immature texture is characterized by angular clastic grains, poor sorting, and a clay content greater than 5 per cent. In a submature texture there is little difference in the degree of sorting and rounding of clastic grains, but the clay content is less than 5 per cent. Thus, the essential difference between submature and immature textures is the removal of clay material by winnowing.

The lower limits for the clay content of both immature and submature textural varieties proposed by Folk is rather low, as few sandstones contain less than 5 per cent clay. Furthermore, it is difficult to measure the clay content of Precambrian arenites. As the textural maturity concept of Folk is helpful, a modification of his concept is here proposed for the Huronian arenites. A texturally immature arenite is a rock composed of angular to subangular clastic grains with more than 15 per cent matrix and a sorting index greater than 50. A texturally submature arenite is one composed of subangular to subrounded clastic grains, with between 5 and 15 per cent matrix and a sorting index between 25 and 50. Although the limits for immature and submature textures are arbitrarily fixed, they reflect the effects of increased winnowing action from immature to submature arenites, which is the essential feature of Folk's concept.

syncline ranges from 1,700 feet in most places to 180 feet in the western part of township 149, where the upper formations are absent (*see* Fig. 1). The group is subdivided into three formations, in ascending order; Bruce Conglomerate, Espanola Formation, and Serpent Formation.

Bruce Conglomerate

The Bruce Conglomerate, a persistent horizon marker, is present throughout the Huronian sequence in the Quirke Lake syncline. Although the thickness varies from 15 to 370 feet, it is more commonly between 80 and 120 feet. The thickest section was encountered in a drill-hole north of Stollery Lake, and the thinnest was observed in outcrops between Pecors and Hough Lakes.

This formation is an unsorted polymictic conglomerate composed of a heterogeneous assemblage of boulders, cobbles, and pebbles bedded in a coarse-grained greywacke matrix. These rudaceous components consist of grey and pink granitic rocks, quartz, metavolcanic rocks, and, rarely, metasediments. The greywacke matrix exhibits a disrupted framework structure with sand- and silt-sized particles randomly distributed in a fine white mica matrix. Individual grains are principally quartz, microcline, plagioclase, and granitic and chloritic fragments. Minor constituents are chlorite, muscovite, zircon, calcite, pyrite, pyrrhotite, black iron oxides, and, rarely, garnet. Some crosscutting veinlets of calcite were observed, but generally the feldspars in the matrix are less altered than those in the pebbles.

The packing of the Bruce Conglomerate varies and conglomeratic greywacke bands are common. However, a perceptibly bedded greywacke with randomly distributed pebbles and cobbles is present near the middle of the formation, and the upper part of the conglomerate is noticeably calcareous. Although the Bruce Conglomerate is similar to the polymictic conglomerate at the base of the Whiskey Formation, it is commonly thicker, more uniform in character, and has a more quartzose matrix. Both the lower and upper contacts are sharp.

The Bruce Conglomerate was probably deposited by mudflows, which is essentially the same mode of formation as the polymictic conglomerate at the base of the Whiskey Formation. The quartzose matrix of the conglomerate indicates, however, more winnowing at the depositional site. Collins (1925) suggested a continental mode of deposition as he believed mudflows to be incapable of producing such widespread deposits. Coalescing mudflows are, however, capable of dumping unifacial deposits over a large area. A glacial agency is also capable of depositing such heterogeneous debris, but, as Collins concluded, no confirmatory evidence was found for a glacial origin. Furthermore, the deposition of this conglomerate required a sudden change in the intensity of tectonic activity during the accumulation of the upper part of the Mississagi Formation. As such a sudden change in tectonic activity commonly triggers mudflows, it seems more logical to postulate a mudflow origin for the Bruce Conglomerate.

Espanola Formation

This formation consists mainly of intercalated limestone, siltstone, and calcareous arenite beds with minor intraformational breccias and conglomerates. The lower contact with the Bruce Conglomerate is sharp, but the upper contact with the Serpent Formation is gradational. The Espanola Formation varies in thickness from 800 feet round Quirke Lake to 80 feet in the western part of township 149. It is subdivided into three members, from the bottom to the top: Bruce Limestone, Espanola Greywacke, and Espanola Limestone.

Bruce Limestone

The Bruce Limestone consists of thin-bedded, white limestone and green siltstone, and forms a diagnostic horizon marker in the Huronian sequence. It varies in thickness from 80 to 200 feet. The lower part is commonly thin-banded, calcareous siltstone, which grades upward into a thick section of fine-grained, white limestone beds alternating with thin siltstone partings. The upper part (approximately 10 feet thick) is composed of a calcareous siltstone that grades into a calcareous arenite of the Espanola Greywacke. Another characteristic feature of the lower calcareous siltstone is the abundance of disseminated pyrrhotite blebs, especially near the base of the member. Collins (1925) also reported thin iron-formation bands in this member in township 149.

The thin-bedded Bruce Limestone displays complex crenulations and is drag-folded in local areas. These crenulations may be due to the incompetency of this unit during folding and faulting, but as pointed out by Hart (1955), they may also have resulted from soft sediment slumping. Some drag-folds may be related to local faults, but no detailed studies were made.

The fine-grained, white limestone is mainly composed of calcite with a few scattered clastic grains. Where the limestone is more coarsely crystalline, dolomite constitutes up to 15 per cent of the rock. This was detected by staining limestone sections with cupric nitrate solutions. Collins (1925) recorded an analysis of limestone from Quirke Lake that returned 25.12 per cent lime and 11.68 per cent magnesia. Such a sample contains 53.7 per cent dolomite, obviously much more than any of the thin sections examined.

The greenish siltstone layers are composed of silt-sized grains of quartz and feldspar dispersed in a matrix of fine white mica and calcite. The contact between limestone and siltstone layers is normally gradational and the limestone close to the contact contains abundant clastic grains.

Espanola Greywacke

This member is composed of intercalated beds of calcareous greywacke, calcareous siltstone, and intraformational breccias and conglomerates. The lowermost section of the unit, approximately 30 to 100 feet thick, consists mainly of massive greywacke and siltstone that are noticeably poor in calcareous material.

Individual subrounded, sand-sized grains are principally quartz, microcline, plagioclase, and rock fragments in a matrix of fine white mica and minor calcite. Pyrrhotite, pyrite, chlorite, and black iron oxides are present in minor quantities. In some places the greywacke is fine grained and grades into a siltstone.

Intraformational conglomerates are commonly present near the base of the lowermost part of the member. They consist of thin, flat, yellowish green fragments of argillite and siltstone sparsely distributed in calcareous greywacke and siltstone. Most of these fragments have subrounded corners and edges and are between 5 mm and 40 mm long. Another polymictic conglomerate is present in the lowermost part of the member, but above the intraformational conglomerate. This conglomerate, up to 10 feet thick, occurs along the east shore of Quirke Lake and farther east. It consists of angular to subrounded pebbles of argillite, siltstone, granitic rocks, quartz, and metavolcanic rocks randomly dispersed through a calcareous greywacke matrix.

The lowermost beds grade upward into the upper beds that consist of alternating calcareous siltstones and greywackes. Thin silty limestone beds are also present. The composition of these rocks is approximately the same as that of lower rocks except that they are much more calcareous. An intraformational breccia occurs near the top of the Espanola Greywacke on an island in Quirke Lake. A similar breccia was observed at the same stratigraphic position on an island 6,000 feet east of the above locality, but the full extent of this breccia is not known. These breccias consist of angular blocks of banded calcareous siltstone up to 5 feet long and cemented by calcareous material. Beds above and below are undisturbed, which suggests that the brecciation resulted from slumpage of fairly well consolidated material rather than from tectonism.

Ripple-marks are common in this member, and Collins (1925) reported sandstone dykes and mud-cracks. Most of the ripple-marks are oriented in an easterly direction (Roscoe, 1957a). Gentle folds observed in this formation on an island in Quirke Lake are undoubtedly related to a fault on the north side of the island.

The upper contact of this member is gradational and difficult to recognize in drill-cores. The lithology of the Espanola Greywacke and Espanola Limestone is similar, and the contact is undoubtedly often placed at different stratigraphic levels. However, the two members are readily distinguished in outcrops and have been mapped as different units by Collins (1925), Abraham (1957), and Robertson (1957).

The combined thickness of the Espanola Greywacke and Limestone members averages 500 feet at Quirke Lake, 550 feet at May Lake, and 450 feet east of Dunlop Lake. Both members are absent in the western part of township 149.

Espanola Limestone

The Espanola Limestone is considerably more calcareous than the Espanola Greywacke and consists of an interbedded assemblage of silty limestone, calcareous siltstone, calcareous quartzite, and thin rusty weathering dolomite bands. The upper contact with the Serpent Formation is gradational and is generally placed at the uppermost dolomite band.

The fine-grained, grey limestone is mainly composed of calcite with randomly distributed silt-sized quartz grains. The greenish to yellowish grey siltstone consists mainly of quartz, calcite, and chlorite fragments in a fine white mica and calcite matrix. A grey, medium-grained quartzite is present in minor amounts. It consists principally of subrounded grains of quartz, with minor plagioclase and microcline in a calcite and white mica matrix. Zircon, pyrite, pyrrhotite, and chlorite fragments are also present. No thin section of the dolomite was available for examination.

Conditions of Deposition

Lithological characteristics of this formation favour tranquil conditions of deposition with intermittent increases in the tectonic activity and periodic withdrawals of the waters. The uniform thickness in most parts supports such a rather stable geological setting. This formation, in contrast to the underlying formations, shows no increase in thickness to the south.

The active tectonic conditions that led to the deposition of the Bruce Conglomerate were followed by a period of quiescence, resulting in the accumulation of the Bruce Limestone member.

The deposition of greywacke, which followed that of the limestone, denotes rapid dumping of poorly weathered debris following an increase in tectonic activity. The lithological attributes of the sedimentary units that followed the accumulation of the greywacke, suggest alternating conditions of tranquility, turbidity, and tectonic instability. Such conditions of deposition may account for the alternating occurrence of the limestone, siltstone, and arenites that form the remainder of the formation. However, the presence of mud-cracks and intraformational conglomerates indicate periodic withdrawals of the waters and subaerial exposures.

The intraformational breccia was probably formed by slumpage following a sudden tremor. This breccia may have formed in either a subaerial or a subaqueous environment.

Serpent Formation

This formation consists of feldspathic quartzite, subgreywacke, and thin beds of polymictic conglomerate and siltstone. It has a characteristic porcelaneous appearance in weathered outcrops and is normally well bedded, finely laminated, and calcareous. The lowermost part is composed of a calcareous subgreywacke, whereas the remainder consists mainly of a medium-grained, white to pink feldspathic quartzite with minor beds of greywacke, siltstone, and polymictic conglomerates. The quartzite of the Serpent is finer grained, better sorted, and more calcareous than that of the Mississagi Formation.

Data on the thickness of the Serpent Formation are scarce. Thicknesses vary from 350 feet at Consolidated Denison mine to 900 feet along the east shore of Quirke Lake. It is approximately 600 feet at May Lake, 750 feet southeast of Dunlop Lake, and the formation is absent in the western part of township 149 (*see* Fig. 1). The contact between the Serpent and Gowganda Formations varies from sharp to gradational. However, south of Consolidated Denison mine shafts, it is corrugated or undulating and bedding in the Serpent quartzite appears to be truncated by the overlying Gowganda Formation. This indicates erosion prior to the deposition of the Gowganda Formation.

Sedimentary structures in the Serpent Formation are mainly crossbedding, mud-cracks, and ripple-marks. Trough crossbedding is the most common, but planar and simple crossbedding were also observed. Ripple-marks and gigantic mud-cracks are present at several stratigraphic levels in this formation.

Modal analyses of the arenites are plotted in Figure 4.

Feldspathic Quartzites

This even-grained feldspathic quartzite is principally composed of subrounded grains of quartz, chert, plagioclase (An_{12-26}), and microcline in a matrix of fine white mica. Minor constituents include pyrite, calcite, chlorite, leucoxene-coated black iron oxides, zircon, and, rarely apatite. Veinlets of calcite are also present and some quartz grains are fractured and have serrated grain boundaries. Roscoe (1957a) reported authigenic overgrowths on the quartz grains, but none was observed in thin sections examined. This quartzite is a texturally submature arenite, with a 'fair' average sorting index of 18. The average soda feldspar: potash feldspar ratio is 2.

Subgreywacke

The subgreywacke is a grey, medium-grained, calcareous rock, containing both silt- and sand-sized detritus. Individual subangular grains are principally quartz, chert, plagioclase, microcline, and chloritic rock fragments. The matrix is fine white mica and has a high percentage of calcite. Pyrite, black iron oxide, and zircon are present in minor quantities. Rock fragments constitute 4 per cent of the rock. It has a 'fair' sorting index of 63.

Greywacke

This dark grey, medium-grained arenite has a 'poor' sorting index of 90 and exhibits typical disrupted framework structure. It contains up to 15 per cent rock fragments. The greywackes are composed of angular to subangular, sand- and silt-sized grains of quartz, chert, microcline, biotite, plagioclase, and chloritic and argillitic rock fragments in fine white mica and minor calcite. Minor constituents are essentially the same as the subgreywacke.

Siltstone

This yellowish grey, even-grained rock is composed of silt-sized particles of quartz, feldspar, and chlorite in a slightly calcareous, fine white mica matrix.

Polymictic Conglomerates

Two types of polymictic conglomerates are present in the Serpent Formation. One type, commonly in beds one pebble thick, occurs at intervals throughout the formation. It consists mainly of quartz, chert, and granitic pebbles and cobbles in a siltstone matrix. The other type, up to 10 feet thick, is found near the top of the formation. This conglomerate is composed of quartz, chert, granitic, and metavolcanic pebbles and cobbles in a quartzose greywacke matrix. It is often difficult to distinguish from the polymictic conglomerates of the Gowganda Formation.

Chemical Composition

A sample of feldspathic quartzite from the Serpent Formation was analyzed and the results tabulated in Table VIII.

The Serpent feldspathic quartzite has a higher silica content than most other Huronian arenites. It also has a higher soda and lower potash content. The latter is probably the most diagnostic feature of the Serpent Formation.

The high silica content confirms the conclusion that this feldspathic quartzite is a texturally submature arenite. This suggests pronounced winnowing resulting in an increased quartz content. On the other hand, the low Al_2O_3:Na_2O ratio indicates a chemically immature detritus and implies poor chemical weathering of the source rock. This seems a plausible explanation, as no evidence was found to suggest that the high soda content may be ascribed to soda metasomatism. However, the chemical maturity concept of Nanz (1953) and Kennedy (1951) is also governed by the composition of the provenance. If the source rock is extremely rich in soda, the chemical maturity index may be less significant. Irrespective of the chemical maturity of the Serpent feldspathic quartzite, the low potash content indicates a poor or impoverished potash-source area.

Depositional History

The Serpent Formation displays no marked diagnostic features to indicate the type of depositional environment. However, the good sorting and textural submaturity of the feldspathic quartzite indicate the extensive role played by depositional winnowing agencies. This seems to indicate shallow-water deposition above the wave-base level. The presence of ripple-marks substantiates such an indication. Periodic withdrawals of the waters led to subaerial exposures and the formation of mud-cracks.

The presence of greywacke and subgreywacke beds suggests a rapid rate of deposition of poorly weathered detritus, probably following an increase in tectonic instability. The random distribution of polymictic conglomerates in the sequence, denoting mass transportation, also confirms these periodic increases in tectonic instability.

The feldspathic quartzite was probably deposited under rather stable tectonic conditions near a shoreline. Periodic uplifts were accompanied by the rapid debouching of poorly weathered detritus to form the greywacke. Some of the more intense tectonic uplifts were followed by mudflows depositing the polymictic conglomerates.

Cobalt Group

This group comprises all the sedimentary formations that overlie the Quirke Group (Roscoe, 1957a), and is the equivalent of the Cobalt Series of Collins (1925). Only the lowermost Gowganda Formation of this group is present in the Quirke Lake syncline.

Gowganda Formation

The Gowganda Formation consists of a variable assemblage of polymictic conglomerates, greywacke, siltstone, argillite, arkose, and minor quartzite.

These polymictic conglomerates consist of subrounded pebbles, cobbles and boulders in a dark greenish, silty greywacke matrix. The rudaceous components are mainly reddish granitic rocks, gneisses, meta-gabbro, metavolcanic rocks, quartz and, rarely, metasediments. Some large angular blocks of impure quartzite and siltstone were observed in the basal bed of the Gowganda Formation near Stanrock mine. These polymictic conglomerates are similar to others in the Huronian sequence, but have a higher silty greywacke matrix, and are commonly much thicker. The lower part of this formation is noticeably stratified and the conglomerates are well packed.

Greywackes from this formation have much more matrix than the other Huronian greywackes (*see* Fig. 4). They consist of angular to subangular grains of quartz, microcline, orthoclase, plagioclase (An_{14-32}), and rock fragments in a matrix of fine white mica and chlorite. Rock fragments constitute 11 per cent of the rock and are principally chlorite, chert, and granitic and basic rocks. The 'very poor' sorting index is approximately 150, and the grains vary from coarse-grained sand to silt. Minor constituents are epidote, biotite, black iron oxides, apatite, and pyrite.

A red, medium- to coarse-grained, arkose occurs as lenticular bodies in the Gowganda Formation. It contains subangular to subrounded grains of quartz, plagioclase, microcline, and orthoclase in a matrix of fine white mica and calcite. Minor constituents include apatite, zircon, sphene, and leucoxene-coated black iron oxides.

Laminated argillite and siltstone, and quartzite are also present, but were not examined in detail.

Relationship between Gowganda Formation and Quirke Group

The relationship between the Gowganda Formation and the Quirke Group has been discussed by Roscoe (1957a and b), and no further details can be added. In some parts of the syncline the relationship is conformable, whereas in others it appears to be disconformable. Collins (1925) suggested that there was a regional erosional break at the base of this formation.

In some places east of Quirke Lake the contact is fairly sharp, whereas south of Quirke Lake it is masked by a thick zone of interbedded feldspathic quartzites, greywackes, and polymictic conglomerates. The latter would suggest a continuous cycle of deposition. In many drill-holes the contact between the Gowganda and Serpent Formations cannot be placed with any certainty.

As previously mentioned, scouring of the Serpent Formation as well as truncation by the Gowganda Formation was observed in the Consolidated Denison mine area. These features are sure evidence of erosion prior to the deposition of the Gowganda Formation, but may be local. In addition, Collins (1925) attributed the absence of upper formations of the Quirke Group in the western part of township 149 to erosion.

Although the evidence cited is contradictory, none of it supports a major unconformity. Consequently, until this relationship has been resolved by further study, a local unconformity is tentatively suggested.

Depositional Environment

Collins (1925) suggested that this formation was probably deposited under glacial conditions, although he also concluded that local submergence and deposition in shallow water might account for the stratification. Arnold (1954) quoted the Na_2O:K_2O and CaO:MgO ratios as indicative of the absence of chemical weathering, thus substantiating a glacial origin. Admittedly, these ratios are indicative of chemical immaturity, but greywackes with no glacial affiliations have similar ratios. Striated and soled boulders have also been cited as evidence for glacial deposition. On the other hand, these striations may be imprints of an antecedent milieu. If a glacial mode of deposition is accepted for the Gowganda Formation, the paucity of unstratified conglomerates within the syncline—although they are common outside it—will have to be explained. Furthermore, the presence of crossbedding (Roscoe, private com.) and arkoses are not diagnostic of a glacial environment.

Many of these features may be explained by alternating glacial and fluvioglacial modes of deposition. Such conditions of deposition are difficult to distinguish from intertonguing fluvial and mudflow accumulation. A mudflow mode of deposition was proposed for the similar polymictic boulder conglomerates in the lower formations of the Huronian sequence. It is not known whether mudflows or sheet-flows are capable of depositing beds as thick as some of those in the Gowganda Formation.

Intrusive Rocks

In the Quirke Lake syncline, both Huronian and pre-Huronian rocks have been invaded by dykes and sill-like masses of diabase and lamprophyre. Most of the sill-like bodies are actually dykes and dip slightly steeper than the bedding of the sedimentary rocks. The east-west trending diabase mass extending from Milliken Lake mine to Hough Lake is a gently dipping dyke some 600 feet thick (*see* Fig. 1). Similar dykes are present between Whiskey and Pecors Lakes. The diabase body around Teasdale and Ouellette Lakes has a saucer-like structure. Some diabase masses appear to have been intruded along the nose of the syncline.

These diabase intrusions are from a few feet to 700 feet thick. The steeply dipping dykes are generally the thinnest, whereas the sills and gently dipping dykes are commonly much thicker. The lamprophyre intrusive rocks range from a few inches to 80 feet thick, but most are less than 10 feet thick.

Most of the diabase intrusions strike west or northwest, except for a few that trend northeast. Many of the northwesterly striking dykes are parallel with strong lineaments and a prominent set of faults. Diabase dykes may have been intruded along similar faults and lineaments.

The diabase and lamprophyre intrusions post-date the major period of folding, and the lamprophyre dykes are later than the diabase. In many places the diabase dyke contacts are sheared and displaced by bedding plane and other faults.

All the diabase intrusions examined were of the quartz variety and no olivine diabases were recognized in drill-core. However, Collins (1925) described some olivine diabases as the youngest intrusions in the area.

The quartz diabase is a dark green, fine- to coarse-grained, altered rock with a diabasic texture. Thick intrusions have alternating fine- and coarse-grained zones, which may suggest multiple intrusions. The diabase consists mainly of labradorite (An_{55-60}) and chlorite, with smaller amounts of quartz, brown hornblende, leucoxene-coated black iron oxides, and sphene. Most of the mafic constituents are altered to chlorite. Sphene constitutes up to 1 per cent of the rock in the thin sections examined. Minor constituents are principally epidote, pyrite, calcite, pyrrhotite, and rods of apatite up to 1 mm long. The diabase also contains scattered granophyric segregations and dyklets. These are composed of micrographic intergrowths of quartz and albite (An_{5-8}).

In places where a thin diabase dyke crosses a limestone bed, the dyke is extremely epidotized. This clearly indicates the assimilation of lime and the formation of lime-silicate minerals.

Only one thin section of a coarse-grained, brown lamprophyre was available for examination. It consists mainly of calcite, phlogopite, chlorite, and minor orthoclase, pyrite, quartz, and black iron oxides. This lamprophyre is the type known as minette.

Metasomatic Effects of Diabase Intrusions

Diabase intrusions commonly effect only minor alteration on wall-rock. In the syncline, feldspathic quartzites are bleached for a few feet from the contact, but hematite and chloritic alteration in joints and along bedding planes may extend up to 70 feet. Around Whiskey and Pecors Lakes and south of Stintson Lake, zones of albitization along joints and bedding planes in the quartzite are closely associated with diabase intrusions. These zones are commonly only a few inches thick, but south of Stintson Lake a zone 4 feet thick was seen. These albitized zones may contain as much as 60 per cent of fresh albite. The remainder is quartz and minor antiperthite. This conversion of a feldspathic quartzite to an albitite was probably accomplished by soda metasomatism. Soda-bearing solutions may have been derived from late stage differentiates of a crystallizing diabase magma.

Metasomatic replacement along joints, faults, and bedding plane have also been observed close to a diabase dyke in the ore zone at Nordic mine. This phenomenon is described in Chapter III.

Radioactivity in the Diabase

The presence of uranium minerals associated with chalcopyrite in granophyre masses in diabase sills was reported by Roscoe (1957a) from Rawhide and Cobre Lakes. These are 9 and 15 miles northwest of Quirke mine, respectively. It is significant to note that these deposits contain extremely small amounts of thorium.

Numerous diabase intrusions in the syncline were tested for radioactivity, but only one granophyre dyklet in a diabase near Teasdale Lake was more radioactive than the background. Furthermore, no conspicuous change in radioactivity was detected where diabase dykes cut the ore zone.

Structural Geology

No detailed study was made of the structures in the area but the following remarks may be of interest. They are based on information obtained from drill-holes, maps, underground workings, and a cursory examination of parts of the syncline.

Folds

The Huronian rocks have been folded into a syncline that plunges west at an angle of 1 degree to 18 degrees. The plunge is steepest in the Whiskey-McCool Lakes area, and decreases towards the west. East of Quirke Lake there is a slight deviation in the azimuth of the synclinal axis.

The north limb of the syncline dips 15° to 65°S, and the south limb 5° to 25°N. Dips up to 20°W were measured along the nose of the syncline at Whiskey Lake.

Secondary folds are fairly common locally. Robertson (1957) recorded an east-west trending syncline south of Ouellette Lake and a northeast-trending anticline northwest of May Lake (*see* Fig. 1). Stratigraphic horizons also are repeated in a number of drill-holes north of Poppy Lake and between Ouellette and May Lakes (*see* Fig. 6, section AB). It is difficult to ascertain whether these repetitions are the result of folding or reverse faulting. Folds and drag-folds at Hough Lake and along the west shore of Pecors Lake are attributed to faulting. However, Roscoe (1957a) concluded that small-scale drag-folds and the incipient slaty cleavage in the incompetent beds were probably formed during the period of major folding.

The brecciation, crumpling, distortion, and crenulation of bedding and laminations seen in the incompetent Whiskey and Espanola Formations were described previously and attributed partly to the incompetency of these units during faulting and folding and partly to soft sediment slumping.

Faults

The faults post-date the ore mineralization and no obvious change in the tenor of the ore has been recognized near faults. Most of the information about the faults is incomplete and contradictory and only the general features will be described.

The faults may be divided into three groups: east-west-trending, northwest-trending, and northeast-trending.

East-West-Trending Faults

One of the most important faults of this group is the low-angle thrust fault in the Quirke Lake area (Roscoe, 1957a). This thrust fault is visible in an outcrop south of the north shaft of Consolidated Denison mine and it has been traced westward by Abraham (1957). Its easterly continuation is less distinct, but it repeats the Bruce Conglomerate on the western islands in Quirke Lake. Displacement along the fault appears to decrease towards the east. The southerly continuation of this thrust fault has been established by diamond drilling and it repeats the ore-bearing conglomerates in the Spanish American and Stanrock mines (*see* Fig. 6, section AB). It dips 30°S, some 5 to 10 degrees steeper than the bedding at Consolidated Denison mine (Roscoe, 1957a), but the dip decreases towards the south. Vertical displacement on the thrust fault varies from 90 to 250 feet and the dip-slip movement from 900 to 1,800 feet. The intersection of the fault with the base of the Huronian rocks is shown in Figure 6, as well as the decrease in overlap to the north. In the western shaft of Spanish American mine the thrust fault is displaced by a northwest-trending fault. Another east-west fault was observed in underground workings at Stanleigh mine. It dips 50°S and has a vertical displacement of 20 feet. The north side has moved down relative to the south side. Many similar faults, with small displacements, have been observed in outcrops and in many of the underground workings.

Northwest-Trending Faults

Faults of this group are parallel with many of the diabase dykes and lineaments. Three prominent ones occur at Horne Lake, south of Hough Lake, and in the underground workings at Quirke mine (*see* Fig. 1). All have right-hand movement, the northeast sides having moved down relative to the southwest sides. The fault at Horne Lake has an apparent vertical displacement of 400 feet, but its displacement decreases towards the northwest (*see* Fig. 6). Bateman (1955) correlated the fault south of Hough Lake with the Webbwood fault some 30 miles to the southeast. Robertson (1957), however, found no evidence for the southeast continuation of this fault in the pre-Huronian basement, and the correlation is doubtful. The fault south of Hough Lake apparently cuts the northeast-trending faults. Another feature of this fault is the apparently large strike separation at Pecors Lake. This separation is difficult to assess, as little of the Matinenda

Formation was deposited in the southwestern part of Pecors Lake. Drill-hole data suggest that this area was a pre-Huronian topographical high. The pre-Huronian basement configuration may, therefore, exaggerate the actual strike separation.

Another fault with right-hand movement occurs north of Rangers Lake. The southwest side of this fault, however, has moved down relative to the northeast side.

Faults of this group with left-hand movement occur south of Elliot Lake and at Spanish American mine. Both have displacements in the opposite sense to those mentioned above, the southwest sides having moved down relative to the northeast. The fault at Spanish American mine displaces the east-west thrust fault and dips 65°NE. It has a vertical displacement of between 80 and 120 feet. Furthermore, lateral movement along the fault has been inferred from drill-hole data, the southwest block having moved southeast relative to the northeast block.

Northeast-Trending Faults

This group includes all faults that strike northeast or from N15° to 25°E. The most important fault of this group is at Hough Lake and shows the largest strike separation in the area. The east side of this fault has moved down relative to the west side. Other small faults belonging to this group are abundant in underground workings and outcrops. They commonly have displacements in the opposite sense to the fault at Hough Lake. Faults forming a graben in the western part of Consolidated Denison mine probably also belong to this group.

In addition to these groups, bedding plane faults and low-angle faults that dip slightly steeper than the bedding, are common underground.

A repetition of the Whiskey and Matinenda Formations was observed at Batty Lake. Dilatancy on the diabase intrusions does not seem sufficient to account for the entire repetition, and as shearing is present on the east shore of Batty Lake, a low-angle thrust fault is tentatively suggested.

Information from available geological maps shows that all northwest-trending faults and some of the northeast-trending faults cut the diabase intrusions. On the other hand, some of the diabase intrusions post-date a few of the northeast-trending faults, although they may be of the younger olivine type. The relationship between diabase intrusions and east-west trending faults is unknown.

Joints

The joints were not studied in detail but five sets of joints are present in the syncline. They are:

East-west-striking joints that are parallel with the strike of Huronian rocks and dip normal to the bedding.

North-south-striking joints.

Northeast-striking joints that are parallel with the northeast group of faults.

Northwest-striking joints that are parallel with northwest-trending faults, diabase dykes, and lineaments.

A set of joints that strike N80°W to N55°W. These joints create a mining hazard, especially where they intersect east-west-striking joints. Stope backs are there considerably weakened and require support. Methodical mapping of these joints would no doubt assist mining operations.

Joint planes are commonly stained with red iron oxide, and many are chloritized and sericitized. In rare cases they are albitized. As yet no appreciable amounts of radioactivity has been detected along the joint planes.

Chapter III

STRATIGRAPHY OF THE ELLIOT GROUP

The basal group of Huronian sedimentary rocks in the Quirke Lake syncline has tentatively been called the Elliot Group by Roscoe (1957a). It is subdivided into a lower, Matinenda Formation, and an upper, Nordic Formation. The Matinenda belongs to the subarkose suite, whereas the Nordic consists of interbedded lutites and arenites and occurs only along the south flank of the syncline. This group has been the subject of special study, the results of which are embodied in this report.

In this presentation the Matinenda Formation is further subdivided into a lower and an upper member. The lower member is mainly composed of coarse-grained subarkose, grits, and uraniferous oligomictic conglomerates, and the upper member of medium-grained subarkoses, quartzites, and nonradioactive polymictic conglomerates. Both the lower and upper members are present in most places along the south flank, but elsewhere in the syncline the entire Matinenda Formation is correlated with the lower member. This correlation is based entirely on lithological similarities, and does not imply time-stratigraphic equivalence. Actually, significant differences were detected between subarkoses from the southern and northern parts of the syncline.

Drill-hole data show that the Elliot Group varies in thickness from 0 to 950 feet, showing a general but decidedly non-uniform thickening from north to south as described by previous investigators (Roscoe, 1957a).

As the uraniferous conglomerates lie near the base of the lower member, distribution of this member is of paramount importance. An isopach map shows that it varies greatly in thickness and is missing in large areas of the syncline. Thick sections of the lower member occur in widely separated southeast-trending troughs that correspond with similar trending pre-Huronian valleys (*see* Fig. 6). The trend of these troughs in the lower member is also parallel with the direction of detrital transport inferred from crossbedding. It is believed that palaeocurrents first filled the pre-Huronian valleys with sediments and then spread a thin veneer over the intervalley areas. In local areas, probably corresponding to pre-Huronian hills and ridges, no sediments were deposited, and there the lower member of the Matinenda Formation is missing.

The upper member consists of arenites and rudites which have been more extensively winnowed and sorted than the sediments of the lower member. In many places this member overlaps the lower member. A lithofacies map of the lowermost conglomeratic unit of this member suggests that it was deposited in channels.

The Nordic Formation is present only along the south flank of the syncline and decreases in thickness towards the east. Lithological characteristics of arenites and lutites comprising this formation indicate intermittent deposition in deep water.

The base of the Nordic Formation is placed at a lowermost distinctive olive-green siltstone bed. This siltstone bed, 10 to 25 feet thick, is underlain by a fine-grained, sugary quartzite and overlain by an argillite-greywacke suite.

Roscoe (1957a) believed that the contact between the Matinenda Formation and the Nordic Formation was gradational and that the two formations intertongued. Not recognizing the olive-green siltstone layer as a reliable horizon marker, he noted that in many places quartzite was interbedded with greywacke in the lower part of the argillite-greywacke sequence and thought it was necessary arbitrarily to define the base of the Nordic Formation as "the horizon above which greywacke beds are thicker than intervening quartzite layers". The writer, however, has been able to trace the olive-green siltstone bed throughout the area in which the Nordic Formation occurs, and believes it is more logical to designate this bed as the base of the formation. This would slightly lower the position of the contact from that chosen by Roscoe in many places, but not everywhere, and most important it would automatically eliminate any possibility of an intertonguing relationship between the two formations.

Thus, the Matinenda Formation is defined to include all sedimentary units between the pre-Huronian basement and the lowermost, thick siltstone bed. Naturally, in areas where the Nordic Formation is absent, the Matinenda Formation includes all the sedimentary rocks from the pre-Huronian basement to the base of the polymictic boulder conglomerate of the Whiskey Formation. The Nordic Formation includes all sedimentary units between the base of the lowermost thick siltstone bed and the base of the polymictic boulder conglomerate of the Whiskey Formation.

Matinenda Formation

Distribution and Thickness

The Matinenda Formation varies in thickness from 0 to 340 feet in the northern part of the syncline and from 0 to 740 feet along the south flank. Regionally it thickens from the north to the south and west to east, but this trend is complicated by pronounced local thickening and the absence of the formation in many parts of the syncline. Thick sections commonly occur in southeast-trending troughs that reflect the topography of the pre-Huronian surface.

Subdivisions

Both Roscoe (1957a) and McDowell (1957) observed lithological differences between the upper and lower parts of the Matinenda Formation along the south limb of the syncline. They described the upper part as a white, fine- to medium-grained feldspathic quartzite with better sorting and rounding of clastic grains than the remaining arenites of the Matinenda Formation. Roscoe believed that the lower part grades upward and laterally to the southeast into the fine-grained upper part. Recent investigations, however, failed to support this gradational concept and a subdivision of the Matinenda Formation into an upper and lower member is tentatively suggested, the dividing line to be at a lower stratigraphic level than that suggested by either Roscoe or McDowell.

The reasons for such a subdivision are based on the following lithological and structural features:

1. The contact between the upper and lower members of the Matinenda Formation is sharp and easily recognizable in both drill-cores and outcrops. This contact is marked by a sharp change from the underlying yellowish green, ill-sorted, coarse-grained subarkoses to the overlying well-sorted, yellowish grey, medium-grained conglomeratic subarkoses. In some places, especially northeast of Elliot Lake and east of Pecors Lake, this change is indicated by a thick polymictic conglomerate displaying excellent graded bedding. Furthermore, the subarkoses and interbedded quartzite beds of the upper member are less feldspathic, less crossbedded, and more massive than the coarse-grained subarkoses of the lower member.

2. Figure 7 shows sections of the contact between the upper and lower members in the west shaft of Stanleigh mine. These sections clearly show the undulating contact between the two members, as well as the truncation of beds of the lower member by the conglomerate of the upper member. A similar undulating contact was observed in the east shaft of Stanleigh mine and the north shaft of Milliken Lake mine, but in neither of these was any evidence of truncation found. The truncation in the west shaft of Stanleigh mine may therefore be due to a local scour channel. The above-mentioned features suggest minor local erosion of the lower member prior to the deposition of the upper member—a break in sedimentation.

3. The upper member overlaps the depositional edge of the lower member (*see* Figs. 8 and 17), (Pienaar, 1958). This may be interpreted as the advance of a shoreline, but may also indicate local removal by erosion of the underlying unit. In view of the scouring observed in the mine shafts, perhaps the latter interpretation is the more acceptable.

The sharp contact and change of lithology, as well as the overlap relationship between the upper and lower members, must imply a perceptible change in depositional conditions. Furthermore, the scouring of the lower member prior to the deposition of the upper member clearly suggests a break in sedimentation. These features must have some genetic significance and warrant a subdivision of the Matinenda Formation.

The lower member is defined to include all the coarse-grained subarkoses and related rock types below the contact with the medium-grained conglomeratic subarkose unit, and the upper member to include rocks above it. In areas where the upper member is absent, the entire Matinenda sequence is correlated with the lower member. This correlation, as stated previously, is based entirely on lithological similarities.

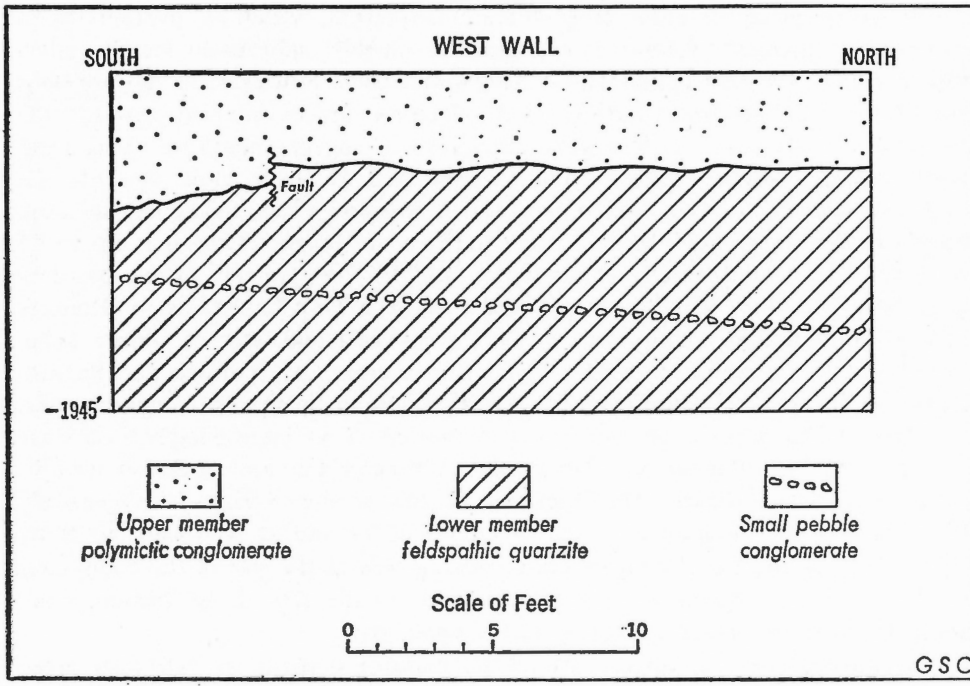

FIGURE 7. Section through part of Matinenda Formation in west shaft of Stanleigh mine showing contact between lower and upper members.

Lower Member

This member is composed of subarkoses of various types, pyritic uraniferous oligomictic conglomerates, and basal conglomerates. Its thickness ranges from 0 to 340 feet along the north limb of the syncline, and from 0 to 720 feet along the south limb.

The subarkose beds range from a few inches to 4 feet in thickness, and most are lenticular. Many are outlined by thin green siltstone partings. The conglomerate beds vary from layers one pebble thick to beds up to 10 feet thick. Other sedimentary structures are mainly crossbedding, but ripple-marks have also been observed. Trough crossbedding is the prevalent type, but planar crossbedding, though less abundant, is also present. The direction of detrital transport inferred from the crossbedding was from northwest to southeast (Fig. 20).

For descriptive purposes the lower member may be arbitrarily subdivided into lower, central, and upper parts. The lower part comprises the lithologically variable assemblage between the pre-Huronian basement and the base of the main uraniferous conglomerate zone. It varies from 0 to 130 feet in thickness. Where these rocks are absent the main uraniferous conglomerates rest on the pre-Huronian basement. The variation in thickness of this section probably reflects irregularities in the underlying pre-Huronian surface; it is thicker in the depressions and thinner or absent over ridges.

In some places a basal conglomerate is present, which is overlain by a brownish to greenish yellow, coarse-grained, pebbly subarkose locally interbedded with a few thin oligomictic conglomerate beds. However, in the northern part of the syncline, this coarse-grained subarkose grades laterally towards the southeast and east into a light grey, fine-grained, sugary subarkose. This local facies variation occurs mainly from Consolidated Denison mine towards the southeast, and east of Can Met mine towards Rangers Lake, thickening in these directions. At Poppy Lake it is 125 feet thick; near Rangers Lake it is up to 75 feet thick. The southeasterly continuation of this fine-grained facies becomes progressively less distinct from Poppy Lake towards May Lake. East of Rangers Lake its continuation is unknown. In local areas, east and west of Quirke mine, a similar facies variation up to 35 feet thick, is present. At Stanrock and Spanish mines it is up to 75 feet thick, and is directly overlain by the ore conglomerates.

The central part of the member is composed of an interbedded assemblage of highly pyritic, radioactive oligomictic conglomerates and greenish yellow, coarse-grained subarkoses. The thickness of this section varies; it is generally poorly developed southeast and east of Quirke Lake and at Whiskey and Batty Lakes. The thicknesses of conglomerate beds, as well as the size of the component pebble, decrease progressively from the bottom to the top of the section. Conglomerate beds are also less frequent in the upper part.

In most places the upper part of the member consists of yellowish green subarkoses and grits[1]. The thickening of the upper part commonly corresponds with a general increase in thickness of the entire member. From west of Stanleigh mine to Nordic mine the thickness of the lower member increases from 200 to 500 feet and that of the upper part correspondingly from 50 to 250 feet. A similar trend is present west of Stintson Lake. The upper part of the member is absent at Quirke mine and varies from 0 to 50 feet at Quirke Lake, but it increases rapidly to the southeast and is up to 550 feet thick at Batty Lake.

In addition to the lithological differences noted above, there is a general change in the character of the subarkose in the areas east of the Can Met and Panel mines shafts, and east of Poppy Lake towards Whiskey Lake. In these areas, beds of a grey, 'better washed' subarkose with a low matrix content are commonly intercalated with the normal impure greenish yellow type. This variation is attributed to more extensive winnowing of the 'better washed' beds. It is also significant that siltstone beds, mostly only a few inches thick, are up to 18 inches thick and more common in the above-mentioned areas. As such interbedded siltstones are normally accumulations of fine winnowed products, their abundance and thicknesses provide additional evidence for more extensive winnowing of sediments in these areas. Apparently, the environmental conditions under which the lower Matinenda sediments were deposited in the eastern and northeastern parts of the syncline, were more conducive to winnowing than those in the rest of the area. This is a general change of depositional conditions and excludes the facies variation at the base of the member.

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[1] A grit is defined as a sedimentary rock composed of angular to subangular, very coarse-grained and sand-sized particles.

Distribution and Structure

The distribution pattern of isopachs of the lower member (*see* Fig. 8) is characterized by several separate thick zones, roughly trough-like in appearance, separated by local areas of non-deposition. A large trough is present in both the northern and southern parts of the syncline. Two similar structures are present at Pecors and Whiskey Lakes in the southeastern part. Data on the areas between the trough in the northern part of the syncline and those in the southern part are lacking, and the continuation and lateral extension of these trough-like structures can in consequence only be assumed.

The thickness of this member varies within each trough, but generally increases from feather edges at the margins to a maximum thickness near the centre. Isopachal trends, especially in the thicker parts of the various troughs, are from the northwest to the southeast. As noted by Roscoe (1957a), this trend is roughly parallel with the direction of detrital transport, shown by the mean azimuth of the crossbedding (*see* Fig. 20). Such close correspondence between isopachal and crossbedding trends have also been described by Potter, *et al.* (1958) in the Chester sandstone of the Illinois Basin and by Wanless (1955) in the Pennsylvanian rocks of the eastern Interior Basin. Pettijohn (1957a) mentioned additional occurrences displaying a similar correspondence.

It is also interesting to note that the trend of these troughs is at an angle to the regional strike of the beds. Moreover they are linear and of limited length. These features suggest that strong strand line currents were not present during the deposition of this member, and favours an alluvial mode of deposition.

The influence of the topography at the time of sedimentation has been studied by comparing the isopach map (Fig. 8) with the structure contour map (Fig. 6). This shows the close correspondence between the troughs, especially the thicker parts of them, and the shallow valleys or depressions in the pre-Huronian surface. Furthermore, this member is absent over pre-existing hills and ridges. Thinning of the stratigraphic sequence in local areas is thus attributed to wedging out against buried hills. Although the presence of pre-Huronian hills in these areas is not always easy to detect on the structure contour map, the absence of the lower stratigraphic sequence of this member clearly suggests wedging out against an ancestral hill. Such effects of base configuration on sedimentation have been described by Wanless (1955) in the Pennsylvanian rocks of the eastern Interior Basin and by Wilson (1948) in the Oligocene rocks of Baja California, Mexico, and are probably very common. In some places this pre-Huronian relief, as stated previously, is due to differential erosion between the granite and metavolcanic rocks.

The individual troughs exhibit peculiarities that need further description. An area of nondeposition, denoting a pre-Huronian ridge, occurs southeast of Stanrock mine in the northern trough and extends eastward between Ouellette and May Lakes (*see* Fig. 8). The thin stratigraphic sequence between Can Met and Stanrock mines, as well as southeast of these properties, indicates the northwesterly extension of this ancestral ridge. The distribution of the Matinenda Formation on the north and south flank of this pre-Huronian ridge suggests that it divided the main trough into two parts. The main branch of the trough apparently lay along the south flank of the pre-Huronian ridge, whereas the Matinenda rocks along the north flank of the ridge were deposited in a subsidiary trough that extends eastward from Panel and Can Met mines.

The two main occurrences of the fine-grained facies at the base of the formation in the northern trough are also along the north and south flank of the ancestral divide. The northern occurrence extends eastward from Can Met mine and Rangers Lake, and the southern southeasterly from Consolidated Denison mine to Poppy Lake. The southern attains a maximum thickness of 125 feet at Poppy Lake.

The absence of the lower member along the north rim of the syncline, except around Quirke mine, is also credited to nondeposition over topographical highs. This topographical influence is clearly illustrated east and west of Quirke mine, where the member accumulated in local depressions between hills. The stratigraphic thinning around and over tongue-like projections of granite is clearly shown at Panel and Quirke mines, and thus substantiates the idea of differential erosion between granites and metavolcanic rocks.

The Matinenda Formation thickens locally at Consolidated Denison mine and east of Panel mine. It thins from Consolidated Denison mine southeast to Stanrock mine, but thickens again farther southeast towards May Lake. Such a trend is different from the normal isopachal trend and is difficult to explain.

The trough at Pecors Lake is separated from that at Whiskey Lake by an area of nondeposition that overlies a pre-Huronian hill. The lower member attains a miximum thickness of 400 feet at Pecors Lake and 700 feet at Whiskey Lake. Although critical data are lacking, it is believed that both these troughs are connected with the northern trough.

The most striking isopachal trend in the southern trough is from Stanleigh mine in the northwest to Nordic mine in the southeast. This trend reflects deposition in the deepest pre-Huronian valley in the trough. Stratigraphic thinning on both the northeast and southwest flanks of this valley clearly indicates wedging out against pre-Huronian ridges. The anomalous thinning north of Nordic mine and north of Milliken Lake mine is credited to the influence of local pre-Huronian topographical highs. The wedging out of the lower member towards the northwest in the area west of Stanleigh mine is also attributed to the presence of a pre-Huronian ridge. However, drill-holes west of the latter ridge suggest that a subsidiary trough is present in the Elliot Lake area.

Farther east, in township 143, the lower member is uniformly distributed, with a general thickening to the south except for a local subsidiary trough west of Stintson Lake. In this area the member is separated from its counterparts in troughs farther east and north by a narrow strip of nondeposition extending from the western part of Pecors Lake to Flying Goose Lake. This narrow strip of nondeposition is also crossed by two large faults that undoubtedly disrupt the pre-Huronian structure contours and thus obscure detection of a ridge. However, drill-holes not influenced by either of these faults provided the evidence for nondeposition of this member, which most likely indicates a pre-Huronian ridge. The northwesterly continuation of this ridge is unknown.

The two main ore-bearing troughs (townships 149 and 150), as partly outlined by drill-hole data, trend southeast and are separated by a gap of 4½ miles wherein the only subsurface information available is provided by a single drill-hole southeast of Dunlop Lake. This hole intersected a substantial thickness of lower Matinenda-type strata, suggesting that it is located within or on the flank of a trough. It is unlikely that these rocks represent a southerly extension of the northern trough, or a connection between the two troughs, as the southern boundary of the northern trough seems to be fairly well defined by isopach data from drill-holes. The northern boundary of the southern trough is not yet well known, however, and perhaps the isolated drill-hole suggests that this trough may have a substantial extension towards the north. The several drill-holes explored for the northwesterly continuation of the southern ore zone seem to have intersected the Matinenda Formation where it overlies a basement ridge. It is possible that they were located too far to the west to discover the extension, if any exists, of the ore zone.

It may be concluded that the lower member of the Matinenda Formation was deposited on a pre-Huronian surface, characterized by an intricate pattern of valleys and hills or ridges. All these valleys and ridges trend from northwest to southeast or, rarely, west to east. Maximum relief, as far as can be ascertained, never exceeded 250 feet.

Main Uraniferous Conglomerate

The areal distribution of the main conglomerate zones corresponds closely with that of the thick accumulations of the lower member in the troughs along the north and south flank of the syncline. Generally, the conglomerates are thicker and more abundant where this member is thick along pre-Huronian valleys, than in the flanking areas (Roscoe, 1957a). The linear trend of the areas containing the conglomerates is parallel with the prevalent isopachal trend. Furthermore, all the productive mines occur along two 'valleys' that contain the thickest conglomeratic sequences known in the area.

Conglomerate zones and layers are mainly confined to the lowermost stratigraphic sequence of the lower member, although along the south limb of the syncline conglomerates are as much as 150 feet above the pre-Huronian basement and on the north limb up to 280 feet above it. These zones wedge out against the pre-Huronian ridges or hills. In some parts, the lower beds wedge out in this manner and the upper beds continue over the ridges. This was observed east of Nordic and Lake Nordic mines. At many local highs the conglomerates rest directly on the pre-Huronian basement.

The conglomerate zones are generally lenticular, especially those high in the sequence. These are also less continuous than the thicker conglomerates lower down and may lens out in relatively short distances. The feldspathic quartzite or subarkose beds vary in thickness and are also commonly lenticular. Some of the thick conglomerates in the lower part of the sequence are blanket-like in appearance and are continuous over large areas. In most cases, such conglomerates form the ore zones.

The packing[1] and character of the conglomerates change from place to place. The conglomerate may change laterally from a well-packed rudite to an interfingering assemblage of well-packed to loosely packed conglomerate, to conglomeratic and pebble-free feldspathic quartzite.

It is possible to correlate individual conglomeratic zones and some individual beds from drill-hole to drill-hole through considerable distances. These correlations have been studied in detail (Pienaar, 1958) but cannot be simply diagrammed. Some of the more important correlations, tentative correlations, and problems in correlation are summarized below.

The main conglomeratic zones in Milliken and Lake Nordic mines can safely be correlated. The pertinent stratigraphic section there, from basement upwards, can be summarized as follows:

(1) local basal conglomerate
(2) 0 to 50 feet of subarkose (mainly pebbly)
(3) 5 to 15 feet of conglomerate with interbedded subarkose
(4) 0 to 15 feet of subarkose
(5) 15 to 20 feet of conglomerate with interbedded subarkose
(6) 15 to 20 feet of subarkose
(7) 5 to 15 feet of conglomerate with interbedded subarkose.

Most of these units can be traced northwest to the Stanleigh mine and southeast to Algom-Nordic mine—in other words, throughout the southern trough—with a fair degree of confidence. Unit (5) is the main ore-bearing conglomerate zone in all the mines. Unit (3) is a secondary source of ore, important only in the Lake Nordic and Milliken Lake mines. Unit (7) is not considered an ore source as yet but some sections approach ore grade, notably in the northern part of the trough. Unit (6) is a particularly useful horizon marker.

The main conglomerate zone intersected in holes east of the southern trough most probably corresponds to unit (5) above.

The distribution of conglomerates in the northern trough is much more complex than that in the southern trough. The zone containing important conglomerates extends southeast from the Algom-Quirke mine and underlies most of Quirke Lake, corresponding roughly to the poorly defined limits of the trough itself, as described previously. Thin conglomerate beds separated by substantial thicknesses of subarkose beds were encountered in drill-holes southeast and east of the area wherein the trough can be considered reasonably well defined. At Algom-Quirke mine the entire Matinenda Formation is more or less conglomeratic, but it contains a central well-defined conglomeratic zone. In the western and central parts of the Consolidated Denison property, there are several well-defined conglomeratic zones within the formation but the lowermost zone appears to be

[1] The packing of conglomerates was determined by an approximate visual estimation of the volume of gravel components. Subdivisions are as follows:

Conglomeratic subarkoses	—less than 15 per cent pebbles.
Loosely packed conglomerate	—between 15 and 40 per cent pebbles.
Well-packed conglomerate	—greater than 40 per cent pebbles.

the most persistent and is the ore-bearing zone. Locally it rests on the basement but farther east it is as much as 140 feet above basement. Another conglomeratic zone lies near or at the top of the formation, about 150 feet above the main ore zone. It is problematical whether the main ore conglomerate at Algom-Quirke mine should be correlated with the lower or the upper conglomerate at Consolidated Denison, as drill-holes near the boundary between the two properties are widely spaced. The writer has however tentatively correlated it with the lower one (Pienaar, 1958). Farther east and south on Consolidated Denison ground, the upper conglomerate is absent, apparently truncated by the overlying Whiskey boulder conglomerate formation. The lower conglomerate zone, up to 50 feet thick in some places and locally subdivisible, appears to extend south and east through the remainder of the trough and includes the ore zones (or highest grade intersections) in the Spanish American, Stanrock, Panel, Can Met, Conecho, and Roche Long Lac properties. More than one conglomerate zone was intersected in several of the Panel drill-holes, however, so the correlation of the ore zone at Panel and Can Met with that at Consolidated Denison is by no means certain.

North of Elliot Lake and west of the main southern trough drill-holes intersected loosely packed conglomerates, interbedded with thick subarkose beds. South of Elliot Lake a few oligomictic conglomerate zones are present, but most are less than 4 feet thick. East of Nordic and Lake Nordic mines the conglomerates are sheet-like in character, with minor local variations in thickness. These conglomerate zones extend eastwards to Pecors Lake, and wedge out against the pre-Huronian ridge in that area.

A conglomerate zone of substantial thickness has been found in the lower member of the Matinenda Formation at Pecors Lake in township 137 (*see* Fig. 6). Exploration of this trough is not complete and the areal extent of these rudites is unknown. Thin conglomerate beds are also present in the trough at Whiskey Lake, township 137. However, they are extremely lenticular and only present in local areas at the base of the lower member.

The close correspondence between the areal distribution of the conglomerates and the thicker sections of this member indicates that most of the rudites in the sequence were deposited in the original depressions. This clearly illustrates the economic importance of knowing the distribution of the lower Matinenda member, especially the abnormally thick parts, and recognizing the influence of the pre-Huronian topography.

Petrography

Basal Conglomerate

These conglomerates occur at the base of the lower member of the Matinenda Formation and are erratically distributed over the syncline. They vary in thickness from a few inches to 25 feet. A large percentage of their gravel components was derived from the underlying rocks but in most beds these materials have been transported and many pebbles have been added from a foreign source.

Composition varies from place to place. Most occurrences consist mainly of cobbles and pebbles of metavolcanic rocks, quartz, and, rarely, granite. The matrix is impure quartzite composed of quartz, feldspar, angular chloritic fragments, and fine white mica. Pyrrhotite is the most abundant sulphide and commonly occurs in massive form at the base. Disseminated grains of subrounded to euhedral pyrite, up to 5 mm across, are also present. Marcasite is commonly associated with chlorite and calcite close to fractures in the conglomerates.

This conglomerate is noticeably radioactive at Nordic mine and southeast of Stintson Lake. Radioactive minerals are principally zircon and monazite, but a few interstitial grains of highly radioactive material, identified as a two phase uranium-titanium compound[1], were observed in samples from Nordic mine.

Another type of basal conglomerate is present in the northwestern part of Quirke Lake and has been described by Roscoe (1957a). It consists of pebbles and cobbles of metavolcanic rocks, quartz, and, rarely, granite and meta-quartzite, embedded in an arkosic matrix. Pyrrhotite, and rounded pyrite grains up to 10 mm across are present.

A polymictic conglomerate resembling the Bruce Conglomerate was noted at the base of the Huronian sedimentary rocks northeast of Pecors Lake, township 137, and southwest of Stintson Lake. This polymictic conglomerate consists principally of boulders, cobbles, and pebbles of metavolcanic rocks, quartz, and a few of granitic rocks. The matrix varies from a quartzose greywacke to an impure quartzite. Disseminated pyrite and pyrrhotite occur in minor quantities. The unsorted nature of this conglomerate is indicative of mass transportation of debris.

The basal conglomerates are probably debris accumulated in local depressions in the pre-Huronian basement.

Fine-Grained Basal Subarkoses

Fine-grained, sugary subarkose or feldspathic quartzite occurs at the base of the lower member of the Matinenda Formation in the northern part of the syncline, and in several places overlies the basal conglomerates. Distribution of this rock type is shown on Figure 8.

The basal subarkose is commonly interfingered with the coarse-grained subarkoses along their mutual boundary, and is considered to be a facies variation of it. Where the fine-grained subarkose is massive, particularly around Spanish American and Stanrock mines, it is considered to be a reliable horizon marker (Brochure, 1957). There the ore-bearing conglomerate lies directly on this unit.

Although this subarkose is generally even and fine grained, some coarse-grained layers are present locally. It is normally light grey, but greenish layers are rather common. It is extensively brecciated and fractured, which may have resulted from faulting or from folding of such a massive unit. The greenish layers are probably due to sericitization along the fractured and brecciated zones.

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[1] This metamict two phase uranium-titanium compound is generally referred to as brannerite, but no identifiable X-ray diffraction pattern was obtained in this study.

The fine-grained subarkose is composed of subrounded, sand-sized grains of quartz, microcline, and altered plagioclase embedded in a fine white mica matrix. The average potash feldspar:soda feldspar ratio is 6. Minor constituents are principally calcite, black iron oxides, pyrite, and, rarely, titanite. Sorting is fair to good and the sorting index ranges from 10 to 25, but may be as high as 80 in the grit layers.

Several veinlets of white mica and calcite were observed in thin sections. Quartz grain boundaries are serrated and several grains that appear to have recrystallized were noted.

The modal analyses of these arenites are shown graphically in Figure 9. Most contain more feldspar and slightly less matrix than the coarse-grained subarkoses from the north limb. The average low matrix content, fair sorting index, and rounding of clastic grains suggest that this fine-grained subarkose is a texturally submature arenite, which in turn implies fair winnowing at the depositional site.

Coarse-Grained Subarkoses

The coarse-grained subarkoses and grits constitute most of the lower member. Their distribution has previously been discussed.

The clastic grains are commonly subangular to subrounded and range from fine- to coarse-grained, sand-sized particles. In some grit layers, small pebbles of quartz and microcline are present, but are mostly distributed at random. The colour of these arenites varies from greenish yellow to brownish yellow.

Individual grains are principally quartz, microcline, altered plagioclase, and chert embedded in a fine white mica matrix. Occasionally a few shreds of chlorite and calcite are also present in the matrix. The average potash feldspar:soda feldspar ratio from sixteen thin sections is 8.1. The subarkoses are poorly sorted and the average sorting index is 71. This sorting index is much higher than that of other Huronian subarkoses.

Plagioclase grains are always partly replaced by fine white mica and tongue-like projections and embayments of this mineral are common in microcline and other clastic grains. Serrated grain boundaries are ubiquitously present, the result of small embayments of fine white mica along the edges of clastic particles. Quartz grains exhibit strain shadows and many show incipient recrystallization. Effects of cataclastic deformation are clearly illustrated by the crushing and fracturing of clastic grains. In one section, fine white mica, as well as a small grain of zircon, was found in the fracture of a large quartz grain and probably indicates forceful injection.

Minor constituents, forming less than 1 per cent of the arenites, are mainly pyrite, calcite, chlorite, zircon, and, rarely, leucoxene-coated black iron oxides and monazite. Grains of monazite and zircon show evidence of rounding, but the others are mainly anhedral to subhedral in outline. Pyrite, the most abundant minor constituent, is mainly present as disseminated grains in the interstices, but also occurs as seams along the bedding and crossbedding. The pyrite grains contain abundant inclusions of quartz and fine white mica and many replace clastic particles.

In a few of the thin sections veinlets of quartz, pyrite, calcite, chlorite, and epidote were observed. These veinlets may be related to later hydrothermal activity, but there is no noticeable alteration in the adjacent wall-rocks. A few veins of thucholite (a hydrocarbon composed of various amounts of carbon, oxygen, uranium, and thorium) and galena, and some of molybdenite have been noticed in drill-core.

Another noteworthy feature of the subarkoses is the absence of cementing material, authigenic overgrowths, and second cycle quartz grains. The absence of cementing material and overgrowths is indicative of the impermeability of the subarkoses. The absence or apparent absence of second cycle quartz grains suggests that the detritus comprising the subarkoses is predominanty first cycle derivatives from a plutonic source rock.

Modal analyses of the arenites of the lower member are plotted on Figure 9. All but four of the samples fall within the subarkose field. Three of these four exceptions are grits, which commonly have more matrix than the subarkoses and thus fall in the greywacke field. The fourth sample falls in the arkose field, and merely indicates an abnormally high feldspar content.

Figure 9 also shows that the subarkoses from the north limb of the syncline contain substantially less feldspar than those from the south limb. Subarkoses from the northern trough include a sample from the Whiskey Lake area, as well as two samples of better washed subarkoses, and those from the southern trough include a sample from Pecors Lake area (Fig. 8).

The high sorting index, the high average matrix content, and poor rounding of the clastic grains of the subarkoses, clearly show their textural immaturity. This textural immaturity implies the overall lack of winnowing and rapid deposition of the subarkoses. This kind of environmental condition probably existed in most of the depositional sites in the syncline, except in the northeastern and eastern parts. In those areas poorly winnowed subarkoses are interbedded with some that are better washed. Modal analyses of two of these from the north limb of the syncline are shown on Figure 9. They have much less matrix than the other subarkoses, and thus confirm the more extensive winnowing.

The origin of the incipient replacement textures, pyrite, and the high white mica (sericite?) content of the subarkoses is of paramount importance, as these arenites are intimately associated with the uraniferous conglomerates. If, therefore, the uranium was introduced after the rock was formed, the imprints of such a mineralization should be evident in the subarkoses. The randomly distributed veins and veinlets, as well as local albitization near diabase intrusions, might be cited as evidence for later hydrothermal activity. It is however uncertain if all these veinlets are of hydrothermal origin; some may be due to metamorphism. The incipient replacement textures and abundance of white mica are regional features present in all Huronian arenites and therefore cannot be entirely due to local hydrothermal activity. It is unlikely that hydrothermal fluids

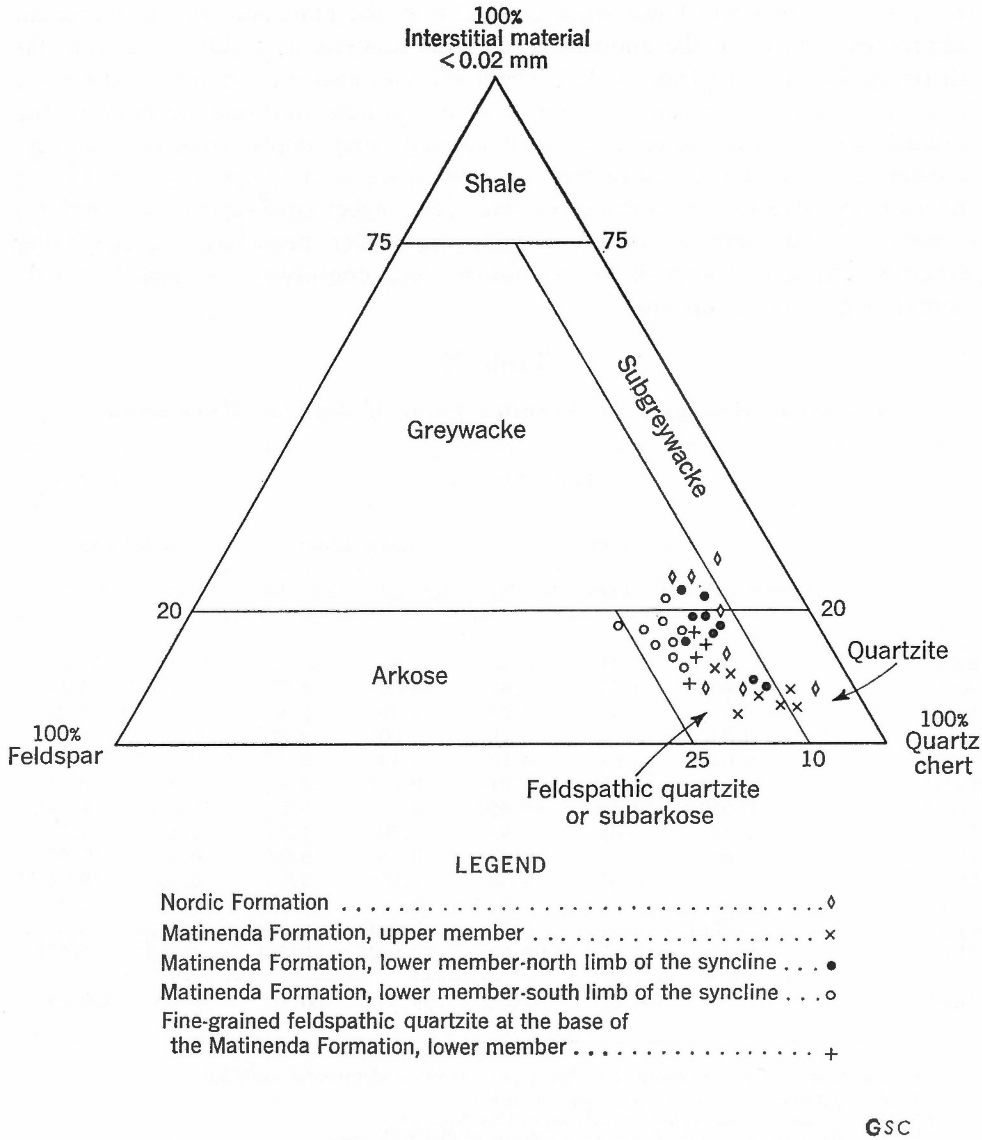

FIGURE 9. Mineralogical classification of arenites from the Elliot Group.

could have pervaded all the rocks as most of them, including subarkoses, are relatively impermeable. Mineralogical adjustments and recrystallization of clay minerals under metamorphic conditions may account for the development of the incipient replacement textures and the white mica respectively.

Chemical Analyses

Five chemical analyses of the subarkoses are given in Table X. These analyses are typical of siliceous feldspathic arenites. They have a higher average alumina and potash content and lower silica content than the remainder of the Huronian subarkoses, except for the anomalous chemical analysis of a subarkose from the Mississagi Formation (Table VIII). These analyses also show that the subarkoses have an abnormally low soda and lime content. As lime and soda are both mobile residual oxides, their presence in small amounts may imply extensive chemical weathering of the debris comprising the subarkoses or a source that was low in these oxides. This feature is discussed later. The higher combined water (900°C) content of some samples merely reflects the higher percentage of micaceous minerals. The low content of the remaining oxide constituents is typical of sedimentary rocks and means little.

Table X

Chemical Analyses of Arenites from Matinenda Formation

	Lower Member					Upper Member	
	North Limb			South Limb		South Limb	
	RF-641	RF-1146	RF-760	RF-250	RF-786	55-81	55-71
SiO_2	89.31	91.44	81.28	81.82	83.62	89.36	93.72
Al_2O_3	7.40	5.20	10.40	10.00	9.70	3.92	3.69
Fe_2O_3	0.41	0.45	0.27	0.79	0.66	0.76	0.24
FeO	0.09	0.00	0.18	0.00	0.00	0.13	0.13
MgO	0.06	0.07	0.10	0.14	0.15	0.37	<0.01
CaO	0.050	0.018	<0.018	0.037	<0.018	0.66	0.15
Na_2O	<0.050	<0.050	<0.050	0.15	0.205	<0.050	<0.050
K_2O	2.19	2.05	3.95	5.40	4.90	2.18	1.75
H_2O(100°)	0.06	0.03	0.03	0.05	0.02	0.06	0.04
H_2O(900°)	0.99	0.60	1.34	1.05	0.92	0.40	0.24
TiO_2	0.18	0.21	0.11	0.16	0.18	0.14	0.10
ZrO_2	0.0064	0.0112	0.0036	0.064	0.0039	0.0168	0.0072
MnO	<0.001	<0.001	<0.001	<0.0020	<0.001	0.0030	0.021
Total	100.75	100.06	97.76	99.56	100.36	98.00	100.09

All samples from drill-core except RF-786, which is from underground workings.
RF-641 Subarkose—Consolidated Denison mine.
RF-1146 Winnowed subarkose—northeast of Can Met mine.
RF-760 Basal fine-grained subarkose, southeast of Stanrock mine.
RF-250 Subarkose—Milliken Lake mine.
RF-786 Subarkose—Nordic mine.
55-81 Subarkose—northwest of Stintson Lake.
55-71 Quartzite—west of Stanleigh mine.
Analyses by G. MacDonald, Miller Research Laboratory, Queen's University.

A comparison of the chemical analyses of the subarkoses shows important compositional differences. Subarkoses (samples RF-250 and RF-786) from the south limb of the syncline contain generally more potash and soda and less silica than those from the north limb (RF-641, 760 and 1146). Such a variation confirms the difference in feldspar content determined by petrographic examinations of the subarkoses from these localities.

A sample (RF-641) from the north limb contains more alumina and less silica than the 'better washed' sample (RF-1146) from the same locality. The relative reduction of the alumina and the increase in silica in the 'better washed' subarkose is attributed to better winnowing, resulting in the removal of aluminous clay minerals. This substantiates the concept that these were more extensively winnowed than the normal subarkoses.

The sample of the fine-grained basal subarkose (RF-760) has more alumina and potash and less silica than other subarkoses from the north limb. It also has a higher alumina and lower potash content than those from the south limb. The higher potash content of this fine-grained arenite than that from the other subarkoses from the north limb is due to its higher feldspar content (Fig. 9). However, its high alumina content is difficult to explain, particularly as it generally has less matrix than the other impure arkoses. This anomaly may be because the sample analyzed had more matrix than normal.

Trace Elements

The results of qualitative spectrographic analyses of *trace elements* in the subarkoses are graphically illustrated in Figure 10, and are tabulated in Table XI.

Table XI

Trace Elements in Arenites from Matinenda Formation

Sample	Cr	V	Ni	Co	Cu
55–71	0.0017	<0.0015	<0.0007	<0.0010	0.0008
55–81	<0.0009	<0.0015	<0.0007	<0.0010	0.0017
RF–250	<0.0009	0.0023	<0.0007	<0.0010	0.0014
RF–760	<0.0009	<0.0015	<0.0007	<0.0010	0.0029
RF–1146	<0.0009	<0.0015	<0.0007	<0.0010	0.0017
RF–641	<0.0009	<0.0015	<0.0007	<0.0010	0.0029

Location of samples as in Table X.
Analyses by G. MacDonald, Miller Research Laboratory, Queen's University.

The trace elements show nearly the same intensity in all the subarkoses, except for the erratic distribution of B, Ag, and Mo. Later in this chapter it is shown that Mo and Ag were introduced in an altered zone near a diabase dyke. The presence of these elements in the subarkoses may therefore be related to local introduction. Very little is known about the geochemical behaviour of B during sedimentary processes; perhaps it is fixed in tourmaline in the hydrolyzates.

Lead commonly substitutes for potassium in potash feldspar and in the subarkoses may be associated with the microcline. Gallium follows alumina closely in the geochemical cycle and is undoubtedly related to the aluminous minerals in the matrix of the arenites.

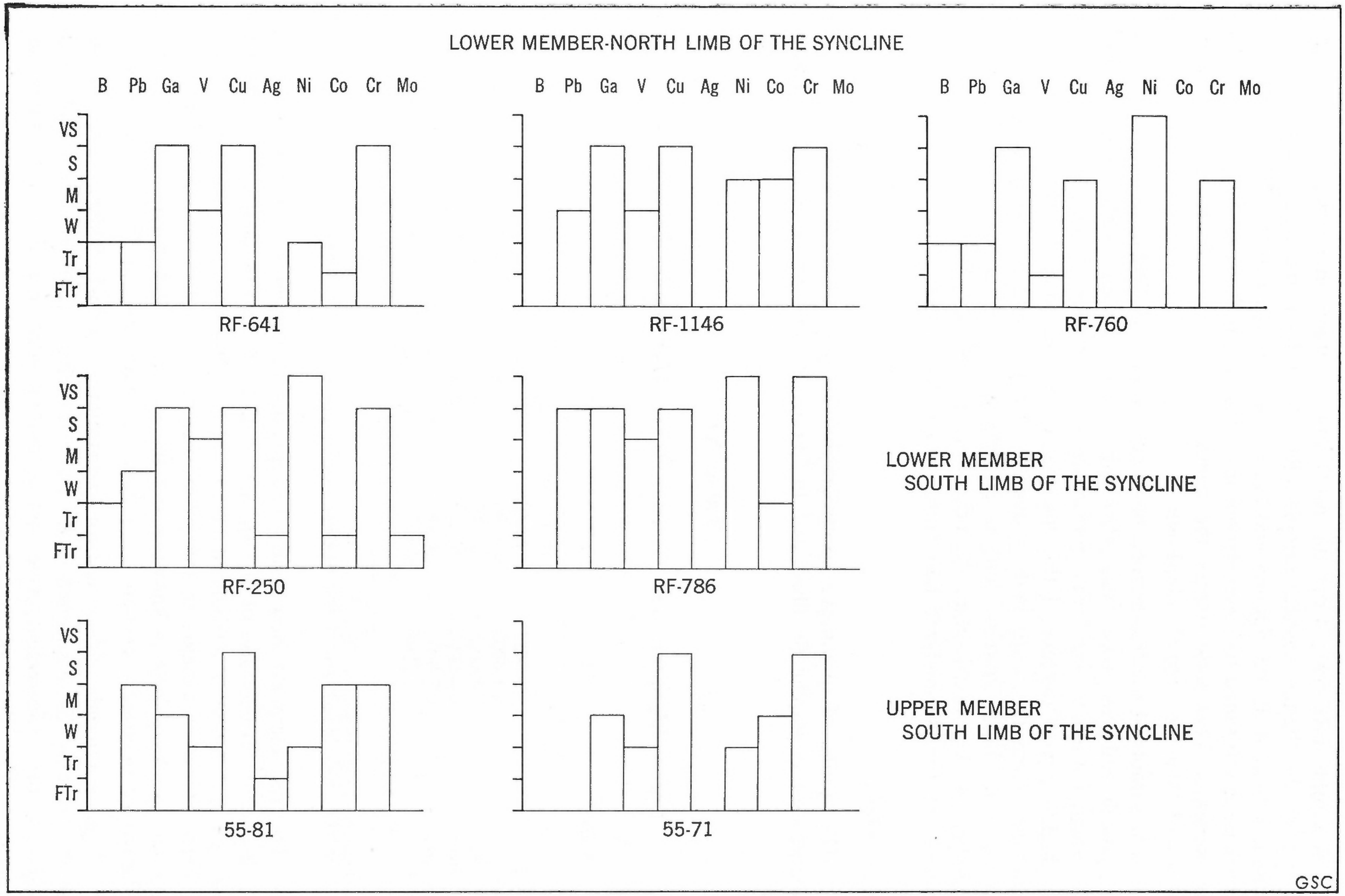

FIGURE 10. Trace element content in subarkoses and quartzites from the Matinenda Formation.

Copper, vanadium and chromium occur mainly in the micaceous minerals in the matrix. Their abundance is markedly reduced by washing the pulverized samples. Nickel and cobalt vary in intensity in different arkoses, but the significance of this variation is uncertain. They also may be fixed in the hydrolyzates of the matrix (Rankama and Sahama, 1950).

Interpretation

The predominance of potash feldspar over plagioclase is the most striking compositional characteristic of the subarkoses from the lower member of the Matinenda Formation. Chemical analyses also confirmed the abundance of potash and the virtual absence of soda. As soda is a more mobile oxide than potash, it may have been removed during intensive chemical weathering of the source rock or the source rock may never have contained much.

The chemical maturity is a measure of the degree of chemical weathering of a sediment and may be expressed by the $Al_2O_3:Na_2O$ ratio (Nanz, 1953). The average $Al_2O_3:Na_2O$ ratio of these subarkoses exceeds 60, which is much higher than the average ratio for orthoquartzites given by Pettijohn (1957a). As an orthoquartzite represents the end product of chemical maturity, the high $Al_2O_3:Na_2O$ ratio of these subarkoses is probably due to factors other than intensive chemical weathering. Furthermore, the general coarse-grained texture of these subarkoses is incompatible with intense chemical weathering of a plutonic source rock.

Pettijohn (1957a) used the quartz:feldspar ratio as another method of expressing the mineralogical maturity of arenites. The average quartz:feldspar ratio of these subarkoses is 3.8. This ratio indicates mineralogical immaturity, which probably reflects poor chemical weathering of the detritus comprising the arenites.

Most of the evidence then favours poor chemical weathering of the subarkoses of the lower Matinenda member, and their low soda content must therefore imply that the constituent material came from a soda-impoverished source. The nature of the source area of an arenite is generally difficult to evaluate with certainty, due to the contribution of detritus from secondary sources.

The subarkoses of the lower member contain no rock fragments except chert, which constitutes less than 2 per cent of the total rock. This implies that the clastic detritus of arenites was mainly derived from plutonic rocks and any contribution from metasediments was insignificant. Furthermore, the abundance of potash feldspar favours a granitic source rock.

Both the chemical analyses and petrographic investigations reveal important compositional differences between subarkoses from the north limb and those from the south limb of the syncline. A summary of these differences is shown in Table XII.

From Table XII it is evident that the subarkoses from the north limb contain more silica and quartz and less soda, potash, alumina, plagioclase, and potash feldspar than those from the south limb of the syncline. Although these differences are small, they clearly show the higher residual character of the subarkoses from the north limb than those from the south limb. Kennedy (1951) detected a similar increase in the residual character of Torridonian arkoses and Norwegian sparagmites from the northwestern to the southeastern parts of the Caledonian geosyncline. He attributed this phenomenon to chemical grading of sediments; undifferentiated sediments accumulated closer to the source area and the differentiated sediments farther away.

Table XII

Compositional Differences of Subarkoses from North and South Limbs of Quirke Lake Syncline

	North limb[1] average		South limb average	
SiO_2	87.38	(3)[2]	82.72	(2)
Al_2O_3	7.66	(3)	9.85	(2)
Na_2O	0.050	(3)	0.178	(2)
K_2O	2.73	(3)	5.15	(2)
Quartz and chert	70.25	(13)	63.63	(8)
Plagioclase	1.83	(13)	2.65	(8)
Potash feldspar	14.17	(13)	18.25	(8)

[1]The subarkoses from the north limb include the basal fine-grained and winnowed subarkoses.
[2]Designates the number of chemical analyses or thin sections studied.

In the Quirke Lake syncline detrital transport was from northwest to southeast, but the decrease of residual character is from north to south. Thus the sedimentary differentiation proposed by Kennedy to account for differences in the residual character of Caledonian arenites does not explain a similar trend in the Quirke Lake syncline. However, another explanation is offered to account for the compositional variation in the latter area. It is suggested that sedimentation commenced in the northern part of the syncline, and that regolithic detritus from this source was laid down by earliest paleostreams. Subsequent migration of the paleostream towards the southwest, while still maintaining a southeasterly course, might have resulted in the deposition of sediments from a less weathered source in the southern part of the syncline.

The sugary, fine-grained, basal subarkoses may have resulted from continued reworking of the particles under shallow-water conditions and slow sedimentation (Brochure, 1957). This may explain the uniform grain size of these arenites, but does not account for the high labile constituent and matrix content. Both labile constituents and matrix material are commonly removed during the reworking of a sandstone. These arenites are probably an accumulation of material washed from normal coarse-grained subarkoses deposited farther to the northwest.

Oligomictic Conglomerate

The uraniferous, pyritic, oligomictic conglomerates are most abundant near the base of the lower member of the Matinenda Formation, but may occur as much as 280 feet above the base. Although the degree of radioactivity varies in the different conglomerate beds, as well as within a single bed, they are markedly more radioactive than the Huronian arenites and the polymictic conglomerates.

The conglomerates range from layers one pebble thick to beds as much as 10 feet thick. The thickness of individual beds is extremely variable and the beds may lens out completely. Closely spaced conglomerates interbedded with conglomeratic subarkoses and pebble-free subarkoses form conglomerate zones up to 50 feet thick. Several such zones are present in some sections and may be separated by as much as 150 feet of subarkose with only occasional thin conglomerate beds. These conglomerate zones are fairly persistent and some can be traced for considerable distances.

Gravel components vary in size from pebbles less than 10 mm across, to cobbles. These rudites are generally poorly sorted, but some well-packed beds show size gradation of the gravel components from the top to the bottom of the bed (Roscoe, 1957a). The packing of the conglomerates also varies, and well-packed beds grade imperceptibly into those that are loosely packed or into conglomeratic subarkose.

The ore zones, varying from 8 to 32 feet in thickness, consist of variously interlayered assemblages of conglomerates, and conglomeratic and pebble-free subarkoses. In many places the ore zones are only a part of a much thicker interlayered conglomeratic assemblage.

To date, diamond-drilling has outlined two main areas underlain by ore-bearing zones. These areas cover abnormally thick valley-like accumulations of the lower Matinenda member and their distribution was discussed previously. One of these zones lies along the north limb of the syncline and includes six mining properties. It is 5 miles long and up to 2 miles wide, and extends from Quirke mine in the northwest to Stanrock mine in the southeast (*see* Fig. 1). The other area occurs along the south limb of the syncline, and extends northwestward from Nordic mine to Stanleigh mine. It is 4 miles long and up to 1½ miles wide, and includes five mining properties.

In many localities several ore zones are found at different stratigraphic levels. They are known locally as upper, middle, and lower ore zones. Generally, the upper zones are substantially thinner than the lower zones.

The ore zones consist of multiple sedimentary units that are generally lenticular and intricately interlayered (*see* Fig. 11A). These sedimentary units are mainly well-packed and loosely packed conglomerates, and conglomeratic and pebble-free subarkoses. Gradations between the different lithological types are common. At Consolidated Denison mine the ore zone is divisible into an upper and lower conglomerate separated by a zone of conglomeratic and pebble-free subarkose beds. The thickness of these divisions, however, varies widely and the conglomerates themselves are composed of several sedimentary units.

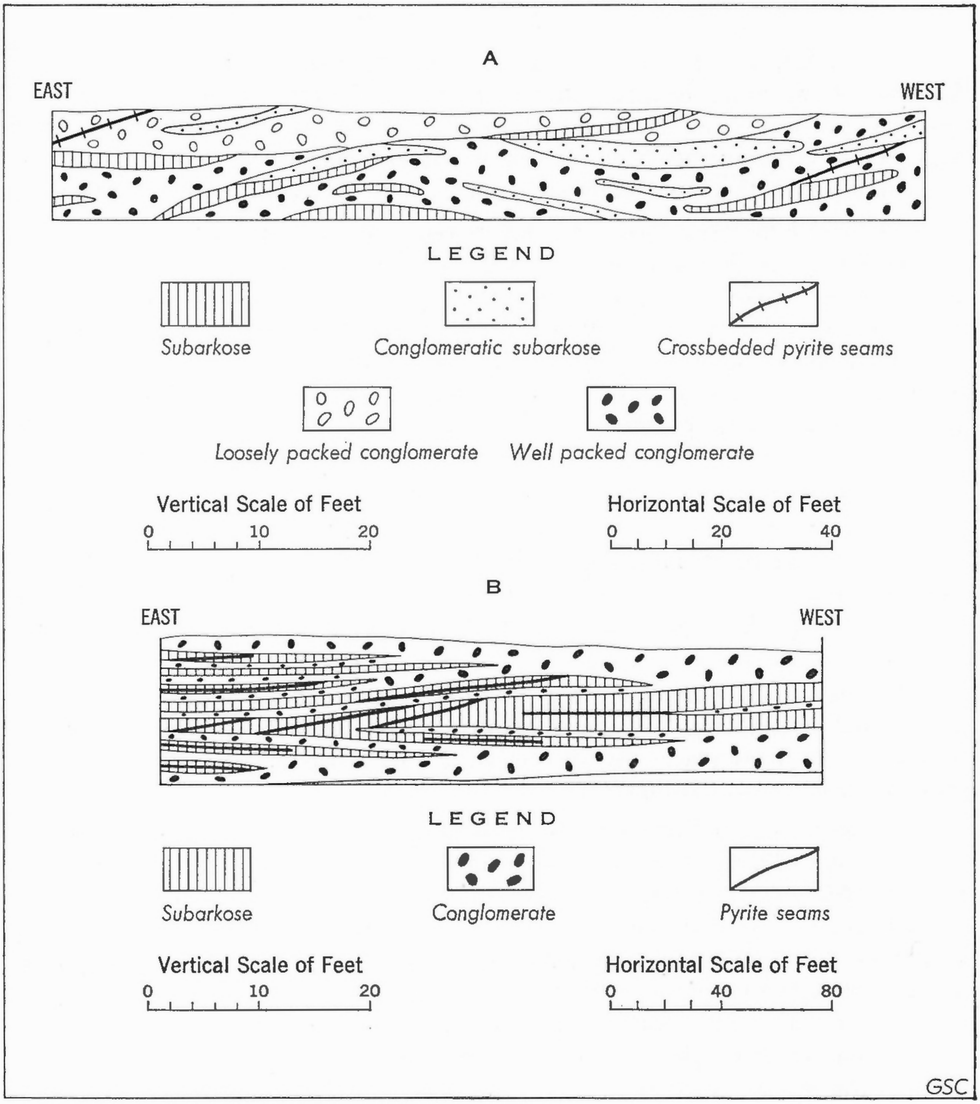

**FIGURE 11. A. Section showing intricate lensing within the ore conglomerate, Quirke mine, 5 Dr. E.
B. Generalized section showing thick conglomerate beds passing into thin pebble layers, Nordic mine, 4 Dr. E.**

In addition to the lensing out of sedimentary units, another rather common feature is illustrated in Figure 11B. More or less massive conglomerate units split into numerous thin pebble layers with pyrite seams intercalated with subarkose lentils. Many pebble layers are only one pebble thick.

Another common characteristic of the ore zones, and also of other oligomictic conglomerates, is the presence of conglomerate layers and pyrite seams following the foreset beds of crossbedding (*see* Fig. 12). Both trough and planar crossbedding are present. These foreset beds intersect the bedding at angles ranging

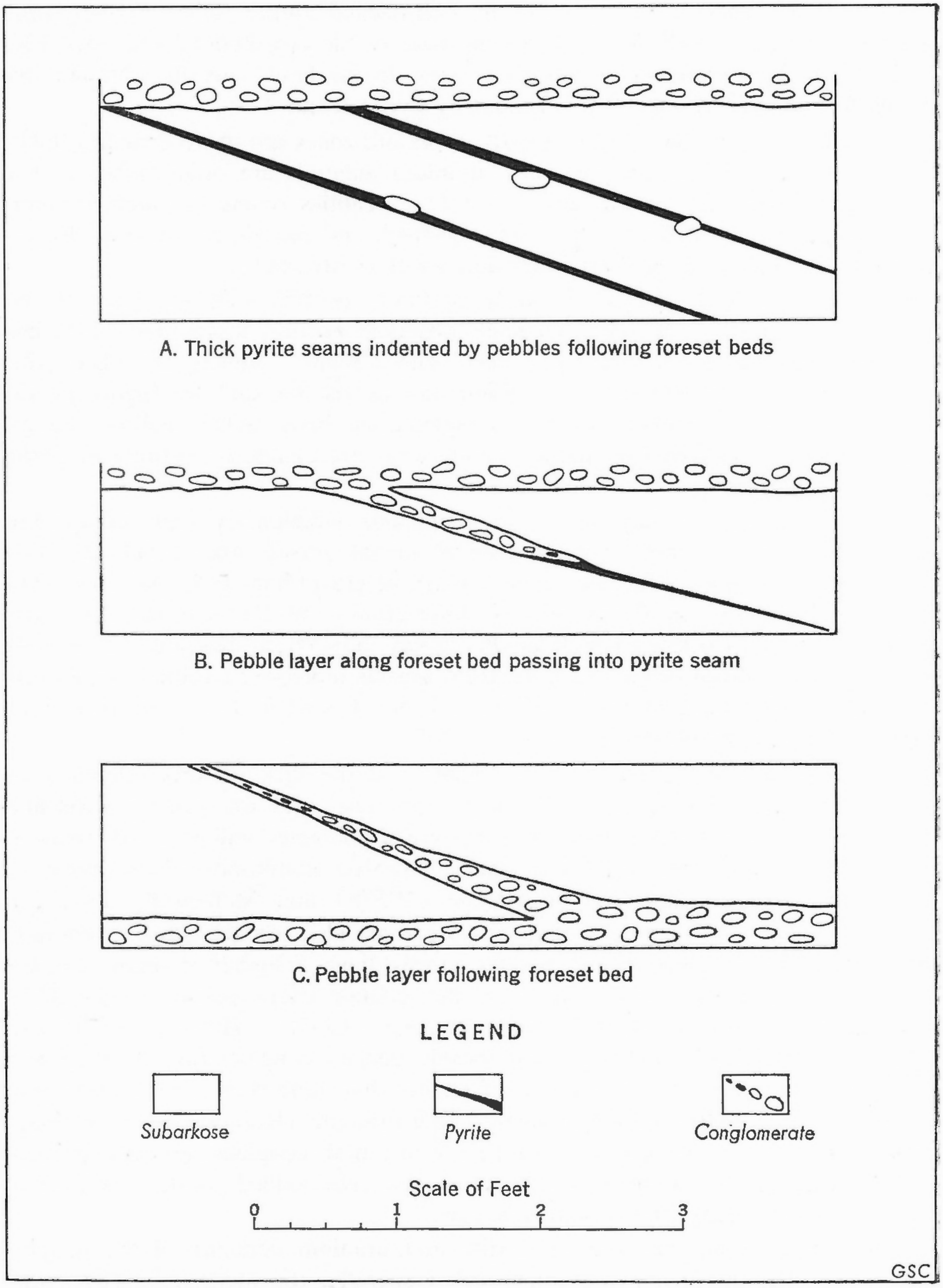

FIGURE 12. Crossbedding features in ore conglomerates.

from a few degrees to 20 degrees. The foreset beds are mainly found in loosely packed conglomerates and conglomeratic and pebble-free subarkose units. They are absent or difficult to recognize in well-packed rudite units. Foreset conglomerate layers may thicken towards the base of the crossbedded unit (*see* Fig. 12C), or lens out completely (*see* Fig. 12B). In the latter case the continuation of the foreset beds is generally indicated by pyrite seams.

Pyrite seams following foreset beds in the ore zones are up to 2 inches thick. They are highly radioactive and black uranium minerals are often visible to the naked eye at the base of the seam. In a few localities seams of black uranium minerals in the crossbeds are up to an inch thick and contain as much as 40 per cent U_3O_8. They are commonly intercalated with pyrite seams.

Scour-and-fill structures are fairly common, especially at the base of the rudite units. Most of the scour channels observed are not more than 12 inches deep but may attain a width of 5 feet. These scour channels are filled with loosely packed conglomerate or conglomeratic subarkoses that are highly pyritic and more radioactive than the main conglomerate beds. Some shallow embayments along the foot-wall of massive rudite units are composed entirely of pyrite and sand-sized detritus.

This interlayered character of the lenticular sedimentary units comprising the conglomerates is more characteristic of fluvial gravels than beach deposits. It is strikingly similar to the interlacing pattern of gravel bars and sands described by Gregory (1915) in fluvial gravels. Furthermore all the features described, including the crossbedded conglomerate layers, have been observed in gravels of indisputable fluvial origin. Such fluviatile gravels include the Pliocence? gravels of southern Maryland (Schlee, 1957a) and the Cenozoic Lafayette gravels of the eastern and middle States (Potter, 1955).

The linear distribution of these rudites and the lack of strike deposits in the Quirke Lake syncline are difficult to reconcile with the general sheet-like character of beach deposits. Rather the physical character and areal distribution suggest that they were deposited under fluviatile conditions. This mode of deposition was also suggested by Roscoe (1957a) and McDowell (1957).

The different lithological units in the ore zones also contain different amounts of uranium. Well-packed conglomerates mostly have a higher uranium content than other lithological units, and they also contain more pyrite, as noted by most previous writers—Hart (1955), Roscoe (1957a), Holmes (1956 and 1958) and the 1957 brochure. Most loosely packed conglomerates contain less uranium and pyrite than the well-packed rudites, but more than the conglomeratic subarkoses. Pebble-free subarkoses carry little uranium (Roscoe, 1957a; Holmes, 1958). However, in local areas, especially where both conglomeratic and pebble-free subarkoses are characterized by numerous crossbedded pyrite seams, they may have abnormally high uranium values.

The relationship between the pyrite and uranium contents of the conglomerates is often more apparent than real. Generally, the most radioactive conglomerates contain much pyrite, but some of the conglomerates from the ore zones at Stanleigh and Lake Nordic mines have relatively little pyrite. On the other hand, many highly pyritic parts of these rudites contain only small amounts of uranium. Pyrite is therefore not an absolute index of the uranium content of a conglomerate (*see also* Hart, 1955).

According to Holmes (1958), the highest uranium values are commonly found near the base of the conglomerates. This generalization may be valid for conglomerates consisting of single lithological units. Many conglomerates are, however, composed of more than a single lithological unit, and if the upper unit is well packed and the lower loosely, the former generally has the higher uranium content. This was observed in drill-cores as well as in underground workings. Thus whether or not higher uranium values occur in the basal bed of a series, conglomerates commonly depend on the lithological character of the lowermost units.

In the areas examined, the uranium content was invariably related to the lithological character of the conglomerates. No obvious evidence was found to suggest that it was influenced or controlled by structural features or intrusive rocks, although a few radioactive thucholite-bearing veins were observed.

Description

The subrounded to rounded gravel components of the oligomictic conglomerates consist mainly of quartz, minor chert, metavolcanic rocks, feldspar, jasper and, very rarely, granite. Gravel sizes range from small pebbles to cobbles. Most of the quartz pebbles are dark grey, especially the highly radioactive conglomerates. Chert pebbles and cobbles constitute up to 3 per cent of the total gravel components. Cobbles of acidic metavolcanic rocks are fairly common in the ore zones at Stanleigh and Lake Nordic mines, but rare elsewhere. Feldspar pebbles are common in the small-pebble conglomerates but are essentially absent in the ore conglomerates. Holmes (1958), Joubin (1954), and many others noted quartzite pebbles in the conglomerates, but none was reported by Traill (1954) or Roscoe (1957a). In this study no pebble with an irrefutable sedimentary texture was found. However, many quartz pebbles have been fractured and exhibit a granular mosaic texture like that of quartzite pebbles. If quartzite pebbles are present, they are probably extremely rare.

The size of the pebble varies from place to place along the strike of the ore conglomerates. These variations were investigated at Quirke and Nordic mines and are graphically illustrated in Figure 13A. Pebbles less than a half a inch in diameter were not recorded. Figure 13A shows that the maximum distribution of the largest pebbles at Quirke mine are found near the shaft, and the proportion of lay pebbles decreases west and east of the shaft. At Nordic mine most of the pebbles are in the 2-to-3-inch range west of the shaft, and in the 1-to-2-inch range east of the shaft. This variation in pebble sizes along strike emphasizes the lack of sorting by strand line currents and provides additional evidence for a fluvial mode of deposition.

Figure 13B illustrates the progressive decrease in pebble size in the direction of detrital transport from northwest to southeast. Along the north limb of the syncline, the pebble sizes decrease from Quirke and Consolidated Denison mines

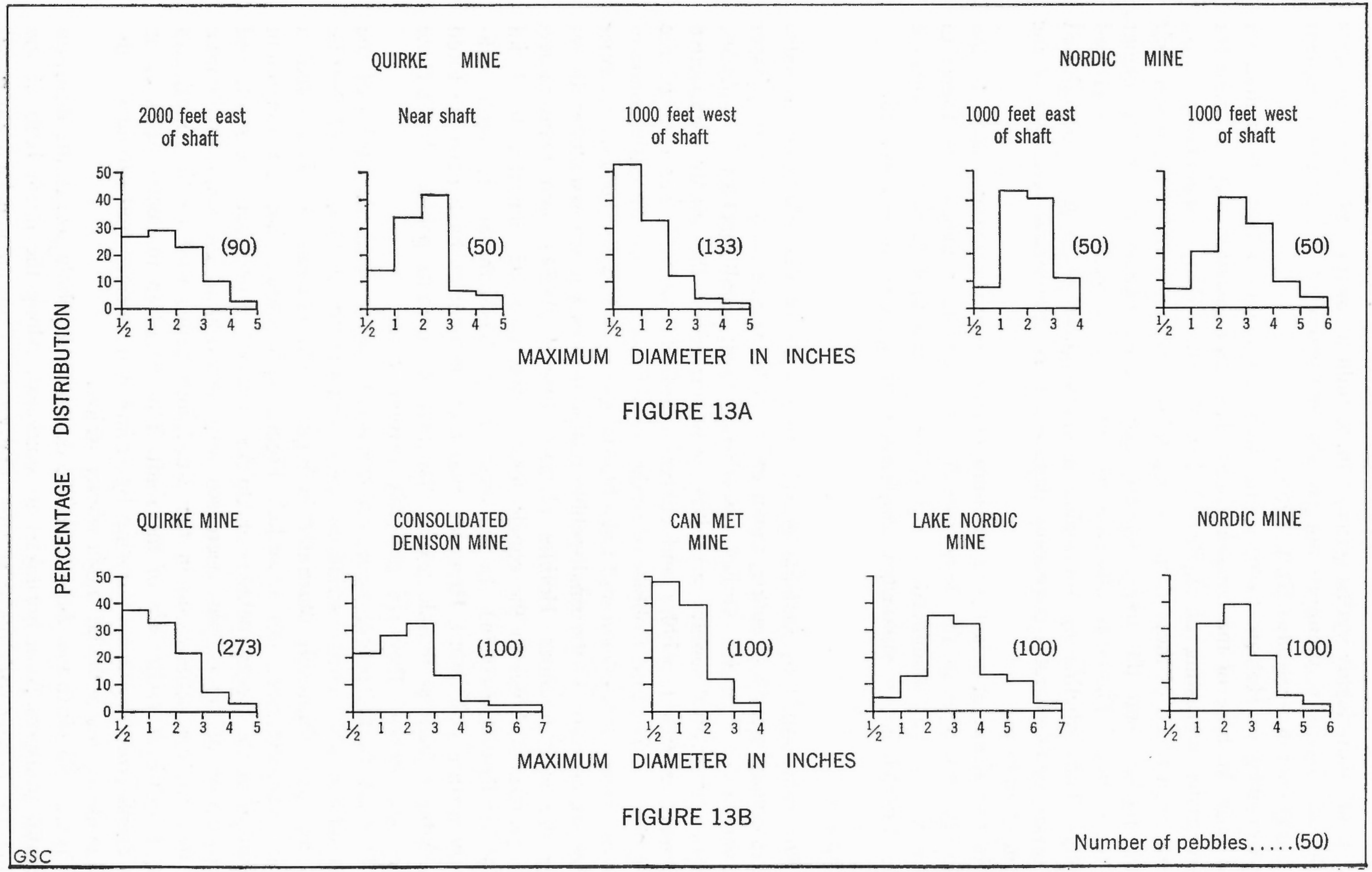

FIGURE 13. A. Differences in pebble size in ore conglomerates along strike.
B. Pebble size in the ore conglomerates at different mines.

in the northwest to Can Met mine in the southeast, although it is somewhat greater at Consolidated Denison mine than at Quirke mine. This anomalous trend is difficult to explain, unless sedimentary by-passing played an important role during deposition near the source. Along the south limb the pebble size decreases from Lake Nordic mine south to Nordic mine. Figure 13B also shows that the pebbles of the conglomerates from the south limb of the syncline are generally larger than those from the north limb. This may indicate that the rudites in the south limb were deposited more rapidly than those in the north limb.

The matrix of the conglomerates consists principally of sand- and silt-sized grains of quartz and highly altered microcline, pyrite, and fine white mica. In some sections the finer parts of the matrix contain minor amounts of calcite and chlorite, and, rarely, epidote. Clastic grains are essentially subangular and poorly sorted. Plagioclase and orthoclase were not recognized in the sections examined.

Minor constituents are principally disseminated in the matrix and consist of muscovite, pyrrhotite, chalcopyrite, galena, marcasite, uraninite, and two phase uranium-titanium compound, magnetite, and several varieties of zircon, monozite, and rutile. Numerous other minerals are present in very minor amounts.

Pyrite is the most abundant sulphide and constitutes from 3 to 12 per cent of the ore zones and up to 20 per cent of highly pyritic conglomerate beds. It occurs mainly as disseminated grains in the interstitial material, but commonly replaces clastic grains and pebbles. The remainder of the sulphides generally constitute less than 2 per cent of the total sulphides.

Monazite is the most abundant radioactive mineral in the oligomictic conglomerates, but the high-grade uranium minerals, such as uraninite and the two phase uranium-titanium compound, are restricted to the ore conglomerates and other highly radioactive rudites. These minerals occur exclusively in the interstitial material.

Molybdenite is found along fractures, and calcite sphalerite and thucholite were observed in veins cutting the conglomerate. In some places pyrite occurs along faults and many joint planes are chloritized. A few veinlets of quartz, calcite, chlorite, and epidote are also present. No radioactivity was detected in these crosscutting veinlets, except in the thucholite veins.

The effects of folding and faulting on the competent conglomerate beds are clearly shown by the abundance of fractured and crushed clastic grains and pebbles. Most of the quartz grains exhibit strain shadows and some show incipient recrystallization (Roscoe, 1957a). Grain boundaries are invariably serrated by white mica embayments and clastic grains are invaded by tongue-like masses of white mica. Large microcline grains are commonly divided into several fragments by white mica veinlets. In the sections examined no siliceous cement or authigenic overgrowths on clastic grains were observed.

The presence of sand-sized particles in the matrix of the conglomerates clearly indicates the bimodal size distribution of the rudites. Bimodal size distribution is a diagnostic feature of fluvial gravel and is fairly uncommon in beach and marine deposits (Pettijohn, 1957a; Emery, 1955). The abundance of the sand-sized particles in the conglomerates suggests that they were deposited simultaneously with the gravel rather than filtrated into open-work gravels later.

Chemical Analyses

Arnold (1954) stressed the importance of potash introduction in the ore conglomerates and the effects of soda metasomatism have often been quoted. In order to investigate the possibility of such introductions, conglomerates differing in lithological character and uranium content were selected for the analyses.

The amount of pebbles varies in the different lithological types of conglomerates and obscures the actual soda and potash contents. Most of the pebbles were therefore removed from each sample by successive heating and quenching and the residual matrix analyzed. Small pebbles and splinters of the larger pebbles were included in the material analyzed, but the dilution is less than 20 per cent.

Chemical analyses of the matrices are tabulated in Table XIII, and quantitative spectrographic analyses of trace elements including the X-ray fluorescence analyses of the ThO_2 and U_3O_8, in Table XIV.

Except for sample PH-478, the silica content of the conglomerates is fairly constant, which indicates that the dilution factor is relatively unimportant. The matrix of the well-packed conglomerate (PH-479) has a higher potash content than that of the loosely packed rudite (PH-478), but the difference is obscured by the higher silica content (probably from dilution) of the latter. By eliminating the masking effect of the silica, there remains no significant difference between the potash in sample PH-478 and sample PH-479. Moreover, the loosely packed conglomerate (PH-281) contains more potash than the well-packed rudite (PH-282). There appears, therefore, to be no significant difference in the potash content of the well-packed and loosely packed conglomerates. The former is more permeable and thus more amenable to introduction of extraneous material. Therefore, if any potash was introduced, it should have been detected in the analyses.

The analyses of the conglomerate matrices are markedly similar to those of subarkoses from the lower member of the Matinenda Formation, except for the total iron, titanium, and zirconium (*see* Table X). (The lime in sample PH-479 is probably due to secondary calcite.) This is to be expected, as they consist essentially of the same clastic components. However, the average potash content of the conglomerates is lower than that of the subarkoses.

The subarkoses from the north limb of the syncline contain less potash than those from the south limb, and a similar variation is present between the conglomerates from Quirke mine on the north limb and those from Nordic mine on the south. Such a persistent trend in the rudites and arenites from the two localities supports the conclusion reached above, that potash was not introduced into the conglomerates.

Table XIII

Chemical Analyses of the Matrices of Loosely Packed and Well-Packed Uraniferous Pyritic Conglomerates[1]

	PH-478	PH-479	PH-281	PH-282
SiO_2	84.99	75.04	78.67	75.44
Al_2O_3	7.40	7.60	9.80	8.80
Fe_2O_3	3.01[2]	10.86[2]	3.07[2]	11.31[2]
MgO	<0.01	0.10	0.14	0.28
CaO	<0.018	0.29	<0.018	<0.018
Na_2O	<0.050	<0.050	<0.050	<0.050
K_2O	1.90	2.45	4.10	3.31
H_2O (110°)	0.05	0.04	0.05	0.05
H_2O (900°)	0.57	1.84	1.10	1.89
TiO_2	0.36	1.42	0.46	0.60
ZrO_2	0.0159	0.0265	0.0235	0.0946
MnO	<0.001	<0.001	<0.001	<0.001
SrO	0.005	0.005	0.006	0.006
Rb_2O	0.0078	0.014	0.0115	0.0108
Total	98.31	99.70	97.44	101.79
Weight per cent of pebbles removed	25.7	44.8	19.9	39.1

[1]All samples selected from ore-bearing oligomictic conglomerates.
[2]Total iron determined by X-ray spectrographic means. Samples heat treated and FeO oxidized to Fe_2O_3.
PH–478—Loosely packed conglomerate—4Dr. E. Quirke mine.
PH–479—Well-packed conglomerate—3 feet below PH–478.
PH–281—Loosely packed conglomerate—2W10 Stope—Nordic mine.
PH–282—Well-packed conglomerate—1 foot below PH–281.

The well-packed conglomerates contain much more U_3O_8 than the loosely packed conglomerates (Table XIV), and there appears to be no clear relationship between the U_3O_8 and potash contents of the conglomerates. Furthermore, soda is virtually absent. Thus, the soda and potash contents of the conglomerates show no obvious relationships to their U_3O_8 values. This is the most outstanding peculiarity of the Blind River uranium deposits, as most other uranium deposits are invariably associated with either potash or soda metasomatism. Admittedly, soda metasomatism is found in a few places in the Quirke Lake syncline, but seems to be entirely local.

The well-packed conglomerates contain more zirconium, titanium, and total iron than the loosely packed, which is irrefutable evidence that the former contain a higher concentration of heavy minerals. However, the total iron is now mainly present in the form of pyrite, which may have been formed from the original iron oxides or been introduced later.

The Rb content of these rudites ranges from 71 to 130 ppm, which is lower than the maximum of 150? ppm reported by Krauskopf (1955) in sandstones. It is also considerably lower than that of the Huronian argillites (Table IX). The

Table XIV

Trace Elements and Minor Constituents of the Matrices of Well-Packed and Loosely Packed Conglomerate

	PH-478	PH-479	PH-281	PH-282
Co	0.006	0.012	<0.001	0.024
Ni	0.003	0.006	<0.0007	0.014
Cr	0.003	0.006	<0.0009	0.008
V	<0.0015	<0.0015	<0.0015	0.011
Mo	<0.002	<0.002	<0.002	<0.002
Cu	0.004	0.006	0.005	0.019
Ag	<0.0002	<0.0002	<0.0002	<0.0002
Y	0.0095	0.0251	0.0095	0.089
Yb	TL	0.0026	TL	0.0097
ThO_2	0.019	0.255	0.025	0.052
U_3O_8	0.035	0.560	0.073	0.164

Location and description of samples are the same as in Table XIII.

K:Rb ratios of these conglomerates vary from 170 to 320, which is within the range of ratios given by Horstman (1957) for sandstones and near-shore sediments.

From Table XIV it is obvious that the well-packed conglomerates contain more Co, Ni, Cr, Cu, and V than those that are loosely packed. It is interesting to note that Ag and Mo, commonly associated with hydrothermal deposits, are absent or present in amounts below the limit of detectability. Both Ni and Co are present in substantial amounts in the pyrite and the differences in the abundance of these elements noted above are partly due to the differences in the amount of pyrite in the two types of conglomerate. On the other hand, Ni, V, Cr, and Cu are commonly concealed in the structures of micaceous minerals of sedimentary rocks, and some of them, especially V, Co, and Cr, may also be concentrated in the black sands of a conglomerate. Thus, it is extremely difficult to attribute these trace elements to a single source in such multi-mineral rocks.

It is interesting to compare the concentrations of trace elements in these rudites with those in the greywacke and subgreywacke (*see* Table IX). In three of the conglomerate samples cobalt is higher than the maximum of 42 ppm in the subgreywacke. As stated previously, the relative enrichment of Co may be due to later hydrothermal introduction. However, Co is also enriched in lateritic iron ores (Rankama and Sahama, 1950), and this high Co content may reflect the abundance of indigenous iron oxide minerals in the rudites. Chromium is generally lower in the conglomerates. Nickel, vanadium, and copper are higher in sample PH-282, but lower in the remaining rudites than in the arenites.

This comparison shows that, except for Co and the Ni, Cu, and V in one sample, there are no significant differences in the concentration of these elements in the permeable rudites and impermeable arenites. Such insignificant variations are difficult to reconcile with any hypothesis of origin of the uranium mineralization that evolves localization of intense hydrothermal activity along the more permeable rudites. If hydrothermal introduction was an important factor in the mineralization of the conglomerates, concentrations of sulphophile elements should be much higher in them than in the arenites. It is possible, however, that Co, Ni, and Cu may have been locally augmented by later hydrothermal soaking.

The well-packed conglomerates also contain more U_3O_8, ThO_2, Y, and Yb than those that are loosely packed. Furthermore, the results shown in Table XIV show no obvious correlation between the rare earth elements and sulphophile elements in the rudites. It is doubtful whether the association of these sulphophile elements with the uranium mineralization, as postulated by Davidson (1957), has any geochemical validity.

It may be concluded that there is no evidence that either potash or soda was introduced into the ore conglomerates. The well-packed conglomerates contain more U_3O_8, ThO_2, and trace elements than those that are loosely packed and there is no evidence for extensive hydrothermal activity, although some sulphophile elements appear to have been enriched by circulating hydrothermal solutions.

Alteration of the Conglomerates

White mica or sericite is the most abundant interstitial constituent of the uraniferous conglomerates, but is rarely found in crosscutting veinlets. The genesis of the sericite is a controversial problem, no final solution can be given. It may have been formed by hydrothermal alteration or by recrystallization of clay minerals during metamorphism. The relative amounts of sericite formed by these two processes are uncertain. However, sericite is as common, if not more abundant, in the less radioactive and polymictic conglomerates, arenites, and grits throughout the entire syncline. This widespread distribution of sericite in rocks with different lithological attributes is difficult to credit entirely to hydrothermal alteration. It is also extremely doubtful if the sericite in the ore conglomerates is a positive criterion for hydrothermal activity.

As stated previously, white mica and pyrite commonly replace clastic detritus. These replacement textures may be differently interpreted but are undoubtedly related to both metamorphism and hydrothermal processes. Locally, albitization and chloritization were observed, but as yet no evidence was found to associate these features directly with the uranium mineralization.

These uranium deposits, unlike many other ore deposits, are not characterized by obvious alteration and replacement along structural features. They have undoubtedly been exposed to some hydrothermal soaking, but the effects are inconspicuous and difficult to distinguish from those of metamorphism.

Intensive chloritization and albitization of the ore conglomerates and subarkoses have occurred near a diabase dyke at Nordic mine, and similar chloritic replacement of the ore conglomerates was observed in some drill-holes on Quirke Lake near Can Met and Panel mines. The former occurrence was studied in detail (*see* Fig. 14).

The sedimentary rocks are completely replaced and converted to a chloritic rock in a zone bordering the dyke, as well as along faults and joints up to 30 feet from the intrusion. This chloritic rock has a slightly schistose appearance and varies in thickness from a few inches to 6 feet. The faults post-date the diabase dyke, and the low angle fault—which dips more steeply than the bedding—cuts all the other structures.

The chloritic rock consists principally of large flakes of chlorite, a few remnants of quartz grains, minor stilpnomelane, and, rarely, albite (An_{3-6}) and sphene. The brown pleochroic stilpnomelane occurs as plates up to 1.2 mm across and is commonly replaced by chlorite along the edges. Both quartz and albite are replaced by chlorite. Two varieties of chlorite, penninite, and prochlorite, have been identified.

In addition to the above minerals, abundant pyrite and minor quantities of uraninite, a two-phase uranium-titanium compound, monazite, apatite, and zircon are also present where conglomerates and conglomeratic subarkoses have been converted to the chloritic rock. Pyrite was apparently not replaced and pyrite seams in crossbeds are preserved in the chloritic rock. Ghost pebbles completely replaced by chlorite are outlined by interstitial pyrite, a condition normally seen in the unaltered conglomerate. A few skeletal grains of uraninite were observed, which indicates a certain amount of leaching. This clearly shows that the replacement and alteration occurred subsequent to the formation of both pyrite and uraninite.

The sedimentary rocks adjacent to the chloritic rock near the dyke, are characterized by a zone of intense albitization and chloritization. In contrast to the chloritic rock, the replacement of the clastic components in this zone is incomplete and albitization is more prevalent. Albitization decreases rapidly away from the dyke and no albite replacement was found beyond 15 feet from the dyke. On the other hand, chloritic alteration extends up to 80 feet from the dyke, especially along joints. Albite (An_{3-6}) replaces detrital grains of quartz and microcline, as well as finer grained material of the sedimentary rocks. A type of antiperthite is developed where detrital microcline grains are partly replaced by albite. Several veinlets of albite are also present. Chlorite veinlets generally cut the albite grains, which suggests that the albitization may have preceded the chloritization. Quartz veinlets are fairly common in this zone, particularly beyond the zone of albitization. Very minor amounts of sphene are also present.

The chemical changes accompanying the chloritization were investigated by analyzing an unaltered subarkose and a highly altered pebbly or conglomeratic subarkose. Results of the chemical analyses are shown in Table XV. It must be emphasized that a fresh subarkose normally contains less titanium, zirconium, and total iron than a pebbly subarkose.

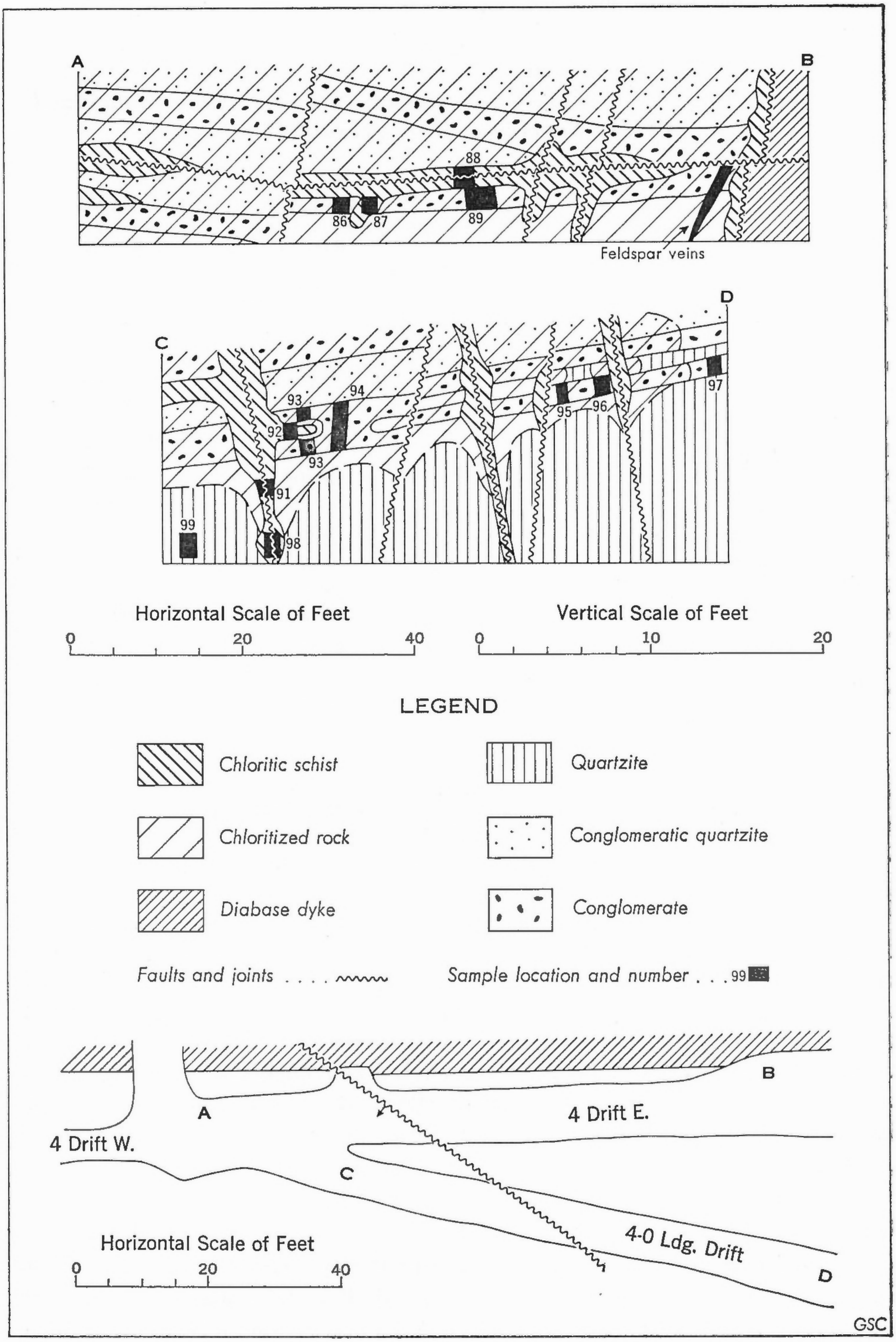

FIGURE 14. Sections showing the chloritization of ore conglomerate near diabase dyke, Nordic mine.

Table XV

Chemical Analyses of Unaltered Subarkose and Highly Chloritized Pebbly Subarkose from Nordic Mine

	Unaltered RF-786	Altered RF-768
SiO_2	83.62	45.63
Al_2O_3	9.70	17.20
Fe_2O_3	0.66	5.84[1]
FeO	0.00	6.97
MgO	0.15	7.08[2]
CaO	0.018	0.080
Na_2O	0.205	6.88
K_2O	4.90	1.20[2]
H_2O (110°)	0.02	0.12
H_2O (900°)	0.92	6.24
TiO_2	0.18	0.46
ZrO_2	0.0039	0.0188
MnO	0.001	0.084
Total	100.36	97.84

[1]Total iron checked by X-ray spectrograph.
[2]Determined by X-ray spectrograph.
Sample RF–768 contains pyrite, but sulphur content not determined.
RF–786—Unaltered subarkose, 70 feet from diabase dyke—4th level Nordic mine.
RF–768—Chloritized pebbly arkose 1 foot from diabase dyke and 2 feet below chlorite schist zone along a bedding plane fault—4th level Nordic mine.
Analyses by G. MacDonald and F. Dunphy, Miller Research Laboratory, Queen's University.

The altered rock (sample RF-768) contains less silica and potash than the unaltered (sample RF-786) but more alumina, soda, magnesia, lime, ferrous and ferric iron, manganese, combined water, zirconium, and titanium. This clearly indicates a significant change in the chemical composition of the altered pebbly subarkose from that of the fresh subarkose. Differences between the titanium and zirconium contents of the altered and unaltered rocks are not of course considered important, for reasons stated above, but the large difference in the total iron content is mainly ascribed to introduction of iron during alteration.

The relative gains and losses of constituents during alteration are shown on Figure 15A using the compositions of the fresh subarkose as a standard.

The constancy of any oxide constituent during hydrothermal alteration is uncertain, and even alumina may have changed. If it did remain constant, then constituents falling to the left in Figure 15A represent gains relative to alumina, whereas those falling to the right represent losses. Thus, relative to alumina,

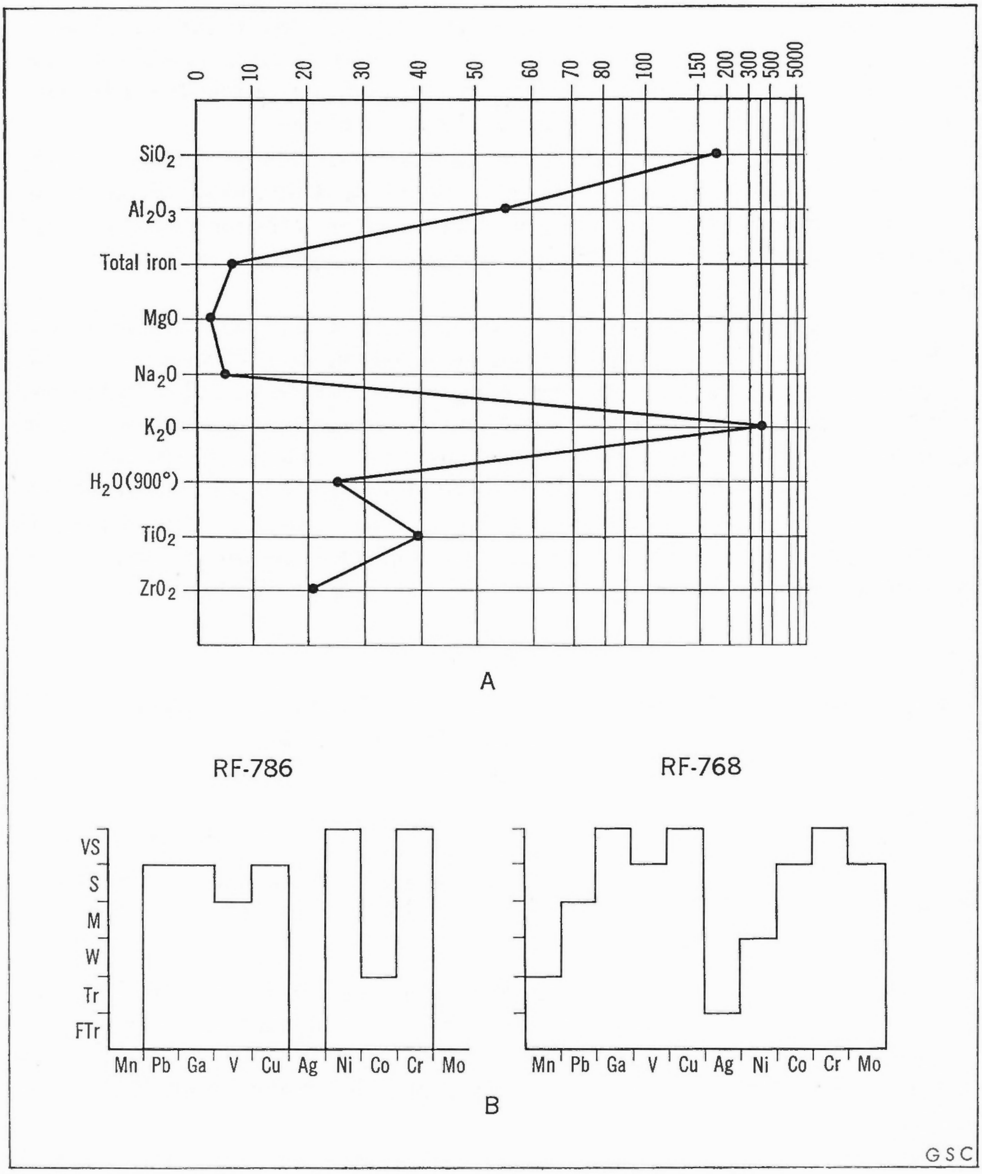

FIGURE 15. A. Relative gains and losses of oxide constituents during chloritization of a pebbly subarkose. B. Trace element content of unaltered subarkose (RF-786) and a chloritized pebbly subarkose (RF-768), Nordic mine.

potash and silica were lost, and total iron, magnesia, soda, and combined water were gained. As stated previously, the relative gains in zirconium and titanium are not considered important.

These relative gains are ascribed to hydrothermal introduction of such constituents during the alteration. On the other hand, the relative losses of potash and silica may be attributed to the removal of these oxides by circulating solutions during the alteration.

The introduction of magnesia, iron, and manganese led to the formation of chlorites and stilpnomelane. Minor amounts of potash, titanium, soda, and lime may be fixed in the stilpnomelane. Most of the potash is associated with antiperthite, whereas soda and minor lime are fixed in the albite.

This mineral assemblage belongs to the muscovite-chlorite subfacies of the greenschist facies (Turner and Verhoogen, 1951). It is diagnostic of the lowest grade of hydrothermal metamorphism. Stilpnomelane commonly accompanies chlorite in this facies if, as is the case here, there is a high ratio of iron oxides to magnesia.

A peculiarity of this assemblage is the absence of muscovite, which is generally the carrier of potash in this facies. It is possible that some of the potash was preferentially removed by the circulating aqueous solutions, rather than being fixed in muscovite. The remainder is held in the microcline remnants existing in equilibrium with the assemblage, and thus was not available for the formation of muscovite. Silica was probably also removed in the highly aqueous environment.

Qualitative spectrographic analyses of the trace elements in an unaltered subarkose and altered pebbly subarkose are graphically shown in Figure 15B. Quantitative analyses of the trace elements are shown in Table XVI.

Table XVI

A Comparison of the Trace Elements of the Unaltered Subarkose and those of the Altered Pebbly Subarkose

Element	Cr	V	Ni	Co	Cu
RF-786	0.0009	0.0015	0.0007	0.0010	0.0011
RF-768	0.0009	0.0105	0.0090	0.0086	0.0043

Both Table XVI and Figure 15B show that the altered rock contains more V, Ni, Co, Cu, Mo, and Ag than the unaltered. These increases can only be credited to later hydrothermal introduction, especially of Ag and Mo. Most of the elements, especially Cr, Ni, V, and Co, are probably mainly concealed in the layered structures of the phyllosilicates.

Mo is commonly associated with acid differentiates, whereas the other of the elements are generally affiliated with more basic rocks. It is suggested that Mo accompanied an earlier phase of soda metasomatism and the other of the elements, the later chloritization.

The intimate relationship between the diabase dyke and the alteration of the sedimentary rocks suggests that both the albitization and chloritization may have been derived from the intrusion. This type of alteration, associated with diabase intrusions, is not unique. Similar occurrences are found in the auriferous conglomerates of the Witwatersrand System at Government Areas and Rose Deep Mines, South Africa.

Relationship Between U_3O_8 Content and Chloritic Alteration

The conglomerates and subarkoses from the hydrothermally altered zone were sampled in an endeavour to ascertain whether the uranium mineralization was associated with the alteration. Samples were taken from the chlorite schist, where the conglomerates are completely replaced by chlorite from the partly altered conglomerates and subarkoses, and two samples from unaltered rocks.

The U_3O_8 values of these samples were determined by radiometric analyses at Algom Uranium Mines and checked by the X-ray fluorescence method. Location of the samples is shown in Figure 14.

Samples of the chlorite schist and the chloritized conglomerate from a single bed were analyzed with the following results:

Chlorite Schist		*Chloritized Conglomerate*	
Sample Nos.	*U_3O_8 in footpounds*[1]	*Sample Nos.*	*U_3O_8 in footpounds*
87	7.35	86	4.65
88	4.67	89	2.40

This seems to indicate that the chlorite schist was enriched in uranium relative to the chloritized conglomerate. However, this is not confirmed by some of the other results. A tongue of chlorite schist in a conglomerate bed, the rest of the chloritized bed, and the whole bed a few feet away from the tongue were sampled (*see* Fig. 14). These results are as follows:

Chlorite Schist Tongue		*Remainder of Bed*		*Entire Bed*	
Sample No.	*U_3O_8 in footpounds*	*Sample No.*	*U_3O_8 in footpounds*	*Sample No.*	*U_3O_8 in footpounds*
92	1.48	93	3.20	94	4.62

The sum of the uranium values of samples Nos. 92 and 93 is essentially the same as that of sample No. 94, which shows that the total uranium content of the bed is not affected by the chlorite schist. Furthermore, there appears to be little difference in the uranium contents of chloritized and unaltered samples from the same conglomerate bed, as can be seen from the following results:

Chloritized Conglomerate		*Unaltered Conglomerate*	
Sample No.	*U_3O_8 in footpounds*	*Sample No.*	*U_3O_8 in footpounds*
95	1.27	97	1.60
96	1.65		

In addition, chloritized subarkoses along a joint plane below a conglomerate bed were sampled, as well as nearby the fresh subarkose. These results are shown below:

Chloritized Subarkose		*Unaltered Subarkose*	
Sample No.	*U_3O_8 in footpounds*	*Sample No.*	*U_3O_8 in footpounds*
91	0.29	99	0.40
98	0.20		

[1] U_3O_8 contents in pounds multiplied by sampled thickness in feet.

This merely indicates that the altered joint planes below the ore conglomerates are apparently not enriched in uranium.

Thus, except for samples 87 and 88, no obvious increases were detected in the uranium contents of the altered conglomerates and subarkoses. Local leaching by aqueous solutions during the alteration and subsequent deposition in suitable sites may account for the enrichment of samples 87 and 88. This seems to be supported by the presence of partly leached uraninite grains seen in a polished section of the altered conglomerate.

Although the number of samples is insufficient for a definite conclusion, there appears to be no clear relationship between the chloritic alteration and the uranium content of the conglomerates. Nor has underground sampling as yet revealed any increase in the tenor of the ore in the altered zones (Pountney, Mine Geologist, pers. com.).

Oligomictic Character of the Conglomerates

Quartz pebbles constitute about 95 per cent of the gravel components of the conglomerate, and the pebbles are subrounded. All features testify to the textural maturity of the conglomerates but the intercalated subarkoses, on the other hand, are texturally immature arenites. This association of mature gravels and immature sands is rather common, and the Lorrain Formation in Ontario and the Upper Witwatersrand System of South Africa can be cited as examples.

Plumley (1948) found that, under the same conditions, gravels achieve maturity much more rapidly than sands. This maturity also implies the removal of the mechanically less durable components from the gravels. If this is correct, then the maturity of the gravels was probably attained during transportation while accompanying sands remained immature.

The oligomictic character of the conglomerates could be due to an accumulation of the most inert residues from a highly weathered source, but the chemical immaturity of the associated sands is not indicative of extensive weathering. Thus, Plumley's explanation for the association of mature gravels and immature sands appears the more tenable.

Upper Member

This member consists mainly of polymictic (mixed) conglomerates, subarkoses, and quartzites. Its thickness varies from 0 to 470 feet, and it is present only along the south limb of the syncline in townships 149, 143, and 137. Graded bedding is fairly common in the arenites, but crossbedding is rare. Individual beds may attain thicknesses up to 5 feet.

The upper member of the Matinenda Formation is divided into an upper and a lower part. The lower part consists principally of polymictic conglomerates, conglomeratic subarkoses, yellowish grey, medium- to coarse-grained subarkoses, and light grey, medium-grained subarkoses. The conglomerates are generally interbedded with the arenites, but west of Stanleigh mine in township 149, they form the entire section. In some parts only thin beds of conglomerate and conglomeratic subarkoses are present in the sequence.

The two types of subarkoses are commonly interbedded, but differ in character from each other. Apart from the difference in colour, the light grey, medium-grained subarkoses are more equigranular and contain less matrix material than the yellowish grey subarkoses. Pyrite seams in crossbeds are more abundant in the former than in the latter. In most places the light grey subarkoses are more abundant in the upper part of this section. Generally, the light grey subarkoses appear to have been more extensively winnowed than the yellowish grey subarkoses.

The subarkoses of the upper member differ from those of the lower member in several lithological aspects. They are more massive, better sorted, less cross-bedded, and contain less matrix material.

The upper part of this member consists entirely of a light grey, equigranular, fine- to medium-grained quartzite. It varies from 0 to 225 feet in thickness and the contact between the upper and lower parts is generally gradational. However, in a few drill-holes a green siltstone bed, up to 8 feet thick, was observed at the contact.

Distribution and Structure

Data on the thickness and distribution of the upper member was obtained from drill-holes and compiled on an isopach map (*see* Fig. 16). Sand:gravel ratios of the lower part of the member were also compiled (*see* Fig. 16).

The continuity of the member along the south limb is disrupted by its absence in a narrow strip along the west shore of Pecors Lake in township 143. This may be due to nondeposition over a pre-Huronian hill, which seems probable as neither the underlying lower member nor the overlying Nordic Formation is present in this area. The Whiskey Formation lies directly on the pre-Huronian basement (*see* Fig. 3).

Although the upper member lenses out towards the north, its actual limit in that direction is unknown. Its thickness in most places decreases towards the south and southeast, but in township 137 it thickens towards the southeast. Isopachal trends are generally from the northwest to the southeast and are similar to those of the lower member.

The upper member of the Matinenda Formation shows pronounced local variations in thickness. It attains a maximum thickness of more than 400 feet west of Stanleigh mine (township 149), more than 350 feet at Flying Goose Lake (township 143), and more than 450 feet northeast of Pecors Lake (township 137).

The sand:gravel ratios of the lower part of the member clearly indicate a southeast-trending, channel-like distribution in township 149. The centre of this channel can be traced southeastward from a point about 2,000 feet west of the Stanleigh shaft, through the Milliken shaft area, south of the Lake Nordic shafts, to its termination at the outcrop of the upper member near the Algom-Nordic shaft. The sand:gravel ratios increase from the centre of this channel towards the margins. Similar, but more poorly defined, channel-like distributions are also present in townships 143 and 137. The linear distribution of the lower gravelly parts of this member clearly suggests the deposition of coarse clastic material along channels. Sands and minor gravels were probably laid down along the sides of the actual channel. Furthermore, it is noteworthy that channels containing the thickest accumulations of the upper member generally occur where the lower member thins or wedges out against the pre-Huronian ancestral ridges.

The upper Matinenda member overlaps the depositional edge of the lower member in at least three areas: northwest of Stanleigh mine, Flying Goose Lake, and northeast of Pecors Lake. Such an overlap relationship may have resulted from the erosion of the depositional edge of the lower member, as well as from transgressions of the shoreline. The former suggestion is supported by the evidence of scouring of the underlying lower Matinenda arenites in the shafts at Stanleigh mine and Milliken Lake mine, prior to the deposition of the upper Matinenda rudites, and by the channel-like distribution of the gravelly parts of the upper member in areas where overlaps were detected. It is believed that the sands and gravels comprising the lower part of this member were initially laid down in scour channels and subsequently in areas adjacent to the actual channels.

The distribution of the upper fine-grained quartzite facies of this member is restricted to township 149 and the west part of township 143. This fine-grained quartzite shows pronounced local variation in thickness (*see* Fig. 17) and is more than 225 feet thick northeast of Elliot Lake. It generally decreases in thickness towards the south and east and is absent north of Flying Goose Lake in township 143.

Petrography

Polymictic Conglomerate

Although these massive conglomerates consist of many different gravel components, they differ in structure and genesis from the other polymictic or mudstone conglomerates in the Hough and Quirke Groups. They have an intact framework structure, little matrix, and are extremely tightly packed, whereas the other polymictic conglomerates have a disrupted framework structure and contain large amounts of unsorted matrix material. The former is deposited by water whereas the latter is a product of mass transportation. The polymictic conglomerates of the upper Matinenda member actually belong to the petromict class described by Pettijohn (1957a).

These conglomerates generally have a mottled appearance and the gravel components are chiefly quartz, metavolcanic rocks, chert, minor granite, and, rarely, quartzite. Quartz pebbles are most abundant, but some conglomerates contain up to 50 per cent metavolcanic pebbles. The size of gravel components ranges from small pebbles to boulders up to 30 inches in diameter. These conglomerates also display excellent size gradation.

The matrix commonly constitutes a small part of the total volume of the conglomerate. It consists of subrounded, sand-sized particles of quartz, chert, chloritic fragments, and minor altered microcline, as well as fine white mica and calcite. Siliceous cement was observed in some conglomerates. Minor constituents are principally magnetite, epidote, garnet, zircon, rutile, monazite, apatite, hematite, ilmenite?, pyrite, and pyrrhotite. Magnetite is much more abundant than in the uraniferous oligomictic conglomerates. Pyrite and pyrrhotite constitute less than one per cent of the total rock. Most of the minor minerals are in the matrix, but some are undoubtedly derived from the gravel components.

These conglomerates contain very little uranium, generally below the sensitivity of the X-ray fluorescence method (0.005% U_3O_8). Monazite was the main radioactive mineral recognized. However, many of the pyrite seams in the intervening subarkoses and conglomeratic subarkoses, which are up to an inch wide, are markedly radioactive. Two of these were analyzed and averaged 0.098% U_3O_8 and 0.132% ThO_2. In addition to monazite, disseminated grains of the two-phase uranium-titanium compound are common in the massive pyrite seams.

Fracturing is more prevalent in these polymictic conglomerates than in the uraniferous oligomictic rudites. This may be due to the higher competency of the former during folding and faulting. Fractures traversing the conglomerate are commonly filled with quartz, chlorite, epidote, pyrite, pyrrhotite, white mica, and calcite. Serrated boundaries are fairly common.

The extremely well sorted character of the conglomerates implies that they were reworked under shallow-water conditions. They contain a much smaller percentage of heavy minerals than the oligomictic rudites; perhaps the reworking was vigorous to flush out heavy mineral grains.

Arenites

The subarkoses are medium- to coarse-grained arenites with subangular to subrounded clastic grains. Sand-sized particles consist chiefly of quartz, microcline, chert, chloritic fragments, and minor highly altered plagioclase. The matrix is mainly fine white mica with minor calcite in some samples. Grain boundaries are serrated and both the plagioclase and microcline are partly replaced by white mica. The average microcline:plagioclase ratio is nine, and the sorting is fair, with an index of 25. Minor amounts of muscovite, apatite, pyrite, zircon, and leucoxene-coated black iron oxides occur in the interstitial spaces. However, a few pyrite grains appear to replace clastic particles.

The quartzite is an equigranular, fine- to medium-grained arenite that consists essentially of the same clastic components as the subarkoses. However, the quartzite contains less feldspar, chloritic fragments, and matrix and more siliceous detritus than the subarkoses. Clastic grains are rounded and the quartzite has a fair sorting index of 10. A few grains exhibit authigenic overgrowths and in some sections siliceous cement was observed.

Modal analyses of these arenites are plotted on Figure 9. This figure clearly shows that all specimens fall in the subarkose field, except two of the fine-grained quartzite, which fall in the quartzite field.

The subarkoses of the upper member have lower matrix content than those of the lower member (*see* Fig. 9). The average sorting index of the former is 25, whereas that of the latter is 71. These features clearly indicate the differences in the rate of deposition and the winnowing of the subarkoses of the two members, and emphasize the significance of dividing the Matinenda Formation into two members.

The arenites of the upper member show abundant effects of cataclastic deformation, such as crushing, fragmentation, and undulatory extinction of quartz grains. Incipient replacement of clastic grains by fine white mica and pyrite are as abundant as in the other Huronian arenites. A few veinlets of quartz and fine white mica were observed in the sections examined.

The subarkoses of this member are texturally submature, whereas the quartzites are texturally mature. This implies that the latter was exposed to more intensive winnowing by depositional agencies.

Chemical Composition

A sample of a light grey, medium-grained subarkose (No. 55-81) and one of a fine-grained quartzite (No. 55-71) were analyzed and the results are shown in Table X.

The compositions are typical of those of the quartzose arenite clan. They differ little from each other except that the subarkose contains less silica and slightly more magnesia, lime, and potash. More intensive winnowing of the quartzite probably resulted in the decrease of magnesia and potash, as well as the increase of the silica. The higher lime content of the subarkose is probably due to secondary calcite. Arenites of the upper member contain more silica, much less alumina, and less potash than subarkoses of the lower member (*see* Table X). This is taken as an indication of the different conditions under which the arenites of the two members were deposited. The depositional environment of the upper member was characterized by intense winnowing of the detritus and removal of the clay fractions, whereas that of the lower member was characterized by rapid burial and negligible winnowing.

Results of qualitative spectrographic analyses of the trace elements in these arenites are shown in Figure 10. Trace elements of these arenites are essentially the same as those of the other arenites in the Matinenda Formation, except for the relatively lower intensity of Ga and Ni. The lower intensity of these elements may be due to the smaller amounts of highly aluminous matrix minerals in the arenites of this member.

Nordic Formation

General Characteristics and Distribution

The Nordic Formation consists of interbedded argillites, siltstone, feldspathic quartzite, subgreywacke and minor greywacke, and quartzite. It is up to 280 feet thick and occurs mainly along the south limb of the syncline. Most of the arenites are crossbedded and show graded bedding.

Distribution of this member is shown on Figure 17, and is mainly restricted to township 149 and the western part of township 143. Another smaller occurrence is present at Pecors Lake near the eastern boundary of township 143.

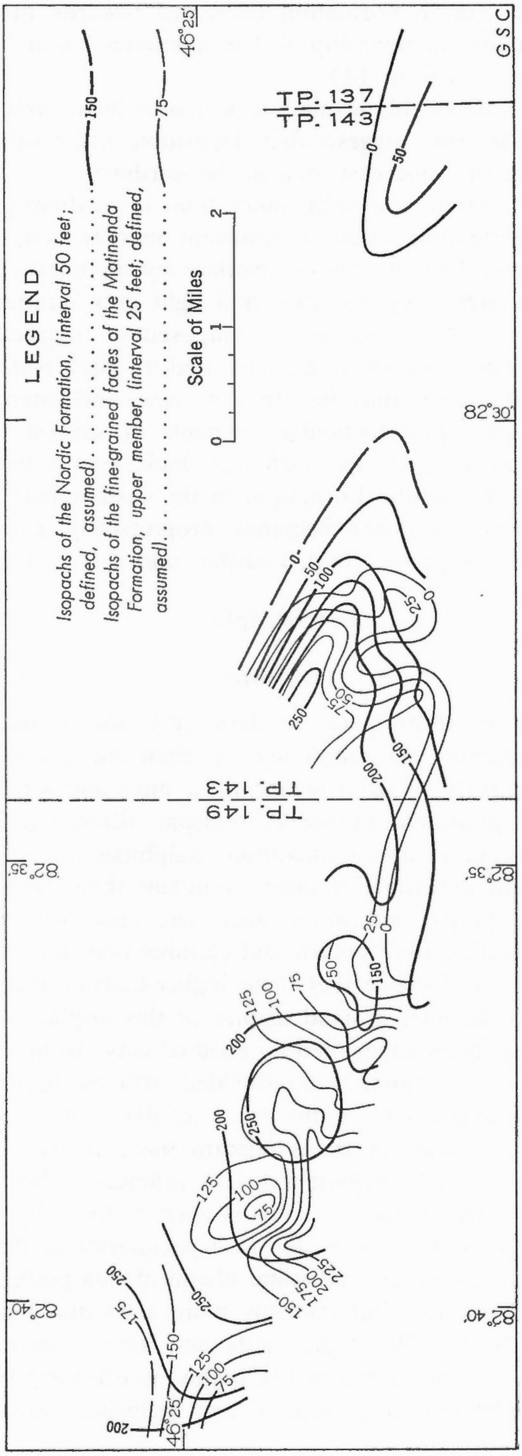

FIGURE 17. Isopachs of the Nordic Formation, Quirke Lake syncline, Blind River area, Algoma district, Ontario.

The thickness of the Nordic Formation decreases towards the south and east. Its northerly continuation in township 149 is unknown but it is absent north of Flying Goose Lake in township 143.

The sand:shale ratio of this formation decreases from three in the northwest to two in the southeast. This suggests that deposition under still-water conditions was more prevalent in the southeast than in the northwest.

An olive-green siltstone unit with minor fine- to medium-grained greywacke at the base of the formation forms a persistent marker bed, ranging from 15 to 30 feet in thickness. The siltstone is overlain by an interbedded sequence of grey subarkose, dark grey subgreywacke, and light grey quartzite up to 60 feet thick. The remainder of the sequence is composed of interbedded argillite and siltstone alternating with greywacke, and separated by thick beds of subgreywacke and subarkose. Argillite beds may be fairly massive and intercalated with beds of siltstone or laminated with lenticular segments of siltstone.

A very coarse-grained grit, up to 25 feet thick, occurs between 60 and 80 feet below the top of the Nordic Formation in the eastern part of township 149. Towards the northwest, this grit becomes progressively coarser grained and contains small pebbles of quartz, chert, feldspar, and a few of granite.

Petrography

Argillite

The argillite varies from black to dark grey and is either laminated or fairly massive. Laminations are commonly less than one quarter inch thick. The argillite consists principally of plates of fine white mica and shreds of chlorite, and of silt-sized grains of quartz and untwinned feldspar. Black iron oxides, pyrrhotite, epidote, and pyrite occur in minor quantities. Sulphides are generally present in disseminated form and pyrrhotite is more abundant than pyrite. A few veinlets of pyrrhotite, pyrite, quartz, and white mica were also observed.

This argillite contains more potash and alumina than the average of 78 post-Precambrian shales (*see* Table VIII). The higher-than-average alumina content may be due either to the finer grained texture of this argillite or to the fact that its alumina content has been augmented by residual clays from a deeply weathered source. As the argillite is intimately interbedded with mechanically derived silts, the latter explanation appears to be the more tenable. On the other hand, Nanz (1953) found that Precambrian slates contain more potash and alumina than post-Precambrian shales and attributed this to differences between Precambrian and later depositional environments. If this is correct, then the higher potash and alumina content of this lutite may be due to a peculiarity of Precambrian lutites.

This argillite has essentially the same chemical composition as the argillite from the Whiskey Formation, but contains more soda and ferric iron, and less alumina (*see* Table VIII). The higher soda and lower alumina content of this argillite suggests that it is composed of less highly weathered products. The higher ferric iron oxide content suggests that it was deposited under more oxidizing conditions.

Table XVII

Chemical Analyses of Lutite and Arenites from Nordic Formation

Sample	RF-573	RF-574	RF-575
SiO_2	58.62	74.87	93.48
Al_2O_3	18.18	9.99	3.30
Fe_2O_3	3.76	0.00	0.50
FeO	4.90	4.94	1.25
MgO	2.07	1.75	0.17
CaO	0.52	3.13	0.21
Na_2O	1.17	1.91	0.92
K_2O	6.21	1.00	1.12
H_2O (110°)	0.09	0.09	0.02
H_2O (900°)	3.55	0.57	0.32
TiO_2	0.81	0.39	0.11
ZrO_2	0.0293	0.0235	0.0095
MnO	0.060	0.090	0.029
SrO	0.008	—	—
Rb_2O	0.028	—	—
Total	100.01	98.75	101.44

Scandium detected, Sc:Sr ratio is 0.67.
RF-573—Massive black argillite—from a bore-hole at Lake Nordic mine.
RF-574—Dark grey subgreywacke—same location.
RF-575—Grey quartzite—same location.
Analyses by G. MacDonald, Miller Research Laboratory, Queen's University.

The trace element content of this argillite was discussed under the Whiskey Formation and is shown in Table IX, Table XVIII, and Figure 5. It was concluded that this argillite contains similar amounts of trace elements as the argillite from the Whiskey Formation, except that there is less Rb and more Mo and Co. Furthermore, it contains substantially larger amounts of Ni, Cr, Co, and V than the Huronian arenites. Boron was detected in qualitative spectrographic analyses, but no tourmaline (the common abode for B) was observed in thin sections examined. Scandium was also detected. Most of these trace elements are probably concealed or absorbed in the structure of the fine micaceous and chloritic minerals although hydrothermal introduction may account for the enrichment of the sulphophile elements.

Siltstone

The siltstone is a greenish grey, equigranular rock composed of subangular to subrounded silt-sized grains and a few of sand size. The principal constituents are quartz, feldspar, and chlorite shreds embedded in a fine white mica matrix with a little calcite. Black iron oxides, epidote, pyrite, pyrrhotite, and zircon are present in small quantities. Sulphides generally occur in the interstices but some larger grains replace the clastic detritus.

Greywacke and Subgreywacke

The greywacke is a dark grey, medium-grained arenite showing a disrupted framework structure. It consists of angular to subangular, sand- and silt-sized grains of quartz, chert, chloritic rock fragments, microcline, and plagioclase in a matrix of fine white mica with some calcite and shreds of chlorite. Rock fragments constitute up to 6 per cent of the total rock. Sorting is poor and the average index is 78. Minor constituents are mainly black iron oxides, biotite, zircon, epidote, pyrite, and pyrrhotite.

Table XVIII

Analyses of Trace Elements in Sedimentary Rocks from the Nordic Formation

A. Quantitative

Sample	Cr	V	Ni	Co	Cu
RF-573	0.0185	0.0255	0.0092	0.0053	0.0059
RF-574	0.0087	0.0035	0.0078	0.0042	0.0088
RF-575	<0.0009	<0.0015	<0.0007	<0.0010	<0.0003

B. Qualitative

Element	RF-573	RF-574	RF-575
B	M	ND	ND
Mn	S	Tr	ND
Pb	W	M	ND
Ca	VS	S	Tr
V	VS	S	Tr
Cu	VS	VS	M
Ag	FTr	Tr	ND
Ni	VS	M	W
Co	S	S	Tr
Cr	E	E	S
Mo	FTr	ND	ND

Elements not detected: Be, Bi, and Sn.
ND—Not detected
FTr—Faint trace
Tr—Trace
W—Weak
M—Medium
S—Strong
VS—Very strong
E—Extremely strong

RF-573—Argillite
RF-574—Subgreywacke
RF-575—Quartzite

Analyses by G. MacDonald, Miller Research Laboratory, Queen's University.

The subgreywacke is a grey, medium-grained arenite that is composed of essentially the same minerals as the greywacke. However, it contains less feldspar and has a slightly better sorting index than the greywacke. Modal analyses of these arenites are shown in Figure 9.

Both greywacke and subgreywacke contain less rock fragments than normally reported in such arenites. However, they are generally poorly sorted, exhibit a disrupted framework structure, and have much matrix material, which are diagnostic characteristics.

The greywacke and subgreywacke exhibit the same effects of cataclastic deformation as the other Huronian arenites. Undulatory extinction of quartz, fracturing of clastic grains, and serrated grain boundaries are common textural features. Incipient replacement of clastic grains by fine white mica and pyrite is fairly common. A few veinlets of calcite, fine white mica, quartz, and pyrite were also observed in thin sections.

The subgreywacke contains less silica and ferric iron and more alumina, magnesia, soda, ferrous iron, and lime than the quartzite (RF-575) (*see* Table XVII). It also has more silica and less alumina, soda, and magnesia than the greywacke from the Whiskey Formation (*see* Table VIII).

The chloritic rock fragments in the subgreywacke may account for its high magnesia content and secondary calcite for most of the lime. The presence of fugitive oxides, such as magnesia, lime and soda, clearly indicate the chemical immaturity of the detritus comprising the subgreywacke, which is diagnostic of this clan. The absence of ferric iron and the high ferrous iron content are difficult to explain, and may be due to deposition in a reducing environment.

Compositional differences between the closely associated subgreywacke and quartzite are attributed to extensive winnowing of the latter. Labile oxide constituents, such as magnesia, soda, and lime, as well as fine aluminous matrix material, are removed or reduced during reworking, which results in the relative enrichment of silica.

Quantitative and qualitative spectrographic analyses of trace elements in the subgreywacke are shown in Table XVIII. The trace elements in the subgreywacke were previously discussed under the Whiskey Formation. It was concluded that the subgreywacke has less V, Cr, and Cu but more Cu, Ni, and Ag than the greywacke from the Whiskey Formation (*see* Table IX, and Fig. 5). The latter elements may have been augmented by later introduction. Generally, the subgreywacke, with more aluminous silicates than subarkoses and quartzites, contains more trace elements.

Subarkose and Quartzite

The subarkoses are grey, medium-grained arenites, composed of subangular to subrounded, sand-sized clastic grains. They consist of quartz, microcline, altered plagioclase, chert, and chloritic fragments set in a fine white mica matrix with some calcite. Chloritic fragments constitute up to one per cent of the total rock. The average microcline:plagioclase ratio is 3.0, which is considerably lower than the average for the subarkoses of the Matinenda Formation. Sorting is fair and the average index is 30. Pyrite, zircon, apatite, epidote, and black iron oxides occur interstitially in minor quantities. Some pyrite occurs along crossbeds.

The quartzites are light grey, medium-grained arenites composed of the same minerals as the subarkoses. They generally contain less feldspar and matrix material than the average subarkose and have a better sorting index (*see* Fig. 9). They are texturally mature arenites, whereas the subarkoses are texturally submature. They show a wide range of matrix content, which probably reflects variations in the degree of winnowing.

A chemical analysis of a quartzite (RF-575) from the Nordic Formation is given in Table XVII. The quartzite contains over 90 per cent of silica and belongs to the typical quartzite clan. It has a composition similar to that of the upper member of the Matinenda Formation, but contains more soda and total iron and less potash (*see* Table X, sample No. 55-71). The higher total iron content is partly due to more abundant pyrite. However, the low potash:soda ratio is more significant, and was confirmed by petrographic studies. This would imply that the detritus comprising the Nordic quartzite was more soda-rich than that of the Matinenda quartzite; either the source area or the provenance of the Nordic Formation was more soda-rich than that of the Matinenda Formation. Such a difference in the nature of the source area between the two formations is substantiated by the abundance of chloritic rock fragments in the arenites of the Nordic Formation, which suggests that metavolcanic rocks were abundant.

Qualitative and quantitative spectrographic analyses of the trace elements in this quartzite (RF-575) are shown in Table XVIII. There are no significant differences between the concentration of trace elements in this quartzite and that of the upper member of the Matinenda Formation (Table XI, sample No. 55-71; Fig. 10), except that it contains slightly more V and less Cu. This quartzite, as might be expected from its high silica and low alumina contents, also contains much smaller concentrations of trace elements than the associated subgreywacke and argillite.

Mode of Deposition

Roscoe (1957a) suggested that the Nordic Formation is a deep-water facies of the Matinenda Formation as deposited farther north. However, the presence of quartzite and subarkose units in the Nordic Formation is not compatible with an entirely deep-water mode of deposition. Lithological characteristics of these rocks denote shallow-water deposition accompanied by extensive winnowing. Furthermore, chemical grading of the potash-rich sediments of the Matinenda Formation could not produce the soda-rich sediments of the Nordic Formation.

Products derived from the sediments of the Matinenda Formation to the north may have been added to the detritus of the Nordic Formation, but a more soda-rich, possibly metavolcanic source, appears to have been an important contributor.

It is suggested that fine residual products from a northerly source were laid down in tranquil waters as argillite, and during periods of turbulence silts were deposited with the argillites. Intermittent changes in the tectonic setting accompanied by minor uplifts resulted in rapid debouching of chemically immature detritus to form the greywacke beds. These changes in the tectonic setting were probably followed by regressions of the strand line during which some sediments were deposited in shallow water. These sediments were extensively winnowed and produced the subgreywackes, subarkoses, and quartzites, depending on the degree of reworking.

Summary

The main features of the Elliot Group are as follows:

1. It is subdivided into two formations: an upper, Nordic, and a lower, Matinenda, formation. The Matinenda Formation along the south flank of the syncline is further subdivided into an upper and lower member. Neither the Nordic Formation nor the upper member of the Matinenda Formation is present along the north limb of the syncline, although the Matinenda Formation occurs in most parts of the syncline.

2. A greenish yellow, coarse-grained subarkose is the predominant rock type in the lower member of the Matinenda. It is a poorly sorted and winnowed arenite, except in the northeastern and eastern parts of the syncline, where there is evidence for more pronounced winnowing. The lower part of this member consists of interbedded subarkoses and uraniferous pyritic oligomictic conglomerates. The conglomerates are thicker and more abundant in abnormally thick sections of the member. The thickness of the conglomeratic section generally decreases towards the southeast and east.

Individual beds are thicker, contain larger pebbles, and are more closely spaced in the lower part of the conglomeratic section than in the upper part. They are lenticular and vary in lithological character, but zones in which closely spaced conglomerates alternate with subarkose beds are more continuous.

3. The configuration of the basement surface played an important role in the distribution and deposition of the lower member. The distribution pattern is characterized by separate southeast-trending, trough-like occurrences with intervening high areas of nondeposition. The thickness of sediments of the lower member in the troughs increases from almost nothing along the margins to a maximum in the centre. Over the ancient ridges they are much thinner or in places altogether absent.

Isopachal trends are most commonly from northwest to southeast and are parallel with the direction of detrital transport inferred from crossbedding. The lack of continuous strike deposits and the linearity of trough-like occurrences of this member suggest that strand line currents were insignificant during deposition. A fluvial mode of deposition is suggested.

4. The residual character of both the subarkoses and conglomerates increases from the southern to the northern part of the syncline, possibly the result of differences in the chemical maturity of the detritus deposited in each part.

5. As the sedimentary rocks comprising this member are potash-rich and contain few rock fragments, they are probably first cycle derivatives of a granitic provenance.

6. The ore-bearing conglomerates are confined to two southeast-trending 'valley-like' accumulations of abnormally thick sections of the lower member. One of these occurs in the northern part and the other in the southern part of the syncline. The ore zones consist of an interlacing assemblage of various kinds of lenticular sedimentary units, mostly well-packed and loosely packed conglomerates and conglomeratic and pebble-free subarkoses. Well-packed conglomerate beds may grade into several thin pebble layers interbedded with lentils of subarkose. Pebble layers and highly uraniferous pyrite seams occur as foreset beds in some localities.

7. The uranium minerals and most of the pyrite occur as separate grains in the matrix of the conglomerates, although some pyrite appears to replace clastic grains and some as occasional cross-cutting veins. Well-packed rudites contain more U_3O_8, ThO_2, rare earths, and trace elements than loosely packed conglomerates.

8. The ore-bearing conglomerates are bimodal and pebble sizes vary along the strike. These features are indicative of a fluvial mode of deposition.

9. No evidence was found to suggest that soda and potash were introduced in the conglomerates except locally where intense albitization and chloritization are found near a diabase dyke. This alteration post-dates the ore mineralization and has no significant effects on the tenor of the ore. The ore mineralization is independent of structural features such as faults, folds, and intrusions.

10. The upper member of the Matinenda Formation consists of a lower part, composed of subarkoses and polymictic conglomerates, and an upper part composed of fine-grained quartzites. The subarkoses are generally finer grained, more massive, less crossbedded, and contain less matrix and potash than the subarkoses of the lower member. The conglomerates are polymictic in character, non-uraniferous, and contain less matrix, sulphides, and heavy minerals than the uraniferous, oligomictic conglomerates. The former are also characterized by abundant fractures and veins of calcite, epidote, quartz, and chlorite.

In several areas, the upper member overlaps the depositional edge of the lower member and rests directly on the pre-Huronian basement. There is evidence that the lower member was eroded in places before the upper member was deposited. The lower or gravelly part of this member appears to have been deposited in southeast-trending channels, whereas the upper part is the product of repeated reworking in shallow water.

11. The Nordic Formation consists of an interbedded assemblage of argillite, siltstone, greywacke, subgreywacke, feldspathic quartzite, and quartzite. The

argillite is a hybrid type characterized by high alumina and potash contents. The arenites are more soda-rich than those of the underlying Matinenda Formation.

12. The effects of cataclastic deformation are common in both the rudites and arenites of the Elliot Group. Clastic grains are fractured and granulated and quartz grains show strain shadows and incipient recrystallization.

13. Serrated grain boundaries and incipient replacement of clastic grains by fine white mica are ubiquitously present in both rudites and arenites of this group. These textural features are ascribed to mineralogical adjustments under metamorphic conditions, and to have been activated in local areas by hydrothermal solutions. The abundance of fine white mica is not considered to be a positive criterion for hydrothermal alteration, as it is present all through both rudites and arenites and rarely occurs in crosscutting veinlets.

14. The mean quantities of trace elements in Huronian sedimentary rocks are summarized in Table XIX.

Table XIX

Trace Elements (in PPM) in Some Typical Huronian Sedimentary Rocks

Rock type	Number of analyses	Cr	V	Ni	Co	Cu	Rb
Argillites	2	173	224	129	53 (1)	54	276
Greywackes	1	117	82	46	BL	135	—
Subgreywackes	1	87	35	78	42	88	—
Subarkoses	8	25 (1)	BL	BL	BL	18	—
Quartzites	2	BL	BL	BL	BL	5	—

(1) denotes the number of samples in which the element was detected.
BL below the limit of detectability.

The argillites generally contain more trace elements than the greywacke and subgreywacke, and these in turn more than the subarkoses and quartzites. As most of these trace elements are believed to be concealed in the structures of micaceous and chloritic matrix minerals, there appears to be a direct relationship between the amount of fine micaceous matrix material and the amount of trace elements in sedimentary rocks. However, some elements were undoubtedly augmented by hydrothermal solutions.

No significant differences were detected in the amount of trace elements in the subarkoses and quartzites from the different Huronian formations. Silver and molybdenum, uncommon elements in sedimentary rocks, are erratically distributed in the Huronian rocks. As these elements are associated with hydrothermally altered zones near diabase intrusions, it is suggested that they were similarly introduced in the other occurrences. Boron is present in the argillites and a few samples of arenites, and is most probably fixed in tourmaline.

Chapter IV

CROSSBEDDING AND CONGLOMERATE FABRIC

Crossbedding

Roscoe noticed the excellent exposures of crossbedding in the Huronian formations during a reconnaissance survey of the Algoma district in 1954. In 1955 a study of crossbedding in the Quirke Lake syncline was commenced during an investigation of the Huronian stratigraphy and it and a study of gravel fabric was completed in 1957.

In 1956 McDowell of the Ontario Department of Mines made an exhaustive study of primary current structures on a regional scale, the results of which were published in 1957.

Previous Investigations

In the past ten years numerous studies of primary current structures in sedimentary rocks have been conducted with encouraging results. Cross-stratification[1], ripple-marks, and gravel fabrics have become useful in determining the directions of paleostreams (Pettijohn, 1957a; McDowell, 1957; Schlee, 1957a,b; Brett, 1955; Walker, 1955; Potter and Olson, 1954); in reconstructing ancient shorelines (Tanner, 1955), and possible provenance areas (Potter and Siever, 1956; Brinkman, 1955).

In the field of economic geology, crossbedding and pebble orientation studies have been useful guides in predicting extensions of channel deposits and paystreaks. Crossbedding has been used in the Colorado Plateau to predict the trend of relatively porous channels that contain orebodies (Lowell, 1955). On the East Rand in South Africa, a consistency was detected between the trend of paystreaks, crossbedding, and the long axes of pebbles in the conglomerate (Reinecke, 1930).

Although crossbedding has been extensively used as an index to the direction of detrital transport, the validity of such usage has been challenged by several authors.

1. Bain (private com.) has pointed out that the direction of sediment transport inferred from crossbedding is sometimes inconsistent with the direction of grain size diminution. However, the decrease in grain size in stream deposits is commonly related partly to independent factors such as lateral migration of streams, paleoslopes, velocity, by-passing, and tributary supply. Thus, variation in grain size may exhibit anomalous results in local areas, and may differ from the crossbedding directions.

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[1] A term used by McKee and Weir (1953) to include both cross-lamination, beds less than 1 cm thick, and crossbedding, greater than 1 cm thick.

2. The river channel pattern in the Shinarump Conglomerate of the Colorado Plateau (Bain, 1952) is at a large angle to the crossbedding direction obtained by McKee (1940).

3. Dunbar and Rodgers (1957) have challenged the accuracy of current directions interpreted from crossbedding for the following reasons:

Migrating sand waves, the common mode of formation of crossbedding, may have an irregular front which produces deltaic lobes. Crossbedding may be developed along the front as well as along the sides of the lobe. Crossbedding produced in such a manner may dip in different directions.

In meandering streams foreset beds may be developed at the concave side of meanders and will indicate a direction at an angle to the general stream direction.

Most of these features are local and are eliminated in a statistically well-sampled area. Paleocurrent directions from crossbedding have been confirmed by the studies of other sedimentary structures, such as ripple-marks and depositional fabrics (Brinkman, 1955; Brett, 1955).

Types of Crossbedding

Crossbedding is present in all the arenites and in some of the rudites in the area, but only those in the Mississagi and Matinenda Formations were studied. Following classification is that suggested by McKee and Weir (1953):

Simple Crossbeds

These are small lenticular crossbedding units and their lower bounding surfaces are nonerosional (*see* Fig. 18C). Simple crossbedding is rare in the Mississagi and Matinenda Formations and was rarely measured in this investigation.

McDowell (1957) suggested that simple crossbedding is formed by continuous deposition from a medium carrying maximum load, probably as microdeltas. If the load of the depositing medium is decreased, a certain amount of erosion will result.

Trough or Festoon Crossbedding

Trough crossbedding exhibits a curved lower bounding surface, which is an erosional surface (*see* Fig. 18A). This type of crossbedding occurs in troughs or channels, and is lens- or wedge-shaped in section. The crossbedded layers may be symmetrical or asymmetrical about the axial plane of the trough, and are more or less tangential to the lower bounding surface.

The intersection of trough crossbedding on a bedding plane is a curved line, concave in the direction of plunge or inclination of the crossbedding. The trace of the entire trough is clearly outlined on the bedding plane, and the direction of the axis of the trough is a reliable guide to the direction of crossbedding.

Trough crossbedding is abundant in both the Matinenda and Mississagi Formations and occurs commonly in ill-sorted silty beds. These structures range from

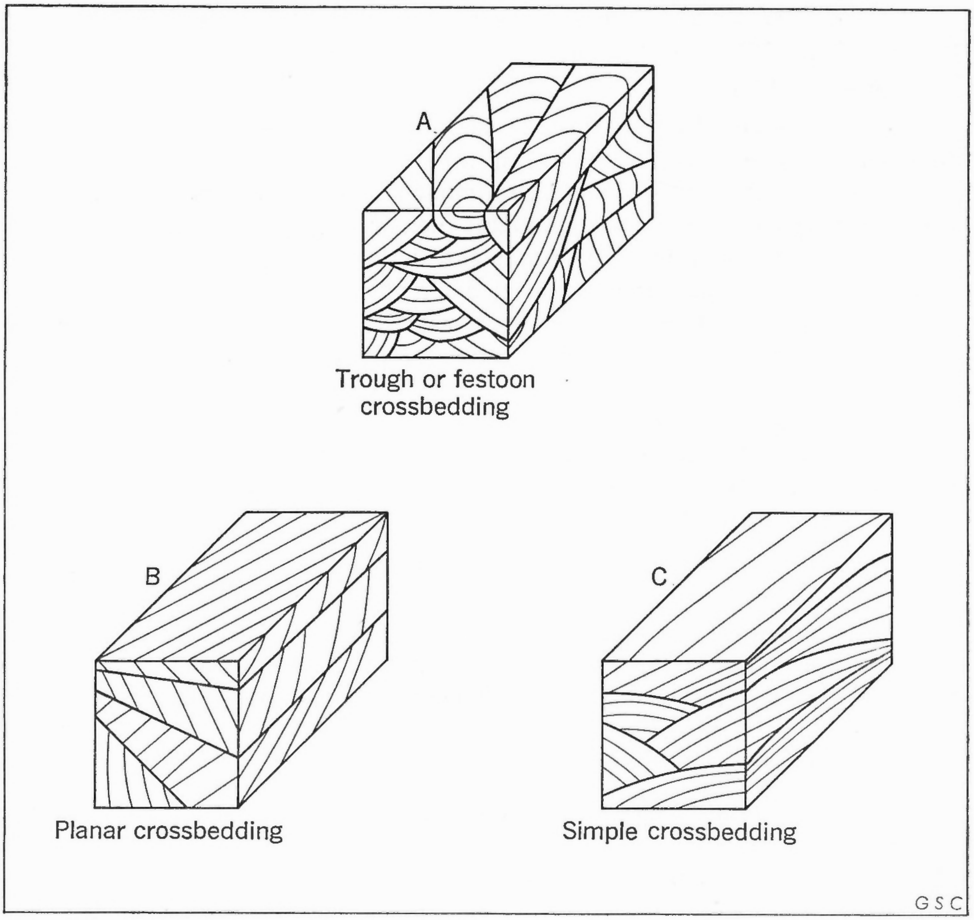

FIGURE 18. Types of crossbedding (*after McKee and Weir, 1953*).

1 inch deep, 3 inches wide, and 24 inches long, to 18 inches deep, 12 feet wide, and more than 20 feet long. Trough crossbedding attains mammoth sizes, and Knight (*in* McDowell, 1957) measured troughs 100 feet deep, 1,000 feet wide, and several thousand feet long. Whether there is a genetic difference between these large-scale troughs and the smaller troughs, such as those encountered in the Blind River area, is uncertain.

The common association of trough crossbedding with silty ill-sorted beds suggests very rapid deposition by high velocity currents, although Fahrig (private com.) reports trough crossbedding in the well-sorted Athabasca sandstones. Trough crossbedding may indeed form under quite different conditions.

Although numerous mechanisms for the formation of trough crossbedding have been proposed, its origin is still uncertain. Knight (*in* McDowell, 1957) described trough crossbedding as plunging erosional troughs filled by crossbedded strata that conform to the shape of the trough. Stokes (*in* Pettijohn, 1957a)

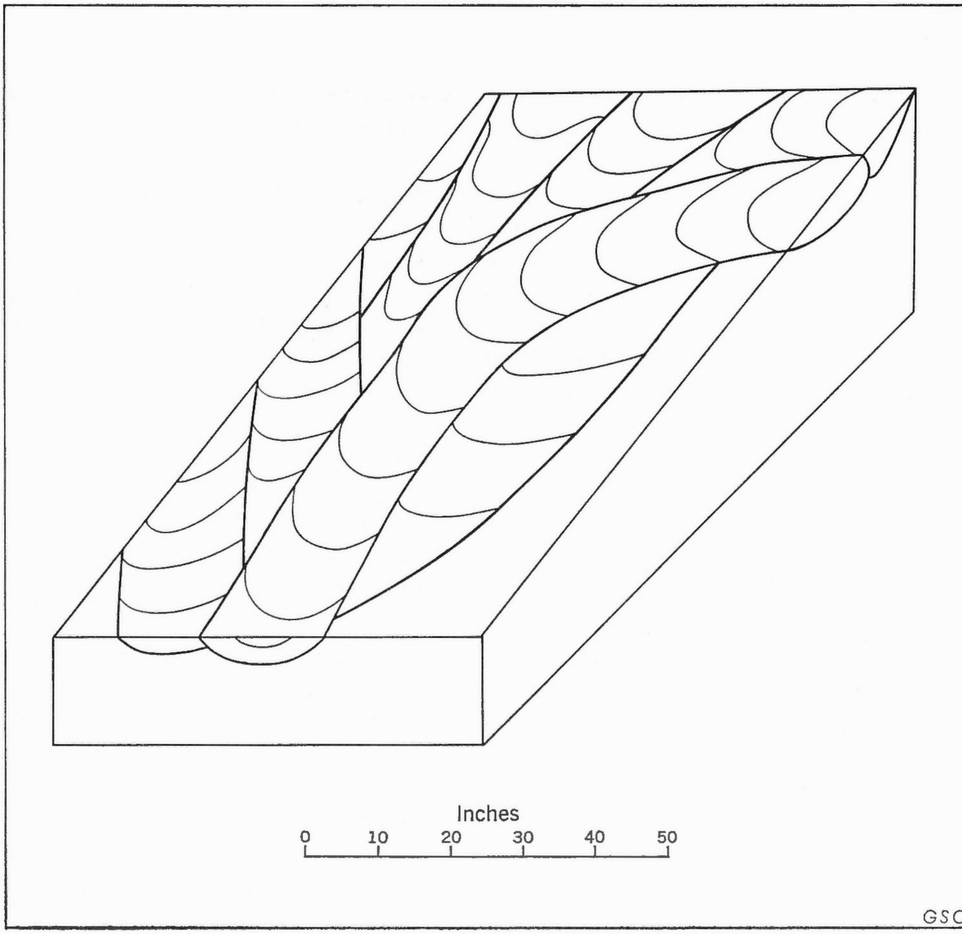

FIGURE 19. Trace of meandering channel showing trough crossbedding on bedding plane, near No. 2 shaft, Milliken Lake uranium mine.

believed that this type of crossbedding formed under turbulent conditions during high water. However, according to Pettijohn (1957a) and McDowell (1957), these mechanisms and others fail to account for the scale, inclination, and orientation of trough crossbedding. Trough crossbedding has never been produced in the laboratory (Pettijohn, 1957a).

The origin of trough crossbedding may be a controversial issue, but cross-bedded meandering channels (*see* Fig. 19) are fairly common in the Huronian arenites. Figure 19 also shows that the crossbedding is confluent with the meandering of the channel, which agrees with the description given by Knight. These channels resemble tortuous scoop-like structures in modern river bottoms, but whether such structures would survive the rigours of sedimentation is not known. It is, however, a possible explanation for the formation of trough crossbedding.

Planar Crossbedding

Planar crossbedding has often been referred to as 'torrential' crossbedding, but this term is a misnomer as the crossbedded layers are fairly even, parallel, and show excellent graded bedding. The term 'torrential' crossbedding has a genetic implication that is misleading.

This type of crossbedding consists of nearly parallel layers with a lower bounding surface that is a planar erosional surface (*see* Fig. 18B). The inclined crossbeds are also nearly planar, but a slight upward concavity is common, so that the base of the crossbed may approach asymtopacy with the lower bounding surface. They also curve along strike with the concave side of the curve facing in the downstream direction. Potter and Siever (1956) suggested that this concavity is due to exceptionally rapid forward growth of sand waves or barchan-like deltas.

The thickness of planar crossbedding, measured in both the Matinenda and Mississagi Formations, ranges from a few inches to 54 inches. Only rarely were the absolute strike extensions of planar crossbedding observed.

The distinction between planar and trough crossbedding in the field is commonly not clear. An exposure that reveals only one section through large-scale trough crossbedding may exhibit all the characteristics of planar crossbedding.

Several authors have attributed the formation of planar crossbedding to migrating sand waves or mammoth ripple-marks (Kindle, 1917; McKee, 1939; McDowell, 1957). Others (Potter and Siever, 1956) related planar crossbedding to the formation and migration of barchan-like deposits. Both these suggestions imply the same mechanism—migrating sand waves.

Kindle (1917) described crossbedding as a phase of mammoth sand ripples, formed when a current is overloaded with sediments. Such sand waves or giant ripples migrate by building foreset beds on the lee side of ripples. Providing there is a constant supply of sediment and deposition exceeds erosion there is an excellent chance of preserving crossbedding although undoubtedly a certain amount of decapitation will take place by the erosion of up-current wave crests. This mechanism for the formation of planar crossbedding was proposed by McDowell (1957) and Potter and Siever (1956), and is further substantiated by the presence of crossbedding in ripple-marks.

Kindle measured some mammoth sand waves with wavelengths ranging from 15 to 35 feet and amplitudes from 2 to 3 feet. Planar crossbedding in the Huronian formations attains thicknesses up to 54 inches. Allowing for some decapitation, the sand waves that produced these thick planar crossbeds must have exceeded 5 feet in amplitude. Ripple-marks of such magnitude are not common in modern deposits.

Measurement of Crossbedding

This study is confined to the local and detailed distribution of sedimentary current structures, and the degree of sampling was to some extent controlled by the extent of rock exposures.

In order to secure a balanced coverage, the area was divided into blocks, in each of which two regularly spaced traverses were run at right angles to strike, from the base to the top of the formation. The bearing of the prevalent crossbedding azimuth of dip of crossbeds in each bed was recorded, as well as the extent of variations. Two traverses commonly provided enough data for a statistical analysis. Both trough and planar crossbedding, and the attitude of the beds were recorded. The blocks in the Matinenda Formation cover an area of 5,000 to 12,000 feet along strike and the complete downdip exposure of the formation. Near the exposures of radioactive rudites, around Nordic mine, the size of the blocks was decreased in order to investigate a shift in the mean direction of the current.

The Matinenda Formation along the north limb of the syncline is not well exposed, and most of the observations were obtained from underground workings. Only 25 per cent of the total readings at Quirke mine were measured on surface exposures (*see* Fig. 20). The crossbedding data from the underground workings at Panel and Can Met mines were too limited to be of much use in the statistical interpretation.

The measurement of the direction of dip crossbedding in underground exposures is extremely difficult. Numerous aberrant trends were noticed, probably associated with local eddies and swirls and the deposition of foreset beds on the side of deltaic lobes. The crossbedding is difficult to see in most places although it is commonly marked by pyrite seams. It is possible, though unlikely, that some measurements were taken on pyrite seams that did not follow crossbeds.

In the Mississagi Formation the unit blocks covered an area ranging from 2 to 4 miles along strike and the complete downdip exposure. Somewhat more than a properly representative proportion of the data was obtained along the shores of Quirke Lake (*see* Fig. 20).

The following methods were employed to measure the direction of crossbedding:

1. The strike and dip of crossbedding were measured. This method requires special conditions and was possible in only a few places.

2. The amount and directions of the apparent dip of crossbedding were measured on two faces of the outcrop at approximately right angles to each other. From these results the strike and dip of the crossbedding were computed. This method, similar to that used by Walker (1955), was facilitated by the presence of two sets of joints striking north and east.

3. The trace of trough crossbedding layers on a bedding plane produces a curved structure, the concavity of which points in the direction of the plunge of the trough and of the direction of sediment transport (*see* Fig. 19). The desired information can thus be obtained by measuring the bearing of the trough axis. The curvature of the trace of planar

crossbedding on the bedding plane is not so easily detected, and, unless grain gradation is exhibited or a cross-section exposed, planar crossbedding cannot be used in this manner.

Data collected by the above methods were corrected for tilt on a Wulff stereonet, assuming that the bedding was essentially horizontal at the time of deposition. Tilt corrections are unnecessary for the bearing of current directions obtained on bedding planes dipping at low angles.

Primary Inclination of Crossbeds

The primary inclinations of crossbeds in the Mississagi Formation were computed from 200 field measurements and are graphically illustrated in Figure 21. The frequency distribution in the Mississagi Formation is compared with that obtained by Pettijohn (1957b) in the Lorrain Formation from Bruce mines.

Inclinations in the Mississagi Formation vary from 5 to 55 degrees and average nearly 21 degrees. In the Lorrain Formation they range from 6 to 41 degrees and average 20.2 degrees.

The striking feature of the inclination of the crossbeds is that 17 per cent in the Mississagi Formation and 10 per cent in the Lorrain Formation exceed the angle of repose for sand in water, which is 33 degrees. These anomalously high inclinations are not only confined to Precambrian quartzites, but were reported from untilted Pennsylvanian sandstones by Potter and Olson (1954), and from Cenozoic gravel deposits by Potter (1955).

Pettijohn (1957b) suggested that the higher inclinations may be due to post-depositional deformation involving an internal 'card-deck' shearing. Although Pettijohn considered deformation as the more important factor, slumping and soft-sediment movement were also cited as possible causes.

In the Quirke Lake syncline, an open folded structure, the aberrant inclinations show a random distribution. Thus, it appears unlikely that deformation is responsible for the high inclinations, and soft-sediment slumping seems the more reasonable interpretation.

Conclusions

The directions of crossbedding were plotted on rose diagrams (*see* Fig. 20), showing the percentage that fell into each 30 degree sector. The rose diagrams are plotted in the centre of each unit block.

In general, the most striking feature is that in every instance the maximum distribution lies in the southeast quadrant. Moreover, the arithmetical mean of the direction of crossbedding in each block falls within, or close to, that of the maximum 30 degree sector. With a few exceptions, such as north of Stintson Lake, the percentage in other sectors is symmetrical about the maximum. As crossbedding is generally accepted as a guide to the direction of sediment transport, this uniformity through both the Matinenda and Mississagi Formations would imply that the paleocurrents maintained the same general direction during the deposition of 3,000 feet of sediments.

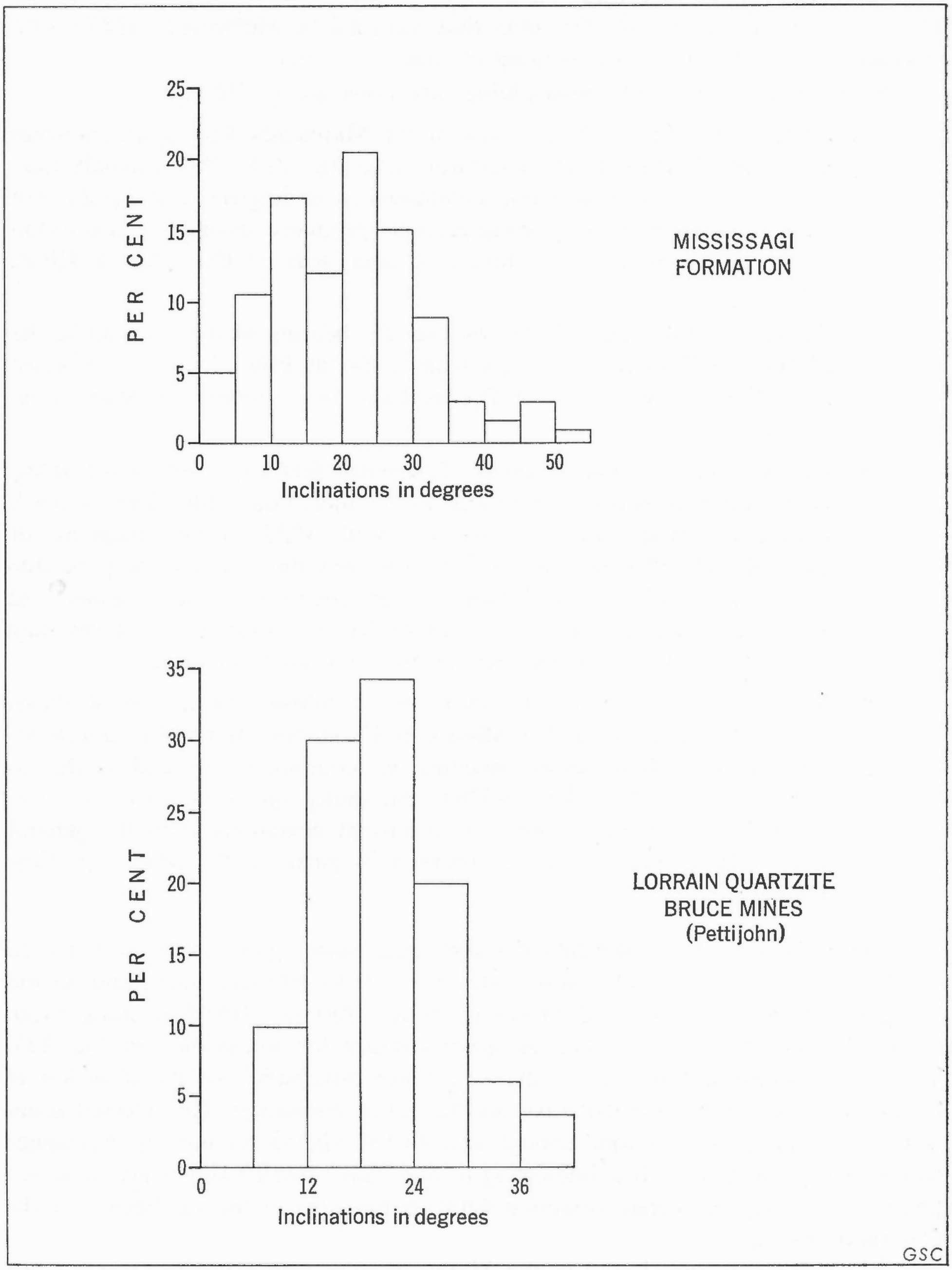

FIGURE 21. Primary inclinations of crossbeds in Huronian arenites.

Although this regional uniformity of crossbedding direction exists, the mean azimuth in the Mississagi Formation is 14°E of that in the Matinenda Formation. This difference is considerably less than that recorded by McDowell (1957) who reported an easterly shift in the bearing of some 49 degrees.

Some other features of crossbedding directions are as follows:

1. At Quirke mine a submaximum in the Matinenda Formation indicates a current direction to the southwest (*see* Fig. 20). This anomaly may be due to the poor sampling conditions in underground workings, but may be attributable to eddying currents produced during the deposition of the gravel, or the formation of foreset beds on the sides of deltaic lobes.
2. Along the south limb of the syncline, the bearing of the maxima in the Matinenda Formation changes from south at Elliot Lake to southeast near Nordic mine. East of Pecors Lake the southerly bearing is resumed.
3. Another common but randomly distributed feature of the crossbedding is its complete reversal in places within individual beds. This is not a unique feature and was observed by Lowell (1955) in the sandstones of the Colorado Plateau. Lowell suggested that this anomaly may be due to alternating directions of flow through channels at the confluence of streams. This mechanism and perhaps the meandering of streams may account for the reversals seen in the Huronian arenites.
4. Some of the rose diagrams show minor submaxima in the northeast quadrant, especially in the Mississagi Formation at Quirke and Stintson Lakes. Such secondary maxima are commonly regarded as due to sampling bias (Pettijohn, 1957b), but faulty sampling does not seem to be the whole answer here, as persistent deviations from the general crossbedding direction were observed in parts of the Mississagi Formation.

Zones from Quirke and Stintson Lakes areas showing deviation as described in (4) were studied in detail. These zones were 20 to 100 feet thick, and all the directions of crossbedding for distances of from 1,500 to 2,000 feet along strike were measured and compared with the general results for that block (*see* Fig. 22). This clearly shows a difference in the abundance distribution of the direction of the crossbedding in the selected zones and the entire formation. The selected zones were not examined over a wide enough area to tell whether or not the divergence was a local phenomenon. It is interesting to note that Lowell (1955) also detected patterns of diverging current direction between horizons in the sandstones of the Colorado Plateau.

The mean direction found in the Matinenda Formation in the Quirke Lake syncline is rather more southerly than that described by McDowell in the same area (he recorded only thirty-two readings) but the regional direction reported by him agrees excellently.

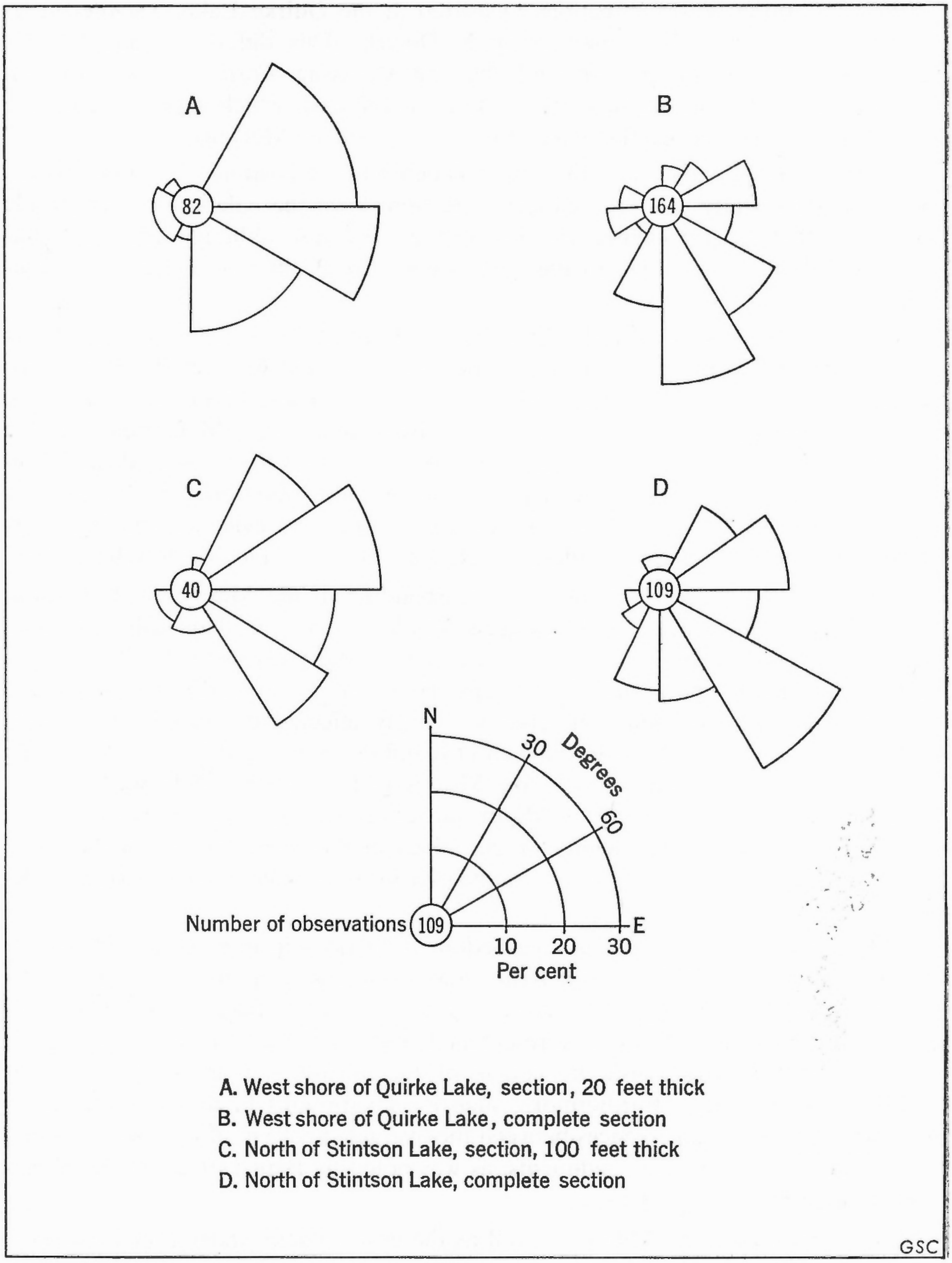

FIGURE 22. Variations in direction of crossbedding, Mississagi Formation.

The mean direction of crossbedding in the Mississagi Formation, however, shows no similarity on either a local or regional scale to McDowell's results. The arithmetical mean of the directions measured in the Quirke Lake syncline differs by 29 degrees from that obtained by McDowell. This difference may be due to 'oversampling' in the present study but the Mississagi Formation does thicken towards the south and southeast rather than to the east, which supports direction of transport suggested by this study rather than that of McDowell.

The results clearly show that the paleocurrents depositing the sands flowed from a northwesterly to a southeasterly direction down the paleoslope. This would also imply that the provenance area was to the northwest, although additional material may have been added to the main stream from different sources by tributaries.

This south to southeasterly direction of sediment transport is in accordance with the general trend of thickening in the Mississagi and Matinenda Formations. Schwarsacher (1953) detected a decrease in the thickness of crossbedding units in a downstream direction from the source area, and McDowell (1957) found that individual crossbedding layers in the Blind River area decrease in thickness towards the southeast. This clearly provides additional evidence for a northwesterly source. Thus it can be concluded that the evidence found in this study agrees with the earlier findings of Roscoe (1957a) and McDowell (1957).

The mean direction obtained for crossbedding in the Matinenda Formation is S23°E whereas that in the Mississagi Formation is S37°E. This difference may have been produced by a shift in the direction of the paleoslope due to changes in the positions of uplifts and downwarps. However, it also could be due to the fact that local pre-Huronian topography strongly affected deposition of immediately overlying Matinenda rocks but had little influence on the direction of currents that prevailed during deposition of the Mississagi Formation (McDowell, 1957). Local influence of topography on Matinenda crossbedding trends are clearly seen east of Elliot Lake in the vicinity of the mines in that area. Trends in this area, overlying a pre-Huronian valley, are southeasterly whereas those in bordering blocks are southerly.

As shown in Figure 22, the crossbedding directions in parts of the Mississagi Formation vary from the general trend. Such differences in the crossbedding directions in parts of a single formation may be due to meandering of a paleocurrent during deposition. If so, a more detailed study of the crossbedding in a single unit might serve to establish the course of the meandering ancestral stream in which it was deposited. Furthermore, such local variations in the trend of crossbedding may explain divergences between the average direction of cross-laminations and the trend of channels of sediments, as was noted by Bain (1952) in the Shinarump Conglomerate of Colorado.

The origin of crossbedding, as well as the environment under which it forms, is still a controversial matter (Pettijohn, 1957a). Abundant data are available on crossbedding from known fluvial deposits, but very little is known about crossbedding from aeolian, marine, or mixed environments.

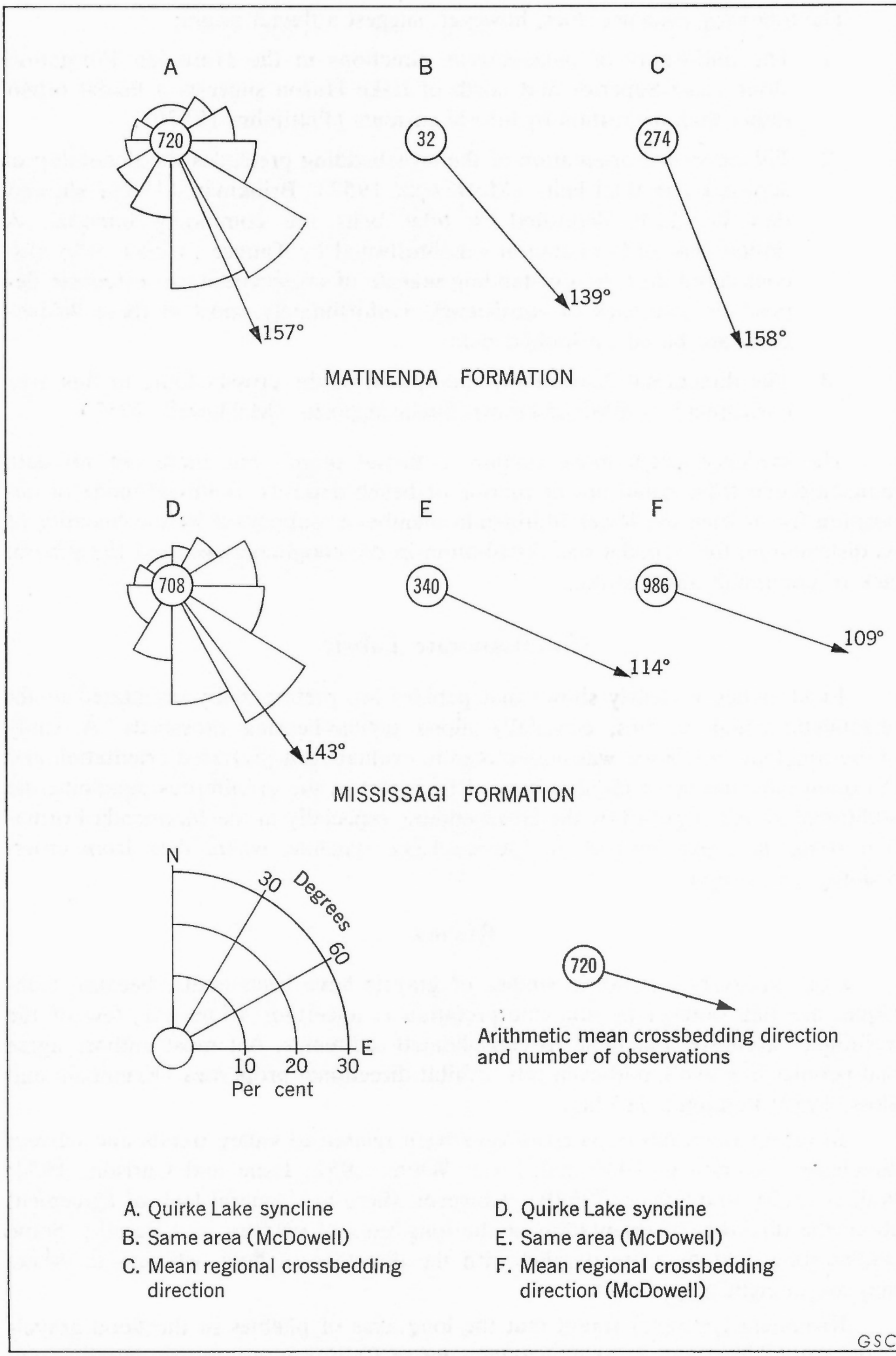

FIGURE 23. Comparison of crossbedding directions in the Quirke Lake syncline and surrounding townships.

The following evidence does, however, suggest a fluvial origin:

1. The uniformity of paleocurrent directions in the Huronian Formation along Lake Superior and north of Lake Huron suggests a fluvial origin rather than deposition by littoral currents (Pettijohn, 1957b).
2. The unimodal orientation of the crossbedding precludes the possibility of deposition in tidal belts (McDowell, 1957). Brinkman (1955) showed that crossbeds deposited in tidal belts are commonly bimodal. A similar bimodal orientation was illustrated by Tanner (1955), who also considered that the outstanding feature of crossbedding in estuarine deposits is their lack of consistency. Unfortunately, most of these distinctions are based on limited data.
3. The directional distribution and spread of the crossbedding in this area correspond to those of known fluvial deposits (McDowell, 1957).

The evidence cited above favours a fluvial origin, but there are no data indicating that these could not be marine or beach deposits. A fluvial mode of deposition for at least the lower Matinenda member is supported by the linearity of its distribution, the bimodal size distribution in the conglomerates, and the general lack of continuity along strike.

Conglomerate Fabric

Field evidence clearly shows that pebbles are preferentially orientated in the oligomictic conglomerates, especially along pebble-bearing crossbeds. A study of the conglomerate fabric was undertaken to evaluate this preferred orientation and to obtain information of the direction of transport in the uraniferous conglomerate additional to that supplied by the crossbedding, especially in the Matinenda Formation along the north limb of the Quirke Lake syncline, where data from crossbedding are meagre.

Review

Comparatively few fabric studies of gravels have been made, because techniques are time-consuming and interpretation is uncertain. Moreover, few of the techniques used are adaptable to consolidated sediments, but most authors agree that pebbles in gravels, and even tills, exhibit directional properties (Krumbein and Sloss, 1953; Pettijohn, 1957a).

In recent years fabric patterns have been related to valley trends and current directions (Krumbein, 1940 and 1942; White, 1952; Lane and Carlson, 1954; Walker, 1955; and Schlee, 1957b). However, there is a general lack of agreement about the direction of orientation of the long axes of pebbles in a current. Some studies show that they are parallel with the direction of flow, whereas in others they are at right angles to it.

Krumbein (op. cit.) found that the long axes of pebbles in the flood gravels of the San Gabriel and Arroyo Seco canyons of California are mostly parallel with the direction of the current and inclined upstream. This orientation was confirmed by Schlee's study of fluvial gravels in Maryland. Schlee (1957a) observed that the short axis of imbricated pebbles slopes downstream at a steep angle. The long axes of rod-shaped pebbles, plotted on standard petrofabric diagrams, show a semicircular scatter of maxima and submaxima that tends to describe a plane that is inclined in an upstream direction. Schlee (1957b) considered the bisectrix of the semicircular concentration of maxima as the current direction.

Some of the maxima in the petrofabric diagrams of both Krumbein and Schlee however are nearly normal to the current directions. This would tend to support the observations of Lane and Carlson (1954) and Fraser and Twenhofel (*in* Pettijohn, 1957a), that the long axes of pebbles are normal to the stream direction. This orientation is further supported by the flume experiments of Schoklitsch (1926) and Sarkisian and Klimova (*in* Schlee, 1957b). In these experiments the long axes of particles were normal to current direction in the centre of the flume but transverse near the sides.

Thus it appears that the long axes of pebbles may be either normal to or parallel with current directions. Walker (1955) detected a similar bimodal orientation in fabric studies of the Millstone grit of England and offered an ingenious explanation: If the deposition was rapid, the long axes of particles tend to lie at right angles to current direction. These particles are obviously frozen in their original rolling position by rapid deposition. On the other hand, if the rate of deposition is slow, they may be reoriented by later readjustments. In such cases the butt end, the area of maximum radius of a pear-shaped particle will tend to act as a fulcrum and the particle will be rotated by the current to a position parallel with the flow direction. It is obvious that this rotation may be arrested at any stage and will produce a scatter in the pattern of the distribution of the direction of the long axes. Some of the factors controlling the inclination and orientation of pebbles are summarized as follows:

1. The physical character of the depositing medium has considerable influence on the orientation of pebbles; the rate of deposition and meandering and deviation of currents around sandbars all affect it (Schlee, 1957b; Walker, 1955).

2. The shape of pebbles controls the ease with which they respond to hydrodynamic conditions.

3. The nature of the bottom where pebbles are deposited exerts a strong influence on the orientation. If a sand base is present, a scouring action of the current occurs at the upstream end of the pebble, undermines it and produces imbrication (Schlee, 1957b). If, on the other hand, a pebble is deposited on a gravel base, the chances of later readjustments are meagre and the pebbles will retain their original orientation and inclination (Lane and Carlson, 1954).

4. The size and size distribution of particles also control fabric patterns. Small among larger ones are poorly aligned (White, 1952; Cailleux

quoted by Schlee, 1957b). Brinkman (1955) reported a pronounced unimodal distribution of long axes in unequal-sized materials and a bi-modal distribution in well-sorted material.

It appears that pebbles deposited with sand are likely to show preferred orientation. In the Blind River area, pebbles in layers a single pebble thick, show a better alignment than those in massive conglomerates.

Shape of Pebbles

The shape of a pebble affects the orientation. This is illustrated by Schlee's (1957a) study of the Maryland gravels, where a more strongly preferred orientation was detected in discoid than in rod-shaped pebbles.

Pebbles were collected at random from underground and surface exposures. Due to the difficulty of removing the well-cemented pebbles from the conglomerate, only 105 and 60 pebbles were collected from the Quirke and Nordic mines respectively.[1] The long, intermediate and short intercepts of these pebbles were measured, and the ratios of the intercepts plotted (*see* Fig. 24) according to the Zingg classification of pebble shapes (Krumbein and Sloss, 1953). Although Figure 24 clearly shows that most of the pebbles fall within the spheroidal class, there are abundant disk- and rod-shaped pebbles and many of the spheroidal pebbles have enough dimensional inequality to be used in fabric studies.

Measurement of Fabric Elements

Fabric investigations of consolidated sediments are confronted with numerous difficulties. Techniques used in unconsolidated sediments are not adaptable. Nonetheless, the apparent inclinations of elongated pebbles were measured by White (1952) in a plane parallel with the long dimension of a Keweenawan conglomerate lens. The mean inclination showed an upstream imbrication from the assumed current direction. This method was not considered suitable for the present study.

The following were the methods used in this study for measuring the orientation of pebbles:

Apparent Long Axes

The directions of the apparent long axes of pebbles were measured on a bedding plane surface. This is actually a measurement of the elongation of a pebble in the plane of the bedding. Only those pebbles exceeding half an inch in length and showing length-breadth ratios of greater than 2:1 were measured.

Where sufficient exposures were available in the underground workings, measurements were made at 1,000-foot intervals from the shaft. Measurements were also made in the polymictic rudites of the upper member of the Matinenda Formation in outcrops. These results were plotted on rose diagrams on Figure 20.

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[1] The measurements of an additional sixty pebbles from Buckles mine were supplied by Dr. Westner of the geological staff at Nordic mine.

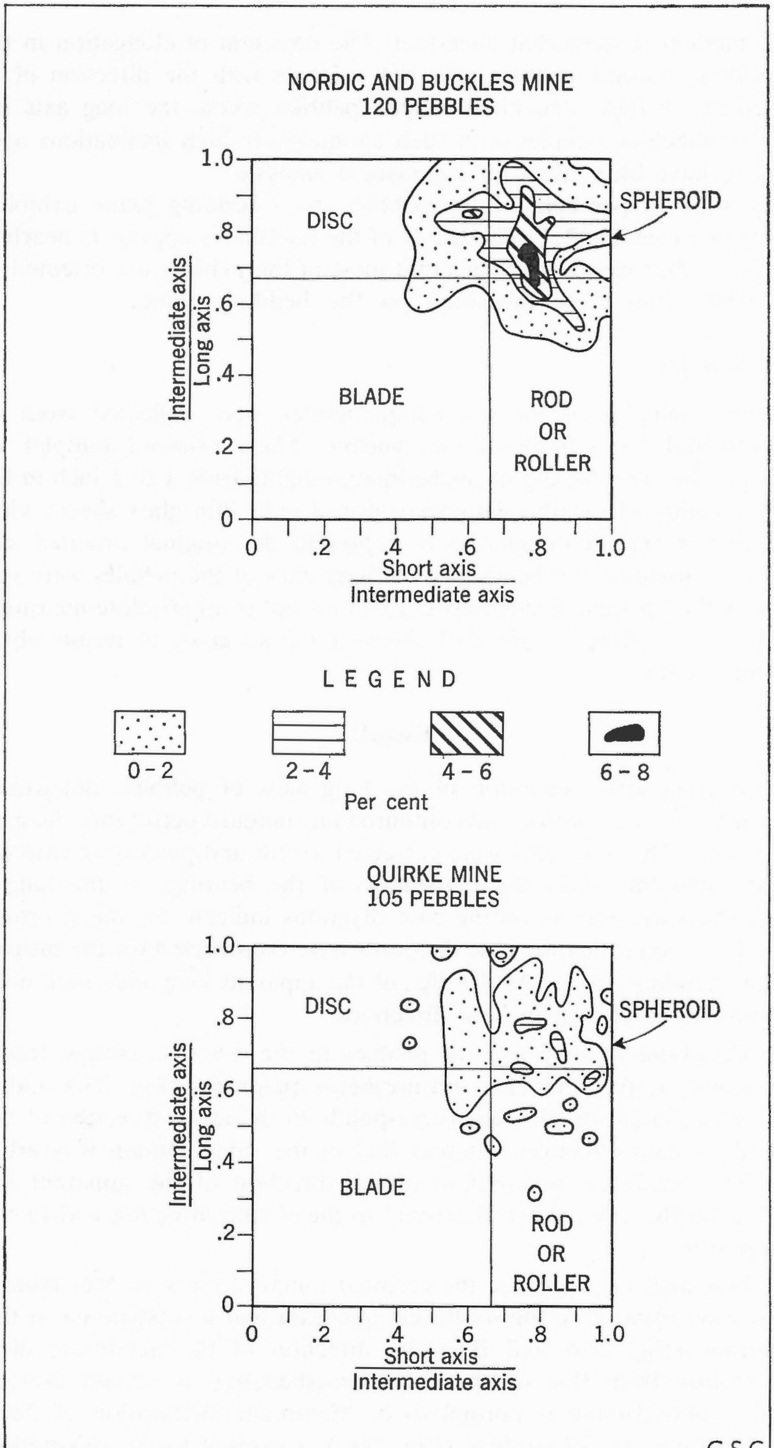

FIGURE 24. **The classification of pebble shapes (Zingg). Ratios of the intercepts contoured.**

This method is somewhat uncertain. The direction of elongation in the plane of the bedding of some pebbles may not coincide with the direction of the long axis, especially in disk- and blade-shaped pebbles where the long axis is steeply inclined. Nonetheless, pebbles with such anomalously high inclinations are sufficiently rare to have little effect on a statistical analysis.

Only 5 to 10 per cent of the pebbles on a bedding plane exhibit length-breadth ratios exceeding 2:1. The traces of the remainder appear as nearly circular cross-sections. This clearly indicates that most of the pebbles are oriented in directions different from those measured on the bedding plane.

Oriented Samples

Oriented samples of the ore conglomerates were collected from localities in the north and south limbs of the syncline. These oriented samples were cut into slabs parallel with the dip of the bedding, ranging from $\frac{1}{4}$ to $\frac{1}{2}$ inch in thickness. The pebble outlines from the slabs were traced onto thin glass sheets which were then oriented in such a manner as to represent the original oriented sample in space. The inclinations and bearing of the long axes of the pebbles were measured.

This method is time consuming and tedious but is an absolute measurement of gravel fabric, and offers a method of checking the accuracy of results obtained by the previous method.

Results

The bearing and inclination of the long axes of pebbles, determined from oriented samples, were plotted and contoured on standard petrofabric diagrams (*see* Figs. 25 to 28). The same data were corrected for tilt and plotted on rose diagrams. These rose diagrams show the percentage of the bearings of the long axes in 30 degree intervals. Arrows on the rose diagrams indicate the mean crossbedding azimuths. In a similar manner rose diagrams were constructed for the measurements obtained on bedding planes. As the dips of the apparent long axes were not known, the elongation was plotted in both directions.

The directions of long axes of pebbles in the oriented sample from Quirke mine are mainly in the southeast and northeast quadrants (Fig. 25A and B). The direction of maximum distribution corresponds to the mean direction of the crossbedding and stream direction, whereas that of the submaximum is nearly normal to them. The maximum distribution of the direction of the apparent long axes (Fig. 25C), on the other hand, is normal to the stream direction and to maximum of the long axes.

The long axes of pebbles in the oriented sample from Can Met mine shows a maximum concentration in the southwest quadrant and a submaxima in the northeast quadrant (Fig. 26A and B). The direction of the maximum distribution deviates slightly from that of the mean crossbedding or stream flow, whereas that of the submaximum is normal to it. Maximum distribution of direction of the apparent long axes of pebbles (Fig. 26C) is normal to the orientation of the maximum above, but not exactly normal to the stream direction.

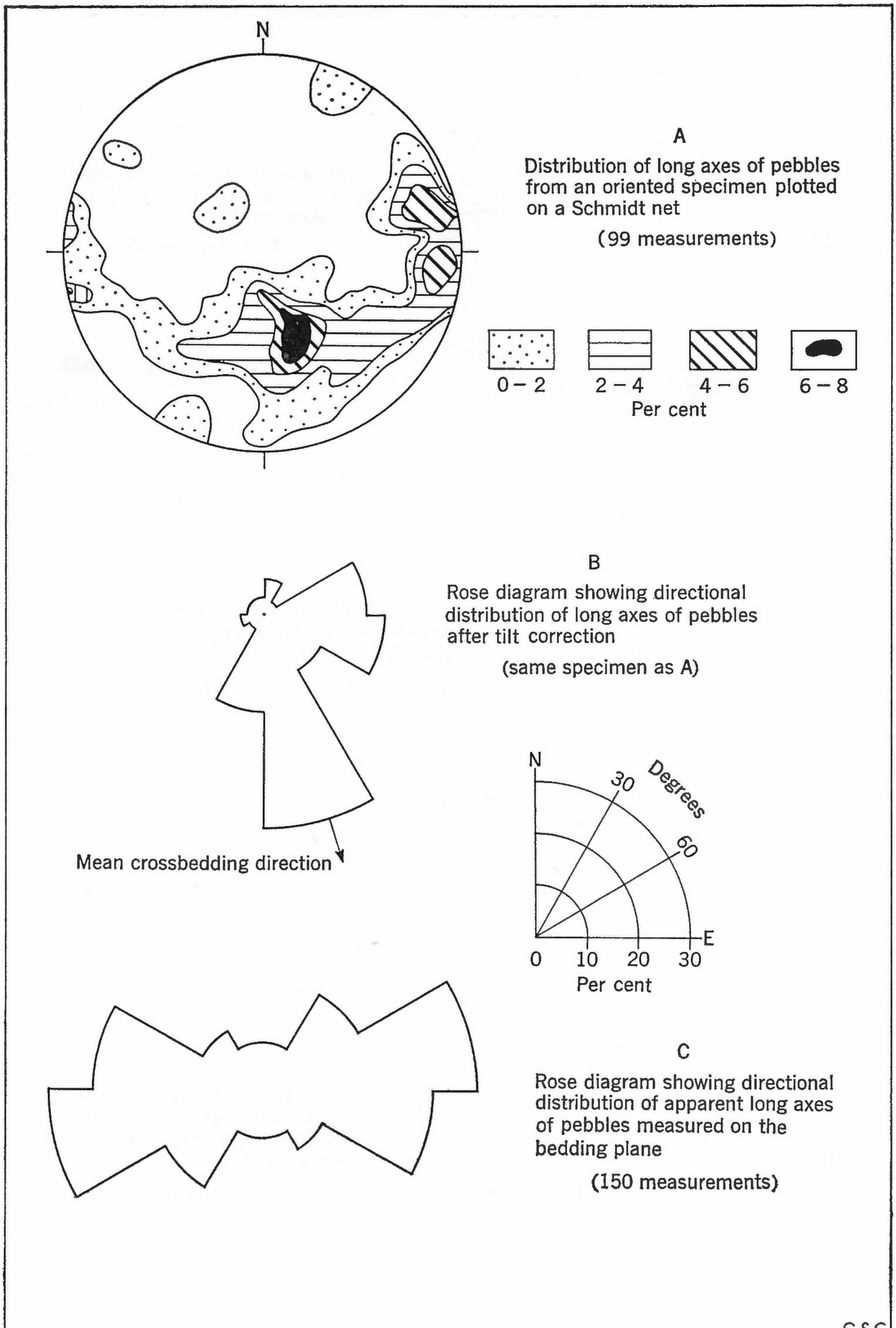

FIGURE 25. Fabric patterns of the uraniferous conglomerate, Quirke mine.

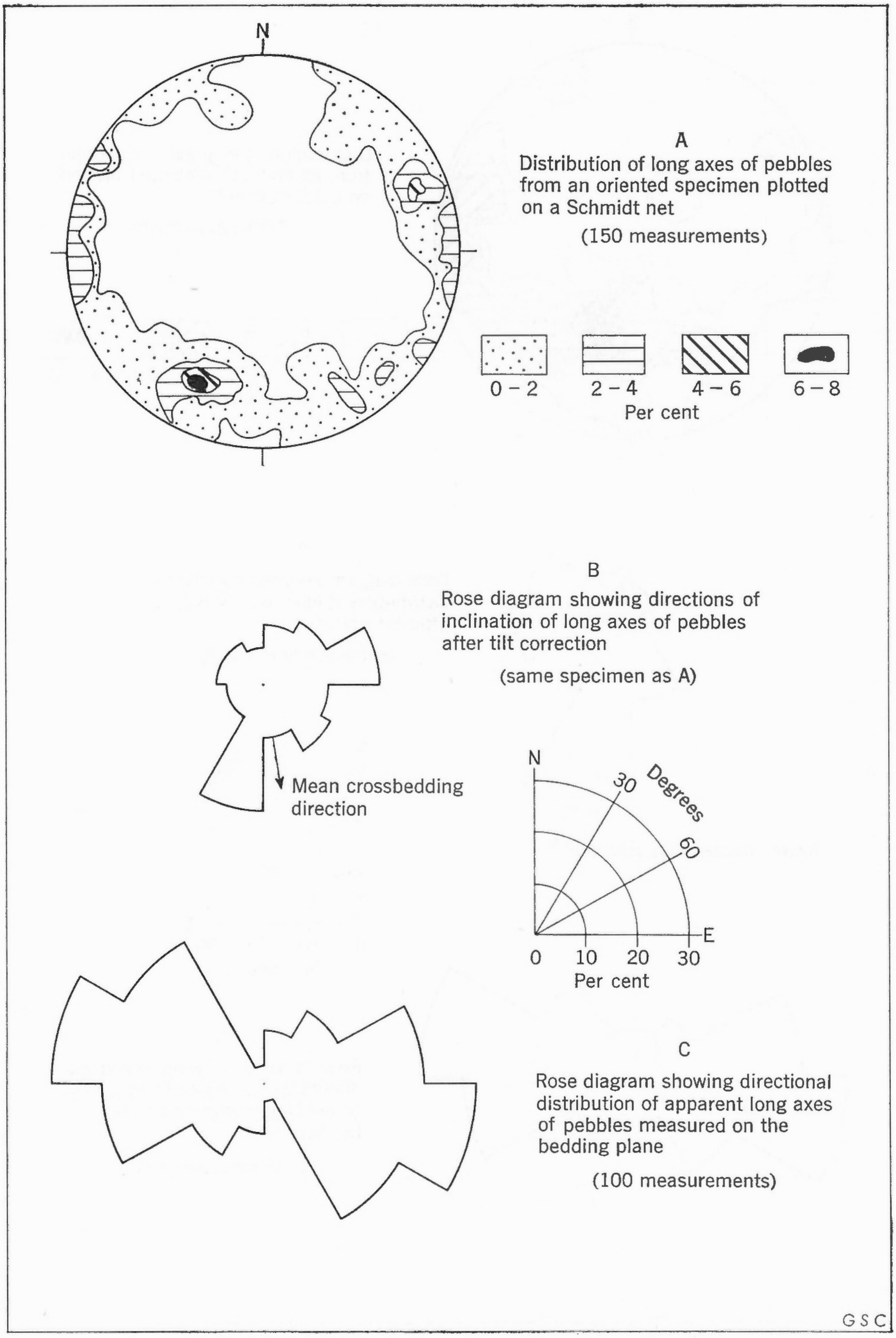

FIGURE 26. Fabric patterns of the uraniferous conglomerate, Can Met mine.

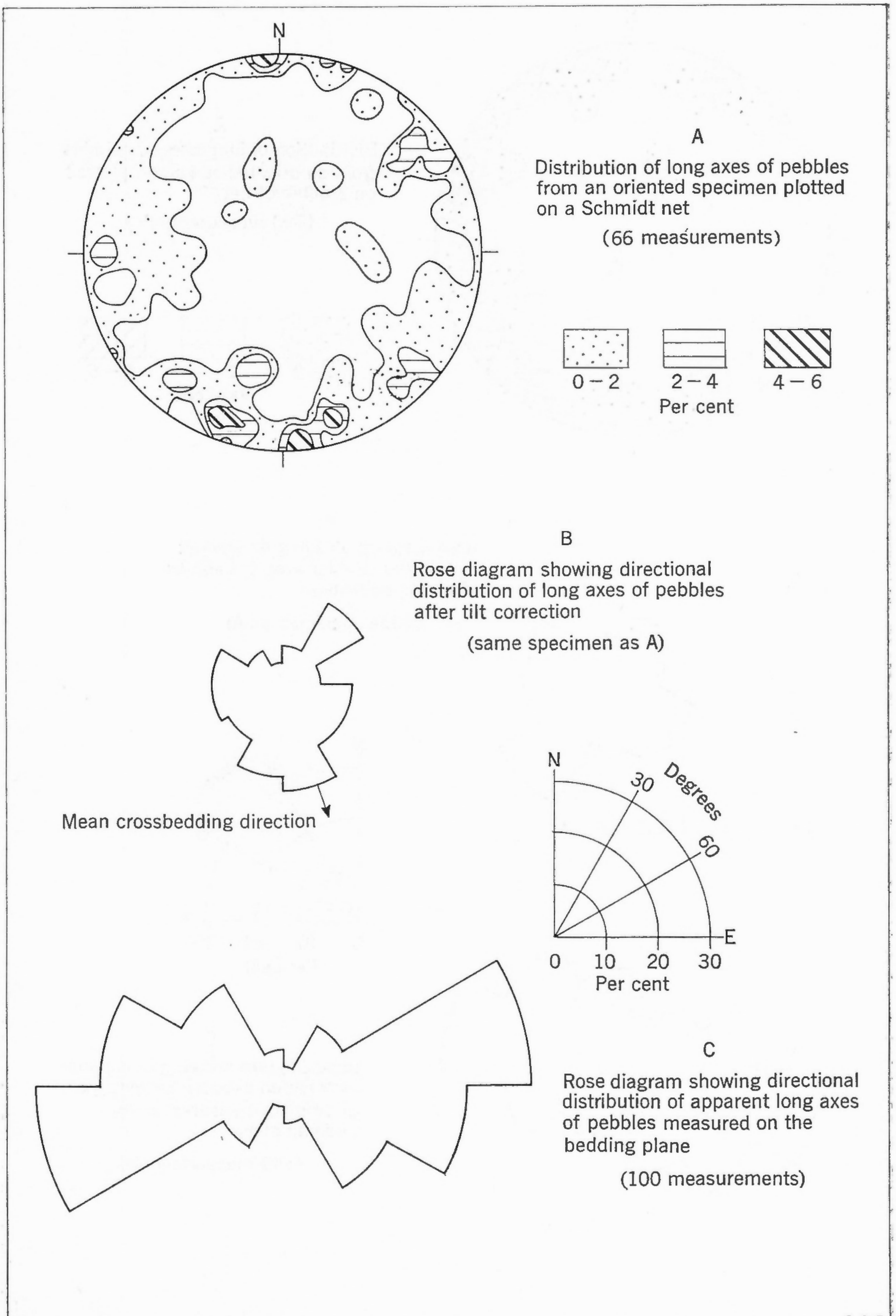

FIGURE 27. Fabric patterns of the uraniferous conglomerate, Lake Nordic mine.

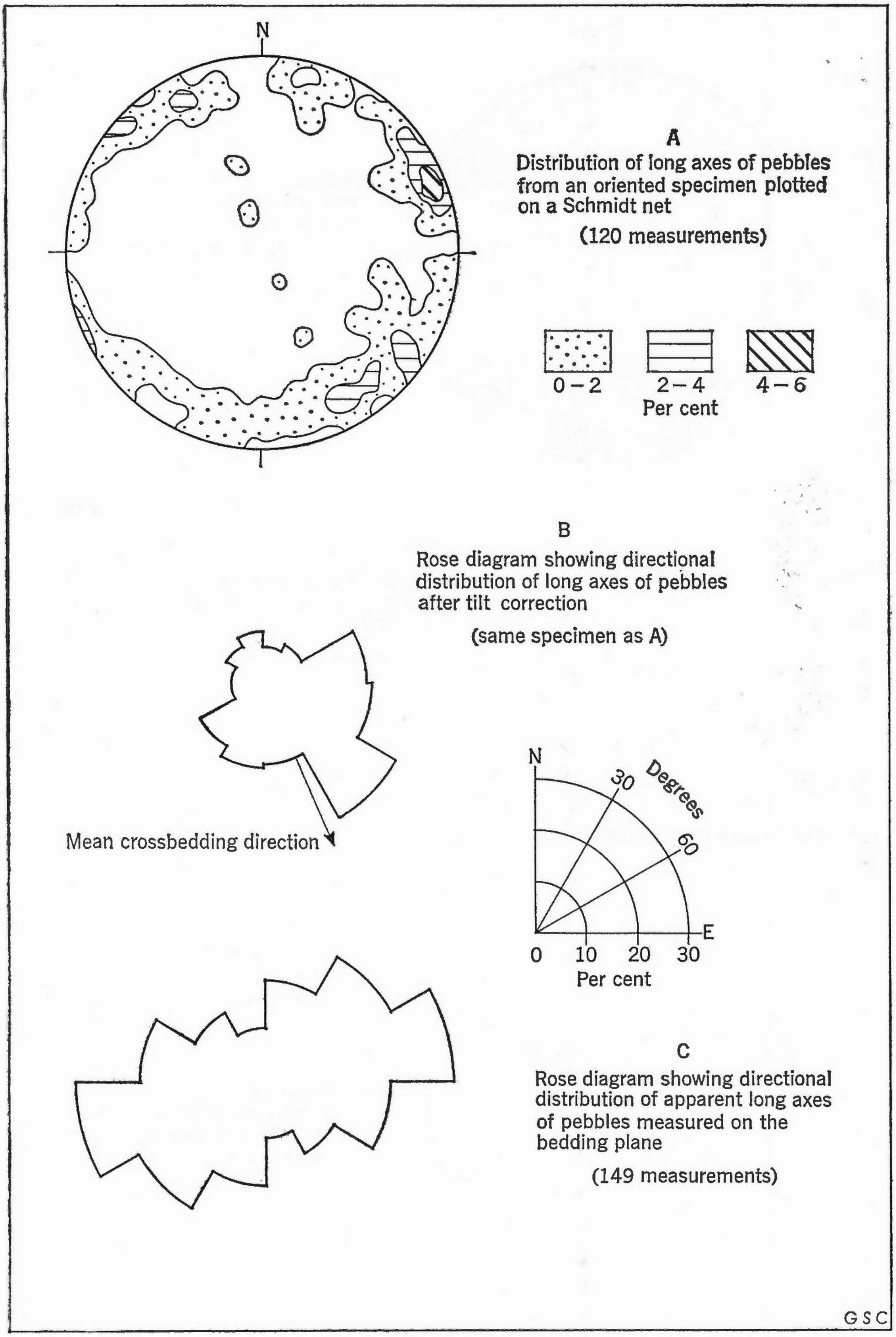

FIGURE 28. Fabric patterns of the uraniferous conglomerate from Nordic mine.

The fabric pattern of the oriented sample from Lake Nordic mine is poorly defined and concentrations are present in all quadrants (Fig. 27A). However, after tilt is corrected, for there is a definite bimodal orientation (Fig. 27B), the maximum distribution is parallel with the mean direction of stream flow crossbedding, and the submaximum is nearly normal to it. As in the other examples, the maximum distribution of apparent long axes (Fig. 27C) is normal to the above maximum and mean stream direction.

The fabric pattern of the oriented sample from Algom Nordic mine, after tilt correction, shows a maximum distribution in the southeast quadrant and secondary concentrations in the northeast quadrant (Fig. 28A and B). The maximum deviates slightly from the mean crossbedding direction. Although the direction of the secondary mode is not clearly defined, it is still evident that the long axes of many pebbles lie nearly normal to the current direction. Maximum direction distribution of apparent long axes (Fig. 28), as before, is normal to the mean direction of the crossbedding.

The study of oriented samples clearly indicates that most of the long axes of pebbles are either parallel with or normal to the direction of stream flow. There are some obvious deviations from these two main directions, but such variations are not important when all the factors that may control pebble orientation are considered. Furthermore, the direction of the long axes of those pebbles oriented normal to the current flow corresponds fairly well with the direction of the apparent long axes of elongate pebbles measured on bedding planes.

Interpretation

The direction of maximum orientation of pebbles in oriented conglomerate samples corresponds closely with the mean direction of crossbedding in the Matinenda Formation. Such a relationship was also observed where pebbles are oriented along foreset beds in the ore conglomerates. This merely indicates that both the conglomerates and arenites of the Matinenda Formation were deposited by the same paleostream system.

The conglomerate fabric patterns in the Matinenda Formation substantiate the hypothesis of a northwesterly to southeasterly direction of detrital transport inferred from crossbedding. Such an interpretation is mainly based on the fact that the maximum direction of pebble alignment is parallel with the mean direction of dip of crossbedding. However, it was found that lesser numbers of pebbles have their long axes oriented normal to the mean stream direction. The direction of stream flow may therefore also be inferred from these.

Furthermore, it was concluded that the maximum of the directions of elongation of pebbles measured on bedding plane surfaces is essentially normal to the mean stream direction (*see also* Fig. 20), although in some places this is not exactly so. This may be attributed to paucity of crossbedding data, especially along the north limb of the syncline, or to other factors controlling the local orientation of pebbles. Despite these minor anomalies, the close agreement between the directional properties of the conglomerate fabric patterns and the crossbedding clearly indicates that both the oligomictic and polymictic rudites of the Matinenda Formation were deposited by paleostream maintaining a northwesterly to southeasterly course.

Moreover, the paleostreams depositing the gravel material flowed in the same direction as those responsible for the deposition of the sands.

The bimodal orientation of pebbles in these conglomerates needs further explanation. After coming to rest, rod-shaped and spheroidal pebbles, exhibiting sufficient dimensional inequalities, will tend to respond to attempts by the currents to orientate them parallel to the direction of current flow. On the other hand, disk- and blade-shaped pebbles will resist such orientation by the current, and retain their original position with their long axes normal to the direction of flow. In addition to these features, the nature of the depositing surfaces has a pronounced influence on the orientation of pebbles. Orientational adjustments of pebbles deposited on a gravelly surface may be impeded and long axes of such pebbles may remain normal to the stream direction. On the other hand, pebbles deposited on a sandy base will respond more easily to hydrodynamic conditions. The latter suggestion is substantiated by the field evidence that single pebble layers show noticeably more preferred orientation of pebbles than massive conglomerates. The above-mentioned features may account for the bimodal distribution of pebbles, and are similar to the explanations offered by Walker (1955) for such a phenomenon.

It must be emphasized, however, that there is a considerable spread of lesser concentrations, which indicates that some pebbles fail to attain maximum orientation. This may be due to impediment during orientation, burial before complete orientation, or to the deposition along the flanks of gravel bars and deltaic lobes. Schlee (1957b) also reported substantial deviations from the direction of maximum orientation as well as from the prevalent trend of the crossbedding. These features clearly illustrate the limitations of using single samples for genetic studies.

A noteworthy feature is the lack of any upstream imbrication, such as is found in flood and fluvial gravels (Krumbein, 1940 and 1942; White, 1952; Pettijohn, 1957b; and Schlee, 1957b). However, Figures 24 to 27 show evidence of a downstream imbrication. This is by no means the first description of a downstream imbrication, as Krumbein (1940) described a similar phenomenon from the flood gravels near the head of the San Gabriel Canyon, California. Krumbein attributed this phenomenon to swirling and eddying currents, but it may merely indicate a rapid rate of deposition, with no later readjustments by the streams.

In the Blind River area most of the long and intermediate axes of pebbles in oligomictic conglomerates lie in a plane inclined in the 'downstream' direction and oriented roughly parallel with crossbeds in associated subarkose and pebbly subarkose. The pebble orientation may therefore merely reflect crossbedding that is not otherwise visible in the massive well-packed conglomerates. Dips of most crossbeds in subarkoses are slightly steeper than the measured inclinations of most of the long axes of pebbles; it is possible therefore that the pebbles, while imbricated downstream with respect to the major bedding, are actually imbricated upstream with respect to the plane of the crossbedding.

Summary and Conclusions

The conclusions reached from the study of the crossbedding and gravel fabrics are summarized as follows:

(1) The Matinenda Formation and associated conglomerates were deposited by aggrading streams flowing down the paleoslope in a southeasterly to southerly direction. The Mississagi Formation was deposited by paleostreams flowing southeast and east of southeast. Although these paleostreams show a persistent regional trend, there is evidence of marked local deviations within zones of the Mississagi Formation.

(2) Fabric studies of the radioactive oligomictic conglomerates revealed a bimodal orientation of pebble long axes. The maximum distribution is parallel with the mean direction of crossbedding, the submaximum is at right angles to that direction.

(3) Most of the pebbles may be classified as spheroids, according to Zingg's shape of classification.

(4) The primary inclination of the crossbedding ranges from 5 to 55 degrees and averages 21 degrees. Inclinations exceeding the angle of repose are thought to be due to slumping.

(5) The striking uniformity of the direction of sediment transport, as determined by crossbedding and conglomerate fabric, over a large area favours a fluvial origin for the sediments. The unimodal distribution of the crossbedding compares favourably with that of known fluvial deposits.

(6) At least part of the conglomerates accumulated on foreset beds.

(7) Pebbles exhibit a strong downstream imbrication; upstream shingling was not detected. The downstream imbrication is actually an orientation of pebbles on the crossbedding planes.

(8) The direction of detrital transport deduced from sedimentary current structures corresponds closely with isopachal trends and the general direction of pebble size diminution. These features clearly indicate a northwesterly to northerly provenance for the sediments comprising the Matinenda Formation.

Chapter V

ORIGIN AND SEDIMENTARY HISTORY

Various investigators have attributed the origin of the Huronian rocks to different sedimentary processes. Collins (1925) believed that the detritus comprising the Bruce Series (the Elliot, Hough, and Quirke Groups) was derived from a northerly source and laid down under conditions of intermittent submergence along the edge of a continent. He also suggested a glacial origin for the Gowganda Formation, accompanied by periodic conditions of submergence. On the other hand Wilson (1948) and Bain (private communication) suggested that the Huronian rocks were derived from the Grenville Mountains to the southeast. However, recent studies of isopachal trends and sedimentary current structures by Roscoe (1957a) and Pettijohn (1957b) confirm the northwesterly to northerly source suggested by Collins.

James and Joubin (1956), and Holmes (1956) suggested that the Matinenda Formation, including the uraniferous conglomerates, was deposited by river processes and later reworked as beach gravels. As stated previously, the linear distribution of the Matinenda Formation and the lack of continuous strike deposits preclude the presence of strong strand line currents during the deposition of this formation. Also, the bimodal distribution, variable size distribution of pebbles along strike, and the interlacing pattern of rudaceous and arenaceous units in the conglomerates are not indicative of a beach environment or of continuous reworking. Thus, collectively these features negate the hypothesis of a beach environment for the conglomerates.

McDowell (1957) suggested a fluvial origin for the Elliot and Hough Groups with periods of shallow submergence during the deposition of the Nordic and Whiskey Formations. In this presentation a similar origin is favoured and only minor modifications can be made to the geological history as proposed by him. It must, however, be pointed out that, although convincing arguments can be advanced for a fluvial origin for the Matinenda Formation, the information on the nature of the environment under which the later formations developed is much less significant.

Source of Material

An attempt was made to correlate the pre-Huronian granitic rocks northwest of the syncline with the granitic cobbles in the polymictic conglomerates within the Huronian sedimentary pile. Polymictic conglomerates are produced by mass transportation, and their gravel components have an excellent chance of surviving the rigors of sedimentation without much leaching. The prevalent types of granitic cobbles in the various polymictic conglomerates were selected and chemically analyzed and compared with samples of pre-Huronian granites collected from the areas to the north and northwest of the syncline, up to 30 miles away (*see* Fig. 1, inset).

Table XX

Modal Analyses of Granitic Cobbles and Boulders in Huronian Polymictic Conglomerates (volume per cent)

	PH-22	PH-163	PH-12	RF-116	RF-120	56-1	56-2	PH-6
Quartz	25	29	21	30	26	31	29	30
Plagioclase and White mica	42	41	43	35	36	33	39	40
	An_{8-10}	An_{14-16}	An_{15-18}	An_{15}	An_{8-10}	An_{10}	An_{18-20}	An_{15}
Microcline	—	21	32	24	30	30	27	20
Orthoclase	9	—	—	—	—	—	—	—
Perthite	15	5	—	8	—	—	—	5
Chlorite	5	2	2	1	2	3	4	1
Biotite	—	P	—	—	3	P	—	1
Epidote	—	—	—	P	—	P	P	P
Calcite	2	1	2	1	1	—	—	2
Zircon	P	P	P	P	P	P	P	P
Apatite	P	P	P	—	—	P	P	—
Sphene	—	—	—	—	—	—	—	P
Allanite	—	—	—	—	—	—	P	—
Pyrite	P	—	—	P	P	—	—	P
Muscovite	—	P	—	—	—	P	P	—
Black iron oxides	P	P	P	P	P	P	P	P

Plagioclase highly altered.
P—present in minor quantities.
Locations the same as in Table XXI.

Petrography

The petrographic descriptions of the pre-Huronian granites are given in Chapter II and the modal analyses in Table IV. Modal analyses of the Huronian granitic cobbles are tabulated in Table XX.

The cobbles are of leucocratic, hypidiomorphic granitic rocks and vary in colour from grey to red. They belong mainly to the granodiorite clan and the textures range from medium to coarse grained. Some porphyritic varieties are also present and the feldspar phenocrysts are up to 15 mm across.

The main constituents are oligoclase (An_{10-20}), quartz, and microcline. Orthoclase was identifed in one sample and both string and patch perthite are present in four samples. Oligoclase grains are highly altered to fine white mica, but the microcline is relatively unaltered. Mafic minerals, as well as part of the biotite, are altered to chlorite and in some sections up to 2 per cent secondary calcite was observed. Minor constituents include muscovite, zircon, apatite, pyrite, black iron oxides, epidote, and, rarely, sphene and allanite.

In most of the sections examined the plagioclase in the granitic cobbles appear to be much more altered than those in the greywacke matrix. In several sections veinlets of calcite traverse both the cobbles and matrix, but no fine white mica veinlets were observed. No evidence was detected to suggest that this difference in the degree of alteration is a post-depositional phenomenon and it is probable that the cobbles were derived from a hydrothermally altered source or that alteration occurred during transportation.

Chemical Composition

The chemical analyses of the various granitic cobbles (*see* Table XXI) show no significant variation, except for their silica content which differs by as much as 7 per cent. Alumina content of samples 56-1 and 56-2 is somewhat lower than that of the other samples. Magnesia is generally low and the lime content of some samples has been augmented by secondary calcite. Five samples contain more soda than potash, and the remainder have slightly higher potash than soda. The rest of the oxide constituents exhibit little variation.

Table XXI

Chemical Analyses of Granitic Cobbles and Boulders in Huronian Polymictic Conglomerates

	PH-22	PH-163	PH-12	RF-116	RF-120	56-1	56-2[1]	PH-6
SiO_2	69.94	71.42	67.76	74.30	71.35	74.50	73.80	72.18
Al_2O_3	17.30	16.16	17.57	14.30	15.30	13.60	12.95	15.40
Fe_2O_3	1.41	0.20	0.83	1.04	0.69	0.22	—	0.75
FeO	1.18	0.56	0.55	0.99	0.38	1.13	—	0.38
MgO	0.32	0.07	0.22	0.16	0.26	0.32	0.63	0.073
CaO	0.63	1.50	2.08	0.88	0.10	1.23	2.41	1.50
Na_2O	4.41	4.93	5.15	4.40	4.55	4.12	3.52	5.02
K_2O	3.20	3.19	4.90	3.95	4.75	4.20	3.58	3.65
$H_2O(100°)$	0.12	0.28	0.02	0.16	0.13	—	—	0.050
$H_2O(900°)$	0.98	0.87	1.24	0.86	0.57	0.27	0.48	0.90
TiO_2	0.29	0.023	0.16	0.11	0.065	0.22	0.28	0.11
ZrO_2	0.0179	0.0045	0.0085	0.0103	0.0067	—	—	0.0045
MnO	0.020	0.010	0.040	0.0160	0.0053	0.030	0.020	0.020
SrO	0.0068	0.020	0.020	0.0067	0.0102	0.014	0.0220	0.0066
Rb_2O	0.0050	0.0053	0.0115	0.0140	0.0175	0.048	0.010	0.0050
Total	99.93	99.22	100.56	101.18	98.17	99.90	97.70	100.05

[1]Total iron = 2%

PH–22	Granitic boulder from the Whiskey Formation.
PH–163	Granitic cobble from the Whiskey Formation.
PH–12	Granitic boulder from the Bruce Formation.
RF–116	Granitic cobble from the Bruce Formation.
RF–120	Granitic cobble from the Serpent Formation.
56–1 and 56–2	Granitic boulders from the Gowganda Formation. Analyses from J. R. Robertson.
PH–6	Granitic cobble from the upper member of the Matinenda Formation.

Trace element concentrations in the granitic cobbles (*see* Table XXII) show no important differences, except for more copper in sample RF-116.

The chemical compositions of the pre-Huronian granitic rocks have been discussed in Chapter II and are tabled in Table V.

Table XXII

Spectrographic Analyses of Trace Elements in Granitic Cobbles and Boulders in Huronian Polymictic Conglomerates
A. Quantitative

	PH-22	PH-163	PH-12	RF-116	RF-120	PH-6
Cr	0.0024	<0.0009	<0.0009	<0.0009	<0.0009	<0.0009
V	0.0020	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Ni	<0.0007	<0.0007	<0.0007	<0.0007	<0.0007	<0.0010
Co	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Cu	0.0008	0.0007	0.0007	0.0110	0.0020	0.0037

B. Qualitative

Element	Pb	Ga	V	Cu	Ni	Co	Cr
Wave-length	2833.0	2943.6	3183.9	3247.5	3492.9	3405.1	4254.3
PH-22	Tr	M	W	S	ND	FTr	Tr
PH-163	FTr	M	FTr	M	FTr	ND	ND
PH-12	W	M	M	S	ND	FTr	Tr
RF-116	W	M	ND	Tr	ND	ND	ND
RF-120	Tr	M	FTr	S	ND	ND	ND
PH-6	Tr	M	ND	VS	W	ND	ND

Elements not detected: Be, B, Mo, Sn and Ag
ND—Not detected
FTr—Faint trace
Tr—Trace
W—Weak
M—Medium
S—Strong
VS—Very strong

In comparing rocks of the granitic clan, soda, lime, and potash are the most sensitive indices of compositional variation, the remaining oxide constituents being of little diagnostic value. The soda, lime, and potash of the boulders and of the pre-Huronian granites have consequently been plotted on a triangular diagram (*see* Fig. 29) and the soda:potash and rubidium:potash ratios shown in Figure 30.

It is obvious from Figures 29 and 30 that the lime, soda, and potash contents and the two ratios considered of the granitic cobbles occupy a rather limited field

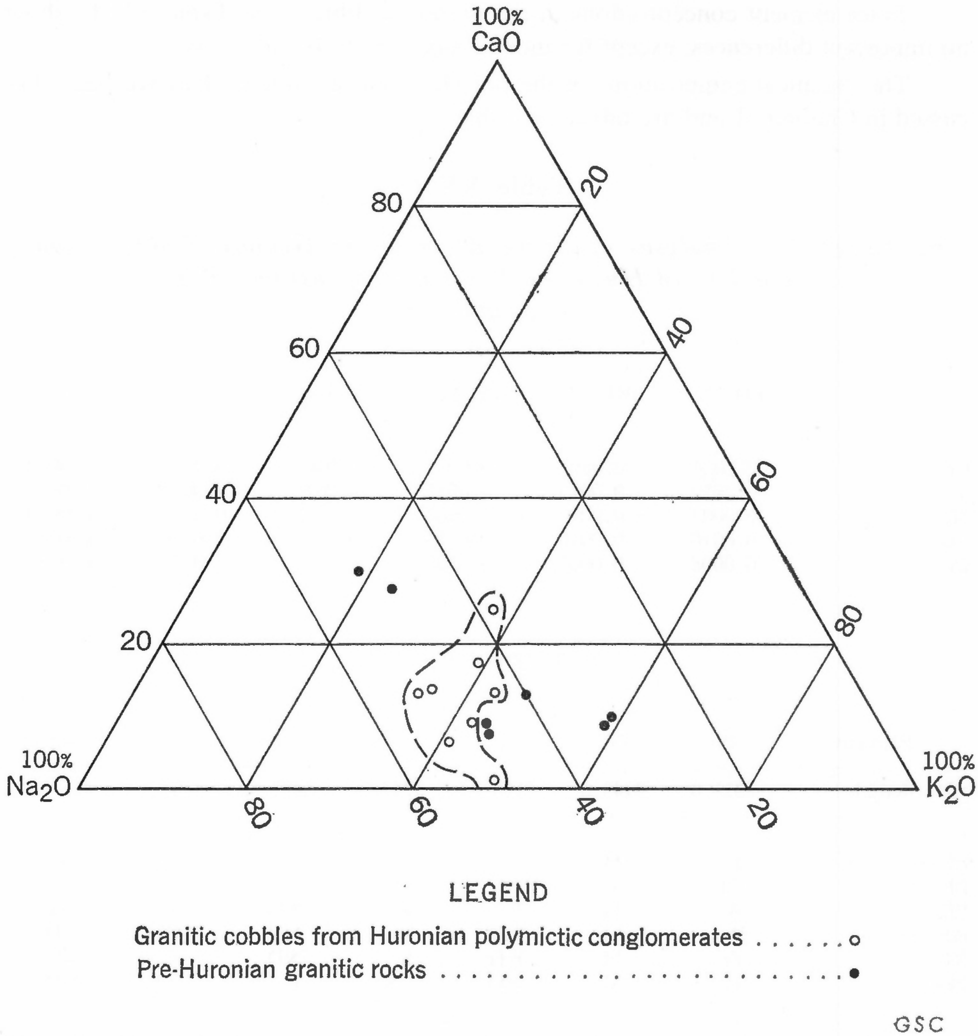

FIGURE 29. A triangular diagram showing the lime, soda and potash content of pre-Huronian granitic rocks and granitic cobbles from Huronian polymictic conglomerates.

within a much larger field covered by the pre-Huronian granitic rocks. Two of the pre-Huronian samples, RF-44 and 55-54, have compositions that closely resemble those of the granitic cobbles, but the remainder are either more potash-rich or more soda-rich. Samples RF-44 and 55-54 are from localities 10 miles northwest of Quirke Lake and just north of Quirke Lake respectively (*see* Fig. 1, inset).

It is interesting to note the small compositional range of granitic cobbles, especially as they were selected from different stratigraphic levels in the Huronian sequence above the base of the upper member of the Matinenda Formation. This implies that the cobbles were derived from a source that did not differ substantially in composition during the accumulation of 4,000 feet of sediments. Unfortunately, the data are too limited for their significance to be evaluated.

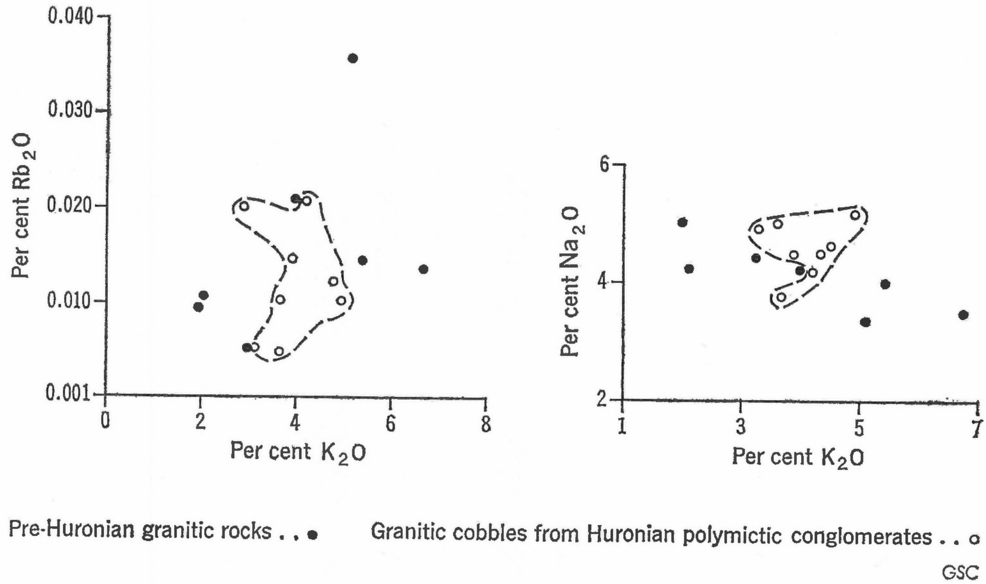

FIGURE 30. A comparison between Na_2O: K_2O and Rb_2O: K_2O ratios of pre-Huronian granitic rocks and those of granitic cobbles from Huronian polymictic conglomerates.

The composition of most of the pre-Huronian granitic rocks is noticeably different from that of the granitic cobbles. Possibly the cobbles were derived from a source much farther north or northwest of the area sampled. Nonetheless, the composition of two samples of the pre-Huronian granitic rocks close to the syncline is similar to that of some of the Huronian cobbles. Moreover, the cobbles were obtained from polymictic conglomerates, and, as these are considered to be products of mass transportation, it is unlikely that the cobbles were transported far. The evidence is inconclusive and contrary. The data are inadequate because:

(*a*) The number of analyses is inadequate.

(*b*) The pre-Huronian granitic samples were not collected systematically from a grid pattern to ensure a statistical coverage. The analyses should moreover have included samples from much farther away.

(*c*) The composition of granitic rocks exposed today may not be identical with that of those exposed during the deposition of the polymictic conglomerates, as much granite may have since been removed by erosion.

Mineral Composition of Huronian Arenites

The average modal analyses of subarkose and quartzites from different Huronian formations are graphically compared in Figure 31. It is fairly evident that the amount of potash feldspar decreases and that of the soda feldspar increases from the lowermost Matinenda Formation to the uppermost Serpent Formation. Chemical analyses of the arenites show a similar trend (*see* Tables VIII, p. 22; X, p. 58; XVII, p. 87) except for a subarkose from the Mississagi Formation.

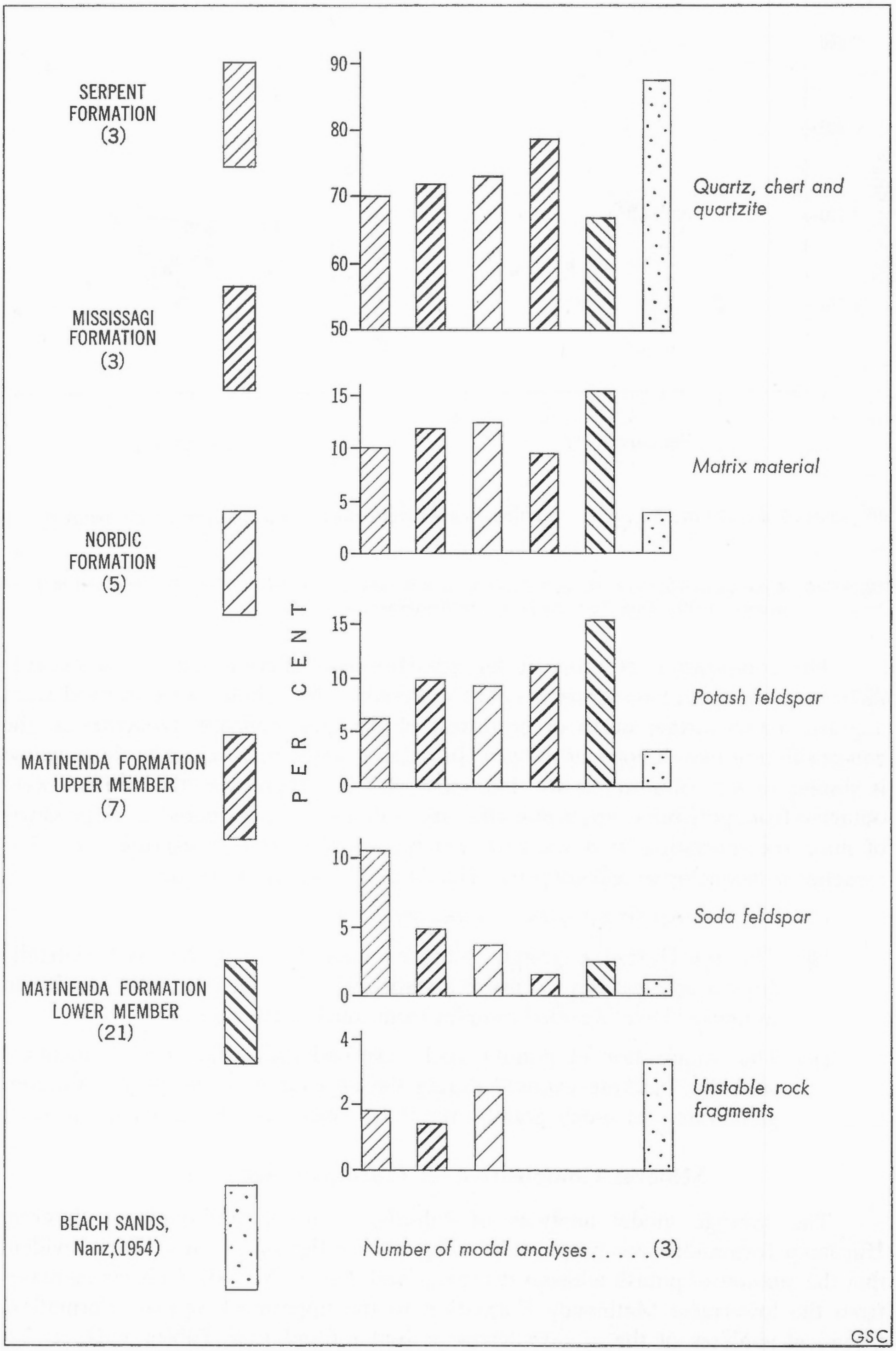

FIGURE 31. Mineral composition of Huronian subarkoses and quartzites and beach sands.

Such a trend may be ascribed to soda metasomatism or to differences in the mineralogical maturity of the arenites comprising the various formations. As no evidence of soda metasomatism was found and there is no substantial difference in the mineralogical maturity of the arenites from the various formations, as indicated by the quartz:feldspar ratios, it seems most probable that the trend detected reflects changes in the composition of the parent rock.

The increase in the soda content of the source rock may have been accomplished by progressively deeper erosion of a single source area with the progressive exposure of more soda-rich rocks, or, if there were several source areas, a soda-rich source may have been a more important contributor during the later stages of sedimentation.

Another peculiarity of the Huronian arenites is the predominance of plagioclase over potash feldspar in the greywackes and subgreywackes of the Nordic and Whiskey Formations. Chemical analyses also show that they have a higher soda content than the underlying and overlying subarkoses (Tables VIII, p. 22; X, p. 58; and XVII, p. 87). A high soda content and a general chemical immaturity are diagnostic of the greywacke-subgreywacke clan, but the problem is whether they were derived from the same source as the associated subarkoses. Differences in the degree of chemical weathering may account for part of the high soda content, but the debris of this clan was probably augmented from soda-rich parent rocks. Greywackes are commonly deposited under conditions of tectonic instability, during which debris may have been flushed into the paleostreams from sources other than the main source.

It may be concluded that the source rock of the lower member of the Matinenda Formation sediments was potash-rich, whereas that of the remainder of the sediments were probably derived soda-rich. Soda-rich detritus comprising the arenites of the upper formations, may also have been derived from a secondary source.

Mode of Deposition

The linear distribution pattern and the general lack of continuous strike deposits of the lower member of the Matinenda Formation preclude dispersal of sediments by strong strand line currents, and are diagnostic of sands laid down by rivers or streams. Also, this member is well stratified and thickens away from the source area, features not characteristic of alluvial fan accumulations. In addition, the bimodal size distribution, variable pebble size distribution along strike, and the interlacing pattern of sand and gravel lentils of the conglomerates are conclusive evidence of a fluvial mode of deposition.

The channel-like distribution of the upper Matinenda member, especially the lowermost section, is suggestive of deposition by stream processes. However, these sediments were exposed to winnowing and reworking, as shown by the textural maturity of the arenites and the excellent size gradation in the rudites. It is unlikely that the excellent size sorting of the conglomerates was accomplished entirely by stream processes. The fine-grained quartzite in the upper part of this member is definitely a product of continuous reworking under shallow-water conditions. Thus, the sediments of the upper Matinenda member were probably deposited by fluvial agents, but were exposed to winnowing and reworking under shallow-water conditions.

Additional evidence for a fluvial origin for the Matinenda Formation is provided by the crossbedding. The striking unimodal distribution of crossbedding clearly indicates that the paleostream flowed in strong preferred directions, which is more characteristic of river deposition than any other form of accumulation. Also, McDowell (1957) has shown the remarkable similarity between the distribution of crossbedding directions in the Matinenda Formation and that of known fluvial deposits.

In the remainder of the Huronian formations only a few sedimentological features are indicative of the depositional processes. The uniform distribution of crossbedding azimuths in the Mississagi Formation is similar to that of the Matinenda Formation and known fluvial deposits (McDowell, 1957). Thus, this formation may also be of fluvial origin.

Ripple-marks are present in the Whiskey, Mississagi, Espanola, and Serpent Formations; both wave and current ripples were observed. These and the presence of the mud-cracks suggest, however, that the sediments were deposited in shallow water with periodic subaerial exposures.

Huronian arenites contain more matrix material and less resistates than beach sands (*see* Fig. 31), so it is unlikely that they were deposited in a littoral or beach environment but they may have been deposited as deltaic sands by fluvial agencies.

Another noteworthy feature of the Huronian sedimentary pile is the repetition of cycles of sedimentation. A cycle is characterized by a polymictic boulder conglomerate at the base, followed by fine-grained sedimentary rocks, which are in turn overlain by coarse-grained arenites. Such a cycle of sedimentation is repeated twice during the accumulation of the Huronian rocks. These cycles are attributed to a repetition of tectonic settings. The boulder conglomerates were probably deposited as mudflows during a sudden increase in the tectonic instability of the area. This would be followed by a submergence of the depositional site and the accumulation of fine-grained sediments. Depositional conditions would gradually change and coarser clastic material be deposited, probably as delta deposits. At the end of this cycle the tectonic conditions apparently once more became unstable and the cycle was repeated.

Similar cyclic repetitions of lithological units were noted in the Precambrian sedimentary rocks of the Witwatersrand System by Sharpe (1949), who also attributed them to particular tectonic settings.

Conclusions

The Huronian sedimentation commenced with an uplift to the northwest of the syncline. Residual products on the pre-Huronian basement were swept into local depressions by streams flowing down the paleoslope from northwest to southeast. Accumulations of the residual products, later covered, formed the basal conglomerates.

The pre-Huronian topography undoubtedly exerted a strong influence on the courses of the paleostreams and the deposition of the lower member of the Matinenda Formation (*see* Fig. 32). Figure 32 shows the influence of the ridges on the direction of the paleostreams. Paleostreams, flowing along the pre-Huronian valleys, dumped their load initially in the depressions and later in the adjacent areas. This effect of base configuration on the directions of the streams may explain the difference between the mean direction of crossbedding in the Matinenda and Mississagi Formations.

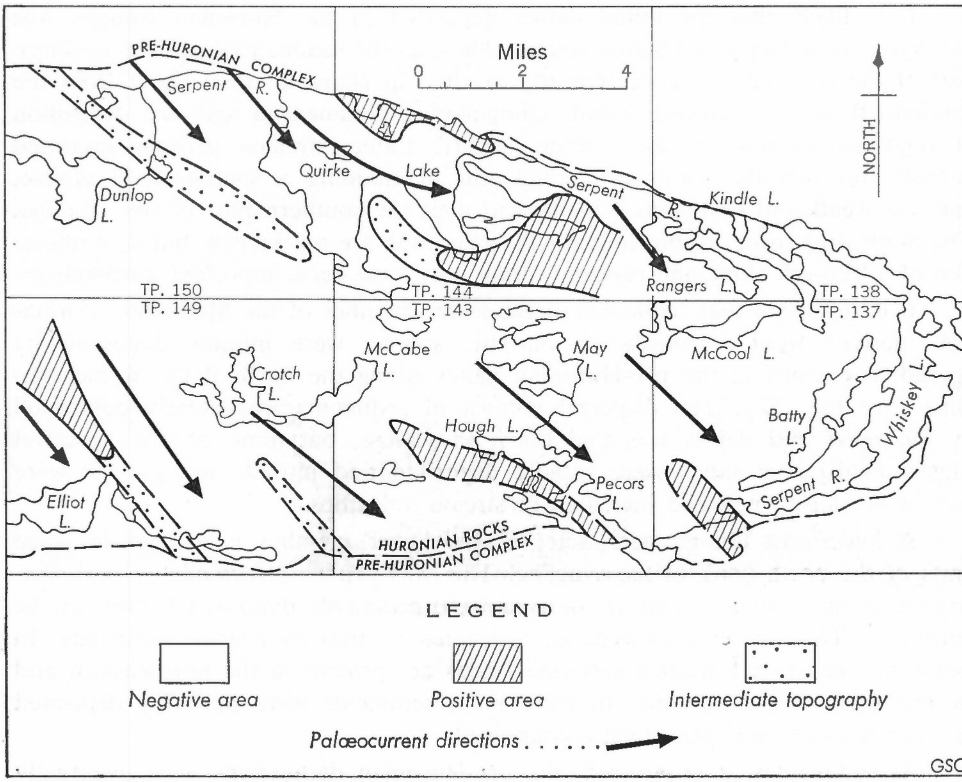

FIGURE 32. Topography of surface on which Matinenda Formation was deposited, Quirke Lake syncline.

The sediments were probably laid down by streams whose channels migrated back and forth across the depositional areas. Crossbedding in the layers and lenses of sand was probably produced by migrating sand waves or megaripples.

The gravels comprising the conglomerates were probably laid down during periodic increases in the current velocity of the stream. Under such conditions oligomictic gravels would be deposited on the bottoms of wide stream channels as gravel bars or lag gravels. As the stream channels shifted, thick deposits of rudaceous material would be formed by lateral accretion of the gravel bars and lag gravels. The interlacing pattern of multiple lithological units in the conglomerates is attributed to periodic fluctuations in the current velocity, as well as to differences in the current velocity in different parts of the channel. Differences in stream velocity probably resulted in differences in the relative amounts of sand and gravel material deposited which may account for the differences in the degree of packing of different conglomerate lenses. Scouring and subsequent filling may also have contributed to the multiplicity of sedimentary units in the conglomerates.

Pebble layers in the crossbedding may have been formed as foreset beds along the front of small deltas or bars of gravel. Some may have formed on the leeward side of sand waves.

It is likely that the initial debris deposited in the Huronian troughs was derived from a deeply weathered source. Thus, as the sediments from the northern part of the syncline are more typically residual in character than those from the southern flank, it is suggested that sedimentation commenced with the deposition of regolithic detritus in the former locality. Later, streams perhaps migrated laterally towards the southwest, while still maintaining a southeasterly course, and less weathered sediments were spread over the southern part of the syncline. The motivating forces responsible for the migration are not known, but a combination of a 'slip-off' slope and regional tilting may have been important mechanisms.

It is suggested that sediments of the lower member of the Matinenda Formation, derived from a potash-rich plutonic source, were initially deposited by aggrading streams in the pre-Huronian valley along the north flank of the syncline (*see* Fig. 32). The dispersal pattern of sediments was closely controlled by the relief and debris was laid down in valleys, but none on the ancestral ridges. Feldspathic sands were rapidly deposited and buried, and gravels were laid down during periodic increases in stream velocities.

A lowermost fine-grained facies of the lower member is present in some parts of the north flank of the syncline. This was probably formed by local winnowing of fine outwash material derived from sediments deposited farther to the northwest. This fine-grained material was later covered by coarser sediments. In addition, some better washed subarkose beds are present in the northeastern and eastern parts of the syncline. In these parts sediments were probably deposited in shallow water and periodically winnowed.

As sedimentation progressed, the pre-Huronian depressions were eventually filled and deposition extended over areas of intermediate height. Streams commenced to migrate towards the southwest and less mature debris was debouched in ancestral valleys along the south flank of the syncline (*see* Fig. 32). These valleys too were filled with sand and gravel before sedimentation commenced on the adjacent higher ground. The final stages of sedimentation consisted mainly of sand accumulation.

As the result of minor uplift, a period of local scouring occurred between the deposition of the lower and upper members of the Matinenda Formation and then southeast-trending streams debouched coarse gravels and sands exclusively in the southern part of the syncline. Gravels of both granitic and metavolcanic parentage were laid down mainly in the scour channels and sands marginal to the actual channels. In general, these sediments were laid down in sites that overlapped the depositional edge of the lower member. Deposition most likely occurred in shallow water, accompanied by winnowing and sorting.

Following the deposition of the Matinenda Formation, the shoreline advanced farther northwards and silts of the Nordic Formation were laid down in places along the south flank of the syncline. The tectonic setting was however unstable and immature soda-rich debris was intermittently 'poured in' to accumulate as greywackes. Winnowing at the depositional sites led to the formation of subgreywackes, subarkoses, and quartzites, depending on the degree of reworking. Argillites were laid down under conditions of quiescence and silts during periods of turbulence.

The deposition of the Nordic Formation was culminated by a sudden increase in the tectonic instability of the source area. Unsorted immature debris was spread over the entire syncline and parts of the pre-Huronian basement by mudflows or some such agent of mass transportation. This heterogeneous debris formed the basal polymictic boulder conglomerate of the Whiskey Formation. Deposition of the boulder conglomerate was followed by a shallow submergence of the entire area.

Finely laminated argillites of the Whiskey Formation were laid down in tranquil waters and interbedded silts during periods of turbulence. Regressions of the shoreline and subaerial exposures may account for the mud-cracks. Uplifts in the source area to the north caused debouching of immature sands that accumulated as greywacke. Interbedded subgreywacke and subarkose may have been formed by winnowing of such material. The final phases of sedimentation of this formation were probably accomplished under shallow-water conditions as indicated by the abundance of crossbedding and ripple-marks.

The depositional environment of the Whiskey Formation gradually changed to one that produced the feldspathic sand of the Mississagi Formation. This may have been accomplished by the advancement of a delta over the Whiskey Formation, as suggested by McDowell (1957). Evidence from crossbedding suggests that the streams responsible for the formation of the delta flowed from northwest to southeast. During this period feldspathic sands mostly were deposited and winnowed under stable conditions. However, some subgreywacke and minor greywacke material was rapidly dumped on the coarse sand deposited at the base of the Mississagi Formation.

These stable conditions were suddenly interrupted by an uplift and the unsorted immature debris of the Bruce Conglomerate was deposited as mudflows. Following this tectonic interruption, the entire area was again submerged and the fine-grained Bruce Limestone was deposited in tranquil shallow waters (Collins, 1925). Intermittent periods of turbulence resulted in the deposition of the interbedded silts.

The lime and silt accumulation was succeeded by the rapid debouching of poorly weathered detrital material of the Espanola greywacke. This was followed by the alternating deposition of sands and silts, as well as lime. Regression of the shoreline led to periodic subaerial exposures and the formation of mud-cracks and intraformational conglomerates. Sediments of the greywacke and limestone members of the Espanola Formation were laid down.

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The depositional environment of the Espanola Formation gradually changed to one that produced the sands of the Serpent Formation. This may have been accomplished by an advancing delta. The accumulation of the Serpent Formation was characterized by periodic conditions of intense instability during which mass transported debris was dumped as mudflows.

The evidence for the events that followed the deposition of the Serpent Formation is contradictory. In some parts of the syncline sedimentation seems to have been interrupted by an interval of erosion prior to the deposition of the Gowganda Formation, whereas in others sedimentation appears to have been continuous. This relationship and the origin of the Gowganda Formation were not, however, studied in detail.

Following the deposition of the Huronian sedimentary pile, the area was folded into a syncline and invaded by diabase and later lamprophyre intrusions. Later, the syncline was cut by faults, probably related to tectonic disturbances to the south and east, although some faults may have preceded the diabase intrusions.

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Line 17 above - *for* Stratigraphic terminology, revision *read* Subarkose