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**GEOCHEMISTRY OF THE ORE CHIMNEY FORMATION AND ASSOCIATED
METAVOLCANIC ROCKS AND GOLD DEPOSITS IN THE FLINTON-HARLOWE
AREA, GRENVILLE PROVINCE, SOUTHEASTERN ONTARIO.**

by

Luc HARNOIS, B.Sc., M.Sc.

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

Department of Earth Sciences

Carleton University

Ottawa, Ontario

December 1987

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ISBN 0-315-40599-6

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ABSTRACT

The Ore Chimney Formation (OCF) is a mid-Proterozoic mafic schist that occurs between mafic to intermediate metavolcanic rocks of the Grenville Supergroup and an overlying metasedimentary succession, the Flinton Group. In the study area it has been regionally metamorphosed to upper greenschist-lower amphibolite facies. It has been interpreted alternatively as a paleoregolith or as a product of hydrothermal alteration of the volcanic rocks, in a major shear zone. Thirty-five samples of the OCF, fifty-one samples of the metavolcanics and fourteen samples of the Flinton Group were analysed for major and twenty-eight trace elements (including REE).

The metavolcanic rocks comprise the Tudor formation (TDF) and the overlying Kashwakamak formation (KWF). TDF is tholeiitic and consists mainly of basaltic flows, whereas KWF is calc-alkaline and comprises mainly andesitic and dacitic rocks. Geochemical modelling using REE, Zr and Y indicates that TDF is not derived from a single parental magma through simple fractional crystallization. The trace element variations are best explained by partial melting of a heterogeneous upper mantle source or by crustal contamination of a magma derived from a homogeneous mantle source. KWF appears to have been derived from a separate partial melting event.

OCF is thin (<10 m), crops out over 40 km along strike and is typically composed of alternating layers of biotite schist, muscovite-biotite schist, hornblende-biotite schist and hornblende schist. It contains coarse porphyroblasts of garnet and less commonly of staurolite, kyanite, epidote and/or hornblende. Immobile trace element ratios (Ti/Zr, Zr/Y, Nb/Y, La/Yb) of OCF are very similar to those of the underlying metavolcanics. Bulk chemistry, field relations and petrographic observations strongly suggest that OCF is a

locally-derived metasedimentary rock.

There is a close spatial relationship between OCF and polymetallic, gold-bearing lode deposits including the Ore Chimney Mine (OCM) and the Addington Mine (ADM). OCM shows a typical opaque mineral association of galena-sphalerite-pyrite-chalcopyrite-pyrrhotite-sulphosalt-ilmenite. The quartz-carbonate vein system is hosted by a 4 m thick biotite schist enclosed by metabasaltic flows, that are unconformably overlain successively by OCF and the Flinton Group. OCM occurs 30 m below this regional unconformity.

ADM, 8 km along strike from OCM, has a typical opaque mineral association of arsenopyrite-pyrite-chalcopyrite-pyrrhotite-ilmenite. The vein system is hosted by OCF.

Vein material deposition was associated with a weak carbonatization of the wall rock. Arsenopyrite geothermometry and sphalerite geobarometry yield temperatures and pressures ranging from 420 to 530°C and 0.35 to 0.59 GPa, garnet-biotite geothermometry of the biotite schist host of both deposits gives temperatures ranging from 475 to 535°C. Vein formation and mineralization occurred during the main episode of metamorphism and deformation. Gold and base metals may have been remobilized from pre-existing concentrations, carried by a metamorphic fluid and deposited at a redox front on or near the unconformity.

ACKNOWLEDGMENTS

Dr. J.M. Moore's encouragement and guidance at all stages of this project are gratefully acknowledged.

K. Sethuraman of Campbell Resources Limited, and Wayne Johnson of Target Exploration Services Limited, arranged for us to log and sample the Addington Mine drill core, and Albert Banner kindly permitted complete access to the Ore Chimney property, including underground sampling during the brief period when the mine was partly dewatered in 1983. K.L. Daughtry, A. Banner, J. Poirier and C.F. Roots provided valuable information, advice and help in the field. Peter Jones and Dan Marshall assisted with computer programming. Whole rock volatile analyses were performed by the Chemical Laboratory staff (Geological Survey of Canada); the other whole rock chemical analyses were performed by the author at Ottawa and Carleton Universities and Université du Québec à Montréal (INAA), with advice and assistance from John Loop, Raymond Mincau, Maurice Morency, Peter Belanger, and Ron Hartree. Electron microprobe analyses were performed by the author and Peter Jones at Carleton University. D.F. Sangster, D. Francis, and Richard P. Taylor critically read earlier drafts of parts of the thesis and contributed many valuable suggestions for their improvement.

This project was financially supported by Brian Resources Limited, NSERC (research grants to JMM) and Carleton University.

Table of Contents

	<u>Page</u>
Abstract.....	iii
Acknowledgements.....	v
Table of Contents.....	vi
List of Figures.....	x
List of Tables.....	xiii
List of Plates.....	xvi
Introduction.....	1
References.....	2
<u>Chapter I</u> - Major and trace element geochemistry of Proterozoic metavolcanic rocks from the Central Metasedimentary Belt of the Grenville Province, southeastern Ontario	3
Abstract.....	4
Introduction.....	5
General geology and geochronology.....	7
Description of the igneous rocks.....	8
Volcanic rocks.....	8
Tudor formation.....	8
Kashwakamak formation.....	10
Mazinaw Lake formation.....	12
Plutonic rocks.....	13
Geochemistry.....	13
Sampling and analytical techniques...	13
Alteration and metasomatism.....	16
Chemistry of volcanic rocks.....	18
Discussion.....	23
Tectonic setting.....	23
Petrogenesis of the Tudor formation volcanics.....	27
Model I.....	32
Model II.....	32
Kashwakamak formation.....	35
Conclusions.....	37
References.....	38

Table of Contents (continued)

	<u>Page</u>
<u>Chapter II</u> - Geochemistry and origin of the Ore Chimney Formation, Grenville Province, southeastern Ontario.....	43
Abstract.....	44
Introduction.....	45
General geology and geochronology.....	45
Description of the rock units.....	51
Volcanic rocks.....	51
Ore Chimney Formation.....	52
Bishop Corners Formation.....	55
Plutonic rocks.....	55
Description of the sample profiles.....	56
Profiles 1 & 2.....	56
Profile 3.....	56
Profile 4.....	58
Profile 5.....	58
Geochemistry.....	58
Analytical techniques.....	58
Sampling.....	62
Results.....	62
Discussion.....	74
Origin of the Ore Chimney Formation..	74
Chemical changes during weathering, diagenesis and hydrothermal alteration.....	77
Weathering.....	78
Diagenesis.....	78
Hydrothermal alteration.....	79
Bulk chemical composition of the Ore Chimney Formation.....	82
Chemical relations of the OCF to the volcanic rocks.....	84
Conclusions.....	86
References.....	87
 <u>Chapter III</u> - Geochemistry and genesis of two unconformity-associated lode gold deposits at the base of the Flinton Group, Grenville Province, southeastern Ontario	 92
Abstract.....	93
Introduction.....	94
General geology and geochronology.....	99
Gold deposits of the Flinton-Fernleigh area.....	103
Group I Deposits (A-G and OCM).....	103
Group II Deposits (H-S).....	103
Group III Deposits (T-V and ADM).....	103
Group IV Deposits (W, X and Y).....	104

Table of Contents (continued)

	<u>Page</u>
Addington Mine.....	104
History and economic features.....	104
Geological setting.....	107
Tudor formation.....	107
Ore Chimney Formation.....	108
Bishop Corners Formation.....	109
Sampling.....	109
Gold and sulphide distribution.....	109
Ore Chimney Mine.....	114
History and economic features.....	114
Geological setting.....	116
Tudor formation.....	117
Ore Chimney Formation.....	117
Bishop Corners Formation.....	117
Sampling.....	118
Gold and sulphide distribution.....	118
Geothermobarometry.....	124
Whole rock chemistry.....	126
Analytical techniques.....	126
Results.....	126
Addington Mine.....	126
Ore Chimney Mine.....	132
Discussion.....	134
Origin of the Ore Chimney Formation..	135
Hydrothermal alteration.....	136
The mineralized zone of the Ore Chim-	
ney Mine.....	149
Possible gold preconcentration mecha-	
nisms.....	140
Composition of the mineralizing fluid	142
Mechanisms of gold deposition.....	145
Conclusions.....	146
References.....	147
Summary of conclusions.....	153
<u>Appendix I</u> - Petrography and sample localities..	156
Petrography.....	157
Sample localities.....	157
<u>Appendix II</u> - Analytical procedures and chemical	
data.....	164
Analytical procedures.....	165
Data, accuracy, precision and	
detection limits.....	166
References.....	188

Table of Contents (continued)

	<u>Page</u>
<u>Appendix III - Mineral chemistry and geothermo-</u>	
<u>barometry</u>.....	189
Mineral chemistry: analytical	
methods.....	190
Sphalerite geobarometry.....	191
Arsenopyrite geothermometry.....	198
Sulphur fugacity and sulphur	
equilibrium domains.....	201
Garnet-biotite geothermometry....	201
Garnet.....	203
Biotite.....	203
Thermometry.....	203
Garnet-hornblende geothermometry.	206
References.....	207
 <u>Appendix IV - MIXING: a computer program for trace</u>	
<u>element geochemical modelling</u>.....	210

List of Figures

Page

Chapter I

Figure 1	- General geology of part of eastern Ontario.....	6
Figure 2	- Chondrite-normalized plot of Tudor formation volcanics.....	17
Figure 3	- Zr/TiO ₂ -Nb/Y plot of Tudor and Kashwakamak formations volcanics..	19
Figure 4	- Jensen cation plot of Tudor and Kashwakamak formations volcanics..	20
Figure 5	- Chondrite-normalized REE plot of Tudor and Kashwakamak volcanics...	22
Figure 6	- Trace element discriminant plots of Tudor formation basalts and basaltic andesites.....	25
Figure 7	- Trace element plot of felsic rocks	26
Figure 8	- La/Yb-Sm/Yb and Zr/Y-Sm/Y plots of Tudor volcanics.....	29
Figure 9	- Partial melting model calculations	30
Figure 10	- Crustal contamination model calculations.....	33

Chapter II

Figure 1	- General geology of part of eastern Ontario.....	46
Figure 2	- Geological map of the Ore Chimney Mine area.....	57
Figure 3	- Chemical profile at Addington Mine (DDH 81-6).....	63
Figure 4	- Chemical profile at Addington Mine (DDH 82-3).....	64
Figure 5	- Chemical profile at Harlowe.....	65
Figure 6	- Chemical profile at Ore Chimney Mine	66

List of Figures (continued)

	<u>Page</u>
Figure 7 - Fe-Mg-Al cation plot of the Ore Chimney Formation and of the underlying volcanic rocks.....	68
Figure 8 - Chondrite-normalized REE patterns of the Ore Chimney Formation.....	69
Figure 9 - Ti/Zr and (La/Yb) _N vs ACNRATIO.....	71
Figure 10 - Chondrite-normalized REE patterns of the Ore Chimney Formation and underlying volcanics.....	72
Figure 11 - Fe-Mg-Al cation plot of the Bishop Corners Formation and Northbrook batholith.....	73
Figure 12 - Zr/TiO ₂ -Nb/Y plot of Tudor and Kashwakamak volcanic rocks.....	75

Chapter III

Figure 1 - Gold occurrences in the Grenville Province of southeastern Ontario..	95
Figure 2 - General geology of Anglesea, Barrie, Clarendon, Kaladar and Kennebec Townships.....	97
Figure 3 - Geology of the Addington Mine area	105
Figure 4 - Underground workings of the Addington Mine.....	106
Figure 5 - Geology of the Ore Chimney Mine area.....	112
Figure 6 - Underground workings of the Ore Chimney Mine.....	113
Figure 7 - Quartz veins in biotite schist, Ore Chimney Mine.....	119
Figure 8 - Chemical profiles through the Ore Chimney Formation (Addington Mine)	130
Figure 9 - Composite profile through the biotite schist zone of the Ore Chimney Mine	131

List of Figures (continued)PageAppendix I

Figure AI.1	- Sample locality map (Ore Chimney Mine area).....	in pocket
Figure AI.2	- Sample locality map (Harlowe area).....	in pocket
Figure AI.3	- Sample locality map (Reid Lakes).....	in pocket
Figure AI.4	- Sample locality map (Ore Chimney Mine, 150-foot level).	in pocket

Appendix III

Figure AIII.1	- Plot of pressure <u>vs</u> iron content in sphalerite.....	193
Figure AIII.2	- Sphalerite composition in the system Fe-Zn-S.....	194
Figure AIII.3	- Arsenopyrite composition in the system Fe-As-S.....	197
Figure AIII.4	- Garnet-biotite and arsenopyrite geothermometry.....	200
Figure AIII.5	- Calibrations for garnet-biotite geothermometry.....	202

List of TablesPageChapter I

Table 1	- Table of Formations.....	9
Table 2	- Typical analyses of volcanic rocks from the Tudor and Kashwakamak formations.....	14
Table 3	- Weighted means of volcanic rocks from the Tudor and Kashwakamak formations.....	15
Table 4	- Mantle source compositions for Tudor volcanics.....	31

Chapter II

Table 1	- Table of Formations.....	48
Table 2	- Representative analyses of rocks from the Flinton-Harlowe area.....	59
Table 3	- Weighted means of chemical data for rocks from the Flinton-Harlowe area	60
Table 4	- Weighted means of volatile contents of rocks from the Flinton-Harlowe area.....	61
Table 5	- Average compositions of Proterozoic sedimentary rocks.....	83

Chapter III

Table 1	- Gold deposits of the Flinton-Harlowe area.....	98
Table 2	- Table of Formations.....	100
Table 3	- Chemical analyses of arsenopyrite from the Addington Mine (DDH 82-3).	115
Table 4	- Chemical analyses of argentian tetrahedrite and freibergite from the Ore Chimney Mine.....	121
Table 5	- Chemical analyses of sphalerite from the Ore Chimney Mine.....	123

List of Tables (continued)

	<u>Page</u>
Table 6 - Summary of geothermobarometry data for the Addington and Ore Chimney mines.....	125
Table 7 - Weighted mean major and trace elements in rocks from the Addington and Ore Chimney Mine.....	127
Table 8 - Weighted mean volatile contents in rocks from the Addington and Ore Chimney mines.....	128
Table 9 - Correlation matrix of selected elements (Addington Mine).....	133
Table 10 - Correlation matrix of selected elements (Ore Chimney Mine).....	133

Appendix I

Table AI.1 - Semi-quantitative mineralogical composition of samples 1-98 and 107-133.....	158
Table AI.2 - Mineralogical composition of samples 99-106 and 134-154.....	163

Appendix II

Table AII.1 - Analytical data for samples 1-10...	168
Table AII.2 - Analytical data for samples 11-20..	169
Table AII.3 - Analytical data for samples 21-30..	170
Table AII.4 - Analytical data for samples 31-40..	171
Table AII.5 - Analytical data for samples 41-50..	172
Table AII.6 - Analytical data for samples 51-60..	173
Table AII.7 - Analytical data for samples 61-70..	174
Table AII.8 - Analytical data for samples 71-80..	175
Table AII.9 - Analytical data for samples 81-90..	176
Table AII.10 - Analytical data for samples 91-100.	177
Table AII.11 - Analytical data for samples 101-110	178

List of Tables (continued)

	<u>Page</u>
Table AII.12 - Analytical data for samples 111-120	179
Table AII.13 - Analytical data for samples 121-130	180
Table AII.14 - Analytical data for samples 131-133	181
Table AII.15 - Analytical data for samples 134-140	182
Table AII.16 - Analytical data for samples 141-147	182
Table AII.17 - Analytical data for samples 148-154	182
Table AII.18 - Analytical data for standards MRG-1, SY-2 and G-2.....	183
Table AII.19 - Abundances of Ag, As, Au, Cu, Li, Pb, Sb and V in international standards.....	185
Table AII.20 - Duplicate analyses of samples 115 and 129.....	186
Table AII.21 - Duplicate analyses (volatile con- tents of sample 127).....	187
Table AII.22 - Detection limit of selected trace elements.....	187

Appendix III

Table AIII.1 - Chemical analyses of sphalerite....	192
Table AIII.2 - Chemical analyses of arsenopyrite..	195
Table AIII.3 - Chemical analyses of arsenopyrite..	196
Table AIII.4 - Chemical analyses of garnet, bio- tite and hornblende.....	204

List of PlatesPageChapter II

Plate 1 54

- 1a - Cross-bedded quartzite of the Bishop
Corners Formation.
- 1b - Quartz-pebble-rich layer, Ore Chimney
Formation.
- 1c - Metamorphosed pillow lava of the Tudor
formation.
- 1d - Poorly layered garnet-bearing biotite
schist of the Ore Chimney Formation.
- 1e - Contact between the Ore Chimney
Formation and the Kashwakamak
formation.

Chapter III

Plate 1 111

- 1a - Photomicrograph of gold and bismuthi-
nite in a quartz-tourmaline vein
(Addington Mine).
- 1b - Sulphide-bearing quartz vein (Ore
Chimney Mine).

INTRODUCTION

The Ore Chimney Formation is a distinctive stratum of black garnet-biotite schist that occurs between basaltic to intermediate metavolcanic rocks of the Grenville Supergroup, and the overlying metasedimentary succession of the Flinton Group. The origin of the Ore Chimney Formation is unknown, and the status of this stratum as a formation is somewhat controversial. It has been suggested that the Ore Chimney Formation represents either a mafic metasediment (Moore and Thompson, 1980) or the sheared and metasomatised equivalents of the underlying metavolcanics (Springer, 1982). There is a close spatial relationship between the Ore Chimney Formation and polymetallic, gold-bearing mineral deposits. In these deposits, for which no genetic model has been proposed to date, the gold is contained in a network of quartz or quartz-carbonate veins concordant to sub-concordant with the stratigraphy and metamorphic fabric, either within or immediately underlying the Ore Chimney Formation.

The principal aims of this thesis are:

- 1.- to describe and geochemically characterize the Ore Chimney Formation, and to determine its origin using geological and geochemical evidence.
- 2.- to describe and geochemically characterize the Addington Mine and the Ore Chimney Mine, which are the two largest gold deposits associated with the Ore Chimney Formation, and to propose a genetic model for these deposits.

Because of the close association between the Ore Chimney Formation and the underlying metavolcanic rocks (it has not been recorded overlying other rock types), and in order to test the hypothesis that the Ore Chimney Formation is derived from the metavolcanics,

major and trace element analyses were also performed on these rocks. Geochemical data and modelling bear new and important implications for the origin and evolution of these metavolcanics.

The results of this work are compiled and presented as a series of papers which are in the process of being submitted for publication. Each chapter presented as a paper is self-contained, beginning with an abstract and ending with a separate reference list. Metavolcanic rocks and the Ore Chimney Formation are dealt with in Chapters I and II, respectively. Chapter III is devoted to the geochemistry and genesis of the Addington and Ore Chimney gold deposits. Conclusions are summarized at the end of the thesis. Petrography and whole rock chemical analyses of all samples analysed are listed in Appendices I and II, respectively; samples are located on maps in the pocket. Appendix III deals with mineral chemistry and geothermobarometry. Appendix IV contains listings of the computer program used in trace element geochemical modelling.

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- Springer, J.S. 1982. Gold and base-metal vein deposits in eastern Ontario: Structural inferences and the significance of vein mineralogy. In Summary of Field Work, 1982. Edited by J. Wood, O.L. White, R.B. Barlow, and A.C. Colvine. Ontario Geological survey, Miscellaneous Paper 106, pages 210-217.

CHAPTER I

**MAJOR AND TRACE ELEMENT GEOCHEMISTRY OF PROTEROZOIC
METAVOLCANIC ROCKS FROM THE CENTRAL-METASEDIMENTARY BELT
OF THE GRENVILLE PROVINCE, SOUTHEASTERN ONTARIO.**

ABSTRACT

Samples of two subalkaline metavolcanic suites, the Tudor formation (ca. 1.28 Ga) and the overlying Kashwakamak formation, have been analyzed for major and 27 trace elements (including rare earth elements). The Tudor formation is tholeiitic and contains mainly basaltic flows, whereas the Kashwakamak formation is calc-alkaline and contains mainly andesitic rocks. The succession has been regionally metamorphosed to upper greenschist-lower amphibolite facies.

Geochemical modelling using REE, Zr and Y indicates that the Tudor volcanics are not derived from a single parental magma through simple fractional crystallization. The internal trace element variations are best explained by partial melting of an heterogeneous upper mantle source or by crustal contamination of a magma derived from a homogeneous mantle source. The intermediate to felsic rocks of the Kashwakamak formation appear to have been derived from a separate partial melting event. The data are consistent with either 1) ensialic origin of both TDF and KWF, or 2) accretion of an ensimatic arc to a continental margin between the time of extrusion of TDF and that of KWF.

INTRODUCTION

The Central Metasedimentary Belt (Wynne-Edwards, 1972) is one of the very few parts of the Grenville Province containing a large volume of rocks of undisputed volcanic origin. Only limited chemical data on these volcanics have been published. The Tudor formation (TDF) and the Kashwakamak formation (KWF) are two sub-alkaline volcanic successions which occur in the Flinton-Harlowe area, south-eastern Ontario (Fig. 1). The petrography and geochemistry of the TDF and KWF have been studied by Sethuraman and Moore (1973) who sampled and analysed a east-west cross-section through the volcanic succession, and by Moore and Morton (1986). Brown *et al.* (1975) recognized a lower unit of tholeiitic basalt overlain by a calc-alkaline suite composed mainly of andesite; they proposed that the succession related to the development of an ensimatic island arc. Trace element data of some samples from the area were later used by Condie and Moore (1977) to support the island arc model and to put more constraints on the genesis of the volcanic rocks. They also suggested that the TDF and KWF are two different volcanic successions. Holm *et al.* (1985, 1986) suggested that the TDF and Turriff formation metavolcanics in Dungannon, Limerick and Tudor Townships, 60 km northwest of the present study area, erupted on continental crust.

In the course of a study of the Ore Chimney Formation, a metasedimentary unit that overlies the volcanic rocks (Chapter II), many new chemical analyses of the volcanics were performed, more precise and complete than those previously available. The new contributions of this study emphasize internal trace element variations of TDF and KWF, and the petrogenesis of these two volcanic suites. Geochemical modelling (REE, Zr, Y) is used to infer mantle source composition

Figure 1. General geology of part of eastern Ontario, showing distribution of metavolcanic rock units. Based on mapping by Moore and Morton (1986). All rocks are metamorphosed; original lithology is indicated. TDF: Tudor formation. KWF: Kashwakamak formation. MLF: Mazinaw Lake formation. Place names (BI: Bishop Corners; CI: Cloyne; FI: Flinton; MC: Myer Cave) and sample localities (ADM: Addington Mine; OCM: Ore Chimney Mine; HA: Harlowe) are abbreviated.

for TDF volcanics, and the problem of the mobility of major and trace elements is also addressed.

GENERAL GEOLOGY AND GEOCHRONOLOGY

The study area lies within the Elzevir terrane (or subzone IV) of the Central Metasedimentary Belt (Wynne-Edwards, 1972; Davidson, 1986). It is underlain by late Precambrian metavolcanic and metasedimentary rocks of the Grenville Supergroup, metagranitoid intrusive bodies and metasediments of the Flinton Group (Fig. 1). The geology of the area has been described by Harding (1944), Sethuraman and Moore (1973), Moore and Thompson (1980), Wolff (1982) and Moore and Morton (1986). All rock units of the area are metamorphosed, but as protoliths are readily identified the prefix "meta" will hereafter be omitted in this chapter.

The oldest rocks in the area are the TDF volcanics (Heron Group; Lumbers, 1967). They are tholeiitic basalts and minor intermediate pyroclastics (Sethuraman and Moore, 1973) which have been dated at 1279 ± 3 Ma by U-Pb isotopic method on zircon (Heaman *et al.*, 1987). These are overlain by basaltic to felsic subalkaline volcanic rocks of the Mazinaw Lake formation (Ayer, 1979) and the KWF, clastic sedimentary rocks and carbonate rocks (Moore and Morton, 1986). This succession has been intruded by large granitoid plutonic bodies, of which the Elzevir batholith (Fig. 1) has been dated by U-Pb isotopic method at 1226 ± 25 Ma and at 1240 ± 50 Ma by whole rock Rb-Sr (Bell and Blenkinsop, 1980; Connelly, 1987). The volcanic rocks are unconformably overlain by the Ore Ghimney Formation, a pelitic sedimentary unit of local derivation (Moore and Thompson, 1980; Harnois and Moore, 1985; Chapter II).

The Flinton Group was identified by Thompson (1972) and Moore and Thompson (1980) as a succession of clastic sediments that over-

lies the Ore Chimney Formation conformably (?) and the older stratified and plutonic rocks with major angular unconformity. The stratigraphic order established by these authors in the study area is reproduced, slightly modified, in Table 1.

Metamorphic mineral zoning has been defined in calcareous and pelitic rocks of the Flinton Group and in older carbonate and volcanic rocks. Metamorphic grade varies from uppermost greenschist at Bishop Corners (Fig. 1) to upper middle amphibolite facies east and south of the study area. The rocks described in this paper are at upper greenschist to lower amphibolite grade (staurolite zone). An average peak metamorphic temperature of 500°C was obtained using the garnet-biotite geothermometer at the Addington and Ore Chimney Mines (Fig. 1; Appendix III; Harnois and Moore, 1986). Sethuraman and Moore (1973) concluded from mineral assemblages and mineral chemistry in pelitic and volcanic rocks that the physical conditions of metamorphism in the region were those of an intermediate pressure facies series; mineral associations correspond to Carmichael's (1978) bathozone 4.

DESCRIPTION OF THE IGNEOUS ROCKS

Volcanic rocks

Tudor formation

Basalt flows are the most abundant rocks of the TDF. In the study area they dip steeply, face easterly and display a wide variety of primary textures and structures such as chilled flow contacts, varioles, amygdules, relict plagioclase phenocrysts, flow top and bottom breccia, pillows and pillow breccia. Pillowed flows compose approximately 10 per cent of the succession, occurring mainly near the midpoint and the top. The TDF has a total exposed thickness of

TABLE 1
Table of Formations

flinton Group: Clastic and carbonate metasediments.

minor unconformity (?)

Ore Chimney Formation: Pelitic metasediments.

major unconformity

Plutonic rocks: Metagranite to metatonalite batholiths.

intrusive contact

G Metasediments: Marble, wacke.

R

E Mazinaw Lake formation:

N Metarhyolite ignimbrites and

V minor flows.

I Meta-andesite flows and pyro-

L clastic rocks.

L Metabasaltic andesite flows and

E pyroclastic rocks.

Metabasalt flows and pyroclastic

S rocks.

U Minor epiclastic metasediments.

P Minor metamorphosed subvolcanic

E intrusions.

R

G Metasediments: Wacke, tuff, marble.

R

Q Tudor formation: Metabasalt flows, pillowed flows, flow and pillow breccia.

U Minor metagabbroic intrusions.

P Minor mafic interflow metasediments.

Kashwakamak formation:

Meta-andesite and metadacite flows, flow

breccia, tuff-breccia, lapilli-tuff,

autoclastic breccia, debris flows.

Metabasalt flows, pillowed flows, breccia,

Metadacite and metarhyolite lapilli-tuff,

tuff-breccia, ash-flow tuff, epiclastic

metasediments.

Small metamorphosed intermediate intrusions.

Minor quartzofeldspathic interflow meta-
sediments.

After Ayer (1979), Moore and Thompson (1980) and Moore and Morton (1986).

four kilometres in the study area, in which individual flows vary from one to fifteen metres thick. The flows are cut by basaltic dykes and sills that are typically 30 to 100 cm wide, fine-grained, uniform, and similar in composition to the flows (Moore and Morton, 1986).

The pillowed flows and low vesicularity throughout the succession, as well as the probable occurrence of sodium enrichment (see below), indicate the submarine origin of the TDF. Allowing for extensional strain, the succession may have been at least twice its present thickness (ca. eight kilometres) before deformation, thus its deposition represents a major period of effusion, probably from submarine fissures. South of the study area, the TDF is concordantly underlain by mafic intrusive rocks, suggested by Brown *et al.* (1975) to represent oceanic crust. Elsewhere, the lower boundary is an intrusive contact with granitoid batholiths.

The volcanic rocks of the TDF analysed in this study are tholeiitic basalt and basaltic andesite from the Addington Mine and Ore Chimney Mine areas (Fig. 1). They are fine- to medium-grained, completely recrystallized to massive and foliated amphibolite, and composed mainly of hornblende and plagioclase with minor quartz. Accessory minerals include epidote, biotite, garnet, cummingtonite, and carbonates (in fractures). Felsic lapilli-tuff and breccia, although present, are a minor component (<1%) of the volcanic succession at these two localities. Rare biotite schist layers within the amphibolites range in thickness from 30 cm at the Addington Mine up to four metres at the Ore Chimney Mine.

Kashwakamak formation

The informal name of Kashwakamak formation (KWF; after Kashwakamak Lake) is proposed in this paper for the volcanic succession

that overlies the TDF, marble and volcanoclastic rocks east of Cloyne and Bishop Corners (Fig. 1). These volcanic rocks were described by Sethuraman and Moore (1973) and Moore and Morton (1986; units 1b, 2 and 3, Ontario Geological Survey Map 2499).

The KWF has a minimum total thickness of two and half kilometres and is mainly composed of volcanic rocks of andesitic and dacitic composition. A basal unit of high-alumina basalt, locally pillowed, is overlain by thick deposits of massive to weakly layered andesitic lapilli-tuff, tuff-breccia and coarse epiclastic breccia/conglomerate, exposed north of Harlowe and west of Myer Cave (Fig. 1). The deposits consist of 20 to 70 per cent angular to subround fragments of andesite, basalt, gabbro, diorite, quartz diorite, volcanoclastic rocks, and minor dacite. Fragments vary from two millimetres to one and half metre across; average size is six centimetres in tuff-breccia and one centimetre in lapilli-tuff. Fragmental rocks are estimated to compose 70 per cent of the andesitic succession; individual units range from two to 100 m in thickness. Rare top indicators show that the succession faces northerly to northeasterly, and is overlain by marble.

Andesite flow rocks include both amygdaloidal and massive types and flow breccia. Pillow lava is rare; andesite dykes are common near the western limit of the KWF.

Dacite lapilli-tuff and tuff-breccia containing a wide variety of andesite and dacite rock fragments are abundant six to ten kilometres northeast of Harlowe (Fig. 1). These rocks overlie andesite lapilli-tuff and are in turn overlain by massive marble. To the west they interfinger with andesitic fragmental rocks and are themselves interlayered with dacite flow and volcanoclastic rocks; the fragment size increases towards the west. The KWF attains its greatest thick-

ness (of at least two and half kilometres after flattening), north of Harlowe. There, the concentration of small dioritic stocks and dykes, together with coarsely fragmental rocks and local hydrothermal alteration and sulphide mineralization, suggest a vent area (Moore and Morton, 1986). Rhyolitic dykes are common throughout the upper part of the KWF succession. The predominance of ill-sorted and weakly layered fragmental rocks in the KWF suggests that an emergent andesitic volcano was centred near Harlowe.

The rocks analysed in this study were sampled east of the village of Harlowe; their composition ranges from basaltic andesite to rhyolite. These intermediate to felsic volcanics are composed of metamorphic plagioclase, quartz, biotite and hornblende with accessory muscovite, epidote, chlorite and tourmaline (the latter occurring in fractures); the felsic rocks typically contains recrystallized alkali feldspar phenocrysts. One to two metre-thick, sulphide-bearing quartzofeldspathic interflow sediments are also a minor component of this volcanic succession.

Mazinaw Lake formation

The Mazinaw Lake formation (MLF; Ayer, 1979; Moore and Morton, 1986) is a bimodal tholeiitic succession of limited extent that conformably overlies the Tudor formation north of Cloyne (Fig. 1). The MLF is composed mainly of pyroclastic rocks of rhyolitic and andesitic composition. The proportion of rhyolite to other volcanic rocks is definitely higher in this formation than in the TDF and the KWF. The succession also includes clastic sediments mineralogically similar to the andesitic volcanics, and is cut by a variety of small intrusions. The andesitic pyroclastic rocks are physically similar to those of the KWF; rhyolite ash-flow tuffs exhibit relict eutaxitic textures. No sample from this formation has been analysed in

this study.

Plutonic rocks

The three major plutons within the limits of Figure 1 are the Northbrook and Elzevir batholiths (granodiorite, tonalite, minor granite), and the Mazinaw Lake granite (granite, granite porphyry). The Northbrook and Elzevir bodies show intrusive relations with mafic volcanic rocks, whereas the Mazinaw Lake granite intrudes the MLF and overlying metasedimentary rocks of the Grenville Supergroup.

GEOCHEMISTRY

Sampling and analytical techniques

Thirty-seven TDF volcanic rocks from the Addington Mine (samples from two diamond drill holes) and the Ore Chimney Mine (underground and surface samples) were sampled and analyzed. The Ore Chimney Mine is stratigraphically located at the top of the TDF volcanics (Fig. 1) and, because this succession strikes north-south in the area (Moore and Morton, 1986), the Addington Mine is located significantly lower in the succession. The KWF volcanics (14 samples) were sampled near Harlowe (Fig. 1). Four samples from the Northbrook batholith were also collected south of the Ore Chimney Mine. Only samples free of fractures containing secondary minerals were selected for analysis.

Major elements, Ba, Cr, Nb, Ni, Rb, Sr, Y, Zn, and Zr were determined by X-ray fluorescence; Co, Cs, Hf, Sc, Th, U, La, Sm, Eu, Yb, and Lu by instrumental neutron activation analysis (INAA, Muecke, 1980); CO₂, H₂O, S by volatilization and non-dispersive infrared absorptiometry (Bouvier and Abbey, 1980); ferrous iron by a modified cold Wilson method (Johnson and Maxwell, 1981); Au by flameless atomic absorption spectroscopy (Culver, 1975); As, Ga, Sb by direct current plasma atomic emission spectroscopy (DCP-AES); Ag,

TABLE 2: TYPICAL ANALYSES OF VOLCANIC ROCKS
FROM THE TUDOR AND KASHWAKAMAK FORMATIONS

	Tudor formation					Kashwakamak formation		
Sample no.	126	97	127	96	29	7	52	12
SiO ₂	47.43	48.05	50.10	50.51	53.61	57.45	58.98	74.97
Al ₂ O ₃	14.53	13.13	13.21	18.27	15.11	17.53	16.71	13.78
Fe ₂ O ₃	2.84	2.46	1.67	1.12	2.25	1.07	0.52	0.48
FeO	10.84	12.20	17.30	5.52	9.05	5.29	4.01	0.23
MgO	7.83	7.10	7.52	5.94	4.06	4.49	4.00	0.08
CaO	9.91	10.03	12.02	10.35	8.43	6.09	7.15	1.78
Na ₂ O	3.12	2.14	2.34	3.69	2.99	6.22	0.36	5.07
K ₂ O	0.26	0.20	0.37	0.60	0.45	0.05	3.25	1.31
TiO ₂	1.35	1.60	0.57	0.34	0.94	0.80	0.57	0.13
P ₂ O ₅	0.22	0.22	0.14	0.11	0.13	0.31	0.32	0.05
MnO	0.22	0.25	0.14	0.11	0.18	0.10	0.11	0.03
S	0.06	0.22	0.14	0.11	0.01	0.01	0.01	0.01
CO ₂ T	0.20	0.90	3.60	2.10	0.60	0.60	2.00	1.00
H ₂ O ^T	1.90	1.50	1.90	0.90	1.10	0.60	1.60	0.60
TOTAL	100.29	99.78	100.74	99.45	98.91	100.01	99.58	99.51
Mg*	54	50	63	65	42	59	64	20
Peralu. ind.	0.62	0.60	0.51	0.71	0.73	0.82	0.98	1.06
Peralk. ind.	2.68	3.51	3.11	2.72	2.79	1.70	4.06	1.41
Normative minerals								
Qtz	0	0.5	1.1	0	8.2	2.0	24.0	37.1
Crn	0	0	0	0	0	0	0.4	0.9
Or	1.6	1.2	2.3	3.6	2.7	0.3	20.0	7.9
Ab	26.9	18.6	20.8	32.4	26.0	52.9	3.21	43.4
An	25.3	26.5	25.7	32.7	27.4	19.9	34.7	8.6
Ne	0	0	0	0	0	0	0	0
Cpx	20.3	20.5	30.0	16.6	12.5	6.8	0	0
Opx	1.2	25.0	15.8	2.6	17.5	12.5	12.7	0.2
Hem	0	0	0	0	0	0	0	1.7
Ol	17.9	0	0	8.6	0	0	0	0
Mag	4.2	4.6	3.2	2.8	3.6	3.4	3.12	0
Ilm	2.6	3.1	1.1	0.7	1.8	1.5	1.1	0
Ap	0	0	0	0	0.3	0.7	0.8	0.1
Trace elements								
Ag	--	--	--	3	--	--	3	--
As	--	14	<1	5	--	<1	--	<1
Au (ppb)	--	18	--	17	<12	--	17	<12
Ba	87	55	102	962	117	38	1077	278
Co	54	113	36	38	37	24	17	1
Cr	165	156	469	184	89	115	181	73
Cs	2.3	1	6.1	201	<0.5	<0.3	1.6	0.6
Cu	77	23	3	14	105	33	22	4
Ga	n.d.	25	n.d.	20	26	18	20	22
Hf	1.9	0.8	0.5	<0.5	4.4	8.8	4	9.2
Nb	--	--	--	--	--	<5	5	7
Ni	152	50	152	47	24	139	54	4
Pb	4	2	4	3	2	--	7	2
Rb	27	--	27	16	5	--	77	29
Sb	--	--	--	--	<1	<1	--	1
Sc	42	n.d.	42	36	32	23	15	2
Sr	85	118	85	97	279	660	209	113
Th	--	--	--	--	2.4	15	6.7	52
U	<0.5	--	<0.5	<0.5	--	--	2	18
Y	40	43	21	11	29	24	19	23
Zn	114	114	64	41	90	92	46	33
Zr	79	83	19	9	56	133	161	119
La	3.72	2.97	1.05	0.44	3.52	19.11	55.85	39.40
Sm	3.27	2.46	1.27	0.71	2.31	4.03	9.56	6.27
Eu	1.16	1.74	0.47	0.39	1.11	1.57	2.25	1.08
Yb	5.90	4.03	2.60	0.61	1.60	1.70	2.09	1.16
Lu	0.87	n.d.	0.46	0.10	0.30	0.25	2.00	0.28
(La/Yb) _N	0.4	0.5	0.3	0.5	1.5	17	18	23
Ti/Zr	102	116	180	226	101	36	21	7

Major elements, S, CO₂^T and H₂O are in weight per cent. Trace elements are in parts per million (ppm) unless otherwise stated. CO₂^T is total carbon as CO₂. H₂O^T is total water. --: not detected. n.d.: not determined. Mg* = (Mg/Mg+Fe²⁺) x 100, assuming Fe²⁺ = 0.9 total Fe. Peralu. ind.: peraluminous index, molecular Al₂O₃/(CaO+Na₂O+K₂O). Peralk. ind.: peralkaline index, molecular Al₂O₃/(Na₂O+K₂O). (La/Yb)_N: chondrite-normalized ratio. Note that the Ba abundance of sample 52 is anomalously high.

TABLE 3: WEIGHTED MEANS OF VOLCANIC ROCKS FROM THE TUDOR AND KASHWAKAMAK FORMATIONS

	-1-		-2-		-3-		-4-		-5-		-6-	
n =	10		10		13		5		33		4	
	$\bar{x}_w$	SD	$\bar{x}_w$	SD	$\bar{x}_w$	SD	$\bar{x}_w$	SD	$\bar{x}_w$	SD	$\bar{x}_w$	SD
SiO ₂	49.27	1.7	54.21	2.6	51.00	1.3	56.18	3.3	58.32	3.5	72.40	3.8
Al ₂ O ₃	13.77	1.9	15.47	1.1	14.87	1.3	17.38	1.3	17.00	1.3	15.66	1.3
Fe ₂ O ₃	2.78	0.9	3.79	1.0	2.28	0.7	1.26	0.5	1.65	0.4	1.27	1.3
FeO	11.90	2.4	8.15	2.0	10.94	1.4	6.30	1.3	5.10	1.6	0.57	0.5
MgO	7.67	1.5	4.94	0.9	6.75	1.3	5.48	1.7	6.28	1.8	0.70	0.5
CaO	10.30	1.7	8.89	1.3	8.91	1.3	7.75	0.7	6.28	1.8	2.29	0.5
Na ₂ O	2.15	1.1	3.04	0.9	3.51	0.8	3.98	2.5	4.14	1.0	4.41	0.8
K ₂ O	0.40	0.4	0.32	0.4	0.10	0.8	0.12	1.4	1.40	1.2	2.26	1.0
TiO ₂	1.52	0.5	0.91	0.2	1.29	0.6	1.04	0.4	0.75	0.3	0.29	0.2
P ₂ O ₅	--	n.d.	0.08	.07	0.14	.18	0.40	.32	0.26	.18	0.11	.03
MnO	0.24	.05	0.20	.03	0.21	.03	0.11	.02	0.09	.04	0.04	.01
TOTAL	100.00		100.00		100.00		100.00		100.00		100.00	
Ag	--	n.d.	--	n.d.	n.d.	n.d.	--	n.d.	n.d.	n.d.	--	n.d.
As	3	20	1	6.3	n.d.	n.d.	1	7.7	n.d.	n.d.	<1	n.d.
Au (ppb)	16	29	--	n.d.	n.d.	n.d.	16	9	n.d.	n.d.	15	8
Ba	96	72	77	111	25	113	110	438	301	163	334	211
Co	48	30	36	7	n.d.	n.d.	28	8	n.d.	n.d.	5	3.5
Cr	157	104	81	32	82	75	151	118	89	196	68	15
Cs	17	30	<1	n.d.	n.d.	n.d.	1	0.8	n.d.	n.d.	2	0.6
Cu	41	138	62	37	54	50	27	9	29	22	8	4.9
Ga	25	4	24	2	n.d.	n.d.	20	3	n.d.	n.d.	20	2
Hf	2	0.8	2	1.4	n.d.	n.d.	11	5	n.d.	n.d.	11	1
Nb	--	n.d.	--	n.d.	17	4	5	2.8	7	3.5	7	2
Ni	41	40	20	15	48	23	47	44	50	35	6	2.5
Pb	3	4.5	3	4.1	n.d.	n.d.	3	2.9	n.d.	n.d.	2	0.0
Rb	11	15	<2	n.d.	70	38	--	n.d.	58	30	52	23
Sb	--	n.d.	<1	n.d.	n.d.	n.d.	1	0.4	n.d.	n.d.	1	0.0
Sc	48	8	34	5	n.d.	n.d.	24	5	n.d.	n.d.	3	2.8
Sr	104	25	288	121	156	73	551	268	363	148	219	82
Th	--	n.d.	1	0.7	n.d.	n.d.	17	8	n.d.	n.d.	37	15
U	<1	n.d.	1	0.9	n.d.	n.d.	--	n.d.	n.d.	n.d.	5	8
Y	41	12	28	6	65	7	26	5	18	10	18	5
Zn	93	31	108	22	97	42	104	33	95	38	36	4
Zr	72	29	56	10	164	83	163	47	171	56	148	15
La	2.2	1.3	6.6	1.9	n.d.	n.d.	37.6	17.3	n.d.	n.d.	28.9	15.5
Sm	2.8	1.8	3.1	0.7	n.d.	n.d.	8.5	3.6	n.d.	n.d.	5.2	1.5
Eu	1.0	0.4	1.1	0.2	n.d.	n.d.	2.5	1.0	n.d.	n.d.	1.1	0.2
Yb	3.4	1.8	2.6	0.9	n.d.	n.d.	2.0	0.3	n.d.	n.d.	1.2	0.2
Lu	0.5	0.3	0.4	0.4	n.d.	n.d.	0.3	0.8	n.d.	n.d.	0.3	0.1
(La/Yb) _w	0.4	0.2	1.7	0.7	n.d.	n.d.	11.8	4.6	n.d.	n.d.	17.6	7.2
Ti/Zr	129	41	99	26	57	13	37	8	28	9	11	9
OXIRATIO	18	3	29	9	n.d.	n.d.	15	3	n.d.	n.d.	62	22

$\bar{x}_w$: weighted mean. SD: one standard deviation. n: number of samples averaged. Major oxide values are weight per cent recalculated on a volatile free basis. Trace element abundances are in parts per million (ppm) otherwise stated. --, n.d. and (La/Yb)_w as in Table 2. 1: Tudor formation, Addington Mine, this work; REE data based on 9 samples. 2: Tudor formation, Ore Chimney Mine, this work. 3: Tudor formation, Moore and Morton (1986). 4: Kashwakamak formation, intermediate volcanics, this work. 5: Kashwakamak formation, intermediate volcanics, Moore and Morton (1986). 6: Kashwakamak formation, felsic volcanics, this work.

Cu, Pb, by atomic absorption spectroscopy; Sb by INAA or DCP-AES. The analytical procedures are described in detail in Appendix II.

Typical analyses of volcanics of the TDF and the KWF are listed in Table 2, and weighted mean analyses of the volcanic rocks of both formations are listed in Table 3. Other analyses of these units are presented in Sethuraman and Moore (1973), Condie and Moore (1977), and Moore and Morton (1986).

Alteration and metasomatism

The samples analyzed do not contain any high chlorine- or fluorine-bearing phases, and no evidence of intense carbonatization, silicification, chloritization, epidotization, or sericitization has been found in the rocks. Under such circumstances the elements Nb, Zr, Ti, Y, Hf and the heavy rare earth (HREE) elements generally retain their original concentrations in the rocks, but alkalis (Rb, K, Na) and other elements are nonetheless subject to large changes (Winchester and Floyd, 1977; Floyd and Winchester, 1978; Finlow-Bates and Stumpfl, 1981; Colman, 1982; Schau and Henderson, 1983; Nesbitt and Young, 1984; Murphy and Hynes, 1986).

Elemental concentrations may result in part from magmatic processes and in part from post-magmatic alteration; it is therefore important to determine as accurately as possible which elements had their concentrations modified by post-magmatic processes.

All analyses of samples immediately adjacent to the Ore Chimney Formation, which is a potassium-rich rock unit, were rejected. Samples bearing normative nepheline were also rejected (Güinas et al., 1982). Only samples with low H_2O and CO_2 were selected; cut-off values of $H_2O < 5$ wt.% and $CO_2 < 3.6$ wt.% were arbitrarily chosen and are intended to filter out samples that have been excessively carbonatized or hydrated. Out of the 51 volcanics analysed, 29

Figure 2. Chondrite-normalized REE plot of Tudor formation volcanics (Addington Mine).

Open symbols: CO_2 -poor samples.

Sample 79: 1.3% CO_2 , 2.8% H_2O , 0.16% S.

Sample 80: 1.1% CO_2 , 2.0% H_2O , 0.00% S.

Filled symbols: CO_2 -rich samples.

Sample 95: 3.5% CO_2 , 1.5% H_2O , 0.25% S.

Sample 122: 2.4% CO_2 , 4.4% H_2O , 2.28% S.

Sample 123: 2.0% CO_2 , 4.8% H_2O , 1.49% S.

Samples 96, 97, 126 and 127 as in Table 2.

passed our screening test, and their chemistry is compiled in Table 3.

In Fig. 2, REE patterns of CO₂-rich samples (2.0-3.5 wt.% CO₂) are compared with CO₂-poor samples (0.2-1.3 wt.% CO₂) from the same locality. There is no significant difference between the two groups, indicating that carbonatization simply diluted the REE without fractionating them, with the possible exception of Eu. Positive Eu anomalies such as those of samples 96 and 97 could be explained by interaction of the rock with a reduced fluid (Kerrick and Fryer, 1979). The negative Eu anomalies are interpreted as inherited magmatic features for which plagioclase fractionation is responsible.

Nb, Zr, Ti, Y and Hf have small standard deviations (Table 3), and Ti/Zr, Zr/Y and Nb/Y ratios of CO₂-rich and hydrated samples are not significantly different from those of the CO₂-poor and least hydrated samples. It is thus concluded that Nb, Ti, Y and Hf behaved as immobile elements. The large standard deviations of K₂O, P₂O₅, Ba and Cs (Table 3) suggest that these elements, and also possibly Rb, were at least locally remobilized.

Chemistry of the volcanic rocks

Figure 3 shows that both the TDF and KWF suites are sub-alkaline according to the criteria of Floyd and Winchester (1977). The TDF samples are basaltic, and the KWF samples are predominantly intermediate and felsic. On a Jensen (1976) cation plot (Fig. 4), the TDF and KWF suites plot in the tholeiitic and calc-alkaline fields, respectively.

Six out of the twenty TDF samples analysed have normative olivine. None has normative corundum, whereas half of the KWF volcanics are corundum-normative. Half of KWF volcanics analysed are also peraluminous (molar Al₂O₃ > [CaO+Na₂O+K₂O]), and half are metalumi-

Figure 3. Zr/TiO_2 - Nb/Y plot (Winchester and Floyd, 1977) of Tudor and Kashwakamak formations volcanics. Filled and open squares: Tudor formation. Filled and open circles: Kashwakamak formation. Filled symbols: this work. Open symbols: Moore and Morton (1986).

Figure 4. Jensen (1976) cation plots of Tudor and Kashwakamak formations volcanics. Symbols as in Figure 3.

nous ($[\text{Na}_2\text{O}+\text{K}_2\text{O}] < \text{Al}_2\text{O}_3 < [\text{CaO}+\text{Na}_2\text{O}+\text{K}_2\text{O}]$). The TDF volcanics analysed are all metaluminous.

The TDF volcanics at Addington Mine have LREE-depleted patterns whereas those at Ore Chimney Mine have REE patterns nearly flat to slightly enriched in LREE (Fig. 5). The MREE and HREE of the TDF volcanics at Ore Chimney Mine vary from 10X to 30X chondrite and are well within the range of those from Addington Mine. The KWF intermediate volcanics have greater REE contents than the KWF felsic volcanics, but overlap the felsic volcanic envelope from La to Lu (Fig. 5).

In Figures 3 and 4, and in Table 3, the volcanic rocks analysed in this study are compared to volcanic rocks that passed our screens, from the same formations, presented by Moore and Morton (1986). Three TDF samples come from the northernmost exposure of this formation in the area of Figure 1; the other TDF sample localities are evenly distributed along a southwest-northeast traverse between Cloyne and the eastern limit of the Elzevir batholith. The KWF sample localities are scattered throughout the exposed area of this formation within Figure 1. Moore and Morton's KWF samples occupy roughly the same fields on the Zr/TiO_2 -Nb/Y plot (Fig. 2), as the rocks analysed in this study. These samples also plot in the same fields as those of this study on the Jensen (1976) cation plot (Fig. 4), which suggests that the samples analysed in this study, although from three small areas (Fig. 1), are representative of the overall composition of their respective formations. Table 3 shows that there are no significant differences between the volcanics analysed by Moore and Morton (1986) and those analysed in this study with respect to major elements. The TDF analyses of Moore and Morton (1986) however show higher Nb and Zr contents (Table 3) than those

Figure 5. Chondrite-normalized REE plot of Tudor and Kashwakamak volcanics. TDF: Tudor formation. KWF: Kashwakamak formation.

of this study, and as a result they have a lower Ti/Zr ratio.

DISCUSSION

Primitive melts in equilibrium with refractory residuum of the Earth's mantle have Mg^* values (molar $[Mg/Mg+Fe^{+2}] \times 100$; assuming $Fe^{+2} = 0.9$ total Fe; Brooks, 1976) ranging from 70 to 83 and nickel contents in the range 200 to 450 ppm (Basaltic Volcanism Study Project, 1981). None of the volcanics analysed has these characteristics. The highest Mg^* value and nickel content for the TDF volcanics analysed are 65 and 152 ppm, respectively, suggesting that all volcanics analysed were fractionated, at least by olivine separation, to some extent before their extrusion. A few samples have small or imperceptible negative Eu anomalies, which indicate loss of plagioclase during magma ascent.

Tectonic setting

Windley (1986) has presented evidence that the Grenvillian plate tectonic regime is comparable to that of modern times, which suggests that trace element discriminant diagrams designed for Phanerozoic igneous rocks can be applied to their late Proterozoic equivalents. The TDF basalts and basaltic andesites have been plotted on discriminant diagrams based on various ratios of Ti, Zr and Y (Fig. 6). Because of the considerable overlap between the mid-ocean ridge basalt (MORB) and the island arc basalt (IAB) fields in Figures 6b and 6c, and because the TDF volcanics plot in the ocean floor as well as in the island arc field in the Zr-Ti-Y diagram (Fig. 6a), the data are not conclusive. Nevertheless, the data are most consistent with island arc origin, which is supported by their very low Nb, which is characteristic of volcanic arc rocks (Pearce and Gale, 1977; Wood et al., 1979).

Figure 6. Trace element discriminant plots of Tudor formation basalts and basaltic andesites. A) island arc basalts plot in fields A, B, C. Ocean floor basalts plot in field B. Within-plate basalts plot in field D. Field boundaries are from Pearce and Cann (1973). B) and C) MORB: mid-ocean ridge basalt. IAB: island arc basalt. WPB: within plate basalt. Field boundaries are from Pearce (1980).

Figure 2. Trace element plots of felsic rocks. Diamonds: Northbrook-granodiorite batholith (this work). Open circles: Kashwakamak formation (Moore and Morton, 1986). Filled circles: Kashwakamak formation (this work). ORG: ocean-ridge granite. SCG: syn-collisional granite. VAG: volcanic arc granite. WPG: within plate granite. Field boundaries are from Pearce *et al.* (1984).

More specific results are obtained using trace element diagrams for felsic rocks (Fig. 7). The KWF volcanics plot well in the volcanic arc granite (VAG) field on a Nb/Y diagram (Fig. 7). Four samples of the Northbrook granodiorite batholith analysed in this study plot in the same field as the KWF felsic volcanics on these discriminant diagrams (Fig. 7). Our data thus support the island arc origin postulated for the TDF and KWF volcanics, on the basis of less satisfactory criteria by Brown *et al.* (1975) and Condie and Moore (1977).

Petrogenesis of the Tudor formation volcanics

Figures 8a and 8b are La/Yb-Sm/Yb and Zr/Y-Sm/Y plots of TDF volcanics. On these plots, fractional crystallization of olivine, orthopyroxene, clinopyroxene, plagioclase and magnetite has essentially no effect. Therefore, fractional crystallization of a single parental magma cannot account for the dispersion of the TDF data points on these plots; neither can it be explained by mixing of episodically injected primitive magmas into fractionating magma chambers containing more evolved, cogenetic magmas. The cause of this scatter must be sought in other igneous processes.

Various petrogenetic processes have been tested by geochemical modelling to determine which could have produced the parental magma(s) of the TDF. There are two end member models for melting: batch partial melting and fractional partial melting (Shaw, 1970; Allgre and Minster, 1978; Hanson, 1980). In batch melting the melt and solid residue are in equilibrium as melting proceeds until enough melt accumulates that it can migrate away from the zone of melting; melting then ceases. In fractional melting (or Rayleigh melting), small fractions are continuously and completely removed as melting proceeds.

Figure 8. La/Yb-Sm/Yb and Zr/Y-Sm/Y plots of Tudor volcanics. Filled squares: samples from the Addington Mine. Open squares: samples from the Ore Chimney Mine. Sample 127: see text. Triangle: melt composition produced by 30% batch partial melting (no residual spinel) of Condie and Moore's (1977) mantle source for the Tudor volcanics. Shaded area: melt composition for batch partial melting of a LREE-enriched source (E) and a LREE-depleted source (D). Melt fractions (0.1-0.5) are indicated. There is essentially no change in incompatible element ratios in melt fractions greater than 0.5. Mineralogical composition of source: 50% olivine, 25% orthopyroxene, 25% clinopyroxene. Melting proportions: 15% olivine, 35% orthopyroxene, 50% clinopyroxene. Chemical composition of sources as in Table 4. Partition coefficients from Arth and Hanson (1975), Pearce and Norry (1979) and Frey (1980). Accuracy and precision for Zr, Y and REE at these levels of abundances is 10% or better; the error box has the limits A: La+10%/Yb-10%, La-10%/Yb+10%, Sm+10%/Yb-10%, Sm-10%/Yb+10%; B: Zr+10%/Y-10%, Zr-10%/Y+10%, Sm+10%/Y-10%, Sm-10%/Y+10%. The error box thus represents the maximum combined error.

Figure 2. Partial melting model calculations. Shaded fields: composition of Tudor formation volcanics, taken from Figure 5. Solid lines define REE content of the liquid produced by 10%, 20% and 30% batch partial melting of a LREE depleted source (Addington Mine) and of a LREE enriched source (Ore Chimney Mine). Parameters of melting as in Figure 8. Chemical composition of the sources as in Table 4.

TABLE 4
MANTLE SOURCE COMPOSITIONS FOR TUDOR VOLCANICS

=====				
		-1-	-2-	-3-
	Chondrite		X chondrite	
	(ppm)			
La	0.245	4	0.50	4
Sm	0.154	4	1	4
Eu	0.058	4	1	3
Yb	0.165	4	2	2
Y	2.0	2	2	4
Zr	6.84	1	0.25	2
(La/Yb) _N		1	0.25	2

=====

REE chondrite abundances from Evensen et al. (1978). Y and Zr chondrite abundances from Thompson et al. (1983). 1: mantle source composition from Condie and Moore (1977). 2: LREE-depleted source, this work. 3: LREE-enriched source, this work. (La/Yb)_N: chondrite-normalized ratio.

During fractional melting there is a rapid decrease of incompatible element concentration and of the La/Yb ratio in successive melts to value below those in the original source (Figure 14.1b of Cox, Bell and Pankhurst, 1979). This melting model for the TDF volcanics is rejected because the TDF volcanics at Ore Chimney Mine are stratigraphically above and hence younger, than those at Addington Mine and have higher La/Yb values (Fig. 5). Of the batch melting models tested, two can account for the internal REE, Zr and Y variations of the TDF volcanics.

Model I

Based on geochemical modelling of only one composite sample, Condie and Moore (1977) proposed a model involving 30% batch melting of a lherzolite having REE 4X chondrite (Figs. 8a and 8b; Table 4). The process is actually more complex, and this type of single, or homogeneous, unfractionated REE mantle source is inadequate. Model calculations (Figs. 8 and 9) show that TDF volcanics are bracketed by melts produced by 10 to 30% batch melting of a LREE-depleted source and by 10 to 30% batch melting of a LREE-enriched source, both sources having HREE 2X chondrite and $Zr/Y < 1$ (Table 4). TDF samples having La/Yb, Sm/Yb, Zr/Y and Sm/Y ratios values intermediate between these two compositions can be accounted for by batch melting of sources of intermediate compositions or by mixing of the LREE-depleted and LREE-enriched melts. Lherzolite or garnet lherzolite are possible parents, providing that garnet is not a residual phase. This model implies heterogeneities in the Proterozoic upper mantle.

Model II

Crustal contamination of TDF volcanics has been tested by geochemical modelling (Fig. 10). There is no outcrop of possible

Figure 10. Crustal contamination model calculations. Filled squares: Tudor volcanics from the Addington Mine. Open squares: Tudor volcanics from the Ore Chimney Mine. Sample 127 is used as initial magma in computation of FC and AFC trends, see text. FC: simple fractional crystallization trend (Allgre, and Minster, 1978). AFC: combined assimilation and fractional crystallization trend (DePaolo, 1981). Calculations have been done using the Canadian Shield (1) as the contaminant and an assimilation/crystallization rate = 0.4. Proportions of crystallizing phases for both trends: 50% plagioclase, 45% clinopyroxene, 5% olivine. Melt fractions for both trends are given. Triangles: contaminants. 1: Canadian Precambrian Shield. 2: Precambrian Shield of southwestern Quebec. 3: Precambrian Shield of southern Saskatchewan. 4: Precambrian Shield of Baffin Island. 5: Precambrian Shield of northern Quebec. 6: Earth continental crust. 7: upper continental crust. 8: lower continental crust. 9: Archean upper crust. 1, 2, 3, 4 and 5 from Shaw *et al.* (1976). 6, 7, 8 and 9 from Taylor and McLennan (1981). The error box has the limits La+10%/Yb-10%, La-10%/Yb+10%, Sm+10%, Sm-10%.

basement in the study area, therefore various Precambrian Shield and average continental crust compositions were selected as possible contaminants. Crustal contamination is a complex process (Watson, 1982), however it can be approximated using DePaolo's (1981) equations for combined wall rock assimilation and fractional crystallization. Model calculations (Fig. 10) show that TDF volcanics with high La/Yb (1.9-4.0) plot near the contamination trend and could have been derived from low La/Yb basaltic melts similar to sample 127 through combined assimilation of crustal material and fractional crystallization. Sample 127 was used in the computation of the AFC and FC trends (Fig. 10) because it has high Mg^* values and high MgO , Ni and Cr contents (Table 2) compared to the other volcanics analysed, which indicates that it is the most primitive. Calculations were done using the mean composition of the Canadian Shield (Shaw *et al.*, 1976) as the contaminant; using any other contaminant plotted on Fig. 10 or another assimilation rate does not change the conclusion. The range of Sm abundances (0.7-4.5 ppm; Fig. 10) of the low La/Yb group requires large variations in the degree of partial melting (<5-40%) of a single source combined with up to 40% low pressure fractional crystallization. The range of La/Yb of this group of samples (0.4-1.1) can be accounted for by small degrees of crustal contamination. Geochemical modelling indicates that crustal contamination is possible and that model II requires only one homogeneous mantle source.

In conclusion, the geochemical data do not demonstrate whether the arc was ensimatic or ensialic. The absence of sialic basement in the exposed rocks of the area, and the presence of tectonically-emplaced ultramafic plutonic bodies associated with the mafic volcanics, 10-15 km south of Flinton, are consistent with a basement of

ancient oceanic crust (Brown, *et al.*, 1975). The stratigraphy and physical features of the volcanic rocks suggest that they are remained below sea level for a substantial period in its early history, becoming emergent only at a later stage when activity changed from tholeiitic (TDF) to calc-alkaline (KWF). This is consistent with an origin of the arc either on oceanic crust, or on thinned continental crust, as would be expected under a continental rift zone or rifted margin. If model I is applicable, basaltic melts produced by batch melting of an heterogeneous upper mantle (e.g. Frey and Green, 1974; Wood *et al.*, 1979) could have been extruded on oceanic crust. If model II is correct, the arc would have necessarily been ensialic.

Kashwakamak formation

Condie and Moore (1977) have shown that the KWF volcanics cannot be derived by fractional crystallization of the TDF basaltic volcanics. They also showed that 30% batch melting of eclogite and 50% batch melting of siliceous garnet granulite produce magma most similar to the KWF intermediate and felsic volcanics, respectively, with respect to REE and other trace elements. Geochemical modelling using our data indicates that 30-50% batch partial melting of siliceous garnet granulite could produce magmas similar to the KWF intermediate and felsic volcanics with respect to REE.

As the geochemical data require that at least part of the KWF have been generated from sial, the arc complex must have been underlain by continental crust at the time of extrusion of the calc-alkalic rocks. This requirement is consistent with either: 1) ensialic origin of both TDF and KWF (required by model II, above), or 2) accretion of an ensimatic arc to a continental margin between the

time of extrusion of the TDF and that of KWF (as suggested by Pride and Moore, 1983).

CONCLUSIONS

Two distinct subalkaline volcanic successions, the TDF and the KWF, occur in the Flinton-Harlowe area. The TDF volcanics are predominantly basaltic and tholeiitic in composition, whereas intermediate and felsic calc-alkaline volcanics predominate in the KWF.

The chemistry of the TDF volcanics shows that none of them has the characteristics of a primitive basalt, and that all volcanics were fractionated to some extent before their extrusion.

Trace element discriminant plots of the TDF basalts and basaltic andesites are consistent with either a mid-ocean ridge or an island arc setting. However, discriminant plots of the KWF felsic volcanics indicate an island arc origin, which is supported by the samples of the Northbrook granodiorite batholith which plot in the same field on these plots.

Trace element data (including REE) indicate that the TDF volcanic rocks are not derived from a single parental magma through fractional crystallization, nor can KWF rocks be derived from TDF by this means. Variations in incompatible element ratios of the TDF volcanics may have been caused through selective contamination by continental crust material, or through partial fusion of a heterogeneous Proterozoic upper mantle and erupted on oceanic crust.

The KWF intermediate to felsic volcanics cannot be derived from the upper mantle by partial melting and fractional crystallization, and they cannot be derived by fractional crystallization of the TDF basalts. The origin of the KWF volcanics is best explained by partial melting of siliceous garnet granulite in the lower crust (Condie and Moore, 1977; Holm et al., 1986).

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CHAPTER II

GEOCHEMISTRY AND ORIGIN OF THE ORE CHIMNEY FORMATION, GRENVILLE PROVINCE, SOUTHEASTERN ONTARIO.

ABSTRACT

The Ore Chimney Formation is a mid Proterozoic metapelitic rock unit which occurs between underlying mafic to intermediate metavolcanic rocks of the Grenville Supergroup and an overlying metasedimentary succession, the Flinton Group. It has been interpreted alternatively as a paleoregolith or a product of hydrothermal alteration of the volcanic rocks, in a major shear zone. The Formation is thin (<10 m), massive to poorly layered, crops out over 40 km along strike and is typically composed of alternating layers of biotite schist, muscovite-biotite schist, hornblende-biotite schist and hornblende schist. It typically contains coarse porphyroblasts of garnet and less commonly of staurolite, kyanite, epidote and/or hornblende. Thirty-five samples of the Ore Chimney Formation, fifty samples of the underlying metavolcanics and fourteen samples of the overlying clastic metasediments were analysed for major and twenty-eight trace elements (including REE). Immobile trace element ratios (Ti/Zr, Zr/Y, Nb/Y, La/Yb) indicate that the Ore Chimney Formation is locally derived from the underlying metavolcanics. Bulk chemistry, field relations and petrographic observations strongly suggest that the Ore Chimney Formation is a detrital or a locally-reworked residual metasedimentary rock.

INTRODUCTION

The Ore Chimney Formation (OCF) is a distinctive stratum of black garnet-biotite schist which occurs between basaltic to intermediate metavolcanic rocks of the Grenville Supergroup, and the overlying metasedimentary succession of the Flinton Group in southeastern Ontario (Moore and Thompson, 1980). All of these late Precambrian rocks are distinctive for their relatively low metamorphic grade in comparison with most of the rocks elsewhere in the Grenville Province.

There is a close spatial relationship between the OCF and polymetallic, gold-bearing mineral occurrences, among which the Addington Mine is a former producer (Fig. 1). The nearby Ore Chimney Mine, although it never produced gold, underwent extensive surface and underground development. At all these localities, the mineralization is contained in a network of quartz or quartz-carbonate veins concordant to sub-concordant with the stratigraphy and metamorphic fabric, either within or immediately underlying the OCF rocks (Dillon, 1985; Harnois and Moore, 1986).

It has been suggested that the OCF represents either a mafic metasediment or sheared and metasomatised equivalents of mafic metavolcanics (Harding, 1944; Moore and Thompson, 1980; Springer, 1982). The controversial origin of the OCF and its potential role as a control on gold deposition has generated interest in this rock unit. The aim of this chapter is to describe and geochemically characterize the OCF, and to determine its origin using geological and geochemical evidence.

GENERAL GEOLOGY AND GEOCHRONOLOGY

The study area lies within the Elzevir terrane (or subzone IV) of the Central Metasedimentary Belt (Wynne-Edwards, 1972; Davidson,

Figure 1. General geology of part of eastern Ontario, showing distribution of the Flinton Group. Based on mapping by Moore and Thompson (1980). All rocks are metamorphosed; original lithology is indicated. Place names (BI: Bishop Corners; CI: Cloyne; FI: Flinton) and sample localities (ADM: Addington Mine; HA: Harlowe; OCM: Ore Chimney Mine; RE: Reid Lakes) are abbreviated.

1986) and is underlain by late Precambrian metavolcanic and meta-sedimentary rocks and metagranitoid intrusive bodies (Fig. 1). The geology of the area has been described by Harding (1944), Meen (1944), Sethuraman and Moore (1973), Moore and Thompson (1980), Wolff (1982) and Moore and Morton (1986). Because all rock units of the area are metamorphosed, and most protoliths readily identified, the prefix "meta" will hereafter be omitted.

The oldest rocks in the area are the volcanics of the Tudor formation (Hermon Group, Grenville Supergroup; Lumbers, 1967). They are tholeiitic basalts and minor intermediate pyroclastics (Sethuraman and Moore, 1973) which have been dated at 1279 ± 3 Ma by U-Pb isotopic method on zircon (Heaman *et al.*, 1987). These are overlain by basaltic to felsic subalkaline volcanic rocks (the Mazinaw Lake and the Kashwakamak formations; Ayer, 1979; Harnois and Moore, 1987; Chapter I) and by clastic and carbonate sedimentary rocks (Moore and Morton, 1986). This succession has been intruded by large granitoid plutonic bodies, of which the Elzevir batholith (Fig. 1) has been dated by U-Pb isotopic method at 1226 ± 25 Ma and at 1240 ± 50 Ma by Rb-Sr (Bell and Blenkinsop, 1980; Connelly, 1987). The OCF is a mafic, aluminous schist, <1-10 m thick, which overlies the volcanic rocks; it has not been recorded as overlying other rock types and is not included in the Flinton Group by Moore and Thompson (1980). The stratigraphic order established by these authors in the study area is reproduced, slightly modified, in Table 1. Moore and Thompson (1980, p. 1693) suggested that the OCF is a regolith, produced by pre-Flinton weathering of the volcanic rocks.

The Flinton Group (Thompson, 1972; Moore and Thompson, 1980) is a succession of clastic sediments that overlies the OCF conformably and the older rocks with major angular unconformity. In the study

TABLE 1
Table of Formations

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F	
L G	Lessard Formation: Biotite-carbonate schist, calcareous quartzo-feldspathic
I R	metapsammite, plutonic pebble metaconglomerate.
N O	
T U	
O P	Bishop Corners Formation: Quartzite, metapsammite, metaconglomerate.
N	
	minor unconformity (?)
	Ore Chimney Formation: Pelitic metasediments (biotite schist, garnet-biotite
	schist, muscovite-biotite schist, hornblende-biotite
	schist, hornblende schist).
	major unconformity
	Plutonic rocks: Metagranite to metatonalite batholiths.
	intrusive contact
G	
R	Metasediments: Marble, wacke, minor metamorphosed shallow intrusions.
E	
N	Mazinaw Lake formation:
V	Predominantly felsic to basaltic
I	metavolcanic rocks.
L	Minor epiclastic metasediments and
L	metamorphosed subvolcanic intrusions.
E	
	Kashwakamak formation:
	Felsic to basaltic metavolcanic
	rocks (predominantly andesitic).
	Minor epiclastic metasediments,
	metamorphosed intrusions and
	quartzofeldspathic interflow
	metasediments.
S	
U	Metasediments: Wacke, tuff, marble.
P	
E	Tudor formation: Metabasalt flows, pillowed flows, flow and pillow breccia.
R	Minor metagabbroic intrusions.
G	Minor mafic interflow metasediments.
R	
O	
U	
P	

=====

After Ayer (1979), Moore and Thompson (1980) and Moore and Morton (1986).

area, the Flinton Group is composed essentially of two formations: the Bishop Corners Formation and the Lessard Formation. The Bishop Corners Formation is a clastic siliceous succession composed mainly of quartzite and quartzofeldspathic sandstone units, both of which contain conglomeratic beds. The Lessard Formation is composed of carbonate-bearing clastic sediments and, within and near the study area, includes units of polymictic, granitic-pebble conglomerate with a calc-silicate matrix, carbonate-bearing quartzofeldspathic sandstone, and carbonate-biotite schist.

Connelly (1985, 1987) suggested that the Flinton Group was emplaced tectonically into its present position, and thus that the supposed unconformity is a folded thrust plane. The close lithologic relationships cited by Moore and Thompson (1980), between certain pre-Flinton and Flinton rock units, preclude however any major displacements along the base of the Flinton Group.

Angular discordance between layering and contacts in pre-Flinton rock units and the base of the Flinton Group was invoked by Moore and Thompson (1980) to demonstrate the existence of at least one period of deformation before Flinton sedimentation. Xenoliths of volcanic rocks, with variably oriented hornblende schistosity and lineation, are found in relatively undeformed rocks of the Elzevir batholith. These relationships show that metamorphism as well as deformation preceded the Flinton Group. However the polyphase deformation responsible for the major map pattern, and the regional metamorphic zonation, clearly postdate all units of the Flinton Group.

Thompson (1972) recognized four post-Flinton phases of deformation. Isoclinal synclines formed during D_1 , in which are preserved the rocks of the Flinton Group (Fig. 1), were refolded during the

second phase of deformation (D_2) about axial surfaces with a north-east trend. D_1 and D_2 structures are warped by open folds D_3 with northwest trending axial surfaces. This phase could be a late stage of D_2 , representing the time when the northwest-southeast compression, which formed the D_2 structures, bent the folds around the plutonic intrusions. Centimetre- to metre-scale folds and greenschistation (D_4) in schistose rocks of the Flinton Group have developed after the third phase of deformation.

Only one period of regional metamorphism affected the sedimentary rocks of the Flinton Group. The metamorphic grade was increasing during D_1 , attained a maximum shortly before D_2 , remained high for some time, and, before D_3 , began to decrease. Metamorphic recrystallization had essentially ceased when D_4 occurred. Regional isograds thus transect the major structural trends and show no evidence of close folding (Thompson, 1972).

Metamorphic mineral zoning has been defined in calcareous and pelitic rocks of the Flinton Group and in older carbonate and volcanic rocks (Carmichael *et al.*, 1978). Metamorphic grade varies from uppermost greenschist at Bishop Corners (Fig. 1) to upper middle amphibolite facies east and south of the study area. The localities described here are at lower amphibolite grade (staurolite zone). An average peak metamorphic temperature of 500°C was obtained using the garnet-biotite geothermometer at the Addington and Ore Chimney mines (Appendix III; Harnois and Moore, 1986). Sethuraman and Moore (1973) concluded from mineral assemblages and mineral chemistry in pelitic and volcanic rocks that the physical conditions of metamorphism in the region were those of an intermediate pressure facies series; mineral associations correspond to Carmichael's (1978) bathozone 4 (0.4 to 0.5 GPa).

Moore and Thompson (1980) estimated that deposition of the Flinton Group occurred in the time range 1050-1080 ($\pm$ 25) Ma. More recent data (Heaman *et al.*, 1987) however suggest that the regional metamorphism took place between 1090 and 1240 Ma, thus requiring that Flinton sedimentation be older than previously believed. In any case the deformation events and accompanying regional metamorphism occurred near the end of the tectonic history of the Grenville Province. The only known post-Flinton intrusive rocks are granitic pegmatite sills and dykes, present in areas of mid-amphibolite grade metamorphism south and southwest of the study area.

DESCRIPTION OF THE ROCK UNITS

Volcanic rocks

The volcanic rocks of the Tudor formation at the Addington Mine and the Ore Chimney Mine are tholeiitic basalt and basaltic andesite. They are fine to medium-grained, massive to foliated amphibolite, composed mainly of hornblende and plagioclase with minor quartz. Accessory minerals include epidote, biotite, garnet, cumingtonite, pyrite, magnetite, tourmaline and carbonates. Plagioclase is slightly to moderately altered to sericite. The biotite content of the volcanics increases sharply near the contact (<50 cm) with the overlying OCF. Felsic lapilli-tuff and breccia, although present, are a minor component (<1%) of the volcanic succession at these two localities. Rare biotite schist layers within the amphibolites range in thickness from 30 cm at the Addington Mine up to four metres at the Ore Chimney Mine.

At the Addington Mine, the amphibolite immediately adjacent to the contact with the OCF may contain up to 30% tourmaline. Sulphide-free calcite veinlets up to two millimetres wide are common. The

amount of tourmaline and the frequency of calcite veinlets decrease as the distance from the contact with the OCF increases. Actinolite, although rare, locally constitutes 30% of the rocks at Addington Mine.

The volcanic rocks of the Kashwakamak formation underlie the OCF at Harlowe. They are calc-alkaline basaltic andesite flows, andesite and dacite tuff and lapilli-tuff. These intermediate to felsic volcanics are composed of plagioclase, quartz, biotite and hornblende with accessory muscovite, epidote, chlorite, alkali feldspar and tourmaline (the latter occurring in fractures).

Ore Chimney Formation

Where Flinton Group sediments overlie mafic to intermediate volcanic rocks they are separated from the underlying rocks by a distinctive stratum of black schist. Where seen, the contact between the OCF and the underlying volcanics is sharp (Plate 1c). This contact is best exposed one kilometre southeast of the village of Harlowe (Fig. 1), and can be inferred within few centimetres at the Ore Chimney Mine. This massive to poorly layered rock unit is nowhere more than 10 m thick, but crops out intermittently over 40 km along strike and is typically composed of alternating layers of garnet-free and garnet-bearing biotite schist (Plate 1d), muscovite-biotite schist, hornblende-biotite schist and hornblende schist. These layers are lenticular and cannot be followed for more than few metres. Southeast of Harlowe, where the Ore Chimney Formation is well exposed, quartzite layers and quartz pebble-rich layers 10 to 20 cm thick were found within it (Plate 1b). The OCF typically contains coarse porphyroblasts of garnet and less commonly staurolite, kyanite, epidote and/or hornblende in a fine- to medium-grained, granoblastic matrix of quartz, plagioclase and abundant

P L A T E 1

- (a) Hematitic laminae in cross-bedded quartzite of the Bishop Corners Formation, Ore Chimney Mine (UTM 18298601). Lens cap is 6 cm in diameter.
- (b) Quartz-pebble-rich layer, Ore Chimney Formation, Harlowe (UTM 18360620).
- (c) Metamorphosed pillow lava typical of flows near the top of Tudor formation, Highway 41 near Bishop Corners (UTM 18279614). Note concentric zones of varioles.
- (d) Poorly layered garnet-bearing biotite schist of the Ore Chimney Formation, Ore Chimney Mine (UTM 18297599). Arrows: garnet porphyroblasts.
- (e) Contact between the Ore Chimney Formation (OCF) and underlying intermediate metavolcanic flow of the Kashwakamak formation (KWF), Harlowe (UTM 18360620). Drill hole (sample 31, at left) is 3 cm in diameter.

biotite. Magnetite is present with or without hematite; pyrite and chalcopyrite are also found in places. Accessory minerals include chlorite, apatite, tourmaline, and titanite (Harnois and Moore, 1985). Plagioclase is moderately to strongly altered to sericite. The OCF at Addington Mine, unlike other localities where this rock unit has been examined, contains 0.5 to 2 mm wide sulphide-free calcite veinlets which are erratically distributed and may compose up to 5% of the rock. At localities other than Addington Mine, the OCF has low tourmaline, carbonate and sulphide contents.

Bishop Corners Formation

The Bishop Corners Formation is generally composed of a 15 m thick basal fine grained quartzite, overlain successively by a conglomerate at least 60 m thick and a 20-100 m thick psammitic unit. At the Ore Chimney Mine, a five metre thick layer of magnetite-bearing muscovite-quartz schist, typically containing small flattened clasts of quartz, quartzite and mica schist (rarely staurolite-bearing), lies between the Ore Chimney Formation and the quartzite. At Reid Lakes, the basal unit of the Bishop Corners Formation is an epidote-bearing, feldspathic muscovite schist.

The quartzite is light grey or white and exhibits cross-bedding throughout, marked by hematitic laminae (Plate 1a). Abruptly overlying the quartzite is an oligomictic conglomerate comprising a clast-supported framework mainly of quartzite pebbles and cobbles, with a hematitic muscovite-quartz schist matrix. The conglomerate is overlain by quartzofeldspathic pebbly psammite, that locally contains granitic and felsic volcanic pebbles, in addition to the predominant quartzite and quartz.

Plutonic rocks

The three major plutons within the limits of Figure 1 are the

Northbrook and Elzevir batholiths (granodiorite, tonalite, minor granite), and the Mazinaw Lake granite (granite, granite porphyry). Only the Northbrook batholith, on which lies the Bishop Corners Formation, was analyzed in this study. The rocks of this batholith are uniformly medium to coarse-grained, essentially granoblastic but showing relict igneous textures in thin section. The mode (Moore and Morton, 1986) is relatively uniform, being typically oligoclase (50%), quartz (25%), microcline (10%), biotite (5%), hornblende (3%), and epidote (1%), with accessory titanite, allanite, zircon, and magnetite. The pluton becomes finer grained within 10 to 20 m of the contact with the volcanics, where it typically contains abundant lenticular inclusions of amphibolite.

DESCRIPTION AND LOCATION OF THE SAMPLE PROFILES

Five profiles from four localities (Addington Mine, Ore Chimney Mine, Harlowe, Reid Lakes; see Fig. 1) were sampled perpendicular to strike. Detailed sample locality maps are given in Appendix I.

Profiles 1 & 2

These profiles are cores from two diamond drill holes (profile 1: DDH 81-6, profile 2: DDH 82-3) from the Addington Mine property. Both profiles (DDH 81-6: UTM 18275531, DDH 82-3: UTM 18277539) penetrate the OCF, which hosts the ore zone, from the Bishop Corners Formation to the basaltic volcanics of the Tudor Formation (Universal Transverse Mercator grid references are to the collar locality of the drill holes, and to the point of intersection of the surface sample profiles - see below - with the unconformity).

Profile 3

The OCF and associated rocks are well exposed on the Ore Chimney Mine property and the sampled profile (UTM 18298602) intersects the contact Tudor formation-Ore Chimney Formation in a pit 160 m

Figure 2. Geological map of the Ore Chimney Mine area (modified from Moore and Morton, 1986). Dotted lines: mineralized zone projected to surface.

northeast of the mine shaft. The gold- and sulphide-bearing zone is hosted by a four metre-thick biotite schist layer in the Tudor formation, 30 m stratigraphically below the OCF (Fig. 2) and parallel to the base of the Flinton Group. None of the samples analysed in this study is from the mineralized zone.

Profile 4

This profile is a composite profile (UTM 18360620) sampled about one kilometre southeast of the village of Harlowe. This is one of the best exposures of the OCF and the only place where the contact between this formation and the underlying volcanics was seen. No sample of the Bishop Corners Formation from this locality was analysed.

Profile 5

Here the OCF is absent and the Bishop Corners Formation sediments overlie a thin layer (1.3 m thick) of amphibolite that separates them from the Northbrook batholith (UTM 18306586).

GEOCHEMISTRY

Analytical techniques

Major elements, Ba, Cr, Nb, Ni, Rb, Sr, Y, Zn and Zr were determined by X-ray fluorescence; Co, Cs, Hf, Sc, Th, U, La, Sm, Eu, Yb and Lu by instrumental neutron activation analysis (INAA, Muecke, 1980); CO₂, H₂O and S by volatilization and non-dispersive infrared absorptiometry (Bouvier and Abbey, 1980); ferrous iron by a modified cold Wilson method combined with the use of a Teflon-lined steel bomb for the staurolite-bearing samples (Johnson and Maxwell, 1981); Au by flameless atomic absorption spectroscopy (Culver, 1975); Li by atomic absorption using a calibration curve made up of natural standards; As, Ga and Sb by direct current plasma atomic emission

TABLE 2: REPRESENTATIVE ANALYSES OF ROCKS FROM THE FLINTON-HARLOWE AREA

Sample No	Ore Chimney Formation						Bishop Corners Formation				
	Addington Mine		Ore Chimney Mine			Harlowe		Ore Chimney Mine Reid Lakes			
	-69-	-90-	-25-	-108-	-109-	-3-	-4-	-26-	-34-	-133-	-54-
SiO ₂	48.13	44.71	52.63	62.29	53.23	67.00	67.68	61.27	78.29	93.18	66.71
Al ₂ O ₃	15.66	17.39	15.67	12.59	18.65	12.66	16.35	22.11	7.76	3.27	15.61
Fe ₂ O ₃	1.39	0.98	3.30	1.64	7.99	1.52	0.75	0.81	4.12	0.83	1.45
FeO	10.93	8.59	7.27	11.20	5.34	8.14	3.53	4.55	2.43	0.35	1.80
MgO	7.06	6.34	5.12	2.32	2.32	2.62	2.57	4.83	2.29	0.46	2.67
CaO	4.44	10.00	6.08	2.22	2.06	1.70	1.56	0.74	0.19	0.35	3.37
Na ₂ O	0.47	1.09	0.68	0.80	0.96	0.59	0.99	0.77	0.22	--	1.29
K ₂ O	4.52	3.08	4.46	3.67	5.50	2.91	4.36	3.05	1.22	0.48	3.58
TiO ₂	1.65	0.93	0.87	0.39	1.00	0.69	0.50	0.74	0.95	0.21	0.43
P ₂ O ₅	0.09	--	0.20	0.13	0.40	0.21	0.25	0.21	0.17	0.08	0.10
MnO	0.20	0.18	0.19	0.08	0.09	0.09	0.04	0.08	0.06	0.01	0.05
S	0.13	0.23	0.20	--	0.25	0.02	--	--	0.01	--	--
CO ₂ ^T	0.70	3.50	1.20	0.50	--	--	0.10	--	0.10	--	0.50
H ₂ O ^T	2.70	2.00	2.20	2.60	3.90	1.60	2.20	1.50	2.00	0.40	1.60
TOTAL	98.07	99.02	99.89	100.43	101.69	99.75	100.88	100.66	99.81	99.62	99.16
Ag	--	--	--	3	3	3	--	3	--	n.d.	--
As	30	400	--	10	1	--	--	--	--	n.d.	<1
Au (ppb)	16	22	44	--	--	<12	<12	--	--	n.d.	<12
Ba	826	349	390	219	434	548	848	477	239	n.d.	549
Co	68	63	34	15	36	13	13	22	25	n.d.	8
Cr	568	197	96	98	105	163	72	164	161	34	81
Cs	361	91	4.4	2.8	3.6	3.9	3.9	2.5	1.6	n.d.	n.d.
Cu	19	31	114	3	2	84	14	4	30	n.d.	16
Ga	28	23	25	n.d.	n.d.	19	26	16	17	n.d.	25
Hf	2.6	0.5	4	0.7	2.1	10	12.4	8.4	20	n.d.	n.d.
Li	23	n.d.	27	22	23	21	18	31	18	n.d.	31
Nb	<5	--	--	--	<5	<5	8	5	9	<5	8
Ni	228	40	17	25	38	975	39	42	54	--	10
Pb	5	6	4	4	4	4	3	2	--	n.d.	2
Rb	142	58	131	91	113	87	78	74	36	11	90
Sb	--	--	2	--	--	2	2	1	1	n.d.	--
Sc	51	35	27	15	30	14	6	17	11	n.d.	n.d.
Sr	81	210	283	152	145	75	97	181	82	80	181
Th	--	<0.5	5.2	0.6	1.6	13	26	6.4	48	n.d.	n.d.
U	1.4	0.3	1.2	0.6	0.8	18	8.8	6	12	n.d.	n.d.
V	n.d.	n.d.	296	<100	--	n.d.	117	n.d.	<100	7	<100
Y	28	22	24	38	11	45	17	13	29	20	9
Zn	93	56	129	76	61	348	111	253	151	27	32
Zr	95	48	57	23	60	127	171	129	267	85	152
La	3.36	1.72	6.55	5.70	5.74	24.46	23.63	9.20	4.97	n.d.	16.90
Sm	2.70	n.d.	4.20	3.36	2.46	9.39	6.70	3.46	2.77	n.d.	2.27
Eu	1.09	1.36	1.04	1.45	0.88	1.87	1.25	0.81	1.13	n.d.	1.28
Yb	2.23	1.41	2.37	3.30	1.75	4.43	1.80	0.85	3.06	n.d.	0.40
Lu	0.46	0.30	0.49	0.39	0.26	0.77	0.34	0.20	0.77	n.d.	n.d.

Major elements are in weight per cent. Trace elements are in parts per million (ppm) unless otherwise stated. --: not detected. n.d.: not determined. CO₂^T is total carbon as CO₂. H₂O^T is total water.

TABLE 3: WEIGHTED MEANS OF CHEMICAL DATA FOR ROCKS FROM THE FLINTON-HARLOWE AREA

	-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-
	R_w	R_w	R_w	R_w	R_w	R_w	R_w	R_w	R_w	R_w
	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD
SiO ₂	49.07	4.2	52.76	3.5	64.41	7.2	50.38	4.9	53.27	4.7
Al ₂ O ₃	16.71	2.6	16.26	1.2	16.43	1.4	17.79	1.2	17.13	2.1
FeO	11.89	3.2	8.642	2.1	3.93	2.6	11.39	2.7	8.37	2.2
(FeO ^T)	(13.92)	3.5	(11.98)	1.9	(4.88)	2.6	(13.13)	3.3	(11.70)	1.2
MgO	7.55	1.9	5.17	0.9	5.41	2.4	6.32	1.2	4.51	1.5
CaO	10.38	2.4	8.68	1.4	4.62	2.4	5.33	1.9	5.77	2.3
MnO	2.28	1.1	2.74	0.7	3.01	2.2	0.80	0.8	0.85	0.3
K ₂ O	0.34	0.4	0.82	1.2	2.22	1.5	3.82	1.2	5.04	0.6
TiO ₂	1.32	0.5	0.91	0.2	0.61	0.4	1.46	0.2	0.97	0.2
P ₂ O ₅	—	n.d.	0.15	.07	0.23	.25	0.07	.07	0.19	.10
H ₂ O	0.20	.05	0.19	.05	0.08	.04	0.21	.04	0.19	.06
TOTAL	100.00		100.00		100.00		100.00		100.00	
Ag	—	n.d.	—	n.d.	—	n.d.	—	n.d.	—	n.d.
As	4	46	<1	n.d.	—	n.d.	—	n.d.	—	n.d.
Bi	80	61	194	202	13	9.8	17	1872	<12	n.d.
Co	46	29	36	7	16	12	47	13	35	11
Cr	135	141	77	36	120	91	225	173	99	4
Cs	6	27	1	1.7	2	1.4	126	177	5	1.5
Cu	41	165	59	42	23	30	17	21	3	156
Eu	26	8	25	2	21	3	25	4	25	1
Hf	2	0.7	3	1.5	9	3.9	3	1.3	3	1.5
Li	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	25	6	25	4
Nb	—	n.d.	—	n.d.	—	n.d.	—	n.d.	—	n.d.
NI	45	41	19	12	35	39	61	73	26	11
Pb	3	36	3	3.1	3	2.7	4	6.9	4	0.6
Rb	3	12	15	32	53	35	90	72	127	17
Sb	—	n.d.	—	n.d.	—	n.d.	—	n.d.	—	n.d.
Sc	48	9	34	5	13	6.8	47	12	50	6
Sr	115	75	258	112	216	236	115	66	194	93
Th	—	n.d.	—	n.d.	—	n.d.	—	n.d.	—	n.d.
U	—	n.d.	—	n.d.	—	n.d.	—	n.d.	—	n.d.
V	37	12	27	5	22	7	28	12	22	8
Y	87	31	111	22	80	71	72	24	99	40
Zn	63	29	55	9	150	35	81	39	58	14
Zr	—	n.d.	—	n.d.	—	n.d.	—	n.d.	—	n.d.

TABLE 3 (continued)

	La	1.8	1.1	5.2	2.4	32.9	16	2.0	1.2	6.2	1.3	15.9	17	55.3	20	8.2	7.2	21.4	11	23.4	3.5
La	0.45	0.17	1.59	0.87	14.04	9.03	0.74	0.32	1.61	0.32	4.59	4.59	7.59	1.27	1.42	1.24	25.04	11.47	25.57	12.14	
Ti/Zr	129	48	102	19	25	11	120	26	102	4	26	28	17	2	25	11	17	1	17	1	
Zr/Y	1.67	0.51	2.31	0.33	7.12	2.75	2.56	1.41	2.53	1.44	4.92	2.73	12.6	4.20	7.91	2.47	16.56	4.24	11.73	0.91	
Me/Y	<0.10	n.d.	<0.10	n.d.	0.25	0.16	<0.10	n.d.	<0.10	n.d.	0.24	0.13	0.23	0.10	0.16	0.12	0.95	0.32	0.69	0.06	
OXIDRATIO	17	8	28	9	15	27	13	4	29	18	20	7	16	4	60	10	46	7	23	5	
ALURATIO	7	412	16	17	41	33	74	12	79	3	70	12	81	20	71	19	65	8	17	2	
K ₂ O/Na ₂ O	0.11	0.30	0.25	0.67	0.56	3.20	5.04	3.31	5.82	1.81	3.33	2.76	5.83	23.44	3.58	2.41	2.76	1.02	0.30	0.04	
K ₂ O/CaO	0.03	0.04	0.09	0.18	0.66	0.61	0.73	0.83	0.83	0.73	1.71	1.16	1.48	0.58	1.27	5.09	0.98	0.45	0.34	0.18	
CaO/Na ₂ O	4.73	1.99	3.07	2.41	1.80	5.50	6.92	4.47	8.06	3.05	2.44	1.53	3.31	18.43	1.28	0.67	2.54	0.22	0.58	0.18	
K/Rb	>1000	n.d.	>1000	n.d.	n.d.	n.d.	333	80	337	44	323	70	325	53	308	91	351	35	340	34	
Ba/Rb	>1000	n.d.	>1000	n.d.	n.d.	n.d.	6.35	1.37	3.73	1.25	7.51	3.36	4.97	1.72	6.78	3.09	6.88	0.95	13.79	2.85	

TABLE 4: WEIGHTED MEANS OF VOLATILE CONTENTS OF ROCKS FROM THE FLINTON-HARLOWE AREA

	-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-
n	18	19	14	20	7	8	4	6	4	4
Σ _i	Σ _i	Σ _i	Σ _i	Σ _i	Σ _i	Σ _i	Σ _i	Σ _i	Σ _i	Σ _i
SD	SD	SD	SD	SD	SD	SD	SD	SD	SD	SD
S	0.13	1.02	0.01	0.03	—	0.30	0.36	0.01	0.14	—
CO ₂ T	1.97	1.18	0.48	0.75	0.24	0.60	0.31	1.63	1.28	1.28
H ₂ O	1.79	1.15	1.49	0.31	1.23	0.52	2.66	0.75	2.78	0.75

Table 3 and 4: Weighted means of chemical data for rocks of the Flinton-Harlowe area.

- (1) Amphibolite, Tudor formation, Addington Mine; REE based on 16 samples. (6) Sc Nist, Ore Chimney formation, Harlowe.
 (2) Amphibolite, Tudor formation, Ore Chimney Mine. (7) Quartzite, Bishop Corners formation, Addington Mine.
 (3) Intermediate to felsic metavolcanics, Kaskawakum formation, Harlowe. (8) Quartzite (2 samples) and conglomeratic muscovite schist (4 samples), Bishop Corners formation, Ore Chimney Mine.
 (4) Sc Nist, Ore Chimney formation, Addington Mine. (9) Feldspathic muscovite schist, Bishop Corners formation, Reid Lakes.
 (5) Sc Nist, Ore Chimney formation, Ore Chimney Mine. (10) Metagranite to metatuffite, Northbrook batholith, Reid Lakes.

Major elements are in weight per cent recalculated on a volatile-free basis. Trace elements are in parts per million (ppm) unless otherwise stated. $\bar{x}_i$: weighted mean; n: number of analyses averaged; SD: standard deviation, absolute value; (La/Yb)_N: chondrite-normalized ratio; ALURATIO = $(K_2O/(Na_2O+K_2O)) \times 100$ (molecular proportions); ALURATIO = $(Al_2O_3/(Al_2O_3+CaO+Na_2O)) \times 100$ (molecular proportions); OXIRATIO = $(Fe_2O_3/(Fe_2O_3+FeO)) \times 100$ (molecular proportions); S: sulphur; CO₂: total carbon as CO₂; H₂O: total water.

spectroscopy (DCP-AES); Ag, Cu, Pb and V by atomic absorption spectroscopy; and Sb by INAA or DCP-AES. The analytical procedures are described in detail in Appendix II.

Sampling

Typical samples of the volcanic and plutonic rocks were analysed (Tables 2,3 and 4); the average chemical compositions given in Tables 3 and 4 are believed to be representative of the overall chemical composition of their respective rock types (other analyses of these units are presented in Sethuraman and Moore, 1973 and Moore and Morton, 1986). Only the most pelitic layers of the OCF were analysed at each locality. The samples from the Bishop Corners Formation include quartzite, pebbly micaceous quartzite, and conglomerate, and may not be representative of the overall composition of this heterogeneous unit.

Results

Figures 3 to 6 and Tables 3 and 4 summarize the chemical results obtained in this study; in Figures 3 to 6, the sample chemistry is plotted against distance from the angular unconformity.

SiO₂ is slightly enriched in the OCF in profile 3, and variable in all other profiles. Only in profile 1 is Al₂O₃ concentrated in the sediments. CaO and Na₂O are substantially depleted in the OCF; K₂O is strongly enriched. P₂O₅ is marginally but consistently higher in the OCF, except in profile 3. The OXIRATIO ($[(2\text{Fe}_2\text{O}_3)/(2\text{Fe}_2\text{O}_3 + \text{FeO})] \times 100$; molecular proportions) becomes more variable, in rocks of profiles 1,3 and 4, as the unconformity is approached. The ACNRATIO ($[(\text{Al}_2\text{O}_3)/(\text{Al}_2\text{O}_3 + \text{CaO} + \text{Na}_2\text{O})] \times 100$; molecular proportions) is consistently larger in the sediments than in the underlying rocks. The OXIRATIO of the OCF is about the same as the underlying volcanics. The OXIRATIO of the Bishop Corners Formation

Figure 2. Chemical profile at Addington Mine. UNC: unconformity. VOLC: volcanic rocks of the Tudor formation. OCF: Ore Chimney Formation. BCF: quartzite of the Bishop Corners Formation. Major element concentrations are in weight per cent recalculated on a volatile-free basis.

Figure 4. Chemical profile at the Addington Mine. See caption to Figure 3 for explanation.

Figure 5. Chemical profile at Harlowe. UNC: unconformity. VOLC: intermediate to felsic volcanic rocks. OCF: Ore Chimney Formation. Star: average of four samples. Major elements are in weight percent recalculated on a volatile free basis.

Figure 6. Chemical profile at Ore Chimney Mine and Reid Lakes. NBK: Northbrook batholith. VOLC: volcanic rocks of the Tudor Formation. OCF: Ore Chimney Formation. BCF: Bishop Corners Formation. Square in profile 5: amphibolite layer. Star: average of three samples.

at Ore Chimney Mine and Reid Lakes is greater than the underlying OCF and plutonic rocks respectively. Fe-Mg-Al cation plots (Fig. 7) show that the OCF has the same or slightly higher $\text{Fe}+\text{Al}/\text{Fe}+\text{Mg}+\text{Al}$ ratio than the underlying volcanics.

The REE patterns of the OCF at Addington and Ore Chimney mines are nearly flat to LREE depleted (Fig. 8a) and HREE abundances are 10X to 30X chondrite. Typically, the OCF at Harlowe is LREE enriched and has a negative Eu anomaly. Trace elements, including REE, (Table 3) are closely comparable in the OCF and underlying rocks, although the $(\text{La}/\text{Yb})_N$ ratio of the OCF at Harlowe is much lower than the $(\text{La}/\text{Yb})_N$ of the underlying volcanics. Ba, Cr, Ni and Rb are significantly enriched in OCF, and Cu is depleted. The similarities between OCF and underlying rocks in a given profile, and differences between profiles, are particularly marked for Zr and the ratios: $(\text{La}/\text{Yb})_N$, Ti/Zr , Zr/Y and Nb/Y (Fig. 9; Table 3). Figure 10 shows that at each locality, the REE patterns of the OCF are closely similar to those of the immediately underlying volcanics.

The magnetite-bearing conglomeratic muscovite schist at the base of the Bishop Corners Formation (unit 4a, Fig. 2), lying between the quartzite and the OCF at Ore Chimney Mine, is chemically different from the quartzite in several respects. This schist has higher Fe:Al (Fig. 11), and higher Ti/Zr ratio (22-43) than the quartzite at Addington and Ore Chimney mines ($\text{Ti}/\text{Zr} = 14-24$). The muscovite schist contains dark, magnetite-bearing mica schist clasts for which there are no other likely protoliths than the OCF or the rare biotite schist layers within the basaltic volcanics. The absence of amphibolite clasts within unit 4a suggests that the basaltic rocks (and thus the interlayered sediments) did not survive weathering, which leaves the OCF as the only suitable protolith and im-

Figure 7. Fe-Mg-Al cation plots of the Ore Chimney Formation (dots) and of the underlying volcanic rocks (filled squares). ADM: Addington Mine. OCM: Ore Chimney Mine. HARL: Harlowe. Fields occupied by the volcanics has been drawn on the corresponding Ore Chimney Formation plot (dashed lines).

B). CO₂-rich Ore Chimney Formation samples:

Sample 23: 2.2% CO₂, 2.3% H₂O, 0.00% S.
 Sample 24: 3.4% CO₂, 2.0% H₂O, 0.00% S.
 Sample 70: 6.4% CO₂, 3.1% H₂O, 0.87% S.
 Sample 71: 2.9% CO₂, 2.0% H₂O, 0.03% S.
 Sample 90: 3.5% CO₂, 2.0% H₂O, 0.23% S.
 Sample 107: 2.1% CO₂, 3.1% H₂O, 0.07% S.
 Sample 118: 2.3% CO₂, 2.4% H₂O, 0.00% S.

Figure 8. Chondrite-normalized rare earth element patterns of rock from the Ore Chimney Formation. Filled symbols: Ore Chimney Mine. Stars: Harlowe. Other open symbols: Addington Mine.

A). Typical samples from Table 2.

plies that these clasts are oxidised OCF.

The Bishop Corners Formation is generally silica-enriched and depleted in Al_2O_3 , MgO and CaO with respect both to the volcanics and the OCF. At Reid Lakes, however, its composition closely reflects that of the underlying rocks of the Northbrook batholith, with respect to all constituents save Cr, CaO and alkali metals, and it plots close to the Northbrook batholith on the Fe-Mg-Al cation plot (Fig. 11); it is also more oxidized than the plutonic rocks. The Ti/Zr ratio of the Bishop Corners Formation is remarkably constant, ranging from 16 to 31, in the same range as that of the Northbrook batholith (Table 3) and of the nearby Elzevir pluton (Pride and Moore, 1983); it is distinct from that of the underlying volcanics (Table 3).

The water content of the OCF is typically in the range 2-3% (Table 4). The carbonate content of the OCF is extremely variable: the OCF rocks at Harlowe are almost CO_2 -free and at the Ore Chimney Mine their CO_2 content averages 1.28% (with a large standard deviation). At the Addington Mine the mean CO_2 content of the OCF rocks analysed is 0.31%, but some sections of the drill cores containing up to 5% calcite veinlets were not analysed, thus these analytical results are biased towards low CO_2 . At Ore Chimney Mine and Harlowe, the mean sulphur content of the OCF is very low (<0.01%). The sulphur and carbonate contents of the Bishop Corners Formation invariably low, and the water content rarely exceeds 2%.

The average major element composition of the Northbrook batholith (Table 3) is very close to the average of Pride and Moore (1983) for samples of this batholith and of the Elzevir batholith, the two main granitoid masses of the study area, with respect to major elements and Ba, Rb and Zr. However, its Cr content is high

Figure 2. Ti/Zr and $(La/Yb)_N$ VS ACNRATIO. Filled circles: OCF; squares: Bishop Corners Formation; open circles: underlying igneous rocks. ACNRATIO: $[Al_2O_3/(Al_2O_3+CaO+Na_2O)] \times 100$ (molecular proportions).

Figure 10. Chondrite-normalized REE patterns of the Ore Chimney Formation and underlying volcanics. OCF: Ore Chimney Formation. TDF: Tudor formation. KWF: Kashwakamak formation.

Figure 11. Fe-Mg-Al cation plot of the Bishop Corners Formation and Northbrook batholith. Diamonds: quartzite, Bishop Corners Formation, Addington Mine. Open triangle: magnetite-bearing muscovite schist, Bishop Corners Formation, Ore Chimney Mine. Filled triangle: quartzite, Bishop Corners Formation, Ore Chimney Mine. Star: feldspathic muscovite schist, Bishop Corners Formation, Reid Lakes. Stippled area: Northbrook batholith (4 samples), Reid Lakes. 1-5: average compositions of Proterozoic sedimentary rocks, see Table 5.

(Cr = 100 ppm; standard deviation = 15) compared to other batholiths of the Central Metasedimentary Belt, which have generally from 5 to 31 ppm Cr (Wu and Kerrich, 1986).

Figure 12 shows that the volcanic rocks are subalkaline and become more felsic from west to east, the volcanics at Addington and Ore Chimney mines being basaltic, whereas those at Harlowe are andesitic, a feature already noted by Sethuraman and Moore (1973) and Moore and Morton (1986). An increase in silica of the volcanics from west to east is associated with a decreasing content of iron, magnesium, calcium, and a decrease of the Ti/Zr ratio (Table 3). The Tudor formation is tholeiitic, with relatively flat REE patterns (slightly LREE-depleted at Addington Mine; Fig. 10). The Kashwakamak volcanics at Harlowe are calc-alkaline (Harnois and Moore, 1987), with typical strong LREE enrichment (Fig. 10).

DISCUSSION

Origin of the Ore Chimney Formation

It has been suggested that the OCF represents either a mafic metasediment (Moore and Thompson, 1980) or a shear zone alteration product. The Addington Mine deposit has been reported to occur in a shear zone at the contact between the Tudor mafic volcanics and the quartzite of the Bishop Corners Formation (Carter, 1984; Malczak *et al.*, 1985) which would negate the existence of the OCF as a sedimentary unit and imply that this gold deposit occurs in sheared and metasomatised equivalents of the metavolcanics as suggested by Harding (1944), Springer (1982) and Laing *et al.* (1987). Any hypothesis concerning the origin of the OCF must however account for the three following points:

1. The OCF is massive to poorly layered, and quartzite and quartz pebble-rich layers 10 to 20 cm thick were ob-

Figure 12. Zr/TiO_2 - Nb/Y plot of Tudor and Kashwakamak volcanic rocks. Filled diamonds: Tudor formation, Addington Mine. Filled squares: Tudor formation, Ore Chimney Mine. Filled circles: Kashwakamak formation. Field boundaries from Floyd and Winchester (1977).

served within this rock unit at Harlowe. There is no evidence suggesting that these layers have been tectonically emplaced. Similar layers occurring within the OCF on the Addington Mine property were reported by Young (1985). The presence of these layers, which do not occur in the Tudor formation, strongly supports a sedimentary origin (reworked residual or detrital) for the OCF. Furthermore, the presence in the basal Bishop Corners Formation of clasts resembling the OCF suggests that the OCF was reworked during Flinton Group deposition, and thus must have been present at that time.

2.- The OCF on the Ore Chimney Mine property is deformed into upright, steeply plunging isoclinal folds. It thickens in the hinges of the folds (Fig. 2), and only one fabric, parallel to axial surfaces and concordant with the regional foliation, was observed in the limbs and the hinges of the folds. If the OCF is a folded major shear zone, these observations require a) that the shearing and K-metasomatism which produced the biotite schist from a mafic protolith must have occurred along a zone coincident with the Tudor-Flinton contact; b) that the shear zone was subhorizontal at the onset of D_1 ; and c) that any resulting fabric was completely obliterated during D_1 . This coincidence is unlikely (particularly the third requirement), thus the folding of the OCF and the absence of a folded fabric argue against a shear zone origin.

3.- Titanium, zirconium and yttrium are considered to be the least mobile elements under most conditions of alteration (Winchester and Floyd, 1977; Floyd and Winchester,

1978; Finlow-Bates and Stumpfl, 1981). The OCF rocks analysed, which show no evidence of intense carbonatization, epidotization, silicification, sericitization or tourmalinization, have Ti/Zr and Zr/Y ratios similar to those of the underlying volcanics (Table 3). This is consistent either with a metasomatic origin or with an origin as a mafic sediment, locally derived from the volcanics, if no significant separation of Ti, Zr and Y in surficial processes is assumed. The validity of this assumption is supported by the studies of Spencer (1966) and Il'ina *et al.* (1970) on the distribution of Ti and Zr in Phanerozoic sandstones, siltstones and shales. The significant difference between the Ti/Zr and Zr/Y ratios of the OCF and the overlying Bishop Corners Formation (Table 3) preclude that the OCF rocks are sheared and metasomatised equivalents of the Bishop Corners Formation. The only rocks in the area which can match the Ti/Zr and Zr/Y values of the OCF are the underlying volcanics, indicating that the OCF is derived from them.

In balance the hypothesis of origin as a mafic sediment accounts most satisfactorily for these three points. Such an origin does not preclude a local overprint of shearing and/or metasomatism after deposition.

Chemical changes during weathering, diagenesis and hydrothermal alteration

Processes which may change the chemical composition of rocks and sediments include weathering, diagenesis and hydrothermal alteration. The extent to which these processes may have influenced the chemical composition of the OCF warrants discussion.

Weathering

The intensity of the weathering which produced the OCF sediments from a mafic to intermediate volcanic protolith is not accurately known. However, the red bed character of the hematite- and magnetite-bearing Bishop Corners Formation sediments and the lack of unstable clasts in these sediments suggest that the weathering was relatively intense and proceeded under a warm climate, either dry or humid (Moore and Thompson, 1980; Walker, 1974). The chemical trends of the pre-Flinton volcanics during weathering can be inferred with respect to some elements by analogy with Precambrian and Phanerozoic paleosols and other weathered residues (Button and Tyler, 1981; Colman, 1982; Schau and Henderson, 1983; Nesbitt and Young, 1984; Retallack, 1986; Kronberg *et al.*, 1987). During the weathering of granite and basalt, SiO_2 , MgO , CaO and Na_2O are leached; Al_2O_3 , TiO_2 and Zr remain in the system and accumulate in the residue, so that weathering products have higher ACNRATIO than their source rocks (Harnois, *in press*). Because ferric iron is much less soluble than ferrous iron, the proportion of iron remaining in the residue is partly a function of the redox conditions of the system. K_2O is leached in some paleosols and enriched in others; this K_2O enrichment is common to most Precambrian paleosols and is possibly a diagenetic feature (Retallack, 1986). The ACNRATIO and K_2O content of the OCF are higher than those of the underlying volcanics (Fig. 9), consistent with the hypothesis that the OCF is a sediment derived from them.

Diagenesis

Only limited data are available on bulk chemical changes of argillaceous and clastic sediments during diagenesis (Ernst, 1970; Gieskes, 1975; Sayles and Manheim, 1975; Nesbitt, 1980). Hesse

(1986) in a recent review of this topic points out that the extent of these chemical changes are partly a function of the rate of sedimentation and the mode of pore-water circulation, which are unknown in this specific case. Thus, only general trends for some elements can be inferred. Generally, during diagenesis, the K content of the sediments increases significantly; Na and Mg increase slightly; and there is a slight decrease in Ca and Sr. Mn appears to be mobile only under highly reducing conditions (Colley *et al.*, 1984).

The Handbook of Geochemistry (Heier and Billings, 1970) gives the following population statistics for K_2O (in weight per cent) in sedimentary rocks: argillaceous sediments, mean (90 samples) = 2.81%, range = 0.49-4.34%; shales, mean (1433 samples) = 2.45%, range = 0.01-8.51%. Although the K_2O content of the OCF (weighted mean on a volatile-free basis = 3.96%, standard deviation = 1.1; Table 5) is high, its value is still in the range of K_2O contents reported for the shales and argillaceous sediments.

Hydrothermal alteration

The high K_2O and low Na_2O and CaO contents of the OCF rocks, compared to the volcanics (Figs. 3-6) are consistent with those of an isochemically metamorphosed argillaceous sediment with or without a superimposed potassic alteration. Although the chemical composition of the OCF, with respect to major and most trace elements, is compatible with that of an argillaceous sediment, the high Ba and Cs contents of the OCF at Addington Mine (621 ppm Ba and 126 ppm Cs) compared to those of the underlying metavolcanics (80 ppm Ba and 6 ppm Cs; Table 3), suggest that these rocks were altered. The high tourmaline content associated with the sulphide- and gold-bearing veins, and the presence of numerous small carbonate veins, in the

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Micro-D

OCF at Addington Mine also suggest that these rocks were affected by hydrothermal alteration. In contrast, there are no such chemical anomalies or alteration at Ore Chimney Mine.

CO₂ content of the amphibolite (TDF) and biotite schist (OCF) at the Addington Mine, and of the OCF biotite schist at the Ore Chimney Mine (Table 3) may be of sedimentary origin but alternatively suggests that these rocks were weakly carbonatized. This suggestion is substantiated by the presence of numerous small calcite veinlets in the amphibolite and biotite schist at Addington Mine, and indicates that carbonatization is not restricted to the OCF, nor is it restricted to the biotite schist lithology. Staurolite, kyanite, garnet and hornblende do not show evidence of reaction textures with carbonate, indicating that any carbonatization occurred before peak metamorphism.

Potassic alteration is a common feature of gold deposits occurring in Archean greenstone belts. Such an alteration is typically associated with intense carbonatization, an increase of K and a decrease of Na as the alteration proceeds (Kerrick, 1983). However, Roberts (1987) noted that significant exceptions to this decrease in Na do exist. Although the OCF, as a unit, contains more K₂O than the adjacent rock units (Figs. 3-6), the OCF rock analyses show no significant correlation between K₂O and CO₂. The main difference between the OCF rocks at the Addington Mine and Ore Chimney Mine properties is that the OCF rocks of the former are mineralized and carbonatized, and those of the latter are only carbonatized. There are no significant differences between the K₂O/Na₂O, K₂O/CaO, CaO/Na₂O and K/Rb ratios of the OCF at Addington and Ore Chimney mines (Table 3). The coherence of these ratios suggests that the mineralizing process increased the As, Au, B, Ba, Cs, S and carbo-

nate contents of the OCF rocks at Addington Mine, without changing significantly the K_2O content of these rocks. It also suggests that potassic alteration associated with mineralization was very weak or absent. The large values of the standard deviation of the K_2O/CaO ratio may however have been caused by a slight mobility of Ca or K or both during metamorphism and/or hydrothermal alteration.

Another possible explanation for the high K_2O content of the OCF is that this entire formation, over its 40 km strike length, is a potassium-metasomatised rock unit. This hypothesis implies that, at mineralized as well as unmineralized localities as much as 8 km apart, a common potassium-rich fluid flowing through a huge plumbing system represented by the regional unconformity produced rocks with similar K/Rb, K_2O/Na_2O , K_2O/CaO , and CaO/Na_2O ratios from similar protoliths. It also implies that this hypothetical K-metasomatic event is not related to gold mineralization. Furthermore, as shown previously, the K_2O content of the OCF is in the range of K_2O content of argillaceous sediments, and there is no need to invoke K-metasomatism to explain the "high" potassium content of the OCF. Because staurolite, kyanite, garnet and hornblende do not show evidence of reaction texture with biotite (i.e. biotitization), this K-metasomatic event, if it ever occurred, took place before peak metamorphism.

The only convincing evidence of K-metasomatism is of very local scale. The biotite content of the amphibolite underlying the OCF increases sharply within 0.5 m from the contact between the two rock units, suggesting that, at some time before peak metamorphism, potassium moved from the OCF to the underlying volcanic rocks over a short distance. This increase in potassium may however be simply a result of K-enrichment of the volcanic rocks most exposed to paleo-

weathering.

Hynes (1980) and Murphy and Hynes (1986) showed that Ti, Y and Zr may be mobile during carbonatization. The lack of any significant correlation between CO_2 and these elements, the small range in concentrations of Ti, Y and Zr, and the coherence of the ratios Ti/Zr and Zr/Y indicates that these elements remained relatively immobile in the OCF. The $(\text{La/Yb})_N$ ratio of the OCF samples varies from one locality to another, but samples from a given locality do not show greater variation in $(\text{La/Yb})_N$ ratio than do the underlying volcanics, if the standard deviation of each group of samples is expressed as percentage of the weighted mean value reported. REE patterns of all OCF samples having more than 2 wt % CO_2 have been drawn on a chondrite-normalized plot (Fig. 8b). There is no selective enrichment of LREE or HREE with respect to MREE and, except for the positive Eu anomaly of samples 71 and 90, the shape of the patterns is not significantly different from those of the CO_2 -poor OCF rocks (Fig. 8a). The strong positive Eu anomaly of samples 71 and 90, from Addington Mine, may be a result of alteration by a reduced hydrothermal fluid (Kerrick and Fryer, 1979). The similar shape of the REE patterns of the CO_2 -rich and CO_2 -poor samples indicates however that carbonatization simply diluted the REE.

Bulk Chemical Composition of the Ore Chimney Formation

In Table 5, the OCF is compared chemically with average compositions of some other Proterozoic sedimentary populations, which collectively should approximate an "average" (tonalitic to granodioritic) continental crustal source. The tillites are included because they represent essentially unweathered detritus, as indicated by their high Na_2O and low ACNRATIO relative to the clastic assemblages of columns 1 and 4 (Table 5). The Carmichael (1982; column 3) ave-

TABLE 5
AVERAGE COMPOSITIONS OF PROTEROZOIC SEDIMENTARY ROCKS

	-1- n=12	-2- n=15	-3- n=68	-4- n=277	-5- n=35	SD
Weight %						
SiO ₂	70.42	68.94	61.96	63.45	54.30	9.5
Al ₂ O ₃	14.59	15.59	16.68	18.00	17.55	3.2
FeO	5.53	5.77	7.03	6.70	12.04	3.9
MgO	2.12	2.81	3.49	2.79	5.30	2.2
CaO	1.71	1.41	3.37	2.36	4.76	3.0
Na ₂ O	1.81	4.63	2.21	1.72	0.82	0.4
K ₂ O	3.22	1.99	4.11	3.87	3.86	1.1
TiO ₂	0.60	0.67	0.83	0.84	1.17	0.6
P ₂ O ₅	n.d.	0.12	0.22	0.17	0.13	.18
MnO	n.d.	0.07	0.11	0.10	0.17	.09
TOTAL	100.00	100.00	100.00	100.00	100.00	
ACNRATIO	72	62	64	73	65	12
ALKRATIO	54	22	55	60	76	11

(1): Average of Proterozoic clastic sedimentary assemblages, McLennan (1982).

(2): Average of tillite matrix from the Gowganda Formation (Huronian Supergroup, Proterozoic), McLennan *et al.* (1979).

(3): Average tillite, Carmichael (1982, Table 87).

(4): Average shale, Carmichael (1982, Table 88).

(5): Weighted mean, Ore Chimney Formation, study area.

n: Number of samples averaged.

n.d.: Not determined.

SD: Standard deviation, absolute value.

ACNRATIO: $[Al_2O_3 / (Al_2O_3 + CaO + Na_2O)] \times 100$ (molecular proportions).

ALKRATIO: $[K_2O / (Na_2O + K_2O)] \times 100$ (molecular proportions).

rage has high K_2O which suggests K-fixation by these fine grained sediments. The OCF has lower SiO_2 and higher FeO^T , MgO and TiO_2 than the other sedimentary rocks, as would be expected of a sediment derived from a weathered mafic rock source.

Chemical relations of the OCF to the volcanic rocks

The spatial variations of silica, iron, magnesium, calcium, titanium, and zirconium of the OCF sediments correspond closely to those of the underlying volcanic rocks. REE, Ga, Hf, Nb, Ni, Sc, and Th also show this correlation well (Fig. 10; Table 3).

The $(La/Yb)_N$ ratio of the volcanic rocks increases from west to east, being 0.45 at Addington Mine, 1.59 at Ore Chimney Mine, and 13.4 at Harlowe (Table 3). The spatial variations of the REE abundances and of the $(La/Yb)_N$ ratio in the OCF sediments mimic those of the underlying volcanics (Figs. 9, 10), which range from 0.74 at the Addington Mine to 5.34 at Harlowe. Although quite variable, the $(La/Yb)_N$ ratio of the Bishop Corners Formation is definitely higher at Reid Lakes than elsewhere, and the REE abundances of the Formation are similar to those of the underlying Northbrook batholith (Table 3).

The fact that the chemistry of the OCF sediments so closely follows the chemistry of the underlying volcanics suggests that these sediments were very locally derived and were deposited in small independent basins. Transportation over a long distance and/or deposition in a large basin common to all sediments would have caused much better homogenization of the OCF.

The high $(La/Yb)_N$ and Nb/Y and the low Ti/Zr ratios of the Bishop Corners Formation (Table 3) indicate that a major proportion of these sediments are derived from a source having a granitic composition. Granitoid batholiths such as the Northbrook and Elzevir

plutons are a possible source of these sediments. In general, there are no evident spatial variations in the Bishop Corners samples analyzed, suggesting a broader provenance than for the OCF. At Reid Lakes however, the chemistry suggests local derivation of the Bishop Corners sediments, which is supported by their relatively immature, feldspathic character at that locality.

CONCLUSIONS

The presence of quartzite and quartz pebble-rich layers within the OCF (Young, 1985; this work) are evidence that this formation has a sedimentary origin. The source rock for the OCF sediments has been identified as the underlying volcanic rocks, particularly on the basis of REE abundances, Ti/Zr and Zr/Y ratios. The systematic spatial variations in the chemistry of the OCF closely mimic those of the immediately underlying volcanics and suggest that the OCF is very locally derived.

The chemistry of the OCF, especially the low Na_2O and CaO and high K_2O contents, is well explained by normal weathering and sedimentary processes and therefore there is no need to infer metasomatism, associated or not with metamorphism, and/or shearing-deformation processes to explain the presence of this biotite schist between the volcanics and the quartzite.

The trace element ratios of the Bishop Corners Formation indicate that these sediments are derived from a source having a granitic composition. Granitoid batholiths such as the nearby Northbrook and Elzevir plutons are a possible source of these sediments, but only at Reid Lakes was evidence found of a very local source.

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CHAPTER III

GEOCHEMISTRY AND GENESIS OF TWO UNCONFORMITY-ASSOCIATED GOLD DEPOSITS AT THE BASE OF THE FLINTON GROUP, GRENVILLE PROVINCE, SOUTHEASTERN ONTARIO.

ABSTRACT

The Addington Mine and Ore Chimney Mine are Proterozoic gold-bearing quartz-carbonate vein deposits which occur in lower amphibolite facies metamorphic rocks, on and near a major regional unconformity.

The Ore Chimney deposit has a typical opaque mineral association of galena-sphalerite-pyrite-chalcopyrite-pyrrhotite-sulphosalt-ilmenite. The sulphosalt is a Ag-rich tetrahedrite. The vein system is hosted by a 4 m thick biotite schist enclosed by metabasaltic lava flows. The metavolcanic rocks are unconformably overlain successively by a 10 m thick metapelitic garnet-biotite schist (the Ore Chimney Formation) and a coarse siliciclastic succession (the Flinton Group). The Ore Chimney deposit occurs 30 m below the unconformity.

The Addington deposit has a typical opaque mineral assemblage of arsenopyrite-pyrite-chalcopyrite-pyrrhotite-ilmenite. This deposit is hosted by the Ore Chimney Formation and is located 8 km along strike from the Ore Chimney Mine.

Arsenopyrite geothermometry and sphalerite geobarometry yield temperature and pressure estimates ranging from 420 to 530°C and 0.35 to 0.59 GPa, respectively. Application of the garnet-biotite geothermometer to the biotite schist host of both deposits gives temperatures ranging from 475 to 535°C. Geochemical and field evidence suggest that vein formation and mineralization occurred during the main episode of metamorphism and deformation and that gold was deposited by metamorphic fluids. The mineralizing process was associated with weak carbonatization of the wall rock. Gold and base metals may have been remobilized from pre-existing concentrations.

INTRODUCTION

Gold deposits in the Grenville Province of southeastern Ontario are essentially restricted to a region of relatively low-grade metamorphism (Fig. 1) that is underlain by the largest volume of rocks of volcanic origin in the Central Metasedimentary Belt. Gold-quartz vein deposits constitute by far the most important and most abundant gold deposit type in this region. There are two major concentrations of deposits: in greenschist facies rocks around Madoc and in upper greenschist-lower amphibolite facies rocks of the Flinton-Fernleigh area (Figs. 1, 2).

The aim of this paper is to describe and geochemically characterize two deposits of this type, the Addington Mine and the Ore Chimney Mine, and to propose a genetic model for them. These two deposits were selected because they have greater proven tonnage and grade than other deposits of the group; the Addington Mine is a past producer. Availability of underground samples was also an important factor in the selection. During the summer of 1983, the Ore Chimney Mine was dewatered and retimbered to the 150-foot level, allowing sampling and examination of the vein system, which is not exposed on surface. Drill cores of the Addington Mine were available through a drilling program underway on this property at the time of field work.

Although various gold deposit associations are exhibited in both areas (see below), many deposits in the Flinton-Fernleigh area are strikingly associated with the base of the Flinton Group, a clastic metasedimentary succession that unconformably overlies the metavolcanic rocks (Fig. 2; Table 1). These are of particular interest because the unconformity is a widespread, readily-recognized exploration target. Most of these gold deposits were originally

Figure 1. Gold occurrences in the Grenville Province of south-eastern Ontario. Gold deposits are from Gordon (1977) and Malczak *et al.*, (1985). Metamorphic boundaries are modified from the metamorphic map of the Canadian Shield (Geological Survey of Canada, Map 1475A, 1978). The area of Figure 2 is outlined.

Figure 2. General geology of Anglesea, Barrie, Clarendon, Kaladar and Kennebec Townships, south-eastern Ontario (from Moore and Thompson, 1980). All rocks are metamorphosed; original lithology is indicated. Star: village; Fl: Flinton; Fe: Fernleigh. Solid circle: gold deposit; ADM: Addington Mine; OCM: Ore Chimney Mine; A: O'Donnell I; B: O'Donnell II; C: O'Donnell III; D: Kennefic; E: Ultimate Energy; F: Gold Base; G: Cobalt-Frontenac; H: Mill; I: Natto; J: Star; K: Big Dipper; L: Stead; M: Helena; N: Kashwakamak; O: Pay Rock; P: Dome; Q: Webber; R: Boerth; S: Cook; T: Ewing; U: Stone; V: Emery; W: International; X: Gough-Hardie; Y: Mazinaw Base Metal (see Table 1).

TABLE 1: GOLD DEPOSITS OF THE FLINTON-FERNEIGH AREA

GROUP	DEPOSIT	STATUS	TOWNSHIP	LOT	CONCESSION	HOST	MINERALOGY
I	(A) O'Donnell I	0	Anglesee	8	II	maf. volc.	apy, ccp, gn, sp, py, men, po
I	(B) O'Donnell II	0	Anglesee	7	III	maf. volc.	py, ccp
I	(C) O'Donnell III	0	Anglesee	6	III	maf. volc.	apy, py, gn, sp, ccp, men
I	(D) Kennecott	0	Anglesee	7	V	maf. volc.	apy
I	(E) Uitimate Energy	0	Anglesee	6	IV	sed., maf. volc.	py, apy, po, ccp
I	(F) Gold Base	0	Kennebec	30	V	maf. volc., marb.	py, ccp
I	(G) Cobalt-Frontenac	0	Barrie	13	I	Int. volc.	sp, py, po
I	(Q24) Ore Chimney Mine	PD	Barrie	35	I	maf. volc.	gn, sp, py, ccp, po, tth, ilm, mar, apy, co
II	(H) Mill	0	Barrie	36	II	dol.	tth, apy, py, ccp
II	(I) Netto	0	Barrie	30-32	III, IV	dol., maf. volc.	py, apy, tth, ccp, bart, sp
II	(J) Star Mine	PP	Barrie	24, 25	X	dol., dac. volc.	py, ccp, sch, tur, bart, po
II	(K) Big Dipper	P	Barrie	16	X	gran., dltc.	py, tur, meg, jas, bul
II	(L) Sreed	P	Barrie	25	VI	calc., dol.	sp, gn, py, ccp, tth, hem, cnn
II	(M) Helena	P	Barrie	20	VI	marb., gran.	py, ccp, po, sp
II	(N) Kashakamak	0	Barrie	14	VI	dol.	ccp, tth, tur, py, sp, gn
II	(O) Pay Rock	0	Barrie	16	I	dol.	?
II	(P) Dome	P	Kennebec	32	II	dol., maf. volc.	py, ccp, cc, gn, hem
II	(Q) Webber	P	Clarendon	28	IX	pgn., dol.	py, apy
II	(R) Boerth	P	Clarendon	29	IX	cl-sed., calc.	py, apy, tur, po, ccp
II	(S) Cook	0	Clarendon	23	IX	dior., marb.	apy
III	(T) Ewing	0	Kaladar	20	IV	sed., maf. volc.	po, py, tur
III	(U) Stone	0	Kaladar	25	V	sed., maf. volc.	apy, py, ccp, po, gn, sp
III	(Q24) Addington Mine	PP	Kaladar	24, 25	VI	sed., maf. volc.	apy, py, tur, ccp, ilm, po, bart, gn, sp, mar
III	(V) Emery	0	Kennebec	31	II, III	maf. volc., cl-sed.	py, apy, sp, gn
IV	(W) International	0	Barrie	8	IX	dol.	tth, sp, ccp, py, bul, jas, apy
IV	(X) Gough-Hardie	P	Barrie	3	IX	dol., cl-sed.	py, sp, apy, bul, ccp, tth, hem, tur
IV	(Y) Mazinaw Base Metal	0	Barrie	12	VIII	dol., cl-sed.	sp, tth, ccp, bul, py, apy, jas, bul

Group I, II, III and IV: see text. Deposits are keyed to Figure 2. O: occurrence; P: prospect; PD: prospect developed; PP: past-producer. maf. volc.: mafic metavolcanic; Int. volc.: intermediate metavolcanics; dac. volc.: dacitic metavolcanic; gran.: mafic granitic; dior.: mafic diorite; sed.: sedimentary; cl-sed.: clastic metasediments; pgn.: paragneiss; marb.: marble; calc.: calcitic marble; dol.: dolomitic marble. Mineralogy listed for each deposit is compiled from various sources, and all minerals do not necessarily occur in a single sample. apy: arsenopyrite; bart: bisulfite; bul: Boulangerite; ccp: chalcopyrite; co: cobaltite; cnn: cinnabar; gn: galena; hem: hematite; ilm: ilmenite; jas: jamesonite; meg: magnetite; mar: marcasite; men: meneghinite; po: pyrrhotite; py: pyrite; sp: sphalerite; tth: tetrahedrite; tur: tourmaline (Kretz, 1983). Compiled mainly from Matczak et al. (1985).

described by Harding (1944) and Meen (1944), and all of them were recently re-examined by Malczak *et al.* (1985). The most typical and most interesting deposits were remapped in detail by Flegg (1983; deposit OCM; Fig. 2 and Table 1), Young (1985; deposit ADM), Dillon (1985; deposits ADM and OCM), Barron (1985; deposits A, B, C, E, J, L, Q, R, X) and Moore and Morton (1986; deposit OCM). However, these studies were essentially descriptive and involved mapping and petrography, with very little chemistry. Limited mineral and whole rock chemical data for deposits ADM and OCM were provided by Harnois and Moore (1986), Laing (1986) and Laing *et al.* (1987). Carter (1981) provided fluid inclusion data for the Cu-Sb-Au-Ag deposits of the Lavant-Darling area, 20 km northeast of Clarendon Township (Figs. 1 and 2).

Metallogeny of the Grenville Province in southeastern Ontario has been reviewed and summarized by Sangster (1970), Sangster and Bourne (1982), Carter (1984) and Carter and Colvine (1985).

GENERAL GEOLOGY AND GEOCHRONOLOGY

The study area lies within the Elzevir terrane (or subzone IV) of the Central Metasedimentary Belt (Wynne-Edwards, 1972; Davidson, 1986) and is underlain by late Precambrian metavolcanic and metasedimentary rocks of the Grenville Supergroup, metasedimentary rocks of the Flinton Group and metagranitoid intrusive bodies (Fig. 2 and Table 2). The geology of the area has been described by Harding (1944), Meen (1944), Sethuraman and Moore (1973), Moore and Thompson (1980), Wolff (1982) and Moore and Morton (1986). All rock units of the area have been metamorphosed, but the degree of metamorphism and deformation is relatively low compared to most of the Grenville Province, as protoliths are readily identified, the prefix "meta" will hereafter be omitted in this chapter. The oldest rocks in the

TABLE 2
Table of Formations

F		
L	G	
I	R	Myer Cave Formation: Dolomitic marble, graphite metapelite, carbonate metaconglomerate.
N	O	
T	U	
O	P	Bishop Corners Formation: Quartzite, metapsammite, metaconglomerate.
N		
		minor unconformity (?)
		Ore Chimney Formation: Pelitic metasediments (biotite schist, garnet-biotite schist; muscovite-biotite schist, hornblende-biotite schist, hornblende schist).
		major unconformity
		Plutonic rocks: Metagranite to metatonalite batholiths.
		intrusive contact
G		
R		Metasediments: Marble, wacke, minor metamorphosed shallow intrusions.
E		
N		Mazinaw Lake formation:
V		Predominantly felsic to basaltic
I		metavolcanic rocks.
L		Minor epiclastic metasediments and
L		metamorphosed subvolcanic intrusions.
E		
S		
U		Metasediments: Wacke, tuff, marble.
P		
E		Tudor formation: Metabasalt flows, pillowed flows, flow and pillow breccia.
R		Minor metagabbroic intrusions.
G		Minor mafic interflow metasediments.
R		
O		
U		
P		

After Ayer (1979), Moore and Thompson (1980) and Moore and Morton (1986).

area are the volcanics of the Tudor formation (TDF; Hermon Group; Lumbers, 1967). They are tholeiitic basalts and minor intermediate pyroclastics (Sethuraman and Moore, 1973) which have been dated at 1279 ± 3 Ma by U-Pb isotopic method on zircons (Herman *et al.*, 1987). These are overlain successively by basaltic to felsic sub-alkaline volcanic rocks of the Mazinaw Lake formation (Ayer, 1979) and the Kashwakamak formation (Chapter I) and by sedimentary clastic and carbonate rocks with an abundance of small mafic to intermediate intrusions (Moore and Morton, 1986). This succession has been intruded by large granitoid plutonic bodies, of which the Elzevir batholith (Fig. 2) has been dated at 1240 ± 50 Ma by whole rock Rb-Sr and at 1226 ± 25 Ma by U-Pb isotopic method on zircons (Bell and Blenkinsop, 1980; Connelly, 1987). The volcanic rocks are unconformably overlain by the OCF, a thin pelitic sedimentary unit of local derivation (Moore and Thompson, 1980; Chapter II).

The Flinton Group (Thompson, 1972; Moore and Thompson, 1980) is a succession of clastic sediments that overlies the OCF with a minor unconformity (?) and the older rocks with major angular unconformity. The stratigraphic order established by these authors in the study area based on well-preserved crossbeds is reproduced, slightly modified, in Table 2.

Angular discordance between layering and contacts in pre-Flinton rock units and the base of the Flinton Group was invoked by Moore and Thompson (1980) to demonstrate the existence of at least one period of deformation before Flinton sedimentation. Xenoliths of volcanic rocks, with variably oriented hornblende schistosity and lineation, are found in relatively undeformed rocks of the Elzevir batholith, which is overlain by Flinton rocks. These relationships show that metamorphism as well as deformation preceded deposition of

the Flinton Group. However the polyphase deformation responsible for the major map pattern, and the regional metamorphic zonation, clearly postdate all units of the Flinton Group.

Thompson (1972) recognized four post-Flinton phases of deformation. Isoclinal synclines, in which the Flinton Group is preserved (Fig. 2), formed during D_1 and were refolded during the second phase of deformation (D_2) about axial surfaces with a northeast trend. D_1 and D_2 structures are warped by open D_3 folds with northwest-trending axial surfaces. This phase could be a late stage of D_2 , representing the time when the northwest-southeast compression, which formed the D_2 structures, bent the folds around the plutonic intrusions. Centimetre- to metre-scale folds and crenulation (D_4) in schistose rocks developed after the third phase of deformation.

Connelly (1985, 1987) suggested that the Flinton Group was tectonically emplaced into its present position, and thus that the supposed unconformity is a folded thrust plane. However, the close lithologic relationships cited by Moore and Thompson (1980) between pre-Flinton and Flinton rock units (supported by data of this study, Chapter II) preclude any major displacements along the base of the Flinton Group.

Only one period of regional metamorphism affected the sedimentary rocks of the Flinton Group. Metamorphic grade increased during D_1 , attained a maximum shortly before D_2 , remained high for some time, and, before D_3 , began to decrease. Metamorphic recrystallization had essentially ceased when D_4 occurred. Regional isograds thus transect the major structural trends (Thompson, 1972). The rocks described in this chapter are at lower amphibolite grade (staurolite zone, Fig. 1).

GOLD DEPOSITS OF THE FLINTON-FERNLEIGH AREA

The 27 known gold deposits of the Flinton-Fernleigh area (Fig. 2) occur within the volcanics and carbonate sediments of the Grenville Supergroup, within the OCF and in carbonate rocks in the lower part of the Flinton Group. The gold is contained in networks of concordant to subconcordant quartz and quartz-carbonate veins. The deposits are separable into four groups on the basis of their host rock lithology and stratigraphic position (Table I):

Group I Deposits (A-G and OCM)

The deposits of this group are mafic to intermediate volcanic-hosted. Deposits G and OCM occur close to the base of the Flinton Group. Chalcopyrite is abundant and antimony sulphosalts are rare. Arsenopyrite is abundant in deposits A, C, D and E. Some of these deposits (A, B, C, E, G, OCM) are reported by Malczak *et al.* (1985) to occur within shear zones.

Group II Deposits (H-S)

Deposits H to S are marble-hosted and occur in the pre-Flinton carbonate sediments. Antimony sulphosalts are common and arsenopyrite less abundant than in the volcanic-hosted deposits. All these deposits are associated with at least one mafic to felsic shallow intrusive body (generally a sill or dyke) or are close to the contact with the underlying volcanics. Approximately 4170 grams of gold were produced by the Star Mine (deposit J) which is the only past producer of this group.

Group III Deposits (T-V and ADM)

These deposits are either hosted by the OCF (deposits T, U and ADM) which is overlain by the Bishop Corners Formation (Flinton Group) or occur in an analogous stratigraphic position (deposit V). Arsenopyrite is the main sulphide in deposits U and ADM, and sulpho-

salts are rare.

Group IV Deposits (W, X and Y)

Deposits W, X and Y occur within the carbonate and clastic sediments of the lower part of the Flinton Group (Myer Cave Formation). Antimony sulphosalts are common and arsenopyrite is rare.

Sulphide content of all four groups is highly variable and erratic and includes, in addition to the above-mentioned minerals, sphalerite, galena and pyrite.

Although the Addington and Ore Chimney deposits (ADM and OCM; Fig. 2 and Table 1) were chosen as representing deposits associated with the base of the Flinton Group, detailed study has shown them to be very different in many respects. For example, the Addington deposit is As-rich and hosted by the OCF, whereas the Ore Chimney deposit is Cu-Pb-Zn-rich and lies in mafic volcanics just below the OCF.

ADDINGTON MINE

History and economic features

The Addington Mine (Figs. 2, 3 and 4) was discovered in 1881 and first known as the "Golden Fleece". Little work was done on the property before 1887, when two shallow shafts were sunk and visible gold was exposed. Up to the end of 1921 total production is reported to have been valued at \$10000 (Harding, 1944), which corresponds to a production of 14800 grams of gold assuming a price of \$0.675/g Au (\$21/ounce Au). Attempts to operate the mine since 1921 have not been successful. The property was acquired under option by E & B Explorations in 1980 and re-evaluated based on diamond drilling carried out from 1981 to 1983; it has since been optioned by Campbell Resources Ltd. The mine is presently flooded.

The deposit has been explored to a depth of approximately 220 m

Figure 3. Geology of the Addington Mine area (modified from Dillon, 1985).

Figure 4. Underground workings of the Addington Mine Modified from Harding (1944) and Young (1985).

and a length of 1700 m by a large number of diamond drill holes and a substantial amount of underground development (Fig. 4). Underground development totalled 221 m of raising, 2262 m of drifting and 1055 m of cross-cutting on six levels (Carter, 1984). Harding (1944) provided a plan of the underground workings. Reserves are 256 000 tonnes grading 5 g/t Au (Carter, 1984).

Geological setting

The Addington Mine lies within the pelitic OCF, between the TDF mafic volcanic rocks and the Bishop Corners Formation sediments. These strata (Fig. 3) are tightly folded into synclines and anticlines that plunge moderately to steeply toward the north. There is a poorly preserved, earlier foliation within the volcanics that strikes northeasterly (Dillon, 1985). The biotite schists of the OCF have been reported to be a shear zone (Harding, 1944; Dillon, 1985; Young, 1985).

Tudor formation

The mafic volcanic rocks are dark green, foliated, fine- to coarse-grained amphibolites. These rocks comprise euhedral to anhedral hornblende in a fine-grained matrix of plagioclase and quartz with minor chlorite and biotite. Tourmaline, pyrite, magnetite and carbonate are present as accessories; the last occurs in part as inclusions in hornblende. Plagioclase is slightly to moderately altered to sericite. The amphibolite immediately adjacent to the contact with the OCF contains up to 30% tourmaline. Sulphide-free, millimetre-wide or less, calcite veinlets are common. The amount of tourmaline and the frequency of calcite veinlets decrease as the distance from the contact with the OCF increases. Actinolite, although rare, locally constitutes up to 30% of the rocks. Rare biotite schist layers up to 30 cm thick occur within the amphibolites.

Ore Chimney Formation

This formation is composed of alternating layers of garnet-free and garnet-bearing mafic biotite schist, hornblende schist and hornblende-biotite schist. Chlorite and muscovite contents each commonly vary from 0 to 15%. Tourmaline and apatite are present as accessory minerals, as well as kyanite and staurolite, which are less common. Tourmaline may constitute up to 40% of the rocks. A few garnet (with inclusions of ilmenite, arsenopyrite, chalcopyrite, pyrrhotite and tourmaline) and hornblende porphyroblasts have syn- to post-tectonic growth textures. Sulphide-free calcite veinlets, 0.5 to 2 mm wide, are concordant to subconcordant with the schistosity, erratically distributed within the biotite schist and may compose up to 5% of the rock. Calcite occurs also as disseminated grains in the matrix and as inclusions in hornblende porphyroblasts. Plagioclase is moderately to strongly altered to sericite. Within the limits of the Addington Mine property, this unit contains numerous sulphide-bearing quartz-carbonate-tourmaline veins. Semi-quantitative electron microprobe analyses of 20 tourmaline grains of the OCF and of the mineralized zones at the Addington and Ore Chimney mines indicate that the tourmaline is not significantly different from one setting to another. Quantitative partial analyses of three selected grains indicate that the tourmaline has molar $Fe/(Fe+Mg) = 0.33$ to 0.50 and is an intermediate member of the series schorl-dravite.

Young (1985) found micaceous quartzite interbedded with the mafic schists. The contacts between this rock unit and the TDF and Bishop Corners Formation are said to be gradational (Dillon, 1985; Easton *et al.*, 1986) however the contacts are sharp in the two drill holes examined in this study.

Bishop Corners Formation

Immediately overlying the OCF is a 10-30 m thickness of massive, fine- to medium-grained, feldspathic quartzite with minor magnetite, hematite, and lepidoblastic muscovite and biotite. Overlying the quartzite, in sharp contact, is a quartzite-pebble conglomerate which also contains 0.5 to 2 m thick discontinuous quartzite interbeds.

Sampling

All samples used in whole rock and mineral chemistry are from drill holes DDH 81-6 and DDH 82-3 (Figs. 3 and 4).

Gold and sulphide distribution

Lenses and stringers of quartz are irregularly distributed throughout the OCF, with a tendency toward concentration within certain sections. The lenses usually are parallel to the penetrative planar metamorphic fabric but in places transect it (Carter, 1984; Easton *et al.*, 1986). Young (1985) recognized deformed early barren quartz veins cut by late, sulphide-bearing, quartz-carbonate-tourmaline veins which transect the foliation at angles ranging from 5° to 90° . The quartz-carbonate-tourmaline veins contain up to 10 per cent sulphide minerals, range from 1 to 20 cm in thickness and constitute up to 15 per cent of the biotite schist; none of these veins contains more than five per cent carbonate minerals by volume. The predominant carbonate is ferroan calcite (identified by chemical staining; Dickson, 1965), but Harding (1944) and Young (1985) reported lesser amounts of ankerite. The quartz is medium grained ($> 1\text{mm}$) and shows no evidence of mylonitic texture or grain size reduction. A few veins of DDH 82-3 are essentially composed of fine grained tourmaline and subordinate sulphides. Four ore zones have been outlined within the OCF (Fig. 4); they grade into lower-grade mate-

P L A T E 1

- (a) Photomicrograph (reflected light) of gold (Au) and bismuthinite (Bmt), identified by electron microprobe, in a quartz-tourmaline vein. Sample 106, DDH 82-3, Addington Mine (UTM 18276539).
- (b) Sulphide-bearing quartz vein: (1) pyrite and marcasite with minor chalcopyrite; dark minerals are galena and sphalerite; (2) sulphides possibly remobilized into late planar fractures. Sample from shaft ca. 20 m depth, Ore Chimney Mine (UTM 18298602).

Figure 5. Geology of the Ore Chimney Mine area (modified from Moore and Morton, 1986). Dotted lines: mineralized zone projected to surface.

Figure 6. Underground workings of the Ore Chimney Mine. Shaded pattern: 1.0 to 1.3 metre wide zone containing 7500 tonnes of rock averaging 8 g/t Au; in this zone, gold concentration varies from 5 to 12 g/t and increases with depth. Dotted pattern: lower grade mineralized zones in which gold concentration is erratic, but varies commonly between 1 and 3 g/t. Source of data: original blueprints, assessment files, Ontario Geological Survey, Toronto.

rial both along strike and down-dip (Malczak *et al.*, 1985). These ore zones are steeply-plunging, subparallel to the stretching lineation defined by the long axes of deformed quartz clasts (Fig. 3; Dillon, 1985; Young, 1985).

The typical opaque mineral associations are:

(DDH 81-6) pyrite-chalcopyrite-pyrrhotite-ilmenite

(DDH 82-3) arsenopyrite-pyrite-chalcopyrite-pyrrhotite-ilmenite

Sulphide minerals and tourmaline are strongly segregated at the vein margins. Coarse euhedral arsenopyrite (Table 3), anhedral pyrite and chalcopyrite are by far the most abundant sulphides. Arsenopyrite contains rare tourmaline, chalcopyrite and pyrrhotite inclusions. Pyrrhotite occurs also as independent anhedral to euhedral grains. Traces of anhedral bismuthinite and gold (Plate 1a) having an average grain size of 10 microns and occurring between quartz grains were observed in one sample from DDH 82-3 containing 17220 ppb Au, in addition to the typical opaque mineral association. No arsenopyrite was seen in samples from DDH 81-6. Ubiquitous ilmenite is disseminated in the silicate gangue as anhedral to euhedral (lath shaped) grains. Pyrite is partly replaced by marcasite. Arsenopyrite is commonly fractured. Subordinate amounts of scheelite, galena and sphalerite have been reported to occur (Carter, 1984; Young, 1985). However, galena and sphalerite were not observed in any of the 45 polished thin sections examined from DDH 81-6 and DDH 82-3. All samples from both drill holes were examined under short wave ultra-violet light and failed to reveal scheelite.

ORE CHIMNEY MINE

History and economic features

Gold was first discovered at Ore Chimney Mine (Figs. 5 and 6) in 1902, and the Ore Chimney Mining Company carried out the first

TABLE 3: CHEMICAL ANALYSES OF ARSENOPYRITE FROM THE ADDINGTON MINE (DDH 82-3)

	APY-1		APY-2		APY-3		APY-4		APY-5	
	n=6		n=6		n=6		n=6		n=6	
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %
Fe	33.47	32.4	33.56	32.7	34.11	32.6	34.13	33.1	34.01	33.1
As	45.93	33.2	45.99	33.4	45.59	32.9	45.56	32.9	45.29	32.9
S	20.09	34.0	19.81	33.5	20.56	34.4	20.04	33.9	20.01	33.9
Co	0.40	0.4	0.40	0.4	0.07	0.1	0.07	0.1	0.07	0.1
Ni	--		0.03		0.03		0.03		0.03	
Total	99.90		99.79		100.36		99.83		99.41	

	APY-6		APY-7		APY-8		APY-9		APY-10	
	n=4		n=4		n=4		n=4		n=4	
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %
Fe	33.79	33.1	34.19	33.0	33.66	32.9	34.25	32.7	34.65	33.1
As	43.60	31.9	44.43	32.1	44.23	32.3	46.52	33.1	45.91	32.8
S	20.31	34.7	20.41	34.6	20.08	34.4	20.29	33.8	20.25	33.8
Co	0.31	0.3	0.27	0.3	0.42	0.4	0.49	0.4	0.30	0.3
Total	98.01		99.30		98.39		99.83		101.11	

	APY-11		APY-12		APY-13		APY-14	
	n=4		n=4		n=11		n=13	
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %
Fe	34.46	33.1	34.43	32.8	34.11	33.1	34.13	33.0
As	45.62	32.6	46.37	33.0	46.54	33.7	45.99	33.4
S	20.26	33.8	20.31	33.8	19.44	33.0	19.60	33.4
Co	0.49	0.5	0.51	0.4	0.23	0.2	0.20	0.2
Sb	n.d.		n.d.		--		n.d.	
Ni	n.d.		n.d.		--		n.d.	
Bi	n.d.		n.d.		0.13		n.d.	
Total	100.83		101.62		100.45		99.92	

n: number of individual "spot" analyses averaged in a single grain. --: not detected. n.d.: not determined. Grains 1 to 5 are from sample 858.5; grains 6 to 8 are from sample 864.9; grains 9 to 12 are from sample 868.1; grains 13 and 14 are from sample 883.6. All samples + pyrite + pyrrhotite.

underground workings in 1909. A 400-foot shaft was sunk and several northeasterly drifts were established. Geological work (including diamond drilling, underground development, surface geological mapping) was undertaken intermittently up to 1958. Little work has been done since then. As of 1932, when the mine was flooded, development workings in the form of crosscuts and drifts totaled 663 m distributed on seven levels (108-, 150-, 250-, 300-, 332-, 400-, and 500-foot), the longest drift being the 400-foot level (200 m); the 500-foot level is connected to the 400-foot level through a winze inclined at 85° southeast. In 1982, the property was acquired by Mr Albert Bannér. From January to August 1983, the mine was dewatered and retimbered to the 150-foot level; it is presently flooded. During summer 1987, a 1500-m drilling program was carried out by Sands Minerals Corp. to test the known mineralized zone both along strike and at depth (Northern Miner, 1987). Eleven thousand tonnes of material grading 7 g/t Au and 193 g/t Ag are estimated to be present between the 108- and 500-foot levels (Carter, 1984).

Geological setting

The old mine workings are situated within the TDF volcanics close to the contact of the overlying sediments (Fig. 5). Mafic volcanics of the TDF are overlain successively to the southeast by pelitic sediments (OCF), cross-bedded quartzite and quartzite-pebble conglomerate (Bishop Corners Formation). All rocks on the property are moderately to well-foliated on planes striking 230° to 265° , and dipping 80° to 90° northwest. Mapping of the contacts, Flinton stratigraphy, and minor structures reveals a number of isoclinal to open folds plunging steeply northeastward, with axial planes parallel to foliation. The mine shaft is situated near the hinge of the easternmost fold. Although the short limb of the major fold appears

to be faulted along the cleavage, the cross-fault shown on earlier maps (see Meen, 1944) is absent. The lateral offset of the TDF-OCF contact is entirely the result of folding. Carbonate sediments overlying the amphibolite occur in the southern part of the mine property (Fig. 5), indicating that the deposit occurs stratigraphically near the top of the basaltic succession.

Tudor formation

The mafic volcanic rocks exposed on the property are massive to foliated, fine- to medium-grained dark green amphibolites composed of green hornblende, plagioclase, and minor quartz. Hornblende porphyroblasts exhibit syn- to post-tectonic growth. Accessory minerals include epidote, biotite, garnet, chlorite, cummingtonite, pyrite, magnetite, and carbonates. Rare sulphide-free, millimetric, quartz-calcite veinlets occur within the amphibolite. Felsic lapilli-tuff layers 0.5-1 m thick are a minor component (<1%) of the volcanic succession, which also includes rare biotite schist layers averaging 50 cm in thickness.

Ore Chimney Formation

The OCF, well-exposed on the mine property, is composed of fine- to medium-grained mafic biotite schist, muscovite-biotite schist and hornblende-biotite schist, alternating in layers up to 0.5 m thick. The schist is typically studded with garnet and less commonly contains staurolite and epidote porphyroblasts. Accessory minerals include apatite, pyrite and magnetite.

Bishop Corners Formation

At the Ore Chimney Mine, a five metre-thick layer of magnetite-bearing muscovite-quartz schist, typically containing small flattened clasts, lies between the OCF and the quartzite. The quartzite is light grey or white and exhibits cross-bedding throughout, marked

by hematitic laminae. Abruptly overlying the quartzite is an oligomictic conglomerate comprising a framework mainly of quartzite pebbles and cobbles in a hematite-bearing muscovite schist matrix. The conglomerate is overlain by quartzofeldspathic pebbly psammite.

Sampling

Samples used in whole rock and mineral chemistry are from the mine shaft and the 108- and 150-foot levels. Another group of samples (amphibolite and biotite schist) was collected on surface.

Gold and sulphide distribution

Detailed mapping (Fig. 5; Moore and Morton, 1986) indicates that the zone containing the gold and the sulphides is hosted by a biotite schist layer, within the TDF, the top of which is about 30 m below the TDF-OCF unconformity. This layer strikes 030° - 040° and dips 85° to the southeast, parallel to the base of the Flinton Group. A biotite schist layer exposed in a trench, 30 m southwest of the mine shaft, is correlated with the biotite schist zone of the mine which otherwise was not observed on surface (see Figure 5 of Moore and Morton, 1986). Examination in 1983 showed that this zone, to the 150-foot level, comprises a layer of mafic biotite and biotite-hornblende schist, locally with muscovite and chlorite, averaging four metres in thickness and enclosed by amphibolite. A one to two-metre thick zone, within the schist is occupied by an irregular system of lenticular, sulphide-bearing, white quartz veins (3 mm to 1 m wide) with subordinate carbonate. The vein system consists in places of a single dominant quartz-carbonate vein 0.5-1 m thick. The quartz-carbonate veins are primarily concordant with the main foliation but locally cut it at angles up to 90° (Fig. 7). The veins are commonly folded on steeply-plunging hinges that are parallel to D_1 hinges; the folds have D_1 cleavage as their axial

Figure 7. Quartz veins in biotite schist, Ore Chimney Mine (drawn from photographs). V: quartz vein. F: subhorizontal late fault. N: north. Straight lines: schistosity. A) Shaft, 3 m below surface, looking northeast. Sample 141 (Appendix I) is from the centre of the vein. B) Back of 108-foot level, northeastern drift.

surfaces. The quartz is coarse grained (>1 mm) and shows no evidence of mylonitic texture or grain size reduction. These observations combined indicate that the veins were emplaced during D_1 . The two carbonate minerals identified by chemical staining (Dickson, 1965) are ferroan calcite and ferroan dolomite, the former being by far predominant; the average calcite and dolomite content of the veins is less than five per cent by volume but may locally compose up to twenty per cent. Carbonate minerals occur also disseminated within the matrix of the biotite schist and as inclusions in hornblende porphyroblasts. Tourmaline is present as an accessory mineral in the biotite schist and the quartz-carbonate veins but is much less abundant than at the Addington Mine. Sulphide minerals constitute up to 20 per cent of vein and associated wall rock; they occur as disseminations and pods up to 10 cm across concentrated mainly along quartz vein margins, and as disseminations within host rocks between quartz stringers. The biotite schist zone hosting the gold and the sulphides was interpreted by Meen (1944), Dillon (1985) and Malczak et al. (1985) to be a shear zone. However, no kinematic features indicative of simple shear deformation such as en echelon veins, S-C fabrics, shear bands or mylonites were observed, so this contention could not be supported.

The typical opaque mineral association is:

galena-sphalerite-pyrite-chalcopyrite-pyrrhotite-sulphosalt-ilmenite

In addition to the typical opaque mineral association, traces of cobaltite and arsenopyrite were observed in two samples. The only sulphosalt observed consists of anhedral grains penetrating (and included within?) galena. It is a Ag-rich member of the tetrahedrite group with molar Ag:Cu ranging from 0.7 to 1.5 (Table 4), the main substitution being that of Ag for Cu. The terms argentian

TABLE 4: CHEMICAL ANALYSES OF ARGENTIAN TETRAHEDRITE AND FREIBERGITE FROM
THE ORE CHIMNEY MINE

	OL108-6		OL108-14		OSH-9		OSH-55
	TTH n=1	TTH n=1	TTH n=3	TTH n=3	FRB n=3	FRB n=3	FRB n=3
weight %							
Ag	25.22	25.56	25.25	26.16	33.32	33.58	34.38
Cu	20.57	20.50	20.14	19.29	14.39	13.59	14.24
Fe	5.36	5.37	5.30	5.15	5.03	4.90	4.66
Sb	26.96	26.87	26.58	26.66	25.60	25.94	25.69
S	22.74	22.27	22.31	22.43	20.90	20.51	20.38
TOTAL	100.80	100.70	99.58	99.69	99.24	100.32	99.35
	Formula						
Ag	4.28	4.45	4.36	4.49	6.15	6.31	6.49
Cu	5.87	5.98	5.88	5.58	4.48	4.30	4.55
Fe	1.76	1.79	1.77	1.71	1.79	1.78	1.69
Sb	4.04	4.11	4.07	4.06	4.18	4.32	4.31
S	13.00	13.00	13.00	13.00	13.00	13.00	13.00

TTH: argentine tetrahedrite. FRB: freibergite. n: number of individual "spot" analyses averaged in a single grain.

tetrahedrite and freibergite are both appropriate for this mineral, because molar Ag varies from less than to greater than Cu (Riley, 1974; Fleischer, 1975). The freibergite from the Ore Chimney Mine with the highest Ag (OSH-55; Table 4) has 34.38 wt % Ag and the formula $(\text{Ag}_{6.49}\text{Cu}_{4.55}\text{Fe}_{1.69})\text{Sb}_{4.31}\text{S}_{13.00}$. This is very close to the most Ag-rich freibergite (for which a complete analysis is available) from the Mount Isa deposit which has 36.0 wt % Ag and the formula $(\text{Ag}_{6.37}\text{Cu}_{3.72}\text{Fe}_{1.41}\text{Zn}_{0.18})(\text{Sb}_{3.95}\text{As}_{0.13})\text{S}_{13.00}$ (Riley, 1974). Freibergite occurring in the Mount Isa deposit has a very high Ag content compared to freibergite of other deposits.

Anhedral galena and sphalerite (Table 5) are the most common sulphides. Sphalerite contains a small amount of chalcopyrite and exsolved pyrrhotite inclusions. Chalcopyrite and pyrrhotite occur also as anhedral masses and euhedral grains, respectively. Chalcopyrite is commonly twinned. Ubiquitous anhedral to euhedral, lath shaped, ilmenite crystals are disseminated in the gangue. Gold was not observed in any of the 45 polished thin sections examined. However, Moore and Morton (1986) reported one occurrence of visible gold in a sulphide-free sample of biotite schist. Galena, sphalerite, pyrite and exsolved pyrrhotite are partly replaced by marcasite. A few quartz-filled millimetric fractures cut galena, sphalerite, pyrite and marcasite and clearly postdate the marcasite replacement event. Sphalerite, typically red in thin section, is partly altered to a yellow, iron-poor, sphalerite. Galena crystals and coarse lath shaped ilmenite are bent. Late planar fractures, 1-2 mm wide, filled with chalcopyrite, marcasite, galena and pyrite cut the main quartz-carbonate veins (Plate 1b); the sulphides may have been remobilized into these fractures.

TABLE 5: CHEMICAL ANALYSES OF SPHALERITE FROM THE ORE CHIMNEY MINE

	SP-1u		SP-2u		SP-3u		SP-4u	
	n=8		n=3		n=4		n=4	
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %
Fe	8.85	7.7	8.29	7.1	8.56	7.2	8.81	7.7
Zn	57.01	41.7	57.44	42.3	57.54	42.0	57.55	42.4
S	33.73	50.3	33.88	50.6	33.81	50.5	33.01	49.6
Cu	--	--	--	--	0.03	--	--	--
Cd	0.67	0.3	n.d.	--	0.67	--	0.71	0.3
Mn	n.d.	--	n.d.	--	n.d.	--	0.05	--
Total	100.26		99.61		100.61		100.13	

	SP-5u		SP-6u		SP-7a	
	n=4		n=3		n=3	
	wt %	atom %	wt %	atom %	wt %	atom %
Fe	8.51	7.2	8.33	7.3	2.71	2.4
Zn	57.96	42.9	58.48	44.0	64.12	47.2
S	32.95	49.6	31.91	48.7	32.38	50.4
Cu	--	--	--	--	--	--
Cd	0.73	0.3	n.d.	--	n.d.	--
Mn	0.04	--	n.d.	--	n.d.	--
Total	100.19		98.73		99.21	

	SP-8u		SP-8a		SP-9u		SP-9a	
	n=2		n=2		n=8		n=1	
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %
Fe	9.54	8.1	1.70	1.5	7.77	6.8	1.95	1.7
Zn	57.70	42.5	66.25	49.5	58.71	44.2	65.80	49.6
S	32.99	49.4	32.25	49.0	32.05	49.0	31.82	48.7
Cu	--	--	--	--	0.07	--	--	--
Cd	n.d.	--	n.d.	--	n.d.	--	n.d.	--
Mn	n.d.	--	n.d.	--	n.d.	--	n.d.	--
Total	100.23		100.20		98.60		99.57	

n: number of individual "spot" analyses averaged in a single grain. u: unaltered. a: altered. --: not detected. n.d.: not determined. Grains 1 and 2 are from sample OSM-9 (+ pyrite); grains 3, 4 and 5 are from sample OL108-2 (+ pyrite); grains 6 and 7 are from sample OL108-32 (+ pyrite + pyrrhotite); grains 8 and 9 are from sample OL108-31 (+ pyrite + pyrrhotite).

GEOOTHERMOBAROMETRY

The metamorphism in the Flinton-Fernleigh area has been discussed and summarized by Sethuraman and Moore (1973); Carmichael *et al.* (1978) provided maps of the isograds.

Metamorphic conditions at Addington and Ore Chimney mines are above the upper stability limit of chloritoid; biotite and garnet are a widespread mineral pair, and staurolite and kyanite are also found in nearby biotite-rich pelites. In the mafic volcanic rocks hornblende coexists with biotite and chlorite, and cummingtonite is also present in some samples.

Both gold deposits are thus within the staurolite zone of the lower amphibolite facies, although they lie very close to the transition upper greenschist-lower amphibolite. Regionally, the metamorphic grade increases from west to east, and staurolite in the pelites is stable up to the sillimanite isograd, which indicates that the regional pressure lay near, but higher than, the aluminosilicate triple point (Sethuraman and Moore, 1973). The pressure of metamorphism in the region thus corresponds to that of Carmichael's (1978) bathozone 4 (0.4 to 0.5 GPa).

Mineral chemistry and application of the sphalerite geobarometer (Hutchison and Scott, 1981), and of the arsenopyrite and garnet-biotite geothermometers (Thompson, 1976; Sharp *et al.*, 1985) are discussed in detail in Appendix III and summarized in Table 6. Arsenopyrite geothermometry and sphalerite geobarometry yield temperatures and pressure estimates ranging from 420 to 530°C and 0.35 to 0.59 GPa, respectively. Application of the garnet-biotite geothermometer to the biotite schist host of both deposits gives temperatures ranging from 475 to 535°C. At a pressure of 0.5 GPa and temperature range of 420-530°C (Table 6), $\log f_{S_2} = -2.8$ to -5.5 using the pyr-

TABLE 6: SUMMARY OF GEOTHERMOSBAROMETRY DATA FOR THE ADDINGTON AND ORE CHIMNEY MINES

METHOD (and calibration)	RESULTS	MATERIAL ANALYSED
Sphalerite geobarometry (Hutchison and Scott, 1981)	P = 0.35-0.59 GPa	Unaltered sphalerite (Table 5) from quartz-carbonate veins. Ore Chimney Mine.
Arsenopyrite geothermometry (Sharp <u>et al.</u> , 1985)	T = 420-530°C	Arsenopyrite (Table 4) from quartz-tourmaline veins. Addington Mine.
Garnet-biotite geothermometry (Thompson, 1976)	T = 475-535°C	Garnet and biotite from biotite schist host rocks. Addington and Ore Chimney mines.

rhodite-pyrite relationships in the Fe-S system determined experimentally by Toulmin and Barton (1964) and Sharp *et al.* (1985).

WHOLE ROCK CHEMISTRY

Analytical techniques

Samples of host rocks and veins from the Addington and Ore Chimney deposits were analysed. Major elements, Ba, Cr, Nb, Ni, Rb, Sr, Y, Zn, and Zr were determined by X-ray fluorescence; Co, Cs, Hf, Sc, Th, U, La, Sm, Eu, Yb, and Lu by instrumental neutron activation analysis (INAA, Muecke, 1980); CO₂, H₂O, S by volatilization and non-dispersive infrared absorptiometry (Bouvier and Abbey, 1980); ferrous iron by a modified cold Wilson method (Johnson and Maxwell, 1981); Au by flameless atomic absorption spectroscopy (Culver, 1975); As, Ga, Sb by direct current plasma atomic emission spectroscopy (DCP-AES); Ag, Cu, Pb, by atomic absorption spectroscopy; Sb by INAA or DCP-AES. The analytical procedures are described in detail in Appendix II.

Results

Addington Mine

The biotite schist of the OCF is significantly enriched in Al₂O₃, K₂O, Ba, Cs, Rb, S and H₂O and depleted in CaO, Na₂O and Cu compared to the underlying TDF amphibolite (Tables 7 and 8). Some sections of the drill cores containing up to 5% sulphide-free calcite veinlets were not analysed, thus the analytical results are biased towards low CO₂. The two chemical profiles through the OCF (DDH 81-6 and DDH 82-3; Fig. 8) show that both biotite schist and quartz veins of this zone have a greater Au and Ag content than the TDF rocks. Sb is anomalously high only in three quartz veins of DDH 82-3. The quartz veins of the OCF and TDF have low Zn abundances compared to the biotite schist and amphibolite. Rocks of the OCF in

TABLE 7
WEIGHTED MEAN MAJOR AND TRACE ELEMENTS IN ROCKS FROM THE ADDINGTON AND ORE CHIMNEY MINES

	-1-		-2-		-3-		-4-		-5-	
n =	18		20		19		9		7	
	$\bar{x}_w$	SD	$\bar{x}_w$	SD	$\bar{x}_w$	SD	$\bar{x}_w$	SD	$\bar{x}_w$	SD
SiO ₂	49.07	4.2	50.68	4.9	52.76	3.5	49.60	6.9	53.27	4.7
Al ₂ O ₃	14.71	2.8	17.79	1.2	16.26	1.2	17.74	2.0	17.13	2.1
Fe ₂ O ₃	2.35	1.1	1.93	1.0	3.71	1.0	1.64	0.8	3.70	2.8
FeO	11.80	3.2	11.39	2.7	8.64	2.1	11.48	3.0	8.37	2.2
(FeO) ^T	(13.92)	3.5	(13.13)	3.3	(11.98)	1.9	(12.96)	3.2	(11.70)	1.2
MgO	7.55	1.9	6.32	1.2	5.17	0.9	5.20	2.3	4.51	1.5
CaO	10.38	2.4	5.53	1.9	8.68	1.4	6.57	2.2	5.77	2.3
Na ₂ O	2.28	1.1	0.80	0.8	2.74	0.7	1.45	0.9	0.85	0.3
K ₂ O	0.34	0.4	3.82	1.2	0.82	1.2	4.89	1.8	5.04	0.6
TiO ₂	1.32	0.5	1.46	0.2	0.91	0.2	1.04	0.2	0.97	0.2
P ₂ O ₅	--	n.d.	0.07	.07	0.13	.07	0.19	.09	0.20	.10
MnO	0.20	.03	0.21	.04	0.19	.03	0.20	.05	0.19	.06
TOTAL	100.00		100.00		100.00		100.00		100.00	
Ag	--	n.d.	3	1.5	--	n.d.	3	34	3	1.1
As	4	46	8	695	<1	n.d.	--	n.d.	<1	n.d.
Au (ppb)	<12	n.d.	17	1872	--	n.d.	23	30	<12	n.d.
Ba	80	61	621	255	194	202	458	135	459	169
Co	46	29	47	13	38	7	36	15	35	11
Cr	155	141	225	125	77	36	86	165	99	4
Cs	6	27	126	177	1	1.7	2	0.8	5	1.3
Cu	41	166	17	21	59	42	40	111	3	158
Ga	26	8	25	4	25	2	28	5	25	1
Hf	2	0.7	3	1.3	3	1.5	4	1.6	3	1.5
Nb	--	n.d.	--	n.d.	--	n.d.	<5	n.d.	--	n.d.
Ni	45	41	61	73	19	12	14	34	26	11
Pb	3	38	4	6.9	3	3.1	9	1734	4	0.8
Rb	3	12	90	72	15	32	90	39	127	17
Sb	--	n.d.	--	n.d.	1	1.1	1	1.4	--	n.d.
Sc	48	9	47	12	34	5	32	9	30	6
Sr	115	75	115	66	258	112	207	70	194	93
Th	--	n.d.	--	n.d.	--	1.5	4	3.8	2	1.5
U	--	n.d.	1	0.7	--	1.6	1	1.1	1	0.5
Y	37	12	28	12	27	5	21	6	22	8
Zn	87	31	72	24	111	22	304	2192	99	40
Zr	63	29	81	39	95	9	59	45	58	14
La	1.8	1.1	2.0	1.2	5.2	2.4	3.5	17.1	6.2	1.3
Sm	2.3	1.2	2.8	1.0	3.1	0.6	2.7	1.3	4.0	0.7
Eu	0.9	0.5	1.2	0.1	1.1	0.2	1.1	0.5	1.1	0.2
Yb	2.7	1.6	2.2	1.3	2.4	0.9	1.8	0.8	2.7	0.7
Lu	0.4	0.2	0.5	0.2	0.4	0.3	0.4	0.2	0.5	0.1
OXIRATIO	17	8	13	4	28	9	12	6	29	18
(La/Yb) _N	0.45	0.17	0.74	0.32	1.59	0.87	0.72	12.2	1.61	0.32
Ti/Zr	129	48	120	26	102	19	109	37	102	4
Zr/Y	1.67	0.51	2.56	1.41	2.11	0.33	2.83	2.82	2.53	1.44
Nb/Y	<0.10	n.d.	<0.10	n.d.	<0.10	n.d.	<0.10	n.d.	<0.10	n.d.
K ₂ O/Na ₂ O	0.11	0.30	5.04	3.31	0.25	0.67	5.27	5.17	5.82	1.81
K ₂ O/CaO	0.03	0.04	0.73	0.83	0.09	0.18	0.72	0.61	0.83	0.75
CaO/Na ₂ O	4.73	1.99	6.92	4.47	3.07	2.41	5.85	6.71	8.06	3.05
K/Rb	>1000	n.d.	333	80	>1000	n.d.	435	61	337	44
Ba/Rb	>1000	n.d.	6.35	1.57	>1000	n.d.	4.96	1.29	3.73	1.25

- (1) Amphibolite, Tudor formation, Addington Mine; REE based on 16 samples.
 (2) Schist, Ore Chimney Formation, Addington Mine.
 (3) Amphibolite, Tudor formation, Ore Chimney Mine.
 (4) Biotite schist, mineralized zone, Ore Chimney Mine.
 (5) Schist, Ore Chimney Formation, Ore Chimney Mine.

Major elements are in weight per cent. Trace element abundances are in parts per million (ppm)-unless otherwise stated. n: number of samples averaged. $\bar{x}$: weighted mean. SD: one standard deviation, absolute value. n.d.: not determined. --: not detected. FeO^T is total iron as FeO. OXIRATIO = $[2\text{Fe}_2\text{O}_3/(\text{FeO}+2\text{Fe}_2\text{O}_3)] \times 100$ (molecular proportions). (La/Yb)_N: chondrite-normalized ratio.

TABLE 8
WEIGHTED MEAN VOLATILE CONTENTS IN ROCKS FROM THE ADDINGTON AND ORE CHIMNEY MINES

	-1-		-2-		-3-		-4-		-5-	
n =	18		20		19		9		7	
	x_w	SD	x_w	SD	x_w	SD	x_w	SD	x_w	SD
S	0.13	1.02	0.30	0.36	0.01	0.03	0.26	0.30	0.01	0.14
CO ₂ T	1.97	1.18	0.31	1.63	0.48	0.75	3.26	1.96	1.28	1.28
H ₂ O ^T	1.79	1.15	2.66	0.75	1.49	0.31	2.76	1.06	2.78	0.75

Column headings are the same as in Table 7. Values are in weight per cent. S: sulphur.
CO₂T: total carbon as CO₂. H₂O^T: total water.

Figure 8. Chemical profiles through the Ore Chimney Formation (Addington Mine). Major oxide values are weight per cent recalculated on a volatile free basis. Volatiles are in weight per cent. Gold abundances are in parts per billion (ppb). Other trace elements are in parts per million (ppm). Major elements and volatiles are plotted on a linear scale, and trace elements on a log scale. Stars: quartzite of the Bishop Corners Formation (BCF). Solid circles: biotite schist of the Ore Chimney Formation (OCF) and amphibolite of the Tudor formation (TDF). Squares: quartz-carbonate-tourmaline vein. Vertical scale is distance from the drill hole collar.

Figure 2. Composite profile through the biotite schist zone of the Ore Chimney Mine (150-foot level, near the mine shaft). Concentrations plotted as in Figure 12. Solid circles: biotite schist of the mineralized zone. Diamond: amphibolite. Star: arithmetic mean and range of 13 samples from the quartz-carbonate veins of the mineralized zone. Square: subsidiary quartz vein.

DDH 82-3 have greater As content than in DDH 81-6; TDF rocks have low As content compared to the rocks of the OCF. Cu, Ni and Pb are variable.

Ore Chimney Mine

The biotite schist of the mineralized zone is significantly enriched in S, CO_2 , H_2O , K_2O , Ba, Rb, Zn and is depleted in CaO and Na_2O compared to the enclosing amphibolite (Tables 7 and 8). The Ag, Au and Pb contents of the biotite schist are slightly greater than in the amphibolite. Figure 9, which is an underground composite profile through the mineralized zone, shows that As and Ni are variable.

The OCF at Ore Chimney Mine has much lower S and carbonate mineral contents, and is more oxidized than at the Addington Mine and in comparison with the mineralized biotite schist at Ore Chimney Mine. The biotite schist of the mineralized zone, the amphibolite and the OCF at the Ore Chimney Mine have greater Sr and $(\text{La}/\text{Yb})_N$ and lower Cr and Ni than the biotite schist of the OCF and the amphibolite at Addington Mine. The large standard deviation of $\text{K}_2\text{O}/\text{Na}_2\text{O}$ in the volcanics is a result of the very low abundance of K_2O in these rocks.

Correlation matrices (Tables 9 and 10) of biotite schist and quartz veins from the OCF at Addington Mine and the mineralized zone at the Ore Chimney Mine show that there is no good correlation between gold and any major components of the sulphides. This strongly suggests that the gold occurs free in the quartz veins and the biotite schist and is not associated with a particular sulphide. Ag has a good positive correlation (0.84) with Pb in the mineralized zone of the Ore Chimney Mine and reflects the close association Ag-rich tetrahedrite with galena.

TABLE 9: CORRELATION OF SELECTED ELEMENTS (ADDINGTON MINE)

CORRELATION MATRIX OF SELECTED ELEMENTS FROM SAMPLES OF THE ORE CHIMNEY FORMATION

	Ag	As	Au	Cu	Pb	Sb	Zn	Fe	S	CO ₂
Ag	1.00									
As	-0.20	1.00								
Au	-0.01	0.67	1.00							
Cu	0.16	-0.08	0.26	1.00						
Pb	-0.11	-0.04	-0.03	-0.02	1.00					
Sb	-0.24	0.98	0.69	-0.06	0.03	1.00				
Zn	0.61	-0.25	-0.14	0.11	-0.24	-0.33	1.00			
Fe	0.68	-0.12	-0.01	0.17	-0.21	-0.19	0.86	1.00		
S	0.18	0.12	0.43	0.89	0.02	0.13	0.15	0.24	1.00	
CO ₂	-0.02	0.00	0.02	0.05	0.12	-0.06	0.13	0.10	0.14	1.00

Correlation matrix of selected elements from 26 samples (biotite schist and quartz-carbonate-tourmaline veins) of the Ore Chimney Formation (Addington Mine).

TABLE 10: CORRELATION OF SELECTED ELEMENTS (ORE CHIMNEY MINE)

CORRELATION MATRIX OF SELECTED ELEMENTS FROM SAMPLES OF THE MINERALIZED ZONE

	Ag	As	Au	Cu	Pb	Sb	Zn	Fe	S	CO ₂
Ag	1.00									
As	0.42	1.00								
Au	0.43	0.42	1.00							
Cu	0.52	0.72	0.10	1.00						
Pb	0.84	0.47	0.43	0.45	1.00					
Sb	0.28	0.36	0.53	-0.02	0.31	1.00				
Zn	0.54	0.20	0.65	-0.03	0.62	0.31	1.00			
Fe	0.30	0.12	-0.09	0.36	0.32	-0.10	-0.03	1.00		
S	0.73	0.76	0.49	0.77	0.78	0.30	0.57	0.33	1.00	
CO ₂	0.39	0.15	0.25	0.24	0.30	0.18	0.15	0.65	0.36	1.00

Correlation matrix of selected elements from 23 samples (biotite schist and quartz-carbonate veins) of the mineralized zone (Ore Chimney Mine).

DISCUSSION

In comparing the Addington and the Ore Chimney deposits with Archean lode gold deposits of the Canadian Shield as described by Boyle (1979), Hodgson and MacGeehan (1982), Kerrich (1983), Colvine *et al.* (1984) and Roberts (1987), several similarities are evident. The Archean deposits are typically surrounded by a narrow carbonate alteration halo, with or without other types of alteration. Minerals commonly associated with the deposits include pyrite, arsenopyrite, pyrrhotite, sphalerite, chalcopyrite, galena, scheelite and tourmaline, pyrite being the most abundant sulphide. Most deposits are associated with tholeiitic basalts and, on a regional scale at least, are also associated with major geological breaks and with a volcanic-sedimentary (greywacke + shale) contact. However differences also exist. Most Archean lode deposits have komatiitic flows interlayered with the tholeiitic basalts, contain felsic intrusive and/or extrusive rocks within the mine workings and occur in greenschist facies terranes. The Addington and Ore Chimney deposits are not evidently related to small intrusions and, occurring in a lower amphibolite rather than greenschist facies terrane, may represent a slightly higher temperature of mineralization. Another salient difference is the size of the Proterozoic deposits compared to the Archean ones. The Proterozoic lode gold deposits of the Canadian Shield are much smaller than their Archean counterparts, although some of them, such as the Nor Acme deposit in the Churchill Province of Manitoba, from which 20×10^6 grams of gold were extracted, have produced a significant amount of gold or have substantial reserves (Franklin and Thorpe, 1982; Galley *et al.*, 1985, 1986; Clark, 1986).

Kerrich (1983; see also Roberts, 1987) has reviewed the genetic

models for Archean lode gold deposits. The principal models are:

1.- The syngenetic-remobilization model. According to this model, gold is leached and transported by hot, convecting sea water, and then concentrated principally by chemical precipitation in exhalite sediments and banded iron formation. Gold and associated minerals are remobilized from the sediments to vein structures by post-depositional processes such as compaction and diagenesis, deformation and metamorphism, and igneous emplacement-related processes.

2.- The multistage metamorphic fluid model. In this model, fluids released during metamorphic outgassing stream toward the sea floor, debouching to form gold-rich chemical sediments. Vein deposits may be generated coevally with the chemical sediments and later during basin closure, at deeper crustal levels.

These models may well apply to pre-concentration processes related to the deposits of this study. The ultimate deposition of gold at Addington and Ore Chimney mines, however, appears to be more a function of metamorphic processes acting on the entire rock succession at the two localities.

Origin of the Ore Chimney Formation

It has been suggested that the OCF represents either a mafic sediment (Moore and Thompson, 1980) or a shear zone alteration product. The Addington Mine deposit has been reported to occur in a shear zone at the contact between the Tudor mafic volcanics and the quartzite of the Bishop Corners Formation (Carter, 1984; Malczak *et al.*, 1985), which would negate the existence of the OCF as a sedimentary unit and imply that this gold deposit occurs in sheared and

metasomatised equivalents of the volcanics as suggested by Harding (1944), Springer (1982) and Laing *et al.* (1987). The origin of the OCF and its geochemistry are discussed in detail in Chapter II. The main conclusions relevant to its origin are summarized below:

- 1.- The presence of quartzite and quartz pebble-rich layers, which do not occur in the TDF, within the OCF strongly supports a sedimentary origin.
- 2.- The folding of the OCF (see Fig. 5), together with the absence of a folded fabric within this unit argue against a shear zone origin.
- 3.- The immobile trace element ratios Ti/Zr and Zr/Y indicate that most of the OCF is locally derived from the underlying volcanics.

In balance the hypothesis of origin as a mafic sediment accounts most satisfactorily for these three points. Such an origin does not preclude an overprint of shearing and/or metasomatism after deposition.

Hydrothermal alteration

The high K_2O and low Na_2O and CaO contents of the OCF rocks, compared to the volcanics (Fig. 8) are consistent with those of an isochemically metamorphosed argillaceous sediment with or without a superimposed potassic alteration. Although the chemical composition of the OCF, with respect to major and most trace elements, is compatible with that of an argillaceous sediment, the high Ba and Cs contents of the OCF at Addington Mine (621 ppm Ba and 126 ppm Cs) compared to those of the underlying volcanics (80 ppm Ba and 6 ppm Cs; Table 7), suggest that these rocks were altered. The high tourmaline content associated with the sulphide- and gold-bearing veins, in the OCF the presence of numerous small carbonate veins at Addington

ton Mine also suggest that these rocks were affected by hydrothermal alteration. In contrast, there are no such chemical anomalies or alteration at Ore Chimney Mine.

The CO_2 analyses (Table 8) and the presence of accessory carbonate minerals and small calcite veins suggest that the amphibolite (TDF) and the biotite schist (OCF) at the Addington Mine, and the biotite schist of the OCF at the Ore Chimney Mine were weakly carbonatized. This evidence indicates that carbonatization is not restricted to the OCF, nor is it restricted to the biotite schist lithology. Staurolite, kyanite, garnet and hornblende do not show evidence of reaction textures with carbonate, indicating that any carbonatization occurred before peak metamorphism. Hynes (1980) and Murphy and Hynes (1986) showed that Ti, Y and Zr may be mobile during carbonatization. The lack of any significant correlation between CO_2 and these elements, the small range in concentrations of Ti, Y and Zr, and the coherence of the ratios Ti/Zr and Zr/Y indicates that these elements remained relatively immobile in the OCF.

Potassic alteration is a common feature of gold deposits occurring in Archean greenstone belts. Such an alteration is typically associated with intense carbonatization, an increase of K and a decrease of Na as the alteration proceeds (Kerrick, 1983). However, Roberts (1987) noted that significant exceptions to this decrease in Na do exist. Although the OCF, as a unit, contains more K_2O than the adjacent rock units (Fig. 8), the OCF rock analyses show no significant correlation between K_2O and CO_2 . The main difference between the OCF rocks at the Addington Mine and Ore Chimney Mine properties is that the OCF rocks of the former are mineralized and carbonatized, and those of the latter are only carbonatized. There are no significant differences between the $\text{K}_2\text{O}/\text{Na}_2\text{O}$, $\text{K}_2\text{O}/\text{CaO}$, $\text{CaO}/\text{Na}_2\text{O}$ and

K/Rb ratios of the OCF at Addington and Ore Chimney mines (Table 7). The coherence of these ratios suggests that the mineralizing process increased the As, Au, B, Ba, Cs, S and carbonate contents of the OCF rocks at Addington Mine without changing significantly the K_2O content of these rocks. It also suggests that potassic alteration associated with mineralization was very weak or absent. The large values of the standard deviation of the K_2O/CaO ratio may however have been caused by a slight mobility of Ca or K or both during metamorphism and/or hydrothermal alteration.

Another possible explanation for the high K_2O content of the OCF is that this entire formation, over its 40 km strike length, is a potassium-metasomatised rock unit. This hypothesis implies that at mineralized as well as unmineralized localities as much as 8 km apart, a common potassium-rich fluid flowing through a huge plumbing system represented by the regional unconformity produced rocks with similar K/Rb, K_2O/Na_2O , K_2O/CaO and CaO/Na_2O ratios from similar protoliths. It also implies that this hypothetical K-metasomatic event is not related to gold mineralization. Furthermore, as shown in Chapter II, the K_2O content of the OCF is in the range of K_2O content of shales and argillaceous sediments, and there is no need to invoke K-metasomatism to explain the "high" potassium content of the OCF. Because staurolite, kyanite, garnet and hornblende do not show evidence of reaction textures with biotite (i.e. biotitization), this K-metasomatic event, if it ever occurred, took place before peak metamorphism.

The only convincing evidence of K-metasomatism is of very local scale. The biotite content of the amphibolite underlying the OCF increases sharply within 0.5 m from the contact between the two rock units, suggesting that at some time before peak metamorphism, potas-

sium moved from the OCF to the underlying volcanic rocks over a short distance. This increase in potassium may however be simply a result of K-enrichment of the volcanic rocks most exposed to palaeo-weathering.

The mineralized zone of the Ore Chimney Mine

The mineralized biotite schist zone of the Ore Chimney Mine is, chemically, quite similar to the OCF rocks hosting the Addington deposit, except for Cs and Ba (Tables 7 and 8). The absolute abundances as well as the K_2O/Na_2O , K_2O/CaO , CaO/Na_2O and the immobile element ratios are not significantly different. The chemistry of this biotite schist zone is compatible with either of these two origins:

- 1.- The rocks are metamorphosed interflow sediments (or mafic tuff); with or without a superimposed potassic alteration.
- 2.- The biotite schist is an altered equivalent of the surrounding amphibolite.

The isocon graphical method of Grant (1986) neither rules out nor confirms hypothesis 2 because the immobile element contents of the biotite schist are within the range of variation of the enclosing mafic lava flows. The biotite shows no evidence of reaction textures with other minerals; therefore the timing of any possible K-metasomatism, with respect to peak metamorphism, is similar to that at Addington Mine.

The high CO_2 content of the biotite schist from the mineralized zone, compared to the enclosing amphibolite, may be of sedimentary origin but alternatively suggests that gold and sulphide deposition was associated with a weak carbonatization of the wall rock.

Possible gold preconcentration mechanisms

The overlap in mineralogy of the pre-Flinton marble-hosted deposits, volcanic-hosted deposits and the deposits associated with the base of the Flinton Group (Table 1) suggest similar mineralizing fluids. This is supported by limited lead isotope data of Fletcher and Farquhar (1977, 1982) for deposits OCM, W and a marble-hosted base metal occurrence near Fernleigh not listed in Table 1. The Pb isotopic ratios of galenas from these deposits are fairly similar to each other and are the most radiogenic of the entire Central Metasedimentary Belt data set of these authors. They concluded that the genesis of these galenas required substantial interaction of the mineralizing fluid with the country rocks.

It is reasonable to speculate that the gold and the base metals were mechanically and/or chemically concentrated before being locally remobilized by metamorphic fluids during the main episode of metamorphism and deformation. Possible concentration mechanisms include eluvial-alluvial processes and synvolcanic-hydrothermal processes:

- 1.- Gold concentration in a paleosol derived from basaltic rocks has been documented by Martini (1986). Gold may have been concentrated in a regolith developed on TDF volcanics. This Au-enriched regolith may then have been transported and alluvially deposited as OCF sediments, thus providing an Au-enriched source bed for the gold deposits associated with the base of the Flinton Group and the OCF (Group III deposits; Table 1 and Fig. 2).
- 2.- Gold-arsenic occurrences (A-E, Table 1 and Fig. 2) probably of volcanic-exhalative origin, occur well within the TDF, associated with interflow sediments. Although it

is possible that this mechanism was a preconcentration of Au at Addington Mine, the absence of documented interflow sediments in the vicinity makes this suggestion highly speculative.

3.- Gold may have been deposited as volcanic- and/or, sediment-hosted epithermal vein deposits (Park and MacDiarmid, 1970) prior to the main metamorphic event.

4.- Marble-hosted gold deposits of Group II (Table 1 and Fig. 2) are all associated with at least one shallow intrusion, or are close to the contact with the underlying volcanics. The presence of an abundance of small mafic to intermediate intrusions within the sedimentary clastic and carbonate rocks intercalated with, and overlying, the volcanics of the Flinton-Fernleigh area indicates that igneous activity was continuing at the time of sedimentation, providing thermal energy for hydrothermal systems. Gold may have been leached from the underlying volcanics, in a process similar to that occurring in modern ocean floor basalts (Nesbitt *et al.*, 1987), and precipitated with sediments. Such a process may have contributed to the genesis of the volcanic-hosted gold deposits of Group I (Table 1 and Fig. 2), and more specifically to the genesis of the Ore Chimney deposit. This hypothesis is supported by the occurrence of marble and calcitic schist in the southern part of the Ore Chimney Mine property, below the OCF (Fig. 5), and by the location of this deposit close to the inferred top of the TDF in the area.

The formation of the two significant gold deposits near the base of, and immediately below, the Flinton Group may be related to

the difference between the mechanical properties of the coarse clastic sediments of the Flinton Group and the underlying rocks, and to the presence of a regional unconformity. Mills and Eyrich (1966) have stressed the role of unconformities as potential plumbing systems. The regional unconformity may have focussed the discharge of the mineralizing fluids.

Probable porosity and permeability contrasts between the pre-Flinton rocks and the clastic sediments of the Flinton Group raise the possibility that vein formation through hydraulic fracturing occurred. Approximately 5 wt % structural water is released from a rock of basaltic composition during metamorphic outgassing at the greenschist-amphibolite transition (Fyfe and Kerrich, 1984). A possible, although unproven, scenario would be: the fluid escaping from the TDF volcanics was trapped below impermeable quartzite of the Bishop Corners Formation and accumulated within the OCF. As pore fluid accumulation increased, the overpressure became so severe that brittle failure resulted. As the pore fluids created more porosity and eventually permeability for themselves, vein formation occurred.

Composition of the mineralizing fluid

The nearest well-documented gold deposits are the small Cu-Sb-Au-Ag deposits of the Lavant-Darling area (20 km northeast of Clarendon Township, Fig. 1) studied by Carter (1981, 1984). They consist of stratabound networks of dolomitic marble-hosted quartz-dolomite veins occurring in greenschist facies rocks within a major shear zone. Carter concluded, based mainly on fluid inclusion studies, that vein formation was late and that the mineralizing fluid was a metamorphic fluid, initially CO₂-rich which evolved into an aqueous brine of variable salinity (with 5-25 wt % equivalent NaCl); vein formation and mineralization in the Lavant-Darling area occur-

red between 140 and 400°C at 0.3 GPa or less. Carter's contention that the contained metals were derived by remobilization of pre-existing concentrations of metallic sulphides in the host rocks and that the gold deposits of the Flinton-Fernleigh area were formed in a way similar to those of the Lavant-Darling area, although possible, is not supported by any geological nor geochemical study. Differences in the structural setting, lithology and P-T features of these two concentrations of deposits weaken this contention.

At the Addington and Ore Chimney deposits the gold- and sulphide-bearing quartz veins exhibit comparable strain and fold geometry to their host rocks, indicating that they were present throughout most of the deformation history. Although approximately concordant to the main regional, axial plane foliation, they locally cut the schistosity (Fig. 7), suggesting that these veins were synchronous with deformation (D_1). At the Addington Mine, garnet porphyroblasts overgrowing the foliation have sulphide and tourmaline inclusions, indicating that metamorphism outlasted the mineralizing event. The agreement between arsenopyrite geothermometry (420-530°C) and garnet-biotite geothermometry (475-535°C) and between sphalerite geobarometry (0.35-0.59 GPa) and the pressure range deduced from metamorphic mineral assemblages (0.4-0.5 GPa) suggests that the gold- and sulphide-bearing quartz veins were formed near peak metamorphic conditions and that the mineralizing fluid was a supercritical metamorphic fluid. The absence of post-peak metamorphic hydrothermal activity, and the close association of gold with the sulphide-bearing veins suggest that gold and base metals were transported and deposited by the same fluid.

The composition of the ore-forming fluid and the physico-chemical conditions under which gold was carried and deposited can-

not be accurately specified. However, some generalizations and inferences can be made using experimental and calculated data on gold solubility in hydrothermal systems (Seward, 1973, 1984; Cathles, 1986; Romberger, 1986), and by analogy with known Archean and modern ore-forming environments. Seward (1973, 1984) has shown that Au^+ complexes are by far predominant over other gold complexes in aqueous solutions at high temperatures and pressures, and ore-forming fluids are generally not more than 1.5 pH unit removed from neutral (Seward, 1984).

The assemblage pyrite + pyrrhotite ± arsenopyrite occurs at conditions of relatively low oxygen fugacity ($<10^{-20}$ at 500°C and 0.5 GPa; Fröese, 1976) and high sulphur fugacity ($10^{-3.5}$ at 500°C and 0.5 GPa; Toulmin and Barton, 1964; Sharp *et al.*, 1985). In such reduced conditions gold is soluble as a bisulphide complex over a wide range of pH (Romberger, 1986). The most important of these complexes are HS^- and S^{2-} . Possibly, thioarsenide ligands such as AsS_2^- or $\text{As}_2\text{S}_4^{2-}$ may carry gold in reduced hydrothermal fluids; however, their stability limits (Romberger, 1986) are unknown, and their existence in nature has not been demonstrated. Gold is also soluble as chloride complexes (Henley, 1973).

The high carbonate content of the mineralized zones at both deposits raises the possibility that gold could have been carried as CO (carbonyl) complexes (Fyfe and Kerrich, 1984). However, because the carbonyl bond with Au(I) is weak, Seward (1984) considers that these complexes do not contribute significantly to gold transportation.

Experimental and calculated solubilities for gold indicate that slightly alkaline solutions with low concentrations of total sulphur are capable of transporting gold in comparatively high concentration

as thio-complexes at low oxygen fugacity; chloride complexes are capable of carrying a significant quantity of gold in acid oxidizing solutions. Solubility of gold decreases as the departure from these conditions increases (Henley, 1973; Seward, 1973, 1984; Cathles, 1986; Romberger, 1986).

Mechanisms of gold deposition

Mechanisms of precipitation of gold include: (1) a decrease or increase in pH, (2) dilution or reduction of the activity of the ligand species carrying gold, and (3) changes in the redox conditions of the fluid (Henley, 1973; Cathles, 1986; Romberger, 1986; see also Barnes, 1979).

The Addington and Orc Chimney deposits are stratigraphically 0-10 m and 30 m, respectively, below the Bishop Corners Formation. The mafic volcanics and the OCF (hornblende, biotite, garnet, staurolite, epidote, iron sulphides, ilmenite, magnetite) are more reduced than the overlying magnetite- and hematite-bearing coarse clastic sediments, thus there is a redox front, a rather sharp change in redox properties of the rocks at the boundary between the OCF and the Bishop Corners Formation.

It is suggested that this redox front played a major role in gold deposition of the two deposits studied in this paper, and therefore that process (3) was the predominant mechanism of gold deposition. As the circulating gold-bearing fluid approached the redox front, oxidation of the fluid caused destabilization of the Au-carrying complexes and precipitation of gold under pyrite-pyrrhotite equilibrium conditions. However, precipitation of gold by a combination of the three processes mentioned above is not ruled out.

CONCLUSIONS

Mineralization and vein formation at the Addington and Ore Chimney gold deposits occurred during the main episode of deformation (D_1) and near peak metamorphism (475-535°C and 0.4 to 0.5 GPa).

Gold was carried under reduced conditions in a metamorphic fluid, which was most likely focussed through the unconformity plumbing system. The redox front at the boundary between the OCF and the Bishop Corners Formation may have been a major factor in gold deposition. The mineralizing process was associated with a weak carbonatization of the wall rock. Gold and base metals may have been remobilized from pre-existing concentrations.

The Flinton-Fernleigh area has not yet been explored to the extent that the presence of potentially economic gold deposits can be discounted. Moreover, the presence of a sub-economic gold deposit, such as the Addington Mine, in this area raises the possibility that larger and/or higher grade gold deposits might exist. Future exploration work should be directed primarily towards carbonatized biotite schists near or at the base of the Flinton Group, where it overlies mafic volcanic rocks. The occurrence of several marble-hosted gold deposits, such as the formerly producing Star Mine (deposit J; Table 1 and Fig. 2), near the contact with the volcanic rocks suggests that this contact is also an interesting target. The highest gold potential in the region may occur where this contact is overlain by rocks of the Flinton Group.

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SUMMARY OF CONCLUSIONS

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Trace element discriminant plots of the Tudor formation (TDF; tholeiitic metabasalts) are consistent with either a mid-ocean ridge or an island arc setting. However, discriminant plots of the Kashwakamak formation (KWF; intermediate to felsic calc-alkaline metavolcanics) felsic volcanics indicate an island arc origin. Trace element data (including REE) indicate that the TDF volcanic rocks are not derived from a single parental magma, through fractional crystallization, nor can KWF rocks be derived from TDF by this means. Variations in incompatible element ratios of the TDF volcanics may have been caused through selective contamination by continental crust material, or through partial fusion of a heterogeneous Proterozoic upper mantle and erupted on oceanic crust.

The KWF intermediate to felsic volcanics cannot be derived from the upper mantle by partial melting and fractional crystallization, and they cannot be derived by fractional crystallization of the TDF basalts. The origin of the KWF volcanics is best explained by partial melting of siliceous garnet granulite in the lower crust.

The metapelitic Ore Chimney Formation is locally derived from the underlying metavolcanics. The presence of quartzite and quartz pebble-rich layers within the Ore Chimney Formation, its folding and the absence of a folded fabric within it, strongly suggest that this Formation is a metasediment (reworked residual or detrital) and argue against a shear zone origin.

The trace element ratios of the overlying Bishop Corners Formation (quartzite, metapsammite, metaconglomerate) indicate that these metasediments are derived from a source having a granitic composition. Granitoid batholiths such as the nearby Northbrook and Elzevir plutons are a possible source of these metasediments.

Mineralization and vein formation at the Addington and Ore Chimney gold deposits occurred during the main episode of deformation (D_1) and near peak metamorphism (475-535°C and 0.4 to 0.5 GPa). Gold was carried under reduced conditions in a metamorphic fluid and focussed through the unconformity plumbing system. The mineralizing process was associated with a weak carbonatization of the wall rock. Gold and base metals may have been remobilized from pre-existing concentrations.

A P P E N D I X I

PETROGRAPHY AND SAMPLE LOCALITIES

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Petrography

Petrography of samples analysed in this study is given in Tables A1.1 and A1.2. All rocks are metamorphosed. No point counting has been done, and it should be stressed that the percentages listed in these tables are only semi-quantitative. Unless otherwise stated, the mineralogical identification is based on microscope (transmitted and reflected light) and electron microprobe work.

Underground samples from Ore Chimney Mine are labelled as follows.

OSH-1 to -5: mine shaft, depth <30 metres.

OSH-9 to -60: mine shaft, sample number is the depth in feet.

OL108-XX: level 108-foot.

OL150-XX: level 150-foot.

Samples from Addington Mine.

The sample numbers are footage from the drill hole collar.

Sample localities

Localities of samples from the Addington Mine (DDH 81-6, DDH 82-3) are described in Chapter II. All other samples are plotted on detailed maps (Figs. A1.1 to A1.4) in back pocket.

TABLE A1.1 (continued)

Lab. no	Field no	Qtz	Pl	Kfs	Act	Hbl	Cum	Bt	Ms	Chl	Grt	St	Ky	Rt	Tur	Ap	Ep	Hem	Zrn	Tm	Cb	Op
61	84-4-13	24	38	2				12	12	1					1	1		tr				tr
62	84-4-15	38	46					10	3	1					2							tr
63	84-5-1	-50						39									4			5		2
64	84-5-3	5	20					39	27								8					1
65	84-5-5	10	45					15	30						1	tr						tr
66	84-5-10	-38				50		9									2					1
67	584.4	-68						17	12	tr					1	tr	tr			1		2
68	586.2	-44						24	19		2				3	1	3	tr		tr		3
69	594.1	5	10			40		25	15													2
70	604.1	15	5			5		30	18								tr			4		2
71	605.4	1	30			58		10												5		2
72	606.55	10	3			32		40	12		2											1
73	612.6	13	5			40		30	8		tr											2
74	612.8	26	40					5	7						3							2
75	613.7	6				1		24	52	1	tr				20							2
76	614.85	-8			37			2	2						8							6
77	615.7	7													37					10		5
78	616.2	-29			29				1						85							8
79	617.9	-37				50		2							38					tr		3
80	620.2	-12			75			3	1						5					2		3
81	850.0	53	18					12	12	1					tr					tr		4
82	860.8	55	15					16	11						tr							1
83	862.55	1	6			28		19	40						tr				tr			2
84	863.2	3	21			1		29	8	tr					30							5
85	866.4	8	10			tr		40	35	tr	1				2							8
86	868.9	1	8			1		30	15	tr					30							5
87	871.9	13	28			15		30	10						3							15
88	876.3	-65				6		20	3	5												2
89	878.4	3	11					40		3			10	30	2							1
90	891.65	5	29			31		33							1	tr					tr	1

TABLE A1.1 (continued)

Lab. no	Field no	Qtz	Pl	Kfs	Act	Hbl	Cum	Bt	Ms	Chl	Grt	St	Ky	Rt	Tur	Ap	Ep	Hem	Zrn	Tm	Cb	Op
129	B-9-1	- 20 -					53	14									6			6	1	
130	658.6	- 25 -					40	7	20											6	2	
131	B-1-19	- 78 -					10											tr		1	12	
132	B-10-1	- 60 -					25	10							1		2				2	
133	H85-1	91						5	2							tr		tr			2	

Mineral abbreviations:

Act: actinolite

Ap: apatite

Bt: biotite

Cb: carbonate

Chl: chlorite

Cum: cummingtonite

Ep: epidote

Grt: garnet

Hem: hematite

Hbl: hornblende

Ky: kyanite

Ms: muscovite

Op: opaque

Pl: plagioclase feldspar

Kfs: potassic feldspar

Qtz: quartz

Rt: rutile

St: staurolite

Tm: titanite

Tur: tourmaline

Zrn: zircon

Remarks:

Sample 13: dyke (?).

Sample 30: the opaque minerals are magnetite and minor hematite.

Sample 31, 33, 131: quartzofeldspathic interflow sediments, the opaque mineral in sample 33 is pyrrhotite.

Sample 35: chlorite schist lens.

Samples 35, 36, 37, 38, 39, 63, 64, 65, 124, 129, 130, 131, 132: mafic tuff, interflow sediments or shear zone rocks.

Samples 40, 42, 43, 46: mafic tuff, interflow sediments, shear zone rocks or mafic metavolcanics.

Sample 58: one metre thick amphibolite layer between the Northbrook batholith and the Bishop Corners Formation.

Sample 59: contains traces of allanite.

Sample 62: the opaque mineral is pyrite.

Sample 77: quartz-tourmaline vein; the opaque minerals are pyrite, chalcopyrite and ilmenite.

Sample 84: the opaque minerals are arsenopyrite, pyrite, ilmenite, chalcopyrite, marcasite and pyrrhotite.

Sample 86: the opaque minerals are arsenopyrite and ilmenite.

Sample 87: the opaque minerals are arsenopyrite, pyrrhotite, ilmenite, marcasite and chalcopyrite.

Sample 112: the opaque minerals are magnetite and ilmenite.

Sample 131: the opaque minerals are pyrrhotite, chalcopyrite (traces) and sphalerite (traces).

TABLE A1.2: MINERALOGICAL COMPOSITION OF SAMPLES 99-106 AND 134-154

Lab. no	Field no	Location	Total opaques	1- Opaque minerals 2- Gangue
99	OL108-2	OCMU	20%	Sp, Gn, Ccp, Py, Po, Tth, Mrc Qtz vein in a Ms schist
100	OL108-9	OCMU	50%	Sp, Gn, Ccp, Py, Po, Tth, Mrc Qtz vein with 10% Cb and 10% Bt
101	OSH-4	OCMU	60%	Sp, Gn, Mrc, Ccp, Py, Po, Tth Qtz vein; minor Bt and Chl
102	OSH-5	OCMU	20%	Sp, Mrc, Gn, Ccp, Py, Po Qtz vein; minor Bt, Ms and Chl
103	606.8	ADM1	5%	Py, Ilm, Ccp, Po Qtz-Tur vein
104	642.6	ADM1	15%	Py, Ilm, Ccp, Pb, Mrc Tur vein; minor Act
105	886.6	ADM2	5%	Apy, Ilm, Ccp, Py, Po Qtz-Cb-Tur vein
106	890.0	ADM2	10%	Apy, Ilm, traces of gold and Bmt Qtz-Tur vein; minor Ms
134	OL150-9	OCMU	5%	Ccp, Gn, traces of Po, Mr and Py Qtz vein; 15-20% Bt, minor Cb
135	OL150-24	OCMU	<1%	Ccp Qtz vein
136	OL150-61	OCMU	50%	Mrc, Ccp, Gn, Py, Sp Bt-Ms schist
137	OL150-72a	OCMU	<1%	Traces of Py, Gn, Po and Sp Qtz vein in a Grt-bearing Chl-Bt schist
138	OL150-72b	OCMU	<1%	Traces of Gn Qtz vein; 1-9% Chl, traces of Grt, Hbl and Bt
139	OL150-87	OCMU	0%	---
140	OSH-1	OCMU	25%	Qtz vein; minor Hbl, traces of Bt Ccp, Mrc, Sp, Gn, Py, Tth
141	OSH-9	OCMU	15%	Qtz vein; minor Chl, Ms and Bt Sp, Gn, Apy, Po, Mrc, Ccp, Py, Tth, Ilm
142*	OSH-12	OCMU	0%	Qtz vein; minor Cb ---
143	OSH-37	OCMU	0%	Qtz vein ---
144	OSH-60	OCMU	1%	Qtz vein; 1% Ms Ccp, Ilm, Po
145	602.8	ADM1	5%	Qtz vein; minor Bt Py, Ccp, Ilm
146*	606.8	ADM1	<1%	Qtz-Tur vein; 15% Act, minor Cb Py
147	607.2	ADM1	30%	Qtz vein; 10-20% Tur Py, Ilm, Ccp, Po
148	610.3	ADM1	<1%	Qtz-Tur vein Py, Ccp, Po, Ilm
149	646.7	ADM1	<1%	Qtz-Tur vein; Cb <1% Ccp, Py
150	862.0	ADM2	10%	Qtz vein; 1% Tur Apy, Ilm, Mrc
151	869.7	ADM2	5%	Tur vein Apy, Ilm, Py, Ccp, Po
152	883.6	ADM2	3%	Qtz-Tur vein Apy, Py, Ilm, Po, Ccp, Mrc
153	885.5	ADM2	5%	Tur vein; minor Bt and Act Apy
154	892.8	ADM2	1%	Qtz-Tur vein; minor Bt and Cb, traces of Rt Ccp, Py Qtz vein in schist

ADM1: Addington Mine, DDH81-6. ADM2: Addington Mine, DDH82-3. OCMU: Ore Chimney Mine.
 *: hand sample description. The opaque minerals are listed in order of decreasing abundance. The approximate total volume of opaque minerals in each sample is also given.
 Mineral abbreviations:

Act: actinolite	Ccp: chalcopyrite	Mrc: marcasite	Rt: rutile
Apy: arsenopyrite	Gn: galena	Ms: muscovite	Sp: sphalerite
Bt: biotite	Grt: garnet	Po: pyrrhotite	Tur: tourmaline
Bmt: bismuthinite	Hbl: hornblende	Py: pyrite	
Cb: carbonate	Ilm: ilmenite	Qtz: quartz	

APPENDIX II

ANALYTICAL PROCEDURES AND CHEMICAL DATA

ANALYTICAL PROCEDURES AND CHEMICAL DATA

Analytical procedures

All analyses, except volatiles, were done by the author. Major elements, Ba, Cr, Nb, Ni, Rb, Sr, Y, Zn and Zr were determined by X-ray fluorescence (XRF) at the University of Ottawa on a fused glass disk containing 1.300 g rock powder, 3.900 g lithium tetraborate ($\text{Li}_2\text{B}_4\text{O}_7$) and 0.433 g lithium carbonate (Li_2CO_3) by means of a fully automated Phillips PW 1410 spectrometer.

Co, Cs, Hf, Sc, Th, U, La, Ce, Nd, Sm, Eu, Tb, Yb and Lu were determined by instrumental neutron activation analysis (INAA; Muecke, 1980) at Université du Québec à Montréal (UQAM). A coaxial Gamma-X HPGe (N-type) detector (resolution= 1.80 keV at 1.333 MeV; efficiency= 10% at 1.333 MeV) coupled to a ORTEC 7010 multichannel analyser (4096 channels; calibrated at 0.40 keV/channel) was used. Samples were irradiated at the nuclear reactor of McMaster University (Hamilton, Ontario) in the RIFLS tubes during 4 to 6 hours at the 2 MW power position. Cerium was determined by enclosing the Fe-Ce doublets (^{59}Fe at 142 keV and ^{141}Ce at 146 keV) between the peak limits and using the photopeak areas of Fe as monitors (Jagan and Muecke, 1980). The iron photopeak ratios measured at UQAM NAA laboratory were: 142 keV/192 keV= 0.40, 142 keV/1099 keV= 0.10, 142 keV/1291 keV= 0.15.

CO_2 , H_2O and S were determined at the Geological Survey of Canada (Ottawa) by volatilization and non-dispersive infrared absorptiometry (Bouvier and Abbey, 1980). Prior to any chemical analysis, the powdered samples were dried at 110°C in an oven so that the water reported as $\text{H}_2\text{O}^{\text{T}}$ is essentially structural water.

As and Ga were determined by direct current plasma atomic emission spectroscopy (DCP-AES) using a Beckman Instruments Spectraspan V. Ag, Cu and Pb were determined by atomic absorption spectroscopy

(AAS) using a Varian Techtron AA-175 unit. In both methods, a HF-HClO₄ decomposition procedure was used. Sb was determined by DCP-AES or INAA. Li was determined by AAS using a calibration curve made up of natural standards. Ferrous iron was determined by a modified cold Wilson method (Johnson and Maxwell, 1981). The method recommended by Ito, (1962) for decomposition of refractory minerals gave inconsistent results, which is in agreement with the conclusion of Sulcek *et al.* (1977). Thus, the separated staurolite residues of rock decomposition were dissolved in a Teflon-lined steel bomb (Johnson and Maxwell, 1981) and analysed independently. Ferric iron is taken as the difference between total iron and ferrous iron ($\text{Fe}_2\text{O}_3 = \text{Fe}_2\text{O}_3^T - [\text{FeO} \times 1.1113]$). Au in 10 g aliquots (aqua regia dissolution procedure) was determined by flameless atomic absorption spectroscopy (FAAS) using a Varian Techtron AA-5 graphitic furnace (Culver, 1975). All DCP-AES, AAS and FAAS analyses were performed at the University of Ottawa.

Data, accuracy, precision and detection limits

The results of chemical analyses are listed in Tables AII.1 to AII.17. Accuracy and precision for each element, based on repeated analysis of international standards, are given in Tables AII.18 to AII.22. Accuracy is generally satisfactory where the element is present in sufficient amount. However the accuracy, precision and detection limit of V are unsatisfactory. For most elements, precision is as good as, or better than, accuracy. Detection limits of selected elements are listed in Table AII.22. They are estimated from (1) repeated analyses of diluted aliquots of samples and standard sample solutions (DCP-AES, AAS, FAAS); (2) analyses of blanks (DCP-AES, AAS, FAAS); (3) peak to background ratio (INAA).

Tables AII.1-AII.14. ADM1: Addington Mine, DDH 81-6. ADM2: Addington Mine, DDH 82-3. OCMS: Ore Chimney Mine, surface sample. OCMU: Ore Chimney Mine, underground sample. HARL: Harlowe. REID: Reid Lakes. BCF: Bishop Corners Formation. OCF: Ore Chimney Formation. TDF: Tudor formation. KWF: Kashwakamak formation. Samples 99-106 are vein material and associated wall rock material; they are not assigned to any specific formation. Dist. UNC: distance (+: above; -: below) from the regional angular unconformity. UTM: Universal Transverse Mercator Co-ordinates, grid 18. All values for major elements and volatiles are in weight per cent. Gold values are in parts per billion (ppb). All other trace element abundances are in parts per million (ppm). *: total iron as FeO . CO_2^T is total carbon as CO_2 . H_2O^T is total water. n.d.: not determined. --: not detected. The normative mineralogy of metamorphosed rocks of undoubted igneous origin is given in weight per cent. The iron oxidation ratio of the CIPW norm was normalized according to the method of Irvine and Baragar (1971). Samples 129, 130, 131 and 132: V determined by XRF.

TABLE AII.1: ANALYTICAL DATA FOR SAMPLES 1-10

Sample No	-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-
Location	HARL	HARL	HARL	HARL	HARL	HARL	HARL	HARL	HARL	HARL
Formation	OCF	OCF	OCF	OCF	KWF	KWF	KWF	KWF	KWF	KWF
Dist. UNC	5.95	5.80	3.97	1.68	-1.83	-3.36	-5.80	-16.2	-263	-260
UTM	360620	360620	360620	360620	360620	360620	360620	360620	360624	360624
SiO ₂	77.93	49.93	67.00	67.68	51.77	53.56	57.45	53.31	69.43	66.28
Al ₂ O ₃	8.57	19.44	12.66	16.35	15.67	17.98	17.53	14.55	15.37	16.93
Fe ₂ O ₃	1.67	3.10	1.52	0.75	1.17	1.56	1.07	1.68	1.53	3.46
FeO	4.32	10.36	8.14	3.53	7.15	6.38	5.29	6.97	0.96	0.05
MgO	1.78	6.27	2.62	2.57	6.00	5.00	4.49	8.07	0.71	1.27
CaO	1.81	1.51	1.70	1.56	7.54	7.40	6.09	7.44	2.13	3.01
Na ₂ O	1.07	0.29	0.59	0.99	4.39	5.68	6.22	1.91	3.85	3.47
K ₂ O	1.51	3.04	2.91	4.36	0.21	0.08	0.05	1.53	3.12	2.92
TiO ₂	0.33	2.49	0.69	0.50	1.45	0.91	0.80	1.22	0.33	0.63
P ₂ O ₅	0.13	0.64	0.21	0.25	0.97	0.21	0.31	0.56	0.10	0.12
MnO	0.06	0.15	0.09	0.04	0.11	0.12	0.10	0.16	0.04	0.04
S	--	--	0.02	--	0.05	--	0.01	0.01	--	--
CO ₂ T	0.10	--	--	0.10	0.30	--	--	--	1.00	0.60
H ₂ O _T	0.70	3.20	1.60	2.20	0.90	0.70	0.60	1.60	1.10	1.10
TOTAL	99.98	100.42	99.75	100.88	97.68	99.58	100.01	99.01	99.67	99.88
Normative minerals										
Qtz	--	--	--	--	2.5	0	2.0	8.4	30.5	27.4
Crn	--	--	--	--	0	0	0	0	2.1	2.9
Or	--	--	--	--	1.3	0.5	0.3	9.3	18.9	17.6
Ab	--	--	--	--	38.5	48.6	52.9	16.6	33.4	29.9
An	--	--	--	--	23.2	23.6	19.9	27.3	10.2	14.5
Ne	--	--	--	--	0	0	0	0	0	0
Cpx	--	--	--	--	7.2	9.9	6.8	5.5	0	0
Opx	--	--	--	--	17.6	3.5	12.5	25.2	1.8	3.2
Hem	--	--	--	--	0	0	0	0	0.9	0.5
Ol	--	--	--	--	0	8.2	0	0	0	0
Mag	--	--	--	--	4.4	3.5	3.4	4.0	1.4	2.4
Ilm	--	--	--	--	2.9	1.7	1.5	2.4	0.6	1.2
Ap	--	--	--	--	2.4	0.5	0.7	1.4	0.2	0.3
Trace elements										
Ag	--	6	3	--	--	--	--	--	--	--
As	--	--	--	--	<1	1	<1	18	--	--
Au (ppb)	--	--	<12	<12	<12	16	--	--	<12	--
Ba	388	388	548	848	107	67	38	239	710	395
Co	13	54	13	13	31	29	24	39	6	9
Cr	122	354	163	72	158	151	115	409	60	61
Cs	4.2	2.9	3.9	3.9	1.2	0.33	<0.3	1.6	1.5	1.7
Cu	4	9	84	14	29	14	33	38	12	13
Ga	14	14	19	26	24	22	18	17	18	21
Hf	0.4	13	10	12	16	10	9	14	11	11
Li	16	29	21	18	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Nb	5	5	<5	8	11	5	<5	6	7	<5
Ni	42	103	975	39	56	28	139	6	10	10
Pb	3	3	4	3	3	--	--	3	2	2
Rb	48	82	87	78	--	--	--	42	80	61
Sb	2	2	2	2	<1	<1	<1	<1	1	1
Sc	10	40	14	6	23	27	23	25	4	8
Sr	156	61	75	97	819	701	660	294	281	279
Th	12	5.2	13	26	30	15	15	20	46	19
U	10	8.4	18	8.8	--	--	--	--	2.2	--
V	n.d.	n.d.	n.d.	117	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Y	22	30	45	17	31	25	24	30	12	15
Zn	132	560	348	111	109	103	92	137	40	39
Zr	80	149	127	171	269	138	133	184	149	144
La	3.39	11.74	24.46	23.63	53.74	21.42	19.11	37.71	21.20	11.02
Ce	n.d.	34.43	65.28	68.48	136.84	58.37	54.78	98.56	n.d.	31.55
Sm	2.96	6.89	9.39	6.70	12.94	5.60	4.03	10.46	3.78	4.03
Eu	0.72	1.55	1.87	1.25	3.81	1.70	1.57	3.14	1.11	0.95
Tb	5.60	0.81	1.30	0.91	1.47	0.91	0.74	1.30	0.74	0.63
Yb	2.24	2.37	4.43	1.80	2.27	1.70	1.70	2.44	0.91	1.15
Lu	0.46	0.61	0.77	0.34	0.30	0.31	0.25	0.34	0.27	0.20

TABLE A11.2: ANALYTICAL DATA FOR SAMPLES 11-20

Sample No	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-	-19-	-20-
Location	HARL	HARL	OCMS	OCMS	OCMS	OCMS	OCMS	OCMS	OCMS	OCMS
Formation	KWF	KWF	TDF	BCF	TDF	TDF	TDF	TDF	TDF	TDF
Dist. UNC	-320	-321	n.d.	6.33	-12.6	-4.47	-1.87	-0.47	-0.24	-0.20
UTM	361625	361624	298602	299603	299603	299603	299603	299603	299603	299603
SiO ₂	71.16	74.97	67.76	66.18	50.59	50.80	57.24	48.63	49.67	49.94
Al ₂ O ₃	15.03	13.78	15.80	10.53	16.03	16.36	14.30	16.25	16.82	16.21
Fe ₂ O ₃	0.93	0.48	3.10	5.72	3.44	4.82	4.86	4.35	5.28	4.52
FeO	0.97	0.23	0.76	5.64	8.62	7.42	4.91	8.70	7.97	7.26
MgO	0.66	0.08	1.98	2.94	4.75	4.95	3.11	5.41	5.30	4.70
CaO	2.31	1.78	2.54	2.34	8.52	8.05	11.90	6.97	6.25	8.47
Na ₂ O	4.80	5.07	3.77	1.06	2.80	3.08	0.92	2.25	2.53	2.48
K ₂ O	1.46	1.31	2.52	2.47	1.16	1.34	0.15	3.08	3.04	1.76
TiO ₂	0.22	0.13	0.47	1.00	0.93	0.95	0.77	0.96	0.93	0.89
P ₂ O ₅	0.11	0.05	0.18	0.13	0.14	0.18	0.02	0.22	0.15	0.13
MnO	0.05	0.03	0.04	0.18	0.20	0.20	0.17	0.19	0.17	0.21
S	--	--	--	--	--	--	--	--	--	0.01
CO ₂ T	1.00	1.00	--	0.20	0.70	0.10	0.10	1.60	1.20	1.90
H ₂ O _T	1.00	-0.60	0.90	1.60	1.40	1.40	1.10	1.70	1.60	1.40
TOTAL	99.70	99.51	99.82	99.99	99.28	99.65	99.55	100.71	100.91	99.88
Normative minerals										
Qtz	32.8	37.1	28.2		1.6	0	22.2	0	0	0.7
Crn	1.7	0.9	2.7		0	0	0	0	0	0
Or	8.9	7.9	15.1		7.1	8.1	0.9	18.8	18.4	10.8
Ab	41.4	43.4	32.3		24.4	26.6	7.9	19.7	21.9	21.8
An	11.1	8.7	11.6		28.6	27.4	35.1	26.0	26.1	29.0
Ne	0	0	0		0	0	0	0	0	0
Cpx	0	0	0		11.7	10.1	20.8	6.9	3.8	11.5
Opx	1.7	0.2	5.9		21.0	21.1	8.1	10.7	12.8	20.6
Hem	1.5	1.7	0		0	0	0	0	0	0
Ol	0	0	0		0	0.7	0	11.8	11.2	0
Mag	0.3	0	2.9		3.6	3.6	3.4	3.7	3.6	3.6
Ilm	0.4	0	0.9		1.8	1.8	1.5	1.9	1.8	1.8
Ap	0.3	0.1	0.4		0.3	0.4	0	0.5	0.4	0.3
Trace elements										
Ag	3	--	3	--	--	3	3	3	--	3
As	1	<1	3	--	1	2	2	--	--	--
Au (ppb)	<12	<12	--	--	--	<12	--	<12	<12	21
Ba	250	278	376	283	286	325	40	569	462	287
Co	3	1	10	45	36	46	25	48	36	35
Cr	92	73	56	195	70	61	83	66	63	72
Cs	1.4	0.6	1.1	6.0	0.6	1.6	0.6	5.3	4.8	2.1
Cu	4	4	3	5	13	114	28	104	37	165
Ga	18	22	27	21	23	22	24	27	29	25
Hf	11	9.2	4.0	4.5	1.8	1.4	1.6	1.7	1.1	4.0
Li	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Nb	7	7	7	--	--	<5	<5	--	<5	<5
Ni	6	4	6	60	16	19	15	8	12	23
Pb	2	2	2	3	2	2	4	2	2	2
Rb	39	29	69	105	30	32	--	85	79	40
Sb	<1	1	--	--	--	--	<3	<3	3	1
Sc	2	2	7	30	35	36	29	33	35	33
Sr	181	113	166	320	334	254	436	210	187	237
Th	30	52	4.9	3.7	0.9	0.6	0.6	1.2	1.1	3.2
U	7.2	18	1.4	3.0	n.d.	<0.5	0.9	0.9	0.8	2.8
V	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Y	21	23	11	16	27	28	28	28	26	29
Zn	33	33	65	111	117	147	73	121	126	106
Zr	152	119	162	141	54	58	54	57	95	52
La	44.12	39.40	31.17	3.81	6.85	7.17	6.09	6.92	6.78	5.13
Ce	81.28	75.52	67.84	n.d.	20.10	14.21	21.95	n.d.	20.03	17.56
Sm	6.63	6.27	4.52	2.29	2.46	4.56	3.77	3.52	4.65	3.08
Eu	1.33	1.08	1.20	0.78	1.62	1.28	1.10	1.35	1.13	1.03
Tb	0.98	1.02	n.d.	0.38	n.d.	0.53	0.55	0.55	0.55	0.77
Yb	1.46	1.16	1.61	1.91	2.26	1.79	1.55	1.77	1.65	2.09
Lu	0.39	0.28	0.17	0.44	1.67	0.32	0.27	0.39	0.31	0.42

TABLE A11.3: ANALYTICAL DATA FOR SAMPLES 21-30

170

Sample No	-21-	-22-	-23-	-24-	-25-	-26-	-27-	-28-	-29-	-30-
Location	OCMS	OCMS	OCMS	OCMS	OCMS	HARL	OCMS	OCMS	OCMS	OCMS
Formation	TDF	TDF	OCF	OCF	OCF	OCF	TDF	TDF	TDF	BCF
Dist. UNC	-0.13	-0.04	0.13	0.21	2.43	1.00	-131	-121	-83.8	n.d.
UTM	299603	299603	299603	299603	299603	360620	298604	298604	298604	298602
SiO ₂	49.30	46.26	48.24	49.92	52.63	61.27	49.40	52.38	53.61	57.49
Al ₂ O ₃	16.70	16.94	16.24	15.69	15.67	22.11	13.13	14.33	15.11	11.71
Fe ₂ O ₃	2.68	4.15	2.84	1.85	3.30	0.81	3.07	3.35	2.25	11.62
FeO	8.73	9.87	9.80	8.77	7.27	4.55	11.12	10.04	9.05	6.35
MgO	4.46	5.85	5.04	4.80	5.12	4.83	6.38	5.21	4.06	3.87
CaO	7.84	6.85	6.20	6.55	6.08	0.74	9.25	7.99	8.43	1.30
Na ₂ O	2.33	1.50	0.69	1.27	0.68	0.77	2.69	3.17	2.99	1.09
K ₂ O	2.79	4.11	5.00	4.73	4.46	3.05	0.26	0.22	0.45	1.38
TiO ₂	0.90	0.95	0.91	0.86	0.87	0.74	1.49	1.24	0.94	0.81
P ₂ O ₅	0.16	0.21	0.21	0.19	0.20	0.21	--	--	0.13	0.24
MnO	0.18	0.18	0.20	0.20	0.19	0.08	0.25	0.19	0.18	0.09
S	--	--	--	--	0.20	--	--	0.12	0.01	0.07
CO ₂ T	2.50	1.90	2.20	3.40	1.20	--	0.40	0.20	0.60	0.50
H ₂ O _T	1.60	2.20	2.30	2.00	2.20	1.50	1.10	1.50	1.10	3.00
TOTAL	100.19	100.97	99.89	100.23	99.89	100.66	98.54	99.94	98.91	99.52
Normative minerals										
Qtz	0	0					1.2	4.7	8.2	
Crn	0	0						0	0	
Or	17.2	25.1					1.6	1.3	2.7	
Ab	20.5	13.0					23.5	27.4	26.0	
An	28.0	28.3					23.7	24.7	27.3	
Ne	0	0.1					0	0	0	
Cpx	9.5	4.5					19.5	13.1	12.5	
Opx	14.3	0					23.1	22.3	17.5	
Hem	0	0					0	0	0	
Ol	4.6	22.9					0	0	0	
Mag	3.6	3.7					4.5	4.1	3.6	
Ilm	1.8	1.9					2.9	2.4	1.8	
Ap	0.4	0.5					0	0	0.3	
Trace elements										
Ag	3	3	3	3	--	3	--	--	--	--
As	--	--	--	--	--	--	<1	--	--	--
Au (ppb)	23	16	16	<12	44	--	--	--	<12	<12
Ba	563	670	682	593	390	477	62	77	117	307
Co	32	46	46	46	34	22	49	45	37	54
Cr	64	74	94	98	96	164	77	101	89	167
Cs	3.6	5.4	5.9	6.1	4.4	2.5	<0.5	<0.5	<0.5	0.6
Cu	70	37	3	4	114	4	20	77	105	46
Ga	28	26	26	25	25	16	25	26	26	25
Hf	4.8	4.8	4.8	4.0	4.0	8.4	4.4	4.8	4.4	10
Li	n.d.	n.d.	30	22	27	31	n.d.	n.d.	n.d.	35
Nb	--	--	<5	<5	--	5	--	--	--	--
Ni	12	16	19	23	17	42	12	21	24	83
Pb	2	3	2	4	4	2	--	4	2	8
Rb	65	96	128	123	131	74	--	--	5	31
Sb	1	2	2	3	2	1	2	<1	<1	2
Sc	34	36	32	29	27	17	46	38	32	17
Sr	208	137	102	116	283	181	154	168	279	2064
Th	4.4	5.2	4.0	2.8	5.2	6.4	2.8	2.4	2.4	16
U	--	6.8	1.6	2.0	1.2	6.0	2.0	3.2	--	11
V	n.d.	n.d.	365	336	296	n.d.	n.d.	n.d.	n.d.	219
Y	26	23	23	22	24	13	35	35	29	48
Zn	126	150	112	92	129	253	105	106	90	184
Zr	52	53	55	51	57	129	59	68	56	209
La	5.34	5.61	6.37	6.60	6.55	9.20	3.06	3.56	3.52	20.97
Ce	n.d.	n.d.	14.71	15.16	19.30	21.24	n.d.	13.09	n.d.	48.70
Sm	3.00	3.38	4.20	4.33	4.20	3.46	2.64	2.81	2.31	6.37
Eu	1.12	1.27	1.21	1.06	1.04	0.81	1.13	1.12	1.11	1.67
Tb	0.77	0.67	0.77	0.56	0.51	0.46	0.74	0.84	0.63	1.86
Yb	2.11	1.63	2.55	2.92	2.37	0.85	2.85	4.30	1.60	4.61
Lu	0.31	0.47	0.61	0.54	0.49	0.20	0.56	0.72	0.30	1.09

TABLE A11.4: ANALYTICAL DATA FOR SAMPLES 31-40

171

Sample No	-31-	-32-	-33-	-34-	-35-	-36-	-37-	-38-	-39-	-40-
Location	HARL	HARL	HARL	OCMS	OCMU	OCMU	OCMU	OCMU	OCMU	OCMU
Formation	OCF	OCF	KWF	BCF	TDF	TDF	TDF	TDF	TDF	TDF
Dist. UNC	0.13	0.43	-1.52	n.d.	-27.0	-28.0	-27.0	-27.0	-27.0	-30.0
UTM	360620	360620	360620	298599	298602	298602	298602	298602	298602	298602
SiO ₂	75.76	76.94	65.30	78.29	38.19	38.72	45.62	43.97	48.16	49.21
Al ₂ O ₃	10.82	11.74	11.79	7.76	19.34	15.98	15.68	15.52	16.50	15.86
Fe ₂ O ₃	0.65	1.36	n.d.	4.12	1.93	1.19	--	0.88	1.81	2.41
FeO	3.98	2.70	9.60*	2.43	12.77	11.36	11.56	9.62	10.28	9.94
MgO	1.47	0.98	3.72	2.29	9.76	6.34	4.50	4.11	4.09	6.12
CaO	2.44	1.18	2.28	0.19	5.85	7.52	5.46	7.91	5.67	8.72
Na ₂ O	0.79	0.68	2.49	0.22	2.40	0.34	0.42	0.87	0.69	3.19
K ₂ O	1.82	1.93	2.17	1.22	0.91	5.13	5.26	4.73	5.25	0.68
TiO ₂	0.33	0.49	0.61	0.95	1.10	0.87	0.87	0.91	0.92	0.86
P ₂ O ₅	0.04	0.10	0.26	0.17	0.15	0.14	0.19	0.16	0.25	0.12
MnO	0.04	0.03	0.07	0.06	0.17	0.21	0.18	0.18	0.14	0.36
S	0.08	--	3.71	0.01	0.01	0.37	0.80	0.26	0.67	0.02
CO ₂ T	--	0.10	1.50	0.10	2.7	6.90	2.90	4.40	3.40	1.50
H ₂ O ^T	1.30	1.00	2.20	2.00	5.1	3.30	3.20	2.50	3.30	1.50
TOTAL	99.52	99.23	101.80	99.81	100.38	98.61	96.64	96.02	101.13	100.49
Normative minerals										
Qtz										
Crn										
Or										
Ab										
An										
Ne										
Cpx										
Opx										
Hem										
Ol										
Mag										
Ilm										
Ap										
Trace elements										
Ag	--	3	--	--	3	4	79	81	4	3
As	--	2	--	--	--	--	--	--	2	<1
Au (ppb)	--	<12	--	--	--	40	78	71	19	<12
Ba	530	677	224	239	135	425	446	414	565	122
Co	5	6	26	25	53	41	12	38	38	43
Cr	118	114	180	161	574	51	125	98	70	54
Cs	2.7	1.7	1.6	1.6	1.0	2.1	1.4	0.4	1.5	0.8
Cu	28	29	56	30	35	11	57	370	38	52
Ga	18	12	14	17	34	28	25	22	24	21
Hf	13	11	9.6	20	4.4	3.2	4.4	4.8	4.0	4.4
Li	17	14	18	18	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Nb	8	6	<5	9	3	--	--	2	--	--
Ni	55	41	85	54	113	8	--	25	16	12
Pb	4	4	6	--	6	51	5244	10	295	5
Rb	60	44	59	36	17	110	87	92	104	14
Sb	2	1	<1	1	<1	2	4	<3	1	<1
Sc	9	13	1	11	28	33	33	33	31	31
Sr	107	87	127	82	306	154	161	259	160	437
Th	23	18	13	48	14	3.6	4.8	4.0	4.0	3.2
U	17	12	9.6	12	--	2.4	1.2	--	--	2.0
V	172	195	<100	<100	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Y	34	22	22	29	18	21	10	27	20	26
Zn	72	81	138	151	280	347	6873	975	1137	137
Zr	156	128	119	267	133	52	41	54	52	54
La	14.38	58.97	11.85	4.97	9.48	4.26	1.46	2.30	1.33	1.96
Ce	37.18	67.20	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sm	6.26	8.99	5.66	2.77	2.78	2.64	2.09	3.42	2.32	2.99
Eu	1.42	1.79	1.39	1.13	1.53	0.94	0.95	1.05	0.88	1.01
Tb	0.98	0.84	0.64	0.74	0.81	0.51	0.51	0.77	0.49	0.84
Yb	2.79	2.57	1.48	3.06	1.21	2.00	1.83	2.44	2.72	2.24
Lu	0.71	0.41	0.34	0.77	0.19	0.33	0.40	0.63	0.50	0.33

TABLE A11.5: ANALYTICAL DATA FOR SAMPLES 41-50

172

Sample No	-41-	-42-	-43-	-44-	-45-	-46-	-47-	-48-	-49-	-50-
Location	OCMU	OCMU	OCMU	OCMU	OCMU	OCMU	HARL	HARL	HARL	HARL
Formation	TDF	TDF	TDF	TDF	TDF	TDF	OCF	KWF	KWF	KWF
Dist. UNC	-31.0	-32.0	-33.0	-33.0	-32.0	-28.0	0.01	-0.09	-0.15	-0.21
UTM	298602	298602	298602	298602	298602	298602	360620	360620	360620	360620
SiO ₂	52.89	51.94	52.88	48.98	42.12	48.78	56.36	65.95	63.30	59.65
Al ₂ O ₃	15.78	14.45	16.66	16.56	16.96	14.23	17.99	13.71	15.60	16.44
Fe ₂ O ₃	2.09	2.31	1.39	2.17	3.08	1.53	2.00	1.20	1.21	0.85
FeO	9.30	8.57	9.35	10.00	13.91	10.44	4.73	4.69	4.90	5.78
MgO	5.06	4.54	6.18	5.80	7.17	5.06	4.22	4.07	4.08	5.03
CaO	7.75	7.77	4.43	9.22	10.72	7.26	3.17	2.35	2.02	3.51
Na ₂ O	3.32	3.24	2.79	2.59	1.81	1.79	0.69	0.46	0.82	0.66
K ₂ O	0.72	1.38	3.14	0.82	0.42	3.27	2.66	2.85	4.11	4.12
TiO ₂	0.90	0.81	0.96	0.93	0.73	1.31	0.95	0.63	0.66	0.61
P ₂ O ₅	0.16	0.12	0.27	0.16	0.02	0.17	0.70	0.22	0.32	0.46
MnO	0.19	0.18	0.13	0.20	0.26	0.21	0.06	0.06	0.06	0.08
S	--	0.67	0.01	0.02	0.02	0.36	0.51	0.18	--	--
CO ₂ T	0.20	2.00	0.10	0.90	0.30	3.50	0.10	0.10	--	--
H ₂ O ^T	1.20	1.80	1.90	1.60	2.10	2.30	2.60	2.00	2.00	1.90
TOTAL	99.56	99.78	100.19	99.95	99.62	100.21	96.54	98.47	99.08	99.09
Normative minerals										
Qtz	3.6			0	0			41.5	32.1	24.3
Crn	0			0	0			6.4	7.1	5.8
Or	4.3			5.0	2.6			17.5	25.0	25.0
Ab	28.8			22.5	11.2			4.0	7.1	5.7
An	26.5			32.0	38.1			10.6	8.2	14.8
Ne	0			0	0			2.5	0	0
Cpx	9.6			11.5	13.9			0	0	0
Opx	21.6			20.6	0			15.0	15.2	18.9
Hem	0			0	0			0	0	0
Ol	0			2.5	27.0			0	0	0
Mag	3.5			3.6	3.3			3.2	3.2	3.1
Ilm	1.74			1.81	1.42			1.24	1.29	1.19
Ap	0.4			0.4	0			0.5	0.8	1.1
Trace elements										
Ag	3	3	3	3	--	3	3	3	--	--
As	<1	--	--	<1	10	--	--	--	--	--
Au (ppb)	--	<12	<12	20	--	<12	--	<12	--	<12
Ba	224	329	529	147	70	324	470	464	746	605
Co	38	32	34	36	44	40	43	18	16	22
Cr	94	101	93	180	53	49	181	157	145	180
Cs	1.0	2.0	3.2	0.8	0.5	2.2	2.4	3.7	3.6	5.1
Cu	13	45	17	51	3	44	91	66	25	34
Ga	21	17	23	23	27	21	16	16	22	23
Hf	3.6	3.6	3.6	4.8	4.0	7.2	12	9.2	8.0	2.7
Li	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Nb	--	--	--	<5	<5	3	9	<5	<5	<5
Ni	19	11	18	24	25	8	65	67	70	65
Pb	4	3	5	5	3	21	6	4	5	5
Rb	11	33	81	16	--	69	68	72	88	105
Sb	<1	<1	2	<1	<1	2	2	2	2	9
Sc	31	29	30	38	45	31	33	15	16	14
Sr	293	292	317	332	83	326	156	110	112	145
Th	4.0	4.0	3.6	4.8	4.0	4.8	20	17	15	6.2
U	<2	--	--	--	3.2	2.4	14	11	10	3.2
V	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Y	24	26	23	29	34	29	39	23	22	27
Zn	89	97	72	83	133	211	148	136	254	223
Zr	55	52	60	63	42	87	181	124	124	157
La	1.45	1.90	1.23	1.02	0.51	3.57	18.27	8.83	18.73	49.09
Ce	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	52.93	n.d.	47.36	114.25
Sm	3.17	2.97	3.12	3.30	2.76	2.83	9.22	3.65	4.74	8.45
Eu	1.15	0.97	1.01	1.36	1.00	1.44	1.55	1.05	1.04	2.31
Tb	0.63	0.74	0.46	0.49	0.51	0.57	0.56	0.49	0.51	0.78
Yb	2.78	2.15	2.44	3.37	4.16	3.01	3.09	2.57	2.12	1.67
Lu	0.53	0.50	0.45	0.55	0.68	0.53	0.72	0.54	0.42	0.34

TABLE A11.6: ANALYTICAL DATA FOR SAMPLES 51-60

173

Sample No	-51-	-52-	-53-	-54-	-55-	-56-	-57-	-58-	-59-	-60-
Location	HARL	HARL	HARL	REID	REID	REID	REID	REID	REID	REID
Formation	KWF	KWF	KWF	BCF	BCF	BCF	BCF	----	NBK	NBK
Dist. UNC	-0.70	-2.20	-0.01	2.85	2.45	1.60	1.15	-0.80	-1.65	-2.65
UTM	360620	360620	360620	306586	306586	306586	306586	306586	306586	306586
SiO ₂	65.44	58.98	66.38	66.71	66.58	68.72	68.40	50.05	68.67	68.16
Al ₂ O ₃	15.98	16.71	18.26	15.61	16.15	16.41	16.39	15.43	15.81	15.63
Fe ₂ O ₃	0.46	0.52	0.16	1.45	1.30	1.78	1.41	3.18	1.13	0.95
FeO	3.20	4.01	2.32	1.80	1.64	1.19	1.35	5.29	2.15	2.24
MgO	2.83	4.00	1.76	2.67	2.65	1.65	1.88	7.90	1.56	1.38
CaO	5.23	7.15	5.12	3.37	4.18	3.74	2.38	10.42	2.80	3.56
Na ₂ O	0.44	0.36	3.16	1.29	1.70	1.28	0.97	2.30	5.05	4.41
K ₂ O	2.86	3.25	1.71	3.58	3.10	3.51	4.22	0.93	1.27	4.42
TiO ₂	0.48	0.57	0.55	0.43	0.44	0.43	0.46	0.98	0.42	0.41
P ₂ O ₅	0.15	0.32	0.20	0.10	0.09	0.09	0.12	0.62	0.09	0.09
MnO	0.07	0.11	0.04	0.05	0.05	0.04	0.04	0.14	0.04	0.05
S	0.01	--	--	--	--	--	--	--	--	--
CO ₂ T	0.50	2.00	--	0.50	0.50	0.30	0.40	0.40	0.10	0.90
H ₂ O _T	1.40	1.60	0.70	1.60	1.50	1.70	2.00	1.40	0.70	0.90
TOTAL	99.05	99.58	100.36	99.16	99.88	100.84	100.02	99.04	99.79	100.10
Normative minerals										
Qtz	37.5	24.0	28.5					1.5	25.5	26.8
Crn	3.1	0.4	2.4					0	1.3	0.6
Or	17.4	20.0	10.1					5.7	7.6	8.5
Ab	3.8	3.2	26.7					20.0	43.2	38.0
An	25.7	34.7	24.3					29.9	13.4	17.4
Ne	0	0	0					0	0	0
Cpx	0	0	0					15.4	0	0
Opx	8.3	12.7	4.4					20.4	6.3	6.3
Hem	0	0	1.7					0	0	0
Ol	0	0	0					0	0	0
Mag	3.0	3.1	0.5					3.7	1.7	1.4
Ilm	0.9	1.1	1.1					1.9	0.8	0.8
Ap	0.4	0.8	0.5					1.5	0.2	0.2
Trace elements										
Ag	3	3	3	--	--	--	--	--	--	--
As	--	--	--	<1	--	<1	1	1	--	--
Au (ppb)	36	17	<12	<12	<12	--	<12	--	<12	<12
Ba	635	1077	393	549	500	647	674	218	389	555
Co	6	17	7	8	10	6	7	40	10	10
Cr	57	181	77	81	81	80	75	235	86	120
Cs	2.1	1.6	3.4	n.d.	1.0	0.8	1.0	1.1	1.2	1.2
Cu	117	22	15	16	19	3	15	2	52	8
Ga	22	20	29	25	27	25	24	22	25	22
Hf	3.9	4.0	4.3	n.d.	4.2	3.8	4.7	4	3.5	4.2
Li	n.d.	n.d.	n.d.	31	28	22	25	n.d.	n.d.	n.d.
Nb	8	5	6	8	8	9	10	24	8	10
Ni	3	54	9	10	9	9	4	78	8	7
Pb	8	7	14	2	2	2	24	3	5	2
Rb	84	77	45	90	83	82	90	25	31	35
Sb	--	--	--	--	--	--	--	--	--	--
Sc	6	15	6	n.d.	7	6	7	25	7	7
Sr	196	209	303	181	234	219	156	585	273	186
Th	5.7	6.7	7.3	n.d.	6.7	6.1	6.3	9.9	5.4	5.3
U	2.2	2.0	1.9	n.d.	0.6	0.7	0.6	1.5	0.4	2.7
V	n.d.	n.d.	n.d.	<100	<100	<100	<100	n.d.	n.d.	n.d.
Y	13	19	18	9	12	9	7	37	12	14
Zn	51	46	44	32	39	19	33	115	58	60
Zr	169	161	201	152	156	146	162	174	150	150
La	40.30	55.85	40.58	16.90	35.17	24.73	9.67	87.02	24.20	23.12
Ce	77.66	100.00	91.38	24.50	65.21	49.65	n.d.	198.35	48.52	53.89
Sm	7.52	9.58	8.42	2.27	3.92	3.19	2.86	n.d.	3.78	3.47
Eu	1.31	2.25	1.79	1.28	1.08	0.86	0.77	3.73	0.96	1.10
Tb	0.58	0.75	0.50	n.d.	0.55	0.49	0.40	1.40	0.38	0.35
Yb	0.73	2.09	1.59	0.40	0.54	0.88	0.32	1.89	0.65	0.60
Lu	0.11	2.00	0.16	n.d.	0.30	0.20	n.d.	n.d.	0.30	0.20

TABLE A11.7: ANALYTICAL DATA FOR SAMPLES 61-70

Sample No	-61-	-62-	-63-	-64-	-65-	-66-	-67-	-68-	-69-	-70-
Location	REID	REID	OCMS	OCMS	OCMS	OCMS	ADM1	ADM1	ADM1	ADM1
Formation	NBK	NBK	TDF	TDF	TDF	TDF	BCF	BCF	OCF	OCF
Dist. UNC	-17.2	-500	n.d.	n.d.	n.d.	n.d.	9.12	8.57	6.16	3.11
UTM	306586	310582	298602	298602	298602	298602	275531	275531	275531	275531
SiO ₂	68.45	69.07	50.82	41.58	62.70	53.21	76.28	61.41	48.13	40.87
Al ₂ O ₃	15.80	15.20	15.41	20.94	17.86	15.59	9.10	14.61	15.66	14.41
Fe ₂ O ₃	0.75	0.65	2.41	2.51	0.97	3.37	0.87	1.86	1.39	1.90
FeO	2.42	2.25	7.37	12.66	4.33	7.20	4.61	7.81	10.93	9.69
MgO	1.48	1.43	3.89	6.63	2.58	4.77	1.16	2.61	7.06	5.86
CaO	1.97	2.69	7.77	3.38	2.54	9.22	1.36	1.50	4.44	10.82
Na ₂ O	5.51	4.50	1.86	1.20	2.68	2.69	1.24	0.82	0.47	0.50
K ₂ O	1.59	1.60	3.65	7.11	3.90	0.77	1.90	3.85	4.52	4.37
TiO ₂	0.44	0.39	0.85	1.21	0.52	0.85	1.67	2.09	1.65	1.23
P ₂ O ₅	0.12	0.13	0.17	0.45	0.24	0.12	0.16	0.17	0.09	--
MnO	0.05	0.04	0.19	0.18	0.06	0.18	0.08	0.13	0.20	0.24
S	--	--	0.02	--	--	--	0.02	0.06	0.13	0.87
CO ₂ T	0.30	0.20	4.00	0.60	0.40	0.90	0.40	0.20	0.70	6.40
H ₂ O _T	0.90	0.60	1.60	3.00	1.70	1.20	1.00	2.30	2.70	3.10
TOTAL	99.78	98.75	100.00	101.45	100.48	100.07	99.85	99.42	98.07	100.26
Normative minerals										
Qtz	23.2	28.3				6.5				
Crn	1.7	1.5				0				
Or	9.5	9.7				4.7				
Ab	47.3	38.9				23.3				
An	9.1	12.8				28.8				
Ne	0	0				0				
Cpx	0	0				14.2				
Opx	7.0	6.7				17.2				
Hem	0	0				0				
Ol	0	0				0				
Mag	1.1	1.0				3.5				
Ilm	0.8	0.8				1.7				
Ap	0.3	0.3				0.3				
Trace elements										
Ag	--	3	4	--	--	--	--	3	--	--
As	1	--	--	--	--	<1	--	--	30	--
Au (ppb)	<12	--	24	--	--	<12	--	<12	16	22
Ba	417	536	491	589	456	161	273	694	826	553
Co	11	8	26	60	19	32	12	30	68	62
Cr	92	106	117	98	78	133	228	286	568	80
Cs	1.7	1.2	1.5	3.0	1.2	0.8	9.0	56	361	46
Cu	18	32	70	29	38	63	5	14	19	27
Ga	27	28	28	35	32	24	17	24	28	25
Hf	4.2	4.3	1.7	1.7	4.7	1.8	20	19	2.6	1.4
Li	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	12	24	23	30
Nb	11	8	--	<5	6	--	15	11	<5	--
Ni	8	6	18	22	13	27	19	41	228	27
Pb	3	2	5	4	2	2	4	5	5	7
Rb	42	34	87	167	80	12	57	85	142	101
Sb	--	--	--	--	--	--	--	--	--	--
Sc	7	6	29	40	7	32	14	22	51	49
Sr	322	375	236	141	186	393	131	81	81	140
Th	5.4	4.3	0.9	1.0	5.3	1.0	27	36	--	--
U	1.3	1.7	0.9	0.8	2.7	0.7	5.4	6.8	1.4	<0.4
V	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Y	14	12	23	22	17	25	54	51	28	32
Zn	86	29	59	152	48	89	33	44	93	53
Zr	157	150	54	69	175	56	749	838	95	62
La	22.93	30.37	1.38	6.31	54.35	2.44	64.17	59.84	3.36	1.81
Ce	50.82	54.34	n.d.	n.d.	100.48	n.d.	126.34	n.d.	n.d.	n.d.
Sm	2.68	4.24	3.13	2.78	6.52	2.45	11.13	10.99	2.70	2.19
Eu	1.01	1.05	0.99	1.40	2.28	1.07	1.89	2.42	1.09	0.90
Tb	0.38	0.48	0.45	0.30	0.58	0.48	n.d.	n.d.	0.68	0.50
Yb	1.97	0.55	1.54	0.88	0.97	1.44	5.24	5.64	2.23	2.57
Lu	0.16	0.09	0.35	<0.30	0.16	0.35	0.70	0.85	0.46	0.47

TABLE A11.8: ANALYTICAL DATA FOR SAMPLES 71-80

Sample No	-71-	-72-	-73-	-74-	-75-	-76-	-77-	-78-	-79-	-80-
Location	ADM1	ADM1	ADM1	ADM1	ADM1	ADM1	ADM1	ADM1	ADM1	ADM1
Formation	OCF	OCF	OCF	OCF	OCF	TDF	TDF	TDF	TDF	TDF
Dist. UNC	2.71	2.36	0.52	0.46	0.18	-0.17	-0.43	-0.58	-1.10	-1.80
LITH	275531	275531	275531	275532	275531	275531	275531	275531	275531	275531
SiO ₂	49.88	42.00	45.56	50.19	48.62	36.15	67.43	59.26	47.43	45.91
Al ₂ O ₃	13.74	18.05	15.80	18.26	17.81	18.86	14.71	13.71	12.89	13.55
Fe ₂ O ₃	1.71	2.88	1.97	2.28	1.41	n.d.	4.49	3.65	3.44	2.90
FeO	11.85	16.19	12.50	7.66	10.68	15.02*	2.04	4.99	12.15	11.12
MgO	4.63	4.87	5.68	3.40	5.09	8.99	4.04	7.06	7.66	8.07
CaO	7.36	6.35	5.09	3.39	3.62	5.33	1.52	3.91	7.53	9.79
Na ₂ O	0.55	0.68	0.82	1.33	0.60	1.09	0.76	0.81	0.85	1.34
K ₂ O	2.75	3.56	2.95	3.43	4.44	0.03	0.01	0.04	0.80	1.35
TiO ₂	1.66	1.46	1.33	1.20	2.07	1.91	0.60	1.31	1.35	1.25
P ₂ O ₅	0.02	0.04	0.14	0.09	0.17	0.10	--	0.05	--	--
MnO	0.18	0.43	0.23	0.15	0.17	0.15	0.03	0.12	0.22	0.26
S	0.03	0.07	0.22	0.78	0.26	3.84	0.77	0.42	0.16	--
CO ₂ ^T	2.90	0.40	0.20	0.20	0.20	2.60	0.70	1.50	1.30	1.10
H ₂ O ^T	2.00	2.50	2.70	2.80	3.40	4.10	2.00	2.10	2.80	2.00
TOTAL	99.26	99.48	95.19	95.16	98.54	98.17	99.10	98.93	98.58	98.64
Normative minerals										
Qtz						0		34.6	5.4	0
Crn						8.6		5.6	0	0
Or						0.2		0.2	5.0	8.4
Ab						10.5		7.2	7.6	11.9
An						29.4		20.2	30.8	28.3
Ne						0		0	0	0
Cpx						0		0	7.3	18.6
Opx						34.7		25.1	36.7	17.7
Hem						0		0	0	0
Ol						6.6		0	0	8.5
Mag						5.6		4.3	4.4	4.2
Ilm						4.1		2.6	2.7	2.5
Ap						0.3		0.1	0	0
Trace elements										
Ag	3	3	3	--	--	5	3	4	--	--
As	--	--	1	--	103	6	17	10	2	2
Au (ppb)	8398	16	17	<12	22	51	27	24	16	<12
Ba	572	930	747	979	985	44	36	54	148	286
Co	38	79	46	38	47	62	13	27	42	46
Cr	104	189	146	181	362	251	240	470	137	140
Cs	73	188	236	266	475	3.0	n.d.	3.0	83	74
Cu	16	19	17	11	21	608	164	195	88	37
Ga	25	32	29	30	34	7	4	5	18	27
Hf	3.1	2.5	4.8	2.9	3.2	2.3	n.d.	1.3	2.0	2.0
Li	25	29	25	24	37	n.d.	n.d.	n.d.	n.d.	n.d.
Nb	--	--	<5	<5	5	11	--	5	--	<5
Ni	20	61	58	45	115	84	28	24	24	35
Pb	32	16	6	4	5	158	26	58	17	2
Rb	85	109	98	112	237	--	--	1	23	44
Sb	--	--	--	--	--	3	--	--	--	--
Sc	51	71	42	37	48	53	n.d.	38	57	52
Sr	112	49	57	142	130	239	366	303	51	113
Th	--	0.9	4.2	3.1	<0.5	<0.5	n.d.	0.8	<0.5	--
U	<0.5	--	1.8	0.6	2.5	0.5	n.d.	0.4	--	<0.5
V	315	197	231	160	206	n.d.	n.d.	n.d.	n.d.	n.d.
Y	53	23	29	34	26	37	6	34	41	37
Zn	73	95	60	51	6	121	61	95	91	112
Zr	77	66	161	125	125	105	8	68	62	59
La	1.88	1.80	5.71	3.82	1.39	1.80	25.80	7.72	1.64	1.76
Ce	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sm	1.57	2.77	4.07	4.19	3.94	2.37	n.d.	1.48	3.03	3.17
Eu	1.80	1.39	1.31	1.33	1.62	0.75	n.d.	0.59	1.10	0.94
Tb	n.d.	0.58	0.88	0.68	0.65	0.63	n.d.	0.30	0.60	0.68
Yb	1.54	2.32	2.72	2.58	1.66	2.18	n.d.	1.37	2.87	2.77
Lu	0.39	n.d.	0.55	0.48	0.42	0.43	0.59	0.26	0.47	0.34

TABLE A11.9: ANALYTICAL DATA FOR SAMPLES 81-90

176

Sample No	-81-	-82-	-83-	-84-	-85-	-86-	-87-	-88-	-89-	-90-
Location	ADM2	ADM2	ADM2	ADM2	ADM2	ADM2	ADM2	ADM2	ADM2	ADM2
Formation	BCF	BCF	OCF	OCF	OCF	OCF	OCF	OCF	OCF	OCF
Dist. UNC	12.8	9.52	8.99	8.78	7.81	7.05	6.13	4.79	4.15	0.11
UTM	276539	276539	276539	276539	276539	276539	276539	276539	276539	276539
SiO ₂	78.74	69.51	44.71	46.78	57.59	51.81	44.64	51.67	59.57	44.71
Al ₂ O ₃	7.80	8.71	17.27	15.52	11.02	20.24	21.24	15.83	18.49	17.39
Fe ₂ O ₃	0.56	0.60	4.02	3.43	1.99	0.93	2.08	1.46	1.06	0.98
FeO	2.56	6.32	13.16	12.87	11.80	7.05	9.52	9.90	6.11	8.59
MgO	1.55	2.55	5.58	6.59	5.67	4.11	6.53	7.13	5.34	6.34
CaO	1.40	1.99	4.59	2.40	2.35	5.06	4.48	6.31	1.51	10.00
Na ₂ O	0.20	0.05	0.61	0.33	0.34	1.11	0.58	0.76	1.07	1.09
K ₂ O	2.25	2.60	3.21	4.62	2.88	3.90	4.69	2.33	2.97	3.08
TiO ₂	0.69	1.74	2.35	2.15	1.29	0.65	0.83	1.27	0.72	0.93
P ₂ O ₅	0.08	0.19	0.20	0.45	0.16	--	0.02	--	0.17	--
MnO	0.05	0.12	0.35	0.22	0.17	0.15	0.22	0.30	0.13	0.18
S	0.08	0.15	0.55	0.88	0.99	0.96	0.57	0.32	--	0.23
CO ₂ I	0.70	1.00	0.40	--	--	--	0.10	0.10	--	3.50
H ₂ OI	1.20	1.80	2.70	3.00	2.50	2.70	2.90	2.00	1.90	2.00
TOTAL	97.86	97.33	99.70	99.24	98.75	98.67	98.40	99.38	99.04	99.02
Normative minerals										
Qtz										
Crn										
Or										
Ab										
An										
Ne										
Cpx										
Opx										
Hem										
Ol										
Mag										
Ilm										
Ap										
Trace elements										
Ag	--	3	3	3	--	3	3	--	--	--
As	13	22	357	265	109	3066	899	15	2	400
Au (ppb)	<12	<12	378	27	22	27	<12	16	<12	22
Ba	298	349	609	588	489	735	738	307	365	349
Co	--	--	28	44	41	31	39	50	32	63
Cr	182	259	199	185	167	165	282	279	285	197
Cs	--	<1.0	60	146	111	119	210	114	77	91
Cu	6	9	42	61	73	23	14	12	2	31
Ga	13	16	22	22	18	26	26	24	20	23
Hf	--	0.3	2.5	3.7	2.5	1.7	<0.5	1.0	1.1	0.5
Li	20	60	26	26	18	24	26	18	15	n.d.
Nb	5	20	--	--	<5	--	--	<5	--	--
Ni	9	14	41	40	38	47	81	61	73	40
Pb	4	9	5	4	3	4	5	5	2	6
Rb	69	65	78	112	73	94	131	58	68	58
Sb	--	--	--	--	--	--	--	--	--	--
Sc	0.5	0.5	57	60	43	33	73	55	36	35
Sr	62	64	87	50	28	190	145	118	123	210
Th	<0.5	<0.5	--	0.5	1.4	--	--	--	<0.5	<0.5
U	3.1	7.4	1.0	0.8	1.9	--	<0.5	0.4	0.4	0.3
V	<100	107	153	336	265	150	128	292	189	n.d.
Y	35	52	58	48	30	25	26	30	19	22
Zn	32	30	82	90	88	33	79	75	65	56
Zr	229	605	122	129	100	35	40	50	32	48
La	20.29	50.10	2.00	1.36	2.92	1.84	1.55	2.04	1.80	1.72
Ce	n.d.	162.00	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sm	5.42	10.80	4.64	2.74	3.31	1.74	2.43	2.95	1.74	n.d.
Eu	4.32	4.13	1.52	1.60	1.15	0.61	0.96	1.21	0.73	1.36
Tb	n.d.	n.d.	n.d.	0.70	0.58	0.33	n.d.	0.63	0.35	0.32
Yb	2.43	4.05	4.82	2.03	2.63	1.22	1.82	1.77	1.30	1.41
Lu	0.51	n.d.	0.92	0.56	0.63	0.40	0.45	0.32	0.22	0.30

3

MicroD

TABLE A11.10: ANALYTICAL DATA FOR SAMPLES 91-100

177

Sample No	-91-	-92-	-93-	-94-	-95-	-96-	-97-	-98-	-99-	-100-
Location	ADM2	ADM2	ADM2	ADM2	ADM2	ADM2	ADM2	ADM2	OCHU	OCHU
Formation	TDF	TDF	TDF	TDF	TDF	TDF	TDF	TDF	----	----
Dist. UNC	-0.10	-0.31	-1.04	-1.95	-6.95	-12.4	-17.8	-26.9	-28.0	-28.0
UTM	276539	276539	276539	276539	276539	276539	276539	276539	298602	298602
=====										
SiO ₂	49.19	48.21	49.03	43.01	46.42	50.51	48.05	45.44	n.d.	n.d.
Al ₂ O ₃	19.03	16.69	19.02	16.72	13.47	18.27	13.13	13.18	n.d.	n.d.
Fe ₂ O ₃	1.29	2.27	0.55	1.58	2.04	1.12	2.46	2.48	n.d.	n.d.
FeO	5.52	9.06	5.33	12.02	10.73	5.52	12.20	11.46	n.d.	n.d.
MgO	4.77	5.95	3.98	7.98	5.73	5.94	7.10	6.44	n.d.	n.d.
CaO	11.82	10.05	12.37	10.08	10.42	10.35	10.03	11.78	n.d.	n.d.
Na ₂ O	3.26	2.59	3.90	2.02	3.22	3.69	2.14	2.06	n.d.	n.d.
K ₂ O	0.44	0.51	0.35	1.33	0.18	0.60	0.20	0.38	n.d.	n.d.
TiO ₂	0.56	1.25	0.42	1.56	1.61	0.34	1.60	1.45	n.d.	n.d.
P ₂ O ₅	--	--	--	--	0.03	--	--	--	n.d.	n.d.
MnO	0.13	0.17	0.12	0.22	0.24	0.11	0.25	0.24	n.d.	n.d.
S	--	0.22	--	0.20	0.25	--	0.22	0.34	6.95	9.16
CO ₂ T	2.70	1.20	4.10	0.90	3.50	2.10	0.90	3.30	3.30	3.50
H ₂ O _T	0.90	1.50	0.90	2.10	1.50	0.90	1.50	1.70	2.90	4.30
TOTAL	99.61	99.67	100.07	99.72	99.34	99.45	99.78	100.35	n.d.	n.d.
=====										
Normative minerals										
Qtz	0	0	0	0	0	0	0.5	0		
Crn	0	0	0	0	0	0	0	0		
Or	2.7	3.1	2.2	8.1	1.1	3.7	1.2	2.4		
Ab	28.7	22.7	28.6	11.3	29.0	32.4	18.6	18.4		
An	37.5	33.5	35.1	33.8	23.1	32.7	26.4	27.0		
Ne	0	0	3.3	3.5	0	0	0	0		
Cpx	19.1	14.8	23.9	14.7	26.1	16.6	20.5	28.6		
Opx	2.5	17.2	0	0	3.0	2.6	25.0	7.8		
Hem	0	0	0	0	0	0	0	0		
Ol	5.3	2.1	3.2	20.9	9.6	8.6	0	8.5		
Mag	3.1	4.1	2.9	4.6	4.8	2.8	4.6	4.5		
Ilm	1.1	2.5	0.8	3.1	3.3	0.7	3.1	2.9		
Ap	0	0	0	0	0.1	0	0	0		
=====										
Trace elements										
Ag	3	3	3	--	3	3	--	--	65	72
As	--	105	68	167	5	5	14	65	4	2
Au (ppb)	--	<12	<12	<12	<12	17	18	125	7160	7110
Ba	97	35	60	103	63	96	55	112	n.d.	n.d.
Co	14	18	9	68	42	38	113	117	6	27
Cr	104	124	134	173	99	184	156	176	n.d.	n.d.
Cs	8.4	15	10	64	3.7	20	1.0	36	n.d.	n.d.
Cu	24	38	36	53	57	14	23	29	183	469
Ga	24	26	26	29	26	20	25	27	5	8
Hf	0.6	1.8	0.6	1.7	2.7	<0.5	0.8	2.0	n.d.	n.d.
Li	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Nb	--	--	--	--	--	--	--	--	n.d.	n.d.
Ni	32	35	31	49	22	47	50	42	n.d.	n.d.
Pb	6	4	22	2	4	3	2	4	3460	3630
Rb	1	5	--	20	--	16	--	7	n.d.	n.d.
Sb	--	--	--	--	--	--	--	--	860	--
Sc	29	n.d.	n.d.	58	39	36	n.d.	53	n.d.	n.d.
Sr	320	161	196	114	133	97	118	125	n.d.	n.d.
Th	--	<0.5	0.7	--	0.5	--	--	1.2	n.d.	n.d.
U	--	--	--	<0.5	1.0	<0.5	--	--	n.d.	n.d.
V	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Y	17	34	11	41	41	11	43	41	n.d.	n.d.
Zn	38	66	34	82	151	41	114	94	44460	95060
Zr	24	64	9	73	98	9	83	77	n.d.	n.d.
La	0.39	1.80	n.d.	1.92	2.91	0.44	2.97	n.d.	n.d.	n.d.
Ce	n.d.	7.92	n.d.	n.d.	n.d.	n.d.	11.30	n.d.	n.d.	n.d.
Sm	0.83	2.09	n.d.	3.15	4.10	0.71	2.46	n.d.	n.d.	n.d.
Eu	0.64	1.97	n.d.	1.13	1.51	0.39	1.74	n.d.	n.d.	n.d.
Tb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Yb	1.64	2.80	n.d.	3.43	3.08	0.61	4.03	n.d.	n.d.	n.d.
Lu	0.30	n.d.	n.d.	0.63	0.64	0.10	n.d.	n.d.	n.d.	n.d.

TABLE A11.11: ANALYTICAL DATA FOR SAMPLES 101-110

178

Sample No	-101-	-102-	-103-	-104-	-105-	-106-	-107-	-108-	-109-	-110-
Location	OCMU	OCMU	ADM1	ADM1	ADM2	ADM2	OCMS	OCMS	OCMS	OCMS
Formation	---	---	---	---	---	---	OCF	OCF	OCF	OCF
Dist. UNC	-28.0	-28.0	2.29	-8.60	1.65	0.61	2.53	3.23	3.58	3.93
UTM	298602	298602	275531	275531	276539	276539	299603	299603	299603	299603
SiO ₂	n.d.	n.d.	27.65	33.43	40.69	n.d.	49.07	62.29	53.23	49.28
Al ₂ O ₃	n.d.	n.d.	17.61	22.62	27.10	n.d.	16.03	12.59	18.65	18.73
Fe ₂ O ₃	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.24	1.64	7.99	7.99
FeO	n.d.	n.d.	17.47	14.97	6.41*	n.d.	7.64	11.20	5.34	5.77
MgO	n.d.	n.d.	3.71	7.54	4.07	n.d.	5.49	2.32	2.32	3.13
CaO	n.d.	n.d.	2.58	6.89	6.97	n.d.	7.49	2.22	2.06	4.97
Na ₂ O	n.d.	n.d.	1.08	0.63	1.01	n.d.	0.92	0.80	0.96	0.55
K ₂ O	n.d.	n.d.	0.03	0.18	2.74	n.d.	4.59	3.67	5.50	4.99
TiO ₂	n.d.	n.d.	0.73	4.08	0.38	n.d.	0.90	0.39	1.00	1.02
P ₂ O ₅	n.d.	n.d.	0.02	0.24	--	n.d.	0.21	0.13	0.40	0.36
MnO	n.d.	n.d.	0.03	0.19	0.15	n.d.	0.21	0.08	0.09	0.16
S	6.02	6.18	11.50	3.25	0.61	2.46	0.07	--	0.25	0.34
CO ₂ T	0.40	2.90	2.10	3.30	4.30	0.20	2.10	0.50	--	--
H ₂ O _T	4.80	3.60	5.90	3.60	2.90	2.70	3.10	2.60	3.90	3.70
TOTAL	n.d.	n.d.	90.41	100.92	97.49	n.d.	101.06	100.43	101.69	100.99
Normative minerals										
Qtz										
Crn										
Or										
Ab										
An										
Ne										
Cpx										
Opx										
Hem										
Ol										
Mag										
Ilm										
Ap										
Trace elements										
Ag	71	59	3	--	--	--	3	3	3	3
As	<1	4	10	4	12890	54690	10	10	1	2
Au (ppb)	366	11140	8450	48	384	17220	--	--	--	--
Ba	n.d.	n.d.	51	n.d.	109	n.d.	307	219	434	589
Co	6	22	83	67	19	25	27	15	36	31
Cr	n.d.	n.d.	250	312	--	n.d.	103	98	105	100
Cs	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	6.0	2.8	3.8	4.2
Cu	296	2290	595	319	4	30	425	3	2	2
Ga	18	6	5	8	11	14	n.d.	n.d.	n.d.	n.d.
Hf	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.5	0.7	2.1	1.7
Li	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	33	22	23	24
Nb	n.d.	n.d.	--	11	25	n.d.	--	--	<5	--
Ni	n.d.	n.d.	203	73	55	n.d.	48	25	38	26
Pb	4200	2480	8	13	7	5	4	4	4	4
Rb	n.d.	n.d.	--	8	48	n.d.	145	91	113	128
Sb	1	114	--	--	1	11	--	--	--	--
Sc	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	29	15	30	30
Sr	n.d.	n.d.	174	174	176	n.d.	329	152	145	280
Th	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.6	0.6	1.6	1.5
U	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.0	0.6	0.8	1.1
V	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	242	<100	--	--
Y	n.d.	n.d.	30	64	33	n.d.	20	38	11	21
Zn	65392	29700	88	47	60	5	180	76	61	88
Zr	n.d.	n.d.	33	209	19	n.d.	58	23	60	63
La	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	9.53	5.70	5.74	6.09
Ce	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sm	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4.12	3.36	2.46	3.30
Eu	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.19	1.45	0.88	1.04
Tb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Yb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4.04	3.30	1.75	2.68
Lu	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.61	0.39	0.26	0.35

TABLE AII.12: ANALYTICAL DATA FOR SAMPLES 111-120

Sample No	-111-	-112-	-113-	-114-	-115-	-116-	-117-	-118-	-119-	-120-
Location	OCMS	OCMS	OCMS	OCMS	OCMS	OCMS	ADM1	ADM1	ADM1	ADM1
Formation	BCF	BCF	TDF	TDF	TDF	TDF	OCF	OCF	OCF	OCF
Dist. UNC	5.03	7.43	4.30	3.10	1.20	9.57	8.24	7.50	6.65	4.91
UTM	299603	299603	299603	299603	299603	299603	275531	275531	275531	275531
SiO ₂	68.33	80.97	51.68	53.76	53.48	57.34	39.92	46.02	48.33	45.66
Al ₂ O ₃	9.42	9.26	15.15	15.83	15.89	13.66	17.08	14.34	18.98	18.34
Fe ₂ O ₃	4.90	2.21	3.90	3.96	4.73	2.42	2.65	2.43	0.89	1.83
FeO	5.69	1.21	8.70	6.92	6.49	6.16	13.11	10.89	6.02	12.17
MgO	3.00	0.47	5.37	4.41	4.21	5.43	9.12	6.86	9.14	3.47
CaO	1.69	0.20	8.36	9.24	9.77	7.61	8.48	10.28	5.57	6.57
Na ₂ O	1.00	0.39	3.11	3.04	2.17	4.30	0.89	1.22	1.00	2.55
K ₂ O	2.72	2.74	0.91	0.35	0.30	0.28	3.06	1.76	4.09	3.40
TiO ₂	0.93	0.74	0.89	0.80	0.83	0.75	1.56	1.43	0.31	1.78
P ₂ O ₅	0.14	0.13	0.13	0.08	0.10	--	--	--	--	0.06
MnO	0.16	0.02	0.22	0.20	0.18	0.16	0.27	0.26	0.13	0.18
S	--	--	--	0.01	--	0.10	0.04	--	--	0.16
CO ₂ T	0.30	--	--	--	0.10	0.30	0.80	2.30	1.10	1.80
H ₂ O _T	2.10	1.70	1.80	1.50	1.70	1.60	3.60	2.40	5.10	2.40
TOTAL	100.38	100.04	100.22	100.10	99.95	100.11	100.58	100.19	100.66	100.37
Normative minerals										
Qtz	--	--	1.1	6.7	10.4	7.5	--	--	--	--
Crn	--	--	0	0	0	0	--	--	--	--
Or	--	--	5.5	2.1	1.8	1.7	--	--	--	--
Ab	--	--	26.8	26.1	18.8	37.1	--	--	--	--
An	--	--	25.2	29.0	33.5	17.5	--	--	--	--
Ne	--	--	0	0	0	0	--	--	--	--
Cpx	--	--	13.5	14.2	12.8	17.1	--	--	--	--
Opx	--	--	22.5	16.8	17.4	14.3	--	--	--	--
Hem	--	--	0	0	0	0	--	--	--	--
Ol	--	--	0	0	0	0	--	--	--	--
Mag	--	--	3.5	3.4	3.5	3.3	--	--	--	--
Ilm	--	--	1.7	1.5	1.6	1.5	--	--	--	--
Ap	--	--	0.3	0.2	0.2	0	--	--	--	--
Trace elements										
Ag	--	--	--	--	--	--	3	3	3	--
As	104	5	31	2	1	14	3	--	11	--
Au (ppb)	--	--	--	--	--	--	--	--	--	--
Ba	441	399	206	25	44	36	517	243	399	621
Co	34	3	35	33	32	35	63	56	45	46
Cr	186	110	63	76	109	171	449	180	406	170
Cs	5.1	0.9	1.2	--	--	--	83	54	134	43
Cu	6	3	65	83	32	86	4	13	2	66
Ga	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Hf	4.1	6.0	1.7	1.4	1.6	2.2	3.0	1.8	--	2.6
Li	26	10	n.d.	n.d.	n.d.	n.d.	26	16	37	22
Nb	5	6	--	--	--	--	--	--	--	--
Ni	169	20	20	28	50	56	317	76	127	87
Pb	13	3	5	4	15	2	4	2	--	3
Rb	111	57	--	26	5	--	72	39	113	78
Sb	--	--	--	--	3	--	--	--	--	--
Sc	31	10	34	29	33	34	68	44	32	45
Sr	172	118	184	364	528	265	64	165	175	294
Th	4.6	11	1.0	0.9	1.1	0.9	0.8	<0.5	--	<0.5
U	1.5	1.8	<0.5	0.6	0.5	0.5	0.5	<0.5	<0.5	<0.5
V	--	119	n.d.	n.d.	n.d.	n.d.	232	433	120	250
Y	189	21	20	19	24	38	43	28	7	31
Zn	88	23	136	112	113	89	104	91	46	62
Zr	141	206	52	51	58	86	72	72	15	117
La	13.30	n.d.	6.47	6.57	6.81	8.72	1.79	4.22	1.45	3.61
Ce	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sm	3.65	n.d.	3.36	3.12	3.17	3.60	3.14	2.57	0.69	3.11
Eu	1.16	n.d.	1.12	1.00	1.09	1.29	1.27	1.26	0.40	1.44
Tb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Yb	2.46	n.d.	3.20	3.50	2.23	3.27	6.04	2.99	0.73	4.08
Lu	0.34	n.d.	0.50	0.45	0.30	0.41	0.88	0.49	0.14	0.60

TABLE A11.13: ANALYTICAL DATA FOR SAMPLES 121-130

Sample No	-121-	-122-	-123-	-124-	-125-	-126-	-127-	-128-	-129-	-130-
Location	ADM1	ADM1	ADM1	ADM1	ADM1	ADM1	ADM1	ADM1	OCMS	ADM1
Formation	OCF	TDF	TDF	TDF	TDF	TDF	TDF	TDF	TDF	TDF
Dist. UNC	0.15	-3.17	-6.68	-11.7	-17.0	-24.7	-28.6	-32.2	-45.0	-13.4
UTM	275531	275531	275531	275531	275531	275531	275531	275531	298601	275531
SiO ₂	53.10	43.55	46.00	39.24	46.92	47.43	50.10	46.48	45.17	42.98
Al ₂ O ₃	13.01	10.07	11.69	11.23	13.76	14.53	13.21	15.43	18.26	9.96
Fe ₂ O ₃	1.38	3.32	3.72	1.27	2.24	2.84	1.67	2.17	2.37	0.84
FeO	11.47	10.88	11.33	9.83	10.36	10.84	7.30	9.80	6.72	8.66
MgO	8.13	10.03	8.44	10.16	7.36	7.83	7.52	10.47	5.09	10.16
CaO	1.31	8.46	6.36	8.63	11.95	9.91	12.02	9.72	7.69	9.40
Na ₂ O	0.55	0.87	0.93	0.63	2.65	3.12	2.34	2.84	0.44	--
K ₂ O	4.91	0.10	0.39	4.68	0.27	0.26	0.37	0.17	5.40	3.20
TiO ₂	1.49	1.42	1.79	1.97	1.07	1.35	0.57	0.87	0.95	2.78
P ₂ O ₅	0.13	--	0.06	1.21	--	--	--	--	0.16	2.53
MnO	0.12	0.21	0.20	0.13	0.22	0.22	0.14	0.20	0.16	0.12
S	0.15	2.28	1.49	0.68	0.01	0.06	--	--	--	0.25
CO ₂ T	0.20	2.40	2.00	6.90	2.10	0.20	3.60	--	4.80	5.40
H ₂ O ^T	3.80	4.40	4.80	4.40	1.90	1.90	1.90	2.20	2.80	3.30
TOTAL	99.75	97.99	99.20	100.96	100.81	100.49	100.74	100.35	100.01	99.58
Normative minerals										
Qtz	--	2.0	7.5	--	0	--	1.1	0	--	--
Crn	--	0	0	--	0	--	0	0	--	--
Or	--	0.7	2.5	--	1.6	1.6	2.3	1.0	--	--
Ab	--	8.3	8.7	--	22.6	26.9	20.8	23.3	--	--
An	--	26.2	29.3	--	25.7	25.3	25.7	29.4	--	--
Ne	--	0	0	--	0.3	0	0	0.6	--	--
Cpx	--	17.2	4.1	--	29.2	20.3	30.0	16.0	--	--
Opx	--	37.9	38.8	--	0	1.2	15.8	0	--	--
Hem	--	0	0	--	0	0	0	0	--	--
Ol	--	0	0	--	14.6	17.9	0	24.4	--	--
Mag	--	4.8	5.3	--	3.9	4.2	3.2	3.5	--	--
Ilm	--	3.0	3.7	--	2.1	2.6	1.1	1.7	--	--
Ap	--	0	0.2	--	0	0	0	0	--	--
Trace elements										
Ag	--	--	3	4	--	--	--	--	n.d.	n.d.
As	48	6	2	--	--	--	<1	<1	n.d.	n.d.
Au (ppb)	38	27	103	--	--	--	--	--	n.d.	n.d.
Ba	1197	25	129	2560	109	87	102	17	820	1435
Co	47	61	54	46	45	54	36	57	n.d.	n.d.
Cr	364	233	139	251	170	165	469	585	146	345
Cs	766	4.9	38	66	1.6	2.3	6.1	2.2	n.d.	n.d.
Cu	15	387	335	119	62	77	3	3	n.d.	n.d.
Ga	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Hf	2.7	1.7	2.6	5	1.6	1.9	0.5	1.2	n.d.	n.d.
Li	36	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Nb	<5	<5	<5	43	--	--	--	--	--	152
Ni	136	104	49	154	68	52	152	161	48	162
Pb	2	3	3	6	4	3	4	3	n.d.	n.d.
Rb	362	--	12	73	--	--	27	11	124	89
Sb	--	--	--	--	--	--	--	--	n.d.	n.d.
Sc	39	44	60	34	52	48	42	47	n.d.	n.d.
Sr	51	118	94	267	90	84	85	117	226	239
Th	--	0.6	--	1.3	--	--	--	--	n.d.	n.d.
U	<0.5	1.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	n.d.	n.d.
V	368	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	330	118
Y	13	43	54	36	34	40	21	24	20	29
Zn	91	78	79	97	79	114	64	96	55	98
Zr	82	65	87	224	53	79	19	39	55	611
La	3.03	3.37	3.85	60.30	2.38	3.72	1.05	1.42	n.d.	n.d.
Ce	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sm	2.84	3.92	4.40	9.95	2.51	3.27	1.27	1.78	n.d.	n.d.
Eu	1.13	1.02	1.44	2.99	0.97	1.16	0.47	0.73	n.d.	n.d.
Tb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Yb	3.57	6.70	4.72	4.22	3.04	5.90	2.60	1.85	n.d.	n.d.
Lu	0.64	0.88	0.60	0.58	0.39	0.87	0.46	0.26	n.d.	n.d.

TABLE A11.14: ANALYTICAL DATA
FOR SAMPLES 131-133

Sample No	-131-	-132-	-133-
Location	HARL	OCMS	OCMS
Formation	KWF	TDF	BCF
Dist. UNC	-4.27	n.d.	38.0
UTM	360620	360620	360620

SiO ₂	67.29	62.55	93.18
Al ₂ O ₃	12.96	14.10	3.27
Fe ₂ O ₃	3.53	4.53	0.83
FeO	2.30	5.96	0.35
MgO	1.91	2.47	0.46
CaO	3.19	1.12	0.35
Na ₂ O	0.99	0.14	--
K ₂ O	2.82	4.50	0.48
TiO ₂	0.36	1.40	0.21
P ₂ O ₅	0.06	0.25	0.08
MnO	0.05	0.12	0.01
S	2.26	0.25	--
CO ₂ I	1.20	0.40	--
H ₂ OI	1.10	1.80	0.40
TOTAL	100.02	99.59	99.62

Normative minerals

Qtz
Crn
Or
Ab
An
Ne
Cpx
Opx
Hem
Ol
Mag
Ilm
Ap

Trace elements

Ag	n.d.	n.d.	n.d.
As	n.d.	n.d.	n.d.
Au (ppb)	n.d.	n.d.	n.d.
Ba	486	817	115
Co	n.d.	n.d.	n.d.
Cr	37	195	34
Cs	n.d.	n.d.	n.d.
Cu	n.d.	n.d.	n.d.
Ga	n.d.	n.d.	n.d.
Hf	n.d.	n.d.	n.d.
Li	n.d.	n.d.	n.d.
Nb	<5	6	<5
Ni	34	87	--
Pb	n.d.	n.d.	n.d.
Rb	62	109	11
Sb	n.d.	n.d.	n.d.
Sc	n.d.	n.d.	n.d.
Sr	150.	91	80
Th	n.d.	n.d.	n.d.
U	n.d.	n.d.	n.d.
V	77	125	n.d.
Y	27	34	20
Zn	295	65	27
Zr	127	314	85
La	n.d.	n.d.	n.d.
Ce	n.d.	n.d.	n.d.
Sm	n.d.	n.d.	n.d.
Eu	n.d.	n.d.	n.d.
Tb	n.d.	n.d.	n.d.
Yb	n.d.	n.d.	n.d.
Lu	n.d.	n.d.	n.d.

Other results:

Sample 15 (DCP-AES): Nd= 11.0 ppm, Gd= 4.11 ppm,
Er= 2.29 ppm.
Sample 52: Nd= 51.22 ppm.
Sample 53: Nd= 39.72 ppm.
Sample 54 (DCP-AES): Nd= 13.9 ppm, Gd= 1.34 ppm,
Dy= 1.14 ppm, Er= 0.55 ppm.
Sample 55: Nd= 41.65 ppm.
Sample 56: Nd= 25.83 ppm.
Sample 58: Nd= 116.76 ppm.
Sample 67: Nd= 51.73 ppm.
Sample 68: Nd= 43.63 ppm.
Sample 77 (DCP-AES): Gd= 2.71 ppm, Er= 1.78 ppm.
Sample 82: Nd= 64.90 ppm.
Sample 92 (DCP-AES): Nd= 6.62 ppm, Gd= 4.14 ppm,
Er= 3.03 ppm.
Sample 97: Nd= 9.33 ppm.
Sample 124: Nd= 63.62 ppm.

TABLE AII.15: ANALYTICAL DATA FOR SAMPLES 134-140

Sample No	-134-	-135-	-136-	-137-	-138-	-139-	-140-
Location	OCMU	OCMU	OCMU	OCMU	OCMU	OCMU	OCMU
S %	0.07	0.05	15.6	0.06	--	--	0.24
CO ₂ ^T %	21.4	3.40	3.50	0.20	0.40	0.30	2.00
H ₂ O ^T %	0.50	0.10	4.30	0.60	0.40	--	0.10
Fe %	4.75	3.17	13.89	2.36	0.58	0.16	0.40
Ag (ppm)	--	4	95	--	--	--	39
As (ppm)	3.9	0.5	7.0	0.5	0.7	2.6	0.9
Au (ppb)	6	12	8	2	4	--	105
Cu (ppm)	35	362	8500	3	7	5	400
Pb (ppm)	73	10	4689	13	6	8	475
Sb (ppm)	0.5	0.2	17.0	<0.1	<0.1	<0.1	7.2
Zn (ppm)	2	--	1	4	1	1	7

TABLE AII.16: ANALYTICAL DATA FOR SAMPLES 141-147

Sample No	-141-	-142-	-143-	-144-	-145-	-146-	-147-
Location	OCMU	OCMU	OCMU	OCMU	ADM1	ADM1	ADM1
S %	1.29	0.04	0.09	0.73	1.08	0.76	0.14
CO ₂ ^T %	0.20	0.10	0.50	15.80	3.00	0.40	0.50
H ₂ O ^T %	0.20	--	0.40	--	0.30	0.20	--
Fe %	0.80	0.03	0.54	0.37	1.19	0.73	0.19
Ag (ppm)	50	--	3	33	--	--	--
As (ppm)	2.2	0.1	1.7	1.2	0.4	0.4	1.7
Au (ppb)	371	--	317	285	11500	55	356
Cu (ppm)	1150	12	345	2125	47	275	4
Pb (ppm)	3985	2	250	37	4	3	--
Sb (ppm)	>30	<0.1	2.2	5.1	0.3	0.4	0.2
Zn (ppm)	13	4	3	3	12	3	1

TABLE AII.17: ANALYTICAL DATA FOR SAMPLES 148-154

Sample No	-148-	-149-	-150-	-151-	-152-	-153-	-154-
Location	ADM1	ADM1	ADM2	ADM2	ADM2	ADM2	ADM2
S %	0.06	0.03	1.35	1.11	1.23	0.04	0.03
CO ₂ ^T %	0.20	0.20	0.60	2.70	0.60	0.90	2.00
H ₂ O ^T %	--	--	2.00	1.40	0.40	0.30	0.20
Fe %	0.80	0.04	2.12	2.06	1.85	0.40	0.40
Ag (ppm)	--	--	--	--	--	--	--
As (ppm)	0.9	1.4	4390	3250	1230	122	10.6
Au (ppb)	2	7	101	15	20	5	10
Cu (ppm)	78	8	16	22	78	2	17
Pb (ppm)	8	4	38	37	77	2	4
Sb (ppm)	<0.1	0.2	1.3	1.4	0.8	0.5	0.8
Zn (ppm)	11	2	13	7	7	4	5

CO₂^T, H₂O^T and -- as in Tables AII.1-AII.14. Fe determined by AAS and is total iron reported as Fe weight per cent. Samples 134-154 were dissolved in aqua regia. Sample 136: H₂O^T by gravimetric method (Courville, 1962). S <2% determined by volatilization and infrared absorptiometry (Bouvier and Abbey, 1980). S >2% determined by combustion and titration (LECO; Johnson and Maxwell, 1981).

TABLE A11.18
ANALYTICAL DATA FOR STANDARDS MRG-1, SY-2 AND G-2

	M R G - 1				S Y - 2				G - 2						
	$\bar{x}$	n	RANGE	RV	ACC %	$\bar{x}$	n	RANGE	RV	ACC %	$\bar{x}$	n	RANGE	RV	ACC %
SiO ₂	38.71	3	0.56	39.32	1.6	60.18	10	0.50	60.10	0.1	69.21	1	0	69.22	0.0
Al ₂ O ₃	8.45	3	0.22	8.50	0.6	12.23	10	0.31	12.12	0.9	15.34	1	0	15.40	0.4
Fe ₂ O ₃	8.03	3	0.14	8.26	2.3	6.25*	10	0.11	6.28*	0.5	0.88	1	0	1.07	18
FeO	8.73	14	0.96	8.63	1.2	n.d.					1.62	6	0.24	1.44	13
MgO	13.51	3	0.15	13.49	1.3	2.69	10	0.14	2.70	0.4	0.64	1	0	0.75	15
CaO	14.72	3	0.09	14.77	0.3	7.96	10	0.18	7.98*	0.3	1.90	1	0	1.96	3.1
MgO	0.76	3	0.10	0.71	7.0	4.37	10	0.20	4.34	0.7	4.03	1	0	4.06	0.7
K ₂ O	0.18	3	0.00	0.18	0.0	4.52	10	0.12	4.48	0.9	4.53	1	0	4.46	1.6
TiO ₂	3.70	3	0.02	3.69	0.3	0.14	10	0.02	0.14	0.0	0.47	1	0	0.48	2.1
P ₂ O ₅	—	3	n.d.	0.06		0.43	10	0.05	0.43	0.0	0.12	1	0	0.13	7.7
MnO	0.17	3	0.01	0.17	0.0	0.33	10	0.00	0.32	3.0	0.04	1	0	0.03	33
S	0.05	6	0.06	0.06	18	n.d.			0.01		—	1	0	0.01	
CO ₂ T	4.2	6	0.1	1.00	20	n.d.			0.26		—	1	0	0.08	
H ₂ O _T	1.0	6	0.3	0.98**	2.0	n.d.			0.43**		0.6	1	0	0.5**	20
TOTAL	99.01			99.82		99.10			99.36		99.38			99.59	

$\bar{x}$: arithmetic mean; n: number of analyses averaged. RANGE: spread, in absolute value, of the data averaged. RV: recommended value (Abbey, 1963). ACC: accuracy, $((\bar{x}-RV)/RV) \times 100$. CO₂: total carbon as CO₂; H₂O_T: total water. Major elements and volatiles are in weight per cent. Au is in parts per billion (ppb). All other trace element abundances are in parts per million (ppm). n.d.: not determined. —: not detected. *: total iron as Fe₂O₃; **: H₂O⁺.

TABLE A11.18 (continued)

	M R G - 1				S Y - 2				G - 2						
	$\bar{x}$	n	RANGE	RV	ACC %	$\bar{x}$	n	RANGE	RV	ACC %	$\bar{x}$	n	RANGE	RV	ACC %
As	n.d.					12	2	1	18	33	n.d.	1	0	1900	2.6
Ba	n.d.					467	10	15	460	1.5	1850	5	0.5	3.5	46
Co	93.	5	23	86	8.1	n.d.					5.1	5	0.5	8	13
Cr	414	3	15	450	8.0	10	10	24	12	17	9	1	0	1.4	0.0
Cs	0.9	10	0.8	0.6	33	n.d.					1.4	5	0.7	10	30
Cu	87	7	47	135	36	2	1	0	5	60	7	2	0	23	35
Ge	31	8	2	18	72	n.d.					31	6	3	8	10
Hf	3.4	10	1.4	3.5	2.9	n.d.					7.2	5	2.5		
Li	n.d.					90	1	0	93	3.2	n.d.				
Nb	20	3	4	20	0.0	n.d.					11	1	0	13	15
Ni	154	3	3	195	21	2.1	10	10	10	79	—	1	0	3.5	
Pb	8	2	4	10	20	74.	2	12	80	7.5	n.d.				
Rb	4	3	1	8	50	222	10	12	220	0.9	172	1	0	170	1.2
Sb	0.1	2	0.03	0.4	75	0.5	1	0	0.2	150	0.1	5	0.1	0.06	67
Sc	54	10	8.4	48	13	n.d.					3.4	5	0.1	3.5	2.9
Sr	256	3	5	260	1.5	256	10	21	275	6.9	384	1	0	480	0.8
Th	0.8	9	0.6	1	20	n.d.					26	5	3	25	4.0
U	0.7	5	0.8	0.3	133	n.d.					2.2	6	2.4	2.1	4.8
V	n.d.					35	1	0	52	33	n.d.				
Y	20	3	4	16	25	123	10	8	130	5.4	8	1	0	11	2.7
Zn	188	3	8	190	1.1	239	10	96	250	4.4	92	1	0	84	9.5
Zr	96	3	2	105	8.6	269	10	11	280	3.9	327	1	0	324	0.9
La	8.52	10	5.6	10	15	n.d.					85	6	24	92	7.6
Ce	n.d.					n.d.					139	2	2	160	13
Nd	19.5	6	4.7	19	2.6	n.d.					52	2	9	58	10
Sm	4.40	10	2.3	5	12	n.d.					7.06	5	0.9	7.2	1.9
Eu	1.48	10	0.3	1.4	5.7	n.d.					1.39	5	0.1	1.4	0.7
Tb	0.45	5	0.3	0.5	10	n.d.					0.46	5	0.1	0.5	8.0
Yb	0.93	9	0.8	1	7.0	n.d.					0.96	6	0.4	0.86	12
Lu	0.17	10	0.1	0.2	15	n.d.					0.11	6	0.1	0.1	10

TABLE A11.19: ABUNDANCES OF Ag, As, Au, Cu, Li, Pb, Sb AND V
IN INTERNATIONAL STANDARDS

		CPB-1	CZM-1	MA-2	SY-3	G-1	GSP-1	W-1
Ag	$\bar{x}$	594	81					
	n	2	2					
	R	40	16					
	RV	526	93					
	ACC	13%	13%					
As	$\bar{x}$	606	283		15			
	n	4	2		2			
	R	60	6		0			
	RV	560	260		20			
	ACC	8.2%	8.8%		25%			
Au	$\bar{x}$	146	110	1877				
	n	2	2	2				
	R	20	40	6				
	RV	170	90	1860				
	ACC	14%	22%	0.9%				
Cu	$\bar{x}$				12			
	n				1			
	R				0			
	RV				16			
	ACC				25%			
Li	$\bar{x}$					23	30	16
	n					7	5	1
	R					2	5	0
	RV					22	30	14.5
	ACC					4.5%	0.0%	10%
Pb	$\bar{x}$	406000	2500		132			
	n	1			2			
	R	0	0		13			
	RV	647400	74500		130			
	ACC	37%	11%		1.5%			
Sb	$\bar{x}$	3472	505		1.7			
	n	2	1		1			
	R	15	0		0			
	RV	3600	520		0.3			
	ACC	3.6%	2.9%		467%			
V	$\bar{x}$					55	105	342
	n					2	3	4
	R					2	22	36
	RV					17	54	260
	ACC					223%	94%	32%

The recommended values (RV) are from Faye et al. (1979a, 1979b; CPB-1, CZM-1), Steger and Bowman (1981; MA-2), Abbey (1983; SY-3, G-1, GSP-1, W-1). Au abundances are in parts per billion (ppb). All other trace element abundances are in parts per million (ppm). R: spread, in absolute value, of the data averaged. $\bar{x}$ and n as in Table A11.18.

TABLE A11.20
DUPLICATE ANALYSES

Sample No	115	115-DUP	129	129-DUP
SiO ₂	53.48	53.52	45.17	45.27
Al ₂ O ₃ ^T	15.89	15.92	18.26	18.26
Fe ₂ O ₃	11.93	11.98	9.83	9.82
MgO	4.21	4.24	5.09	5.13
CaO	9.77	9.75	7.69	7.70
Na ₂ O	2.17	2.20	0.44	0.50
K ₂ O	0.30	0.30	5.40	5.38
TiO ₂	0.83	0.84	0.95	0.95
P ₂ O ₅	0.10	0.10	0.16	0.16
MnO	0.18	0.18	0.16	0.16
TOTAL	98.86	99.03	93.15	93.33

Trace elements

Ba	44	19	820	798
Cr	109	88	146	153
Nb	--	--	--	--
Ni	50	45	48	45
Rb	5	--	124	125
Sr	528	524	226	228
Y	24	21	20	22
Zn	113	114	55	53
Zr	58	52	55	52

Major elements are in weight per cent.
Trace element abundances are in parts per million. Fe₂O₃^T is total iron as Fe₂O₃. --: not detected. DUP: duplicate analysis.

TABLE AII.21

DUPLICATE ANALYSES: volatile contents of sample 127

DUP No	DUP-A	DUP-B	DUP-C	DUP-D
S	--	--	0.01	--
CO ₂ ^T	3.7	3.7	3.5	3.5
H ₂ O ^T	1.9	1.9	1.6	1.6

Values are in weight per cent. DUP: duplicate analysis. CO₂^T is total carbon as CO₂. H₂O^T is total water. DUP-A and DUP-B were run at the same time and are aliquots of the same rock powder. DUP-C and DUP-D are aliquots of a separately crushed and ground portion of rock sample 127 which were run one year later than DUP-A and DUP-B.

TABLE AII.22
DETECTION LIMIT
OF SELECTED TRACE ELEMENTS

ELEMENT	DETECTION LIMIT
Ag (ppm)	3
As (ppm)	0.5
Au (ppb)	10 (samples 1-133)
Au (ppb)	1 (samples 134-154)
Cs (ppm)	0.1
Pb (ppm)	2
Sb (ppm)	0.5
Th (ppm)	0.2
U (ppm)	0.2

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APPENDIX III

GEOTHERMOBAROMETRY

GEO-THERMOBAROMETRY

The metamorphism in the Flinton-Fernleigh area has been discussed and summarized by Sethuraman and Moore (1973); Carmichael *et al.* (1978) provided maps of the isograds.

Metamorphic conditions at Addington and Ore Chimney mines are above the upper stability limit of chloritoid; biotite and garnet are a widespread mineral pair, and staurolite and kyanite are also found in nearby biotite-rich metapelites. In the mafic metavolcanic rocks hornblende coexists with biotite and chlorite, and cummingtonite is also present in some samples.

Both gold deposits are thus within the staurolite zone of the lower amphibolite facies, although they lie very close to the transition upper greenschist-lower amphibolite. Regionally, the metamorphic grade increases from west to east, and staurolite in the metapelites is stable up to the sillimanite isograd, which indicates that the regional pressure lay near, but higher than, the aluminosilicate triple point (Sethuraman and Moore, 1973). The pressure of metamorphism in the region thus corresponds to that of Carmichael's (1978) bathozone 4 (0.4 to 0.5 GPa).

Mineral chemistry: analytical methods

The compositions of arsenopyrite, sphalerite, argentian tetrahedrite-freibergite, garnet, biotite and hornblende were determined at Carleton University by wavelength dispersive spectrometry using a Cambridge Microscan 5 electron microprobe. An acceleration voltage of 20 kV (25 kV for arsenopyrite) and specimen current of 50 nA were used for the sulphides; 15 kV and 40 nA were used for the silicates. The EMPADR VII computer program of Rucklidge and Gasparri (1969) was used for data reduction. Accuracy for major elements is 1.0 to 1.5 per cent (1.0% for Fe, Mg and As) of the amount present. Precision is better than, or as good as, the accuracy. Semi-quantitative

energy dispersive spectrometry was used for opaque and silicate mineral identification.

Sphalerite geobarometry

It has been shown experimentally that the amount of FeS in solid solution in sphalerite is independent of temperature and is a function of pressure and FeS activity in the range 300 to 600°C and 0 to 0.10 GPa (Scott, 1973; Hutcheon, 1978; Lusk and Ford, 1978; Hutchison and Scott, 1981). Pyrrhotite + pyrite provide the requisite buffering of FeS activity such that the composition of a co-existing sphalerite is dependent only on the confining pressure (Fig. AIII.1). The refractory nature of sphalerite has allowed successful application of this geobarometer (Scott, 1976; Scott et al., 1977; Burglum and Ekström, 1980; Hutchison and Scott, 1980; Shimizu and Shimazaki, 1981; De Waal and Johnson, 1981; Moles, 1983; Scott, 1983; Sundblad et al., 1984).

Samples from the Ore Chimney deposit have sphalerite grains of differing colour in the same rock, and irregular variation of colour (yellow to red) in a single sphalerite grain is commonly observed in transmitted light. Microprobe analyses have confirmed that these variations in colour correspond to variations in the FeS content of sphalerite (Fig. AIII.2 and Table AIII.1). The yellow sphalerite (analyses with the suffix "a" in Table AIII.1) is iron-poor with respect to the red sphalerite (analyses with the suffix "u" in Table AIII.1), and has evidently re-equilibrated after the peak metamorphic event. Figure AIII.2 shows that zinc substituted for iron in these altered sphalerites at approximately constant S. The ferroan, unaltered sphalerite has been used in this study to apply the sphalerite geobarometer.

Pyrrhotite occasionally occurs as small inclusions in sphale-

TABLE AIII.1: CHEMICAL ANALYSES OF SPHALERITE

	SP-1u		SP-2u		SP-3u		SP-4u	
	n=8		n=3		n=4		n=4	
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %
Fe	8.85	7.7	8.29	7.1	8.56	7.2	8.81	7.7
Zn	57.01	41.7	57.44	42.3	57.54	42.0	57.55	42.4
S	33.73	50.3	33.88	50.6	33.81	50.5	33.01	49.6
Cu	--		--		0.03		--	
Cd	0.67	0.3	n.d.		0.67		0.71	0.3
Mn	n.d.		n.d.		n.d.		0.05	
Total	100.26		99.61		100.61		100.13	

	SP-5u		SP-6u		SP-7a	
	n=4		n=3		n=3	
	wt %	atom %	wt %	atom %	wt %	atom %
Fe	8.51	7.2	8.33	7.3	2.71	2.4
Zn	57.96	42.9	58.48	44.0	64.12	47.2
S	32.95	49.6	31.91	48.7	32.38	50.4
Cu	--		--		--	
Cd	0.73	0.3	n.d.		n.d.	
Mn	0.04		n.d.		n.d.	
Total	100.19		98.72		99.21	

	SP-8u		SP-8a		SP-9u		SP-9a	
	n=2		n=2		n=8		n=1	
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %
Fe	9.54	8.1	1.70	1.5	7.77	6.8	1.95	1.7
Zn	57.70	42.5	66.25	49.9	58.71	44.2	65.80	49.6
S	32.99	49.4	32.25	49.0	32.05	49.0	31.82	48.7
Cu	--		--		0.07		--	
Cd	n.d.		n.d.		n.d.		n.d.	
Mn	n.d.		n.d.		n.d.		n.d.	
Total	100.23		100.20		98.60		99.57	

Chemical analyses of sphalerite from the Ore Chimney Mine. SP-1 and -2: sample OSH-9 (+ pyrite). SP-3 to -5: sample OL108-2 (+ pyrite). SP-6 and -7: sample OL108-32 (+ pyrite + pyrrhotite). SP-8 and -9: sample OL108-31 (+ pyrite + pyrrhotite). n: number of individual spot analyses averaged. n.d.: not determined. --: not detected. u: unaltered. a: altered.

Figure AIII.1. Plot of pressure vs iron content in sphalerite. Solid circles: unaltered sphalerite from the Ore Chimney Mine (SP-6u, SP-8u, SP-9u). $P/10 = 42.30 - (32.10 \times \log \text{mole \% FeS})$, where P is pressure in GPa (Hutchison and Scott, 1981).

Figure AIII.2. Sphalerite composition (atom per cent), from the Ore Chimney Mine, in the system Fe-Zn-S. Solid circles: unaltered sphalerite. Open circles: altered sphalerite. Tie lines join altered and unaltered parts of the same grain.

TABLE AIII.2: CHEMICAL ANALYSES OF ARSENOPYRITE

=====										
	APY-1		APY-2		APY-3		APY-4		APY-5	
	n=6		n=6		n=6		n=6		n=6	
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %
Fe	33.47	32.4	33.56	32.7	34.11	32.6	34.13	33.1	34.01	33.1
As	45.93	33.2	45.99	33.4	45.59	32.9	45.56	32.9	45.29	32.9
S	20.09	34.0	19.81	33.5	20.56	34.4	20.04	33.9	20.01	33.9
Co	0.40	0.4	0.40	0.4	0.07	0.1	0.07	0.1	0.07	0.1
Ni	--		0.03		0.03		0.03		0.03	
Total	99.90		99.79		100.36		99.83		99.41	
=====										
	APY-6		APY-7		APY-8		APY-9		APY-10	
	n=4		n=4		n=4		n=4		n=4	
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %
Fe	33.79	33.1	34.19	33.0	33.66	32.9	34.25	32.7	34.65	33.1
As	43.60	31.9	44.43	32.1	44.23	32.3	46.52	33.1	45.91	32.8
S	20.31	34.7	20.41	34.6	20.08	34.4	20.29	33.8	20.25	33.8
Co	0.31	0.3	0.27	0.3	0.42	0.4	0.49	0.4	0.30	0.3
Total	98.01		99.30		98.39		99.83		101.11	
=====										
	APY-11		APY-12		APY-13		APY-14			
	n=4		n=4		n=11		n=13			
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %		
Fe	34.46	33.1	34.43	32.8	34.11	33.1	34.13	33.0		
As	45.62	32.6	46.37	33.0	46.54	33.7	45.99	33.4		
S	20.26	33.8	20.31	33.8	19.44	33.0	19.60	33.4		
Co	0.49	0.5	0.51	0.4	0.23	0.2	0.20	0.2		
Sb	n.d.		n.d.		--		n.d.			
Ni	n.d.		n.d.		--		n.d.			
Bi	n.d.		n.d.		0.13		n.d.			
Total	100.83		101.62		100.45		99.92			
=====										

Chemical analyses of arsenopyrite from the Addington Mine used in geothermometry.
 APY-1 to -5: sample DDH 82-3, 858.5. APY-6 to -8: sample DDH 82-3, 864.8.
 APY-9 to -12: sample DDH 82-3, 868.1. APY-13 and -14: sample DDH 82-3, 883.6.
 All samples + pyrite + pyrrhotite, n: number of individual spot analyses averaged.
 n.d.: not determined. --: not detected.

TABLE A111.3: CHEMICAL ANALYSES OF ARSENOPYRITE

	APY-15		APY-16		APY-17		APY-18	
	n=10		n=6		n=5		n=4	
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %
Fe	34.29	33.2	34.61	33.3	33.69	32.7	34.45	33.4
As	44.90	32.5	45.43	32.6	45.09	32.6	45.17	32.6
S	20.16	34.1	20.18	33.9	20.34	34.5	19.91	33.7
Co	0.19	0.2	0.22	0.2	0.21	0.2	0.30	0.3
Sb	n.d.		n.d.		--		n.d.	
Ni	n.d.		n.d.		--		n.d.	
Bi	n.d.		n.d.		--		n.d.	
Total	99.54		100.44		99.33		99.83	

	APY-19		APY-20		APY-21		APY-22		APY-23	
	n=9		n=8		n=6		n=8		n=6	
	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %	wt %	atom %
Fe	34.12	33.0	34.28	33.0	34.24	32.9	34.11	32.6	34.24	33.2
As	46.11	33.2	46.06	33.2	45.89	32.9	45.95	32.7	45.29	32.8
S	19.97	33.7	19.92	33.7	20.30	34.1	20.75	34.6	20.01	33.9
Co	0.11	0.1	0.10	0.1	0.09	0.1	0.09	0.1	0.10	0.1
Sb	0.04		0.03		0.05		0.04		0.03	
Ni	--		--		--		--		--	
Total	100.35		100.39		100.57		100.94		99.67	

Chemical analyses of arsenopyrite from the Addington Mine not used in geothermometry. These analyses were not used in thermometry because the internal As variations within a single grain exceed 1.0 atomic % (APY-15 to APY-18), or because the buffering phases are not present (APY-19 to APY-23). n: number of individual spot analyses averaged. n.d.: not determined. --: not detected.

APY-15, -16, -17: sample DDH 82-3, 871.9. APY-18: sample DDH 82-3, 868.1.

APY-15, -16, -17: arsenopyrite + pyrrhotite + pyrite.

APY-19 to -23: sample ADM-9 (from the mine dump), arsenopyrite is the only sulphide present.

Figure A11.3. Arsenopyrite composition (atom per cent) in the system Fe-As-S. Solid circles: arsenopyrite from the Addington Mine. Fields for Balmat (B), Cordillera Real (C) and Geco (G) are from Sharp *et al.* (1985).

rite. These inclusions may be crystallographically oriented. FeS content of the host ferroan sphalerite is depleted around these inclusions (11.0 to 12.2 mole % FeS at a distance of 20 to 50 microns from the pyrrhotite inclusions) compared to the FeS content of the ferroan sphalerite farther from the inclusions (13.6 to 16.2 mole % FeS at >1000 microns), indicating that this pyrrhotite formed by exsolution from the sphalerite. Chalcopyrite may be randomly dispersed in sphalerite or oriented along crystallographic planes. Overall, chalcopyrite and pyrrhotite inclusions are less than one per cent by volume of the sphalerite.

All analyses used in pressure determinations were made on areas of red, unaltered, sphalerite, free of pyrrhotite and chalcopyrite inclusions. Only three unaltered, almost inclusion-free, sphalerite grains were found in contact with pyrrhotite and pyrite, or at a distance less than three millimetres from these two phases. They yield pressure values ranging from 0.35 to 0.59 GPa (Fig. AIII.1). Five other sphalerite grains in contact with, or close to, pyrite (<3 mm) yield a maximum pressure ranging from 0.42 to 0.53 GPa.

Arsenopyrite geothermometry

The arsenopyrite geothermometer was studied and calibrated by Kretschmar and Scott (1976), and reconfirmed by Sharp *et al.* (1985). The basic principle is that, in a sulphide mineral assemblage that buffers the sulphur fugacity, the arsenic content of arsenopyrite is a function of temperature. At the Addington Mine the buffering assemblage is pyrrhotite + pyrite. Because arsenopyrite is one of the most refractory sulphides, it does not readily re-equilibrate to lower temperature conditions, which has allowed successful applications of this geological geothermometer (Berglund and Ekström, 1980; Lowell and Gasparrini, 1982; Scott, 1983; Sundblad *et al.*, 1984).

Kretschmar and Scott (1976) and Sundblad *et al.* (1984) recom-

mended against using arsenopyrite grains with a total amount of Co + Ni + Sb exceeding one weight per cent for geothermometric purposes. The arsenopyrite grains analysed in this study fulfill this requirement as the total amount of Co + Ni + Sb + Bi is less than 0.4 wt % in arsenopyrite grains in which they were determined (Tables AIII.2 and AIII.3). The arsenopyrite grains are not detectably zoned with respect to iron, arsenic and sulphur. All grains used in arsenopyrite geothermometry have an internal As variation less than one atom per cent; data are listed in Table AIII.2. Figure AIII.3 is a plot of arsenopyrite compositions in the system Fe-As-S and shows that the arsenopyrite from the Addington Mine is of constant composition and very close to stoichiometric FeAsS, compared to arsenopyrite from other deposits.

Sundblad *et al.* (1984) applied the arsenopyrite geothermometer to sulphide ores of the Swedish Caledonides. In their study they analysed 225 arsenopyrite grains and found no significant differences between arsenopyrite grains in mutual contact with pyrrhotite and pyrite, and arsenopyrite occurring in the same polished thin section as the pyrrhotite and pyrite but not in contact with them. Because pyrrhotite occurs only sporadically in arsenopyrite-rich samples of the Addington Mine, selection of arsenopyrite grains in mutual contact with both pyrrhotite and pyrite was not always possible. In all cases the distance between arsenopyrite, pyrrhotite and pyrite was less than three millimetres, and there is no correlation between the composition of arsenopyrite and the proximity of pyrite and pyrrhotite.

The As content of arsenopyrite varies from 31.9 to 33.7 atom per cent which corresponds to a temperature range of 420 to 530°C (Fig. AIII.4).

Figure A11.4. Garnet-biotite and arsenopyrite geothermometry. ADM: Addington Mine. OCM: Ore Chimney Mine. Lines join core and rim of the same garnet grain.

Sulphur fugacity and sulphide equilibrium domains

Because the sulphur fugacity of the assemblage pyrrhotite + pyrite is fixed if the temperature is fixed, its value can be obtained using the experimentally determined sulphur fugacity-temperature relationships of pyrrhotite + pyrite assemblages in the Fe-S system given by Toulmin and Barton (1964) and Sharp *et al.* (1985). At a pressure of 0.5 GPa and temperature range of 420 to 530°C, $\log f_{S_2} = -2.8$ to -5.5 . This value is greater than the value of $10^{-7.1}$ for pyrrhotite coexisting with pyrite at 500°C and 0.5 GPa calculated by Froese (1981) using thermochemical data.

The domains of sulphide equilibria vary widely from one deposit to another; they commonly range from a few metres down to less than one millimetre (Scott, 1976; Scott *et al.*, 1977; Moles, 1983). As shown on Fig. AIII.3 and Table AIII.2, the arsenopyrite has a very constant composition throughout the samples. The unaltered sphalerite has also a very constant composition (Fig. AIII.2; Table AIII.1) throughout the biotite schist zone of the Ore Chimney Mine. This is consistent with f_{S_2} equilibrium domains that are metres wide at both gold deposits studied.

Garnet-biotite geothermometry

The partitioning of iron and magnesium between coexisting garnet and biotite has been extensively used as a geological thermometer. It is based on the exchange reaction:

This geothermometer has been calibrated by comparison with isotopic thermometry (Goldman and Albee, 1977), by laboratory experimentation (Ferry and Spear, 1978; Perchuk and Lavrent'eva, 1983) and empirically (Thompson, 1976; Perchuk, 1981) over a restricted compositional range. As shown on Fig. AIII.5 there is significant discrepancy at low and high temperatures between the various cali-

Figure A11.5. Calibrations for garnet-biotite geothermometry. Ferry and Spear (1978) calculated at 0.5 GPa; a X_{Mg} value of 0.10 was assumed in Perchuk's (1981) calibration. Equation 9 of Goldman and Albee (1977) was used.

brations. In general, the garnet-biotite geothermometer does not appear to work well in high-grade rocks and must be regarded as the thermometer of choice for medium-grade regional metamorphic rocks (Essene, 1982).

Eight garnet-biotite pairs of three samples from the biotite schist hosting the gold and sulphides at Addington and Ore Chimney mines, and one sample from the OCF, 250 m south of the Ore Chimney Mine shaft, were analysed for thermometric purposes (Table AIII.4).

Garnet

The garnet ($\text{Alm}_{61.4-68.5}$ $\text{Grs}_{9.2-21.2}$ $\text{Sps}_{4.9-18.2}$ $\text{Prp}_{5.2-10.7}$ $\text{Adr}_{0.1-0.5}$ $\text{Uvr}_{0.0-0.2}$) is a grossularite- and spessartine-rich almandine with minor pyrope and andradite component. The garnet is significantly zoned with respect to iron, magnesium and manganese, the Fe/Mg ratio of the rim being generally lower than that of the core. The MnO content is quite variable, ranging from 2.16 to 7.94 wt %; the core has a greater Mn content than the rim in all garnet grains. The garnet porphyroblasts are all euhedral, except GRT-5 (Table AIII.4) which is anhedral and poikiloblastic.

Biotite

The biotite has a composition intermediate between the annite and phlogopite end-members ($X_{\text{ann}} = 0.46$ to 0.60), and the TiO_2 content ranges from 1.48 to 2.22 wt % (Table 6).

Thermometry

Garnet cores and matrix biotite isolated from the garnet are least affected by late Fe-Mg exchange and are most suitable for calculating peak KD and temperatures (Edwards and Essene, 1981; Indares and Martignole, 1985). Among the calibrations proposed for the garnet-biotite geothermometer (Fig. AIII.5), the Thompson (1976) calibration was chosen (Fig. AIII.4). However, the choice of a

TABLE A111.4 (Continued)

Wt %	CHEMICAL ANALYSES OF BIOTITE (core)								FERRO-TSCHERMAKITE (core)		
	1	2	3	4	5	6	7	8	1	2	n=3
	n=3	n=3	n=3	n=3	n=3	n=3	n=3	n=3	n=3	n=3	n=3
SiO ₂	34.77	35.51	34.27	34.92	35.67	34.86	35.71	36.60	39.61	39.62	
Al ₂ O ₃	18.48	19.07	17.91	18.08	18.99	18.42	18.60	19.35	19.48	19.07	
TiO ₂	2.22	2.10	2.16	2.09	1.42	1.54	1.48	1.63	0.31	0.30	
FeO ¹	22.34	21.63	22.24	20.97	18.59	19.94	19.75	17.03	19.75	20.55	
MnO	0.24	0.08	0.13	--	0.05	0.10	0.09	0.09	0.13	0.15	
MgO	8.39	8.36	9.37	8.36	10.63	10.04	9.99	11.28	4.94	4.32	
CaO	0.19	--	0.04	0.11	--	--	--	0.07	11.42	11.43	
Na ₂ O	0.11	0.16	0.14	0.12	0.09	0.18	0.22	0.17	1.23	1.14	
K ₂ O	8.60	9.10	9.05	9.37	9.23	8.95	9.20	8.92	0.70	0.67	
Total	95.34	96.01	95.31	94.02	94.67	94.03	95.04	95.14	97.59	98.26	
CATIONS PER 23 OXYGENS											
Si	5.359	5.406	5.306	5.441	5.432	5.392	5.451	5.480	5.995	5.966	
Al	3.358	3.423	3.269	3.321	3.409	3.359	3.347	3.416	3.474	3.565	
Ti	0.257	0.240	0.251	0.245	0.163	0.179	0.170	0.184	0.035	0.034	
Fe	2.880	2.754	2.880	2.733	2.367	2.579	2.521	2.133	2.499	2.588	
Mn	0.031	0.010	0.017	--	0.006	0.013	0.012	0.011	0.017	0.019	
Mg	1.927	1.897	2.162	1.941	2.412	2.314	2.273	2.517	1.114	0.970	
Ca	0.031	--	0.007	0.018	--	--	--	0.011	1.851	1.844	
Na	0.033	0.047	0.042	0.036	0.026	0.054	0.065	0.049	0.361	0.333	
K	1.691	1.768	1.788	1.863	1.793	1.766	1.792	1.704	0.135	0.129	
X _{ann}	.60	.59	.57	.58	.50	.53	.53	.46	X _{Mg-Fe} K _{Mg-Fe}	4.41	3.66

Mineral having the same assemblage number are considered to be in equilibrium with each other and were used as mineral pairs for geothermometric purposes. Mineral assemblages 1 & 2, and 3 & 4 are from samples 606.5 and 605.9 respectively (DOH 81-6, Ore Chimney Formation, Addington Mine). Mineral assemblage 5 (sample G-11-2) was collected in the Ore Chimney Formation, 250 m south of the Ore Chimney Mine shaft. Mineral assemblages 6 & 7, and 8 are from samples OL108-14 and OL150-91 respectively (108- and 150-foot level, mineralized zone, Ore Chimney Mine). Alm: almandine, Sps: spessartine, Gros: grossularite, Prp: pyrope, Adr: andradite, Uvr: uvarovite, K_{Mg-Fe} and K_{Mg-Fe} are the distribution coefficients of iron and magnesium between garnet and biotite and garnet and ferro-tschermakite, respectively. K_{Mg-Fe}^{grt} = (Fe/Mg)^{grt}/(Fe/Mg)^{bt}, K_{Mg-Fe}^{bt} = (Fe/Mg)^{grt}/(Fe/Mg)^{fs}. T: temperature in °C. X_{ann}: annite mole fraction in biotite, n, -- and n.d., as in Table A111.1.

particular calibration is not critical in this specific case because the average $KD_{\text{Grt-Bt}}^{\text{Mg-Fe}}$ absolute value is about 2 (Fig. AIII.4); Figure AIII.5 shows that the difference between the calibrations is minimal for such a KD value. Because garnet cores and rims analysed have the Mn and Fe/Mg variations so common to prograde metamorphic garnets, and because volume diffusion in garnet is negligible below 600°C (Tracy, 1982), the zoning of the garnet analysed (Table AIII.4) is interpreted as growth zoning, which implies that the rim temperatures, rather than the core temperatures, represent peak metamorphic conditions. The garnet rim-biotite analyses yield a temperature range of 474 to 535°C . A higher temperature range (503 to 560°C) is obtained if the calibrations of Perchuk (1981) or Perchuk and Lavrent'eva (1983), which take the amount of Mn into account in the KD calculations, are used.

Garnet-hornblende geothermometry

The new garnet-hornblende geological thermometer of Graham and Powell (1984) was applied to two mineral pairs (1 and 2 in Table AIII.4). The calculated temperatures are unexpectedly high: 652 and 684°C . Difference between the chemistry (other than the Fe:Mg ratio) of the ferro-tschermakite in the OCF (Leake, 1978; Table AIII.4) and that of the hornblende used by Graham and Powell (1984) to calibrate their geothermometer, and especially the high Ca content of the ferro-tschermakite are the most likely explanation for the unrealistically high temperatures obtained using this geothermometer.

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A P P E N D I X I V

MIXING:

a computer program for trace element geochemical modelling

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10 REM*****
20 REM*****
30 REM
40 REM          M I X I N G      87.02
50 REM
60 REM*****
70 REM*****
80 REM          A COMPUTER PROGRAM IN BASICA
90 REM*****
100 REM  DESIGNED NOV & DEC 1986 BY LUC HARNOIS; CARLETON UNIVERSITY
110 REM*****
120 CLS
130 REM
140 REM*****
150 REM  PROGRAMS STRUCTURE AND EQUATIONS UPDATED [SEPT 18/1987; LH]
160 REM*****
170 REM  KDS UPDATED AND CHECKED [JULY 31/1987; LH].
180 REM*****
190 PRINT
200 PRINT "CHOOSE ONE OF THE FOLLOWING PROGRAMS:"
210 PRINT
220 PRINT
230 PRINT "(M)  EQUILIBRIUM PARTIAL MELTING"
240 PRINT
250 PRINT "(G)  EQUILIBRIUM PARTIAL MELTING IN THE GRANITIC SYSTEM"
260 PRINT
270 PRINT "(C)  SIMPLE FRACTIONAL CRYSTALLIZATION"
280 PRINT
290 PRINT "(A)  COMBINED WALL ROCK ASSIMILATION AND FRACTIONAL"
300 PRINT "      CRYSTALLIZATION"
310 REM*****
320 REM*****
330 XS=INKEY$: IF XS="" THEN 330
340 IF XS="M" OR XS="m" THEN 4160
350 IF XS="C" OR XS="c" THEN 390
360 IF XS="A" OR XS="a" THEN 6160
370 IF XS="G" OR XS="g" THEN 9030
380 GOTO 120
390 CLS
400 PRINT
410 REM*****
420 REM*****
430 PRINT
440 PRINT "SIMPLE FRACTIONAL CRYSTALLIZATION"
450 PRINT
460 PRINT "      LUC HARNOIS"
470 PRINT "      CARLETON UNIVERSITY, NOV/1986"
480 PRINT
490 REM*****
500 REM*****
510 PRINT
520 PRINT "***** TURN ON THE PRINTER *****"
530 PRINT
540 PRINT "TITLE ? (LETTERS ONLY)"
550 PRINT
560 PRINT "(IF YOU DO NOT WANT ANY TITLE ENTER X)"
570 PRINT
580 INPUT TS

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590 IF TS = "X" OR TS = "x" THEN 600
600 CLS
610 PRINT
620 PRINT "KD FOR BASIC (B) OR FELSIC (F) COMPOSITION ?"
630 PRINT
640 PRINT
650 KS=INKEY$: IF KS="" THEN 650
660 IF KS="B" OR KS="b" THEN 700
670 IF KS="F" OR KS="f" THEN 720
680 GOTO 620
690 PRINT
700 KS="BASIC"
710 GOTO 730
720 KS="FELSIC"
730 CLS
740 GOTO 800
750 PRINT
760 IF CMS="B" OR CMS="b" THEN 1560
770 PRINT "CHEMICAL COMPOSITION OF THE INITIAL SOLID (IN PPM) ?"
780 PRINT
790 GOTO 820
800 PRINT "CHEMICAL COMPOSITION OF THE INITIAL LIQUID (IN PPM) ?"
810 PRINT
820 PRINT "TI,BA,RB,SR,Y,ZR,LA,SM,EU,YB"
830 PRINT
840 PRINT "(VALUES MUST BE SEPARATED BY A COMMA)"
850 PRINT
860 INPUT ARRAY(1), ARRAY(2), ARRAY(3), ARRAY(4), ARRAY(5),
      ARRAY(6), ARRAY(7), ARRAY(8), ARRAY(9), ARRAY(10)
870 PRINT "DO YOU WANT TO MODIFY THESE DATA ? (Y, OR N)"
880 PRINT
890 AS=INKEY$: IF AS="" THEN 890
900 IF AS = "Y" OR AS="y" THEN 790
910 IF AS = "N" OR AS="n" THEN 930
920 GOTO 870
930 CLS
940 IF XS="M" OR XS="m" THEN 1070
950 GOTO 1100
960 PRINT
970 PRINT "YOU MADE A MISTAKE, REDO FROM START"
980 IF XS="M" OR XS="m" THEN 1070
990 GOTO 1100
1000 CLS
1010 PRINT "WITH THE SAME PROPORTIONS OF PHASES ? (Y OR N)"
1020 HS=INKEY$ : IF HS="" THEN 1020
1030 IF HS="Y" OR HS="y" THEN 1400
1040 IF HS="N" OR HS="n" THEN 1090
1050 GOTO 1010
1060 GOTO 1090
1070 PRINT "MINERALOGICAL COMPOSITION OF THE INITIAL SOLID"
1080 GOTO 1110
1090 PRINT
1100 PRINT "PROPORTIONS OF CRYSTALLIZING PHASES"
1110 PRINT
1120 PRINT "[OL + OPX + CPX + PLAG + MT(OR KFS) + GRT = 1]"
1130 PRINT
1140 PRINT "OLIVINE="
1150 PRINT

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1160 INPUT OL
1170 PRINT
1180 PRINT "ORTHOPYROXENE="
1190 PRINT
1200 INPUT OX
1210 PRINT
1220 PRINT "CLINOPYROXENE="
1230 PRINT
1240 INPUT CX
1250 PRINT
1260 PRINT "PLAGIOCLASE FELDSPAR="
1270 PRINT
1280 INPUT PL
1290 PRINT
1300 PRINT "MAGNETITE (OR K-FS)="
1310 PRINT
1320 INPUT MT
1330 PRINT "GARNET="
1340 PRINT
1350 INPUT GT
1360 CLS
1370 LET W = OL + OX + CX + PL + MT + GT
1380 IF W <> 1 THEN 970
1390 IF W = 1 THEN 1440
1400 CLS
1410 GOTO 1460
1420 PRINT "YOU MADE A MISTAKE, REDO FROM START"
1430 PRINT
1440 REM
1450 IF XS="M" OR XS="m" THEN 1570
1460 PRINT "PROPORTION OF ORIGINAL LIQUID REMAINING ?"
1470 PRINT
1480 PRINT "(THIS VALUE MUST BE WITHIN THE RANGE 0 TO 1)"
1490 PRINT
1500 INPUT L
1510 IF L < 0 OR L > 1 THEN 1420
1520 IF L >= 0 AND L <= 1 THEN 1530
1530 CLS
1540 GOTO 1650
1550 PRINT "YOU MADE A MISTAKE, REDO FROM START"
1560 PRINT
1570 PRINT "WEIGHT PROPORTION OF MELTED MATERIAL ?"
1580 PRINT
1590 PRINT "(THIS VALUE MUST BE WITHIN THE RANGE 0 TO 1)"
1600 PRINT
1610 INPUT F
1620 IF F < 0 OR F > 1 THEN 1550
1630 CLS
1640 GOTO 1650
1650 ELES(1)="Ti"
1660 ELES(2)="Ba"
1670 ELES(3)="Rb"
1680 ELES(4)="Sr"
1690 ELES(5)="Y"
1700 ELES(6)="Zr"
1710 ELES(7)="La"
1720 ELES(8)="Sm"
1730 ELES(9)="Eu"

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1740      ELES(10)="YB"
1750      REM
1760      REM*****
1770      REM REE CHONDRITE CI VALUES (CH) ARE FROM EVENSEN ET AL (1978),
1780      REM GEOCH. COSMO. ACTA, VOL 42, P. 1199. OTHER TRACE ELEMENT
1790      REM CHONDRITE CI VALUES (CH) ARE FROM THOMPSON ET AL (1983)
1800      REM IN: CONTINENTAL BASALTS AND MANTLE XENOLITHS. EDITED BY
1810      REM C. J. HAWKSWORTH & M. J. MORRIS
1820      REM*****
1830      REM
1840      CH(1)=620
1850      CH(2)=6.9
1860      CH(3)=.35
1870      CH(4)=11.8
1880      CH(5)=2
1890      CH(6)=6.84
1900      CH(7)=.2446
1910      CH(8)=.154
1920      CH(9)=.05802
1930      CH(10)=.1651
1940      REM*****
1950      REM N-TYPE MORB VALUES (MB) ARE FROM SAUNDERS & TARNEY (1984)
1960      REM IN: MARGINAL BASIN GEOLOGY. EDITED BY B. P. KOKELAAR &
1970      REM M. F. HOWELLS, GEOL. SOC. SPEC. PUB. 16.
1980      REM*****
1990      MB(1)=8400
2000      MB(2)=12
2010      MB(3)=1
2020      MB(4)=136
2030      MB(5)=35
2040      MB(6)=88
2050      MB(7)=3
2060      REM MB(8) from Sun and Nesbitt (1977), E.P.S.L., VOL 35, PAGE 429
2070      MB(8)=2.8
2080      MB(9)=1.2
2090      MB(10)=3.5
2100      IF KS="BASIC" THEN 2320
2110      IF KS="FELSIC" THEN 2970
2120      IF XS="MC" THEN 2320
2130      IF XS="MCF" THEN 2970
2140      REM
2150      REM*****
2160      REM KD FOR BASALTIC AND INTERMEDIATE TO FELSIC MELTS ARE FROM:
2170      REM ARTH AND HANSON (1975). GEOCH. COSMOCH. ACTA, VOL 39, PAGE 325.
2180      REM DOSTAL & MUECKE (1978), E.P.S.L., VOL 40, P. 415.
2190      REM PEARCE & MORRIS (1979), CONTR. MINER. PETR., VOL 69, P. 33.
2200      REM HANSON (1977), J. GEOL. SOC. LOND., VOL 134, P. 235.
2210      REM CONDIE & MOORE (1977), GAC SPECIAL PAPER 16.
2220      REM MAHOD & HILDRETH (1983), GEOCH. COSM. ACTA, VOL 47, P. 11.
2230      REM FREY (1980). IN: SHORT COURSE IN NEUTRON ACTIVATION ANALYSIS IN
2240      REM THE GEOSCIENCES. EDITED BY G. K. MUECKE. MINERALOGICAL ASSOCIATION
2250      REM OF CANADA.
2260      REM*****
2270      REM
2280      REM The programs "SIMPLE FRACTIONAL CRYSTALLIZATION" and "EQUILIBRIUM
2290      REM PARTIAL MELTING (NON-MODAL BATCH MELTING)" read the following KDs
2300      REM
2310      REM FOLLOWING LINES ARE KD FOR BASIC MELTS

```

2320 KOL(1)=.02
2330 KOX(1)=.1
2340 KCX(1)=.3
2350 KPL(1)=.04
2360 KMT(1)=7.5
2370 KGT(1)=.3
2380 KOL(2)=.00011
2390 KOX(2)=.001
2400 KCX(2)=.0011
2410 KPL(2)=.023
2420 REM KMT(2), KMT(3), KMT(4): I AM GUESSING, BUT IT IS A GOOD GUESS
2430 KMT(2)=0
2440 KGT(2)=.0015
2450 KOL(3)=.00018
2460 KOX(3)=6.000001E-04
2470 KCX(3)=.0011
2480 KPL(3)=.071
2490 KMT(3)=0
2500 KGT(3)=.007
2510 KOL(4)=.00019
2520 KOX(4)=.007
2530 KCX(4)=.067
2540 KPL(4)=1.83
2550 KMT(4)=0
2560 KGT(4)=.0011
2570 KOL(5)=.01
2580 KOX(5)=.2
2590 KCX(5)=.6
2600 KPL(5)=.03
2610 KMT(5)=.2
2620 KGT(5)=2
2630 KOL(6)=.01
2640 KOX(6)=.03
2650 KCX(6)=.1
2660 KPL(6)=.01
2670 KMT(6)=.1
2680 KGT(6)=.3
2690 KOL(7)=.01
2700 KOX(7)=.03
2710 KCX(7)=.035
2720 KPL(7)=.075
2730 KMT(7)=.05
2740 KGT(7)=.01
2750 KOL(8)=.006
2760 KOX(8)=.047
2770 KCX(8)=9.000001E-02
2780 KPL(8)=.027
2790 KMT(8)=.05
2800 KGT(8)=.1
2810 KOL(9)=.006
2820 KOX(9)=.06
2830 KCX(9)=.091
2840 KPL(9)=.098
2850 KMT(9)=.05
2860 KGT(9)=.2
2870 KOL(10)=8.99999E-03
2880 KOX(10)=.244
2890 KCX(10)=.092

2900 KPL(10)=.019
2910 KMT(10)=.05
2920 KGT(10)=10
2930 IF XS="MC" THEN 5740
2940 IF XS="M" OR XS="m" THEN 4740
2950 GOTO 3600
2960 REM FOLLOWING LINES ARE KD FOR FELSIC MELTS
2970 KOL(1)=.04
2980 KOX(1)=.4
2990 KCX(1)=.7
3000 KPL(1)=.05
3010 REM KMT(J) FOR FELSIC MELTS REFERS TO
3020 REM THE PARTITION COEFFICIENTS OF SANIDINE (K-FS)
3030 KMT(1)=.05
3040 KGT(1)=1.2
3050 KOL(2)=.00018
3060 KOX(2)=.0029
3070 KCX(2)=.131
3080 KPL(2)=.3
3090 KMT(2)=5.2
3100 KGT(2)=.017
3110 KOL(3)=.00018
3120 KOX(3)=.0027
3130 KCX(3)=.032
3140 KPL(3)=.016
3150 KMT(3)=.74
3160 KGT(3)=8.500001E-03
3170 KOL(4)=.00019
3180 KOX(4)=8.500001E-03
3190 KCX(4)=.516
3200 KPL(4)=1.45
3210 KMT(4)=3.87
3220 KGT(4)=.015
3230 KOL(5)=.01
3240 KOX(5)=.45
3250 KCX(5)=1.5
3260 KPL(5)=.1
3270 KMT(5)=.1
3280 KGT(5)=35
3290 KOL(6)=.01
3300 KOX(6)=.08
3310 KCX(6)=.25
3320 KPL(6)=.1
3330 KMT(6)=.1
3340 KGT(6)=1.2
3350 KOL(7)=2.03
3360 KOX(7)=18
3370 KCX(7)=11.8
3380 KPL(7)=.03
3390 KMT(7)=.063
3400 KGT(7)=9.000001E-02
3410 KOL(8)=1.06
3420 KOX(8)=9.270001
3430 KCX(8)=9.55
3440 KPL(8)=.15
3450 KMT(8)=.017
3460 KGT(8)=2.66
3470 KOL(9)=.42

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3480 KOX(9)=3.3
3490 KCX(9)=4.6
3500 KPL(9)=3
3510 KMT(9)=2.8
3520 KGT(9)=1.3
3530 KOL(10)=.98
3540 KOX(10)=2.6
3550 KCX(10)=4.1
3560 KPL(10)=.05
3570 KMT(10)=.022
3580 KGT(10)=39.9
3590 IF XS="MCF" THEN 14660
3600 GOTO 3610
3610 LPRINT
3620 CLS
3630 PRINT "                                I'M WORKING ON IT"
3640 LPRINT "SIMPLE FRACTIONAL CRYSTALLIZATION PROGRAM"
3650 LPRINT
3660 LPRINT, " TITLE: ",TS
3670 LPRINT "OL =",OL,"OPX =",OX,"CPX =",CX
3680 LPRINT "PLAG =",PL,"MT(OR KFS) =",MT,"GRT =",GT
3690 CLS
3700 LPRINT "MELT COMPOSITION =",KS,"LIQUID REMAINING =",L
3710 PRINT "                                I'M WORKING ON IT"
3720 LPRINT "TI =",ARRAY(1),"BA =",ARRAY(2),"RB =",ARRAY(3)
3730 LPRINT "SR =",ARRAY(4),"Y =",ARRAY(5),"ZR =",ARRAY(6)
3740 CLS
3750 LPRINT "LA =",ARRAY(7),"SH =",ARRAY(8),"EU =",ARRAY(9)
3760 LPRINT "YB =",ARRAY(10).
3770 LPRINT
3780 FOR J = 1 TO 10 STEP 1
3790 D =(OL*KOL(J))+(OX*KOX(J))+ (CX*KCX(J))+(PL*KPL(J))+(MT*KMT(J))
3800 CL = ARRAY(J) * (L ^ (D - 1))
3810 REM CL = concentration in the residual liquid
3820 CSI = ( D * ARRAY(J) ) * ( L ^ ( D - 1 ) )
3830 REM CSI = concentration in the instantaneous solid
3840 CS = ARRAY(J) * ( ( 1 - ( L ^ D ) ) / ( 1 - L ) )
3850 REM CS = mean concentration in the cumulate
3860 REM*****
3870 REM Equations for CL, CSI and CS are from Allegre and Minster (1978)
3880 REM E.P.S.L., Vol 38, pages 1-25, section 3.2.1
3890 REM*****
3900 CH = CL / CH(J)
3910 MN = CL / MB(J)
3920 CSICH = CSI / CH(J)
3930 CSCH = CS / CH(J)
3940 PRINT "                                I'M WORKING ON IT"
3950 LPRINT " ELEMENT = ",ELES(J)," CL = ",CL
3960 LPRINT " D =",D," CL / CH = ",CH
3970 CLS
3980 LPRINT " Conc. inst. solid (Csi)=",CSI," Csi / CH = ",CSICH
3990 LPRINT " Mean conc. in the cumulate (Cs)=",CS," Cs / CH = ",CSCH
4000 LPRINT
4010 NEXT J
4020 LPRINT
4030 CLS
4040 PRINT "DO YOU WANT TO DO MORE COMPUTATIONS ? (Y OR N)"
4050 PRINT

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4060 BS=INKEY$: IF BS="" THEN 4060
4070 IF BS = "Y" OR BS = "y" THEN 4100
4080 IF BS = "N" OR BS = "n" THEN 5700
4090 GOTO 4040
4100 PRINT "WITH THE SAME INITIAL COMPOSITION ?" (Y OR N)"
4110 PRINT
4120 GS=INKEY$: IF GS="" THEN 4120
4130 IF GS="Y" OR GS="y" THEN 1000
4140 IF GS="N" OR GS="n" THEN 390
4150 GOTO 4030
4160 CLS
4170 PRINT
4180 REM*****
4190 REM*****
4200 PRINT
4210 PRINT," EQUILIBRIUM PARTIAL MELTING"
4220 PRINT," (NON-MODAL BATCH MELTING)"
4230 PRINT
4240 PRINT," LUC HARNOIS"
4250 PRINT," CARLETON UNIVERSITY, NOV/1986"
4260 PRINT
4270 REM*****
4280 REM*****
4290 PRINT
4300 PRINT,"***** TURN ON THE PRINTER *****"
4310 PRINT
4320 PRINT "TITLE ? (LETTERS ONLY)"
4330 PRINT
4340 PRINT
4350 INPUT TTS
4360 CLS
4370 GOTO 4400
4380 PRINT
4390 PRINT "YOU MADE A MISTAKE REDO FROM START"
4400 REM
4410 REM
4420 CLS
4430 PRINT
4440 PRINT "MELTING PROPORTIONS OF PHASES"
4450 PRINT
4460 PRINT "[OL + OPX + CPX + PLAG + MT(OR KFS) + GRT = 1]"
4470 PRINT
4480 PRINT "OLIVINE="
4490 PRINT
4500 INPUT PQL
4510 PRINT
4520 PRINT "ORTHOPYROXENE="
4530 PRINT
4540 INPUT POX
4550 PRINT
4560 PRINT "CLINOPYROXENE="
4570 PRINT
4580 INPUT PCX
4590 PRINT
4600 PRINT "PLAGIOCLASE FELDSPAR="
4610 PRINT
4620 INPUT PPL
4630 PRINT

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4640 PRINT "MAGNETITE (OR K-FS)="
4650 PRINT
4660 INPUT PMT
4670 PRINT "GARNET="
4680 PRINT
4690 INPUT PGT
4700 CLS
4710 LET PM = POL + POX + PCX + PPL + PMT + PGT
4720 IF PM <> 1 THEN 4380
4730 IF PM = 1 THEN 760
4740 ROL = (OL-(POL*F)) / ((OL-(POL*F))+(OX-(POX*F))+(CX-(PCX*F))
+ (PL-(PPL*F))+(MT-(PMT*F))+(GT-(PGT*F)))
4750 ROX = (OX-(POX*F)) / ((OL-(POL*F))+(OX-(POX*F))+(CX-(PCX*F))
+ (PL-(PPL*F))+(MT-(PMT*F))+(GT-(PGT*F)))
4760 RCX = (CX-(PCX*F)) / ((OL-(POL*F))+(OX-(POX*F))+(CX-(PCX*F))
+ (PL-(PPL*F))+(MT-(PMT*F))+(GT-(PGT*F)))
4770 RPL = (PL-(PPL*F)) / ((OL-(POL*F))+(OX-(POX*F))+(CX-(PCX*F))
+ (PL-(PPL*F))+(MT-(PMT*F))+(GT-(PGT*F)))
4780 RMT = (MT-(PMT*F)) / ((OL-(POL*F))+(OX-(POX*F))+(CX-(PCX*F))
+ (PL-(PPL*F))+(MT-(PMT*F))+(GT-(PGT*F)))
4790 RGT = (GT-(PGT*F)) / ((OL-(POL*F))+(OX-(POX*F))+(CX-(PCX*F))
+ (PL-(PPL*F))+(MT-(PMT*F))+(GT-(PGT*F)))
4800 REM
4810 REM
4820 CLS
4830 PRINT " I'M WORKING ON IT"
4840 LPRINT
4850 LPRINT "EQUILIBRIUM PARTIAL MELTING PROGRAM"
4860 LPRINT " TITLE: ", ITS
4870 LPRINT
4880 LPRINT "MINERALOGICAL COMPOSITION OF THE INITIAL SOLID:"
4890 LPRINT "OL =", OL, "OPX =", OX, "CPX =", CX
4900 LPRINT "PLAG =", PL, "MT(OR KFS) =", MT, "GRT =", GT
4910 CLS
4920 LPRINT "MELTING PROPORTIONS OF PHASES:"
4930 LPRINT "OL =", POL, "OPX =", POX, "CPX =", PCX
4940 LPRINT "PLAG =", PPL, "MT(OR KFS) =", PMT, "GRT =", PGT
4950 LPRINT "PROPORTIONS OF PHASES IN THE RESIDUAL SOLID:"
4960 LPRINT "OL =", ROL, "OPX =", ROX
4970 LPRINT "CPX =", RCX, "PLAG =", RPL
4980 LPRINT "MT(OR KFS) =", RMT, "GRT =", RGT
4990 LPRINT, "DEGREE OF PARTIAL MELTING (F) =", F
5000 PRINT " I'M WORKING ON IT"
5010 LPRINT "CHEMICAL COMPOSITION OF THE INITIAL SOLID (IN PPM):"
5020 LPRINT "TI =", ARRAY(1), "BA =", ARRAY(2), "RB =", ARRAY(3)
5030 LPRINT "SR =", ARRAY(4), "Y =", ARRAY(5), "ZR =", ARRAY(6)
5040 CLS
5050 LPRINT "LA =", ARRAY(7), "SM =", ARRAY(8), "EU =", ARRAY(9)
5060 LPRINT "YB =", ARRAY(10)
5070 LPRINT
5080 FOR J = 1 TO 10 STEP 1
5090 DO = (OL*KOL(J)) + (OX*KOX(J)) + (CX*KCX(J)) + (PL*KPL(J)) + (MT*KMT(J))
+ (GT*KGT(J))
5100 P = (POL*KOL(J)) + (POX*KOX(J)) + (PCX*KCX(J)) + (PPL*KPL(J))
+ (MT*KMT(J)) + (PGT*KGT(J))
5110 CLL = ARRAY(J) / (DO + (F * (1-P)))
5120 REM*****
5130 REM EQUATIONS FOR DO, P, AND CLL ARE EQUATIONS (1), (2), AND (3) OF

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5140 REM ARTH (1976). JOUR. RESEARCH U.S. GEOL. SURVEY, VOL 4, PAGE 41.
5150 REM*****
5160 CNM = CLL / CH(J)
5170 MNM = CLL / MB(J)
5180 LPRINT "ELEMENT = ",ELES(J),"CL = ",CLL
5190 PRINT "                                I'M WORKING ON IT"
5200 LPRINT "Do = ",DO,"CL / CH = ",CNM
5210 LPRINT "P = ",P,"CL / N-TYPE MORB = ",MNM
5220 CLS
5230 LPRINT
5240 NEXT J
5250 LPRINT
5260 LPRINT
5270 LPRINT
5280 CLS
5290 PRINT "DO YOU WANT TO DO MORE COMPUTATIONS ? (Y OR N)"
5300 PRINT
5310 BMS=INKEY$: IF BMS="" THEN 5310
5320 IF BMS = "Y" OR BMS = "y" THEN 5350
5330 IF BMS = "N" OR BMS = "n" THEN 5700
5340 GOTO 5290
5350 CLS
5360 PRINT "WOULD YOU LIKE THE COMPOSITION OF THE MELT OBTAINED IN THE"
5370 PRINT
5380 PRINT "MELTING PROGRAM BE THE INITIAL COMPOSITION OF A"
5390 PRINT
5400 PRINT "FRACTIONAL CRYSTALLIZATION PROCESS ? (Y OR N)"
5410 PRINT
5420 XMS=INKEY$: IF XMS="" THEN 5420
5430 IF XMS="Y" OR XMS="y" THEN 5670
5440 IF XMS="N" OR XMS="n" THEN 5460
5450 GOTO 5350
5460 PRINT
5470 CLS
5480 PRINT "CHOOSE ONE OF THE FOLLOWING ITEMS:"
5490 PRINT
5500 PRINT "(A)  START AT THE BEGINNING OF THE MELTING PROGRAM WITH"
5510 PRINT "      NEW DATA"
5520 PRINT
5530 PRINT "(B)  START WITH THE SAME MINERALOGICAL AND CHEMICAL COM-"
5540 PRINT "      POSITION OF THE INITIAL SOLID"
5550 PRINT
5560 PRINT "(C)  START WITH THE SAME MINERALOGICAL AND CHEMICAL COM-"
5570 PRINT "      POSITION OF THE INITIAL SOLID, AND THE SAME"
5580 PRINT "      MELTING PROPORTIONS"
5590 PRINT
5600 CMS=INKEY$: IF CMS="" THEN 5600
5610 IF CMS="A" OR CMS="a" THEN 4160
5620 IF CMS="B" OR CMS="b" THEN 4400
5630 IF CMS="C" OR CMS="c" THEN 1440
5640 CLS
5650 GOTQ 5470
5660 GOTO 5710
5670 XS="MC"
5680 CLS
5690 GOTO 15080
5700 CLS
5710 PRINT, "AU REVOIR LUC,  BONNE JOURNEE"

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5720 GOTO 5730
5730 END
5740 LPRINT
5750 CLS
5760 PRINT " I'M WORKING ON IT"
5770 LPRINT "FRACTIONAL CRYSTALLIZATION AFTER PARTIAL MELTING"
5780 LPRINT
5790 LPRINT
5800 LPRINT "PROPORTIONS OF CRYSTALLIZING PHASES:"
5810 LPRINT "OL =",CROL,"OPX =",CROX,"CPX =",CRCX
5820 LPRINT "PLAG =",CRPL,"MT(OR KFS) =",CRMT,"GRT =",CRGT
5830 CLS
5840 LPRINT
5850 LPRINT
5860 LPRINT "MELT COMPOSITION: BASIC","LIQUID REMAINING =",L
5870 LPRINT
5880 PRINT " I'M WORKING ON IT"
5890 LPRINT
5900 CLS
5910 FOR J = 1 TO 10 STEP 1
5920 DO = (OL*KOL(J)) + (OX*KOX(J)) + (CX*KCX(J)) + (PL*KPL(J)) + (MT*KMT(J))
      + (GT*KGT(J))
5930 P = (POL*KOL(J)) + (POX*KOX(J)) + (PCX*KCX(J)) + (PPL*KPL(J))
      + (MT*KMT(J)) + (PGT*KGT(J))
5940 CLL = ARRAY(J) / (DO + (F * (1-P)))
5950 REM*****
5960 REM EQUATIONS FOR DO, P, AND CLL ARE EQUATIONS (1), (2), AND (3) OF
5970 REM ARTH (1976). JOUR. RESEARCH U.S. GEOL. SURVEY, VOL 4, PAGE 41.
5980 REM*****
5990 D = (CROL*KOL(J)) + (CROX*KOX(J)) + (CRCX*KCX(J)) + (CRPL*KPL(J))
      + (CRMT*KMT(J))
6000 CL = CLL * (L ^ (D - 1))
6010 CM = CL / CH(J)
6020 MN = CL / MB(J)
6030 PRINT " I'M WORKING ON IT"
6040 LPRINT " ELEMENT = ",ELES(J)," FINAL LIQUID (CL) = ",CL
6050 LPRINT " ELEMENT = ",ELES(J)," INITIAL LIQUID = ",CLL
6060 LPRINT " ELEMENT = ",ELES(J)," CL / CM = ",CM
6070 CLS
6080 LPRINT " D = ",D," CL / N-TYPE MORB = ",MN
6090 LPRINT
6100 NEXT J
6110 LPRINT
6120 LPRINT
6130 LPRINT
6140 LPRINT
6150 GOTO 5290
6160 CLS
6170 PRINT
6180 REM*****
6190 REM*****
6200 PRINT
6210 PRINT,"COMBINED WALL ROCK ASSIMILATION"
6220 PRINT
6230 PRINT,"AND FRACTIONAL CRYSTALLIZATION"
6240 PRINT
6250 PRINT
6260 PRINT," LUC HARNOIS"

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6270 PRINT,"CARLETON UNIVERSITY, NOV/1986"
6280 PRINT
6290 REM*****
6300 REM*****
6310 PRINT
6320 PRINT,"***** TURN ON THE PRINTER *****"
6330 PRINT
6340 PRINT
6350 PRINT,"TITLE ? (LETTERS ONLY)"
6360 PRINT
6370 INPUT TS
6380 CLS
6390 PRINT"ORIGINAL CONCENTRATION OF THE ELEMENTS IN THE MAGMA ?"
6400 PRINT
6410 PRINT"(ALL VALUES ARE PPM, THEY MUST BE SEPARATED BY A COMMA)"
6420 PRINT
6430 PRINT"TI,ZR,LA,SM,Y,YB"
6440 PRINT
6450 INPUT ARRAY(1), ARRAY(2), ARRAY(3), ARRAY(4), ARRAY(5), ARRAY(6)
6460 CLS
6470 PRINT
6480 PRINT"PROPORTIONS OF CRYSTALLIZING PHASES "
6490 PRINT
6500 PRINT"( OLIVINE + PYROXENE + FELDSPAR = 1 )
6510 PRINT
6520 PRINT"OLIVINE ="
6530 PRINT
6540 INPUT OL
6550 PRINT
6560 PRINT"PYROXENE ="
6570 PRINT
6580 PRINT"KD pyroxene = (KD opx + KD cpx) / 2"
6590 PRINT
6600 INPUT PX
6610 PRINT
6620 PRINT"PLAGIOCLASE FELDSPAR ="
6630 PRINT
6640 INPUT FS
6650 LET CP = OL + PX + FS
6660 IF CP = 1 THEN 6680
6670 GOTO 6460
6680 CLS
6690 PRINT
6700 PRINT"CHOOSE ONE OF THE FOLLOWING WALL ROCK COMPOSITIONS:"
6710 PRINT
6720 PRINT"(Q) CANADIAN SHIELD OF SOUTHWESTERN QUEBEC"
6730 PRINT
6740 PRINT"(C) CANADIAN SHIELD (OVERALL MEAN)"
6750 PRINT
6760 PRINT"(A) AVERAGE CONTINENTAL CRUST"
6770 PRINT
6780 PRINT"(O) MAKE UP YOUR OWN DATA FILE"
6790 PRINT
6800 WS=INKEY$: IF WS="" THEN 6800
6810 IF WS="Q" OR WS="q" THEN 7830
6820 IF WS="C" OR WS="c" THEN 7920
6830 IF WS="A" OR WS="a" THEN 7990
6840 IF WS="O" OR WS="o" THEN 8860

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6850      GOTO 6680
6860      CLS
6870      PRINT "WALL ROCK CHEMICAL COMPOSITION (IN PPM)?"
6880      PRINT
6890      PRINT "TI,ZR,LA,SM,Y,YB"
6900      PRINT
6910      PRINT "(VALUES MUST BE SEPARATED BY A COMMA)"
6920      PRINT
6930      INPUT CA(1), CA(2), CA(3), CA(4), CA(5), CA(6)
6940      PRINT
6950      GOTO 8230
6960      CLS
6970      PRINT
6980      PRINT"MASS OF ASSIMILATED WALL ROCK / MASS OF CRYSTALLIZED MAGMA = ?"
6990      PRINT
7000      PRINT" This is the r value (r = Ma / Mc), it has any"
7010      PRINT" positive value; providing that r < 1 or r > 1"
7020      PRINT
7030      INPUT R
7040      IF R = 1 THEN 6960
7050      IF R < 0 THEN 6960
7060      CLS
7070      PRINT
7080      PRINT"MASS FRACTION OF MAGMA (F) REMAINING ?"
7090      PRINT
7100      PRINT"(This value must be within the range 0 to 1)"
7110      PRINT
7120      INPUT F
7130      IF F >= 0 AND F <= 1 THEN 7150
7140      GOTO 7060
7150      CLS
7160      LPRINT
7170      CLS
7180      PRINT "                                I'M WORKING ON IT"
7190      REM
7200      LPRINT"COMBINED WALL ROCK ASSIMILATION AND FRACTIONAL CRYSTALLIZATION"
7210      LPRINT
7220      LPRINT "TITLE :",TS
7230      LPRINT
7240      LPRINT "ORIGINAL CONCENTRATION OF THE ELEMENTS IN THE MAGMA (PPM):"
7250      LPRINT "TI =",ARRAY(1),"ZR =",ARRAY(2),"LA =",ARRAY(3)
7260      LPRINT "SM =",ARRAY(4),"Y =",ARRAY(5),"YB =",ARRAY(6)
7270      CLS
7280      LPRINT
7290      LPRINT "PROPORTIONS OF CRYSTALLIZING PHASES:"
7300      LPRINT "OL =",OL,"OPX + CPX =",PX,"PLAG =",FS
7310      LPRINT
7320      IF W$="Q" OR W$="q" THEN 7360
7330      IF W$="C" OR W$="c" THEN 7380
7340      IF W$="A" OR W$="a" THEN 7400
7350      IF W$="O" OR W$="o" THEN 7420
7360      LPRINT "WALL ROCK COMPOSITION IS PRECAMBRIAN SHIELD OF SW QUEBEC"
7370      GOTO 7470
7380      LPRINT "WALL ROCK COMPOSITION IS CANADIAN PRECAMBRIAN SHIELD"
7390      GOTO 7470
7400      LPRINT "WALL ROCK COMPOSITION IS AVERAGE CONTINENTAL CRUST"
7410      GOTO 7470
7420      LPRINT

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7430 LPRINT "WALL ROCK COMPOSITION [ YOUR OWN DATA SET ]:"
7440 LPRINT "TI =" ,CA(1),"ZR =" ,CA(2),"LA =" ,CA(3)
7450 LPRINT "SM =" ,CA(4),"Y =" ,CA(5),"YB =" ,CA(6)
7460 LPRINT
7470 LPRINT"MASS OF ASSIMILATED WALL ROCK/MASS OF CRYSTALLIZED MAGMA: r=" ,R
7480 LPRINT
7490 LPRINT "MASS FRACTION OF MAGMA (F) REMAINING:" ,F
7500 LPRINT
7510 FOR J = 1 TO 6 STEP 1
7520 PRINT "                                I'M WORKING ON IT"
7530 D = (OL * KOL(J)) + (PX * KPX(J)) + (FS * KFS(J))
7540 Z = ( R + D - 1 ) / ( R - 1 )
7550 ZZ = -Z
7560 CM = ARRAY(J)*((F^ZZ)+((R/(R-1))*(CA(J)/(Z*ARRAY(J)))*(1-(F^ZZ))))
7570 CM = CM / CH(J)
7580 REM*****
7590 REM THE EQUATION FOR (Cm) IS EQUATION (6a) OF DePAOLO (1981).
7600 REM E.P.S.L., VOL 53, PAGE 189.
7610 REM*****
7620 LPRINT ELEM$(J),"CONC. IN MAGMA (Cm) =" ,CM
7630 LPRINT ELEM$(J),"Cm / CHONDRITE =" ,CM
7640 LPRINT "D =" ,D,"Z =" ,Z
7650 CLS
7660 NEXT J
7670 LPRINT
7680 LPRINT
7690 GOTO 8650
7700 REM*****
7710 REM VALUES FOR THE PRECAMBRIAN SHIELD ARE FROM:
7720 REM SHAW ET AL (1976), GEOCHIM. COSMOCHIM. ACTA, VOL 40, PAGE 73.
7730 REM SHAW ET AL (1967), C.J.E.S., VOL 4, PAGE 829.
7740 REM*****
7750 REM
7760 REM FOLLOWING LINES ARE CA VALUES FOR THE PRECAMBRIAN SHIELD OF
7770 REM SOUTHWESTERN QUEBEC
7780 REM
7790 REM
7800 REM
7810 REM
7820 REM
7830 CA(1)=4081
7840 CA(2)=380
7850 CA(3)=41.4
7860 CA(4)=8.21
7870 CA(5)=63.7
7880 CA(6)=3.49
7890 GOTO 8230
7900 REM FOLLOWING LINES ARE CA VALUES FOR THE OVERALL CANADIAN PRECAMBRIAN
7910 REM SHIELD
7920 CA(1)=3117
7930 CA(2)=300
7940 CA(3)=32
7950 CA(4)=4.5
7960 CA(5)=21
7970 CA(6)=1.5
7980 GOTO 8230
7990 REM
8000 REM*****

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8010 REM FOLLOWING LINES ARE CA VALUES FOR THE AVERAGE CONTINENTAL CRUST.
8020 REM DATA FROM TAYLOR (1964), GEOCH. COSMOCH. ACTA, VOL 28, PAGE 1273.
8030 REM*****
8040 REM
8050 REM
8060 CA(1)=3417
8070 CA(2)=165
8080 CA(3)=30
8090 CA(4)=6
8100 CA(5)=33
8110 CA(6)=3
8120 GOTO 8230
8130 REM
8140 REM
8150 REM*****
8160 REM REE CHONDRITE CI VALUES (CH) ARE FROM EVENSEN ET AL (1978).
8170 REM GEOCHIM. COSMOCHIM. ACTA, VOL 42, PAGE 1199.
8180 REM ALL OTHER TRACE ELEMENT CHONDRITE VALUES (CH) ARE FROM
8190 REM THOMPSON ET AL (1983). IN: CONTINENTAL BASALTS AND MANTLE
8200 REM XENOLITHS. EDITED BY C. J. HAWKSWORTH & M. J. MORRIS.
8210 REM*****
8220 REM
8230 CH(1)=620
8240 CH(2)=6.84
8250 CH(3)=.2446
8260 CH(4)=.154
8270 CH(5)=2
8280 CH(6)=.1651
8290 REM
8300 REM*****
8310 REM SEE KD REFERENCES ELSEWHERE IN THIS PROGRAM
8320 REM*****
8330 REM
8340 REM The program "COMBINED WALL ROCK ASSIMILATION AND FRACTIONAL
8350 REM CRYSTALLIZATION" reads the following KDs
8360 REM
8370 REM FOLLOWING LINES ARE KD FOR BASIC MELT
8380 REM KD(PX) IS THE AVERAGE OF KD(OPX) AND KD(CPX), [ 1:1 ]
8390 REM THE FELDSPAR IS PLAGIOCLASE
8400 KOL(1)=.02
8410 KPX(1)=.2
8420 KFS(1)=.04
8430 KOL(2)=.01
8440 KPX(2)=.065
8450 KFS(2)=.01
8460 KOL(3)=.01
8470 KPX(3)=.0325
8480 KFS(3)=.075
8490 KOL(4)=.006
8500 KPX(4)=.069
8510 KFS(4)=.027
8520 KOL(5)=.01
8530 KPX(5)=.35
8540 KFS(5)=.03
8550 KOL(6)=8.999999E-03
8560 KPX(6)=.168
8570 KFS(6)=.019
8580 ELEMS(1)="Ti"

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8590  ELEMS(2)="ZR"
8600  ELEMS(3)="LA"
8610  ELEMS(4)="SM"
8620  ELEMS(5)="Y"
8630  ELEMS(6)="YB"
8640  GOTO 6960
8650  CLS
8660  PRINT
8670  PRINT"CHOOSE ONE OF THE FOLLOWING ITEMS:"
8680  PRINT
8690  PRINT"(A)  QUIT"
8700  PRINT
8710  PRINT"(B)  RESTART WITH NEW DATA"
8720  PRINT
8730  PRINT"(C)  RESTART WITH THE SAME INITIAL COMPOSITION OF THE MAGMA"
8740  PRINT
8750  PRINT"(D)  RESTART WITH THE SAME INITIAL COMPOSITION OF THE MAGMA"
8760  PRINT"      AND THE SAME PROPORTIONS OF CRYSTALLIZING PHASES"
8770  PRINT
8780  PRINT"(E)  RESTART WITH THE SAME INITIAL COMPOSITION OF THE MAGMA,"
8790  PRINT"      THE SAME WALL ROCK COMPOSITION, AND THE SAME"
8800  PRINT"      PROPORTIONS OF CRYSTALLIZING PHASES"
8810  VS=INKEY$: IF VS="" THEN 8810
8820  IF VS="A" OR VS="a" THEN 8880
8830  IF VS="B" OR VS="b" THEN 6160
8840  IF VS="C" OR VS="c" THEN 6460
8850  IF VS="D" OR VS="d" THEN 6680
8860  IF VS="E" OR VS="e" THEN 6950
8870  GOTO 8650
8880  CLS
8890  PRINT
8900  PRINT
8910  PRINT,"AU REVOIR. LUC, BONNE JOURNEE"
8920  END
8930  REM*****
8940  REM*****
8950  REM      THIS IS THE BEGINNING OF THE PROGRAM:
8960  REM      EQUILIBRIUM PARTIAL MELTING
8970  REM      (NON-MODAL BATCH MELTING IN THE GRANITIC SYSTEM)
8980  REM
8990  REM      NOTE: IN THIS PROGRAM, THE PHASES ARE MELTING IN THE
9000  REM      PROPORTIONS  PLAG=1/3, K-FS=1/3, QTZ=1/3
9010  REM*****
9020  REM*****
9030  XS="M"
9040  GOTO 12940
9050  IF XS="M" OR XS="m" THEN 12940
9060  IF XS="C" OR XS="c" THEN 9070
9070  CLS
9080  PRINT
9090  INPUT TS
9100  IF TS = "X" OR TS = "x" THEN 9110
9110  CLS
9120  PRINT
9130  PRINT "KD FOR BASIC (B) OR FELSIC (F) COMPOSITION ?"
9140  PRINT
9150  PRINT
9160  KS=INKEY$: IF KS="" THEN 9160

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9170     IF K$="B" OR K$="b" THEN 9210
9180     IF K$="F" OR K$="f" THEN 9230
9190     GOTO 9130
9200     PRINT
9210     K$="BASIC"
9220     GOTO 9240
9230     K$="FELSIC"
9240     CLS
9250     GOTO 9310
9260     PRINT
9270     IF C$="B" OR C$="b" THEN 10140
9280     PRINT "CHEMICAL COMPOSITION OF THE INITIAL SOLID (IN PPM) ?"
9290     PRINT
9300     GOTO 9330
9310     PRINT "CHEMICAL COMPOSITION OF THE INITIAL LIQUID (IN PPM) ?"
9320     PRINT
9330     PRINT "TI,BA,RB,SR,Y,ZR,LA,SM,EU,YB"
9340     PRINT
9350     PRINT "(VALUES MUST BE SEPARATED BY A COMMA)"
9360     PRINT
9370     INPUT ARRAY(1), ARRAY(2), ARRAY(3), ARRAY(4), ARRAY(5),
        ARRAY(6), ARRAY(7), ARRAY(8), ARRAY(9), ARRAY(10)
9380     PRINT "DO YOU WANT TO MODIFY THESE DATA ? (Y OR N)"
9390     PRINT
9400     AS=INKEY$: IF AS="" THEN 9400
9410     IF AS = "Y" OR AS="y" THEN 9300
9420     IF AS = "N" OR AS="n" THEN 9440
9430     GOTO 9380
9440     CLS
9450     IF X$="M" OR X$="m" THEN 9580
9460     GOTO 9610
9470     PRINT
9480     PRINT "YOU MADE A MISTAKE, REDO FROM START"
9490     IF X$="M" OR X$="m" THEN 9580
9500     GOTO 9610
9510     CLS
9520     PRINT "WITH THE SAME PROPORTIONS OF PHASES ? (Y OR N)"
9530     HS=INKEY$: IF HS="" THEN 9530
9540     IF HS="Y" OR HS="y" THEN 9980
9550     IF HS="N" OR HS="n" THEN 9600
9560     GOTO 9520
9570     GOTO 9600
9580     PRINT "MINERALOGICAL COMPOSITION OF THE INITIAL SOLID"
9590     GOTO 9620
9600     PRINT
9610     PRINT "PROPORTIONS OF CRYSTALLIZING PHASES"
9620     PRINT
9630     PRINT "[HNB + PX + MICA + PLAG + KFS + GRT + QTZ = 1]"
9640     PRINT
9650     PRINT "HORNBLLENDE="
9660     PRINT
9670     INPUT OL
9680     PRINT
9690     PRINT "PYROXENE="
9700     PRINT
9710     PRINT "KD pyroxene = (KD opx + KD cpx) / 2"
9720     PRINT
9730     INPUT OX

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9740 PRINT
9750 PRINT "MICA (BIOTITE)="
9760 PRINT
9770 INPUT CX
9780 PRINT
9790 PRINT "PLAGIOCLASE FELDSPAR="
9800 PRINT
9810 INPUT PL
9820 PRINT
9830 PRINT "POTASSIUM FELDSPAR="
9840 PRINT
9850 INPUT MT
9860 PRINT "GARNET="
9870 PRINT
9880 INPUT GT
9890 PRINT
9900 PRINT "QUARTZ="
9910 PRINT
9920 INPUT QZ
9930 CLS
9940 LET W = OL + OX + CX + PL + MT + GT + QZ
9950 IF W <> 1 THEN 9480
9960 IF W = 1 THEN 10020
9970 GOTO 10020
9980 CLS
9990 GOTO 10040
10000 PRINT "YOU MADE A MISTAKE, REDO FROM START"
10010 PRINT
10020 IF XS="MCF" THEN 10040
10030 IF XS="M" OR XS="m" THEN 10150
10040 PRINT "PROPORTION OF ORIGINAL LIQUID REMAINING ?"
10050 PRINT
10060 PRINT "(THIS VALUE MUST BE WITHIN THE RANGE 0 TO 1)"
10070 PRINT
10080 INPUT L
10090 IF L < 0 OR L > 1 THEN 10000
10100 IF L >= 0 AND L <= 1 THEN 10110
10110 CLS
10120 GOTO 10230
10130 PRINT "YOU MADE A MISTAKE, REDO FROM START"
10140 PRINT
10150 PRINT "WEIGHT PROPORTION OF MELTED MATERIAL ?"
10160 PRINT
10170 PRINT "(THIS VALUE MUST BE WITHIN THE RANGE 0 TO 1)"
10180 PRINT
10190 INPUT F
10200 IF F < 0 OR F > 1 THEN 10130
10210 CLS
10220 GOTO 10230
10230 ELES(1)="TI"
10240 ELES(2)="BA"
10250 ELES(3)="RB"
10260 ELES(4)="SR"
10270 ELES(5)="Y"
10280 ELES(6)="ZR"
10290 ELES(7)="LA"
10300 ELES(8)="SM"
10310 ELES(9)="EU"

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10320      ELES(10)="YB"
10330      REM*****
10340      REM REE CHONDRITE CI VALUES (CH) ARE FROM EVENSEN ET AL (1978),
10350      REM GEOCH. COSMO. ACTA, VOL 42, P. 1199. OTHER TRACE ELEMENT
10360      REM CHONDRITE CI VALUES (CH) ARE FROM THOMPSON ET AL (1983)
10370      REM IN: CONTINENTAL BASALTS AND MANTLE XENOLITHS. EDITED BY
10380      REM C. J. HAWKSWORTH & M. J. NORRY
10390      REM*****
10400      CH(1)=620
10410      CH(2)=6.9
10420      CH(3)=.35
10430      CH(4)=11.8
10440      CH(5)=2
10450      CH(6)=6.84
10460      CH(7)=.2446
10470      CH(8)=.154
10480      CH(9)=.05802
10490      CH(10)=.1651
10500      REM*****
10510      REM N-TYPE MORB VALUES (MB) ARE FROM SAUNDERS & TARNEY (1984)
10520      REM IN: MARGINAL BASIN GEOLOGY. EDITED BY B. P. KOKELAAR &
10530      REM M. F. HOWELLS, GEOL. SOC. SPEC. PUB. 16.
10540      REM*****
10550      MB(1)=8400
10560      MB(2)=12
10570      MB(3)=1
10580      MB(4)=136
10590      MB(5)=35
10600      MB(6)=88
10610      MB(7)=3
10620      REM MB(8) from Sun and Nesbitt (1977), E.P.S.L., VOL 35, PAGE 429
10630      MB(8)=2.8
10640      MB(9)=1.2
10650      MB(10)=3.5
10660      IF KS="BASIC" THEN GOTO 10830
10670      IF KS="FELSIC" THEN GOTO 11660
10680      REM*****
10690      REM KD FOR BASALTIC AND INTERMEDIATE TO FELTIC MELTS ARE FROM:
10700      REM ARTH AND HANSON (1975). GEOCH. COSMOCH. ACTA, VOL 39, PAGE 325.
10710      REM DOSTAL & MUECKE (1978), E.P.S.L., VOL 40, P. 715.
10720      REM PEARCE & NORRY (1979), CONTR. MINER. PETR., VOL 69, P. 33.
10730      REM HANSON (1977), J. GEOL. SOC. LOND., VOL 134, P. 255.
10740      REM CONDIE & MOORE (1977), GAC SPECIAL PAPER 16.
10750      REM MAHOOD & HILDRETH (1983), GEOCH. COSM. ACTA, VOL 47, P. 11.
10760      REM FREY (1980). IN: SHORT COURSE IN NEUTRON ACTIVATION ANALYSIS IN
10770      REM THE GEOSCIENCES. EDITED BY G. K. MUECKE. MINERALOGICAL
10780      REM ASSOCIATION OF CANADA.
10790      REM*****
10800      REM
10810      REM FOLLOWING LINES ARE KD FOR BASIC MELTS
10820      IF XS="M" OR XS="m" THEN 11460
10830      KOL(1)=.02
10840      KOX(1)=.1
10850      KCX(1)=.3
10860      KPL(1)=.04
10870      KMT(1)=7.5
10880      KGT(1)=.3
10890      KOL(2)=.00011

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10900 KOX(2)=.001
10910 KCX(2)=.0011
10920 KPL(2)=.023
10930 KMT(2)=0
10940 KGT(2)=.0015
10950 KOL(3)=.00018
10960 KOX(3)=6.000001E-04
10970 KCX(3)=.0011
10980 KPL(3)=.071
10990 KMT(3)=0
11000 KGT(3)=.007
11010 KOL(4)=.00019
11020 KOX(4)=.007
11030 KCX(4)=.067
11040 KPL(4)=1.83
11050 KMT(4)=0
11060 KGT(4)=.0011
11070 KOL(5)=.01
11080 KOX(5)=.2
11090 KCX(5)=.5
11100 KPL(5)=.03
11110 KMT(5)=.2
11120 KGT(5)=2
11130 KOL(6)=.01
11140 KOX(6)=.03
11150 KCX(6)=.1
11160 KPL(6)=.01
11170 KMT(6)=.1
11180 KGT(6)=.3
11190 KOL(7)=.01
11200 KOX(7)=.03
11210 KCX(7)=.035
11220 KPL(7)=.075
11230 KMT(7)=.05
11240 KGT(7)=.01
11250 KOL(8)=.006
11260 KOX(8)=.047
11270 KCX(8)=9.000001E-02
11280 KPL(8)=.027
11290 KMT(8)=.05
11300 KGT(8)=.1
11310 KOL(9)=.006
11320 KOX(9)=.06
11330 KCX(9)=.091
11340 KPL(9)=.098
11350 KMT(9)=.05
11360 KGT(9)=.2
11370 KOL(10)=8.999999E-03
11380 KOX(10)=.244
11390 KCX(10)=.092
11400 KPL(10)=.019
11410 KMT(10)=.05
11420 KGT(10)=10
11430 IF XS="MC" THEN 14660
11440 GOTO 12370
11450 REM
11460 REM FOLLOWING LINES ARE KD FOR RHYOLITIC MELTS
11470 REM
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11480 REM*****
11490 REM KD VALUES ARE FROM:
11500 REM ARTH AND HANSON (1975). GEOCHIM. COSMOCHIM. ACTA, VOL 39, PAGE 325
11510 REM PEARCE AND NORRIS (1979). CONTRIB. MINER. PETROL., VOL 69, PAGE 33.
11520 REM
11530 REM KD(LA) ARE ESTIMATED BASED ON DATA FROM:
11540 REM MAHOOD & HILDRETH (1983). GEOCHIM. COSMOCHIM. ACTA, VOL 47, PAGE 1
11550 REM AND CONDIE & MOORE (1977). GAC SPECIAL PAPER 16.
11560 REM*****
11570 REM
11580 REM The program "EQUILIBRIUM PARTIAL MELTING (NON-MODAL BATCH
11590 REM MELTING IN THE GRANITIC SYSTEM)" reads the following KDs
11600 REM
11610 REM IN THE FOLLOWING KD SERIES:
11620 REM KD pyroxene= (KD opx + KD cpx) / 2
11630 REM KOL(J) is KD hornblende
11640 REM KMT(J) is KD potassic feldspar
11650 REM
11660 KOL(1)=7
11670 KOX(1)=.55
11680 KCX(1)=2.5
11690 KPL(1)=.05
11700 KMT(1)=.05
11710 KGT(1)=1.2
11720 KQZ(1)=0
11730 KOL(2)=.044
11740 KOX(2)=.06695
11750 KCX(2)=6.36
11760 KPL(2)=.308
11770 KMT(2)=6.12
11780 KGT(2)=.017
11790 KQZ(2)=0
11800 KOL(3)=.014
11810 KOX(3)=.01735
11820 KCX(3)=3.26
11830 KPL(3)=.041
11840 KMT(3)=.366
11850 KGT(3)=8.500001E-03
11860 KQZ(3)=0
11870 KOL(4)=.22
11880 KOX(4)=.3005
11890 KCX(4)=.12
11900 KPL(4)=4.4
11910 KMT(4)=3.87
11920 KGT(4)=.015
11930 KQZ(4)=0
11940 KOL(5)=6
11950 KOX(5)=.25
11960 KCX(5)=2
11970 KPL(5)=.1
11980 KMT(5)=.1
11990 KGT(5)=35
12000 KQZ(5)=0
12010 KOL(6)=4
12020 KOX(6)=.4
12030 KCX(6)=2
12040 KPL(6)=.1
12050 KMT(6)=.1

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12060 KGT(6)=1.2
12070 KQZ(6)=0
12080 KOL(7)=1.111
12090 KOX(7)=.534
12100 KCX(7)=.524
12110 KPL(7)=.26
12120 KMT(7)=.067
12130 KGT(7)=.088
12140 KQZ(7)=0
12150 KOL(8)=7.77
12160 KOX(8)=.97
12170 KCX(8)=.26
12180 KPL(8)=.13
12190 KMT(8)=.018
12200 KGT(8)=2.66
12210 KQZ(8)=0
12220 KOL(9)=5.14
12230 KOX(9)=.865
12240 KCX(9)=.24
12250 KPL(9)=2.15
12260 KMT(9)=1.13
12270 KGT(9)=1.5
12280 KQZ(9)=0
12290 KOL(10)=8.38
12300 KOX(10)=1.22
12310 KCX(10)=.44
12320 KPL(10)=.049
12330 KMT(10)=.012
12340 KGT(10)=39.9
12350 KQZ(10)=0
12360 IF XS="MCF" THEN 14660
12370 GOTO 13610
12380 LPRINT
12390 CLS
12400 PRINT " I'M WORKING ON IT"
12410 LPRINT "SIMPLE FRACTIONAL CRYSTALLIZATION PROGRAM"
12420 LPRINT
12430 LPRINT " TITLE: ",TS
12440 LPRINT
12450 LPRINT
12460 LPRINT "OL =",OL,"OPX =",OX,"CPX =",CX
12470 LPRINT "PLAG =",PL,"MT(OR KFS) =",MT,"GRT =",GT
12480 CLS
12490 LPRINT
12500 LPRINT
12510 LPRINT "MELT COMPOSITION =",KS,"LIQUID REMAINING =",L
12520 LPRINT
12530 PRINT " I'M WORKING ON IT"
12540 LPRINT
12550 LPRINT "TI =",ARRAY(1),"BA =",ARRAY(2),"RB =",ARRAY(3)
12560 LPRINT "SR =",ARRAY(4),"Y =",ARRAY(5),"ZR =",ARRAY(6)
12570 CLS
12580 LPRINT "LA =",ARRAY(7),"SM =",ARRAY(8),"EU =",ARRAY(9)
12590 LPRINT "YB =",ARRAY(10)
12600 LPRINT
12610 LPRINT
12620 FOR J = 1 TO 10 STEP 1
12630 D =(OL*KOL(J))+(OX*KOX(J))+(CX*KCX(J))+(PL*KPL(J))+(MT*KMT(J))

```

```

12640 CL = ARRAY(J) * (L ^ (D - 1))
12650 CN = CL / CH(J)
12660 MN = CL / MB(J)
12670 PRINT "                                I'M WORKING ON IT"
12680 LPRINT " ELEMENT = ",ELES(J)," CL = ",CL
12690 LPRINT " ELEMENT = ",ELES(J)," CL / CH = ",CN
12700 CLS
12710 LPRINT " D = ",D," CL / N-TYPE MORB = ",MN
12720 LPRINT
12730 NEXT J
12740 LPRINT
12750 LPRINT
12760 LPRINT
12770 LPRINT
12780 LPRINT
12790 LPRINT
12800 LPRINT
12810 CLS
12820 PRINT "DO YOU WANT TO DO MORE COMPUTATIONS ? (Y OR N)"
12830 PRINT
12840 BS=INKEY$: IF BS="" THEN 12840
12850 IF BS = "Y" OR BS = "y" THEN 12880
12860 IF BS = "N" OR BS = "n" THEN 14560
12870 GOTO 12820
12880 PRINT "WITH THE SAME INITIAL COMPOSITION ? (Y OR N)"
12890 PRINT
12900 GS=INKEY$: IF GS="" THEN 12900
12910 IF GS="Y" OR GS="y" THEN 9510
12920 IF GS="N" OR GS="n" THEN 9070
12930 GOTO 12810
12940 CLS
12950 PRINT
12960 REM*****
12970 REM*****
12980 PRINT
12990 PRINT,"          EQUILIBRIUM PARTIAL MELTING"
13000 PRINT,"(NON-MODAL BATCH MELTING IN THE GRANITIC SYSTEM)"
13010 PRINT
13020 PRINT,"NOTE: IN THIS PROGRAM THE PHASES ARE MELTING IN THE"
13030 PRINT,"          PROPORTIONS PLAG=1/3, K-FS=1/3, QTZ=1/3"
13040 PRINT
13050 PRINT,"          LUC HARNOIS"
13060 PRINT,"          CARLETON UNIVERSITY, NOV/1986"
13070 PRINT
13080 REM*****
13090 REM*****
13100 PRINT
13110 PRINT,"***** TURN ON THE PRINTER *****"
13120 PRINT
13130 PRINT "TITLE ? (LETTERS ONLY)"
13140 PRINT
13150 PRINT
13160 INPUT TT$
13170 CLS
13180 GOTO 13210
13190 PRINT
13200 PRINT "YOU MADE A MISTAKE, REDO FROM START"
13210 REM

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13220 REM
13230 CLS
13240 GOTO 9270
13250 PRINT
13260 PRINT "PROPORTIONS OF PHASES IN THE RESIDUAL SOLID"
13270 PRINT
13280 PRINT "[HNB + PX + MICA + PLAG + KFS + GRT + QTZ = 1]"
13290 PRINT
13300 PRINT "HORNBLende="
13310 PRINT
13320 INPUT ROL
13330 PRINT
13340 PRINT "PYROXENE="
13350 PRINT
13360 INPUT ROX
13370 PRINT
13380 PRINT "MICA (BIOTITE)="
13390 PRINT
13400 INPUT RCX
13410 PRINT
13420 PRINT "PLAGIOCLASE FELDSPAR="
13430 PRINT
13440 INPUT RPL
13450 PRINT
13460 PRINT "POTASSIUM FELDSPAR="
13470 PRINT
13480 INPUT RMT
13490 PRINT "GARNET="
13500 PRINT
13510 INPUT RGT
13520 PRINT
13530 PRINT "QUARTZ="
13540 PRINT
13550 INPUT RQZ
13560 CLS
13570 LET RW = ROL + ROX + RCX + RPL + RMT + RGT + RQZ
13580 IF RW <> 1 THEN 13190
13590 IF RW = 1 THEN 9270
13600 REM
13610 REM
13620 CLS
13630 PRINT "                                I'M WORKING ON IT"
13640 LPRINT
13650 LPRINT "EQUILIBRIUM PARTIAL MELTING IN THE GRANITIC SYSTEM"
13660 LPRINT
13670 LPRINT " TITLE: ",TTS
13680 LPRINT
13690 LPRINT "MINERALOGICAL COMPOSITION OF THE INITIAL SOLID:"
13700 LPRINT "HB =",OL,"PX =",OX,"BIO =",CX
13710 LPRINT "PLAG =",PL,"K-FS =",MT,"GRT =",GT
13720 CLS
13730 LPRINT "QUARTZ =",OZ
13740 LPRINT
13750 LPRINT "MELTING PROPORTIONS: PLAG= 1/3, K-FS= 1/3, QTZ= 1/3."
13760 LET KS = OZ + MT + PL
13770 LET KR = KS - (( KS * F ) + (( 1 - KS ) * F ))
13780 ROL = (OL / (1 - KS)) * (1 - KR)
13790 ROX = (OX / (1 - KS)) * (1 - KR)

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13800 RCX = (CX / (1 - KS)) * (1 - KR)
13810 RPL = ( PL / KS ) * KR
13820 RMT = ( MT / KS ) * KR
13830 RGT = (GT / (1 - KS)) * (1 - KR)
13840 RQZ = ( QZ / KS ) * KR
13850 LPRINT
13860 LPRINT "PROPORTIONS OF PHASES IN THE RESIDUAL SOLID:"
13870 LPRINT "HB =",ROL,"OPX + CPX =",ROX,"BIO =",RCX
13880 LPRINT "PLAG =",RPL,"K-FS =",RMT,"GRT =",RGT
13890 LPRINT "QUARTZ =",RQZ
13900 LPRINT, "DEGREE OF PARTIAL MELTING =",F
13910 PRINT "                                I'M WORKING ON IT"
13920 LPRINT "CHEMICAL COMPOSITION OF THE INITIAL SOLID (IN PPM):"
13930 LPRINT "TI =",ARRAY(1),"BA =",ARRAY(2),"RB =",ARRAY(3)
13940 LPRINT "SR =",ARRAY(4),"Y  =",ARRAY(5),"ZR =",ARRAY(6)
13950 CLS
13960 LPRINT "LA =",ARRAY(7),"SM =",ARRAY(8),"EU =",ARRAY(9)
13970 LPRINT "YB =",ARRAY(10)
13980 LPRINT
13990 FOR J = 1 TO 10 STEP 1
14000 DO =(OL*KOL(J))+ (OX*KOX(J))+ (CX*KCX(J))+ (PL*KPL(J))+ (MT*KMT(J))
      +(GT*KGT(J))
14010 P = ((1 / 3) * KPL(J)) + ((1 / 3) * KMT(J)) + ((1 / 3) * KQZ(J))
14020 CLL = ARRAY(J) / (DO + (F * (1-P)))
14030 REM*****
14040 REM EQUATIONS FOR DO, P, AND CLL ARE EQUATIONS (1), (2), AND (3) OF
14050 REM ARTH (1976). JOUR. RESEARCH U.S. GEOL. SURVEY, VOL 4, PAGE 41.
14060 REM = = = = =
14070 REM THESE EQUATIONS WERE REARRANGED AND MODIFIED.
14080 REM THIS PROGRAM WILL GIVE REALISTIC RESULTS FOR PARTIAL
14090 REM MELTING OF A ROCK IN THE GRANITIC SYSTEM IN THE
14100 REM PROPORTIONS OF THE EUTECTIC, PROVIDED THAT THE
14110 REM DEGREE OF PARTIAL MELTING IS LESS THAN ca. 35%
14120 REM = = = = =
14130 REM*****
14140 CNM = CLL / CH(J)
14150 MNM = CLL / MB(J)
14160 LPRINT " ELEMENT = ",ELES(J)," CL = ",CLL
14170 PRINT "                                I'M WORKING ON IT"
14180 LPRINT " DO = ",DO," CL / CH = ",CNM
14190 LPRINT " P = ",P," CL / N-TYPE MORB =",MNM
14200 CLS
14210 NEXT J
14220 LPRINT
14230 LPRINT
14240 LPRINT
14250 CLS
14260 PRINT "DO YOU WANT TO DO MORE COMPUTATIONS ? (Y OR N)"
14270 PRINT
14280 BMS=INKEY$: IF BMS="" THEN 14280
14290 IF BMS = "Y" OR BMS = "y" THEN 14320
14300 IF BMS = "N" OR BMS = "n" THEN 14620
14310 GOTO 14260
14320 CLS
14330 PRINT "WOULD YOU LIKE THE COMPOSITION OF THE MELT OBTAINED IN THE"
14340 PRINT
14350 PRINT "MELTING PROGRAM BE THE INITIAL COMPOSITION OF A"
14360 PRINT

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14370 PRINT "FRACTIONAL CRYSTALLIZATION PROCESS ? (Y OR N)"
14380 PRINT
14390 XMS=INKEY$: IF XMS="" THEN 14390
14400 IF XMS="Y" OR XMS="y" THEN 14590
14410 IF XMS="N" OR XMS="n" THEN 14430
14420 GOTO 14330
14430 PRINT
14440 CLS
14450 PRINT "CHOOSE ONE OF THE FOLLOWING ITEMS:"
14460 PRINT
14470 PRINT "(A)  START AT THE BEGINNING OF THE MELTING PROGRAM WITH"
14480 PRINT "      NEW DATA"
14490 PRINT
14500 PRINT "(B)  START WITH THE SAME MINERALOGICAL AND CHEMICAL COM-"
14510 PRINT "      POSITION OF THE INITIAL SOLID"
14520 PRINT
14530 CMS=INKEY$: IF CMS="" THEN 14530
14540 IF CMS="A" OR CMS="a" THEN 12940
14550 IF CMS="B" OR CMS="b" THEN 13210
14560 CLS
14570 GOTO 14450
14580 GOTO 14630
14590 XS="MCF"
14600 CLS
14610 GOTO 15080
14620 CLS
14630 PRINT, "AU REVOIR LUC,  BONNE JOURNEE"
14640 GOTO 14650
14650 END
14660 LPRINT
14670 CLS
14680 PRINT "                      I'M WORKING ON IT"
14690 LPRINT "FRACTIONAL CRYSTALLIZATION AFTER PARTIAL MELTING"
14700 LPRINT "                      IN THE GRANITIC SYSTEM."
14710 LPRINT
14720 LPRINT "PROPORTIONS OF CRYSTALLIZING PHASES:"
14730 LPRINT "OL =",OL,"OPX =",OX,"CPX =",CX
14740 LPRINT "PLAG =",PL,"MT(OR KFS) =",MT,"GRT =",GT
14750 CLS
14760 LPRINT
14770 LPRINT
14780 LPRINT "MELT COMPOSITION: FELSIC", "LIQUID REMAINING =",L
14790 LPRINT
14800 PRINT "                      I'M WORKING ON IT"
14810 LPRINT
14820 CLS
14830 FOR J = 1 TO 10 STEP 1
14840 DO =(OL*KOL(J))+(OX*KOX(J))+(CX*KCX(J))+(PL*KPL(J))+(MT*KMT(J))
      +(GT*KGT(J))
14850 P = ((1 / 3) * KPL(J)) + ((1 / 3) * KMT(J)) + ((1 / 3) * KGT(J))
14860 CLL = ARRAY(J) / (DO + (F * (1-P)))
14870 REM*****
14880 REM EQUATIONS FOR DO, P, AND CLL ARE EQUATIONS (1), (2), AND (3) OF
14890 REM ARTH (1976). JOUR. RESEARCH U.S. GEOL. SURVEY, VOL 4, PAGE 41.
14900 REM*****
14910 D =(CROL*KOL(J))+(CROX*KOX(J))+(CRCX*KCX(J))+(CRPL*KPL(J))
      +(CRMt*KMT(J))
14920 CL = CLL * (L ^ (D - 1))

```

```

14930  CN = CL / CH(J)
14940  MN = CL / MB(J)
14950  PRINT "                                I'M WORKING ON IT"
14960  LPRINT " ELEMENT = ",ELES(J)," FINAL LIQUID (CL) = ",CL
14970  LPRINT " ELEMENT = ",ELES(J)," INITIAL LIQUID = ",CLL
14980  LPRINT " ELEMENT = ",ELES(J)," CL / CH = ",CN
14990  CLS
15000  LPRINT " D = ",D," CL / N-TYPE MORB = ",MN
15010  LPRINT
15020  NEXT J
15030  LPRINT
15040  LPRINT
15050  LPRINT
15060  LPRINT
15070  GOTO 14260
15080  PRINT
15090  PRINT "PROPORTIONS OF CRYSTALLIZING PHASES"
15100  PRINT
15110  PRINT "[OL + OPX + CPX + PLAG + MT(OR KFS) + GRT = 1]"
15120  PRINT
15130  PRINT "OLIVINE="
15140  PRINT
15150  INPUT CROL
15160  PRINT
15170  PRINT "ORTHOPYROXENE="
15180  PRINT
15190  INPUT CROX
15200  PRINT
15210  PRINT "CLINOPYROXENE="
15220  PRINT
15230  INPUT CRCX
15240  PRINT
15250  PRINT "PLAGIOCLASE FELDSPAR="
15260  PRINT
15270  INPUT CRPL
15280  PRINT
15290  PRINT "MAGNETITE (OR K-FS)="
15300  PRINT
15310  INPUT CRMT
15320  PRINT "GARNET="
15330  PRINT
15340  INPUT CRGT
15350  CLS
15360  LET CRW = CROL + CROX + CRCX + CRPL + CRMT + CRGT
15370  IF CRW <> 1 THEN 1530
15380  IF CRW = 1 THEN 1460
15390  END

```

4 of /de 4

Micro-D

General geology of part of southeast

Based on Ontario Geological Survey Map 2499

Figure A1.1: Sample locality map (Ore Chimney Mine area)

Trench, 30 metres southwest of mine shaft

Ore Chimney Mine area

General geology of part of southeastern Ontario

Map 2499

Pit, 160 metres northeast of mine shaft

area

27

15

Figure A1.4: Sample locality map (Ore Chimney Mine, 150-foot level)

GE

LEGEND

Geological contact (observed, assumed)	(1) Biotite schist	Quartz vein
Strike and dip of schistosity	(2) Biotite-hornblende schist to hornblende schist	Stringer zone with variable amount of quartz vein material
Minor fold (shape indicated by symbol)	(3) Hornblende-chlorite schist	Stringer zone containing ~5% of quartz vein material
	(4) Amphibolite	Stringer zone containing ~10% of quartz vein material
	(5) Muscovite schist	Stringer zone containing ~20-25% quartz vein material

• 44 Sample

GEOLOGY OF THE 150-FOOT LEVEL OF THE ORE CHIMNEY

variable amount
al

ing~5% of quartz vein material

ing~10% of quartz vein material

ing~20-25% quartz vein material

YE ORE CHIMNEY MINE

Geology by Luc Harnois, 1983

NE

Figure A1.1: Sample locality map (Ore Chimney Mine area)

Pit, 160 metres northeast of mine shaft

LEGEND

4 BISHOP CORNERS FORMATION

4c Metaconglomerate

4b Quartzite

4a Muscovite schist (locally conglomeratic)

3 ORE CHIMNEY FORMATION

Biotite schist

Garnet-biotite schist

unconformity

2

Biotite-calcite schist

Biotite marble

1 TUDOR FORMATION

1c Dacitic metatuff

1b Biotite schist

1a Amphibolite

☒ Mine shaft

▣ Pit

● 27 Sample

■ Buildings, foundations

88°/↘ Strike and dip of schistosity

84°/↘ Strike and dip of bedding

↗ 80 Trend and plunge of minor fold axis (shape indicated by symbol)

⤿ Geological contact (observed, assumed)

○ Outcrop

Modified from Moore and Morton (1986), Ontario Geological Survey Report 238

Figure A1.2: Sample locality map (Harlowe area)

Biotite schist
Garnet-biotite schist

Buildings, foundations

Geological contact (observed, assumed)

unconformity

2 Biotite calcite schist
Biotite marble

Outcrop

1 UDOR FORMATION

1c Dacitic metatuff

1b Biotite schist

1a Amphibolite

Modified from Moore and Morton (1966), Ontario Geological Survey Report 238

LEGEND

3 BISHOP CORNERS FORMATION

• 33 Sample

3b Quartzite

3a Calcareous metaconglomerate

■ Buildings

2 ORE CHIMNEY FORMATION

Biotite schist

Garnet-biotite schist

Outcrop

unconformity

1 KASHWAKAMAK FORMATION

1b Quartzofeldspathic interflow
metasedimentary rocks

1a Intermediate to felsic
metavolcanic rocks

Geological contact (observed, assumed)

Strike and dip of schistosity

Figure A1.3: Sample locality map (Reid Lakes area)

unconformity

1 KASHWAKAMAK FORMATION

1b Quartzofeldspathic interflow
metasedimentary rocks

1a Intermediate to felsic
metavolcanic rocks

Geological contact (observed, assumed)

Strike and dip of schistosity

Trend and plunge of minor fold axis (shape indicated by symbol)

LEGEND

3 BISHOP CORNERS FORMATION

3b Quartzite-pebble metaconglomerate
intercalated quartzite, pebbly quartzite,
micaceous quartzite, muscovite schist

3a Muscovite schist

unconformity

2 NORTHBROOK BATHOLITH

Metamorphosed granodiorite

intrusive contact

1 Amphibolite

NORTH

65

3a

54, 55

56, 57

59, 60

58

3a

61

2

25 metres

3 BISHOP CORNERS FORMATION

3b Quartzite-pebble metaconglomerate
intercalated quartzite, pebbly quartzite,
micaceous quartzite muscovite schist

3a Muscovite schist

unconformity

2. NORTHBROOK BATHOLITH

Metamorphosed granodiorite

intrusive contact

1 Amphibolite

Geological contact (observed, assumed)

65 Strike and dip of bedding

Outcrop

62 Sample

END

2|2.0|8.88

FIN