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NORTHSIDE RESOURCES

1993

BULK SAMPLING PROGRAM

prepared by

WESTERN DIAMEX
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NORTHSIDE RESOURCES
1993 BULK SAMPLING PROGRAM

In the early summer of 1993 Western Diamex was contracted by Northside Resources and several other companies to carry on an exploration project in an area west of Edmonton Alberta. This area was bounded on the south and east by the Pembina River ; to the north by the city of Whitecourt and to the west by the McLeod River. This first reconnaissance effort was meant to delineate areas of interest for further exploration through indicator mineral testing of existing drainage systems. Our work consisted of small sample sizes with 100 to 200 kilogram raw samples being the norm. These samples were screened and gravity concentrated using a Wilfley Vibrating Table. The heavy fractions were sent to the University of Alberta for mineral picking and analysis. For a more detailed description of the processing the reader is urged to read our Project Pembina Report.

Project Pembia was carried out over a 9000 square kilometer area with 160 different sites being investigated.

DECISION FOR A SECOND PHASE OF EXPLORATION

When the report was made available to the companies involved it was suggested that they should carry on further work on their own claims through larger sample sizes in selected areas based on the Project Pembina Data.

Northside Resources was interested in an immediate follow-up and contracted Western Diamex to carry on the investigation through the end of summer and into the fall of 1993.

This second phase of investigation centered exclusively on the Northside Resources mineral claims with four sites being chosen from the Project Pembina data for further investigation. It was decided that these sites would have much larger samples taken in the hopes that more data could be gleaned through the recovery of the rarer indicator minerals including diamond. It is obvious that the chances of a successful recovery of the rarer mineral species would be enhanced if we increased the probability of a "hit" by investigating more mineral grains.

The four sites chosen had yielded good indicator minerals in the Project Pembina effort so we felt that they would be our best chance for gathering meaningful data. With the indicator minerals that we had seen we were also hopeful that a diamond might be recovered.

SITES FOR BULK TESTING

The four sites were chosen (please see enclosed map) were on the Groat Creek, Beaver Creek, and Paddle River. Two sites were chosen on the Paddle River as it essentially crosses the Northside Claim block from west to east.

If we were dealing with glacially derived minerals then the Paddle river might give us a clue as to the direction of transport.

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INTERIM REPORT FOR NORTHSIDE RESOURCES

FIRST PHASE BULK SAMPLE INVESTIGATION

This exploration project could actually be considered a follow up to the Project Pembina project that Western Diamex undertook early in the summer of 1993. As we expect that this will be an ongoing project calling for several phases and because our efforts are focused on Northside Resources properties exclusively we would prefer to call this exploration effort a "first phase".

This exploration project was to help us follow up on data from Project Pembina in that we wanted to take much larger samples to better our chances of recovering diamonds and certainly gathering a more complete idea of the indicator minerals that were present. Our initial effort was targeted at the drainage sites that gave us the best indicator minerals in the Project Pembina work. These drainages were; Groat Creek, Beaver Creek, and two sites on the Paddle River. This sampling program entailed gathering two tonne bulk samples and field screening them to 3/8 inch minus. The minus fractions were taken to our field camp where they were screened to several size fractions. That material passing 18 tyler mesh was then processed on a Wilfley Vibrating Table to produce a heavy mineral concentrate. The concentrate was sent to the lab for further separation work and for the work needed to pick and analyze the individual mineral grains that might be significant. All size fractions were reserved for further study and we are thankful that we did so as those fractions are now a focus of this project. Literally thousands of individual grains have been examined under the microscope. As we expected the same types of indicator minerals were present as in Project Pembina but we now have enough grains to begin constructing a geochemical model of the indicator minerals we have recovered. To say we have more of the same thing really hasn't given us anything other than more confidence in the exploration effort.

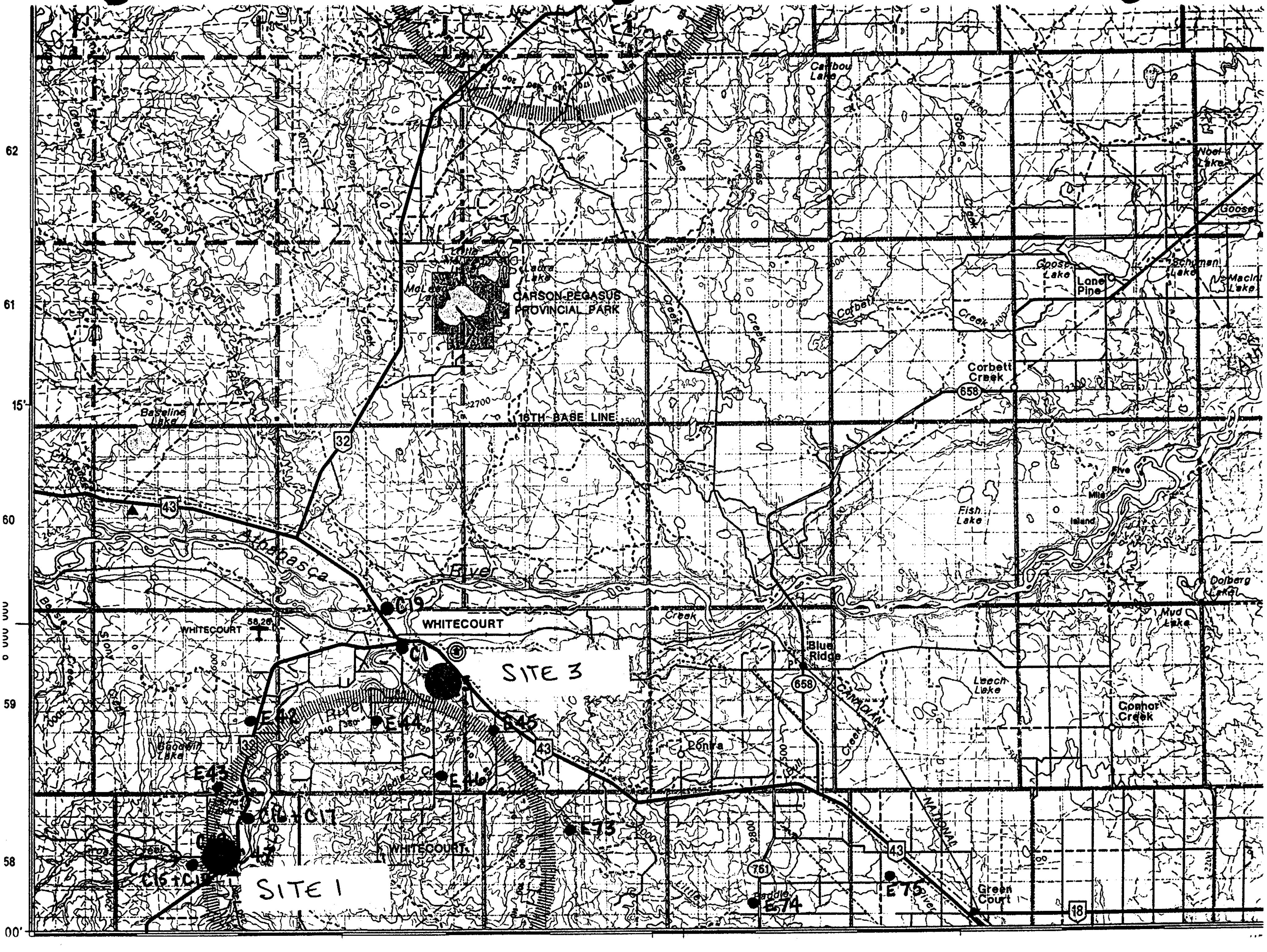
What we have really strived for is the continuation of the trail to a pipe. This means that we have to look for those other minerals that were not evident in our first effort but would be valuable additions to the puzzle. So far the most obvious new mineral has been GRANULITE. While most exploration effort seems to be concentrated on the mantle minerals it must be remembered that a pipe cuts through and samples every rock layer between the mantle and the surface. Granulites are of lower crustal origin and as such have been noted as accessory mineral fragments in diamondiferous pipe matrix. While it is possible that granulites could have come from glacial degradation of precambrian shield in the Northwest Territories their shape and makeup do not suggest it. Of primary importance to our thinking on this matter is we should see a linear pattern to glacial deposition. In other words the glacier would have to have spread a line of these granulites from the Territories to the sites we are recovering them at. As a result we should find granulites of similar appearance and chemistry in the drainages the glacier crossed. If drainage "A" has no granulites but drainage "B" which is further down ice than "A" does have them then the glacier likely picked up the granulites somewhere between "A" and "B". Also if we see granulites in one drainage but further down ice a drainage is blank and then a drainage even further down ice carries granulites it is less likely that the granulite has travelled far. These seem to be examples of what we have observed on the Northside Properties. It is now important to establish if these granulites are from local pipes or from further away. We have begun an in depth study of the larger fractions from each of our samples looking not only for larger granulite fragments but also other fragments that could represent pieces of pipe groundmass. The mineral investigations that have taken place so far have been primarily focused on the finer fractions of the samples because the equipment used to process the samples prefers the smaller mineral grains. We also face some difficulty when dealing with existing sample processing in that many of these pieces of potential groundmass are not heavy enough to report to the heavy fractions which are the primary fractions for investigation. If there are pieces of groundmass they will likely be easily broken down so there is some question if these fragments have the resistance to survive the extreme degradation needed to reduce them to the smaller size fractions. It is likely that these fragments would be better represented in the larger fractions. Because of the wide range of potential specific gravities these fragments might have the utilization of specific gravity concentration devices would not be recommended. Most of the mechanical and chemical concentration techniques are not adaptable to the wide range of variables we must address. For this reason we feel that the larger fractions will have to be sorted strictly by eye one grain at a time. This is as the reader can no doubt imagine an exhausting procedure calling for many hours of technician's time. This work has begun but the sheer volumes of material that must be processed will lengthen the processing time per sample to perhaps months instead of weeks. Of course representative fragment grains may be found in a short time but there will still be the need for analysis to determine the actual identification of the fragment through geochemical means. All of this work will be carried out while the regular work progresses on the "standard" indicator mineral grains that the lab has already picked. Most of that work is now complete as far as the first reconnaissance of the picked grains. Grains of special significance have been flagged for further analysis and we are waiting for time on the microprobe to complete that work. As we noticed in the Project Pembina reports there are chrome augites, chrome diopsides, and G series garnets. Our first look using wide scan analysis (EDS) on the micropobe samples from Phase 1 have given us similar indicator minerals. This is a preliminary analysis only and we will have to wait until we use the more accurate microprobe analysis method (WDS) to determine the subtle geochemistry differences that give us a true indicator mineral. While we have lumped a group of fragments under the classification of granulites this may not in fact be the case as only a few of these fragments have been analyzed. They so closely resemble the mantle derived eclogites except for included sodium which could represent plagioclaze feldspar that we could easily mistake them for each other. We are not going to leave it to chance and have decided that we will scan most if not all of these fragments. One recent development has been some input on research done on granulites as indicators of depth and pressure. There are analytical procedures that allow us to determine the environment the granulites come from. This would allow us to better determine the type of deposit they were derived from and as a result the type of deposit we are searching for.

The preliminary classification of the garnets in this project to possible eclogitic and peridotitic sources will have to wait for WDS scanning before a definitive answer can be given. While the wait and the expense of running mineral grains by WDS can be frustrating we have found it beneficial to do a quick inexpensive look using less exact scanning techniques and then flagging selected grains for in depth analysis. We expect that we will be able to begin running the WDS analysis the week of Dec. 14 1993 with an expected completion date of Dec.17 1993. A much more detailed report will be delivered shortly after that. The ongoing large grain picking will be ongoing and is not expected to finish until the end of January. The analysis of the granulite fragments will be on line the week of Dec. 14 1993 and it is expected that we will have data on the granulite formation environment by Dec. 17 1993.

If you have further questions please contact me at 945-9633.

Tom Bryant

MAP SECTION



62
61
15'
60
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00'
Caribou Lake
Noel Lake
Goose
Goose Lake
Lone Pine
Schuman Lake
Macin Lake
CARSON-PEGASUS PROVINCIAL PARK
Lake
Corbett Creek
658
16TH BASE LINE
Baseline Lake
32
43
Athabasca
River
Fish Lake
Five Mile Island
Dolberg Lake
Mud Lake
C19
WHITECOURT
Creek
C1
SITE 3
Blue Ridge
658
Leech Lake
CANADIAN
NATIONAL
Connor Creek
E42
E44
E45
33
Goodwin Lake
43
Ponra
E43
E46
C16 + C17
E73
WHITECOURT
C15 + C18
SITE 1
761
E74
E75
Green Court
18

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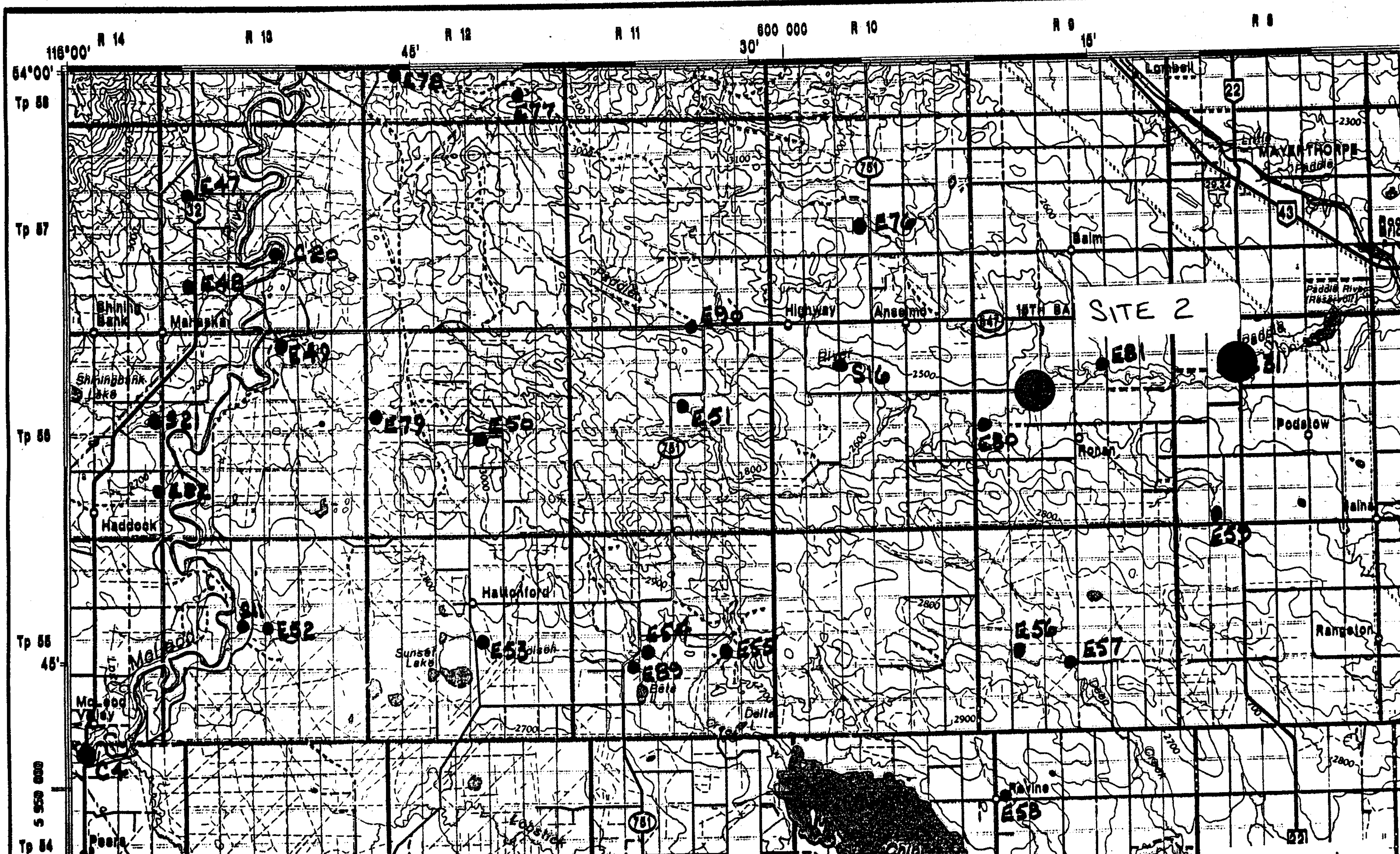

SAMPLE GATHERING AND FIELD PROCESSING

Our samples were taken as two tonne (dry weight) raw material from the selected site. All sites were along existing drainage areas. There was a desire to target our efforts on natural concentration areas to further increase our likelihood of gathering the maximum of the available heavy mineral grains in the area. The samples were wet screened in the field by hand to a minus 3/8 inch field sample with the oversize being discarded. The minus 3/8" field sample was transported to our field camp at Evansburg for further concentration. At the field camp the sample was wet screened by hand.to produce several screened fractions.: 3/8" minus 10 tyler mesh plus, minus 10 mesh plus 18 mesh, and minus 18 mesh. Each of these fractions were reserved with the minus 18 mesh going to one further step to be gravity concentrated. This minus 18 mesh fraction was the one that the lab personnel at the time were most interested in examining. The minus 18 mesh materials were put across a Wilfley Vibrating Table to sort the sample into several fractions according to specific gravity. The heaviest fraction was set at approximately 2.7 specific gravity plus but in practical terms there was some lighter material included in the final concentrate. We felt it was better to handle a rougher concentrate than run the risk of losing heavy minerals. This "dirty" concentrate was taken to the University of Alberta for the heavy mineral laboratory work. All fractions of screened material and table discard were reserved for further work.

It is fortunate that these fractions were held as the composite mineral grains referred to a Granulites in this report were found independently from the regular heavy mineral investigation as we began to study the larger and lighter fractions for pipe fragments and not just individual mineral grains. While we have not yet found composite grains that could be pipe fragments other than the granulites we are continuing to pick suspected pipe materials in the hope of finding matrix materials. Finding the less resistant pipe materials would be a sure indicator of the close proximity of a pipe. The granulite fragments are fairly resistant and would likely survive short distance transport in a drainage system where many other pipe materials would not.

FURTHER WORK IN PROGRESS

With the results of this investigation in mind we are continuing the exploration effort on several fronts. The hand picking of larger rock fragments to find pipe materials continues with input from the Electron Microprobe and Petrographic personnel at the University of Alberta.
Satellite and aireal photo investigations are underway to delineate possible pipe sources through surface expression. Our primary focus is on circular and linear features in light of the extensive dike systems that have been associated with the pipes in the North West Territories.

A continuing research effort is underway to determine what the best indicator minerals might be. We are particularly interested in the site specific nature of many of the indicator minerals from pipes from around the world. The two main minerals mentioned in literature is pyrope garnet and chrome diopside. Further research has indicated that there are known pipes that show very little pyrope but are rich in selected chemistries of almandine and grossular garnet. Recently we became aware of some research into spessartine as an indicator mineral. As we have abundant spessartine in our samples we are now trying to determine the geochemistry of pipe derived spessartine versus metamorphic. Other indicator minerals could be certain high magnesium illmenites as well as several other non standard minerals. Since the indicator mineral information comes from analysis of existing pipes the range of possible indicator minerals is increasing as more work is done on pipes worldwide. There may be a need to send our materials to a specialist in the more exotic indicators as we continue the research effort.

Work also progresses with research into the possible existence of a basement suture zone thought to run under the exploration area. This system could contribute to pipe formation.

NORTHSIDE CLAIM BLOCK
EXPLORATION REPORT

Introduction

As all Diamond Exploration programs are by necessity quite complicated, the purpose of this final report is to summarize the complex process by which the large volume of bulk field samples was reduced by a factor of almost 99% to a small heavy mineral component suitable for examination, and subsequent Microprobe analysis.

It is upon these analyses that the final reccomondation to the client concerning any future exploration work is based.

Sample Handling

Each sample as received from the field was an average weight of approximately 20 Kg., and consisted of a mixture of sand, clay and silt which had been screened to approximately18 mesh.and reprsentative samples of the various over-sized screened fractions

The major focus of the laboratory work was the minus 18 mesh field concentrate generated by the Wilfley Table at the field site.

Referee Samples

The first step in sample processing was to split the samples in half, with one half of the sample being processed and the second half held in reserve as an independent referee sample.

This was done so that, in the event a given sample was lost in processing, an untouched aliquot of original material would be available. These samples are currently being stored by Western Diamex and are available should the client desire any additional testing done in the future, either by Western Diamex or by any independent laboratory.

Sample Handling

The samples as received from the field were heavily contaminated with clays, fine silt, and organics. The presence of these materials makes processing with heavy liquids impossible, so it was necessary that the samples first be soaked in a 4% solution of sodium metahexaphosphate for approximately 18 hours.

(It should be noted that samples from the NorthSide Properties, especially the Beaver River and the Hagman-Paddle sampling sites, required vigorous mixing and washing by hand to free the sand and heavy mineral grains from the silts and clays.)

The washed samples were then carefully dried in an oven at approximately 120 degrees Centigrade. This drying process generally required about 8 hours for each sample.

The dried material was rescreened to 18 mesh, and all larger material was set aside for further work.

The samples were next exposed to a magnetic field to remove the mineral magnetite. This mineral makes up about 90% of all the heavy minerals in the sample and is of no interest in diamond exploration.

The sample, dried, screened and with the magnetite removed, was then ready for heavy liquid separation.

Heavy Liquid Separation

The heavy liquid ethylene tetrabromoethane (TBE) was used to separate the heavy mineral component of the sample from the lighter material (primarily quartz and feldspars).

Processing with TBE allowed a relatively quick separation of the grains of quartz, feldspar and other comparatively light minerals from the heavy mineral grains in which the diamond program is primarily interested. This separation is achieved by allowing the heavy mineral grains to settle through a quantity of TBE over a period of approximately ten hours. The highly toxic TBE, containing the lighter minerals, was then drawn off, and the heavy mineral grains were recovered and washed in acetone to remove the TBE. The so-called light minerals were later separated from the TBE and discarded.

From a split sample of 10 kg, approximately 10 grammes of heavy minerals are recovered.

Hand Picking of Separates

It was determined after careful thought and consideration that, due to the size of the heavy mineral samples, it would be most productive if they were all 'picked' by hand, rather than resorting to mechanical separation using a Frantz Isodynamic Magnetic Separator.

While the recovery rates of the Frantz are usually excellent, it was quite possible that certain critical indicator minerals could be lost in the waste material produced by this type of magnetic separation.

Hand picking, while much more time-consuming than using a Frantz Separator, is much safer for critical samples, as there is no chance that marginal mineral grains may be lost. It was for this reason that the extra time and attention was spent processing each sample by hand.

(This decision was subsequently vindicated when complex rock fragments were found in the samples, which later proved to be Granulites. These important clues would have been lost had magnetic separation been used.)

Polishing

The picked grains were mounted in 154 petroepoxy and polished at the University of Alberta Thin Section Lab.

To facilitate probing, the grains were set out in a matrix consisting of approximately 200 grains per epoxy block.

Microprobe

The samples were probed utilizing the Energy Dispersive System (EDS) and Wavelength Dispersive System (WDS) at the University of Alberta Electron Microprobe Lab. Minerals were identified by their characteristic x-ray spectra and the relative amounts of trace and accessory minerals quantified.

Energy Dispersive System (EDS) and Its Limitations

EDS is a very cost effective method for the examination of a large number of mineral grains. It is best used for a primary reconnaissance as it does not give a definitive analysis of all mineral grains. Those grains which are determined by EDS to be of interest are then examined by WDS.

The EDS system is based on the characteristic x-ray energy released when an accelerated electron removes an inner shell electron of the target atom and an outer shell electron drops back to a lower energy level. The emitted electrons pass through a beryllium window and are detected by a silicon-based detector. The Microprobe's computer compiles this data to produce a spectrum of the energies produced.

While EDS is most cost effective for reconnaissance of a large number of individual grains, it does have its limitations. Elements with an atomic weight lower than Na cannot be analyzed and some emitted X-ray energies overlap and may mask other emissions, or give misleading readings.

Results of the Reconnaissance

Samples were checked for petrographic composition by PhD. student Dave Hauth.under contract to Western Diamex. It was thought that this might give the exploration team a body of information which could allow a precise determination as to the source rock from which the sediments were derived.

These sediments may have originated as fragments of high grade metamorphic or igneous rocks, which are thought to have been broken off the Canadian Shield by the passage of the ice sheet during glaciation. The movement of the ice sheet over the study area is not completely understood, but it has been suggested by some Quaternary geologists that material have been brought into the area from as far away as Hudson Bay.

Some metamorphic (quartzite) and sedimentary (sandstone, shales, limestones, iron carbonates) fragments found in the sediments seem to have come from the west, off the Cordillera. Evidence of this can be seen in the large number of quartzite pebbles and cobbles quite common in the area.

Unfortunately, due to the large amount of contamination caused by glaciation of the area, it has not been possible at this time to arrive at any firm conclusions as to the exact source of the material found in the study area.

This uncertainty in the exact sourcing of study area sediments must be taken into account when evaluating indicator minerals.

While there is a strong possiblity that indicator minerals found in the respective study areas are derived from local sources, the possiblity of glacial contamination must not be discounted.

Sample #1 Groat Creek

This sample contained a mixture of sedimentary fragments (sandstone, shales, iron carbonates, etc.), and igneous and metamorphic fragments (mostly granites and gneisses) typical of the Canadian Shield.

Due to the fact that the study area is covered with till, it is not possible to state with any certainty whether any given mineral grain was derived from a local source or was transported into the area by the ice sheet during glaciation.

This sample yielded 96 grains which were probed using EDS.
(Please see section regarding selected analysis of Micro-probe)
Plug #NS-1 Date Nov 01 1993

Sample # 2 Hagman Paddle

This sample contained far more clays and fine silts than most samples and required vigorous and protracted washing to free the mineral grains for separation. The rock fragments found consisted of sedimentary rocks (shales, sandstones, iron carbonates) and igneous and metamorphic fragments (granites and gneisses).

It should be noted that Sample #2 produced fewer igneous and metamorphic fragments than Groat Creek.

This sample yielded 99 grains which were probed using EDS.
(Please see section re:Micro-probe data)
Sample Plug #NS-2 Date Nov 1 1993

Sample # 3 Beaver Creek

This sample contained less clay and silt than previous samples and more of the fragments were igneous and metamorphic (granites and gneisses) than sedimentary. It was this sample which produced the granulite fragments on which the study has focused during the later stages of the exploration program.

Of particular interest was the recovery of a single G3 garnet classified as a Calcic pyrope-almandine plus a number of low-chrome diopsides

Discovery of Beaver Creek Granulites

We are indeed fortunate that we elected to examine all over-sized frations from our study areas, as that examination of the Beaver Creek samples revealed an unknown composite rock fragment which proved upon microprobe examination to be a granulite.

The pressure and temperature data calculations concerning the granulite fragments yielded results indicating a formation at a depth of approximately 21 km in the crust and at temperature of approximately 400 degrees centigrade.

This is of special sigificance as such complex fragments would have been lost to standard indicator mineral processing, due to the nature of their size (greater than 18 mesh) and their complex specific gravity profile which prevents their seperation using TBE.

While the subject of granulites is extremely complex. For the purpose of our report it is sufficient to state that granulites are metamorphic rocks which are formed in the lower crust and are most unusual to find in sedimentiary basins as they are quite unstable and usually do not travel great distances.from their source

Finding such fragments in the Beaver Creek study area begs the question "how did such complex rocks find their way into the centre of the Western Canada sedimentay basin which underlies our study area".

While this is merely speculation; we have ample evidence from literature detailing granulite transport by deep rooted pipes.

Several authors (See Literature Section: "Geophysical and Petrological Characterisitics of the Basement Rocks of the Western Canada Basin" Burwash, Green, Jessop, and Kanasewich Page 66.)

have suggested that deep seated basement faults underlie certain areas of the Western Canada sedimentary basin. While some of these faults are known and others are inferred, this paper seems to suggest that one such fault underlies the study area.

In other areas of the world such faults have been known to provide pathways for mantle diatremes to reach the surface.

The recovery of granulite fragments from the Beaver Creek Study area is open to several interpetations. While it is known that granulites outcrop in the Canadian Shield, there are few known outcrops of granulite similar in chemical compostion to the recovered fragments.

While it is perhaps premature to draw any firm conclusions from such limited data, it is none the less very encouraging to speculate that such fragments may have be derived from a local source.

Since is not possible to state with any certainty that this is the case, further work; both of a chemical and geophysical nature, in the area of Beaver Creek is most desirable.

CONSULTANT'S

OBSERVATIONS AND RECOMMENDATIONS

As a Professional Prospector consulting to Western Diamex and Northside Resources I have been asked for my input regarding the research to date.

The many G5 garnets we have found could be attributed to a metamorphic source or they can be an indicator mineral of importance. We have located one G3 garnet and one Chromium Diopside that could be from the diamond stability field. The need for more picking would be indicated as the shear number of grains to be investigated is overwhelming. It took a great deal of work to find one G3 garnet. The obvious question would be whether more garnet picking would yield more G3 garnets. It would be my recommendation that we have more picking done with particular emphasis on chromites and illmentites. The picking should be done by an expert that has clearly demonstrated the ability to pick these minerals with a high degree of accuracy. The aim would be to approach the indicator mineral problem from a slightly different angle by concentrating on a new set of possible indicator minerals. Our G3 garnet so closely resembles the G5 garnets that unless they are microprobed we cannot tell them apart. With the high cost of microprobe work it is not practical to probe every garnet but an investigation of other indicator minerals might lead us in a more direct route to pipe derived minerals.

The expansion of the indicator mineral data base may also give us a more definitive idea of the origins of the granulites that have been discovered in this program. Certainly the granulites are interesting. Many references are made to granulites being in pipes. This is logical as granulites are lower and mid crustal and a pipe would have to pass through these zones on its way to the surface. While the granulites we have found may have been brought from the Shield by glacial transport there is the possibility of a nearby source. It would be helpful to have more of these grains investigated as well. I would like to have more data on the chemistry of the garnets in the granulites as well as the chemistry of the granulites in general with a larger number of granulite fragments being investigated. The cost of doing a broader analysis with a large number of granulites prevented that work in this program but we might find that there are several distinct types of granulite to be found representing several crustal zones. With data like that we could better interpret the source of the granulites.

The satellite image of the area has revealed several features that are of interest as they are located near the drainages that have yielded good indicator minerals. These features must be ground-truthed and further study should be carried out on other imagery of the area.

Since the greatest number of interesting minerals have come from the Beaver Creek drainage we may be advised to concentrate our greatest energy around that area of the Northside claim block for the next phase of our program. This would essentially be a greater emphasis on the re-picking of an extended mineral suite from those samples we already have from the Beaver Cr. drainage. Our first ground-truthing attempts should also be concentrated in the Beaver Creek area.

I am in favor of a magnetic survey of the area surrounding the indicator mineral drainages but I would like to see the extended indicator mineral picking and at least some ground-truthing of targets derived from satellite data done first.

If I were to recommend the most beneficial course of action based on the data to date I would suggest:

1. Submit the samples we have for specialized picking by a picker showing a high degree of accuracy.

2. Continue the examination of imagery to find surface expression of possible source systems.

3. Ground-truth the features located on the imagery.

4. Link all of the picking data with the ground-truthing and delineate an area of confidence for a magnetic survey.

This is a logical course of action that could be done over the next couple of months before summer. If Northside wants to accelerate the process a magnetic survey done now may reveal good targets that could be investigated through the summer. It is common practice in the N.W.T. diamond exploration to fly magnetics and then follow up on potential targets by till sampling directly down-ice of the target to look for indicator minerals. If a good idea can be had of the ice direction from a potential magnetic anomaly this technique could be useful to Northside.

[redacted]

Tom Bryant

Professional Prospector

NORTHSIDE RESOURCES

MICRO-PROBE DATA

CONFIDENTIAL

CERTIFICATE

I, Paul A. Wagner, of the City of Edmonton in the Province of Alberta, do hereby certify that:

I am the Facility Operations Manager and sole commercial analyst in the Electron Microprobe Laboratory in the Department of Geology at the University of Alberta.

I further certify that:

I am a graduate of the Department of Geology at the University of Alberta and hold an MSc, Geochemistry (1982) and a BSc, Specialization (1979) in Geology.

I am a registered Professional Geologist and member in good standing with the Association of Professional Engineers, Geologists and Geophysicists of Alberta.

I am a Fellow of the Geological Association of Canada and a member of six (6) additional national and international geological and mineralogical associations.

The data contained herein are the results of quantitative electron microprobe analysis of specimens submitted to this laboratory under contract to the University of Alberta.

I have no direct or indirect interest in the property or properties represented by the mineral specimens, nor the company or companies holding any rights or titles to said property or properties, and do not expect to receive any.

The results of the analyses contained herein may be utilized by the holder(s) of the property or properties for inclusion in a Prospectus or Statement of Material Facts within the limits of liability of the University of Alberta as specified by this contract.

Respectfully submitted
in the City of Edmonton,
Province of Alberta

PROFESSIONAL GEOLOGIST
PAUL A. WAGNER
ALBERTA

Paul A. Wagner, MSc, PGeol
Facility Operations Manager
Electron Microprobe Laboratory
Department of Geology
University of Alberta

University of Alberta
Electron Microprobe Laboratory
Mineral Location Diagram

Plug No. NS-1

Client NORTHSIDE RES

Date 01 NOV 1993

	A	B	C	D	E	F	G	H	I	J	
1	~~Alm~~ py gt ⊛	~~Alm~~ py gt ⊛	Alm gr gt	Alm py gt ⊛ X	Alm gt	Alm gr gt	Alm py gt ⊛ X	Alm gr gt	Alm gt	X	9
2	Alm gr gt	Alm gr gt	Alm gr gt	Alm gr gt	Alm gr gt	Alm gr gt	Alm gr gt	Alm py gt ⊛ X	Alm gr gt	Alm py gt ⊛ X	10
3	Alm gr gt	Alm gr gt	Alm gr gt	Alm gr gt	Alm gr gt	Alm gr gt	Alm gr gt	qtz	Alm py gt ⊛ X	Alm gr gt	10
4	Alm gr gt / Ilm ind	Alm gr gt	mt	Rutile	Alm gr gt	Alm gr gt	Alm gr gt	And gr gt	Alm gr gt	Alm gr gt	10
5	Ilm	Ti-mt / Ch-Ap	Ti-mt +mg ⊛	Ti-mt	Ti-mt	Ti-mt	Ti-mt +mg ⊛	Ilm	Ti-mt +mg ⊛	Ti-mt +mg ⊛	10
6	Ilm	Ti-mt +mg ⊛	Ti-mt	Amph	Chromite ⊛	Amph	Chromite ⊛	Ti-mt +mg ⊛	X	X	8
7	Cpx	gr gt	Amph	Amph	Amph	Cpx	Cpx	Cpx	Cpx	Opx ⊛	10
8	FAS	Opx ⊛	Cpx tr Cr ⊛	Cpx ⊛ Ti / Ti Cpx ⊛	Opx ⊛	FAS	Amph	Epidote	Amph	Amph	10
9	FAS	Cpx Ti ⊛	Amph	Cpx Ti ⊛	Amph	Epidote	Amph	Amph	Cpx	X	9
10	Cpx	Amph	Opx ⊛	Epidote	Opx ⊛	Cpx	Opx ⊛	Amph	Fdsp	Opx ⊛	10

be analyzed: **Total Grains:** 96

: 7 **Px:** 12 **Amph:** Ø **Oxide:** 8 **Others:** Ø **Total:** 27

University of Alberta
Electron Microprobe Laboratory
Mineral Location Diagram

Plug No. NS-2

Client NORTHSIDE RES

Date 01 NOV 1993

	A	B	C	D	E	F	G	H	I	J	
1	Alm gr spess gt	Alm gr gt	Alm py gr gt ⊛	Alm gr gt	Alm gr gt	Alm gt	Alm py gt ⊛	Alm spess gt	Alm gr gt	X	9
2	Alm gr gt	Alm gr gt	Alm spess gt	Alm gr py gt ⊛	Alm gr gt	Alm gr gt	FAS / ILm'%	Alm gt	Alm gr gt	Alm gr gt	10
3	FAS	Alm gr gt	Alm gr gt	Alm gr gt	Alm gr gt	FAS	FAS	Alm gr gt	Alm gr gt	Alm gr gt	10
4	Alm gr gt	Alm gr gt	Zircon	FAS	Alm spess gr gt	Alm gr gt	Alm gr gt	Alm gr gt	FAS	Alm py gr gt ⊛	10
5	Amph	Apatite	OPX ⊛	Fe-Ru	ILm ms ⊛	Ti-mt	Amph	Ilm ms ⊛	Ilm	Ilm	10
6	Cpx	OPX	Ti-mt ms ⊛	Ilm	Ilm	Ilm	Ilm	Ti-mt	Amph	Amph	10
7	Alm py gt? ⊛	CPX	Amph	Amph	Cpx or amph	Cpx	Alm py gt? ⊛	Amph	Cpx	Amph	10
8	C.g.	Cpx ⊛ or amph	Amph	Epidote	Cpx	Amph	Amph	Amph	Cpx ✓ Trem ⊛	Amph	10
9	Cpx	py? Alm gt ⊛	Cpx	Opx ⊛	Cpx	Cpx	Cpx	Cpx	Alm py? gt ⊛	mt	10
10	Cpx	Amph	Amph	Cpx	Amph	FAS	Epidote	Amph	OPX ⊛	C.g.	10

To be analyzed: 2 cpt **Total Grains:** 99

Gt: ~~[illegible]~~ 4+4? **Px:** 6 **Amph:** Ø **Oxide:** 3 **Others:** Ø **Total:** 17

University of Alberta
Electron Microprobe Laboratory
Mineral Location Diagram

Plug No. NS-3

Client NORTHSIDE RES

Date 01 NOV 1993

	A	B	C	D	E	F	G	H	I	J	
1	Alm × py gt	Alm × py gt	Alm gr gt	FAS	Alm spess gr gt	Alm × py gt	Alm spess gt	Alm gr gt	Alm gr gt	X	9
2	Alm py gt / Ilm	Alm gr gt	Alm × gt py	Alm spess gt	Alm gr gt	Alm gr gt	Alm gr gt	Alm gr gt	Alm py × gt	Alm gr gt	11
3	Alm gr gt	Alm gr gt	FAS	Alm × py gt	Alm gr gt	FAS	Alm gt gr	Alm × gr py gt	Alm gr gt	FAS	10
4	Alm gr gt	FAS	Alm gr gt	Alm gr gt	FAS	Alm spess gt	Alm gr gt	Alm × py gt	Zircon	Alm × py gt	10
5	Ilm mg	unknown mineral	Amph	mt	Ilm	Ti-mt ms	Ilm	Amph	Ilm	Ilm	10
6	Ilm	Amph	~~Amph~~ ILm	~~Ilm~~ ILm	~~Ilm~~ ILm	unknown mineral	Chromite Can't analyze pitted & unpolished	Ilm	Ilm ms	Ilm mg	10
7	C.g.	Epidote	Amph	C.g.	cpx	cpx	Amph	Amph	opx	Amph	10
8	cpx	C.g.	cpx ✓ Trcr	cpx	Amph	Amph	cpx	C.g.	Amph	Amph	10
9	cpx	FAS	cpx	Amph	FAS	Epidote	~~Epidote~~ cpx	~~Rlapa~~ Alm spess gt	cpx	×	9
10	Amph	Chlorite	Amph	cpx	Amph	FAS	C.g.	Amph	cpx	×	9

To be analyzed: **Total Grains:** 98

Gt: ~~9~~ 10 **Px:** 2 **Amph:** ∅ **Oxide:** ~~4~~ 5 **Others:** ∅ **Total:** 16

University of Alberta
Electron Microprobe Laboratory
Mineral Location Diagram

Plug No. NS-4

Client NORTHSIDE RES

Date 01 NOV, 1993

	A	B	C	D	E	F	G	H	I	J	
1	Alm x py gt	Alm * py gt	Alm x py gt	Alm x py gt	Alm gr gt	Alm gt	Alm Spess gt	Alm x py gr gt	Alm x sr/py gt	x	9
2	Alm * py gt	Alm gr gt	Alm * py gt	Alm * sr/py gt	Alm * py gt	Alm gt	Alm gr gt	Alm x sr/py gt	Alm x py/gr gt	Alm x sr/py gt	10
3	Alm gt	Alm py/gr gt	Alm sr/py gt	Alm py gt	~~Spess~~ FAS	Alm gr gt	Alm sr/py gt	Alm gr gt	Alm py gt	Alm gr gt	10
4	Alm gt	Alm gt	Alm Spess gt	Alm gt	Alm gr gt	Alm gr gt	Alm gr gt	Alm gr gt	Spess Alm gt	Alm gr gt	10
5	Mt	Ti-mt	Ilm	Ferro Apatite	Amph	Ti-mt Trms	Ti-mt ms	Fe-Ru Trms	Ilm Trmg	unknown mineral	10
6	Ilm	Ti-mt	ILm	Amph	Fe-Ru	Chromite ✓	Ilm	Ti-mt	Amph	unknown mineral	10
7	Amph	CPX	Alm py gt	Amph	Amph	Amph	CPX	Chlorite	~~Cpx~~ Amph	Amph	10
8	Amph	CPX ✓ TrCr	Chlorite or Alm py gt	CPX	Amph	FAS C Ti	CPX	CPX ✓ TrCr	Ilm Nb	Amph	10
9	CPX ✓ TrCr	CPX ✓ TrCr	Amph	Amph	Amph	Amph	CPX ✓ Cr	Amph	Epidote	Amph	10
10	OPX	Chlorite Alm/py or cordierite ??	Amph	CPX	Amph	Amph	Amph	CPX? ✓	~~Cpx~~ Amph	Chlorite Alm/py or cordierite ?	10

To be analyzed: Total Grains: 99

Gt: ~~[illegible]~~ 19 Px: 6 Amph: 0 Oxide: ~~[illegible]~~ 6 Others: 3 Total: 34

University of Alberta
Electron Microprobe Laboratory
Mineral Location Diagram

Plug No. WDNS 2-5

Client NORTHSIDE

Date 15 NOV 1993

2 gts, no px

	A	B	C	D	E	F	G	H	I	J	
1	gt cpx rock	gt opx cpx R	gt cpx R	Alm py gt	Alm spess gt	Alm gr py gt	X	X	X	X	6
2	Alm gr py gt	Alm spess gt	Alm gr py gt	Alm gr gt *	Alm py gr gt	Alm gr py gt	Alm spess gt	Alm py gr gt →	with +magnetite X	pyrite Inclusions X	8
3	Qtz chlorite rock	Amph opx rock	gr Amph rock	cpx	cpx	Epidote	Cr cpx	X	X	X	7
4	gt cpx Amph rock	gt cpx Amph rock	gt cpx Amph rock	gr cpx Amph rock	X	X	X	X	X	X	4
5	Alm py gt	Alm spess gt	Alm gr gt	Alm spess gr gt	Alm/sp gr/py gt	Alm spess gt.	Alm py gt	X	X	X	7
6	Alm spess gt	Alm gr py gt	Alm py gt	Alm spess gr gt	Alm spess gt	Alm gr gt	Alm spess gr gt	X	X	X	7
7											
8											
9											
10											

o be analyzed: **Total Grains:** 39

t: 13 **Px:** 1 **Amph:** 0 **Oxide:** 0 **Others:** 0 **Total:** 14

UNIVERSITY OF ALBERTA ELECTRON MICROPROBE LABORATORY

SILICATE ANALYSIS TYPE: GARNET CLIENT: NORTHSIDE RES DATE: 27JAN94

Grain	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O		Total	
NS1-A1	37.24	0.04	21.47	0.07	32.83	2.48	4.33	2.06	0.05		100.57	
-B1	39.03	0.14	21.44	0.09	24.42	0.66	7.68	6.48	0.04		99.97	
-D1	37.22	0.00	20.89	0.00	35.04	0.88	3.97	2.53	0.00		100.53	
-G1	37.74	0.08	21.35	0.10	28.59	1.11	5.69	5.49	0.03		100.18	
-H2	37.17	0.13	21.19	0.05	34.26	0.67	4.37	3.04	0.02		100.90	
-J2	38.04	0.02	21.33	0.06	31.66	0.55	6.51	2.41	0.06		100.59	
-I3	37.41	0.00	21.17	0.10	34.14	1.23	4.06	3.16	0.04		101.36	
NS3-A1	38.44	0.07	22.20	0.03	29.17	0.45	8.51	1.37	0.00		100.23	
-B1	38.60	0.10	21.60	0.00	31.87	0.59	6.14	2.79	0.03		101.72	
-F1	37.09	0.08	21.26	0.19	34.16	0.72	4.04	3.32	0.02		100.88	
-A2	38.52	0.15	21.18	0.00	28.27	0.40	5.79	6.76	0.00		101.08	
-C2	54.92	0.00	14.48	0.00	25.82	0.97	2.14	2.35	0.02		100.70	NOT gar
-I2	38.70	0.11	21.80	0.08	21.79	0.40	6.11	11.71	0.05		100.75	
-D3	37.86	0.05	21.19	0.05	31.02	0.63	4.86	4.81	0.02		100.50	
-H3	38.05	0.06	21.21	0.07	28.88	1.08	4.65	6.80	0.00		100.80	
-H4	37.86	0.10	21.16	0.03	38.38	0.98	5.34	6.59	0.05		100.50	
-J4	37.65	0.04	21.82	0.00	31.69	0.63	6.09	1.90	0.06		99.88	

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SILICATE ANALYSIS TYPE: **PYROXENE** CLIENT: DATE:

	Grain	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total
NS-1	C-8 CPX	51.64	0.21	4.86	0.29	6.31	0.11	15.06	22.69	0.52	0.01	101.69
D-8	~~D8~~ CPX 1	50.94	0.32	2.60	0.03	12.40	0.42	11.78	21.39	0.38	0.00	100.26
	~~D8~~ CPX 2	50.80	0.27	2.86	0.07	11.95	0.30	12.15	21.99	0.40	0.02	100.82
	B-9 CPX	50.76	0.67	3.35	0.05	13.01	0.26	15.36	16.93	0.10	0.02	100.49
	D-9 CPX	51.51	0.70	2.76	0.00	11.12	0.19	16.55	18.10	0.23	0.00	101.16
NS-2	B-8 CPX	55.25	0.11	2.04	0.16	7.86	0.09	19.57	12.96	0.25	0.01	98.30
	I-8 CPX	51.80	0.57	3.04	0.37	9.02	0.26	13.61	22.25	0.34	0.02	101.29
NS-3	C-8 CPX	50.15	0.22	7.87	0.37	5.21	0.04	20.08	12.83	0.91	0.25	97.94
NS-4	B-8 CPX	50.93	0.22	6.11	0.26	13.39	0.27	14.27	13.01	0.30	0.11	98.89
	A-9 CPX	49.90	0.26	7.62	0.37	12.67	0.22	14.51	12.75	0.44	0.28	99.03
	B-9 CPX	53.39	0.11	2.10	0.13	13.88	0.47	15.11	13.26	0.12	0.05	98.61
	H-8 CPX	52.73	0.05	6.17	0.05	9.45	0.27	17.36	12.42	0.46	0.11	99.08
K*	G-9 CPX	53.39	0.25	1.68	0.72	5.95	0.12	15.36	21.83	0.88	0.00	100.17
	H-10 CPX	48.90	0.98	8.33	0.29	10.60	0.20	16.88	11.63	1.03	0.34	99.18

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OXIDE ANALYSIS TYPE: CLIENT: DATE:

	Grain	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	ZnO	NiO ~~Nb_2O_5~~	Total
NS4	F6 Cr	0.08	0.08	28.13	40.51	15.59	0.28	14.86	0.00	0.24	99.80
NS5	G-6 Cr	0.02	0.11	19.58	48.68	18.52	0.34	12.57	0.12	0.10	100.03
	~~E-6 Cr~~										

UNIVERSITY OF ALBERTA ELECTRON MICROPROBE LABORATORY

SILICATE ANALYSIS TYPE: GARNET CLIENT: NORTHSIDE RES DATE: 27JAN94

Grain	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O		Total
NS4-A1	38.23	0.00	21.89	0.00	28.69	1.92	8.75	0.82	0.02		100.34
-B1	37.33	0.03	21.47	0.05	33.84	0.76	5.22	0.95	0.04		99.69
-C1	38.53	0.06	22.30	0.02	29.00	0.18	9.27	1.20	0.01		100.56
-D1	37.48	0.01	21.14	0.02	33.07	2.88	4.20	1.91	0.02		100.73
-H1	36.46	0.52	21.52	0.03	33.27	0.59	5.19	2.30	0.00		99.87
-I1	37.90	0.00	21.26	0.04	30.19	1.86	3.87	6.05	0.03		101.19
-A2	37.33	0.00	21.57	0.03	33.36	0.69	5.43	1.35	0.00		99.75
-C2	38.17	0.00	22.09	0.03	27.71	3.36	6.86	2.00	0.00		100.22
-D2	37.29	0.00	21.03	0.06	35.30	0.14	4.23	2.36	0.01		100.43
-E2	38.05	0.00	21.98	0.05	33.17	0.57	6.61	0.74	0.04		101.22
-H2	37.24	0.06	20.59	0.03	32.70	0.99	1.99	7.64	0.06		101.30
• -I2	38.92	0.12	21.33	0.01	25.33	0.49	6.99	7.39	0.10		100.67
-J2	38.10	0.15	21.29	0.04	24.65	0.63	5.59	10.04	0.04		100.52
-B3											
-C3											
-D3											
-G3											
-I3											
-C7											

INS 2-5
P ROW GRAIN 1

RNET ALMANDINE ~ GROSSULAR > PYROPE-SPESS
X - Fe Diopside (Hedenbergitic diopside - no Cr)
MPHIBOLE - 2 TYPES
IDOTE
GNETITE
MENITE - NO Mg
GIOCLASE - high Ca
ROW GRAIN 2
RNET - SAME AS GRAIN #1

- AS #1 - ferrodiopside - contains Ti

MENITE - NO Mg
GIOCLASE - high Ca
RT3 IN GARNET

IN 3 TOP ROW

RT3
NET (IDENTICAL TO GRAINS IN (#2)
X
PHIBOLE RIM ON ~~XXX~~ AMPHIBOLE OF DIFFERENT
COMPOSITION
GNETITE
MENITE

) 3 GRAIN 1

3
idite
orite
PAR
gnebite + Ferrorutile

1.3 GRAIN 2

PHIBOLE with high Cr exsolution phase
X?

)

3 Grain 3

nenite
phibole
orite
g
NET - Alm > grossular > Pyrope > spessartine

FOUR, GRAIN 1, GRAIN 2, GRAIN 3 & GRAIN 4

NET - AS IN
nenite
phibole
3
CPX
PLAG

UNIVERSITY OF ALBERTA ELECTRON MICROPROBE LABORATORY

SILICATE ANALYSIS | TYPE: GARNET | CLIENT: NORTHSIDE | DATE: 21 DEC, 1993

	Grain	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O		Total
g1	2-5 A-1-1	38.05	0.13	21.38	0.33	24.75	1.12	3.56	11.49	0.04		100.86
	A-1-2	37.68	0.13	21.39	0.39	24.82	1.08	3.55	11.67	0.01		100.70
	A-1-3	38.04	0.09	21.54	0.18	25.21	1.15	3.57	11.36	0.06		101.20
	A-1-4	37.76	0.06	21.31	0.20	26.71	1.30	3.69	9.74	0.04		100.80
g2	A-1-5	37.60	0.07	21.31	0.24	28.65	1.68	2.97	8.34	0.03		100.90
	A-1-6	37.67	0.05	20.85	0.28	28.80	1.91	2.84	8.16	0.04		100.57
g3	A-1-7	37.83	0.12	21.38	0.23	25.66	1.24	3.44	10.80	0.05		100.72
	A-1-8	37.74	0.09	21.31	0.24	27.71	1.69	3.16	9.12	0.05		101.11
g1	B-1-1	38.30	0.07	22.42	0.23	24.10	0.80	5.59	9.34	0.00		100.85
	B-1-2	38.16	0.07	21.79	0.30	25.18	1.03	4.75	9.54	0.01		100.82
g2	B-1-3	38.78	0.09	22.40	0.30	23.31	0.70	5.65	10.15	0.03		101.40
	B-1-4	38.52	0.09	22.22	0.35	23.88	0.74	5.38	10.32	0.02		101.51
g1	C-1-1	38.36	0.04	21.63	0.22	27.71	0.72	5.10	7.07	0.04		100.89
	C-1-2	38.26	0.07	21.90	0.19	27.10	0.80	5.07	7.13	0.07		100.60
g2	C-1-3	37.89	0.03	21.66	0.19	26.85	0.68	4.73	7.66	0.03		99.70
	C-1-4	37.70	0.04	21.81	0.12	26.79	0.71	5.40	7.38	0.03		99.99
g3	C-1-5	37.91	0.05	21.91	0.18	28.13	0.74	5.07	6.83	0.02		100.84
g4	C-1-6	38.53	0.05	22.06	0.19	26.47	0.67	4.99	8.22	0.02		101.20
g5	C-1-7	38.20	0.03	22.10	0.10	27.63	0.74	5.13	7.18	0.02		101.12

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SILICATE ANALYSIS TYPE: **GARNET** CLIENT: Northside DATE: 21 Dec, 1993

Grain	$Si0_2$	$Ti0_2$	Al_20_3	Cr_20_3	Fe0	Mn0	Mg0	Ca0	Na_20		Total
2-5 D-1	37.58	0.08	22.09	0.00	33.60	1.05	5.29	0.81	0.01		100.51
F-1	37.56	0.08	21.71	0.17	31.15	0.07	3.29	6.81	0.03		100.87
F-2	37.81	0.06	21.67	0.05	31.92	0.50	3.60	5.05	0.05		100.69
E-2	37.43	0.01	21.70	0.01	34.18	0.11	4.28	2.54	0.02		100.27
C-2	36.79	0.10	21.36	0.11	36.76	0.23	2.28	2.73	0.00		100.35
A-2	37.87	0.09	21.23	0.15	29.38	0.23	4.83	6.60	0.00		100.37
A-5	37.69	0.04	21.92	0.00	34.53	0.79	4.67	0.91	0.00		100.55
B-6	37.89	0.07	21.72	0.18	29.02	0.76	4.11	7.19	0.04		100.98
C-6	37.20	0.02	21.70	0.00	34.81	1.57	3.92	1.40	0.00		100.61
G-5	37.79	0.06	22.24	0.00	35.10	0.29	5.44	0.37	0.04		101.32

UNIVERSITY OF ALBERTA ELECTRON MICROPROBE LABORATORY

SILICATE ANALYSIS TYPE: **PYROXENE** CLIENT: NORTHSIDE RES. DATE: 05 JAN 94

2.5

Grain	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total
A-1 CPX-1	50.35	0.17	2.77	0.08	13.66	0.23	11.34	21.70	0.43		100.73
A1-CPX-9	50.14	0.40	3.82	0.07	13.02	0.29	10.98	21.10	0.61		100.42
B-1 CPX-1	52.06	0.19	2.07	0.00	10.62	0.22	12.73	21.17	0.39		99.46
B-1 OPX-1	51.76	0.10	1.69	0.00	27.90	0.36	18.74	0.55	0.02		101.11
B-1 CPX-2	51.75	0.40	2.97	0.00	11.11	0.25	11.30	20.44	0.40		98.61
B-1 ~~OPX 2~~ CPX-3	51.59	0.34	3.00	0.00	11.18	0.22	12.95	21.05	0.44		100.77
B-1 CPX-4	51.54	0.42	3.31	0.03	11.02	0.30	12.19	21.14	0.47		100.42
B-1 OPX 2	50.61	0.11	1.62	0.01	28.17	0.39	17.24	0.56	0.00		98.71
B-1 OPX 3	50.30	0.07	1.21	0.00	28.42	0.40	11.54	0.56	0.01		92.51
C-1 CPX 2											

UNIVERSITY OF ALBERTA ELECTRON MICROPROBE LABORATORY

SILICATE ANALYSIS TYPE: **PYROXENE** CLIENT: NORTHSIDE RES DATE: 05JAN94

2·5

Grain	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total
A-1 CPX 1	50.35	0.17	2.77	0.08	13.66	0.23	11.34	21.70	0.43		100.73
A-1 CPX 2	53.16	0.42	3.39	0.06	12.72	0.24	11.96	15.69	048		98.13
A-1 CPX 3	44.12	0.08	12.67	0.04	22,93	0.19	11.37	11.41	1.19		104.01
A-1 CPX 4	50.87	0.19	2.53	0.07	12.82	0.28	19.17	20.84	0.44		107.2

NORTHSIDE RESOURCES

SELECTED ANALYSIS

OF

MICRO-PROBE DATA

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5a1-1
 Enter analvsis data as oxides:
SiO2? 38.05
TiO2? 0.13
Al2O3? 21.39
Cr2O3? 0.33
FeO? 24.75
MoO? 3.56
CaO? 11.49
Na2O? 0.04
MnO? 1.12
 Data okav? (Y or N): v

Samole              Classification Name
2-5a1-1             G-5            Maonesian almandine
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5a1-2
 Enter analvsis data as oxides:
SiO2? 37.68
TiO2? 0.13
Al2O3? 21.39
Cr2O3? 0.39
FeO? 24.82
MoO? 3.55
CaO? 11.67
Na2O? 0.01
MnO? 1.08
 Data okav? (Y or N): v

Samole              Classification Name
2-5a1-2             G-5            Maonesian almandine
```

MICRO-PROBE DATA CLASSIFICATION

```
 Enter analvsis data as oxides:
SiO2? 38.04
TiO2? 0.09
Al2O3? 21.54
Cr2O3? 0.18
FeO? 25.21
MgO? 3.57
CaO? 11.36
Na2O? 0.06
MnO? 1.15
 Data okav? (Y or N): v

Samole                 Classification Name
2-5 a1-3               G-5            Maonesian almandine
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5a1-4
 Enter analvsis data as oxides:
SiO2? 37.76
TiO2? 0.06
Al2O3? 21.31
Cr2O3? 0.20
FeO? 26.71
MaO? 3.69
CaO? 9.74
Na2O? 0.04
MnO? 1.30
 Data okav? (Y or N): v

Samole                Classification Name
2-5a1-4               G-5              Maonesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Sample Name: 2-5a1-5
 Enter analysis data as oxides:
SiO2? 37.6
TiO2? 0.07
Al2O3? 21.31
Cr2O3? 0.24
FeO? 28.65
MgO? 2.97
CaO? 8.34
Na2O? 0.03
MnO? 1.68
 Data okay? (Y or N): y

Sample                 Classification Name
2-5a1-5                G-5            Magnesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5a1-6
 Enter analvsis data as oxides:
SiO2? 37.67
TiO2? 0.03
Al2O3? 20.85
Cr2O3? 0.28
FeO? 28.8
MoO? 2.84
CaO? 8.16
Na2O? 0.04
MnO? 1.91
 Data okav? (Y or N): v

Samole              Classification Name
2-5a1-6             G-5            Maonesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Enter analvsis data as oxides:
SiO2? 37.83
TiO2? 0.12
Al2O3? 21.38
Cr2O3? 0.23
FeO? 25.66
MgO? 3.44
CaO? 10.80
Na2O? 0.03
MnO? 1.24
 Data okav? (Y or N): v

Samole                Classification Name
2-5a1-7               G-5            Maonesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

Samole Name: 2-5a1-8
Enter analvsis data as oxides:
SiO2? 37.74
TiO2? 0.09
Al2O3? 21.31
Cr2O3? 0.24
FeO? 27.71
MoO? 3.16
CaO? 9.12
Na2O? 0.05
MnO? 1.69
Data okav? (Y or N): v

Samole	Classification	Name
2-5a1-8	G-5	Maonesian almandine

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5b1-1
 Enter analvsis data as oxides:
SiO2? 38.3
TiO2? 0.07
Al2O3? 22.42
Cr2O3? 0.23
FeO? 24.10
MoO? 5.59
CaO? 9.34
Na2O? 0.00
MnO? 0.80
 Data okav? (Y or N): v

Samole
2-5b1-1             Classification Name
                    G-5            Maonesian almandine
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5b1-2
 Enter analvsis data as oxides:
SiO2? 38.16
TiO2? 0.07
Al2O3? 21.79
Cr2O3? 0.30
FeO? 25.18
MoO? 4.75
CaO? 9.54
Na2O? 0.01
MnO? 1.03
 Data okav? (Y or N): v

Samole              Classification Name
2-5b1-2             G-5             Maonesian almandine
```

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5b1-3
 Enter analvsis data as oxides:
SiO2? 38.78
TiO2? 0.07
Al2O3? 22.40
Cr2O3? 0.30
FeO? 23.31
MoO? 5.65
CaO? 10.15
Na2O? 0.03
MnO? 0.74
 Data okav? (Y or N): v

Samole              Classification Name
2-5b1-3             G-5            Maonesian almandine
```

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5c1-1
 Enter analvsis data as oxides:
SiO2? 38.36
TiO2? 0.04
Al2O3? 21.63
Cr2O3? 0.22
FeO? 27.71
MoO? 5.10
CaO? 7.07
Na2O? 0.04
MnO? 0.72
 Data okav? (Y or N): v

Samole                Classification Name
2-5c1-1               G-5            Maonesian almandine
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5c1-2
 Enter analvsis data as oxides:
SiO2? 38.26
TiO2? 0.07
Al2O3? 21.90
Cr2O3? 0.19
FeO? 27.10
MoO? 5.07
CaO? 7.13
Na2O? 0.07
MnO? 0.80
 Data okav? (Y or N): v
```

Samole	Classification	Name
2-5c1-2	G-5	Maonesian almandine

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5c1-3
 Enter analvsis data as oxides:
SiO2? 37.89
TiO2? 0.03
Al2O3? 21.66
Cr2O3? 0.19
FeO? 26.85
MoO? 4.73
CaO? 7.66
Na2O? 0.03
MnO? 0.71
 Data okav? (Y or N): v

Samole              Classification Name
2-5c1-3             G-5            Maonesian almandine
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5c1-4
 Enter analvsis data as oxides:
SiO2? 37.7
TiO2? 0.04
Al2O3? 21.81
Cr2O3? 0.12
FeO? 26.79
MgO? 5.40
CaO? 7.38
Na2O? 0.03
MnO? 0.71
 Data okav? (Y or N): v

Samole              Classification Name
2-5c1-4             G-5            .Magnesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5c1-5
 Enter analvsis data as oxides:
SiO2? 37.91
TiO2? 0.05
Al2O3? 21.91
Cr2O3? 0.18
FeO? 28.13
MgO? 5.07
CaO? 6.83
Na2O? 0.02
MnO? 0.74
 Data okav? (Y or N): v

Samole              Classification Name
2-5c1-5             G-5            Magnesian almandine
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5c1-6
 Enter analvsis data as oxides:
SiO2? 38.53
TiO2? 0.05
Al2O3? 22.06
Cr2O3? 0.19
FeO? 26.47
MoO? 4.99
CaO? 8.22
Na2O? 0.02
MnO? 0.67
 Data okav? (Y or N): v
```

Samole	Classification	Name
2-5c1-6	G-5	Maonesian almandine

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

Samole Name: 2-5c1-7
Enter analvsis data as oxides:
SiO2? 38.20
TiO2? 0.03
Al2O3? 22.10
Cr2O3? 0.10
FeO? 27.63
MaO? 5.13
CaO? 7.18
Na2O? 0.02
MnO? 0.74
Data okav? (Y or N): v

Samole	Classification	Name
2-5c1-7	G-5	Maonesian almandine

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 25-5d1
 Enter analvsis data as oxides:
SiO2? 37.58
TiO2? 0.08
Al2O3? 22.09
Cr2O3? 0.00
FeO? 33.60
MoO? 5.29
CaO? 0.81
Na2O? 0.01
MnO? 1.05
 Data okav? (Y or N): v

Samole                Classification Name
25-5d1                G-5                Magnesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5f1
 Enter analvsis data as oxides:
SiO2? 37.56
TiO2? 0.08
Al2O3? 21.71
Cr2O3? 0.17
FeO? 31.15
MoO? 3.29
CaO? 5.05
Na2O? 0.05
MnO? 0.07
 Data okav? (Y or N): v

Samole               Classification Name
2-5f1                G-5            Maonesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5f2
 Enter analvsis data as oxides:
SiO2? 37.81
TiO2? 0.06
Al2O3? 21.67
Cr2O3? 0.05
FeO? 31.92
MoO? 3.60
CaO? 5.05
Na2O? 0.05
MnO? 0.50
 Data okav? (Y or N): v

Samole                 Classification Name
2-5f2                  G-5            Maonesian almandine
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5e2
 Enter analvsis data as oxides:
SiO2? 37.43
TiO2? 0.01
Al2O3? 21.70
Cr2O3? 0.01
FeO? 34.18
MoO? 4.28
CaO? 2.54
Na2O? 0.02
MnO? 0.11
 Data okav? (Y or N): v
```

Samole	Classification	Name
2-5e2	G-5	Maonesian almandine

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5a2
 Enter analvsis data as oxides:
SiO2? 37.87
TiO2? Ø.09
Al2O3? 21.23
Cr2O3? Ø.15
FeO? 29.38
MoO? 4.83
CaO? 6.6
Na2O? Ø
MnO? Ø.23
 Data okav? (Y or N): v
```

Samole	Classification	Name
2-5a2	G-5	Maonesian almandine

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5a5
 Enter analvsis data as oxides:
SiO2? 37.69
TiO2? 0.04
Al2O3? 21.92
Cr2O3? 0.00
FeO? 34.53
MoO? 4.67
CaO? 0.91
Na2O? 0.00
MnO? 0.79
 Data okav? (Y or N): v

Samole              Classification Name
2-5a5               G-5            Maonesian almandine
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5b6
 Enter analvsis data as oxides:
SiO2? 37.89
TiO2? 0.07
Al2O3? 21.72
Cr2O3? 0.18
FeO? 29.02
MoO? 4.11
CaO? 7.19
Na2O? 0.04
MnO? 0.76
 Data okav? (Y or N): v

Samole              Classification Name
2-5b6               G-5            Maonesian almandine
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5c6
 Enter analvsis data as oxides:
SiO2? 37.20
TiO2? 0.02
Al2O3? 21.70
Cr2O3? 0.00
FeO? 34.81
MoO? 3.92
CaO? 1.40
Na2O? 0.00
MnO? 1.57
 Data okav? (Y or N): v

Samole                Classification Name
2-5c6                 G-5            Maonesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5a5
 Enter analvsis data as oxides:
SiO2? 37.79
TiO2? 0.06
Al2O3? 22.24
Cr2O3? 0.00
FeO? 35.10
MaO? 5.44
CaO? 0.37
Na2O? 0.04
MnO? 0.29
 Data okav? (Y or N): v

Samole              Classification Name
2-5a5               G-5            Maanesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Enter analvsis data as oxides:
SiO2? 37.24
TiO2? 0.04
Al2O3? 21.47
Cr2O3? 0.07
FeO? 32.83
MoO? 4.3
CaO? 2.06
Na2O? 0.05
MnO? 2.48
 Data okav? (Y or N): v

Samole               Classification Name
nsl-al               G-5            Maonesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns1-b1
 Enter analvsis data as oxides:
SiO2? 39.03
TiO2? 0.14
Al2O3? 21.44
Cr2O3? 0.09
FeO? 24.42
MoO? 7.68
CaO? 6.48
Na2O? 0.04
MnO? 0.66
 Data okav? (Y or N): v

Samole               Classification Name
ns1-b1               G-5            Maonesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: nai-di
 Enter analvsis data as oxides:
SiO2? 37.22
TiO2? 0.00
Al2O3? 20.89
Cr2O3? 0.00
FeO? 35.04
MoO? 3.97
CaO? 2.53
Na2O? 0.00
MnO? 0.88
 Data okav? (Y or N): v

Samole              Classification Name
nai-d1              G-5            Maonesian almandine
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: nsl-ol
 Enter analvsis data as oxides:
SiO2? 37.74
TiO2? 0.08
Al2O3? 21.35
Cr2O3? 0.10
FeO? 28.59
MgO? 5.69
CaO? 5.49
Na2O? 0.03
MnO? 1.11
 Data okav? (Y or N): v

Samole               Classification Name
nsl-ol               G-5            Magnesian almandine
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: nsi-h2
 Enter analvsis data as oxides:
SiO2? 37.17
TiO2? 0.13
Al2O3? 21.19
Cr2O3? 0.05
FeO? 34.26
MoO? 4.37
CaO? 3.04
Na2O? 0.02
MnO? 0.67
 Data okav? (Y or N): v

Samole              Classification Name
nsi-h2              G-5            Maonesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: nsl-i2
 Enter analvsis data as oxides:
SiO2? 38.04
TiO2? 0.07
Al2O3? 21.33
Cr2O3? 0.06
FeO? 31.60
MoO? 6.51
CaO? 2.41
Na2O? 0.00
MnO? 0.55
 Data okav? (Y or N): v

Samole              Classification Name
nsl-i2              G-5            Maonesian almandine
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: nsi-i3
 Enter analvsis data as oxides:
SiO2? 37.41
TiO2? 0.00
Al2O3? 21.17
Cr2O3? 0.10
FeO? 34.14
MoO? 4.06
CaO? 3.16
Na2O? 0.04
MnO? 1.23
 Data okav? (Y or N): v

Samole            Classification Name
nsi-i3            G-5            Maonesian almandine
```

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns3-a1
 Enter analvsis data as oxides:
SiO2? 38.44
TiO2? 0.07
Al2O3? 22.2
Cr2O3? 0.03
FeO? 29.17
MgO? 8.51
CaO? 1.37
Na2O? 0.00
MnO? 0.45
 Data okav? (Y or N): v

Samole               Classification Name
ns3-a1               G-5            Magnesian almandine
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns3-b1
 Enter analvsis data as oxides:
SiO2? 38.60
TiO2? 0.10
Al2O3? 21.60
Cr2O3? 0.00
FeO? 31.87
MoO? 6.14
CaO? 2.79
Na2O? 0.03
MnO? 0.59
 Data okav? (Y or N): v

Samole                  Classification Name
ns3-b1                  G-5            Maonesian almandine
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns3-f1
 Enter analvsis data as oxides:
SiO2? 37.09
TiO2? 0.08
Al2O3? 21.26
Cr2O3? 0.19
FeO? 34.16
MoO? 4.04
CaO? 3.32
Na2O? 0.02
MnO? 0.72
 Data okav? (Y or N): v
```

Samole	Classification	Name
ns3-f1	G-5	Maonesian almandine

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns3-a2
 Enter analvsis data as oxides:
SiO2? 38.52
TiO2? 0.15
Al2O3? 21.18
Cr2O3? 0.00
FeO? 28.27
MoO? 5.79
CaO? 6.76
Na2O? 0.00
MnO? 0.40
 Data okav? (Y or N): v

Samole              Classification Name
ns3-a2              G-5            Maonesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns3-i2
 Enter analvsis data as oxides:
SiO2? 38.70
TiO2? 0.11
Al2O3? 21.80
Cr2O3? 0.08
FeO? 21.79
MaO? 6.11
CaO? 11.71
Na2O? 0.05
MnO? 0.40
 Data okav? (Y or N): v

Samole                 Classification Name
ns3-i2                 G-3            Calcic pvrooe-almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns3-d3
 Enter analvsis data as oxides:
SiO2? 37.86
TiO2? 0.05
Al2O3? 21.19
Cr2O3? 0.05
FeO? 31.02
MoO? 4.86
CaO? 4.81
Na2O? 0.02
MnO? 0.63
 Data okav? (Y or N): v

Samole                  Classification Name
ns3-d3                  G-5            Maonesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns3-h3
 Enter analvsis data as oxides:
SiO2? 38.05
TiO2? 0.06
Al2O3? 21.21
Cr2O3? 0.07
FeO? 28.88
MoO? 4.65
CaO? 6.80
Na2O? 0.00
MnO? 1.08
 Data okav? (Y or N): v

Samole                  Classification Name
ns3-h3                  G-5                Maonesian almandine
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Sample Name: ns3-i4
 Enter analysis data as oxides:
SiO2? 37.65
TiO2? 0.04
Al2O3? 21.82
Cr2O3? 0.00
FeO? 31.69
MgO? 6.09
CaO? 1.90
Na2O? 0.06
MnO? 0.63
 Data okay? (Y or N): y

Sample               Classification Name
ns3-i4               G-5            Magnesian almandine
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-a1
 Enter analvsis data as oxides:
SiO2? 38.23
TiO2? 0.00
Al2O3? 21.89
Cr2O3? 0.00
FeO? 28.69
MoO? 8.75
CaO? 0.82
Na2O? 0.02
MnO? 1.92
 Data okav? (Y or N): v

Samole               Classification Name
ns4-a1               G-5            Maonesian almandine
```

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-b1
 Enter analvsis data as oxides:
SiO2? 37.33
TiO2? 0.03
Al2O3? 21.47
Cr2O3? 0.05
FeO? 33.84
MoO? 5.22
CaO? 0.95
Na2O? 0.04
MnO? 0.76
 Data okav? (Y or N): v

Samole                  Classification Name
ns4-b1                  G-5            Maonesian almandine
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-c1
 Enter analvsis data as oxides:
SiO2? 38.53
TiO2? 0.06
Al2O3? 22.30
Cr2O3? 0.02
FeO? 29.00
MoO? 9.27
CaO? 1.20
Na2O? 0.01
MnO? 0.18
 Data okav? (Y or N): v

Samole               Classification Name
ns4-c1               G-5            Maonesian almandine
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-d1
 Enter analvsis data as oxides:
SiO2? 37.48
TiO2? 0.01
Al2O3? 21.14
Cr2O3? 0.02
FeO? 33.07
MoO? 4.20
CaO? 1.91
Na2O? 0.02
MnO? 2.88
 Data okav? (Y or N): v
```

Samole	Classification	Name
ns4-d1	G-5	Maonesian almandine

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-h1
 Enter analvsis data as oxides:
SiO2? 36.46
TiO2? 0.52
Al2O3? 21.52
Cr2O3? 0.03
FeO? 33.27
MoO? 5.19
CaO? 2.30
Na2O? 0.00
MnO? 0.59
 Data okav? (Y or N): v

Samole               Classification Name
ns4-h1               G-5            Maonesian almandine
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-i1
 Enter analvsis data as oxides:
SiO2? 37.90
TiO2? 0.00
Al2O3? 21.26
Cr2O3? 0.04
FeO? 30.19
MoO? 3.87
CaO? 6.05
Na2O? 0.03
MnO? 1.86
 Data okav? (Y or N): v

Samole                Classification Name
ns4-i1                G-5            Maonesian almandine
```

MICRO-PROBE DATA CLASSIFICATION

Samole Name: ns4-a2
Enter analvsis data as oxides:
SiO2? 37.33
TiO2? 0.00
Al2O3? 21.57
Cr2O3? 0.03
FeO? 33.36
MoO? 5.43
CaO? 1.35
Na2O? 0.00
MnO? 0.69
Data okav? (Y or N): v

Samole	Classification	Name
ns4-a2	G-5	Maonesian almandine

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-c2
 Enter analvsis data as oxides:
SiO2? 38.17
TiO2? 0.00
Al2O3? 22.09
Cr2O3? 0.03
FeO? 27.71
MgO? 6.86
CaO? 2.00
Na2O? 0.00
MnO? 3.36
 Data okav? (Y or N): v

Samole               Classification Name
ns4-c2               G-5            Maonesian almandine
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-d2
 Enter analvsis data as oxides:
SiO2? 37.29
TiO2? 0.00
Al2O3? 21.03
Cr2O3? 0.06
FeO? 35.30
MoO? 4.23
CaO? 2.36
Na2O? 0.01
MnO? 0.14
 Data okav? (Y or N): v

Samole                  Classification Name
ns4-d2                  G-5            Maonesian almandine
```

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MICRO-PROBE DATA CLASSIFICATION

Samole Name: ns4-e2
Enter analvsis data as oxides:
SiO2? 38.05
TiO2? 0.00
Al2O3? 21.98
Cr2O3? 0.05
FeO? 33.17
MoO? 6.60
CaO? 0.74
Na2O? 0.06
MnO? 0.57
Data okav? (Y or N): v

Samole	Classification	Name
ns4-e2	G-5	Maonesian almandine

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-h2
 Enter analvsis data as oxides:
SiO2? 37.24
TiO2? 0.06
Al2O3? 20.59
Cr2O3? 0.03
FeO? 32.70
MgO? 1.99
CaO? 7.64
Na2O? 0.06
MnO? 0.99
 Data okav? (Y or N): v

Samole              Classification Name
ns4-h2              G-5            Maonesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Sample Name: ns4-i2
 Enter analysis data as oxides:
SiO2? 38.92
TiO2? 0.12
Al2O3? 21.33
Cr2O3? 0.01
FeO? 25.33
MgO? 6.99
CaO? 7.39
Na2O? 0.10
MnO? 0.49
 Data okay? (Y or N): y

Sample                Classification Name
ns4-i2                G-5            Magnesian almandine
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-i2
 Enter analvsis data as oxides:
SiO2? 38.10
TiO2? 0.15
Al2O3? 21.29
Cr2O3? 0.04
FeO? 24.65
MgO? 5.59
CaO? 10.04
Na2O? 0.04
MnO? 0.63
 Data okav? (Y or N): v
```

Samole	Classification	Name
ns4-i2	G-5	Magnesian almandine

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns1-c8
 Enter analvsis data as oxides:
SiO2? 51.64
TiO2? 0.21
Al2O3? 4.86
Cr2O3? 0.29
FeO? 6.31
MoO? 15.06
CaO? 22.69
Na2O? 0.52
MnO? 0.11
 Data okav? (Y or N): v

Samole              Classification Name
ns1-c8              C-4            Low-Cr-dioDside
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: nsi-d8-1
 Enter analvsis data as oxides:
SiO2? 50.94
TiO2? 0.32
Al2O3? 2.60
Cr2O3? 0.03
FeO? 12.40
MoO? 11.78
CaO? 21.39
Na2O? 0.38
MnO? 0.42
 Data okav? (Y or N): v

Samole              Classification Name
nsi-d8-1            C-4            Low-Cr-diooside
```

CONFIDENTIAL

NORTHSIDE RESOURCES EXPLORATION RERORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: nsi-d8-2
 Enter analvsis data as oxides:
SiO2? 50.80
TiO2? 0.27
Al2O3? 2.86
Cr2O3? 0.07
FeO? 11.95
MgO? 12.15
CaO? 21.99
Na2O? 0.40
MnO? 0.30
 Data okav? (Y or N): v

Samole              Classification Name
nsi-d8-2            C-4            Low-Cr-diopside
```

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns1-b9
 Enter analvsis data as oxides:
SiO2? 50.76
TiO2? 0.67
Al2O3? 3.35
Cr2O3? 0.05
FeO? 13.01
MaO? 15.36
CaO? 16.93
Na2O? 0.10
MnO? 0.42
 Data okav? (Y or N): v
```

Samole	Classification	Name
ns1-b9	C-4	Low-Cr-diooside

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: nsl-d9
 Enter analvsis data as oxides:
SiO2? 51.51
TiO2? 0.70
Al2O3? 2.76
Cr2O3? 0.00
FeO? 11.12
MoO? 16.55
CaO? 18.10
Na2O? 0.23
MnO? 0.19
 Data okav? (Y or N): v

Samole                  Classification Name
nsl-d9                  C-4            Low-Cr-diooside
```

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NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns2-i8
 Enter analvsis data as oxides:
SiO2? 51.80
TiO2? 0.57
Al2O3? 3.04
Cr2O3? 0.37
FeO? 9.02
MoO? 13.61
CaO? 22.25
Na2O? 0.34
MnO? 0.26
 Data okav? (Y or N): v

Samole                 Classification Name
ns2-i8                 C-4            Low-Cr-dioosside
```

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NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-a9
 Enter analvsis data as oxides:
SiO2? 49.90
TiO2? 0.26
Al2O3? 7.62
Cr2O3? 0.37
FeO? 12.67
MgO? 14.51
CaO? 12.75
Na2O? 0.44
MnO? 0.22
 Data okav? (Y or N): v

Samole                Classification Name
ns4-a9                C-4            Low-Cr-diooside
```

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MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-h8
 Enter analvsis data as oxides:
SiO2? 52.73
TiO2? 0.05
Al2O3? 6.17
Cr2O3? 0.05
FeO? 9.45
MoO? 17.36
CaO? 12.42
Na2O? 0.46
MnO? 0.27
 Data okav? (Y or N): v

Samole               Classification Name
ns4-h8               C-1            Sub-calcic diooside
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-o9
 Enter analvsis data as oxides:
SiO2? 53.39
TiO2? 0.25
Al2O3? 1.68
Cr2O3? 0.72
FeO? 5.95
MgO? 15.36
CaO? 21.83
Na2O? 0.88
MnO? 0.12
 Data okav? (Y or N): v

Samole              Classification Name
ns4-o9              C-2            Diooside
```

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NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: ns4-h10
 Enter analvsis data as oxides:
SiO2? 48.90
TiO2? 0.98
Al2O3? 8.33
Cr2O3? 0.29
FeO? 10.60
MoO? 16.88
CaO? 11.63
Na2O? 1.03
MnO? 0.20
 Data okav? (Y or N): v

Samole             Classification Name
ns4-h10            C-4            Low-Cr-diooside
```

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NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5a1-1
 Enter analvsis data as oxides:
SiO2? 50.35
TiO2? 0.17
Al2O3? 2.77
Cr2O3? 0.08
FeO? 13.66
MoO? 11.34
CaO? 21.70
Na2O? 0.43
MnO? 0.23
 Data okav? (Y or N): v

Samole                Classification Name
2-5a1-1               C-4            Low-Cr-diooside
```

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MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5a1-9
 Enter analvsis data as oxides:
SiO2? 50.14
TiO2? 0.40
Al2O3? 3.82
Cr2O3? 0.07
FeO? 13.02
MoO? 10.98
CaO? 21.10
Na2O? 0.61
MnO? 0.29
 Data okav? (Y or N): v

Samole                  Classification Name
2-5a1-9                 C-4            Low-Cr-diooside
```

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5b1-1
 Enter analvsis data as oxides:
SiO2? 52.06
TiO2? 0.19
Al2O3? 2.07
Cr2O3? 0.00
FeO? 10.62
MoO? 12.73
CaO? 21.17
Na2O? 0.39
MnO? 0.22
 Data okav? (Y or N): v
```

Samole	Classification	Name
2-5b1-1	C-4	Low-Cr-dioOside

CONFIDENTIAL

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5b1-2
 Enter analvsis data as oxides:
SiO2? 51.75
TiO2? 0.40
Al2O3? 2.97
Cr2O3? 0.00
FeO? 11.11
MgO? 11.30
CaO? 20.44
Na2O? 0.40
MnO? 0.25
 Data okav? (Y or N): v
```

Samole	Classification	Name
2-5b1-2	C-4	Low-Cr-diopside

NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5b1-3
 Enter analvsis data as oxides:
SiO2? 51.59
TiO2? 0.34
Al2O3? 3.00
Cr2O3? 0.03
FeO? 11.02
MoO? 12.19
CaO? 21.14
Na2O? 0.47
MnO? 0.30
 Data okav? (Y or N): v

Samole                  Classification Name
2-5b1-3                 C-4            Low-Cr-dioosside
```

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NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Enter analysis data as oxides:
SiO2? 51.54
TiO2? 0.42
Al2O3? 3.31
Cr2O3? 0.03
FeO? 11.02
MgO? 12.19
CaO? 21.14
Na2O? 0.47
MnO? 0.30
 Data okay? (Y or N): y

Sample              Classification Name
2-5b1-4             C-4            Low-Cr-diopside
```

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NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5a1-1
 Enter analvsis data as oxides:
SiO2? 50.35
TiO2? 0.17
Al2O3? 2.77
Cr2O3? 0.08
FeO? 13.66
MgO? 11.34
CaO? 21.70
Na2O? 0.43
MnO? 0.23
 Data okav? (Y or N): v
```

Samole	Classification	Name
2-5a1-1	C-4	Low-Cr-diopside

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NORTHSIDE RESOURCES EXPLORATION REPORT

MICRO-PROBE DATA CLASSIFICATION

```
 Samole Name: 2-5ai-2
 Enter analvsis data as oxides:
SiO2? 53.16
TiO2? Ø.42
Al2O3? 3.39
Cr2O3? Ø.06
FeO? 12.72
MgO? 11.96
CaO? 15.69
Na2O? Ø.48
MnO? Ø.24
 Data okav? (Y or N): v

Samole               Classification Name
2-5ai-2              C-4            Low-Cr-diopside
```

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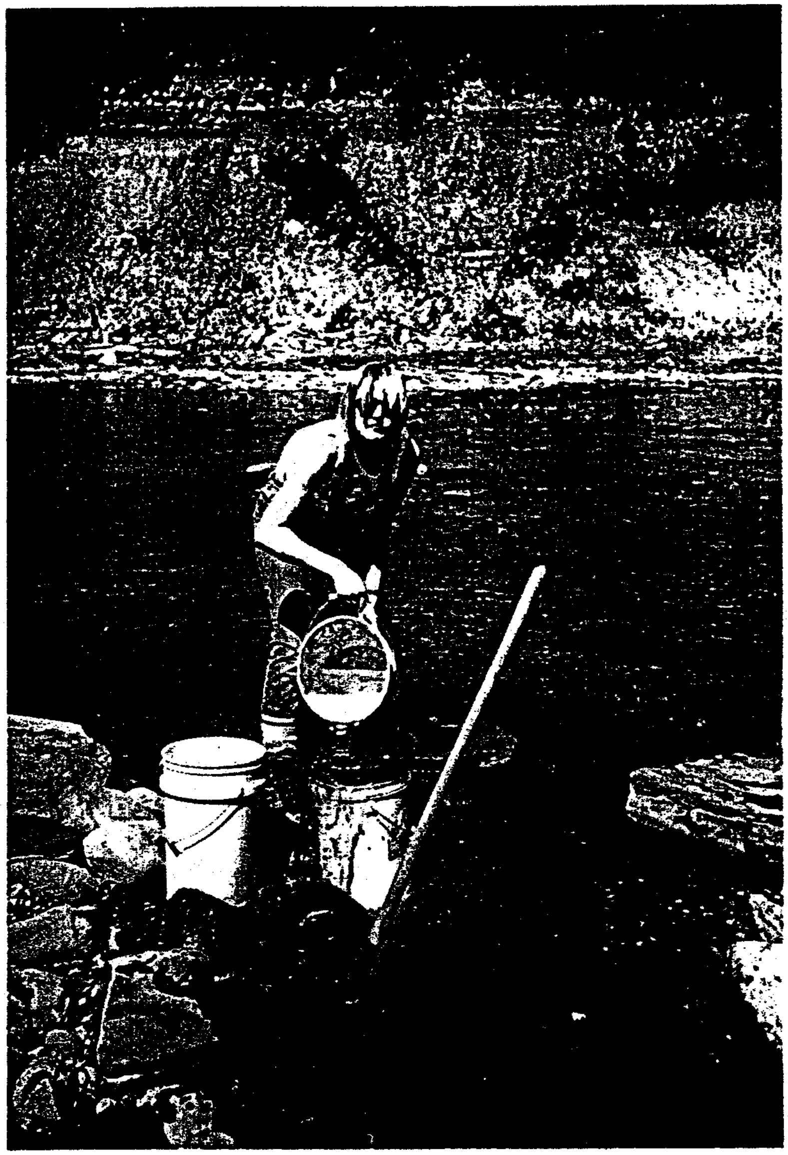
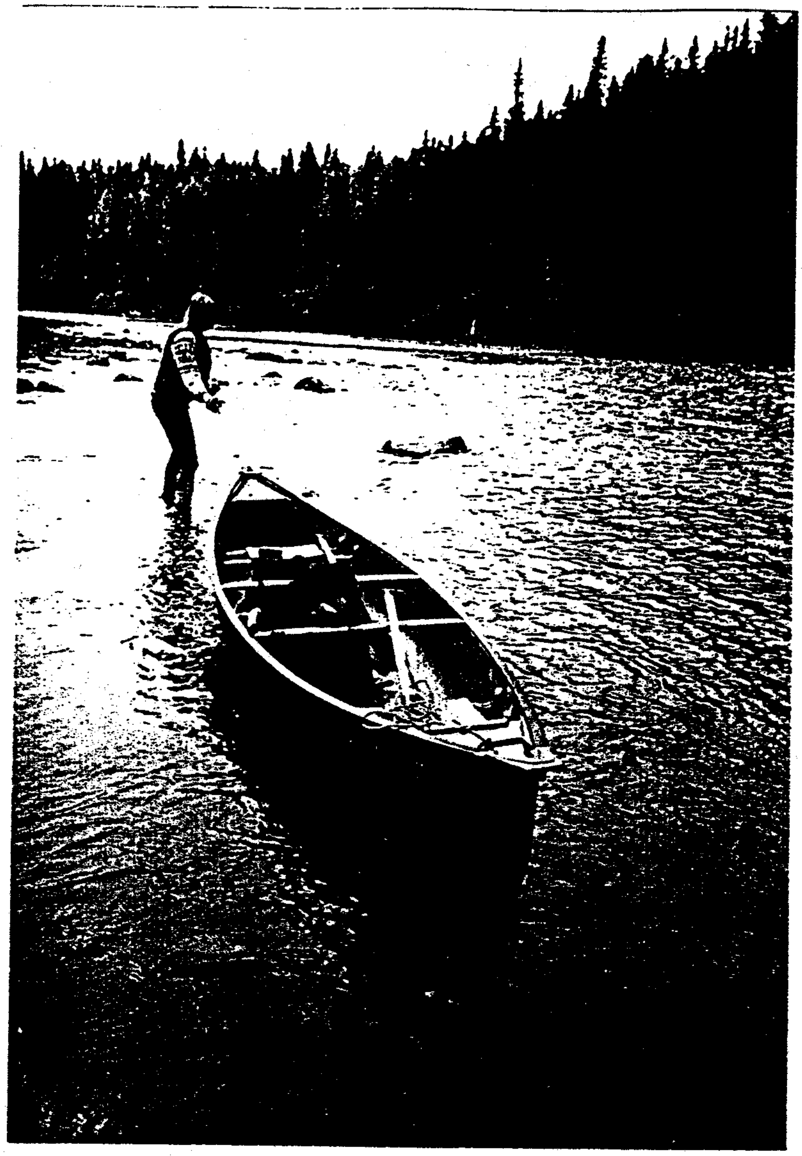
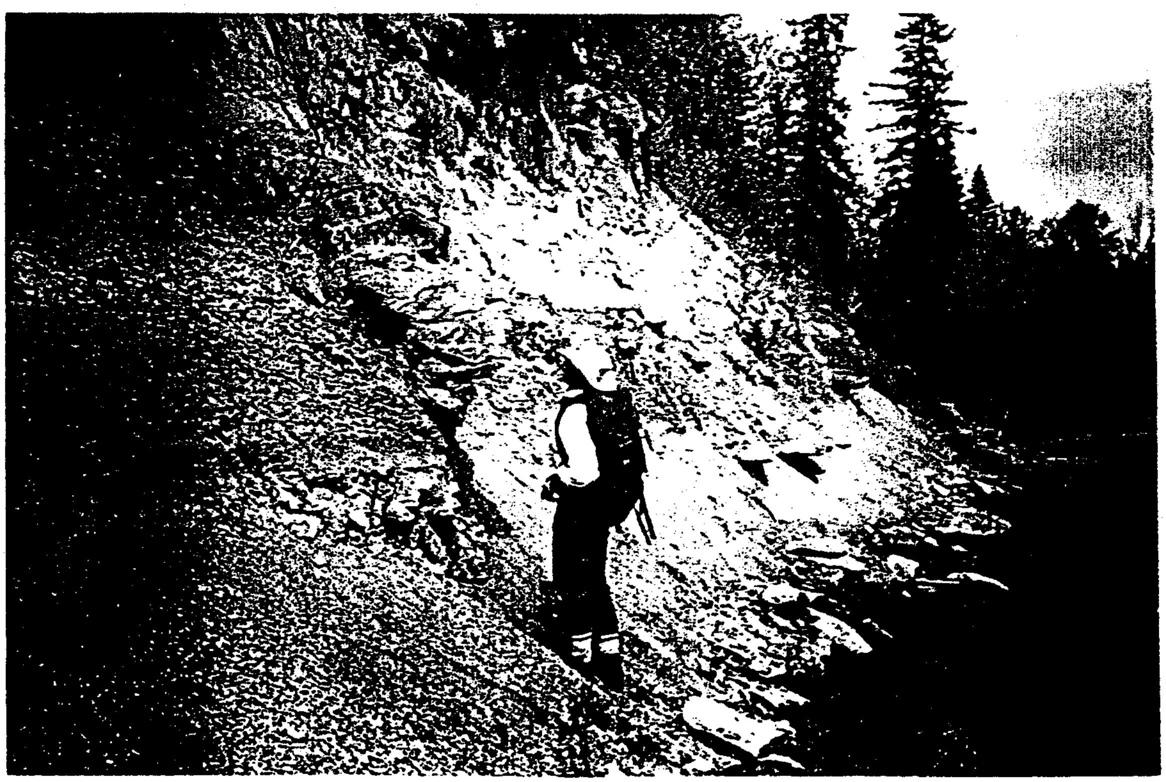
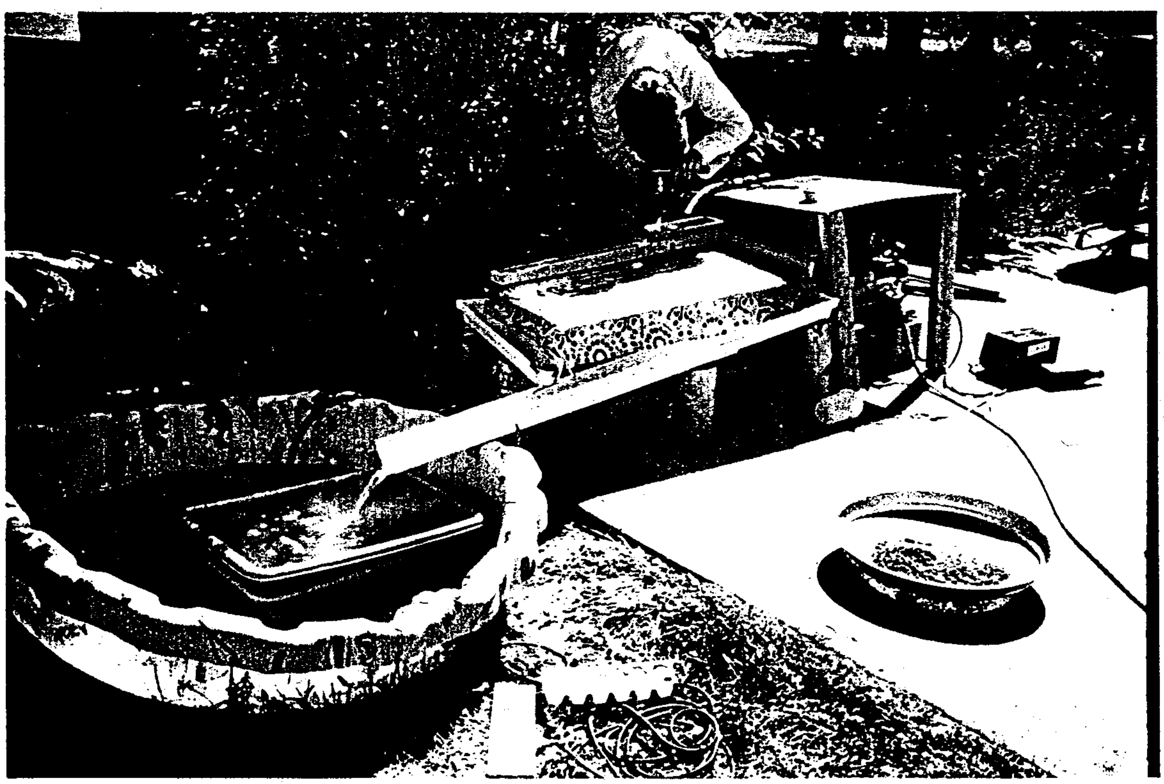
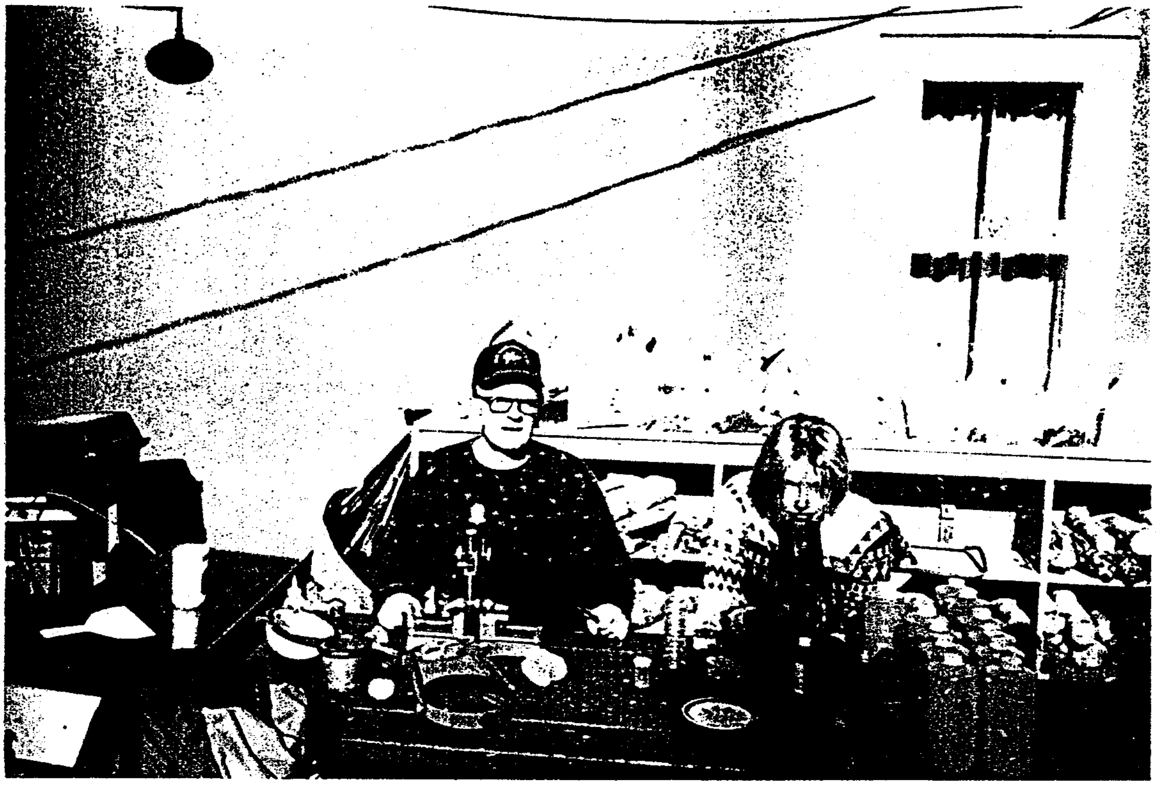
PHOTO SECTION

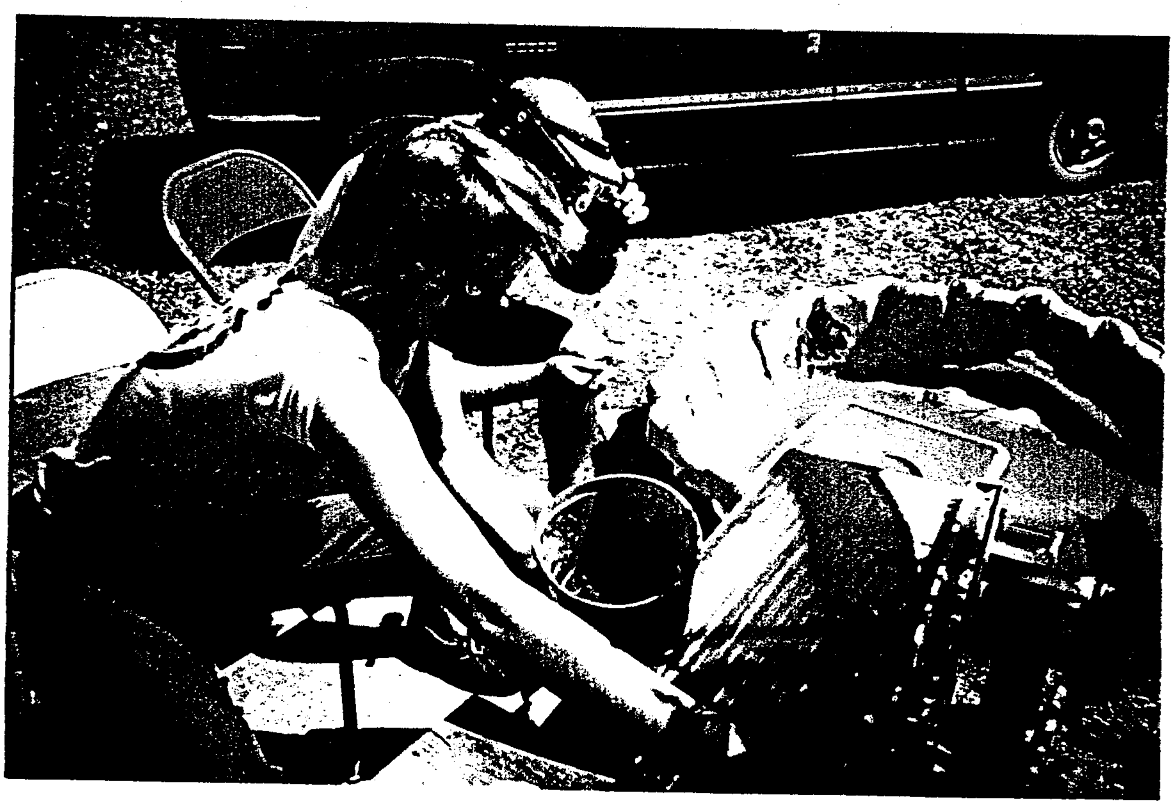












SELECTED LITERATURE
TO ACCOMPANY

NORTHSIDE RESOURCES
EXPLORATION REPORT

MARCH 1994

CONFIDENTIAL

Geophysics and geochronology of the crystalline basement of the Alberta Basin, western Canada[1]

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Although progressively muted by the increasing thickness of Phanerozoic sediments in the Alberta Basin, the geophysical signature of tectonic domains in the Canadian Shield can be traced nearly to the Foothills of the Canadian Cordillera. A combination of potential field data for Alberta and U–Pb zircon and monazite age determinations on drill core samples of crystalline basement recovered during hydrocarbon exploration was used to subdivide the basement of the Alberta Basin into 22 distinct domains. The Canadian Shield was used to ground truth the interpretation of the geophysical signatures and infer possible kinematic relationships between basement domains. Ages of crystalline basement range from 1.7 to 3.2 Ga and demonstrate that a large expanse of 2.1–2.4 Ga crust is present in northern Alberta. This suggests a continuum of tectonic activity and crust formation(?) in Alberta rather than the 2.6 Ga and 2.0–1.8 Ga episodicity apparent in the exposed Canadian Shield.

Malgré un effacement partiel et progressif de la signature géophysique des domaines tectoniques, qui était dû à une accumulation croissante des sédiments phanérozoïques dans le bassin d'Alberta, cette signature peut quand même être tracée près des Foothills de la Cordillère canadienne. Les données du champ potentiel de l'Alberta combinées à des déterminations d'âges U–Pb sur zircon et monazite, extraits de carottes de forage du socle cristallin prélevées durant une campagne d'exploration d'hydrocarbures, ont été utilisées pour subdiviser le socle du bassin d'Alberta en 22 domaines distincts. Le Bouclier canadien a servi de base pour l'interprétation des signatures géophysiques et pour déduire les relations cinématiques pouvant exister entre les domaines du socle. Les âges des roches du socle cristallin varient de 1,7 à 3,2 Ga, indiquant l'existence d'une portion importante de croûte âgée de 2,1–2,4 Ga dans la partie nord de l'Alberta. Ces données témoignent d'une continuité de l'activité tectonique et de la formation de la croûte (?) dans l'Alberta, plutôt que les périodes intermittentes à 2,6 Ga et entre 2,0 et 1,8 Ga, apparentes dans le Bouclier canadien exposé.

[Traduit par la rédaction]

Can. J. Earth Sci. 28, 512–522 (1991)

Introduction

In 1986, a multidisciplinary program was initiated to reexamine the vast region of continental crust that underlies the Alberta Basin. Aeromagnetic and gravity anomaly maps were combined with U–Pb zircon and monazite geochronology of selected samples of crystalline basement to develop an age domain map for Alberta that extends known Canadian Shield elements into the subsurface and delineates new, unexposed tectonic domains. This paper presents a condensed synopsis of this study, with full details of the geochronology and tectonic interpretations presented elsewhere (Villeneuve *et al.*, in press; G. M. Ross, M. E. Villeneuve, R. J. Theriault, and R. R. Parrish, "Precambrian tectonic evolution of continental basement, western Canada," unpublished).

The crystalline basement of Alberta and the limited exposures of the Canadian Shield in northeastern Alberta have been studied extensively (Burwash 1957; Burwash *et al.* 1962; Burwash and Culbert 1976; Godfrey and Langenberg 1978, and references therein). However, the recent availability of high-resolution aeromagnetic data (Geological Survey of Canada 1978) and the development of a tectonic framework for the exposed Shield (Hoffman 1988) makes a reexamination of the subsurface a timely project. In addition, the development of analytical techniques that dramatically increase the precision of U–Pb age determinations for small samples (Krogh 1982; Roddick *et al.* 1987) adds the critical element of geochronologic control, especially in view of the rapidly expanding database for the Canadian Shield. The results of this study provide constraints on the evolution of the Canadian Shield, the sources of detrital zircons in the Canadian Cordillera (Parrish *et al.* 1989; Ross and Bowring 1990; Ross and Parrish 1991), the parentage of basement exposed in structural culminations within the Cordilleran hinterland (Parrish and Armstrong 1983; Parrish and Ross 1990), and a structural framework in which to address subtleties of the Phanerozoic sedimentation history (Ross 1990).

Methods

Detailed public-domain aeromagnetic anomaly data (Fig. 1) were combined with proprietary data provided by Petro-Canada, Inc., for the initial delineation and interpretation of subsuface domains (Fig. 2). (Note: The proprietary aeromagnetic maps of PetroCanada, Inc., are a compilation of data from a variety of sources and is presently unavailable for public inspection. Repeated attempts during the last 12 years by the Geological Survey of Canada to purchase and (or) gain release of this data

[1]Geological Survey of Canada Contribution 55188.

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into the public domain have been unsuccessful. To remedy this problem, a consortium of petroleum companies and the Geological Survey of Canada have undertaken to fly aeromagnetic surveys over the regions of proprietary data during the next three years; this data set will become publicly available at 1 : 5 000 000 scale beginning in 1991 and fully digital data sets and maps at 1 : 250 000 scale will become available beginning in 1995.) The composition and possible tectonic affinities of the anomalies were assessed by comparison with the aeromagnetic expression of exposed tectonic elements in the northwest Canadian Shield. Domains were delineated on the basis of homogeneity of aeromagnetic signature, internal fabric, and crosscutting relationships inferred from the truncation of trends. Gravity, and in particular horizontal gravity gradient, data (Sharpton *et al.* 1987) were used to refine some of the domain boundaries.

This preliminary geophysical subdivision of basement guided our sampling of basement drill core, which concentrated on igneous and meta-igneous lithologies in order to provide a geochronological framework of major magmatic events. In addition, we attempted to provide relatively even areal coverage to each of the domains. Age data reported here are based upon concordant zircon and monazite U–Pb analyses or 4- to 6-point discordant arrays. U–Pb results are summarized in Fig. 2 (Ross *et al.* 1989) and a detailed presentation of analytical techniques, isotope systematics, and petrology are presented elsewhere (Roddick *et al.* 1987; Villeneuve *et al.*, in press).

Results

The crystalline basement of Alberta is segmented by three throughgoing crustal discontinuities recognized on the basis of the juxtaposition of geophysical domains with contrasting internal fabric and (or) signature (Fig. 1). These discontinuities are the Snowbird Tectonic Zone in central Alberta, the Great Slave Lake shear zone in northern Alberta, both of which can be traced from the Canadian Shield, and the Vulcan Low in southern Alberta, which is an entirely subsurface feature. The following discussion of the structure of the subsurface of Alberta centers around each of these discontinuities.

Southern Alberta

One of the most significant geophysical features of southern Alberta is an aeromagnetic and gravity low referred to as the Vulcan Low (J. Peirce, PetroCanada, Inc., personal communication, 1986). This narrow, east-trending feature eventually bifurcates towards the east into a southeast-trending strand and a north-trending strand near the Alberta–Saskatchewan border (Fig. 1). Towards the west it continues beneath the eastern Cordillera, where it apparently terminates within a broad aeromagnetic high (Fig. 1B). A single sample of metabasite from the western end of the Vulcan Low is 2.62 Ga old (Table 1; Fig. 2). The Vulcan Low was originally interpreted as a graben (the southern Alberta "aulacogen"; Kanasewich *et al.* 1969) but has been reinterpreted as a collisional suture based on the truncation of aeromagnetic fabrics (J. Peirce, personal communication, 1986; Hoffman 1988) and the presence of a paired gravity anomaly (Thomas *et al.* 1987). As pointed out by Hoffman (1988), this does not preclude younger reactivation of this boundary to produce the southern Alberta aulacogen.

To the south of the Vulcan Low lies the Medicine Hat Block, a region characterized by a north-northwest-trending fabric of narrow, moderate intensity, positive and negative aeromagnetic anomalies. Drill core samples are composed largely of metaplutonic gneisses that are 2.65–3.27 Ga old. The Medicine Hat Block is separated from the Wyoming Craton of the northern United States by a geophysical discontinuity termed the Great Falls tectonic zone (O'Neill and Lopez 1985; O'Neill *et al.* 1988), which has been interpreted as marking an Early Proterozoic (ca. 1.8 Ga) shear zone. North of the Vulcan Low is the Matzhiwin High, a region with a positive aeromagnetic signature and an east-trending, bulbous outline that terminates against the north-trending strand of the Vulcan Low. The only sample from this domain is a hornblende monzonite with an age of 2.58 Ga.

The broad region north of the Matzhiwin High is referred to as the Loverna Block and is characterized by a neutral aeromagnetic signature with many small, moderate-amplitude, positive aeromagnetic anomalies. Although drill control is sparse we have tentatively inferred an Archean age for this region based on its geophysical continuity with the Archean rocks of western Saskatchewan to the northeast (Green *et al.* 1985). The few basement samples recovered in this region consist of magnetite-bearing biotite granites, which are likely the source of the small positive aeromagnetic anomalies. Two samples of these granites gave zircon crystallization ages of 1.78 and 1.82 Ga, whereas a third granite gave an age of 2.71 Ga (Table 1). These samples are lithologically similar to the ca. 1.8 Ga anorogenic granites of Saskatchewan (Collerson *et al.* 1988), suggesting that these rocks may extend into eastern Alberta.

The Lacombe Domain, which includes the southwest-trending Red Deer trend (Fig. 2), is located along the northwestern edge of the Loverna Block and appears to consist chiefly of undated, supracrustal rocks (metatuff, phyllite, rhyolite) and a single granite that produced a very discordant Early Proterozoic age (ca. 2.2 Ga). These rocks represent the only extensive occurrence of low-grade supracrustal rocks in the Alberta basement.

Near the Alberta–Saskatchewan border, a pronounced, positive aeromagnetic anomaly (Eyehill High; Fig. 2) is separated from the Loverna Block by a narrow north-trending aeromagnetic low that joins with the Vulcan Low to the south. The Eyehill High contains 2.6–2.7 Ga gneisses that are, in part, granulite grade. A strong gravity gradient along the western edge of this domain suggests that there is a sharp break between the Eyehill High gneisses and rocks of the Loverna Block to the west.

Central Alberta

The most prominent structural feature in this region is the subsurface extension of the Snowbird Tectonic Zone, originally referred to as the Edmonton–Kasba gravity low (Burwash and Culbert 1976). The Snowbird Zone is a prominent, northeast-trending, crustal discontinuity that extends from Hudson Bay to the Foothills of the Canadian Cordillera. The exposed northeastern portion of the Snowbird Zone is characterized by anastomosing mylonite zones that enclose crustal-scale augen of granulite-grade gneisses and splits the Churchill Province into two Archean domains (Rae and Hearne provinces), which have been variably affected by Early Proterozoic tectonic activity (Hoffman 1988). In Alberta, the Snowbird Zone is inferred to bifurcate into two separate strands that maintain west to southwest trends and are inferred to structurally enclose a wedge-shaped domain (Wabamun High). The southernmost strand coincides with a narrow, aeromagnetic low (Thorsby Low) that has a sinuous, braided, negative aeromagnetic signature and a strong, colinear gravity gradient. Zircon age determinations from sheared gneiss and gabbro in this zone give

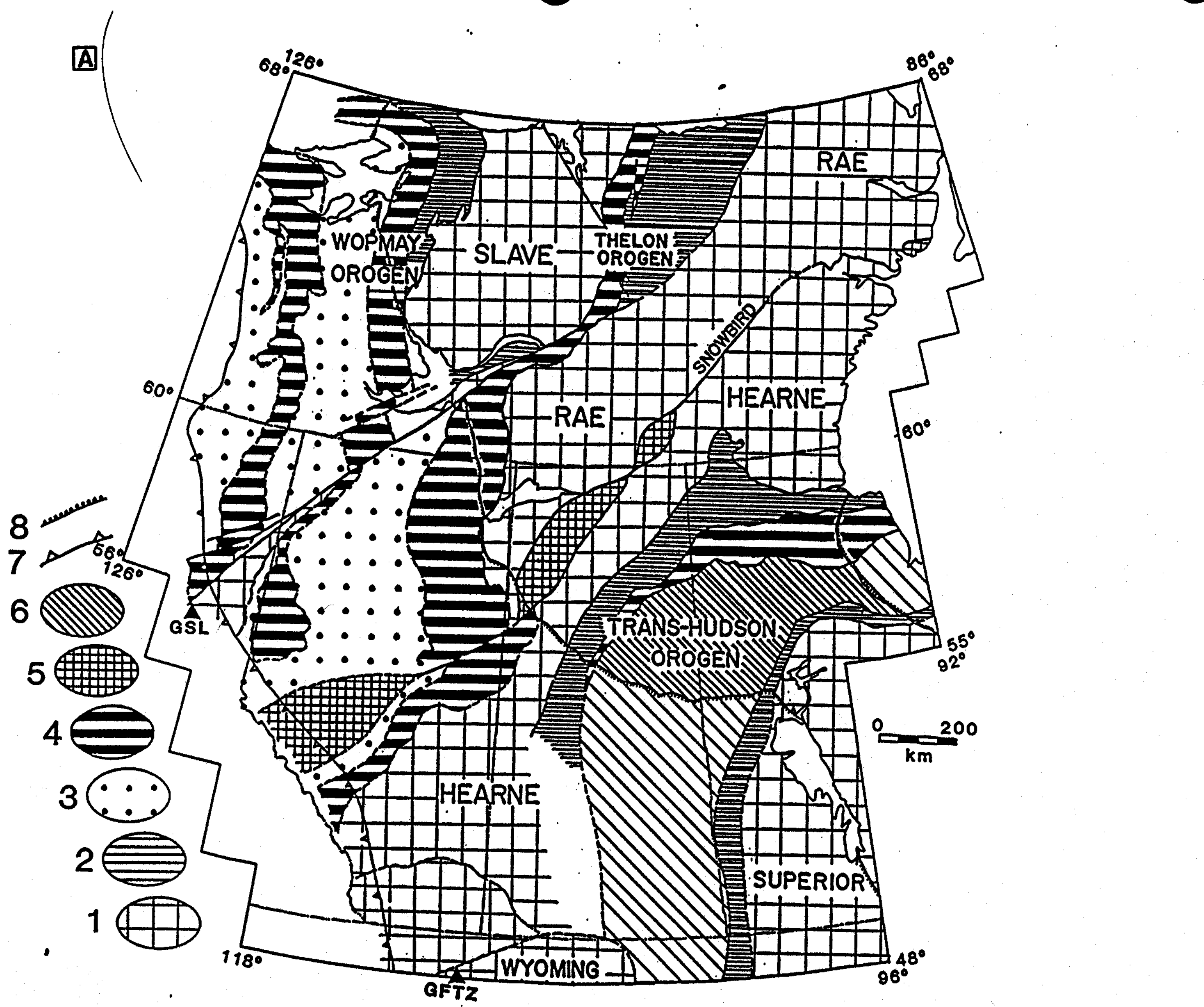


FIG. 1. (A) Major subdivisions and tectonic framework of the exposed (from Hoffman 1988) and buried Canadian Shield (this study). 1, Archean cratonic rocks; 2, 2.0–1.8 Ga orogenic belts; 3, 2.4–2.1 Ga crust; 4, 2.0–1.8 Ga magmatic belts; 5, crustal wedges along the Snowbird Tectonic Zone, locally known to be 2.3 Ga; 6, juvenile Proterozoic terranes of the Trans-Hudson Orogen; 7, edge of Cordilleran deformation; 8, edge of Phanerozoic cover. GSL, Great Slave Lake shear zone; GFTZ, Great Falls tectonic zone.

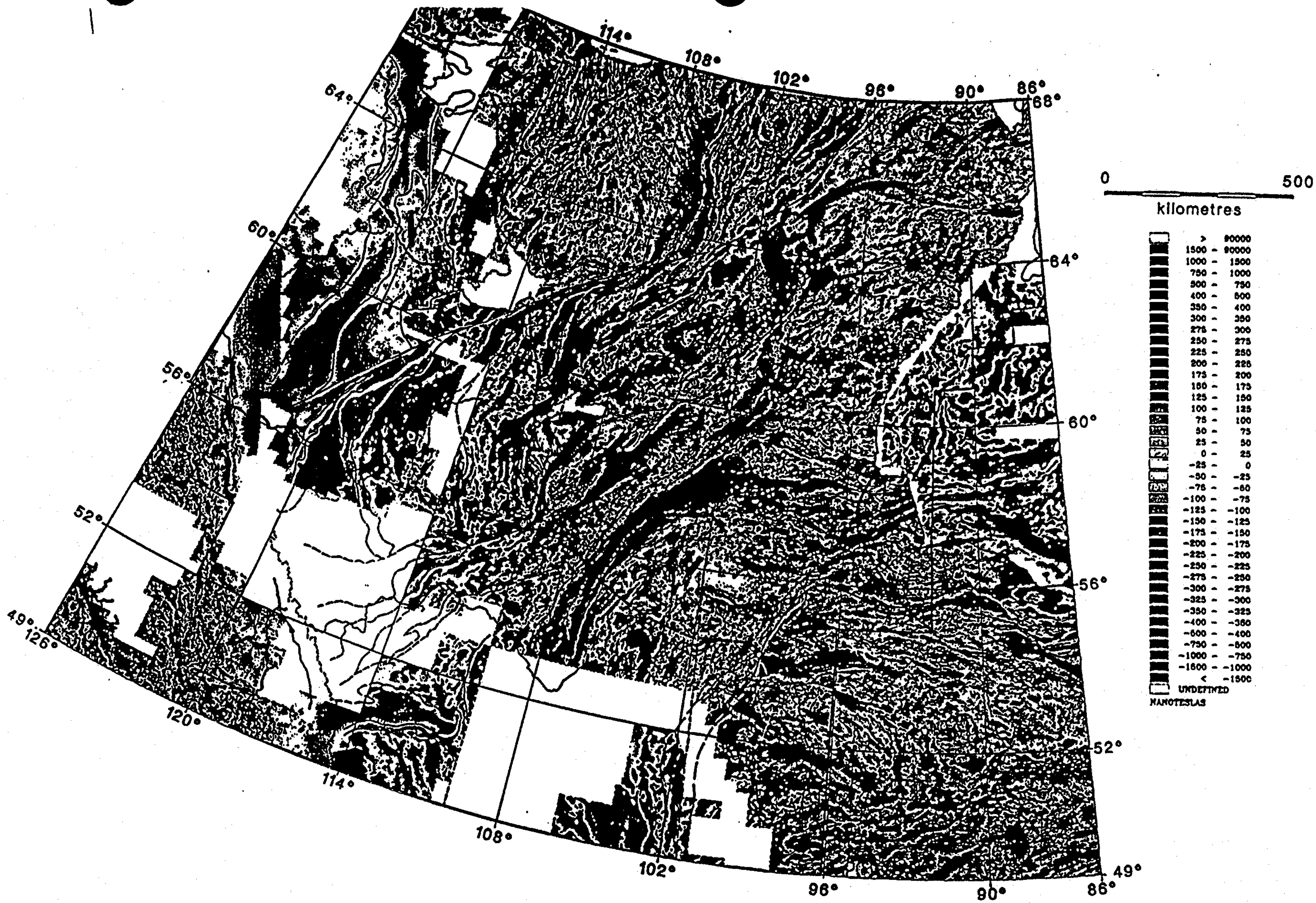


FIG. 1 (*concluded*). (B) Aeromagnetic anomaly map of western Canada demonstrating the continuity of exposed anomalies of the Canadian Shield westward beneath the sedimentary platform of the Western Canada Sedimentary Basin. The edge of the Phanerozoic cover is shown as a bold dashed line. White areas in Alberta and Saskatchewan are regions where detailed aeromagnetic coverage is not publicly available. Dashed lines in Alberta are domain boundaries simplified from a proprietary industry database (courtesy of PetroCanada, Inc.).

TABLE 1. Location, lithology, and age (Z = zircon, M = monazite) of oil well drill core samples from the Alberta basement

Oil well name	Well location	Core lithology	Age (Ma)
		Medicine Hat Block	
1. PCP Travers	01-31-013-20W4	Granodiorite gneiss	2612^{+36}_{-23} (Z)
2. BA Grand Forks	12-14-012-12W4	Biotite–quartz monzonite	2721^{+35}_{-30} (Z)
3. Imp Calstan Lake Newell	05-01-017-14W4	Pegmatite–granitic gneiss	2715^{+41}_{-23} (Z)
4. Home Pacific Knappen	16-29-001-11W4	Mylonitic quartz diorite	3278^{+22}_{-21} (Z)
5. PCP Medicine Hat	12-19-014-4W4	Granodorite gneiss	2751^{+83}_{-48} (Z)
		Vulcan Low	
6. Cal Std Parkland #4-12	04-12-015-27W4	Amphibolite	2627^{+4}_{-3} (Z)
7. CPOG Princess	10-04-019-11W4	Calc-silicate	
		Matzhiwin High	
8. Mobil CPR Hutton	11-18-024-15W4	Hornblende–biotite granitoid	2586^{+12}_{-11} (Z)
		Eyehill High	
9. BA *et al.* Canmer	06-09-031-1W4	Hypersthene–quartz diorite	2568^{+9}_{-8} (Z)
10. Husky DH Lloyd	10-15-049-1W4	Granodiorite gneiss	2601±4 (Z)
11. Calstan Pacific Marwayne	14-29-052-2W4	Pegmatite phase in amphibolite	2612^{+15}_{-13} (Z); 2584, 2561 (M)
		Loverna Block	
12. Cdn Seabd White Rose Elk Pt.	07-14-057-6W4	K-feldspar-rich granitic gneiss	1820±1 (M)
13. PCP Entice	07-05-028-25W4	Granite porphyry	
14. PCP Entice	09-06-028-23W4	Biotite syenogranite	
15. TGT Nacmine	06-08-028-21W4	Granite	
16. Rio Bravo Ronald #1-6	01-06-038-15W4	Biotite granite	2711±5 (Z)
17. Imperial Irma #1	06-14-046-9W5	Granite	
18. Atapco Oyen	07-02-028-4W4	Granite	1779±3 (Z)
		Lacombe Domain	
19. CPOG Oberlin	10-15-038-21W4	Felsic metatuff	
20. Imperial Willingdon #1	14-14-055-15W4	Rhyolite	
21. Imperial Ardrossan #1	08-17-053-21W4	Biotite–muscovite–garnet leucogranite	
22. Imperial Dinant	16-17-048-20W4	Red phyllite	
		Rimbey High	
23. BP Leming	10-10-066-6W4	Garnet–cordierite–sillimanite paragneiss	
24. Esso AEC 85 Fish. Ck	07-11-067-6W4	Granite	1831±6 (Z); 1815±3 (M)
25. Mobil Pan Am Heart Lake	04-03-069-10W4	Biotite monzogranite	1798^{+29}_{-28} (Z)
26. Esso 83 inj Ethel Lk	08-33-064-3W4	Leucogneiss	
27. Imperial Leduc #530	08-17-050-26W4	Biotite leucogranite	1856±3 (M)
28. Imperial Darling	16-19-062-19W4	Granite	
		Thorsby Low	
29. Imperial Clyde #1	09-29-059-24W4	Quartz diorite	2380±20 (Z)
30. Imp. Bailey Selburn Riverdale	01-27-060-26W4	Pegmatitic granite	1915±23 (Z)
31. Home CPOG Brightbank	10-05-052-2W5	Quartz diorite	2294^{+67}_{-45} (Z)
		Wabamun High	
32. Mobil *et al.* Pembina	11-27-049-8W5	Biotite tonalite	2322±8 (Z)
		Taltson Arc	
33. Merrill Arab Chard	05-34-078-6W4	Syenogranite	1972±5 (Z)
34. ROC Watchusk Lake	07-08-083-3W4	Granite	1949±2 (M)
35. Bear Vampire #1	07-28-087-12W4	Biotite monzogranite	
36. Shell Eatha EU	13-31-096-6W4	Syenogranite	
37. RO Corp Janvier	05-23-080-5W4	Granite	
38. Imperial Wolverine	07-24-076-18W4	Syenogranite	1968±1 (M)
39. Cal. Std. Mikkwa	12-23-098-21W4	Granite	1937^{+61}_{-45} (Z)
40. IOE Jack Lakes	08-17-120-1W5	Granite porphyry	1972^{+20}_{-17} (Z)
41. Baysel Birch Hills	09-34-094-14W4	Biotite granite	
		Buffalo Head Terrane (Utikuma Belt)	
42. Imperial Pelican Hills	06-10-077-25W4	Garnet granite	2017^{+2}_{-1} (Z)
43. IOE Sylvia	10-08-073-5W5	Quartz monzonite	2317^{+27}_{-15} (Z)

TABLE 1 (*concluded*)

Oil well name	Well location	Core lithology	Age (Ma)
44. Home *et al.* Regent Swan Hills	08-11-068-10W5	Monzonite augen gneiss	
45. Imperial Joussard	11-11-073-13W5	Biotite–clinopyroxene diorite	2324±1 (Z)
46. Union Red Earth	12-08-087-8W5	Syenogranite gneiss	
47. Chevron Hunt Creek	02-17-091-6W5	Granodiorite	1991^{+225}_{-45} (Z)
48. Fina IOE Buffalo Creek	10-23-087-22W4	Biotite–garnet granitic gneiss	2203^{+197}_{-78} (Z)
49. HB East Virginia Hills	05-31-065-6W5	Quartz diorite	1.95–2.33 Ga (Z)
		Buffalo Head Terrane (Buffalo Head High)	
50. Imperial Virginia Hills	06-36-063-12W5	Hornblende monzonite	1998^{+5}_{-4} (Z)
51. Dome *et al.* Peavine	16-09-075-20W5	Biotite leucogranite	2072±6 (Z)
52. Canhunter *et al.* Golden	06-24-086-15W5	Quartz monzonite	1990^{+13}_{-12} (Z)
53. Chevron Irving Cadotte	13-19-087-21W5	Monzonite gneiss	2165^{+5}_{-4} (Z)
54. CDCOG *et al.* Helen	01-08-088-24W5	Granitic gneiss	2280±3 (Z)
55. Clear Hills 14-10	14-10-088-2W6	Felsic metavolcanic	2257^{+25}_{-21} (Z)
56. Fina Keg River	10-27-102-21W5	Monzonite gneiss	1993^{+10}_{-5} (Z)
57. Fina *et al.* Keg River	10-29-103-19W5	Pegmatite in metasediment	
58. Arco Chevron Lafond	02-23-094-10W5	Granite porphyry	2014^{+7}_{-6} (Z)
59. Chevron Irving Helen	16-20-087-23W5	Quartzite	
60. Imperial Crossroads	15-32-109-19W5	Quartz monzonite	
61. Union CDCOG Slave	11-15-084-14W5	Granite	
62. Texaco Pac-Dix A-1	14-25-086-1W6	Granite	
63. Home Union HB Virginia Hills	16-12-066-13W5	Metabasite	
		Chinchaga Low	
64. S.R. Banff Caribou Mtn. #1	06-23-112-19W5	Granite porphyry	2088^{+23}_{-21} (Z)
65. Chevron *et al.* Sheldon	16-35-074-24W5	Monzonite gneiss	2159^{+11}_{-10} (Z)
66. Two Creek 6-11	06-11-063-16W5	Granitic gneiss	2186^{+68}_{-51} (Z)
67. Cal. Standard Gulf Kaybob	05-35-062-18W5	Amphibolite	
68. We Bakke *et al.* Sturgeon Lake	09-27-070-23W5	Granitic gneiss	
69. Pan Am A-1 Bald Mtn	11-13-068-5W6	Granitic	2175±2 (Z)
70. Pan Am Scurry C-1 Gold Ck	06-17-068-4W6	Quartz diorite	
71. Pan Am G-1 Gold Ck	10-16-069-5W6	Garnet–biotite paragneiss	
72. Pan Am IOE B-1 Chinchaga	06-08-099-7W6	Syenogranite	
73. Imperial Clear Hills	02-28-094-9W6	Monzonite gneiss	
		Ksituan High	
74. Phillips Ksituan	07-36-077-9W6	Quartz monzonite	1986±11 (Z)
75. Honolulu Beloy	06-26-079-3W6	Monzonite	1987±3 (Z)
76. Shell Worsely	10-23-086-9W6	Granitic gneiss	
77. GC *et al.* Farmton	14-27-080-11W6	Granite	1900±1 (Z)
78. Pan Am A-1 Doig River	10-27-090-11W6	Biotite gneiss	
		Nova Domain	
79. Imperial Rainbow Lake 16-18	16-18-107-6W6	Mafic gneiss	2808^{+30}_{-27} (Z)
80. Imperial Rainbow Lake 2-16	02-16-107-6W6	Metarhyolite	
81. Mobil Nova	15-34-109-4W6	Metarhyolite	1990±6 (Z)
		Great Bear Arc	
82. Mobil *et al.* Pert	11-15-123-1W6	Tonalite	1.75–1.95 Ga (Z)
83. Dome *et al.* Steen	03-12-121-22W5	Monzonite gneiss	
84. IOE Steen	12-19-121-21W5	Quartz monzodiorite	
85. Shell Thurston Lake	12-30-125-2W6	Syenogranite	
86. Imperial Bistcho Lake	07-07-124-2W6	Granite	
		Hottah Terrane	
87. Imperial Black Creek	10-27-109-9W6	Tonalite	1870^{+12}_{-11} (Z)
88. BA West Rainbow	06-33-110-10W6	Granodiorite	1845^{+9}_{-58} (Z)
89. Imperial Amber	13-11-116-8W6	Calc-silicate gneiss	
90. Mobil *et al.* Bark Bistcho	14-16-121-7W6	Syenogranite	1924^{+25}_{-24} (Z)

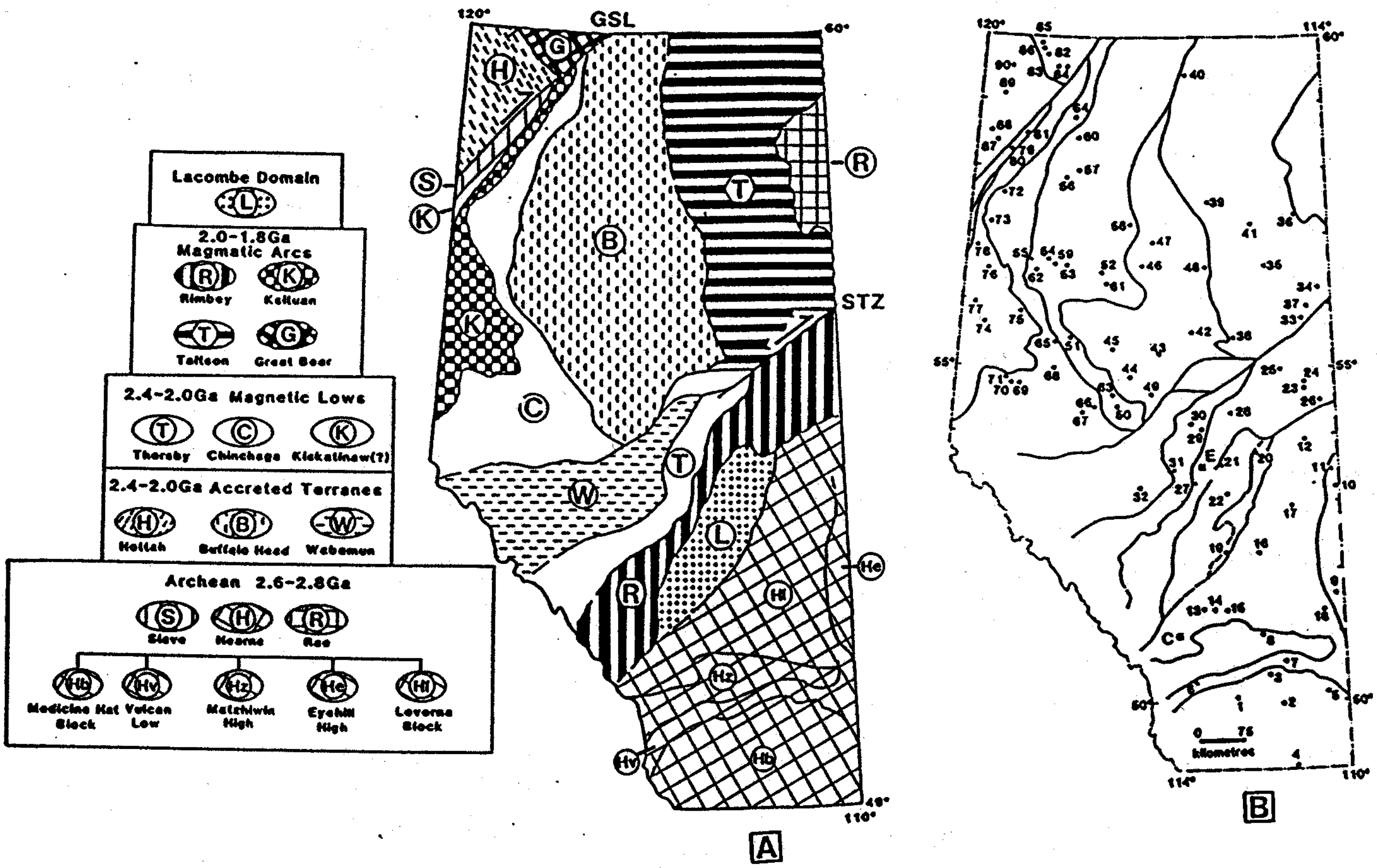


FIG. 2. (A) Age domain map for the subsurface of Alberta based on geophysical properties and U–Pb zircon and monazite age data presented in Villeneuve *et al.* (in press). Arrows show relative sense of displacement along the Great Slave Lake shear zone (GSL) and Snowbird Tectonic Zone (STZ). (B) Compilation of location, lithology, and age of basement intersections used in this study. Domain boundaries are also presented. 52 of the 90 intersections were used for geochronological control. Ages are reported in Table 1.

ages of 2.29 and 2.40 Ga, respectively, and a deformed pegmatite is 1.91 Ga. The Thorsby Low forms the northwestern boundary of the Rimbey High, a northeast-trending, curvilinear belt of moderate-intensity positive aeromagnetic highs that is underlain by undeformed biotite monzogranites with ages between 1.78 and 1.85 Ga. These granites appear to continue into western Saskatchewan, where they are spatially associated with the exposed Snowbird Zone (1.82 Ga Junction granite; MacDonald 1987). The northernmost splay of the Snowbird Zone abruptly truncates the north–south-trending anomalies of northern Alberta and forms the northern boundary of the wedge-shaped Wabumun High. The Wabumun High has a positive aeromagnetic signature and a dome-shaped internal magnetic fabric. It is tentatively dated by a single sample of biotite tonalite 2.32 Ga in age.

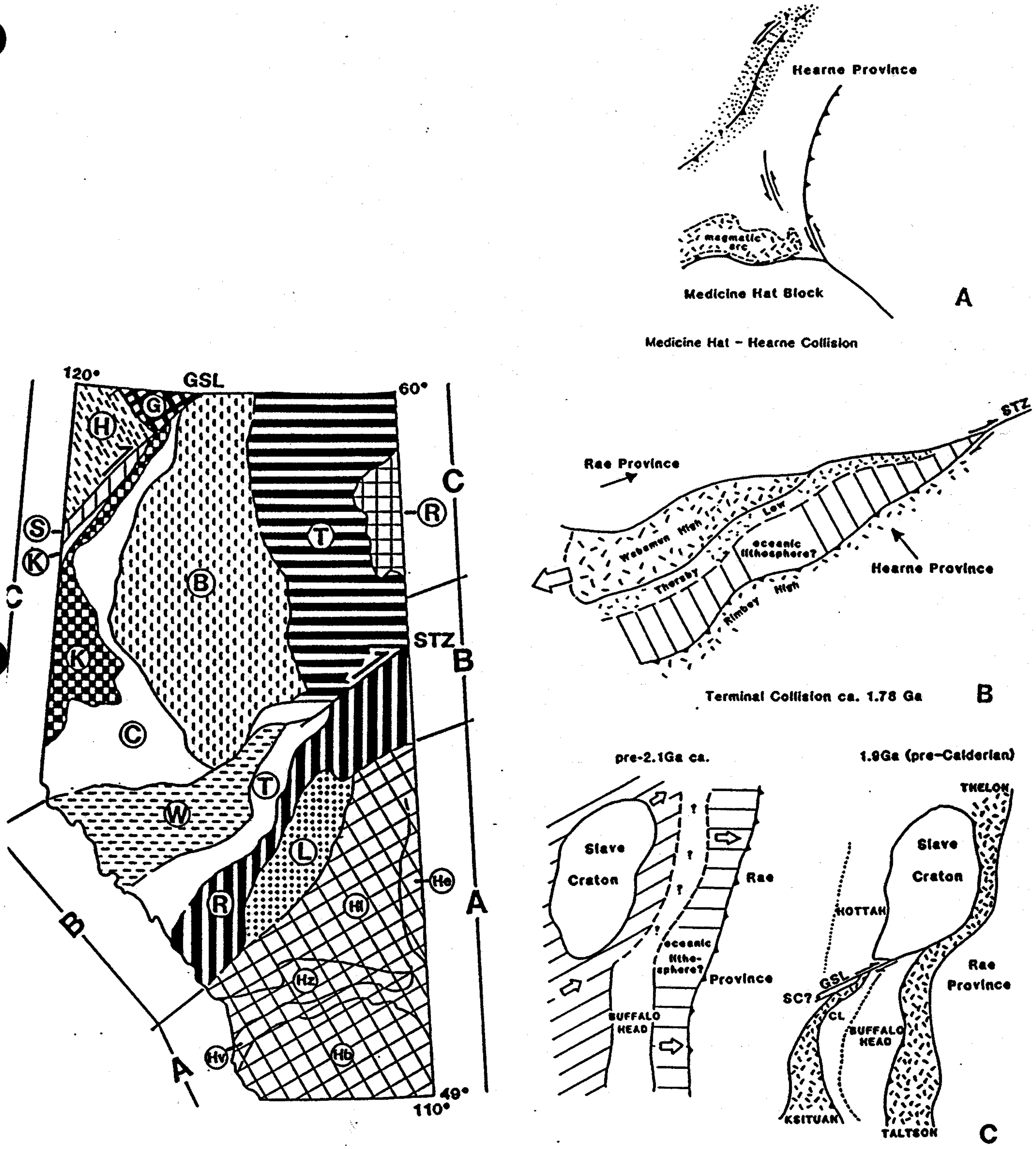
Northern Alberta

Northern Alberta is dominated by north-trending, convex-westward aeromagnetic anomalies that are truncated to the south by the Snowbird Tectonic Zone and can be traced northwards into the exposed Great Slave Lake shear zone. The subsurface extension of the Great Slave Lake shear zone is not marked by an aeromagnetic or gravity anomaly but instead is recognized by the sharp juxtaposition of different aeromagnetic domains. Moreover, this portion of the shear zone is much narrower than the 25 km of width exhibited in its type locality (Hanmer 1988), suggesting dominantly late and brittle motion. This discontinuity was originally referred to as the Hay River fault (Lavoie 1958).

In the northeastern part of Alberta, the Taltson Arc wraps around the Rae Province to the east and forms a broad zone of positive aeromagnetic signature with regions of negative aeromagnetic anomalies that correspond to peraluminous plutonic belts, septa of metasedimentary rocks, and shear zones (Bostock *et al.* 1987). The Taltson is characterized by a sinuous aeromagnetic fabric, interpreted as reflecting the penetrative strain that is typical of this magmatic belt in its exposed portions to the north (Culshaw 1984; Bostock 1987). Zircon ages from the basement range from 1.97 to 1.93 Ga and are in agreement with ages from the exposed Taltson Arc (Bostock *et al.* 1987).

To the west of Taltson Arc is the Buffalo Head Terrane, a composite, largely magmatic belt that comprises metaplutonic and subordinate felsic metavolcanic rocks that have ages of 2.0–2.32 Ga. Such ages are distinctly older than the 1.9–2.0 Ga rocks to the east (Taltson Arc) but have been reported recently from the eastern "hinterland" of the Taltson Arc (Bostock and Loveridge 1988; Van Breemen *et al.* 1990). The Buffalo Head Terrane is characterized by sinuous aeromagnetic patterns and discrete subdomains, suggesting that it is a complex region of crustal fragments, the nature of which cannot be resolved at the present scale of study.

West of the Buffalo Head Terrane is the Chinchaga Low, which is composed of metaplutonic and metasedimentary gneisses characterized by a uniform negative aeromagnetic signature. The metaplutonic gneisses yield zircon crystallization ages of 2.09–2.18 Ga, equivalent in part to Buffalo Head



ꟾG. 3. Speculative tectonic models for the tectonic evolution of the crystalline basement of Alberta. (A) The Hearne Province of southern erta is shown as a collage of Archean age crustal blocks juxtaposed along structural discontinuities such as the Vulcan Low and the hill–Loverna boundary. The Lacombe Domain sedimentary rocks are shown as a thrust belt (stippled). The Matzhiwin High is interpreted as agmatic belt related to northward subduction. Alternatively, it could have been emplaced during largely amagmatic faulting. (B) Central Alberta own as an evolving region of oblique convergence between the Hearne and Rae provinces with possible subduction-related magmatism along imbey High. Alternatively, the Rimbey granites could have been generated during crustal thickening without subduction. The Wabamun High own as a structurally bound block that "escaped" from the collision zone. (C) Northern Alberta evolved during northeastward translation lave Craton and its collision with Churchill Province along the Thelon Orogen. The lack of a rigid indenter outboard of the Churchill Province h of Great Slave Lake shear zone (GSL) was in part responsible for the preservation of Buffalo Head Terrane and Chinchaga Low. CL, nchaga Low; SC, Slave Craton.

Terrane ages. A sharp aeromagnetic boundary separates the Chinchaga Low from the Buffalo Head Terrane on the east and the Ksituan High on the west, possibly suggesting a faulted contact on both sides of this terrane.

The Ksituan High, to the west of the Chinchaga Low, has the strong, positive aeromagnetic expression that is typical of calc-alkaline magmatic belts. Plutonic rocks that are characteristic of this domain have ages between 1.90 and 1.98 Ga. The belt can be traced to the northeast, where it is eventually truncated by the Great Slave Lake shear zone (Hay River fault) (Fig. 1). Two sliver-shaped anomalies, one aeromagnetically negative (Kiskatinaw Low) and the other positive (Nova Domain), are wedged between the Great Slave Lake shear zone and the Ksituan High. A sample of mafic gneiss from the Nova Domain gives an age of 2.80 Ga, suggesting possible correlation with Slave Craton.

Aeromagnetic domains northwest of the Great Slave Lake shear zone – Hay River fault are continuous with the exposed Hottah Terrane and Great Bear Magmatic Arc of Early Proterozoic Wopmay Orogen (Hoffman 1987), with dated granitoids that range from 1.78 to 1.92 Ga in age. These belts cannot be traced southwards across the Great Slave Lake shear zone.

Discussion

The following discussion presents speculative tectonic models for the evolution and assembly of tectonic domains in the subsurface of Alberta. The Canadian Shield is used as an analog where kinematic relationships are constrained by field studies and geochronology. The mosaic of crustal blocks that presently form the basement of the Alberta Basin represents the cumulative product of a long history of deformation and tectonic assembly. There are two different approaches that may be used to infer the history of tectonic processes that produced this. One can postulate that none of the domains bear genetic relationships to one another and that their present juxtaposition is largely the result of essentially amagmatic faulting. The alternative approach is to postulate a genetic relationship between domains. For example the assembly of two domains separated by a magmatic belt must have been accompanied by consumption of oceanic lithosphere and magmatism (e.g., subduction). We have chosen the latter approach based largely on relationships between tectonic domains in the exposed Shield. These models, although highly speculative, provide a framework of crustal geometries that can be examined and tested using seismic reflection imaging and forms the basis for a recently funded Lithoprobe program.

The truncation of geophysical fabric of the Medicine Hat Block in southern Alberta by the Vulcan Low leads us to speculate that this latter feature is a major fault and possibly a collisional suture (Fig. 3A). The age and polarity of the juxtaposition of domains along the Vulcan Low are unknown, but if the Matzhiwin High is interpreted as a magmatic belt, then the suture could have a north-dipping polarity. Alternatively the Vulcan Low could be a largely amagmatic shear zone of Archean age or younger. In addition it appears that the Eyehill High is also structurally bounded, leading us to suggest that the Hearne Province in southern Alberta may represent a collage of Archean blocks.

In central Alberta, the Rimbey–Thorsby–Wabamun region is suggested to be a region of complex plate convergence and transpression along the Snowbird Zone (Fig. 3B) that involved magmatism (Rimbey High) and formation of a tectonic escape wedge (Wabamun High). This interpretation is consistent with the complex structural evolution recognized to the northeast (Hanmer 1987), where the Snowbird Zone forms the boundary between the northern Churchill (Rae) and southern Churchill (Hearne) Province. The 1.78–1.85 Ga Rimbey granitoids may be syntectonic to posttectonic based on correlation with the exposed 1.82 Ga Junction granite in Saskatchewan, which contains xenoliths of Snowbird Zone mylonite and but is weakly foliated (McDonald 1987).

One of the most unexpected surprises of this work is the discovery of large regions of crust in northern and central Alberta with zircon ages between 2.4 and 2.0 Ga. This is unusual because with the exception of areas immediately to the east of Taltson Arc (Van Schmus *et al.* 1987; Bostock and Loveridge 1988; Van Breemen *et al.* 1990) rocks of this age are uncommon in the Canadian Shield and in Precambrian shield regions in general. The preservation of crust of this age in Alberta reflects the peculiarities of the ca. 1.9 Ga tectonic geometry in this region (discussed below) and has general implications for models of the episodicity of tectonic processes and crust formation previously inferred for the Precambrian (Patchett and Arndt 1986).

The Early Proterozoic tectonic history of the western Canadian Shield reflects the collisional interaction of the Slave Craton and the composite Buffalo Head – Chinchaga domains with the Rae Province, although the relationship between the Slave Craton and Buffalo Head Terrane across Great Slave Lake shear zone is unknown (Fig. 3C). The Taltson–Thelon Zone represents the magmatic rocks generated during eastward subduction and collision between 2.02 and 1.91 Ga, contemporaneous with dextral shear within the Great Slave Lake shear zone (Hoffman 1987, 1988). An important observation is that the 2.0–2.4 Ga Buffalo Head – Chinchaga composite block in Alberta is flanked by younger (1.900–1.987 Ga) magmatic rocks of Taltson Arc and Ksituan High, but is apparently not perforated by coeval plutons. A reasonable interpretation of this observation is that the Buffalo Head and Chinchaga domains were flanked by outward-dipping subduction zones that generated the magmatic belts that flank these terranes. In contrast, the contemporaneous collision in the Canadian Shield to the north involved the indentation of the Rae Province by the rigid Slave Craton along an east-dipping subduction zone beneath the Thelon Arc. This may have led to tectonic slivering and escape, analogous to the process in the Red River region east of the Himalayas (Tapponnier *et al.* 1990), as well as uplift and erosion of preexisting Buffalo Head crust. Vestiges of inferred Buffalo Head Terrane material in the Thelon Zone may be found as an inherited component in Thelon granites (Roddick and van Breemen 1989) and as a detrital component in synorogenic sediments (McCormick *et al.* 1989) in the foreland to the Thelon Orogen. Thus the Buffalo Head Terrane was preserved both as a consequence of a lack of younger magmatism as well as the absence of a rigid indenter, such as the Slave Craton.

The widespread occurrence of crust with primary crystallization ages of 2.1–2.4 Ga is unusual in continental shield areas of the northern hemisphere. This apparent episodicity of age data, specifically the occurrence of 2.6 Ga and older crust and 1.8–2.0 Ga crust with a "gap" between 2.5 and 2.1 Ga, has been an important component of recent models of crust–mantle differentiation (Patchett and Arndt 1986; Bennett and DePaolo 1987). This apparent gap has led to the interpretation of "intermediate" Nd T_{DM} model ages (2.4–2.1 Ga), which are widespread on a global basis (Bowring and Podosek 1989), as he result of mixing between Archean crust and a ca. 1.8 Ga uvenile Proterozoic component, rather than as a ca. 2.3 juvenile event. This interpretation has been justified by the apparent lack of zircon crystallization ages indicative of tectonic activity between 2.4 and 2.1 Ga (Patchett and Arndt 1986). The occurrence and preservation of large areas of intermediate-age rust in the subsurface of Alberta suggest that although the nixing model may apply in many areas, Precambrian tectonic ctivity in the western Canadian Shield may have been more ontinuous than previously thought.

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GEOPHYSICAL AND PETROLOGICAL CHARACTERISTICS OF THE BASEMENT ROCKS OF THE WESTERN CANADA BASIN

R.A. Burwash, A.G. Green, A.M. Jessop, and E.R. Kanasewich

INTRODUCTION

R.A. Burwash

Precambrian basement underlying the Interior Plains is a lateral extension of the exposed Canadian Shield. From the trend and width of most of the major tectonic units of the western part of the shield it can be inferred that they extend some distance beneath the sedimentary cover. Recognition of these units on the exposed part of the shield has been based primarily on geological mapping combined with studies of structural style, metamorphic fabric and facies, geochronology, and geophysical characteristics. In those areas of the Shield with an extensive cover of Pleistocene deposits, geophysical surveys have served to trace the boundaries of distinctive rock units. In sedimentary platforms with moderate Phanerozoic cover, geophysical maps are the only practical means of tracing the boundaries of major units. Core samples from wells drilled to basement provide information on rock assemblages, metamorphic history, geochronology, and petrophysical characteristics, but yield little of the detailed structural information that can be obtained from outcrop.

The objectives of this chapter are to present the currently available geophysical and petrological data that characterize the major tectonic units of the basement beneath the Western Canada Basin. An attempt is made to draw a map of the basement within the framework of the structural geology of North America.

Historical background

The western limit of the crystalline rocks of the Canadian Shield was first shown with reasonable accuracy on a map drawn by Sir John Richardson in 1851 (Kupsch, 1979). In his travels from Hudson Bay to the Interior Plains of western Canada, Richardson recognized the boundary between flat-lying Paleozoic rocks and underlying granites at several localities along the canoe routes developed by the fur trade.

During the mapping of the Ottawa and adjacent St. Lawrence valleys, W.E. Logan (1854) recognized an ancient series of metamorphic rocks which lay beneath the younger stratified sequences. He gave the name "Laurentian" to the granite gneisses of the complex. In the same year the word "basement" was first used in its present geological sense by Hugh Miller when referring to the Lewisian gneisses of northwestern Scotland (Murchison, 1859). The observations of Richardson and Logan, coupled with the concept of basement, formed the basis for the assumption that the Interior Plains were floored with an ancient igneous-metamorphic complex.

Within the Interior Plains of western Canada only two small areas of Precambrian granitic rocks are exposed; these are in the rims of meteorite impact structures located west of Lake Winnipeg. These limited Precambrian outcrops are in marked contrast with the number exposed in the United States, where Cenozoic tectonic activity has caused domal uplifts and basement exposures in the Black Hills and Little Belt Mountains. In the Rocky Mountains of the United States, block-faulted uplifts of crystalline basement are common. To date, only a few small fault slices of crystalline basement have been recognized in the Columbian Orogen (Evenchick et al., 1984). In the absence of Precambrian outcrops over an area of 1.8×10^6 km^2, reliance has been placed on data from geophysical surveys and drillholes.

Prior to 1940, basement of the Western Canada Basin had been reached only by four shallow drillholes near Fort McMurray in northeastern Alberta and one near Winnipeg (Fig. 3.1). Regional gravity surveys, started in 1945, led to the publication a decade later of the first Gravity Map of Canada (Dominion Observatory, 1957). Aeromagnetic surveys of the Western Canada Basin by the Geological Survey of Canada, started in the Leduc area in 1951, extended in several years to northeastern Alberta. The compilation of the Magnetic Anomaly Map of Canada (Geological Survey of Canada, 1967), at a scale of 1:5 000 000, made apparent for the first time the continuity of the magnetic anomaly fabric over large areas of exposed and buried Canadian Shield.

Burwash, R.A., Green, A.G., Jessop, A.M., and Kanasewich, E.R.
1993: Geophysical and petrological characteristics of the basement rocks of the Western Canada Basin; Chapter 3 in Sedimentary Cover of the Craton in Canada, D.F. Stott and J.D. Aitken (ed.); Geological Survey of Canada, Geology of Canada, no. 5, p. 55-77 (also Geological Society of America, The Geology of North America, v. D-1).

Studies of heat flow using data from deep drill holes in the Western Canada Basin were first reported by Garland and Lennox (1962). Recognition of the North American Central Plains (NACP) conductivity anomaly in southern Saskatchewan by Alabi et al. (1975) set the stage for much discussion of possible plate boundaries between cratonic blocks.

Most of the exploratory tests drilled to basement were completed in the two decades following the discovery of a large oil pool in a Devonian reef at Leduc, Alberta, in 1947. Core samples from these wells formed the basis for thesis projects by Burwash (1951, 1955) and Peterman (1962), summarized in the Geological History of Western Canada (Burwash et al., 1964). Concurrently, the Basement Rock Project of the American Association of Petroleum Geologists compiled all relevant well data and published the Basement Map of North America (Flawn, 1967).

Limitations

In the preparation of this chapter, several limitations became of concern. The southern half of the sedimentary basin (up to 60°N) has been more extensively studied geophysically and petrologically than the northern half. Even in the southern half the quality of data is far from uniform. Aeromagnetic coverage of northeastern British Columbia and Alberta west of 114°W is limited to a survey flown at an elevation of 3.5 km and line spacing of 37 km (Coles et al., 1976). The resolution of this map is much less than that of the latest Magnetic Anomaly Map of Canada (Dods et al., 1984).

Evolving petroleum exploration philosophies and thin sedimentary cover have left a number of areas with few drillholes to basement. In these areas, delineation of domain boundaries relies heavily on interpretation of geophysical surveys, without the support of direct evidence from core samples.

Acknowledgments

During the past thirty years many of the oil companies in western Canada have generously supplied core samples and information required for basement studies. Grants to R.A. Burwash and E.R. Kanasewich from the Natural Sciences and Engineering Research Council of Canada are gratefully acknowledged. The manuscript was prepared and edited with the assistance of R.W. Burwash.

LITHOSTRUCTURAL DOMAINS OF THE EXPOSED SHIELD

R.A. Burwash

The lithostructural domains (Fig. 3.2) are a synthesis of those suggested by Ayres (1978), Ermanovics and Froese (1978), Lewry et al. (1978), Sims (1980), Hoffman et al. (1982a), Fumerton et al. (1984), Bowring et al. (1984), Green et al. (1985a, b), and Hoffman (1988). Details of the geology of these domains appear elsewhere (see the companion volume, "Precambrian geology of the Craton in Canada and Greenland", Hoffman et al., in prep.). In the following synopsis, only the characteristics of the major divisions and the inter-division boundaries relevant to the Western Canada Basin are discussed.

Both Superior and Slave structural provinces (Fig. 3.2) contain numerous greenstone belts intruded by Archean mesozonal plutons and separated by linear gneissic terranes. The greenschist to lower amphibolite grade of the supracrustal rocks (Fraser et al., 1978) and the persistence of Archean K-Ar radiometric ages from biotite (Stockwell, 1982) indicate a crustal stability that satisfies a strict definition of the word "craton". The northwestern margin of Superior Province is deeply eroded to expose granulites in the Pikwitonei Subprovince (23, Fig. 3.2). The margins of Slave Province are in part onlapped by Early Proterozoic clastic wedges and in part are metamorphic fronts. Granulites are not common in Slave Province.

During the Hudsonian Orogeny (1.9-1.8 Ga) convergence of Slave and Superior cratons resulted in the formation of numerous northeast-trending lithostructural

Figure 3.1. Derrick for Alberta Government Salt Well No. 2; drilled to basement in northeastern Alberta, in 1923 (University of Alberta Archives).

domains. The Wathaman-Chipewyan batholith approximates the thermal axis of the orogen and separates regions with distinctively different lithologies (Fumerton et al., 1984). Needle Falls shear zone (14, Fig. 3.2), along the northwest margin of the batholith, is a domain boundary of regional significance (Lewry et al., 1981). In Cree Lake zone, Archean sialic basement has been remobilized with its miogeoclinal cover. Gneiss domes of relict Archean granulite occur in the Wollaston Fold Belt. Hudsonian hornblende granulite-facies metamorphism is recognized in the cover rocks infolded into the plastic

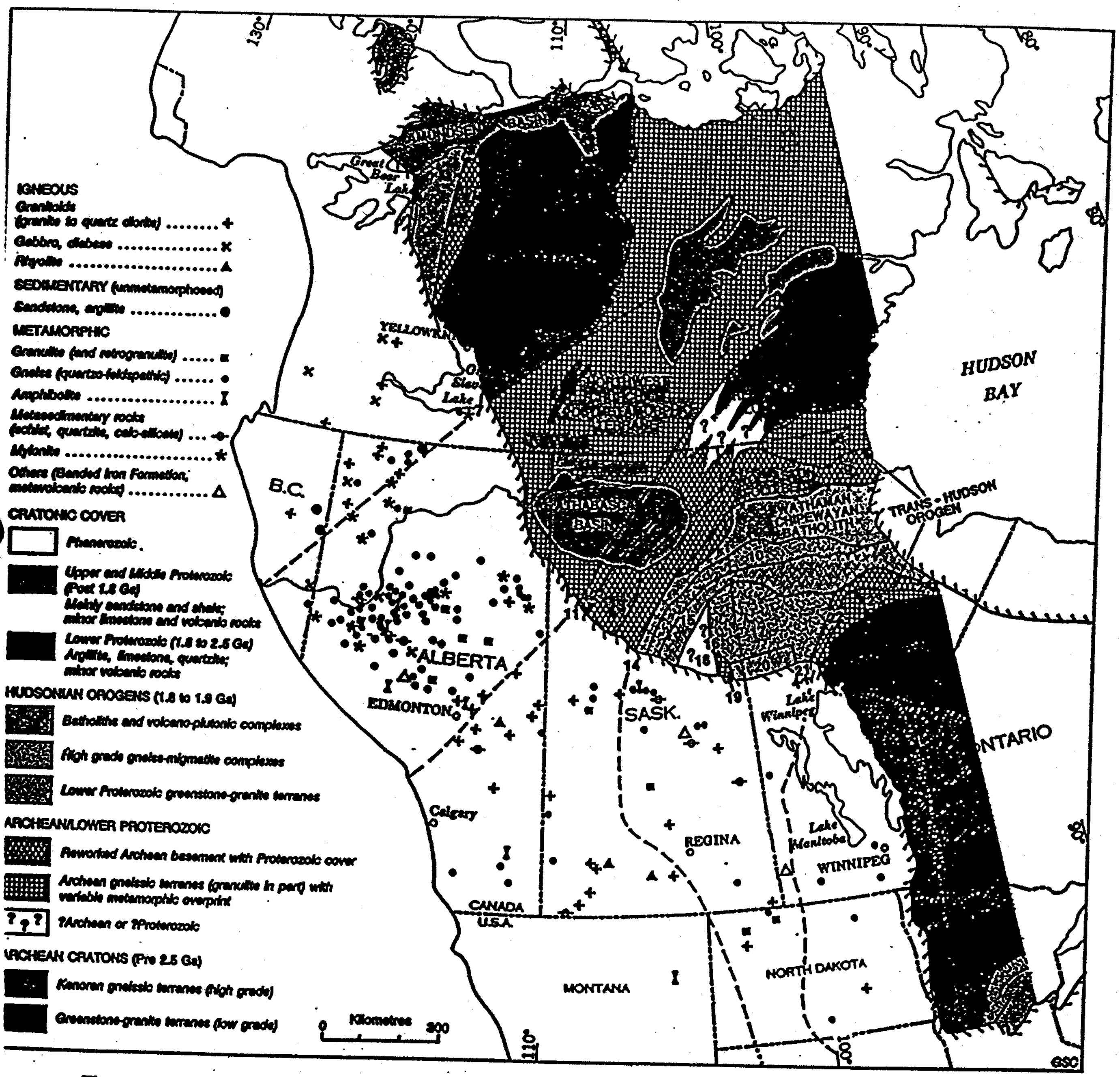


Figure 3.2. Lithostructural domains of the exposed Canadian Shield and lithology of basement cores. WMO = Wopmay Orogen; 1 = WMO, Hottah Terrane; 2 = WMO, Great Bear magmatic arc; 3 = WMO, Hepburn batholithic belt; 4 = WMO, foreland belt; 5 = Thelon Front; 6 = East Arm Fold Belt; 7 = Great Slave Lake Shear Zone; 8 = Nejanilini fold belt; 9 = Seal River fold belt; 10 = Reindeer-Southern Indian belt; 11 = Virgin River shear zone; 12 = Virgin River fold belt; 13 = Mudjatik domain; 14 = Needle Falls shear zone; 15 = LaRonge and Lynn Lake belts; 16 = Tabbernor shear zone; 17 = Kisseynew domain; 18 = Glennie Lake domain; 19 = Hansen Lake block; 20 = Flin Flon and Snow Lake belts; 21 = Setting Lake fault; 22 = Thompson Belt; 23 = Pikwitonei Subprovince; 24 = Fox River belt.

infrastructure of the Mudjatik domain (13, Fig. 3.2). An elongate batholith of Hudsonian granite parallels Virgin River shear zone (11, Fig. 3.2) (Wallis, 1970).

Between Wathaman-Chipewyan batholith and Superior Province, an ensimatic(?) eugeosyncline existed in Early Proterozoic time (Stauffer, 1984). Hudsonian compression produced the arcuate lithotectonic domains shown in Figure 3.2. Mafic to felsic volcanic sequences, greywackes, and pelites are metamorphosed to greenschist-to-granulite facies. A boundary zone of cataclasis and retrograde metamorphism separates the Trans-Hudson Orogen from Superior Province.

The polymetamorphic terrane of northwestern Saskatchewan contains a large number of blocks of granulite separated by linear zones of cataclasis and recrystallization (Beck, 1969). This tectonic style is characteristic of northwest Churchill Province to the bounding Great Slave Lake Shear Zone (7, Fig. 3.2). Granulite-facies metamorphism, circa 2.4 Ga, was documented in northwestern Saskatchewan by Koster and Baadsgaard (1970). The recrystallization is Hudsonian.

In East Arm Fold Belt (6, Fig. 3.2), carbonate and basinal clastic sequences of the Great Slave Supergroup were affected by northeast-directed thrusting but little metamorphism during Hudsonian Orogeny. Calc-alkaline laccoliths (1.86 Ga) postdate the thrusting (Bowring et al., 1984). Middle Proterozoic diabase sills are important lithological units in the belt.

Bounding Slave Craton on the west is the Early Proterozoic Wopmay Orogen (see Fig. 3.11, WMO). Its foreland belt (4, Fig. 3.2) to the east of Great Bear Lake contains sedimentary sequences correlative with those in the Great Slave Supergroup (Hoffman, 1981). West of the Asiak thrust belt, the Hepburn batholithic belt (3, Fig. 3.2) contains domes of reactivated Archean gneiss (Neilsen, 1978). The Great Bear magmatic arc (2, Fig. 3.2) is interpreted by Hoffman and Bowring (1984) as a short-lived volcano – plutonic depression (~1.9 Ga) on continental crust. Volcanic rocks, ranging from basalt to rhyolite, and nonmarine sedimentary rocks are intruded by epizonal and mesozonal calc-alkaline plutons. The poly-deformed Hottah Terrane (1, Fig. 3.2) underlies the western edge of the Great Bear magmatic arc.

Amundsen Basin of Middle and Upper Proterozoic clastic sedimentary rocks onlaps the northwestern edge of the crystalline shield. Several periods of basaltic magmatism are recorded in the basin, of which the Coppermine lavas (1.2 Ga) are the most voluminous. The contemporaneous Mackenzie diabase dykes are of widespread occurrence, both in the western part of the Canadian Shield and in Middle Proterozoic sequences of the eastern Cordillera.

MAGNETIC AND GRAVITY DATA

A.G. Green

Maps of the earth's magnetic and gravity fields are powerful tools for extrapolating our knowledge of Precambrian basement geology beneath younger sedimentary cover. High-resolution magnetic data are particularly sensitive to changes in the geology of the uppermost crust and have long been used to guide mineral exploration and geological mapping programs. On the exposed Canadian Shield, magnetic anomaly patterns commonly correlate precisely with local and regional geology (Kornik and MacLaren, 1966; Hall, 1968; Kornik, 1969, 1971; Bell, 1971a; Wilson, 1971). Many geological structures also have distinctive gravity expressions, but generally there is not the same close correspondence that is observed between surface geology and magnetic data. On the other hand, regional gravity data are useful for mapping deep structural and lithological variations.

Magnetic anomaly map

The magnetic anomaly map (Fig. 3.3) represents a composite of diverse data from a number of sources. High-quality aeromagnetic maps from the Canadian Federal-Provincial series cover the exposed Canadian Shield (Dods et al., 1984), and various maps by oil companies and universities cover the adjacent Interior Plains of Manitoba, Saskatchewan and southern Alberta (Sawatzky and Standing, 1971; Green et al., 1979, 1985a, b; PanCanadian Petroleum Ltd., pers. comm., 1984). Data from a relatively low-resolution aeromagnetic survey (37 km line spacing; Coles et al., 1976) are incorporated in two small areas of northern Saskatchewan and constitute the bulk of information available for the northwestern part of the map. South of the international boundary the map is based on the composite magnetic anomaly map of the United States (Zietz et al., 1982). Technique for matching the southern Canadian data is that of Green et al. (1979a) and details of the United States compilation are given by Zietz et al. (1982).

Most of the lithotectonic units in the Canadian Shield can be delineated on the basis of their magnetic signatures. In particular, characteristic magnetic trends or patterns are associated with Superior Province and its marginal Thompson and Fox River belts (22, 24, Fig. 3.2), the various component units of the Trans-Hudson Orogen, Northwest Churchill polymetamorphic terrane and its marginal Cree Lake zone, Slave craton and its marginal Wopmay Orogen (see Fig. 3.11). Important magnetic lineaments outline many of the bounding and internal fault systems of the lithotectonic units, including Setting Lake fault (21, Fig. 3.2) along the western margin of the Thompson Belt, Tabbernor Shear Zone (16, Fig. 3.2) within the Trans-Hudson Orogen, Needle Falls and Virgin River shear zones (14, 11, Fig. 3.2) along the eastern and western margins respectively of the Cree Lake zone and Great Slave Shear Zone along the northern margin of the Northwest Churchill polymetamorphic terrane (7, Fig. 3.2). These magnetic signatures can mostly be followed for considerable distances across the Interior Plains (Fig. 3.3).

Westerly trending magnetic anomalies reflect the Archean fabric of Superior Province and its extensions beneath the Interior Plains (Wilson and Brisbin, 1962; Kornik and MacLaren, 1966; Stockwell et al., 1968; Kornik, 1969, 1971; Bell, 1971a; Wilson, 1971; Green et al., 1979, 1985a, b). Granite/greenstone belts within Superior Province have low background magnetic fields with moderate high-amplitude elliptical anomalies across igneous rocks and iron formations. High-grade gneissic belts have broad magnetic highs. Toward the northwestern margin of Superior Province lies the Pikwitonei granulite terrane (23, Fig. 3.2) with its "bird's-eye maple pattern" of high-amplitude, ovoid-shaped magnetic anomalies (observed on the larger scale Federal-Provincial magnetic maps; Kornik and MacLaren, 1966; Kornik, 1969, 1971; Bell, 1971a; Green et al., 1979).

The magnetic fabric of Superior Province is abruptly truncated by the southwesterly to southerly trending Thompson magnetic quiet zone (see Fig. 3.11) and its extension to the south. This linear zone of low magnetization, probably the result of Proterozoic metamorphic overprinting of the Superior craton margin and its overlying supracrustal rocks, extends 1500 km from northern Manitoba to a position beneath the Interior Plains of South Dakota. Over most of its length the western edge of the magnetic low is interpreted to be a continuation of Setting Lake fault, which juxtaposes the Thompson Belt and Kisseynew domains (22, 17, Fig. 3.2).

Magnetic anomalies of the Trans-Hudson Orogen (see Fig. 3.2, 3.11) extend westerly from Hudson Bay into northern Saskatchewan and then swing to the southwest

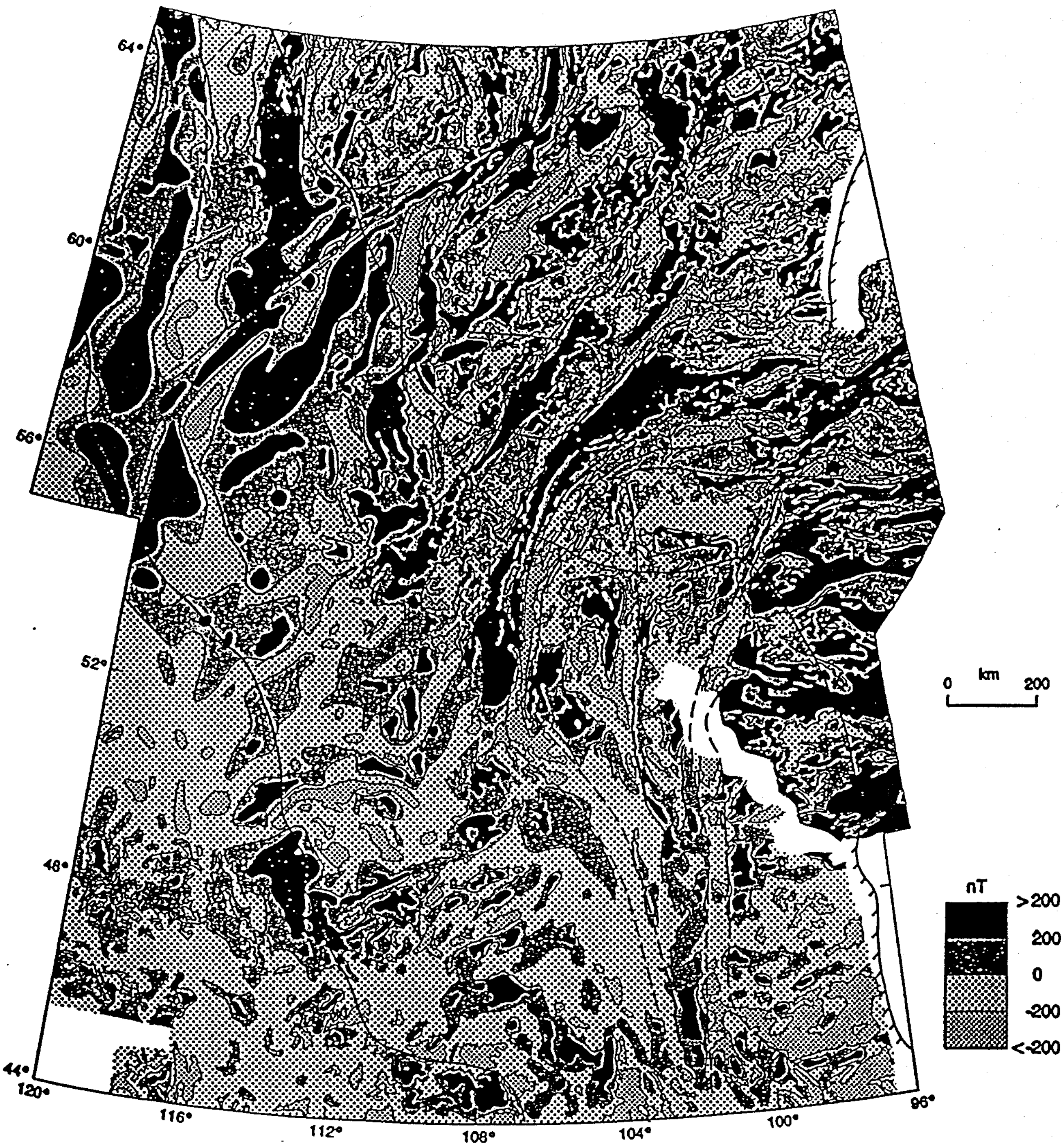


Figure 3.3. Magnetic anomaly map of Western Canada Basin and adjacent areas. Lithotectonic domains of the exposed shield from Figure 3.2 and inferred basement divisions from Figure 3.11 are superimposed.

nd eventually to the south across the Interior Plains Burwash and Culbert, 1976; Green et al., 1979, 1985a, b; utch, 1983). The granite/greenstone rocks of the Flin Flon nd Snow Lake and LaRonge-Lynn Lake belts (20, 15, ig. 3.2) have magnetic expressions similar to the ranite/greenstone rocks of Superior Province, but the redominantly gneissic Kisseynew Domain and eindeer-Southern Indian Belt (17, 10, Fig. 3.2) have low ackground magnetic fields and subdued magnetic relief. n the larger scale Federal-Provincial magnetic maps, the abbernor Shear Zone (16, Fig. 3.2) along the western argins of the Flin Flon and Snow Lake belts and isseynew Domain is delineated by a major change in style f magnetic anomalies.

At the northern and northwestern margins of the rans-Hudson Orogen, the enormous Wathaman-hipewyan Batholith and associated granitic bodies are epresented by broad regions of magnetic high. The haracteristic magnetic expressions of the Reindeer-outhern Indian Belt and the Tabbernor Shear Zone allow he Trans-Hudson Orogen to be mapped as far south as titude 45°N (Fig. 3.3).

Within the Cree Lake zone a pattern of linear and urvilinear magnetic highs and lows extends southwesterly om the northeastern corner of the map to southern askatchewan and Alberta (Wallis, 1970; Burwash and ulbert, 1976; Coles et al., 1976; Green et al., 1985a, b). long its eastern boundary a linear belt of low agnetization coincides with the Needle Falls shear zone 4, Fig. 3.2). A lineament separates terranes of ontrasting magnetic fabric on opposite sides of the Virgin iver shear zone (11, Fig. 3.2). Relatively intense magnetic ighs occur across reworked Proterozoic metasedimentary nd Archean basement rocks of the Wollaston and Virgin iver (12, Fig. 3.2) fold belts and magnetic lows occur ostly across the intervening Mudjatik (13, Fig. 3.2) and he more easterly trending Seal River (9, Fig. 3.2) and ejanilini (8, Fig. 3.2) fold belts.

South of the exposed Canadian Shield, magnetic trends f the Cree Lake zone are truncated near the eastern edge f the Cordillera and by the westerly trending magnetic low verlying the postulated Precambrian rift structure of anasewich et al. (1968). The strikes of magnetic nomalies on the two sides of the "rift" differ noticeably Green et al., 1985a, b); to the north the anomalies trend outh-southeasterly and to the south they trend ast-southeasterly. The region south of the "rift" orresponds to the Archean Wyoming Province as outlined y Peterman (1981) on the basis of radiometric dating of asement outcrops and core samples. Beneath the Interior lains, the eastern boundaries of the Cree Lake zone and he Wyoming Craton are not well resolved by existing data.

A general southwesterly trending magnetic anomaly attern characterizes the reworked Proterozoic and rchean basement rocks of the Northwest Churchill olymetamorphic terrane. This pattern is broken up by ome relatively intense southerly striking magnetic highs nd lows about longitude 112°W, near the margin with the nterior Plains. The significance of these latter features nd whether or not there is a related change in the nature f the Northwest Churchill polymetamorphic terrane eneath the Interior Plains is unclear at the present time. long its northern boundary, Great Slave Lake Shear Zone 7, Fig. 3.2) can be traced from the Thelon Front (5, Fig. 3.2) southwestward almost to the edge of the Cordillera (Burwash and Culbert, 1976; Coles et al., 1976; Thomas et al., 1976). Magnetic anomalies on either side of the fault are sharply terminated by fault-related magnetic lineaments. Great Slave Shear Zone forms the southeastern margin of the East Arm Fold Belt (7, 6, Fig. 3.2).

In the northwestern corner of the map (Fig. 3.3), the southerly trending magnetic anomalies of the granite/greenstone and granite/gneiss terranes of Slave Province are bounded by East Arm Fold Belt and Great Slave Lake Shear Zone in the south and by southerly trending anomalies associated with Wopmay Orogen in the west. The adjacent northern Interior Plains are dominated by a pair of huge, southerly striking linear magnetic highs (Hoffman et al., 1982b). The eastern anomaly corresponds to the subsurface extension of the Great Bear Magmatic Arc (2, Fig. 3.2) of Wopmay Orogen and can be followed southward from exposures on the Canadian Shield to its intersection by the Great Slave Shear Zone (Coles et al., 1976). To the west, across the low magnetic field overlying Hottah terrane (1, Fig. 3.2), an arcuate magnetic high parallels the trend of the Mackenzie foldbelt in the north and the edge of the Cordillera in the south. Possible sources of this latter magnetic anomaly are reviewed in the section on the northern Interior Plains, later in this chapter.

Bouguer gravity anomaly map

The Bouguer gravity map (Fig. 3.4) is based on the Gravity Map of Canada (Earth Physics Branch, 1980) and the Gravity Map of the United States (Lyons and O'Hara, 1982). Many of the lithotectonic units delineated on the magnetic map also affect the gravity field. Notable Precambrian features include: westerly trending anomalies within Superior Province and their truncation near the Nelson River gravity high (4, Fig. 3.4), the westerly to southerly trending gravity gradient along the northern and western margins of the Trans-Hudson Orogen, the general southwesterly fabric of the Northwest Churchill polymetamorphic terrane and its marginal Cree Lake zone, the anomalies that almost surround Slave Province, and the southerly trending Bulmer Lake gravity high (1, Fig. 3.4). The extensive southeasterly trending anomaly pattern in the western and southwestern parts of the map is associated with the edge of the Cordillera.

One of the most studied gravity anomalies of the Canadian Shield, the Nelson River gravity high, occurs near the northwestern boundary of Superior Province with the Trans-Hudson Orogen (Innes, 1960; Wilson and Brisbin, 1962; Green et al., 1979, 1980, 1985a, b; Fountain and Salisbury, 1981). It is parallel or sub-parallel to the edge of Superior Province from Hudson Bay in the northeast to a location beneath the Interior Plains in southern Manitoba. The magnetically defined province margin corresponds to the truncation of the westerly trending gravity fabric, but the Nelson River anomaly itself seems to cut obliquely across the edge of the province. Green et al. (1985a) have suggested that the positive anomaly is a composite of three or more distinct structures generated along the same margin at different times by different boundary processes. Those anomalies overlying the Fox River Belt are caused by mafic/ultramafic dykes of Proterozoic age, those across the Pikwitonei sub-province are sed by granulites, and the anomalies within the eastern eynew Domain and its probable extension to the south caused by Proterozoic gneissic rocks. Together, the er gravity high and the gravity low across the adjacent mpson Belt may constitute a paired gravity anomaly of type described by Gibb and Thomas (1976).

A strong westerly to southerly trending gravity gradient correlates well with the western border of the Trans-Hudson Orogen. The -60mGal contour commonly outlines the border with the Cree Lake zone in the north, and the -80 and -60mGal contours run astride the most probable location of the border with the Wyoming Province in the south.

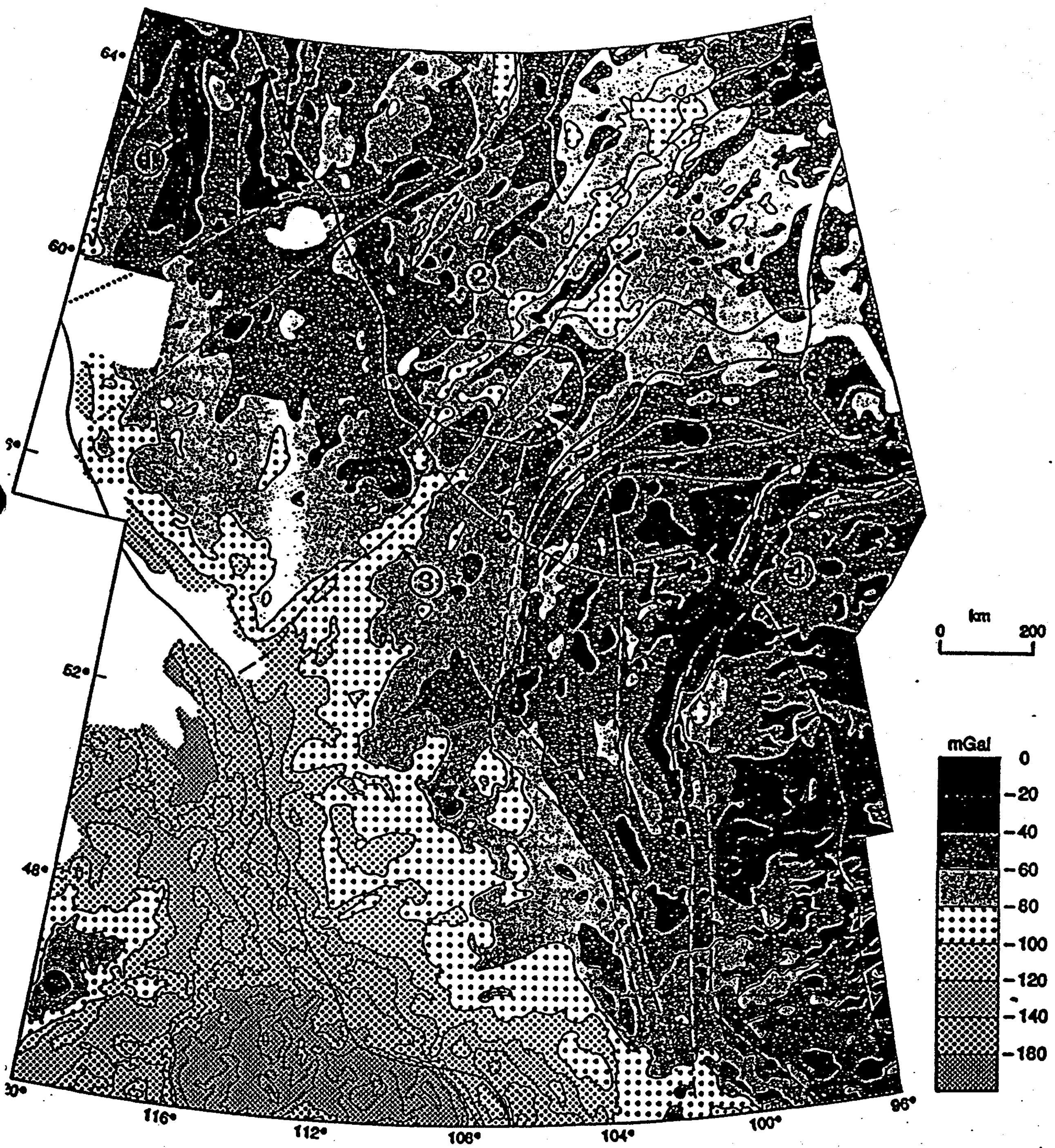


Figure 3.4. Bouguer gravity anomaly map of Western Canada Basin and adjacent areas. Lithotectonic domains of the exposed shield and inferred basement divisions from Figure 3.11 are superimposed. 1 - Bulmer Lake gravity high, 2 - Fond du Lac gravity low, 3 - Kasba Lake-Edmonton gravity low, 4 - Nelson River gravity high

Gravity anomalies within the Northwest Churchill)olymetamorphic terrane and Cree Lake zone strike :outhwesterly. A major belt of linear gravity anomalies)arallels the trend of the Virgin River shear zone and its)roposed southwesterly extension towards the Cordillera Walcott, 1968; Agarwal and Kanasewich, 1968; Wallis, .970; Walcott and Boyd, 1971; Gibb and Halliday, 1974; 3urwash and Culbert, 1976). Included in this belt are :everal gravity highs and the prominent Fond du Lac and Kasba Lake-Edmonton gravity lows (2, 3, Fig. 3.4). The gravity highs are underlain by high-grade metamorphic rocks and mafic/ultramafic intrusions, but the nature of the rocks associated with the gravity lows is largely undetermined because of inadequate outcrop. Walcott (1968) and Gibb and Halliday (1974) have related parts of the Fond du Lac anomaly to exposures of granitic rocks, whereas Wallis (1970) has suggested that the regional gravity lows are related to linear troughs of Proterozoic metasediments.

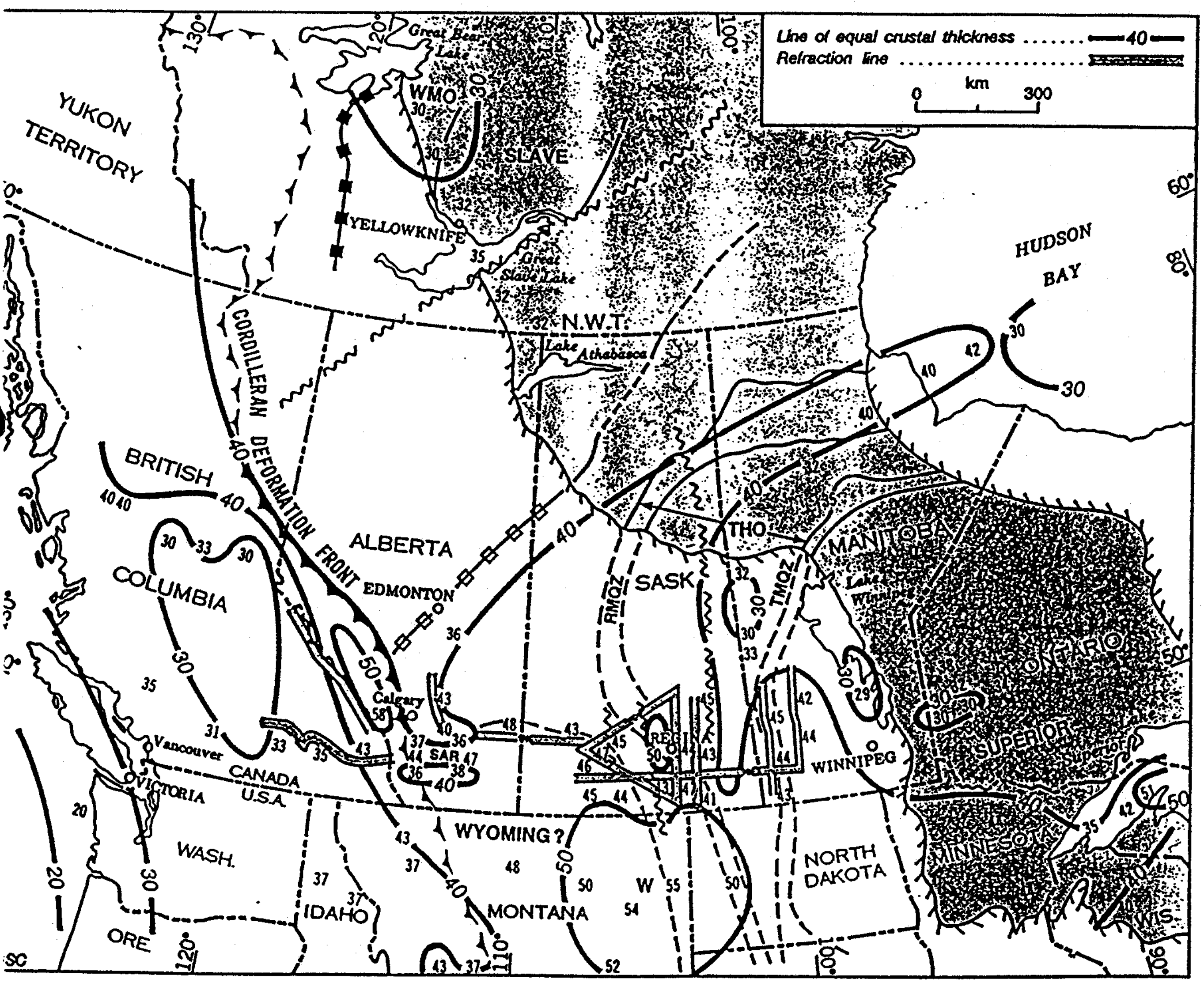


Figure 3.5. Measurements of crustal thickness in kilometres from seismic refraction and reflection studies. Major lithotectonic elements and structures (Fig. 3.11) are indicated. W = Williston basin; WMO = Wopmay Orogen; SAR = Southern Alberta Rift; THO = Trans-Hudson Orogen; RMQZ = Reindeer magnetic quiet zone; TMQZ = Thompson magnetic quiet zone. References for the data are as follows: Asada et al., 1961; Barr, 1971; Bennett et al., 1975; Berry et al., 1971; Berry and Forsyth, 1975; Chandra et al., 1972; Clowes et al., 1984; Congram, 1984; Cumming et al., 1979; DeLandro, 1981; DeLandro et al., 1982; Forsyth et al., 1974; Ganley and Cumming, 1974; Green et al., 1979; Hales and Nation, 1973; Hall and Hajnal, 1969, 1973; Hill and Pakiser, 1967; Johnson and Couch, 1970; Kanasewich, 1966, 1968; Kanasewich and Cumming, 1965; Kanasewich et al., 1985; Kazmierczak, 1980; Macrides and Kanasewich, 1984; Maureau, 1964; Mereu and Hunter, 1969; Mereu et al., 1977; Meyer et al., 1959; Richards and Walker, 1959; Smith et al., 1966; White and Savage, 1965.

Farther to the northwest, the lithotectonic units around ; margins of Slave Province are delineated by a variety gravity anomalies. A gravity low overlies the Thelon nt on its eastern margin and a linear gravity high runs ng the axis of East Arm Fold Belt on its southern urgin. On its western margin, within Wopmay Orogen, ere is a weak paired gravity anomaly adjacent to the iton (Hoffman et al., 1982b) and a stronger positive omaly along the border between the Great Bear igmatic zone and the Hottah terrane. Finally, the gh-amplitude Bulmer Lake gravity high (1, Fig. 3.4) nds southerly near the western edge of Hottah terrane ornal et al., 1970). This anomaly either defines the stern limit of Wopmay Orogen (Meijer Drees, 1975), or presents one-half of a paired gravity anomaly within a ore extensive Wopmay Orogen (Hoffman et al., 1982b).

EEP SEISMIC PROFILES

R. Kanasewich

idies made on the thickness and structure of the itinental crust have been concentrated on the easily essible southern parts of Western Canada. The quality he data is rather uneven and it is being re-interpreted rently at several seismic laboratories. The results resented here will, no doubt, be modified with respect local details, but the broad pattern seems to be well ablished.

The location of the seismic refraction lines and the stal thicknesses are shown in Figure 3.5. The map is ninated by large regions where the continental crust is ; than 40 km thick. Within these areas, significant ts thin to 30 km. These occur within the oldest part of Canadian Shield - Superior and Slave provinces - and part of the Intermontane Belt of southern British umbia. In other areas, such as Williston Basin and the ky Mountains along the continental divide, crustal ckness approaches 55 km. This pattern of crustal ckness variation and the associated data for the ckness of the sedimentary section appears to provide dence for vertical movements over periods of time iging from several million years to over 1 billion years, various basins and arches were formed. A review of the vity anomalies, in conjunction with the seismic evidence inasewich, 1966; Burwash and Krupicka, 1970; Sprenke l Kanasewich, 1983), indicates that the long-term tures have their origin associated with upper mantle isity variations in addition to the horizontal forces ulting from plate interactions. On a shorter time scale, g-wavelength isostatic anomalies in the northeast part he map area indicate overcompensation, due probably incomplete recovery of the lithosphere from the istocene ice sheet. Determination of vertical movement r Williston Basin (U.S. Geodynamics Committee, 1978; icer and Drake, 1982) shows that the area is undergoing ift at rates of 1 to 5 mm per year.

The intracratonic Williston Basin has a well mapped stal thickness approaching 55 km over the basin centre eastern Montana and western North Dakota. Detailed raction studies in southern Saskatchewan disclose aller zones of crustal thickening, up to 50 km. The sidence history of Williston Basin is well documented several thousand well logs. Subsidence has occurred, with interruptions, throughout much of the Phanerozoic Era. Rocks of the Precambrian crystalline basement were eroded extensively prior to the Cambrian, leaving a smooth surface from which 10 km or more of rock had been removed. It is probably significant that, despite this peneplanation, the crust was very thick prior to the Phanerozoic deposition, which added, at most, 5 km of sediment. The cause of epeirogenesis over features such as the Williston, Denver, Michigan, and Illinois basins appears to be related to critical density anomalies, possibly at the lithosphere-asthenosphere boundary in the upper mantle (Kanasewich, 1966), but the dynamic process remains a major enigma at the present time.

Geomagnetic and magnetotelluric studies have indicated the presence of a number of electrical conductivity anomalies in Western Canada. Principal among these is the North American Central Plains (NACP) anomaly (Camfield and Gough, 1977; Alabi et al., 1975). The anomaly is not well defined (Fig. 3.6) because the station spacing is large, seldom under 100 km; towards 54°N latitude it is greater than 250 km. Measurements solely of the magnetic field preclude any depth determination except at a magnetotelluric line at 56.5°N, where Handa and Camfield (1984) placed seven stations. Here one station was over a conductive anomaly, which was

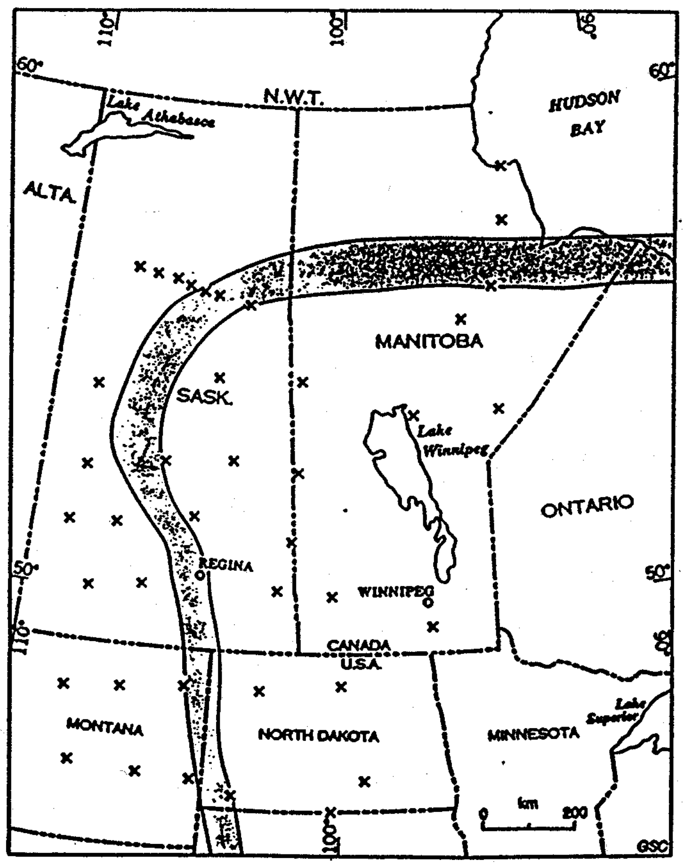


Figure 3.6. Location of the North American Central Plains conductive body (shaded area) and the stations determining its location (from Camfield and Gough, 1977; Handa and Camfield, 1984; Gupta et al., 1985).

modelled to have a resistivity of 10 ohm-metres at crustal depths of 5 to 10 km. A conductive anomaly has been detected between Gillam (56.4°N, 94.7°W) and Back, Manitoba (57.7°N, 94.2°W) near the shore of Hudson Bay (Gupta et al., 1985). However the Gillam-Back conductor is located close to surface exposures of east-trending belts of metasedimentary rocks (Fig. 3.2 and 3.6), whereas the North American Central Plains anomaly is related to more northerly structures. Another conductive zone identified through magnetotelluric studies, distinct from the North American Central Plains anomaly, has been detected by Rankin and Pascal (in press) in southern Saskatchewan at 103°W, east of Weyburn.

Detailed refraction studies near Regina, Saskatchewan support a block-faulted structure in the crystalline basement down to the Mohorovicic discontinuity. Fair evidence exists for a north-striking fault at the level of the Moho at longitude 103° in southern Saskatchewan (Kazmierczak, 1980). Another pair of north-striking faults is indicated on very good seismic broadside refraction data just west of Regina at longitudes 105° and 107°W (Macrides and Kanasewich, 1984; Kanasewich and Chiu, 1985). The fault at 105° coincides with the western edge of the Reindeer magnetic quiet zone (rmqz) and the Trans-Hudson Orogen (see Fig. 3.11) and may correlate with some parts of the North American Central Plains anomaly. Earthquake epicentres along this section (Fig. 3.7) show it to be a tectonically active zone. Another feature of the Regina region that is well established is the presence of one or more low-velocity layers. These occur at depths of 15 to 25 km in southern Saskatchewan. The velocity of the upper mantle at the Moho is between 8.0 and 8.2 km/s in southern Saskatchewan and 7.8 to 8.0 km/s in the Superior Province immediately west of the Nelson Front.

Another area where sufficient detail exists to draw some specific conclusions is in southern Alberta. The buried Cree Lake - Calgary zone is interrupted by an east-west Precambrian rift(?) ("Southern Alberta Aulacogen"), which extends from the Saskatchewan-Alberta border to

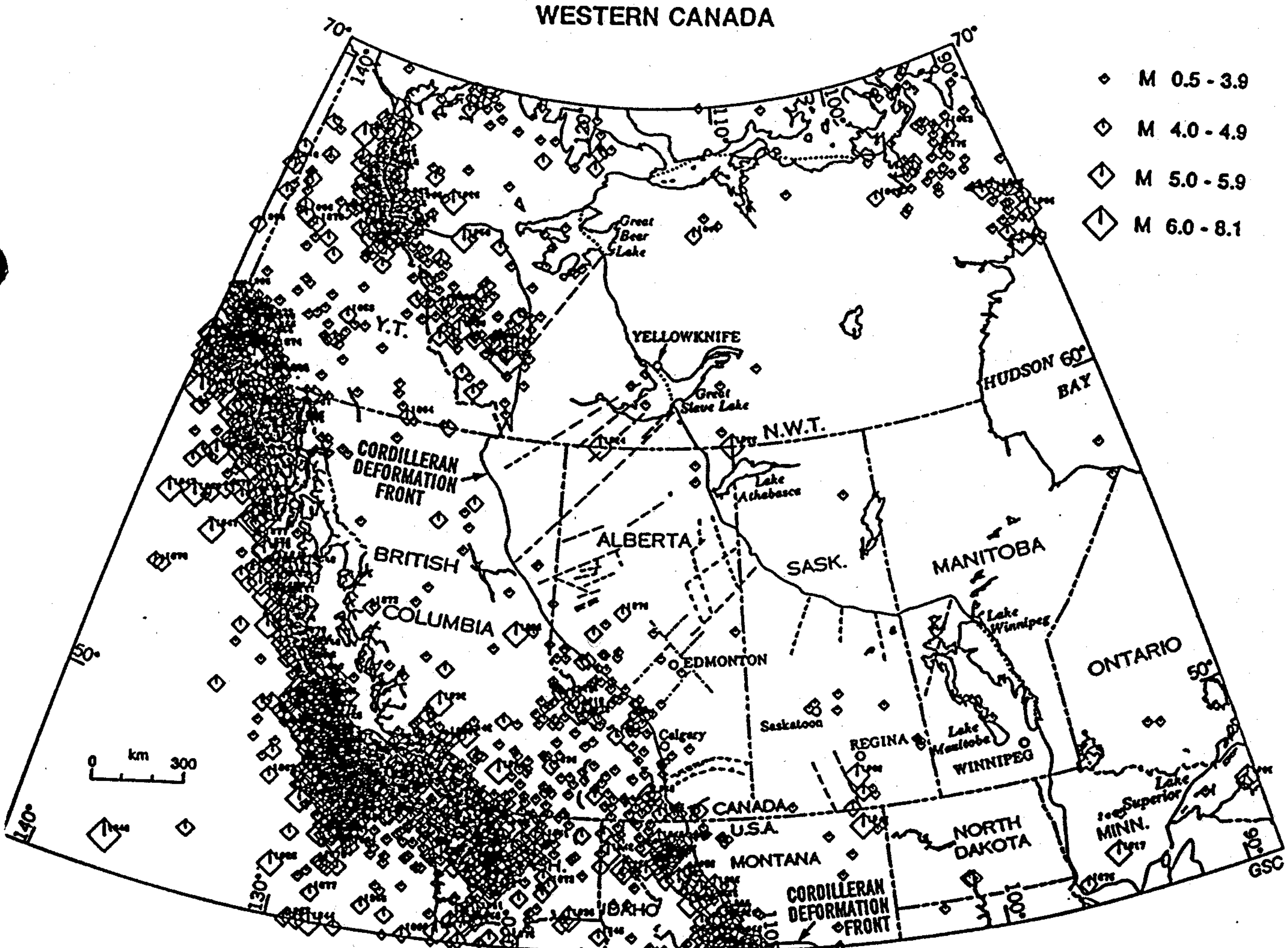


Figure 3.7. Seismic events in relation to known and inferred basement faults. Lineaments from: Aitken and Pugh, 1984; Burwash and Culbert, 1976; Garland and Bower, 1959; Green et al., 1985a; Kanasewich et al., 1968; Meijer Drees, 1975; Robinson et al., 1969; and Williams, 1973.

›erley, British Columbia (Fig. 3.5 and 3.7). The buried ıre has been defined by two seismic reflection lines and ·al refraction studies. The first demonstration that crustal structures in this area could be mapped by the ıic reflection method used a line at 112.6°W, west of ks, Alberta (Kanasewich and Cumming, 1965). The recent line of interest was obtained by Pan Canadian ›leum (Kanasewich et al., 1985). Unlike the earlier .es, which used explosive sources, the new line of data ›btained with a Vibroseis source and common depth ;profiling. The new data are from a 32 km north-south : km east of Vulcan, Alberta, about 100 km west of the :ous line. The results tended to confirm the hypothesis ›rward by Kanasewich (1968) that the feature was a ımbrian rift valley under flat-lying Paleozoic and ›zoic sediments. The Moho changes in depth from 47 : km across a series of east-trending normal faults. ›ugh most of the rifting occurred in Precambrian time, ıew line clearly shows that the rift underwent ›zoic and Mesozoic reactivation. Hoffman (1988) ested that the "rift" either is, or coincides with, an ⁊Proterozoic suture.

he crust thickens westward to over 55 km under the :y Mountains and the Rocky Mountain Trench 3.5). The northern and southern limits of this thick · are unknown, but it is probably confined to the zone ge negative Bouguer gravity anomalies. Anomalously :rust occurs in a northwest-trending domain between)mineca Belt and the Coast Belt of southern British ımbia. This domain corresponds to the southern parts ə allochthonous Stikinia and Cache Creek terranes of ;er and Price (1979). Numerous seismic determinations e Basin and Range province of the United States also crustal thicknesses of 30 km and similar low upper tle compressional velocities of 7.7 to 7.9 km/s. ısewich (1966) pointed out that the anomalous seismic nesses and velocities in central British Columbia are ıbly related to an extension of the East Pacific Rise, eanic spreading centre that enters the continent in the of California. Recent deep crustal seismic reflection from project Lithoprobe suggest that Precambrian nent may extend westward as far as the zone of crustal ısion.

›AT FLOW

. Jessop

ı all sedimentary covers where water may move ıgh permeable formations, the temperature field of the ern Canada Basin is controlled by a combination of nal conductivity and mass transport. The flow of r is driven mainly by the pronounced topographic head :ded by the Rocky Mountains, with more local effects . scales superimposed. Thus the flow pattern and the :ting temperature field are very complex.

emperature data are available from the extensive on oil and gas wells that are kept by the provincial rnments. These data are individually of doubtful ity, but have been interpreted jointly by statistical ›ods to derive isotherms and temperature gradients over a wide area. Thermal conductivity is more difficult to determine, but a knowledge of typical conductivity for each rock type, combined with an analysis of the "net rock" content of each interval, provides a reasonable approximation.

A strong contrast in heat flow between Paleozoic and Mesozoic strata has been observed (Majorowicz et al., 1985; Fig. 3.8). Above the Paleozoic-Mesozoic boundary, heat flow tends to increase from the Rocky Mountains toward the exposed Canadian Shield, while below the boundary the opposite effect is observed. A great deal of local variation is superimposed on these general trends, much of which may be related to surface topography (Hitchon, 1984). In the upper part of the sediments, low temperature gradient tends to coincide with the recharge zones of relatively high land, and high gradient tends to coincide with the valleys. There is a zone of equality of heat flow between Paleozoic and Mesozoic strata; it is sinuous, but follows approximately the 2000 m isopach. This is shown as a line on Figure 3.8, but this is an approximation, and it would be preferable to think of it as a belt winding across the map. The value of heat flow in this zone is regarded as the best available estimate of the true terrestrial heat flow.

Temperature gradient or heat flow in the Precambrian basement beneath the basin is regarded as the only true test of the crustal heat flow, but measurements are lacking. The heat input to the sediments comes from the Precambrian basement, with a distribution that depends on the nature of the cratonic rocks. Some measurements of heat generation of rocks just below the interface have been made (Burwash and Cumming, 1976), but the data are sparse and unevenly distributed. The age of the Precambrian provinces is generally known, and it is possible to estimate the heat flow from averages in the exposed part of the Canadian Shield to the northwest, but the detail cannot be derived in this way. Some heat is absorbed in the chemical transformation of large hydrocarbon molecules to small ones, but this is negligible. It may thus be assumed that all heat entering the sediments from the basement eventually reaches the surface as conducted heat flow or as warm springs on the outcrops of the permeable formations.

At Regina, Saskatchewan, where a detailed and accurate temperature log is available and measurements of conductivity on the well cuttings have been made, there is evidence of upward water migration across the Mesozoic formations, a substantial change in heat flow from Mesozoic to Paleozoic strata, and downward water flow between individual units of the lowermost two formations (Jessop and Vigrass, 1989). A decline of heat flow from 75 mW/m^2 at 300 m to 51 mW/m^2 at 950 m implies an upward water flow of about 8 mm per year in this depth range. The horizontal component is not determined by this analysis, and it is probably varied and dependent on the nature of the strata, which are mainly clastic. In the Paleozoic section the heat flow is uniform at 51 mW/m^2, but there is a major aquifer system in the basal clastic unit, a zone of over 100 m of sandstone, and it cannot be assumed that heat flow in the Paleozoic strata represents heat flow in the Precambrian basement.

EOCHRONOLOGY

.A. Burwash

reconnaissance program of K-Ar isotopic age :terminations on whole-rock samples of basement cores om the Western Canada Basin was started in 1954. A :crease in apparent age toward the west (Shillibeer and urwash, 1956; Burwash, 1957) can be attributed to argon ss during Mesozoic crustal loading and Cordilleran ctonism. Subsequent K-Ar dating of biotite, muscovite, ıd hornblende mineral separates (Fig. 3.9) confirmed that l of the basin except southern Manitoba was affected by udsonian metamorphism between 1.6 and 1.9 Ga Burwash et al., 1962; Peterman, 1962). Apparent ages etween 2.03 and 2.18 Ga for three hornblende samples ere inferred to be "survival values" from Archean ystallization (Burwash et al., 1964). Scattered K-Ar iotite ages of less than 1.6 Ga were generally revised pward by later work (Peterman and Hedge, 1964). Biotite ad hornblende separates from two diabase cores near the est side of the basin are dated as Middle Proterozoic.

Data from U-Pb isotopic analyses of zircon separates and Rb-Sr, Nd-Sm, or Pb-Pb analyses of whole-rock samples are available from only a few widely separated basement cores in the Western Canada Basin (Fig. 3.9). The peak of igneous and metamorphic activity during Early Proterozoic time occurred between 1.8 and 1.9 Ga, with a few early events pre-dating 1.9 Ga. A Late Archean (2.44 Ga) granulite facies event is documented at the edge of the basin in northeastern Alberta by a whole-rock Sm-Nd isochron (Burwash et al., 1985). Sialic crust with an age of approximately 2.9 Ga is indicated by U-Pb dating of zircons from two northwestern North Dakota localities (Peterman and Goldich, 1982); these sample localities lie within the Trans-Hudson Orogen. Eight core samples from southwestern Saskatchewan and adjacent Alberta give an average Sm-Nd crustal residence age of 2.81 Ga (Frost and Burwash, 1986). The geological relationship between the North Dakota and southwest Saskatchewan Archean terranes has not been established.

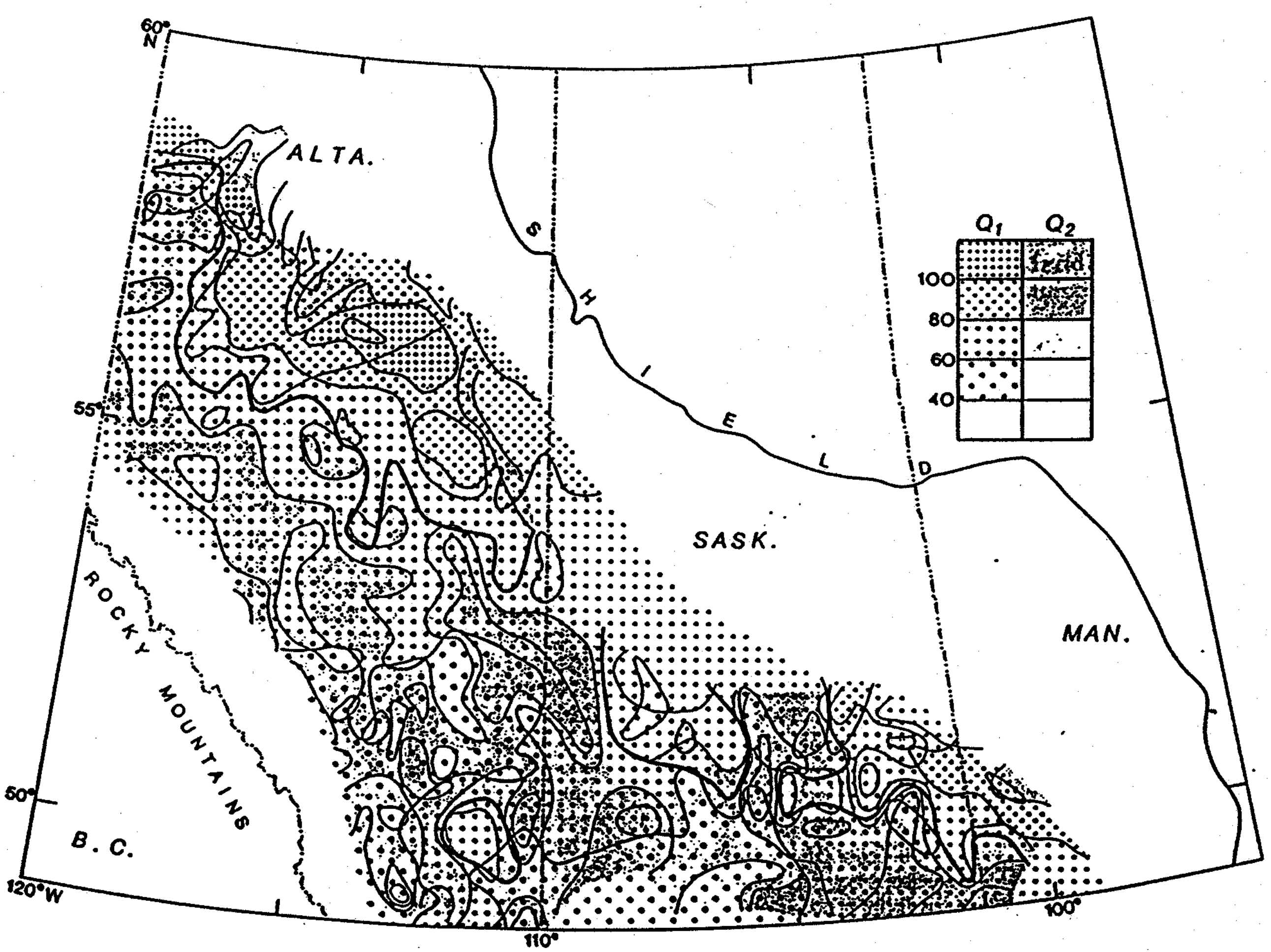


Figure 3.8. Heat flow patterns in the Western Canada Basin. Q1 - heatflow below the Paleozoic-Mesozoic boundary; Q2 - above the boundary.

ITHOSTRUCTURAL DOMAINS OF THE URIED SHIELD

A. Burwash

orthern Interior Plains

ıe Great Bear-Great Slave Plains are bounded on the east ·four major lithotectonic units of the Canadian Shield: mundsen Basin, Wopmay Orogen, Slave Province, and ast Arm Fold Belt. The adjacent units to the west are the ackenzie Fold Belt and the Northern Rocky Mountains)ouglas and Price, 1972). A series of northeast-trending ults and north-trending geophysical anomalies define ve terranes (see Fig. 3.11) underlying the Paleozoic cover.

North of the Fort Norman structure (see Fig. 3.11), rmations of the Upper Proterozoic Mackenzie ountains Supergroup flank the northwest-trending reat Bear Arch (Aitken and Pugh, 1984). Bevelling of ıese formations at the basal Paleozoic unconformity ıggests uplift of Great Bear Arch prior to Cambrian dimentation. The adjacent segment of the arcuate (ackenzie Arch is structurally concordant with Great ear Arch. The Mackenzie Mountains Supergroup is quivalent to the Rae Group in the northward-dipping mundsen Basin (Aitken and Pugh, 1984).

Between the Fort Norman structure and the Leith Ridge fault (Fig. 3.11), formations of the Hornby Bay (1.7-1.2 Ga) and Dismal Lakes groups constitute the Leith Ridge Domain, a southwestward subsurface extension of the Amundsen Basin at the Paleozoic subcrop (Aitken and Pugh, 1984). An estimated 2 km of downfaulted Middle Proterozoic strata are preserved north of the fault beneath Great Bear Lake (McGrath and Hildebrand, 1984).

The region south of the Leith Ridge fault is characterized by three major geophysical anomalies, the Great Bear magnetic high and the Bulmer Lake gravity high (see Fig. 3.3, 3.4, 3.11), and west of them, the Fort Simpson magnetic high (Fig. 3.3). The Great Bear magnetic high can be traced from the thoroughly studied Great Bear magmatic arc (see Fig. 3.11; WMO-2) (Hoffman and Bowring, 1984; Hildebrand and Bowring, 1984) south toward the Great Slave Lake Shear Zone. The intrusion of numerous mesozonal and epizonal plutons into a 100 km wide belt of thick volcanic units has produced a distinctive magnetic domain. The Hepburn belt to the east (WMO-3) and Hottah terrane to the west (WMO-1) are matched by magnetic lows. Between 120° and 122°W, a gravity high, 75 by 400 km with a relief of up to 50 mGal, can be traced from the Leith Ridge fault (LRF) to the northern margin of the Liard Block (Fig. 3.11), where it is abruptly truncated.

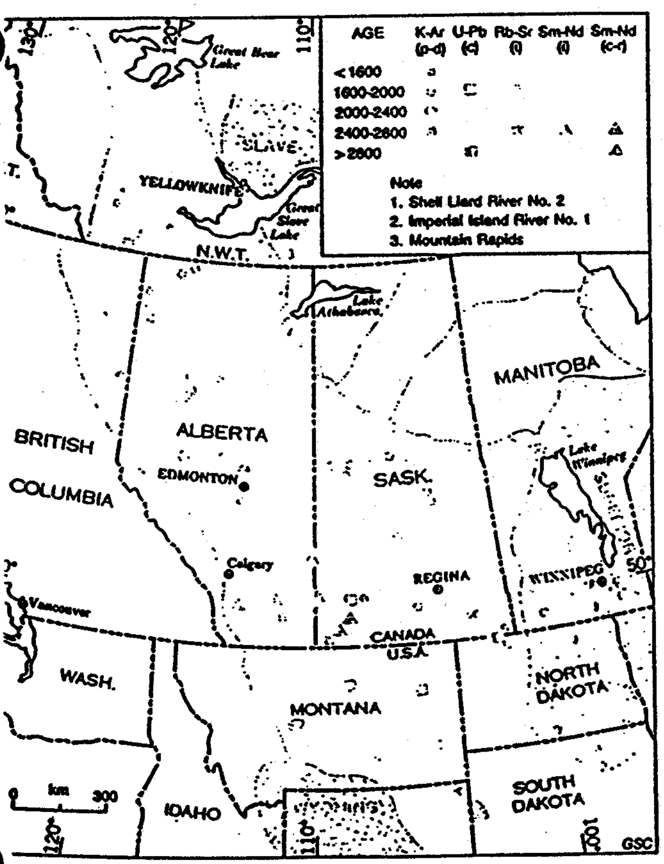


Figure 3.9. Dated basement localities in Western Canada Basin.

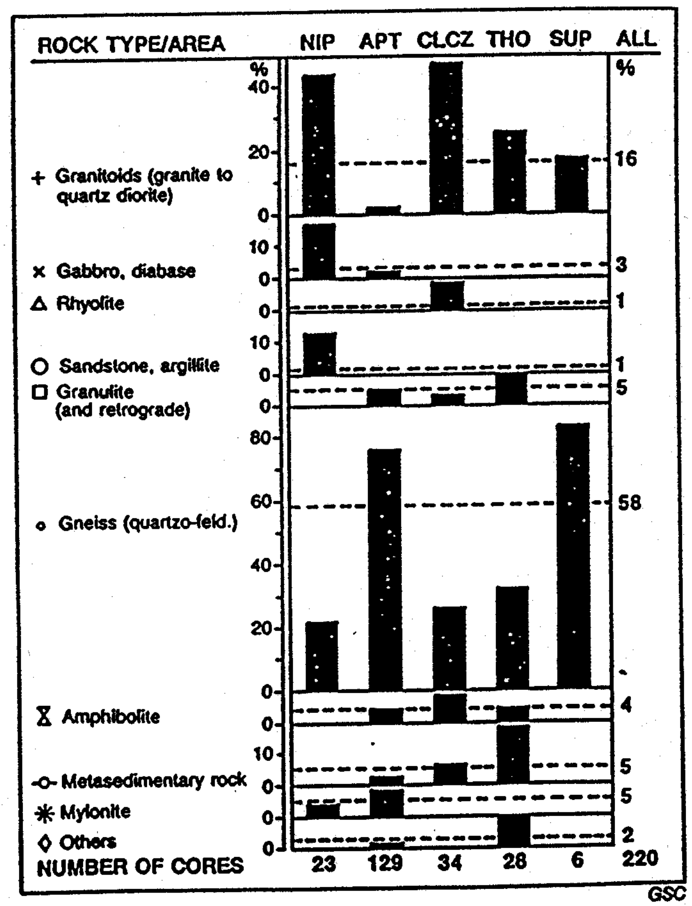
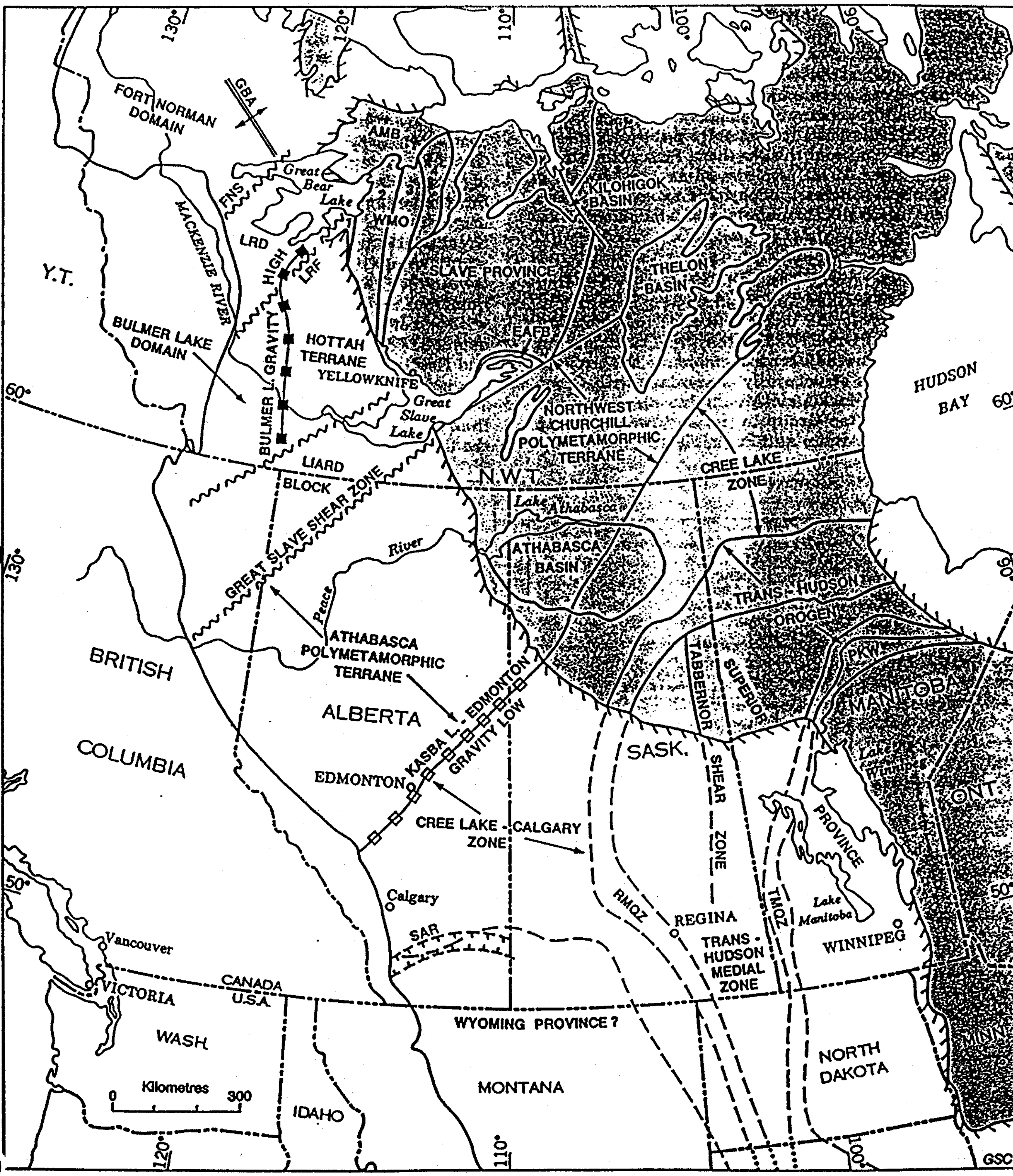


Figure 3.10. Comparative petrography of the lithostructural units of the buried shield. NIP - Northern Interior Plains; CLCZ - Cree Lake-Calgary Zone; THO - Trans-Hudson Orogen; SUP - Superior Province


FORT NORMAN DOMAIN
GBA
Great Bear Lake
FNS
AMB
WMO
LRD
LRF
MACKENZIE RIVER
Y.T.
BULMER L. GRAVITY HIGH
BULMER LAKE DOMAIN
HOTTAH TERRANE
YELLOWKNIFE
Great Slave Lake
SLAVE PROVINCE
KILOHIGOK BASIN
THELON BASIN
EAFB
NORTHWEST CHURCHILL POLYMETAMORPHIC TERRANE
HUDSON BAY
LIARD BLOCK
GREAT SLAVE SHEAR ZONE
N.W.T.
CREE LAKE ZONE
Lake Athabasca
ATHABASCA BASIN
Peace River
ATHABASCA POLYMETAMORPHIC TERRANE
TRANS - HUDSON OROGEN
PKW
MANITOBA
BRITISH COLUMBIA
ALBERTA
KASBA L. - EDMONTON GRAVITY LOW
EDMONTON
TABBERNOR SHEAR ZONE
SUPERIOR PROVINCE
SASK.
Lake Winnipeg
ONT.
CREE LAKE ZONE
CALGARY
Calgary
RMOZ
REGINA
TMOZ
Lake Manitoba
WINNIPEG
TRANS - HUDSON MEDIAL ZONE
Vancouver
VICTORIA
SAR
CANADA
U.S.A.
WYOMING PROVINCE ?
WASH.
MONTANA
IDAHO
NORTH DAKOTA
MINN.
Kilometres
0
300
130°
120°
110°
100°
90°
60°
50°
GSC

; Bulmer Lake gravity high coincides, in part, with a ıgraphic ridge of westward-dipping Middle Proterozoic .ta (Meijer Drees, 1975). Core samples from basement ls adjacent to the topographic high are diabase, gesting that basic sills may be intercalated with the terozoic strata. Shell Liard River No. 2 (Fig. 3.9; . 1), a projected 3500 m "basement test", encountered terozoic formations at a depth of 400 m. The lower m of this hole were in uralitic diabase, which gave a ır age (biotite) of 1100 Ma. These data support ijer Drees' (1975) interpretation of the eastern ndary of the Bulmer Lake gravity anomaly as the ıthward extension of the boundary between the pmay subprovince and the Coppermine homocline of the ır Province". Hoffman (1987, 1988), on the other hand, gested that the magnetic high may be a buried suture ween Wopmay Orogen and a magmatic arc to the west, resented by the magnetic high. East of the Bulmer Lake h, Cambrian strata lie directly on a gneissic basement, southward extension of Hottah terrane.

The Liard Block (Burwash and Krupicka, 1970) is a ıtward extension of the East Arm Fold Belt; however, fold belt occupies only a fraction of the total length of a ıplex fault system, which has remained tectonically ive for almost 2 Ga. The Slave-Chantry mylonite zone ıywood and Schau, 1978) extends the Great Slave Lake ear Zone northeastward to the Arctic Ocean at the base he Boothia Peninsula. The aeromagnetic data of Coles al. (1976) indicate that the zone extends across the erior Plains to the Cordillera. Deflections of gravity, gnetic, and metamorphic trends toward the fault zone licate dextral transcurrent movement. A seismic profile ɔss the zone (Barr, 1971) indicates crustal thickening on ; order of 4 km under the fold belt. Coles et al. (1976) ggested that the intense magnetic high east of the Thelon ɔnt may match a similar magnetic high south of ıcdonald Fault at 114°W. If this interpretation is rect, dextral displacement across the entire fault system uld be of the order of 300 km. Tectonic slices of the Slave ıton occur in East Arm Fold Belt (Burwash and adsgaard, 1962). Farther to the west, fault slices or ɔad arches of crystalline basement related to Wopmay ogen are to be anticipated. Biotite granodiorite from .perial Island River No. 1 (Loc. 2, Fig. 3.8) has been dated at 1860 ± 10 Ma (U-Pb on zircon) by S.A. Bowring (cited by Parrish in Geology of Canada, no.7, Hoffman et al., in prep.). The biotite has been chloritized and gives a K-Ar date of 850 Ma (R.A. Burwash, unpub.). The Island River well lies near the Rabbit fault, one of the multiple branches of the Great Slave fault system (Williams, 1981). Argon loss from biotite during one of the recurrent movements of the fault system could explain the discordant U-Pb and K-Ar ages. Alternatively, a post-Hudsonian regional thermal event might be involved.

Along the western edge of the Interior Plains, a series of major magnetic highs was mapped by Coles et al. (1976). This belt of anomalies extends almost continuously from the Alaska-Yukon boundary at 66°N as a great arc following the tectonic arc, reverses curvature in northeastern British Columbia and extends into western Alberta as far south as 55°N. Coles et al. (1976) suggested that this major magnetic feature may be related to thermal enhancement of magnetic susceptibility in the crystalline basement as a result of high heat flow in the eastern Cordillera at the present time. Hoffman and Bowring (1984) and Hoffman (1987, 1988) link part of this magnetic high (Fort Simpson) to a magmatic arc during a continental collision at 1.8 to 1.9 Ga. If a dextral displacement of the order of 300 km occurred across the Great Slave fault system during a late stage of Hudsonian Orogeny, the southward extension of Wopmay Orogen would be offset 300 km west as it crossed the shear zone. The arcuate pattern of the magnetic anomalies thus may reflect either the metamorphic fabric of the buried Hudsonian crystalline basement or the imposition of present-day reheating on an old metamorphic welt.

Athabasca polymetamorphic terrane

The Athabasca polymetamorphic terrane was described by Burwash and Culbert (1976) as the Athabasca mobile zone. It is the subsurface equivalent of the northwestern zone of Churchill Province (Davidson, 1972). An important characteristic of this zone is the occurrence of numerous relict belts of metamorphic rocks of granulite facies (Fraser et al., 1978).

In establishing the boundaries of Churchill Province, Stockwell (1963) used the criterion of the last period of regional metamorphism, indicated by K-Ar age determinations mainly on biotite. He was aware that older crustal blocks were incorporated in the Churchill Province. In northwest Saskatchewan, a period of granulite-facies metamorphism, circa 2.4 Ga, was documented by Koster and Baadsgaard (1970), using K-Ar ages of hornblende. The granulites were overprinted by lower-grade Hudsonian events at 1.8 to 1.9 Ga. At Hill Island Lake, 200 km to the northeast, a granulite dome shows a histogram peak at 2450 Ma for K-Ar hornblende ages and a separate peak at 2200 Ma for biotite ages (Banks, 1980).

A comprehensive program of geological mapping, Rb-Sr and K-Ar geochronology, and structural studies in northeastern Alberta (Godfrey and Langenberg, 1978; Nielsen et al., 1981; Langenberg, 1983) established Kenoran and Hudsonian events with different P-T fields and different tectonic styles. Burwash et al. (1985) dated mafic granulites at Mountain Rapids on the Slave River (Loc. 3, Fig. 3.9) just south of 60°. A Sm-Nd isochron of 2436 ± 44 Ma is interpreted as the time of granulite

ɪure 3.11. The Precambrian basement of Western Canada ɪsin.

hostructural domains of the buried Shield: LRD = Leith ɪge Domain; RMQZ = Reindeer Magnetic Quiet Zone; ɪQZ = Thompson Magnetic Quiet Zone.

ructural features: GBA = Great Bear Arch; FNS = Fort ɪman structure; LRF = Leith Ridge fault; SAR = Southern erta Rift.

thostructural Domains of the exposed Shield: ɪMB = Amundsen Basin; WMO = Wopmay Orogen ubdivisions: 1 = Hottah Terrane; 2 = Great Bear Magnetic c; 3 = Hepburn batholithic belt; 4 = Foreland Belts); ɪFB = East Arm Fold Belt; PKW = Pikwitonei sub-Province ıetamorphism in this terrane. Aliquots of the same ;amples give a Rb-Sr isochron of 1898 ± 5 Ma, the time of :he Hudsonian overprint.

Direct evidence for granulite-facies metamorphism in he basement is found in ten drill cores (Fig. 3.2), six of vhich are in the Athabasca polymetamorphic terrane. ǝeochronological evidence for Archean crust in this belt is ;iven by K-Ar hornblende survival values in excess of :.0 Ga in three other wells (Fig. 3.9).

The fabric of the domains that form the Athabasca netamorphic terrane is shown by multivariate trend urface analysis of mineralogical, chemical, and textural lata (Burwash and Culbert, 1976). The three strongest t-mode factors, K-metasomatism, chloritization, and hearing, have trends between N10°W and N35°W. The hloritization factor is negative along the axis of greatest <-metasomatism. All trends terminate near the north and outh boundaries of the Athabasca polymetamorphic errane. Polynomial fitting of the data shows that along he axis of the Peace River Arch K-metasomatism extends to he western limit of drillhole sampling, confirming an earlier etrographic evaluation (Burwash and Krupicka, 1970).

Near the western limit of the northwest Churchill olymetamorphic terrane, a direct relationship is observed etween the north-trending Fort Smith radiometric high Charbonneau, 1980), a megacrystic microcline granite 3ostock, 1981), and a broad aeromagnetic low. These rends are all deflected into the Great Slave Shear Zone 3urwash and Cape, 1981). Analysis of the magnetic fabric f northeastern Alberta (Sprenke et al., 1986) gave a ıagnetic autocorrelogram with the major axis N10°E. his fabric can be traced southward to the boundary of the thabasca polymetamorphic terrane, where it is abruptly :uncated (Garland and Bower, 1959).

In 1970, Wallis recognized the Virgin River shear one (11, Fig. 3.2) on the basis of a mylonite belt, levated rhomboidal granulite blocks with dimensions of ıe order of 50 by 100 km, and infolded belts of Lower roterozoic metasedimentary rocks. The granulite locks are generally matched by positive gravity nomalies (Walcott, 1968), whereas the amphibolite-icies metasedimentary belts are gravity lows. There is ıarked aeromagnetic relief over the granulite fault locks. Converging with the Virgin River shear zone ear the Alberta-Saskatchewan boundary is the ominant negative gravity anomaly of Saskatchewan, ıe Fond du Lac low of Walcott (1968; here called the asba Lake-Edmonton gravity low), which can be traced outhwestward to the Rocky Mountains (Walcott and oyd, 1971). Along this gravity low occurs a series of uranium-ch granites, which Burwash (1979) interpreted as the roduct of anatexis along a major shear zone.

A combined geophysical-geological study of the recambrian basement beneath central Alberta by arland and Burwash (1959) suggested a significant ıange in lithology just north of Edmonton. The Kasba ake-Edmonton gravity low (Fig. 3.11), as defined by urwash and Culbert (1976), remains the best documented ıoice of a southern boundary for the northwest Churchill olymetamorphic terrane and the Athabasca poly-etamorphic terrane.

Cree Lake – Calgary Zone

The reactivated Archean basement and its infolded cover as mapped on the exposed Canadian Shield can be traced into the subsurface by several persistent magnetic anomalies. Magnetite-bearing meta-arkose in the Virgin River Fold Belt (12, Fig. 3.2) has been interpreted by Wallis (1970) as the product of low- to medium-grade metamorphism of Lower Proterozoic sediments deposited in a fault trough, 15 to 50 km wide, which cuts across gneisses of granulite facies. Some of the magnetite-bearing horizons contain up to 45% iron. In the Wollaston Fold Belt, cordierite-garnet-magnetite gneisses underlie part of the broad aeromagnetic high that flanks the northwest side of the Wathaman Batholith. On the map of Coles et al. (1976), the Virgin River magnetic lineament can be extended southwestward to the Rocky Mountain Trench. The arcuate Wollaston aeromagnetic trend apparently terminates near 52°N, 108°W.

The lithologic assemblages of the Cree Lake-Calgary Zone (Fig. 3.11) in outcrop do not match those in drill cores from its subsurface extension. The Mudjatik domain (13, Fig. 3.2) appears to be eroded to the katazone, while its flanks record shallower crustal levels. Post-Hudsonian erosion of the western part of the Cree Lake-Calgary Zone to the mesozone could explain the relative abundance of unfoliated granites in the core samples (Fig. 3.2, 3.10) and the preservation of rhyolites in east-central Alberta and southwestern Saskatchewan. The accumulation of helium in basal Paleozoic sandstones above a rhyolite basement high near Swift Current, Saskatchewan, is attributed by Burwash and Cumming (1974) to a subjacent uranium-rich epizonal granitic pluton. The age of this pluton, 1.81 Ga (Rosholt et al., 1970), is late Hudsonian.

Archean basement in the Wollaston Fold Belt (Fig. 3.2), initially recognized on the basis of petrological and structural evidence (Money et al., 1970), was later confirmed by geochronology (Bell and Macdonald, 1982). The single subsurface sample of granulite facies from the Cree Lake-Calgary Zone lies along strike from an Archean charnockite complex in the Wollaston Fold Belt.

Hudsonian thermal overprinting of almost all rock units in the Cree Lake-Calgary Zone was indicated by K-Ar dating in the 1960s (Burwash et al., 1962; Wanless, 1970). K-Ar dates from biotite, hornblende, and muscovite from cores in this zone fall mainly between 1.7 and 1.8 Ga, the time of post-orogenic uplift and stabilization (Fig. 3.9). Sm-Nd isotopic analyses of eight core samples from southern Alberta and southwestern Saskatchewan give Archean crustal residence ages at all localities (Frost and Burwash, 1986). These values represent the time of separation of crust from mantle, and suggest that in the area sampled there is limited juvenile Proterozoic sial in the Cree Lake-Calgary Zone.

Trans-Hudson Orogen

In northern Saskatchewan and Manitoba the Trans-Hudson Orogen (Fig. 3.11) consists of a number of sub-parallel and generally arcuate lithotectonic domains (Lewry, 1981; Fumerton et al., 1984; Green et al., 1985a). The Wathaman-Chipewyan Batholith is a relatively homogenous body of negacrystic granite-granodiorite. It has no comagmatic arly mafic phases and shows no evidence of multiple ıtrusions. If numerous smaller plutons are included, the omposite batholithic belt is 900 km long. By analogy with Iesozoic Pacific rim belts of similar dimensions, Fumerton t al. (1984) interpreted the Wathaman-Chipewyan atholith to be the product of plate collision.

An arcuate positive magnetic anomaly, 900 km long nd up to 100 km wide, corresponds spatially with the orthern region of the Wathaman Batholith and the astern margin of the Wollaston Fold Belt. A linear belt of nagnetic lows, which corresponds mainly to the eindeer-Southern Indian belt (Green et al., 1985a), arallels the magnetic highs. The Reindeer magnetic quiet one (RMQZ) is particularly well defined between 56°N and 2°N (Fig. 3.11). South of 52°N, the pattern of negative nagnetic anomalies increases in width and becomes regular. However, using the trends of the -60 mGal ouguer anomaly contour and the North American Central lains anomaly as corroborative data, the Reindeer nagnetic quiet zone can be traced southward to 45°N, here it loses its identity. Beneath the Interior Plains the estern margin of the Reindeer magnetic quiet zone has een chosen as the nominal boundary of the Trans-Hudson rogen.

In contrast to the Athabasca polymetamorphic terrane ıd the Cree Lake-Calgary Zone, the Trans-Hudson rogen contains only limited evidence of Archean sialic rust. The Hansen Lake block (19, Fig. 3.2), a orth-trending 30 by 70 km terrane west of the Flin Flon anite-greenstone Belt, contains granulites dated at 4 Ga. The geological history of the adjacent Glennie Lake omain (18, Fig. 3.2) is complex. Lewry (1981) suggested ıat it was an Archean or Early Proterozoic icrocontinent. Alternatively, it may be an older asement underlying adjacent Proterozoic terranes (Green al., 1985a).

Basement core samples from the Trans-Hudson Orogen ig. 3.2 and 3.10), although limited in number, suggest veral differences from the Cree Lake-Calgary Zone. If ur wells in northwestern North Dakota are included, ere is evidence that granulite occurs in several areas. otopic ages of the North Dakota granulites are Archean 'eterman and Goldich, 1982). Z.E. Peterman ers. comm., 1983) suggested that "a major high-grade rrane may exist beneath the Williston Basin that mprises reworked Archean rocks."

Five drillholes in east-central Saskatchewan enetrated detrital sedimentary rocks (Fig. 3.2). Cores ken near Nipawin are metamorphosed banded on-formation. Laminations on a scale of several illimetres show enrichment in either magnetite, quartz, biotite. In the absence of documented metavolcanic cks from this area, the Nipawin banded iron-formation ıd associated biotite schists are interpreted as a local dimentary basin rather than a volcanic arc. Direct idence of Early Proterozoic volcanism is limited in ailable samples to one amphibolite core on strike with e La Ronge Belt (15, Fig. 3.2) and one metavolcanic (?) e in southwestern Manitoba.

No petrological evidence was found in basement core mples to document a suture zone. If the Superior oundary zone" is removed from the Trans-Hudson Orogen, the width of the orogen is reduced to the order of 100 km south of 50°N. Within this belt the sparsely distributed core samples are of granitic and gneissic rocks of Hudsonian age. This suggests that the east-west and north-south trending parts of the orogen must be of different fundamental character.

Superior Province

The Churchill-Superior boundary in northern Manitoba has been one of the most controversial tectonic zones in Canada (Bell, 1971b; Green et al., 1979). Because of sparse outcrop along the "nickel belt", exploration for nickel deposits near Thompson relied heavily on geophysical surveys (Zurbrigg, 1963). Linear gravity and magnetic features, in conjunction with seismic, magnetotelluric, and geochronological data, have since been used to define the Superior boundary zone (Green et al., 1985).

The most obvious anomaly associated with the boundary zone is the arcuate Nelson River gravity high (Fig. 3.4), which extends 900 km from northeastern to southwestern Manitoba. On the exposed Canadian Shield it coincides with the Archean granulite-facies gneisses of the Pikwitonei sub-province (Fig. 3.11; Weber and Scoates, 1978). The granulites have a distinctive, short-wavelength "bird's-eye maple" magnetic pattern. The northwest edge of the Pikwitonei sub-province belt has been overprinted in the Thompson structural belt by Hudsonian amphibolite-facies metamorphism, which produced a magnetic quiet zone (Green et al., 1979). The Thompson magnetic quiet zone (TMQZ), (Fig. 3.11) is slightly discordant to the gravity high, the two crossing near 54°N, 99°W.

The eastern margin of the Thompson magnetic quiet zone has been chosen as the limit of the Trans-Hudson Orogen for several reasons. On the exposed Shield it corresponds quite well to the boundary based on isotopic age determinations (Kornik and MacLaren, 1966). In the subsurface it can be traced to 45°N along a series of negative magnetic anomalies. The Thompson belt of northern Manitoba and its subsurface extension are classified as reworked Archean foreland.

The pattern of alternating belts of granite-greenstone and high-grade gneiss, which characterize the western Superior Province (Hoffman et al., 1982a), well shown on the map of metamorphic facies of the Canadian Shield (Fraser et al., 1978), can be recognized clearly on the magnetic anomaly map (Fig. 3.3). A general correlation of magnetic lows with metasedimentary and metavolcanic rocks of low metamorphic grade was observed by MacLaren and Charbonneau (1968). Variation in metamorphic grade from the centre to the edge of steeply dipping greenstone belts (Ayres, 1978), combined with faults bounding the supracrustal sequences, enhance the magnetic lineaments.

The east-trending magnetic fabric of Superior craton is sharply truncated by the Thompson magnetic quiet zone. The Hudsonian amphibolite facies overprint of the pattern of Kenoran regional metamorphism has apparently reduced the contrast in magnetic susceptibility between the various lithotectonic belts. Since the Thompson magnetic quiet zone is essentially the metamorphic front of the Trans-Hudson Orogen, relict Archean isotopic ages can be expected to occur west of the zone.

The number of drill cores available from the subsurface xtension of Superior Province is inadequate to form a tatistically valid petrological sample population ig. 3.10). The only supracrustal rock that might epresent an Archean greenstone belt, an altered ieta-rhyolite(?), occurs in the Thompson magnetic uiet zone near 50°N. Peterman (1962) compared the recambrian basement rock types of Superior and hurchill (structural) provinces in Saskatchewan and lanitoba by plotting modal quartz-K-feldspar-lagioclase for all available cores of silicic plutonic ocks. K-Ar dated rocks from the adjacent exposed anadian Shield were used to augment this sample opulation. He inferred that the plutons of Superior rovince were predominantly granodiorite, while those f the Churchill were quartz monzonite or granite. This onclusion anticipated the use of K:Na ratios in istinguishing Archean from Proterozoic crust (Eade nd Fahrig, 1971; Burwash and Krupicka, 1969).

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ADDENDUM

The Glennie Domain of north central Saskatchewan, identified in Figure 3.2 by question marks, is now inferred to be underlain by Archean basement (Bickford et al., 1988), with ages around 2.5 Ga. Lower Proterozoic cover rocks were thrust over the basement during the Hudsonian Orogeny. Basement rocks of the Glennie Domain are interpreted to be the northwestern edge of the Superior craton. The width of the adjacent Trans-Hudson Orogen is thus reduced from that shown in Figure 3.11.

The various identifiable units of the Precambrian basement beneath the Western Canada Basin have recently been more sharply delineated than was possible at the time of writing, thanks to the aeromagnetic data recently made available by various petroleum exploration companies (Ross et al., 1991).

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EXPLORATION FOR DIAMONDIFEROUS KIMBERLITES & LAMPROITES

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ABSTRACT

Diamonds are recovered mainly from kimberlites and to a lesser extent from lamproites. They occur as xenocrysts brought up from the mantle by kimberlites or lamproites. Of more than 2,000 known kimberlites only about 50 have been economic and of these only about 15 have been major producers. Only one economic lamproite is known.

Kimberlite pipes range up to 216 ha in size and generally occur in clusters of up to 50 in number and with diameters of the cluster up to 50 km. Generally kimberlite emplacement does not have obvious near surface structural controls.

Techniques used in exploration for diamond pipes consist mainly of heavy mineral sampling and airborne or ground magnetics. Other successful techniques used include prospecting, remote sensing, geochemistry, gravity, seismic, electromagnetics and induced polarization.

The use of mineral chemistry with analysis by electron microprobe is now being increasingly used to infer favourable conditions for the presence or preservation of diamonds. Once a diamond host has been found, microdiamond analysis of small samples can be used as a general indicator of macrodiamond potential.

Although an economic diamond mine has not yet been found to date in North America the chances are considered excellent for such a discovery in the next decade.

INTRODUCTION

Diamonds have been treasured by mankind for over 3000 years - originally as an object of rare beauty - more recently because of their extreme scientific curiosity. World production of natural diamonds in 1988 was 98.73 million carats compared to 15.5 million in 1950. This represents a 14 percent per annum growth rate. Diamonds are produced from 20 countries (Table 1) of which Australia, Botswana, South Africa, the Soviet Union and Zaire are the major producers. Botswana (1989 production value was US$1.33 billion), South Africa and Russia are the foremost producers in terms of value.

Diamonds are found in mantle-derived igneous rocks with the principal hosts being kimberlite and lamproite. Secondary diamond deposits, such as the marine deposits of Namibia, are derived by weathering of the host followed by transportation and concentration at favourable localities. Also mined are eluvial concentrations over low grade pipes, e.g. Mbuji Mayi, Zaire.

Of approximately 2,000 known kimberlites in the world, less than 50 can be considered commercial. There have been less than 15 major primary producers with, surprisingly, only five major (+3 million carats per annum) discoveries made in the last 50 years. These are Orapa and Jwaneng in Botswana, Argyle - a lamproite in Australia, Mir in Siberia and the Venetia Pipe in South Africa (scheduled for full production in 1994).

Diamonds rank very high in value of world production. In 1984 diamonds were fifth after Fe, Au, Cu and Zn but ahead of Ni, U, Pt, Pb and Ag.

Table 1 - World Rough Diamond Production 1983-1988 (million carats)

	1983	1984	1985	1986	1987	1988
Australia	6.2	5.7	7.06	29.2	31.0	35.0
Zaire	13.0	18.5	19.6	20.5	24.0	23.0
Botswana	10.7	12.9	12.6	13.0	13.0	15.0
USSR	12.0	12.0	12.0	12.0	12.0	12.0
South Africa	10.0	9.8	9.9	10.2	11.0	9.0
Namibia	0.96	0.93	0.91	1.0	1.0	0.9
South America	1.0	1.0	0.85	0.85	0.85	0.85
Ghana	0.8	0.33	0.6	0.55	0.6	0.3
CAR	0.3	0.3	0.5	0.6	0.6	0.45
Sierra Leone	0.3	0.42	0.4	0.4	0.45	0.3
Liberia	0.4	0.4	0.4	0.3	0.35	0.35
Tanzania	0.37	0.36	0.35	0.3	0.20	0.13
Angola	1.0	0.92	0.9	0.2	0.9	1.0
Other Countries	0.2	0.29	0.47	0.5	0.6	0.45
WORLD TOTALS	57.23	63.85	66.45	89.6	95.95	98.73

KIMBERLITES

Kimberlites remain the main source of diamonds. They are complex potassic ultramafic rocks varying from sedimentary-looking epiclastics, through breccias, to inequigranular or aphanitic- textured hypabyssal facies rocks. Mitchell (in press) gives a detailed review of kimberlites and lamproites so only pertinent details relevant to exploration will be given here. Kimberlites occur as diatremes, dykes, or sills. They are divided into Group 1 megacryst-bearing olivine-rich kimberlites and Group 2 or micaceous kimberlites. Group 1 kimberlites have a megacryst/macrocryst assemblage of picroilmenite, Cr-poor titanian pyrope and subcalcic diopside as well as phlogopite and a variety of spinels. These commonly have abundant xenocrysts of chrome pyrope, chrome diopside and magnesian chromite. Group 2 kimberlites, known so far only from South Africa, lack the megacryst suite found in Group 1. They occur mainly as thin dykes, many of which are very rich in diamonds. Examples of Group 2 diatremes are Finsch and Dokolwayo (Swaziland). The absence of ilmenite makes their detection in covered areas by heavy mineral sampling more difficult.

Kimberlites occur in clusters of three to 50 or more pipes with diameters of the clusters ranging up to 50 km. Individual clusters tend to have one or more larger pipes. The larger pipes in a cluster are generally more likely to be economic than the smaller pipes. It is very unusual for more than one pipe in a cluster to be economic. Only two clusters - Kimberley with five mines (Figure 1) and Orapa with two mines - are known to contain more than one commercial pipe.

Sizes of pipes vary from less than 0.4 ha to 216 ha. Typical sizes and shapes are shown in Figure 2. They are generally round to oval in shape but can be much more elongate. Pipes are mined both as open pits or by underground mining. The Kimberley pipe (South Africa) was mined to a depth of 1073 m. An announcement has just been made that the de Beers Mine (South Africa) will close after 120 years of production. Large (+50 ha) pipes are particularly suited to low cost open pit mining with a strip ratio for the 50 ha mine at Jwaneng (Botswana) estimated to be less than 0.6 to one (waste to ore). A 100 ha mine generates 2.6 million tons per vertical metre so is eminently amenable to high mining rates. At Orapa (Botswana) mill throughput is 20,700 tons per

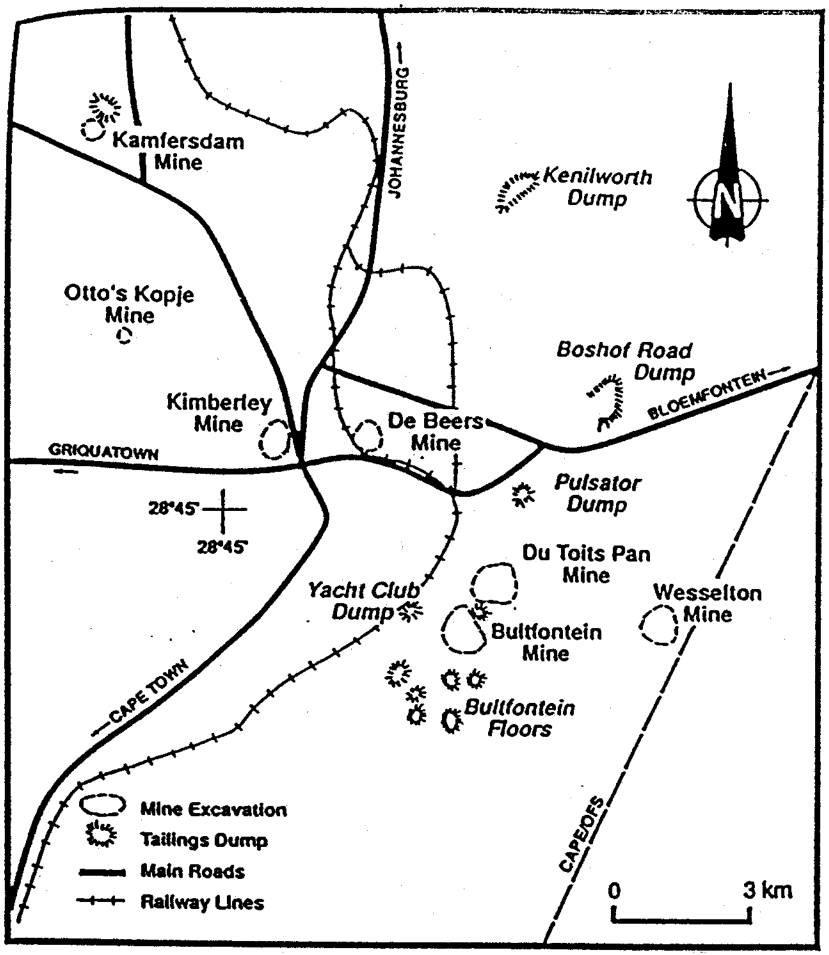


Figure 1 - Plan showing the distribution of diamond mines and old dumps in the Kimberley area - South Africa.

day (7,258,000 tons per annum) while at Jwaneng it is 16,500 tons per day or 5,783,000 metric tons per annum. The narrow widths of kimberlite dyke mines (widths commonly less than one m) require labour intensive high cost mining methods. The higher grade and good quality diamonds commonly found in South African dyke (fissure) mines offset the higher costs.

AGES

Ages of kimberlite pipes range from Archean to Tertiary. Producing pipes range in age from to 1200 million years [Ma] (Premier, South Africa), 1100 Ma for Sierra Leone pipes, 342 Ma for Mir (USSR), 150 Ma for Finsch (South Africa), 90 Ma for Kimberley (South Africa) to 41 Ma for Mwadui in Tanzania with many more of intervening ages. Some knowledge of the expected age of pipes is thus vital in planning an exploration programme for diamonds. Search for older age pipes in a thick sequence of younger sediments would obviously be a waste of time and money.

If the apparent tendency, as seen in Siberia and Southern Africa, of economic diamondiferous pipes to occur towards the centre of the sub-continent is projected to the North American stable platform then Saskatchewan, Manitoba, Ontario and a number of central states in northern U.S.A. should be prime targets for kimberlite exploration.

GENESIS OF DIAMONDS

Diamonds range in size from a few microns to the Cullinan diamond which weighed 3106 carats (0.62 kg). They were formerly thought to have crystallized within kimberlite as a phenocryst phase. Age dating by Richardson *et al.* (1984), and Kramers (1979) has shown that diamonds in 90-100 Ma age pipes are about 3300 Ma. Hence diamond is clearly a xenocryst sampled during ascent of the kimberlite from depths in the upper mantle which lie within the diamond stability field. Studies of minute inclusions in diamonds indicate mutually exclusive peridotitic and eclogitic suites co-existing with diamonds. Nothing is known about the distribution of diamond-bearing peridotitic and eclogitic material at depths of the order of 150 km. Hence it is extremely difficult to predict whether a pipe will sample economic quantities of diamond or not.

Grades of economically viable diamond pipes range from less than four carats per 100 tonnes to 730 carats per 100 tonne. Diamonds are divided into gem, near gem and industrial stones. Percentages of gem plus near gem of total production range from a low of 25% in Liberia, 45% in Australia, 71% in Botswana to 93% in Guinea. A typical pipe may have 20% gem, 24% near gem and 56% industrial diamonds. World production averages about 40% gem plus near gem diamonds with the remaining 60% being of very low value industrial stones.

LAMPROITES

Lamproites are ultrapotassic peralkaline rocks rich in Ba. Diamonds have been found in olivine-bearing lamproites at Argyle and Ellendale in W. Australia, in Arkansas, India and the Ivory Coast (Mitchell, 1990). Lamproite vents, unlike the ice-cream cone-

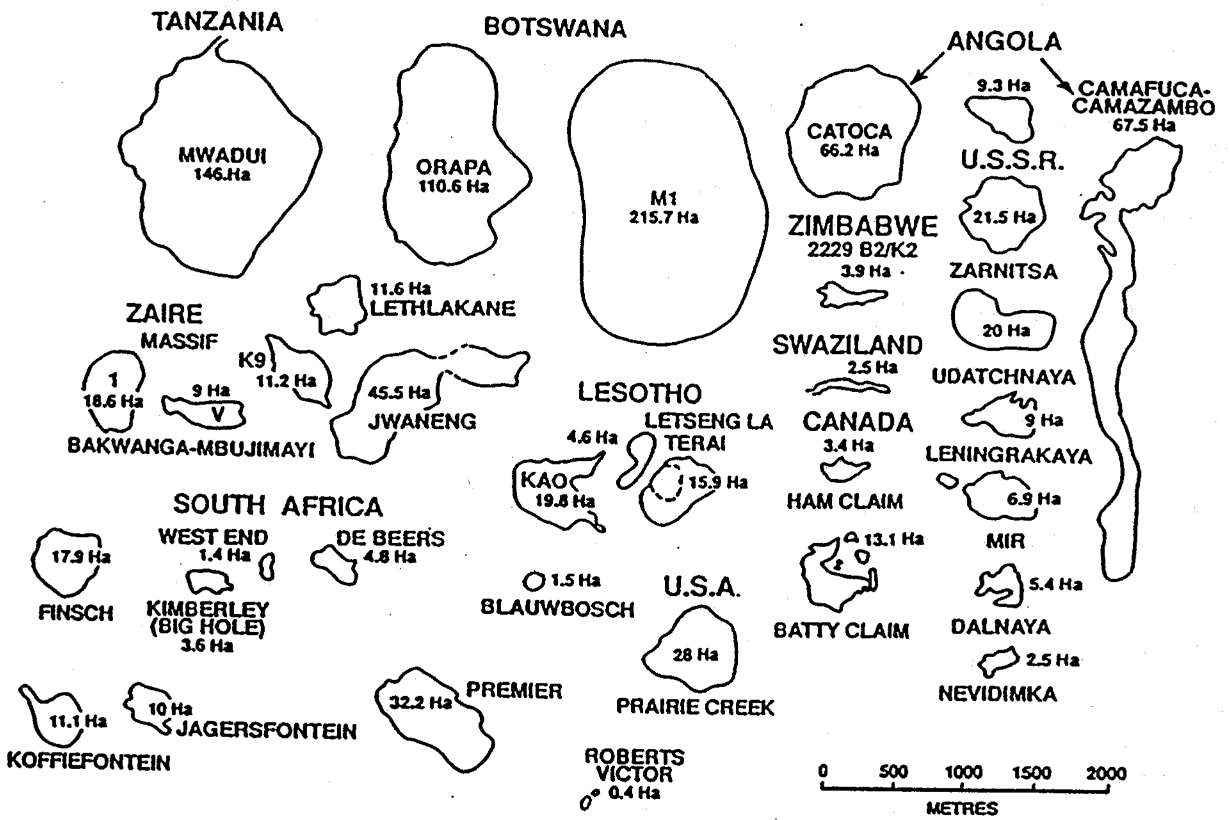


Figure 2 - Shapes and sizes of diamond pipes.

shaped vents of kimberlites, are shaped like a champagne glass. Grades at the Argyle mine are the richest in the world, as much as 730 carats per 100 tons. Quality however is very poor with only 10% being of true gem quality. The average value of diamonds at Argyle is about US$7.50 per carat compared to an average for Botswana of US$87.29 and an average estimated value at Venetia of US$92 per carat.

EXPLORATION FOR LAMPROITES AND KIMBERLITES

Scientific exploration for diamond bearing pipes has doubled the supply of natural stones to the market place since World War II. Large prospective areas remain in the world but are relatively inaccessible because of political reasons, isolation, climate or surficial cover. Despite the great potential for the discovery of economically viable pipes in North America, very little sustained exploration has been carried out partly because of lack of understanding of modern exploration techniques and partly because of the high risk of failure. Diamond discoveries will only be made by those using modern techniques, and those having faith, persistence and courage enough to continue after years of failure, with management and financial backing to continue their search.

In Soviet Russia a State programme consisting of several hundred prospecting teams commenced work in 1945 in a targeted area of four million km^2. In 1953 a 0.1 carat diamond was found hundreds of km from its source. In August 1954 the first barren pipe was found and in June 1955 the first payable pipe (Mir) was found. By 1967 about 400 pipes were known with four of them being economic.

In Botswana exploration for diamonds commenced in 1955 and by April 1967 Orapa (production in 1971) was discovered followed shortly thereafter by Letlhakane (production 1975) and in 1973 by Jwaneng (production in 1982). Approximately 130 pipes are now known in Botswana of which about half were found by Falconbridge Limited. The cost of the exploration phase by de Beers in Botswana was US$1,500,000 up to the discovery of Orapa. Falconbridge spent approximately US$11,000,000 between 1975 and 1982 to discover and evaluate some of their 65 odd pipes.

In Australia a serious exploration programme resulted in the discovery of the Ellendale lamproite pipes in 1976 followed by the discovery of Argyle in August 1979 (production end 1985).

It is probable that the North American Craton will yield as many pipes as the Kaapvaal Craton or the Siberian Shield. The widespread presence of kimberlitic minerals and numerous alluvial diamonds in Alaska, Canada, the Great Lakes states, California, Nevada, Washington, Idaho and the Appalachian states points to a high probability of one or more economic pipes being found in North America. In addition, diamond-bearing kimberlites/lamproites are now known from Somerset Island (N.W.T.), Quebec, Ontario, Saskatchewan, Arkansas and the Wyoming-Colorado State Line area. The diamonds found south of the Great Lakes are of good quality and range up to 21.25 carats in weight.

STRUCTURAL CONTROLS

Kimberlite exploration should be concentrated in areas of major continental cratons whose roots contain diamond-bearing lherzolitic or eclogitic horizons. Where kimberlitic xenoliths are available these should be used to define the paleogeotherm which in turn defines an on- or off-craton source. Although kimberlites appear to have deep seated structural controls for their emplacement, the structures are generally not readily apparent. However they typically occur in areas where tensional forces are important - a spatial relationship to diabase dyke swarms or continental type flood basalts is common. Many kimberlites occur on gentle uplifts reflected by regional warps or around great structural basins or have been intruded along the upper hinge of a flexure (Figure 3). These flexures may have an accompanying regional positive gravity expression. In Angola, kimberlites are emplaced along faults or at fault intersections. In Botswana kimberlite emplacement may be controlled by the intersection of regional WNW anticlinoria with earlier NNE anticlines (Pretorius, 1979).

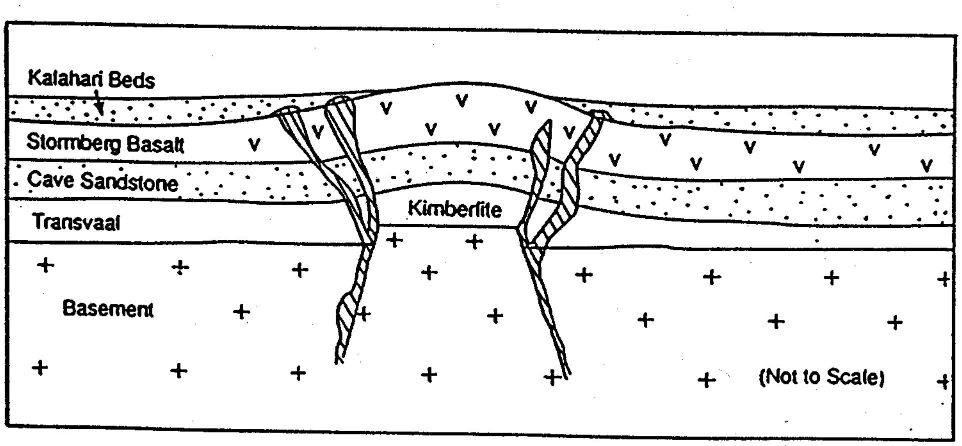


Figure 3 - Distribution of kimberlites around Letlhakane Dome, Botswana.

The Mesozoic intrusions in Liberia, Angola, South Africa, Botswana and Brazil seem to be related to the opening up of the Atlantic Ocean and the breakup of Gondwanaland. Marsh (1973) has noted how kimberlites appear to occur towards the centre of the continent along linear extensions of lines of alkalic intrusive activity towards the coast. These zones may be on great circle extensions of transform faults in the ocean.

MODERN TECHNIQUES FOR DIAMOND EXPLORATION

Modern techniques for diamond exploration include the following: prospecting, remote sensing, geochemistry, heavy mineral sampling, heavy mineral chemistry, radiometric surveys and other geophysical techniques. Each of these techniques will be described briefly.

Prospecting

Geological prospecting for exposed kimberlites, particularly in confined areas of abundant exotic rock types, and crustal and mantle rocks is important. Because of the relatively soft and friable nature of kimberlite it is likely that many will ultimately be found to underlie lakes or muskegs in Canada.

Remote Sensing

Kimberlites may be found using air photography, remote sensing, or satellite imagery. The high percentage of clay minerals in kimberlite may give rise to characteristic spectral signatures. The Orapa and Finsch (South Africa) pipes are clearly visible on aerial photographs.

Geochemistry

Kimberlites characteristically have high Ti, Cr, Ni, Mg, Ba, Nb anomalies in overlying residual soils. Gregory and Tooms (1969) found that significant dispersion patterns occur around the Arkansas lamproites. Caution should be exercised as other alkaline rocks can also give similar geochemical signatures.

Heavy Mineral Sampling

One of the most widely used techniques is heavy mineral sampling. Resistant heavy minerals such as ilmenite, garnet and chromite are commonly sought in stream sediment, esker, basal till, reconnaissance soil, detailed soil, detailed grid loaming or other sampling methods which are tailored to local conditions. Detailed orientation surveys to determine the best type of sampling technique and sample size is required before carrying out a major sampling programme. In Canada, complex transfer of heavy minerals from one till to as many as three younger tills calls for expert knowledge and particular patience in order to decipher the glacial history of the region. The writer believes that ice rafted heavy minerals including chrome diopside may move as much as several hundreds of km.

In South Africa, Botswana and Australia under warm weathering conditions chrome diopside is generally not found more than 10 km from source. In Botswana ilmenites are commonly found less than 20 km from source whereas garnets can be blown by wind for tens of km from source. A distality index can be determined based on ratio of garnet to ilmenite grains.

The surface morphology, i.e. degree of abrasion, roundness, presence or absence of remnants of original surface, remnants of kelyphitic rims on garnets can all be used to determine distance from source in certain areas. Size of grains, as well as numbers present when normalized to a constant weight can also give meaningful results but care should be exercised as many different concentrating mechanisms can give spurious results. In Wyoming chrome diopsides and garnets are known to have gone through a full sedimentary cycle without being destroyed. Afaresev *et al.* (1984) conclude that the mode of transportation has a greater effect on the degree of mechanical wear than the distance from the source. In Wisconsin pyrope garnets and probably diamonds appear to be weathered out of Cambrian sandstones indicating a pre-Cambrian source. Much has still to be learned about the movement of kimberlitic minerals during Pleistocene glaciation. In the case of lamproites, chromites and diamond, as well as zircon and andradite, are the best heavy mineral indicators.

Extraction techniques have to be extremely efficient as a four grain anomaly from a 20 kg sample represents an accuracy of between one in 10 to one in 40 million.

Diamond would be the best indicator of all because of its extreme hardness and its known ability to be transported fluvially for at least 1200 km. However the average grade of a South African pipe is about 200 times less than the average grade of a Canadian gold mine whereas ilmenite and garnet occur in numbers which are orders of magnitude more abundant than diamond.

Heavy Mineral Chemistry

The electron microprobe has revolutionized kimberlite exploration and routine 'probing' of kimberlitic minerals is now carried out by most companies. Following Sobolov (1977) and Gurney (1984) it is now well known that the presence of subcalcic high Cr 'G.10' garnets similar to those found as inclusions in diamonds can be an excellent indicator of a deep mantle tapping kimberlite which has a high probability of carrying diamonds. Similarly +60% Cr_2O_3 chromites with compositions resembling diamond inclusion chromites are good indicators of diamond potential. However, there are always exceptions to the rule, for example the Zero pipe near Kuruman, South Africa. Table 2 shows silicate analyses of typical favourable G.10 garnets in an exploration sample. In eclogitic garnets, high sodium is favourable. Ilmenites are rarely found as inclusions in diamonds. Their composition can indicate the degree of diamond preservation in a kimberlite, i.e. low Fe^{3+} to Fe^{2+} ratios indicate very reducing hence favourable diamond preservation conditions and conversely higher ferric to ferrous ratios are indicative of oxidizing conditions. Economic pipes generally have more than 7% MgO in ilmenites. Chrome versus magnesia plots for ilmenites can be used to predict different kimberlite clusters in exploration samples.

The numbers of diamond inclusion type minerals found in kimberlites can range from nil to 20% of the total present for that mineral. Hence extensive microprobe work may be required to detect diamond inclusion type minerals.

Radiometric Surveys

These should show mica-rich dykes or pipes with little cover.

Geophysics

A variety of geophysical techniques are available, but the most effective methods for diamond/kimberlite exploration include magnetic, gravity, electromagnetics and resistivity.

Magnetics

Magnetic surveys are now fairly widely used for kimberlite exploration. Figure 4 shows a typical magnetic anomaly over a pipe, however, the presence of kimberlite in areas of noisy magnetic background may be difficult or impossible to detect. In addition many pipes are non-magnetic while intrusive plugs of serpentinite, diorite, gabbro, syenite and many other

Table 2 - Diamond Inclusion Type Garnets From An Exploration Sample

SIO2	TIO2	AL2O3	CR2O3	FEO	MNO	MGO	CAO	TOTAL
41.28	0.10	19.37	6.50	6.37	0.30	22.11	3.10	99.13
42.14	0.05	21.19	4.88	5.71	0.24	24.60	1.47	100.28
41.82	0.11	19.73	6.44	6.53	0.32	22.64	2.71	100.30
41.95	0.03	19.63	6.87	6.14	0.28	23.97	1.22	100.09
42.31	0.02	22.41	3.66	6.38	0.34	22.83	2.92	100.87
42.21	0.04	21.10	5.03	6.09	0.28	24.23	1.10	100.08
42.14	0.00	20.61	5.79	6.15	0.28	24.42	1.21	100.60
42.60	0.06	21.12	5.14	6.12	0.28	24.19	1.16	100.67
41.73	0.02	19.71	6.63	6.44	0.32	22.94	2.04	99.83
41.88	0.05	19.32	7.20	6.17	0.30	23.90	1.02	99.84
42.08	0.08	19.91	6.30	6.04	0.25	22.77	2.98	100.41
41.69	0.13	18.66	7.91	6.43	0.35	23.23	2.23	100.63
42.22	0.06	21.14	5.07	6.13	0.30	24.30	1.20	100.42
42.33	0.06	21.29	5.09	6.14	0.28	24.20	1.17	100.56
41.18	0.09	18.42	8.04	6.38	0.30	22.29	2.83	99.53
41.19	0.04	18.12	8.13	6.43	0.35	21.60	3.71	99.57
41.51	0.00	19.48	6.38	6.56	0.39	21.11	3.81	99.24
42.01	0.00	18.98	7.19	6.22	0.27	22.14	3.04	99.85
41.32	0.00	16.61	10.06	6.11	0.32	22.00	3.16	99.58
41.78	0.00	19.83	6.22	6.36	0.32	21.81	3.81	100.13
42.08	0.00	19.25	6.93	6.10	0.31	22.09	3.24	100.00

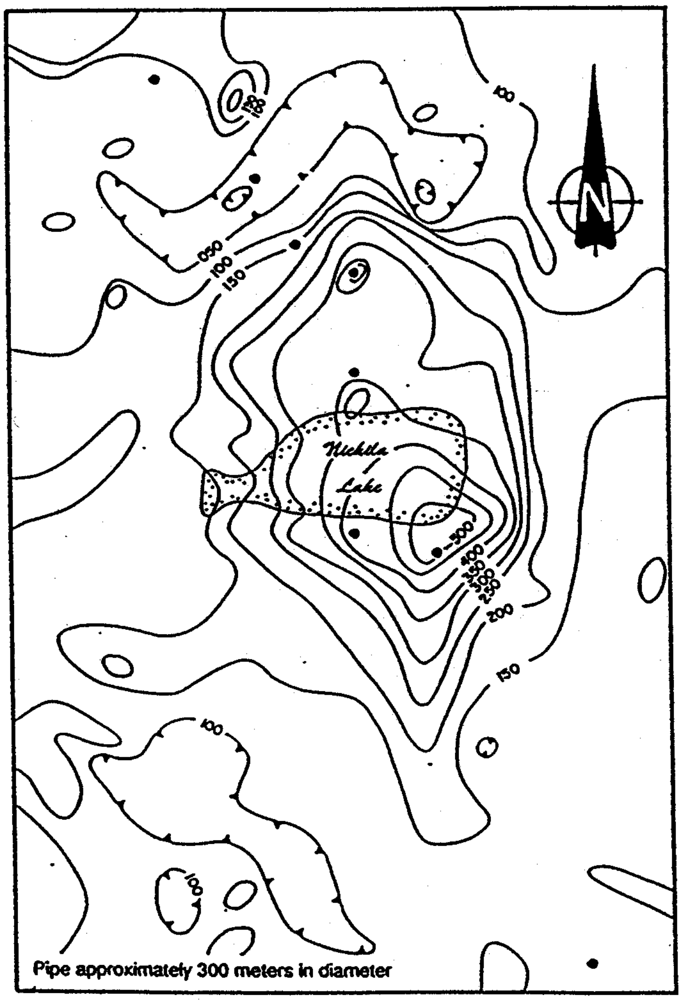


Figure 4 - Ground magnetics over a kimberlite pipe - Ontario.

rock types can give similar signatures. Farmhouses, steel silos, sanitary landfill sites, junk yards and factories can also all give spurious kimberlite-like magnetic signatures. In one area in Botswana less than 25% of boreholes drilled were successful in locating kimberlites using magnetics and other geophysical techniques.

Gravity

Gravity can give excellent confirmatory tests both as to the size of a pipe and to help confirm whether the target is likely to be a kimberlite or not. Figures 5, 6 and 7 show how gravity was able to indicate a much larger pipe than indicated by magnetics alone.

Electromagnetics and Resistivity

In areas of deep weathering, airborne E.M. can be an effective means of locating pipes. Figure 8 shows an INPUT survey flown over a kimberlite at a height of 122 m. Ground E.M. and electrical resistivity have also been used effectively to locate pipe boundaries.

Other Geophysical Methods

Seismics and induced polarization (McNae, 1979) have also been successfully used to locate pipes.

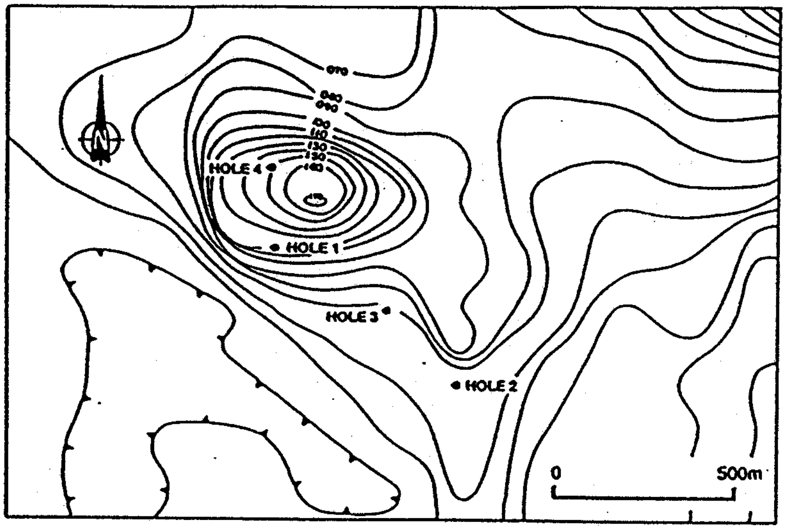
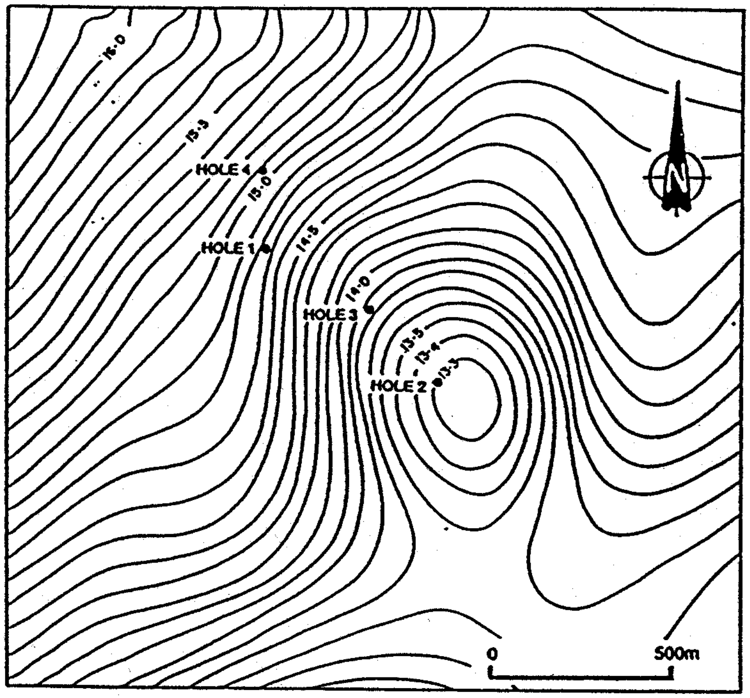


Figure 5 - Ground magnetic survey over a kimberlite pipe.

Figure 6 - Bouguer gravity contour plan over same area as Figure 5.



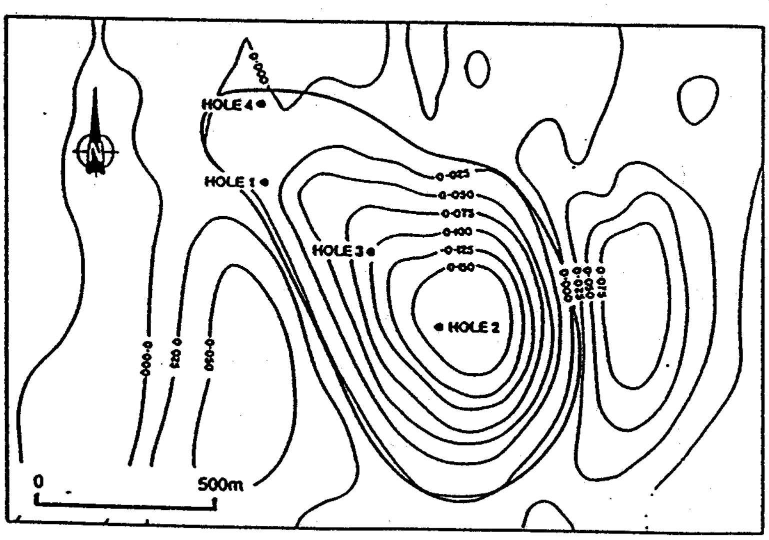


Figure 7 - Bouguer residual gravity contour of same area as Figure 5.

MICRODIAMONDS (MD'S)

Once a pipe has been found, relatively small samples (20 - 100 kg) can be tested for their microdiamond content using some form of dissolution or fusion of the kimberlite. Plotting of either weight or numbers of stones versus stone size can be used to predict size distributions of the macrodiamond population (Figures 9 and 10). In general abundant microdiamonds are necessary for the likelihood of economic pipes, but even very low grade pipes (in terms of macrodiamonds which are greater than 0.5 to one mm) can be economic because of occasional large, high quality, high value stones. These pipes would probably not give high microdiamond counts. Conversely at least one pipe is known to the writer which has high MD counts but has a marked lack of bigger stones and hence a low macrodiamond grade. No barren pipes are known which have high MD contents.

DIAMOND DEPOSIT EVALUATION

Because of the very small amounts of diamond present in an economic pipe and because of the random high values present it is typically very difficult but extremely vital to know the true value of production in the current market. Thus it is very necessary to combine both a highly efficient recovery process with security at the test site. At the evaluation stage the loss of a single high-value stone could negatively affect the evaluation or even render a negative evaluation of the economic feasibility of a pipe. Generally a sample 'parcel' of 5,000 to 10,000 carats may be needed to give both a good idea of the average value and grade of a pipe. Different rock type phases of a kimberlite can have markedly differing grades so this has to be considered when planning the detailed bulk sampling of a pipe.

WHY EXPLORE FOR DIAMONDS IN NORTH AMERICA?

1. We have the largest craton/stable platform in the world.
2. Relative to Siberia and South Africa it appears that hundreds of kimberlites remain to be discovered.
3. North America is underexplored for diamonds.
4. Large, good quality diamonds have been found as alluvials in North America.
5. A number of areas have favourable mineral chemistry.
6. Working costs of kimberlite open pit mines are very low.
7. Capital costs are no greater than other mines. Tailings are benign and non-acid generating and no harmful chemicals are used during extraction.
8. Transport costs for the final product are negligible.
9. Diamond prices generally increase at a level which keeps pace or exceeds inflation.
10. The occasional large diamond (a 100 carat rough gem can be sold for about US$1.7 million) found during production can be regarded as an added bonus.

Despite the above, the risks and costs of a diamond exploration programme can be very high, but the occasional reward can be even greater!

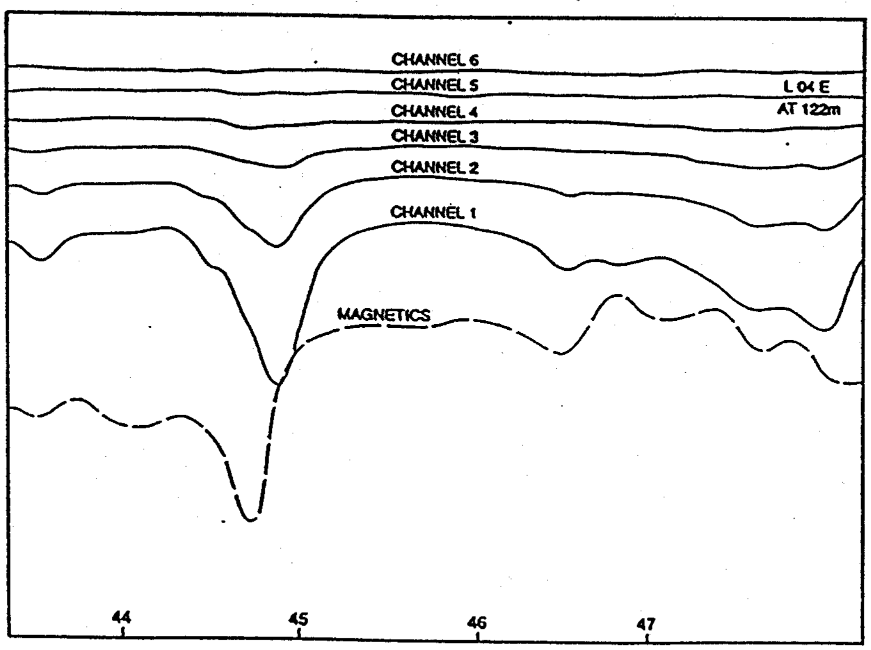


Figure 8 - INPUT and magnetic profile at 122 m above a kimberlite pipe.

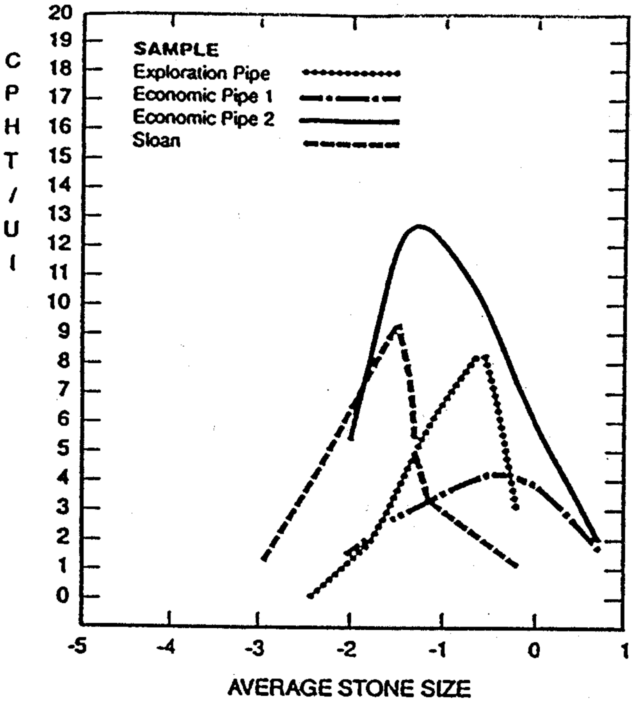


Figure 9 - Microdiamond distribution - carats per 100 tons versus size.

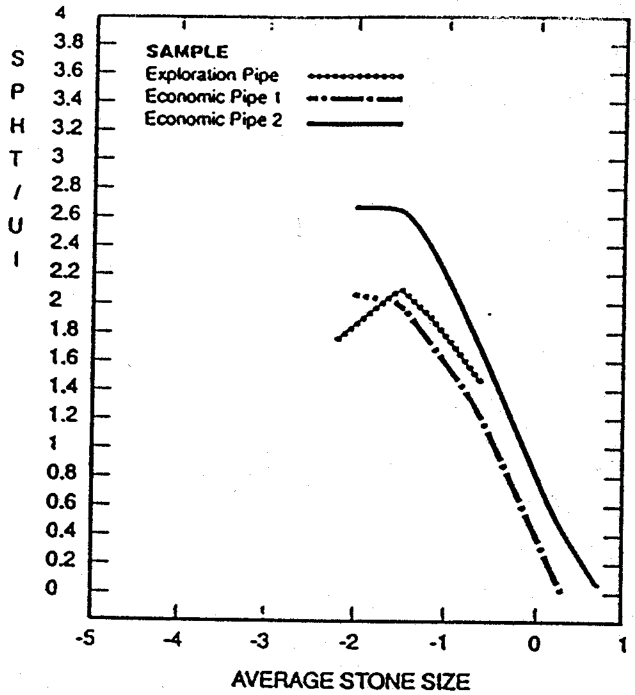


Figure 10 - Microdiamond distribution - number of stones versus size.

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ASSESSMENT REPORT FOR NORTHSIDE MINERALS

Please find enclosed documents to support the assessment requirements on selected portions of the Northside Metallic Minerals Permits.

$15,000 - Project Pembina Report - A regional heavy mineral survey of Northside and neighboring claims to establish broad areas of exploration interest.
$30,000 - Northside Resources Bulk Sampling Program - A targeted heavy mineral survey of selected drainages utilizing large sample sizes. Samples of two tonnes dry weight from four sites.
$9000 - Auger drilling of north side of Groat Creek. Holes to 65 feet in search of indicator minerals. Auger holes 18" in diameter with layers sampled on three foot intervals.
$6480 - Administration.

$60,480 - Total costs to be applied to Northside Permits.

At a $5.00 per hectare assessment requirement the above expenditures justify a permit area of 12096 hectares.

The areas to be retained are as follows:

Twp. 58-R.11-West of 5-Sect. 1-19, 22-24, 25-27,30.
Twp. 57-R.11-West of 5-Sect. 19-23, 25-36.
Twp.57-R.12-West of 5-Sect. 23, 24, 25, 26.

Enclose Project Pembina Report and Northside Report as well as supporting documents for drilling.