MAGMATIC AND HYDROTHERMAL EVOLUTION OF THE BROWNS CREEK INTRUSIVE COMPLEX AND ASSOCIATED GOLD MINERALISATION

Nicola Jane Kovacs

September, 2000

A thesis submitted for the degree of Master of Science of
The Australian National University.

4. Structure

Structure has played a major role in the formation of the Browns Creek deposit. It has provided channelways for intrusives and focused the infiltration of mineralising fluids. The orebody would not have formed in this position if it were not for the unique structural history of the area. However, there has been little agreement by previous researchers regarding specific details on how the structure has influenced the formation of the deposit. The most disputed points are the controlling structures, and syn- to post-mineralisation movement of new and pre-existing structures.

During the research for this study, the structure of the underground mine was closely observed and measured. Structures within the open pit could not be measured as they are mostly inaccessible and unsafe. Pre-existing reports of the geology of the open pit were utilised to obtain information about these structures. Structural measurements were a key tool in determining the relationship between structures in the orebody. All the measurements that were taken are relative to magnetic north, except where noted. Structures within drillcore were not utilised as the mine exploration and development core was unoriented. To incorporate the mine structure with that in the local vicinity, the exploration personnel of Hargraves Resources N.L. were consulted.

4.1 Previous Studies

The structural history of the deposit has been the focus of several company reports. The aim of this was to help determine the continuation of ore at depth. The more detailed reports are by Stephen King (of ERA-Maptec, 1995), Corbett (1997), Wilkins (1998), Vic Bogacz (of Archon Resources, 1999) and Stephen King (of Solid Geology, 1999). These reports were drafted in these researcher's capacity of structural consultants to the mine. All have focused on the classification of the structures observed and their relative importance to mineralisation. The two most recent studies of King and Bogacz were considered the most useful, as these researchers had the most recent and extensive structural data to work with.

4.2 Classification of the Different Structural Trends

The majority of structures can be grouped into three dominant trends; north-south (4000E Fault), northeast and the northwest (Mount David Shear Zone, 340 Fault) trends. A fourth trend (east-west) can also be observed. The latter is less common and have previously been associated with the 300° AMG trend. These four orientations are not unique to the mine and are readily recognisable in the vicinity of the mine (from Hargraves Resources N.L. exploration data). More notable examples are:-

- north-south - Carcoar Fault, Columbine Mountain Fault, Eastern Shear Zone, Wongalong Fault
- northeast - Copperhania Fault, Springvale Shear Zone, Old Nag Shear Zone
- northwest - Mt David Shear Zone, Godolphin Fault
- east-west - Cadia Trend, Lachlan River Lineament

4.3 North-South Structural Trend

The north-south trend is common throughout the mine, particularly in the underground workings. Stereonet projection of measurements taken of these structures indicates a mean strike of 011° and a dip/dip direction of 89°/101°, although this can vary from steeply west to steeply east (figure 4.1). The trend manifests itself as shears, joints, fractures and faults. The appearance of structures with a north-south orientation varies according to structural types. Faults and shears tend to be puggy in appearance and show evidence of recent water flow. Generally,

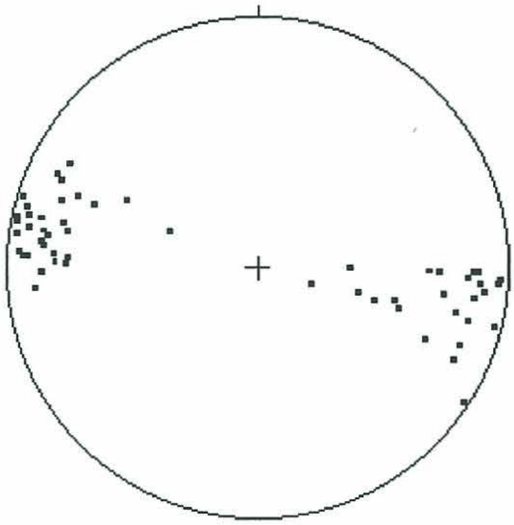
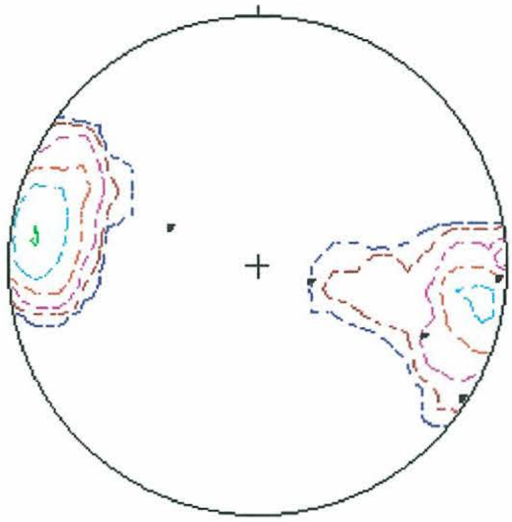
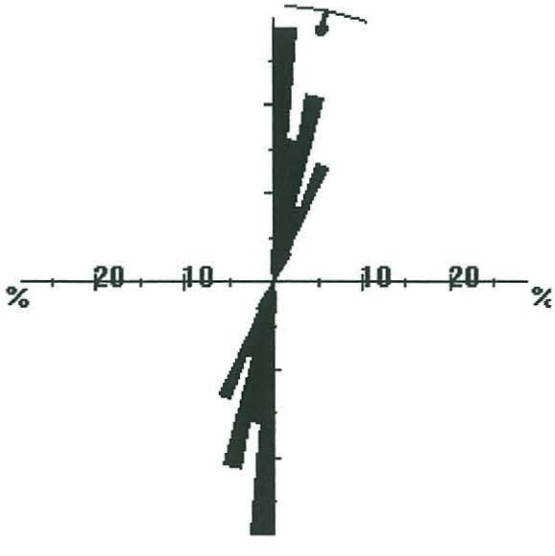


Figure 4.1 (a) Equal area projection - North-south Structural Trend. Preferred direction = 89°/101°. All structures measured by author in underground exposures.



(b) Contour of equal angle projection - North-south Structural Trend

• 1 point (1.79%)
2%
4%
8%
16%
32%
64%
(max. = 67.86%)



(c) Rose diagram - North-south Structural Trend. Vector mean = 011°
(5° sector size)

the structures are mostly planar to undulating and their surface roughness ranges from smooth to slickensided to rough. Faults and shear zones of this orientation tend to be of considerable width, ranging up to several metres. Joints and fractures are typically less than one millimetre in width. Faults and shears usually have been infilled with a chlorite/clay composition, whereas joints and fractures generally contain no infilling material. There appears to be late movement on these faults that may be a result of a compressional environment.

Although the north-south trend is more common in the underground workings, it is also observed in the open-cut where it is dominantly confined to the Carcoar Granodiorite. It manifests as major faults and shears dipping steeply east to steeply west, with a moderate spacing in the order of less than 10m apart. Observations made by Rangott and Bird (1994) infer that there is a strong lateral component of movement along these structures but no definitive sense of movement can be assigned. This is also apparent underground. The complexity of the structural regime makes determining the overall sense of movement difficult. It is highly likely that there has been more than one phase of movement on the structures within the mine area. Therefore, any evidence that is used to indicate sense of movement must be treated with caution and may only indicate the latest movement on any structure.

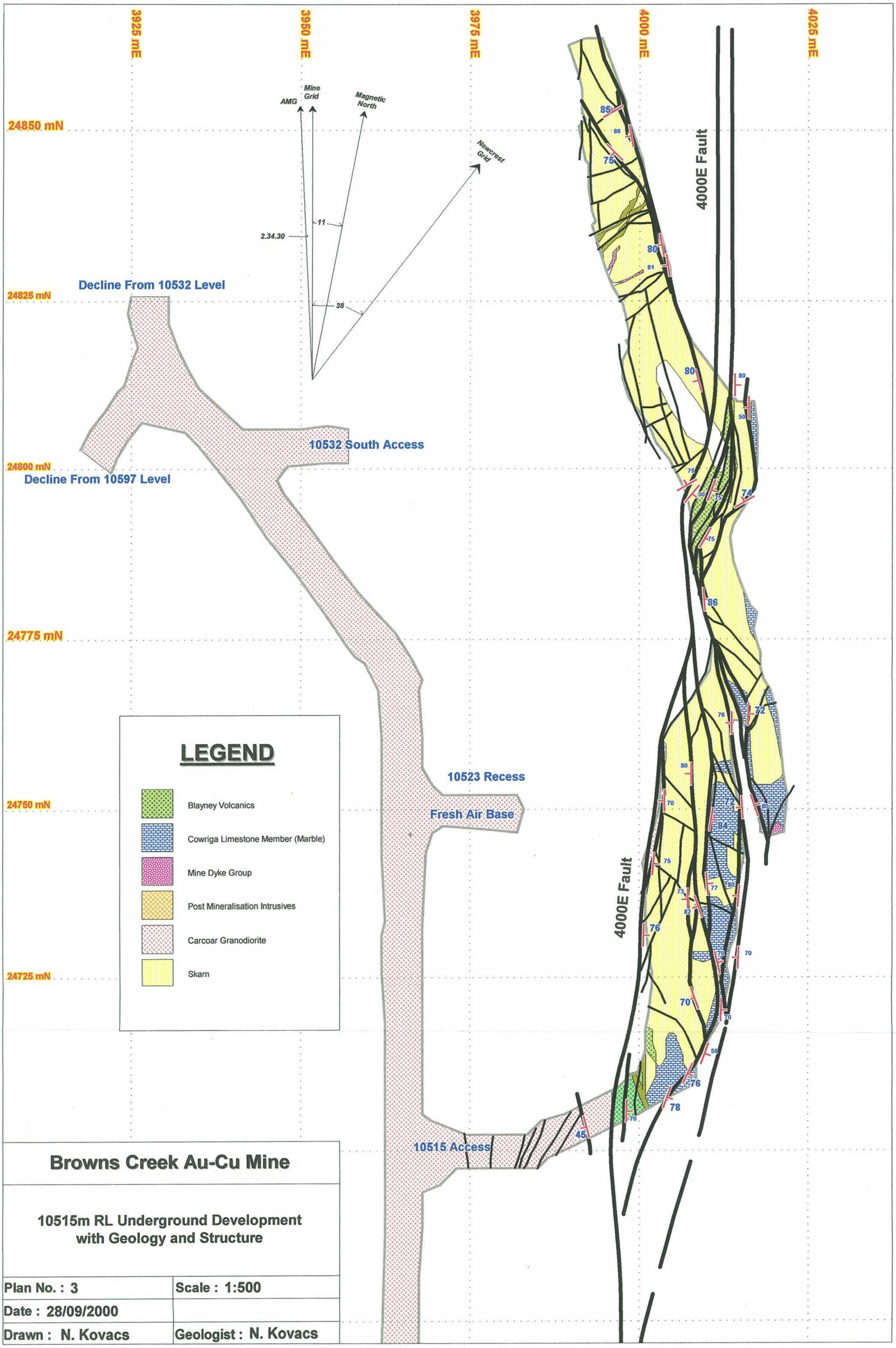
The underground orebody follows an anastomosing steeply west-dipping to vertical, north-south orientation (see plans 1-7). This alone indicates the importance of this structural group in the preparation and formation of the orebody. At the very least, it indicates that at some stage in its history, there must have been extension along the north-south structural trend. This would allow the fluids to pass through the rocks and form the orebody.

4.3.1 4000E Fault Zone

The 4000 East Fault (4000E) (located parallel to the mine grid Easting of the same name) is vertical to steeply east-dipping. The fault is vertically and laterally extensive, ranging in width up to 5m. The full vertical extent has not been identified. It is traceable throughout the mine from the highest underground level (10652mRL) down to about 10300mRL where it continues into the Carcoar Granodiorite and away from the mine workings. In underground exposures, the fault is easily recognisable due to its chloritic and puggy nature.

Projecting the 4000E fault up from the underground exposures, it is expected to occur within the marble hangingwall. However, there is a substantial lack of any north-south oriented structures within the marble in the open pit, with a predominance of structures oriented northwest (as discussed in Section 4.4). Recent mapping by Hargraves Resources N.L. exploration personnel has revealed a north-south oriented shear zone to the south of the pit (Kovacs, G. and Bird D., pers. comm., 1999), that aligns with the projected positioning of the 4000E Fault from underground exposures. In addition, there appears to be a steeply west-dipping north-south striking fault forming the boundary of the Carcoar Granodiorite with the Cowriga Limestone Member (see figure 4.7). This feature remains inaccessible due to the danger of the steep pit walls. Thus, structural measurements and other more detailed observations could not be made. It is postulated that this feature may be the upward extension of the 4000E Fault, truncating the Carcoar Granodiorite.

Underground, the 4000E Fault Zone is first observed beneath the Mount David Fault (Section 4.4) within the marble hangingwall. The overall plunge of the orebody is flatter than the dip of the fault. This results in the fault crosscutting the skarn into the Carcoar Granodiorite at approximately 10515mRL (plan 3). Here, the 4000E Fault is observed as a zone of north-south oriented structures surrounding a series of smooth, undulating multiple fault planes. Mapping by Wilkins (1998) of the upper levels of the underground mine indicates that the sense of movement at this level is normal



Browns Creek Au-Cu Mine

10515m RL Underground Development with Geology and Structure

Plan No. : 3	Scale : 1:500
Date : 28/09/2000	
Drawn : N. Kovacs	Geologist : N. Kovacs

and dextral with little to no vertical displacement. Wilkins (op. cit.) adds that if there had been large displacement along the fault, a ductile shear zone in the order of hundreds of metres wide would have developed and would thus contain no mineralisation. This sense of movement was determined by small scale features on and associated with the individual fault planes. This is one determination for a sense of movement on the 4000E Fault. Corbett (1997) states that movement was mostly normal dip-slip, with a minor dextral component.

Based on drillcore cross-sectional interpretation, moderately dipping northwest trending structures appear to converge with the 4000E fault. This convergence is not directly observed in the mine as it would occur within the Carcoar Granodiorite, west of the orebody. Northwest (northwest orientation) structures are not logged west of the 4000E Fault and may be terminated against it. However, an alternative for the lack of northwest structures could be due to the lack of drilling in this area. This is discussed further in Section 4.4.

4.3.2 Banding and Faulting in Marble

Another north-south trending feature associated with the Browns Creek orebody is the banding observed in the marble hanging wall (figure 4.2). This is described by Wilkins (1998) as the *4075E Hangingwall Fault Zone*, and is mentioned by Corbett (1997). The sub-vertical banding is characterised by alternate light and dark grey to black bands, generally less than 5cm wide and typically only a few millimetres in width. The darker bands may represent original silty material in the former limestone, which has since been altered to sericite (Kjolle, 1991). This banding is mylonite and is not relict bedding as previously thought. The broad north-south trend of the mylonite zone varies in orientation (NNW-NW in the north and SW in the south). On some levels of the mine (for example 10400mRL), the only trend that can be observed is northwest. Bogacz (1999) describes the whole feature as two different structural trends rather than the single feature that varies in orientation.

Figure 4.2 – Mylonite zone in the marble. Photo taken of backs on 10400mRL level. Rock bolt plates are approx. 40cm.

The extent of the mylonite zone is poorly understood due to the lack of drilling and development beyond the ore zone. However, it appears to extend up to 5m beyond the ore zone where it is less strongly developed with individual bands being spaced further apart.

The formation of mylonite is often confused with cataclasite. However, in the latter, the deformation is formed by a loss of cohesion between grains. In the formation of mylonite, banding is developed due to dynamic recrystallisation of grains that are under plastic deformation. The composition of the dark bands is unknown.

Large fragments (up to one metre) of surrounding lithologies, such as intrusives, volcaniclastics, and even skarnified material, are observed within the aphanitic mylonite (figure 4.3). These blocks are commonly rounded to sigmoidal in shape with the banding wrapping around them. Boudinaged mafic dykes occur in the upper levels of the mine within this mylonite zone. This indicates that the initial deformation there has most likely occurred after the skarning event due to the included fragments of skarn.

Figure 4.3 – Photo of blocks within the mylonite zone. Dark blocks are volcaniclastic and top right corner shows block of skarn altered material. Photo taken of backs in 10400mRL level. Rock bolt plates are approx. 40cm

Adding to the complex timing of the north-south trend, it is observed that as the hangingwall is approached from the west, the intensity of the skarn declines. The skarn development is observed to follow fracture and joint sets that must have been dilatant, including the north-south orientation. In many places throughout the mine, the skarn is observed to follow the same orientation as the bands formed by the mylonite process, hence the overall north-south orientation of the orebody.

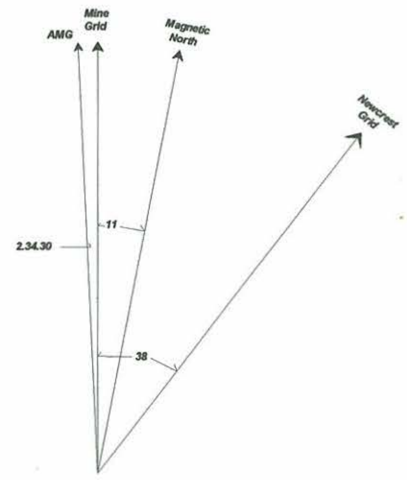
Steep-dipping faults occur on the hangingwall contact parallel to the mylonitic banding. These faults typically occur in the upper levels of the mine (above 10400mRL). At these levels, the 4000E Fault is in relative close proximity to the orebody. Thus, it can be interpreted that the marble faulting may be related to the 4000E Fault and possibly splay from it. However, such structures become more evident deeper in the mine (10320mRL and below, see plans 2, 4, and 7). This faulting remains a constant distance away from the 4000E Fault, with no indication that the two merge. An alternative suggestion is that the faulting associated with the marble is a parallel structure to the 4000E Fault and not a splay from it as suggested by Wilkins (1998). There has been little interpretation of this feature, or the banding, except by Bogacz (1999). As with the banding, the faulting appears to vary in its orientation (to the NW in the north and SW in the south).

4.3.3 Sheeted Intrusions - The "Ore Zone Package"

The lowest pod of ore (below 10365RL) has a north-south trending volcaniclastic/andesite and granitic package, termed the "Ore Zone Package" (plan 4). This laterally and vertically continuous feature runs through the orebody and sub-parallel with its longest dimension. It is located more towards the eastern half of the ore zone. The package consists of a granite dyke that has intruded into a thin unit of Blayney Volcanics. The lithologies are not skarn altered or mineralised. The width of the package is mostly 3-5m. However, it appears to be thickening at depth and at the southern end of the orebody, where it can range up to 10m. It is difficult to determine the positioning of the "Ore Zone Package" with respect to the primary lithologies of the area. It most likely sits on the original contact between the now skarnified Blayney Volcanics and Cowriga Limestone Member. The dip of the package is mostly vertical to sub-vertical however, in the lower levels of the mine the dip varies to approximately 60^{o} west. In some cases, the two components are indiscernible. Volcaniclastic xenoliths contained within the granite dyke indicates that the dyke has intruded the volcaniclastics.

As the "Ore Zone Package" has strongly sheared contacts with the surrounding lithologies, it can be interpreted as a whole package that has been faulted into place. An alternative is that the volcaniclastic/andesitic component was faulted into its present position and the granitic component has intruded into the pre-existing shear or fault systems. This option is preferred as there is no evidence for later faulting of the package after the granitic dyke has intruded.

The "Ore Zone Package" has not been skarnified or mineralised, thus it must have been emplaced after the skarn forming and mineralising events. However, the



LEGEND

- Blayney Volcanics
- Cowriga Limestone Member (Marble)
- Mine Dyke Group
- Post Mineralisation Intrusives
- Carcoar Granodiorite
- Skarn

Browns Creek Au-Cu Mine

10305m RL Underground Development with Geology and Structure

Plan No. : 4	Scale : 1:600
Date : 28/09/2000	
Drawn : N. Kovacs	Geologist : N. Kovacs

granitic component of the package commonly has an envelope of garnet skarn. This is a result of the granitic dyke causing a contact prograde skarn of the already skarn altered country rock. From this it can be inferred that the north-south trend has been active after the main skarning and mineralising events.

It is difficult to infer any relation of the "Ore Zone Package" to the Carcoar Granodiorite as no direct evidence of cross-cutting relations are observed. Geochemical analysis of the two intrusives infers a genetic relation and the dyke has been placed as a member of the Mine Dyke Group (Chapter 6). Its relative timing with respect to ore formation substantiates that this is a late feature. This again infers that the north-south trend has been active post-skarn formation.

4.3.4 Sheeted Quartz Veins

In the upper levels of the mine (down to 10530mRL level) sheeted quartz veins are a dominant feature of the orebody. These veins host 'bonanza' gold grades. This area of the orebody was only observed on one occasion, however vital information was obtained regarding the timing of these veins relative to the Mine Dyke Group. Other information has been sourced from Corbett (1997) and Wilkins (1998).

The steeply dipping sheeted quartz veins are oriented north-south, but can vary in strike from NNW to NNE. They form a northwest trending body located in the northern-most extent of the orebody. The veins are described by Corbett (1997) as narrow veins (1-5mm wide) with crosscutting zones of bornite, chalcopyrite and pyrite. It is suggested by both Corbett (1997) and Wilkins (1998) that these veins are a late feature in the formation of the Browns Creek orebody as their retrograde assemblages overprint calc-silicate assemblages that are associated with the main skarning event. In addition, there is a close spatial and timing relationship with the late-stage Mine Dyke Group. These dykes are located within the sheeted quartz vein zone and are locally cut by the veins.

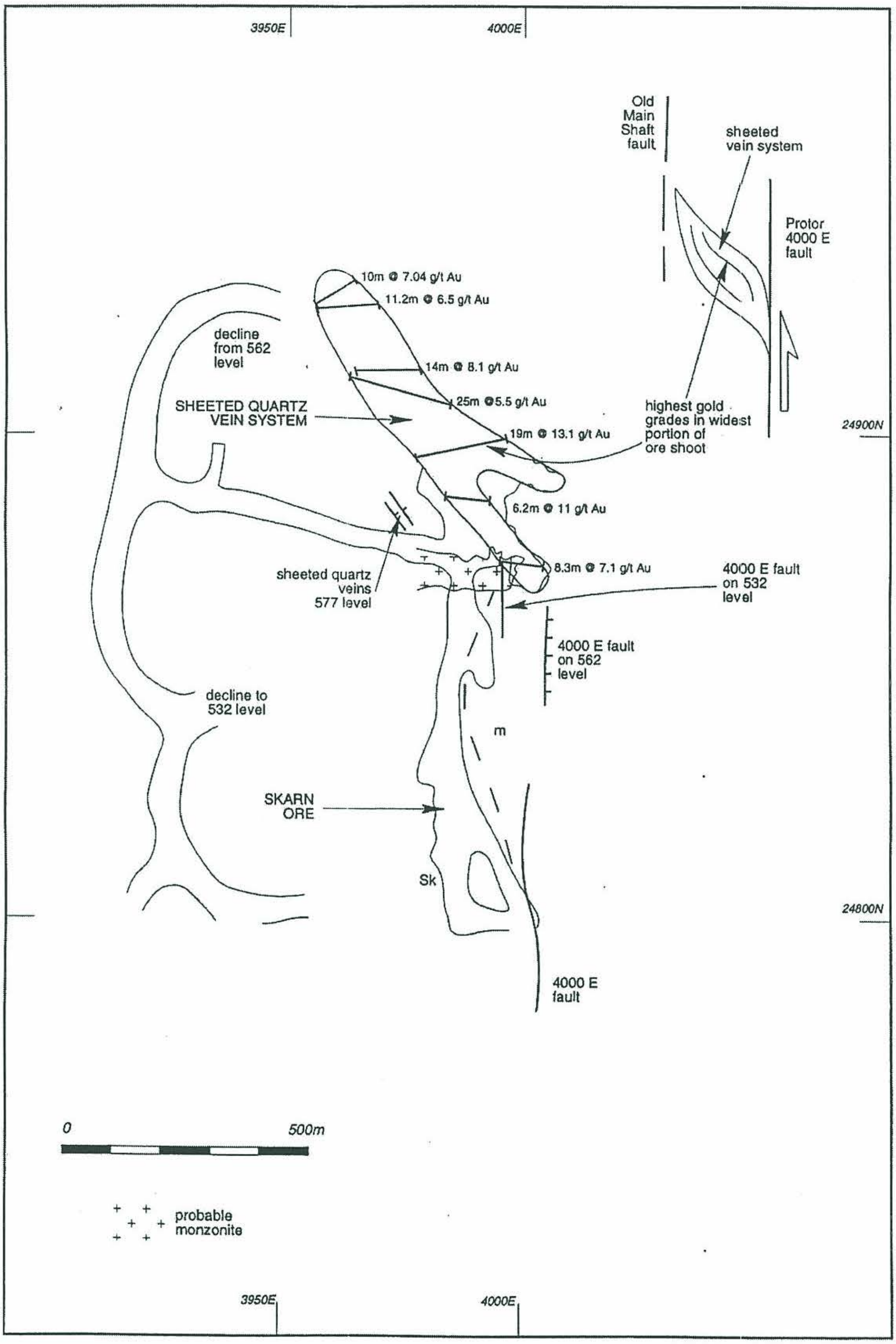


Figure 4.4 – Level plan of 10542mRL to show location of sheeted quartz vein ore and grades. Included is an interpretation of formation (Corbett, 1997).

Wilkins (1998) interprets that the formation of the sheeted quartz veins is controlled by the 4000E Fault, specifically "a phase of normal, dip-slip, transtensional movement". Alternatively, Corbett (1997) interprets that the veins have formed within a dilatant jog between the 4000E Fault and another steeply dipping fault (interpreted from historic records as the Old Main Shaft Fault). Sinistral strike-slip movement crosses over from the 4000E Fault to the Old Main Shaft Fault, creating dilatant zones in a northwest orientation. From the data sighted, it appears that this zone of sheeted quartz veins has formed in the transfer zone of two pre-existing north-south faults. Such faults have been reactivated after the formation of the main orebody and this has formed these veins. This reactivation has occurred at around the same time or slightly before the intrusion of the Mine Dyke Group. This supports previously stated evidence that infers that the north-south structural trend was active after the main skarn formation, and most likely after the main mineralisation event.

4.4 Northwest Structural Trend

The northwest structural trend (strike of 336° from stereographic projection, figure 4.5) is an important local feature of the Browns Creek orebody. However, there has been a certain amount of confusion regarding nomenclature of these structures. The confusion stems from numerous reports and mine geology practices that have split up this structural orientation by dip. Two subgroups were formulated :- a flatter dipping group and a steeper dipping group, both dipping to the southwest. King (Solid Geology, 1999) was one such researcher, and he named the first group as that of the true Mount David Shear Zone orientation, which is observed in the pit. The second group is supposedly a more pervasive trend observed underground, particularly below 10365mRL. However, a stereographic projection (figure 4.5) of all the northwest structures does not convincingly show two distinct groups, rather a continuum of dips. This is consistent with an anastomosing fault system. Therefore, in this study, the northwest structural trend will be considered as a whole group and not separated by dip. The preferred dip/dip direction obtained by stereographic

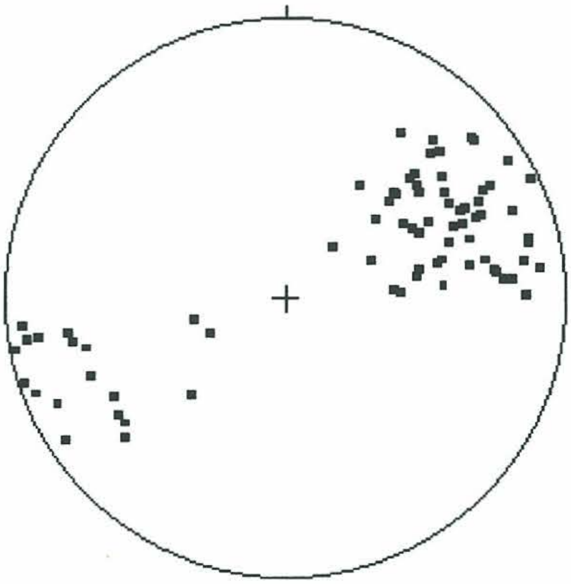
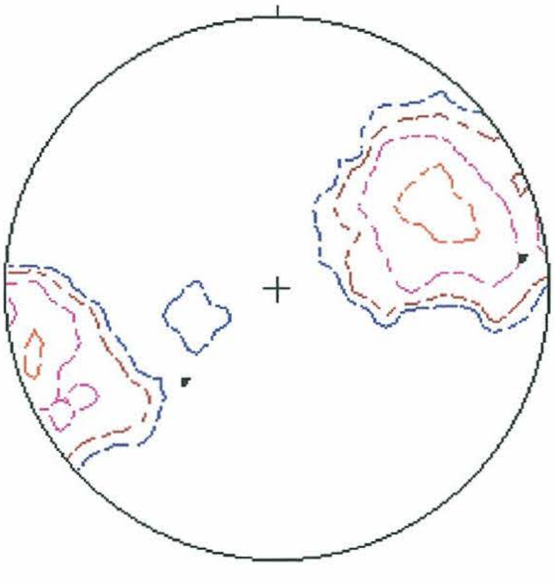
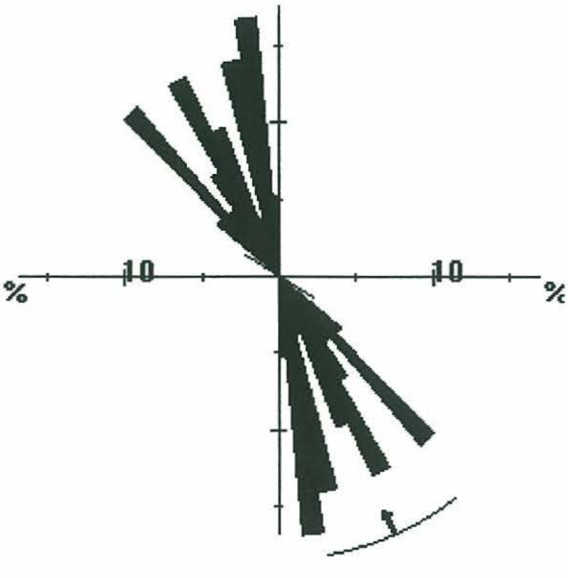


Figure 4.5 (a) Equal area projection - 330° Structural Trend. Preferred direction = 66°/246°. All structures measured by author in underground exposures.



(b) Contour of equal angle projection - 330° Structural Trend

• 1 point (1.30%)
2%
4%
8%
16%
(max. = 22.08%)



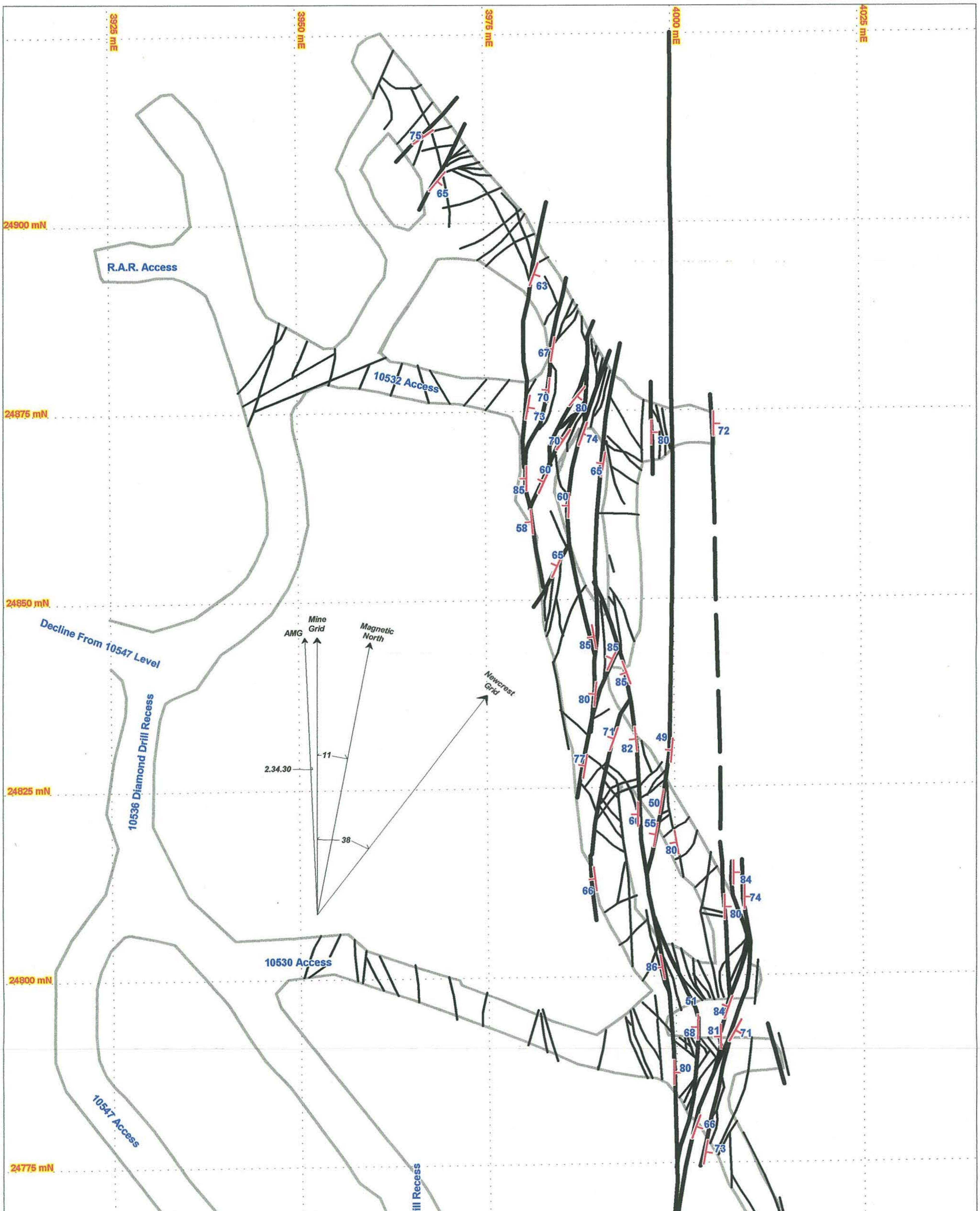
(c) Rose diagram - 330° Structural Trend. Vector mean = 336° (5° sector size) projection is $66^{o}/246^{o}$ (figure 4.5).

The northwest trend manifests itself as major and minor faults, joints, fractures and shears. The lateral and vertical extent of these structures is in the order of tens of metres. They display anastomosing strikes and dip planes. This is most likely the cause of the practice of splitting the trend into two subgroups. The dip of the structure varies greatly from 20^{o} southwest to subvertical. Rare examples were measured where the dip of the plane was towards the northeast. These were mostly minor late stage cross-cutting faults within the ore zone. In the open cut within the Carcoar Granodiorite, the flatter lying (20^{o} to the southwest) Rangott and Bird (1994) reported northwest oriented structures. These structures were close-spaced (less than 10m apart) but were inaccessible for any distinct structural measurements.

The most notable northwest trending feature in the open pit is the Mount David Shear Zone, which has a much steeper dip than the previously mentioned structures. However, due to the regional significance of this structure, it is treated separately later in this section. The rest of the northwest structural set in the open cut ranges in dip from shallow to subvertical. Such structures tend to be minor and small scale.

In underground exposures the northwest structural trend becomes progressively more frequent with depth. Down to 10500mRL, they have rarely been mapped, except as minor fractures and joints. In these levels, the north-south and northeast structural orientations are predominant. However, below this level there are progressively more structures that belong to the northwest trend. It is noted that in this lower half of the underground development, the 4000E Fault is now located on the western side of the orebody. Above 10500mRL, this fault was located to the east of the orebody (see plan 5a and b).

The greatest occurrence of the northwest trend is in the lowest-most levels of the mine (10365mRL to 10285mRL). These structures are major faults and shears, dipping southwest at approximately 40-60 degrees. The faults vary up to 50cm wide



Browns Creek Au-Cu Mine

10532m RL Underground Development with Structure

Plan No. : 5a	**Scale :** 1:500
Date : 25/9/2000	Modified after Wilkins 1998
Drawn : N. Kovacs	**Geologist :** N. Kovacs

Browns Creek Au-Cu Mine

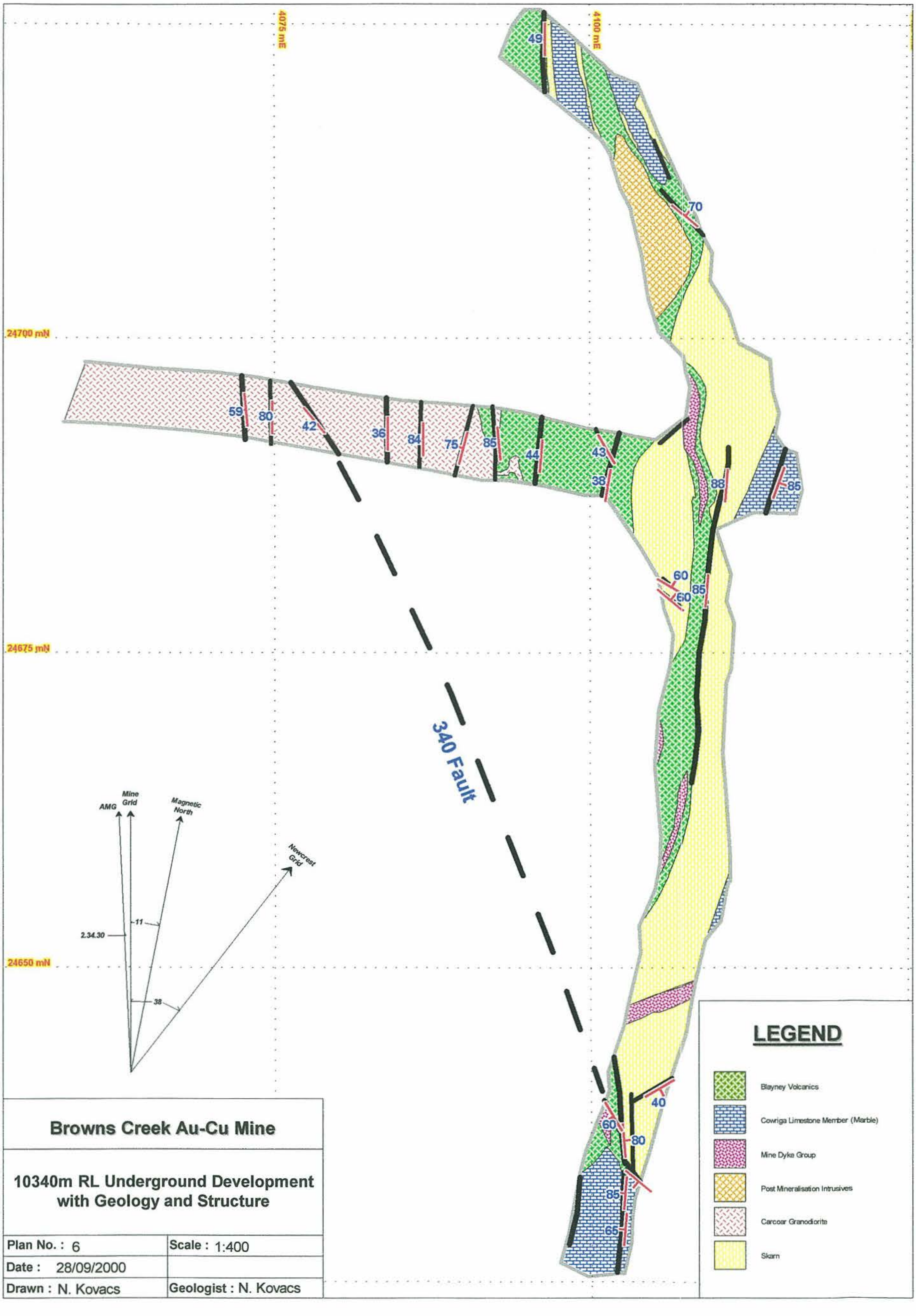
10500m RL Underground Development
with Structure

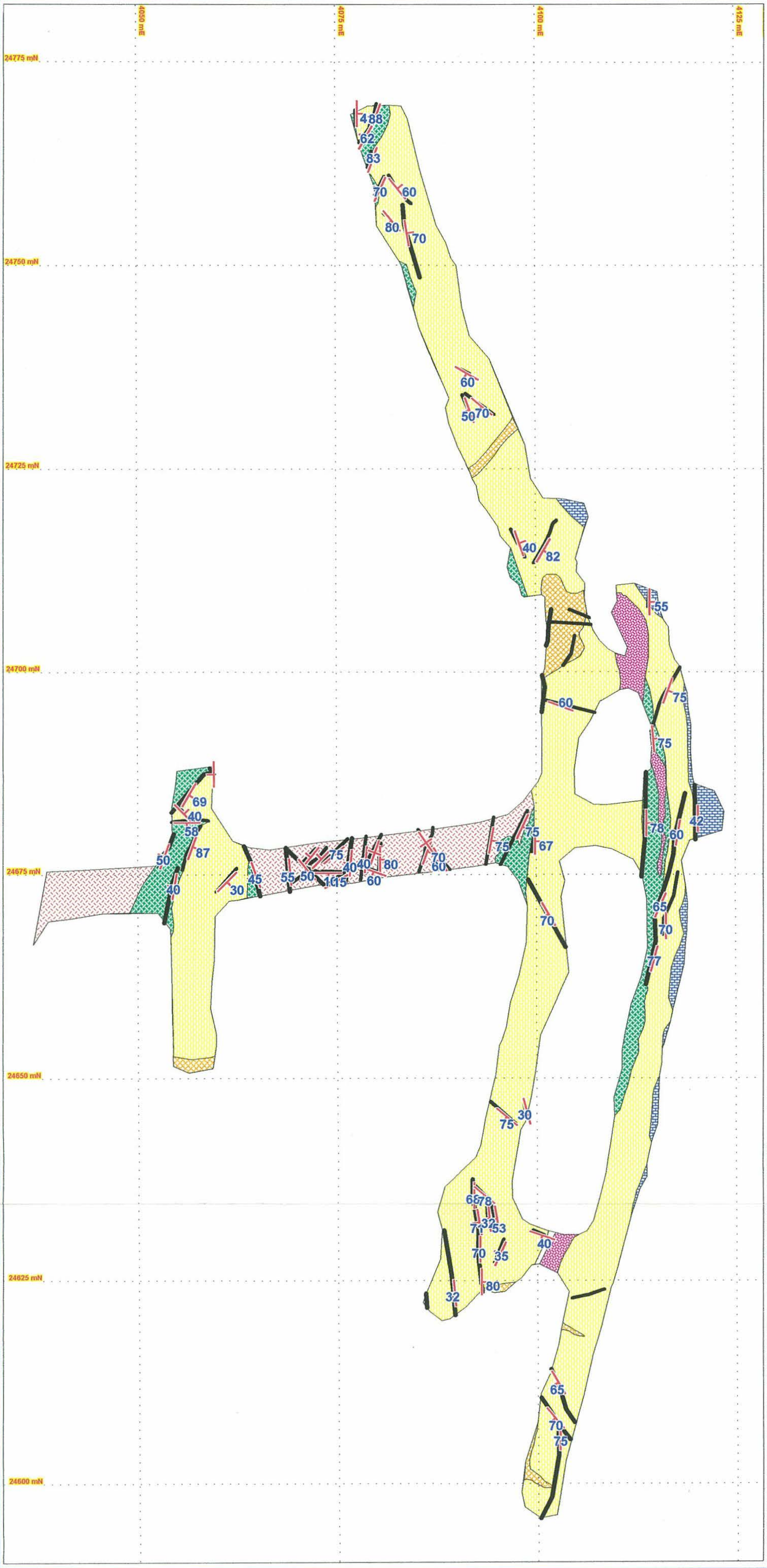
Plan No.: 5b	Scale: 1:500
Date: 28/09/2000	
Drawn: N. Kovacs	Geologist: N. Kovacs

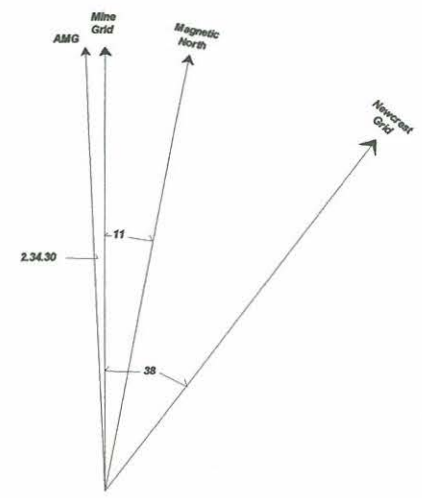
and are usually chloritic with rock gouge. They are traceable both along strike and dip for tens of metres. The trend has been interpreted from drillcore within the Carcoar Granodiorite and visually traced through the main skarn zone. Due to the lack of development and drilling beyond the ore zone, these structures have not been identified beyond the marble hangingwall. However, they appear to become steeper and have been interpreted to eventually merge into the north-south oriented faulting occurring in the marble. Where micro-textures are preserved, reverse movement appears to be the latest movement on these faults and shears. Whether this is the only type of movement experienced by these structures is a topic of present discussion.

One of the dominant northwest structures that occurs in the lowest levels of the mine is the "340 Fault". The name is derived from the 10340mRL level where the fault is first seen to interact with the ore (plan 6). This fault has played a vital role in the extent of the ore in these levels as it terminates the orebody to the south. It appears to be a set of splaying faults that have an anastomosing strike on small scale, however display an overall planar habit on the large scale. The "340 Fault" has a dip that can vary from 27° to 50° towards the southwest. As previously alluded to, the grade of the mineralisation significantly decreases past this fault, although minor skarning is still evident.

On the 10320mRL level, the "340 Fault" appears to have displaced the southern most section of the orebody, creating a pod of ore that essentially sits within the Carcoar Granodiorite (plan 7). If this pod is the southern extension of the orebody, this suggests dextral strike-slip movement along this fault, with a horizontal displacement of 40m. This is the theory of King (Solid Geology, 1999) who states that this fault and the others in this area like it, would have been active post-mineralisation. However, the pod of ore in question is also terminated to the north by a north-south to NNE-trending fault that also terminates the main body of ore to the north in this area of the mine. The pod of ore occurs at the intersection of these two structures. Bogacz (Archon Resources, 1999) states that this is evidence for the two


4075 mE
4100 mE
24700 mN
24675 mN
24650 mN
340 Fault
AMG
Mine Grid
Magnetic North
Newcrest Grid
2.34.30
11
38
49
70
59
80
42
36
84
75
85
44
43
38
88
85
60
60
85
40
60
80
85
65
LEGEND
Blayney Volcanics
Cowriga Limestone Member (Marble)
Mine Dyke Group
Post Mineralisation Intrusives
Carcoar Granodiorite
Skarn
Browns Creek Au-Cu Mine
10340m RL Underground Development with Geology and Structure
Plan No. : 6
Scale : 1:400
Date : 28/09/2000
Drawn : N. Kovacs
Geologist : N. Kovacs





LEGEND

- Blayney Volcanics
- Cowriga Limestone Member (Marble
- Mine Dyke Group
- Post Mineralisation Intrusives
- Carcoar Granodiorite
- Skarn

Browns Creek Au-Cu Mine

10320m RL Underground Development with Geology and Structure

Plan No. : 7	Scale : 1:500
Date : 28/09/2000	
Drawn : N. Kovacs	Geologist : N. Kovacs

structural sets (northwest and north-south and he includes the northeast) as forming at the same time. This has enabled an opening for the skarning fluids and the mineralising fluids to infiltrate the surrounding rock, thus forming the present day orebody. It is that these flatter dipping northwest structures were formed pre-mineralisation.

Cross-sections of the northwest structures that occur in the underground workings, particularly those that occur below 10365mRL, show the variation in strike of these structures in general. Interpretation of drillcore indicates that structures like the "340 Fault" appear to terminate or roll into the 4000E Fault to the west. They appear to do the same to the east with the banding and faulting in the marble. This implies that the northwest trend in these areas were formed prior to the north-south trend.

An alternative suggestion is that the two structural trends formed contemporaneously. If the northwest structures were displaced by the 4000E Fault, then there would be evidence of them west of it. However, as there is no substantial faulting beyond the 4000E Fault, they must have formed at the same time as the north-south trending structures. The formation of the northwest structures in this case, depends on another north-south oriented structure parallel to the 4000E Fault. As previously mentioned, the mylonite is oriented north-south as well as other faulting observed periodically throughout the mine. These could be the bounding features to the east.

Bogacz (Archon Resources, 1999) argues that the northwest trending structures are lower order features within a more dominant north-south trend. All northwest structures are perceived to be of the one set and all normal in displacement. King (Solid Geology, 1999) on the other hand, utilises his theory of two subgroups of the northwest trending group. He perceives that the two groups occurred at different times in the ore formation process. His model has the "flatter-dipping" structures as splays from the 4000E Fault. He interprets the "steeper-dipping" northwest structures as late, post-ore formation, as they appear to have displaced the ore.

However, there is no direct evidence of this. There is not two groups within the northwest trend and while there has been minor movements along such structures after ore formation, the large-scale movements have occurred prior to the mineralisation.

Generally speaking, the northwest trending structures appear to have a reverse sense of movement. This would entail the Mount David Shear Zone thrusting the Carcoar Granodiorite over the top of the skarn in a dominant dip-slip sense of movement. This is the viewpoint of King (Solid Geology, 1999) and movement in the order of tens of metres along dip is required. An alternative view is that these are normal faults with oblique sinistral strike-slip movement (Bogacz in Archon Resources, 1999). Again, the lack of cross-cutting features means that no definitive sense of movement on such structures can be identified. However, certain structures related to the Mount David Shear Zone in the open-cut indicate a dominant strike-slip movement. This may also be the case with other northwest structures.

An interpreted structure located towards the lower part of the orebody (10250mRL) has been termed the Lower Mount David Fault. This was used by some mine personnel to explain the somewhat dramatic shift in the Carcoar Granodiorite contact to the west (figure 4.6). This structure has not been proven and is highly speculative. Diamond drill core cutting this zone show evidence to the contrary. No shearing or faulting is evident and the contact mostly appears to be intrusive. Higher up in the mine, the granodiorite contact is irregular with embayments, supporting an intrusive contact. This indicates that the displacement in these lower levels is a primary feature of the granodiorite contact. In addition, the marble/andesite contact and skarn intersections do not shift west with the granodiorite, as would be expected. Rather, there is a thickening of the volcanic package and thinning of ore zone that does not support the presence of the Lower Mount David Fault.

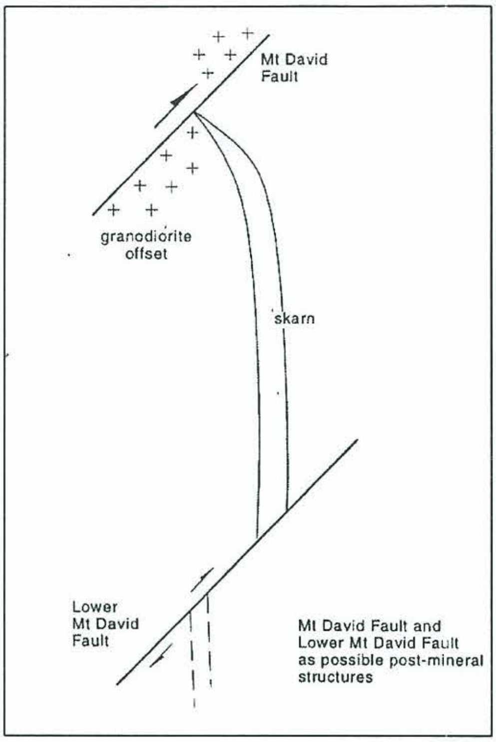


Figure 4.6 – Schematic cross-section showing an interpretation of the "Lower Mt David Fault" (Corbett, 1997).

4.4.1 Mount David Shear Zone

The Mount David Shear Zone is a gently anastomosing northwest oriented structural zone. It is observed in the recrystallised Cowriga Limestone Member (marble) in the open-cut workings. The term of Mount David Shear Zone has been used almost indiscriminately throughout the mine's more recent history, as it has been linked with a broad range of structures from moderately dipping NW-trending structures to steeply dipping N- to NNE-trending structures. However, it has been most commonly defined by steeply dipping northwest shears. The Mount David Shear Zone and related structures are relatively old with respect to the formation of the Browns Creek orebody. It has however, been significant in the structural preparation for the ore formation, namely the emplacement of the Carcoar Granodiorite.

Historical records and mine reports were researched to identify the original terminology of the Mount David Shear Zone. Mine personnel who have been linked with the Browns Creek orebody for a period of 20 years have revealed that the term "Mount David Fault" was given to the structural feature now observed in the southern limits of the open-cut (figure 4.7). This fault system has been misinterpreted in the past as several structures appear to roll into one another. Thus, the term Mount David Shear Zone was applied to the whole feature that is observed and not a single fault plane.

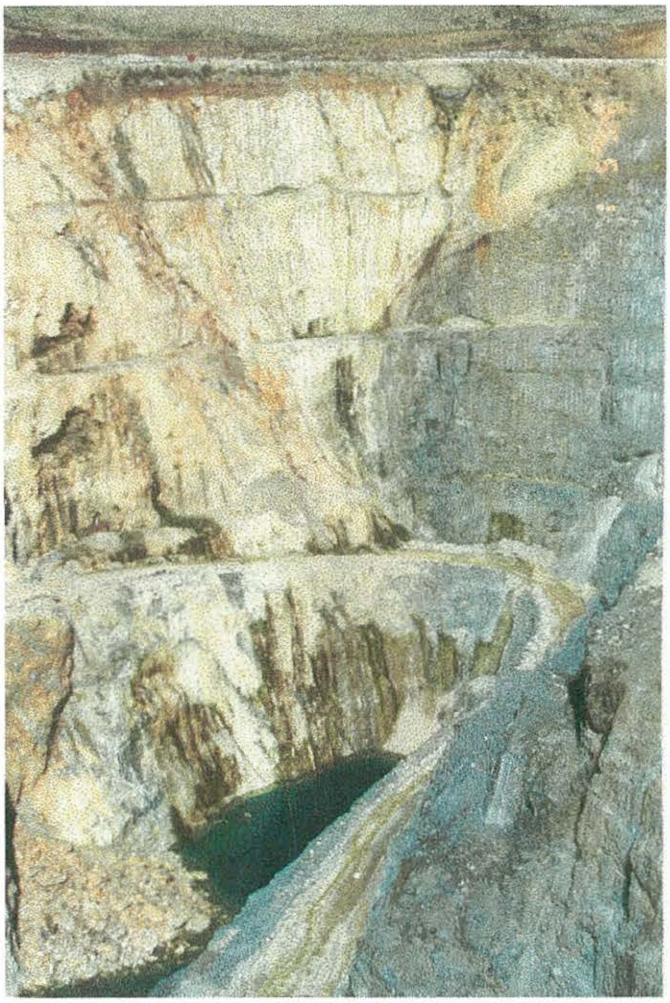


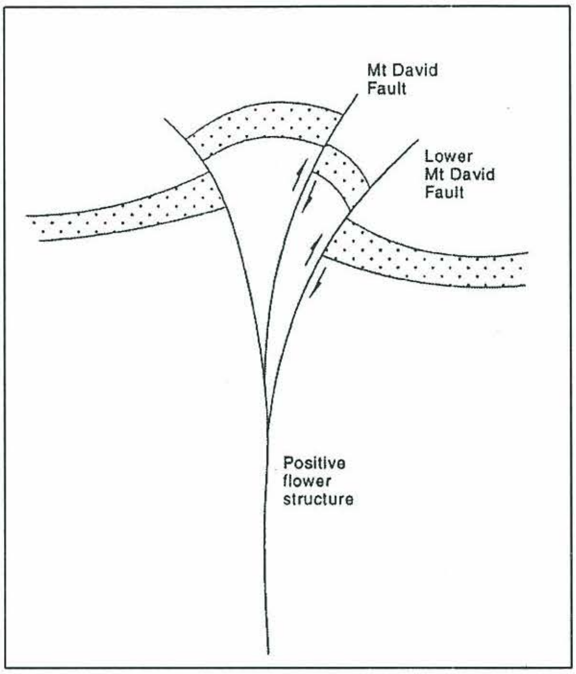
Figure 4.7 – Photo of the Mount David Shear Zone (dipping to the right) in the southeastern end of the open pit. Note faults at contact between granodiorite (right) and marble (left) (dipping to left) (Rangott & Bird, 1994).

The Mount David Shear Zone in the open pit cannot safely be measured, due to its inaccessibility. However, detailed measurements have previously been taken by Rangott and Bird (1994). These measurements of the shear zone, and parallel structures within the marble give a strike orientation of 150° to 180° and a dip of between 60° to 80° west. The variation in strike measurements shows that the shear zone anastomoses throughout the pit. The authors describe these structures as dominantly major and minor faults, with slickensided surfaces. However, as most of these have been solution-altered, a sense and timing of movement could not be determined. Sheared and boudinaged mafic dykes also occur along these planes, implying that there has been extension along these structures.

It is difficult to trace the Mount David Shear Zone through the bottom of the pit into the underground workings. Mapping through the uppermost levels underground (now inaccessible due to backfilling and stoping) does not show the presence of this shear zone. However, the 4000E Fault is noted in these levels but has not been mapped in the open-cut. Compiling the mapping from the open-cut through the upper few levels of the underground developments, it is noted that there is a coincidence between the location of the Mount David Shear Zone and the 4000E Fault. This adds credence to the postulation that the Mount David Shear Zone is the surface expression of the 4000E Fault, a belief held by ERA Maptec (1995) and Wilkins (1998). The former researcher suggests that the north-south oriented structures observed underground are splays from the Mount David Shear Zone. However, there is another structure that appears along the Carcoar Granodiorite contact with the marble in the open-cut. Alternatively, this could be the 4000E Fault. Due to inaccessibility, this structure could not be measured either. However, it does align with other north-south oriented shears south of the pit (section 4.3).

As previously mentioned, the Mount David Shear Zone appears to have other structures roll into it. This can be observed in the southern extent of the pit. Wilkins (1998) describes this as a positive flower structure (figure 4.8), which is also the view of Corbett (1997). A flower or palm-tree structure is formed by the vertical displacement along subsidiary structures to a curved major fault surface. The displacement along these subsidiary structures is normal to the fault surface, under transpression. The subsidiary structures are observed to roll into the main fault surface and are generally upward reversed or thrust faults with a component of strike-slip movement (Ramsay and Huber, 1989). Thus, if the structure that is observed in the southern limits of the pit is an example of a flower structure, it would be expected that the structures that roll into the main Mount David Shear Zone would have a northwest orientation. The structural mapping of this area by

Rangott and Bird (1994) is inconclusive. In addition, this would imply that the movement along the shear zone was dominantly strike-slip under a transpression environment.



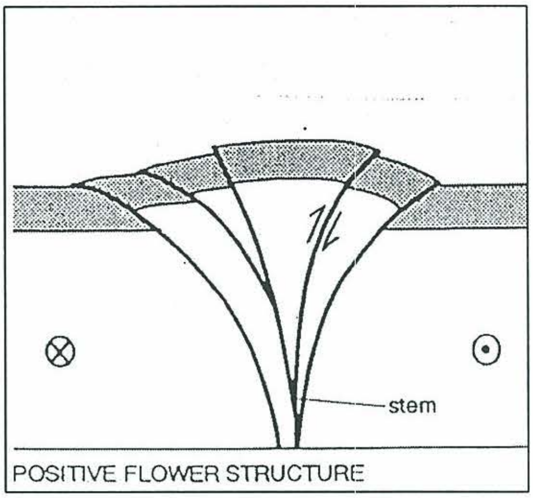


Figure 4.8 – Diagrams to explain the formation of a positive flower structure, from Corbett (1997, left) and Wilkins (1998, right).

The Mount David Shear Zone changes its overall orientation from northwest in the northern part of the pit to north-south in the central and southern limits. Thus, the orientation of the Mount David Shear Zone is dependent on where the measurement is taken. When looking further afield from the immediate mine area, particularly to the southeast, the Mount David Shear Zone again adopts a northwest orientation. However, this is on the other side of a regionally significant northeast structure that appears to have later movement than the northwest structures. It is postulated that the swing in the Mount David Shear Zone observed in the open-pit is a result of movement on the northeast structures, causing a swing around to a more north-south orientation (Section 4.5). An alternative view is that the mine is situated in a unique structural environment, where several structural trends are intersecting each other. If these structures have been reactivated at approximately the same time, the result would be structures merging into and offsetting each other, which is generally the viewpoint of Bogacz (Archon Resources, 1999). An individual structural trend would be difficult to trace through this area of intersection.

4.5 NNE - Northeast Structural Trend

While there is little evidence of any major structures that have a northeast orientation in the mine, there is little doubt of its regional importance and their influence on the mine environment. There are many major structures that occur in the region with a northeast orientation (030°). These extensive structures (of the order of many kilometres) occur to the north and south of the mine. Some have been interpreted by Hargraves Resources N.L. exploration personnel to pass through the location of the present day underground workings. It is proposed that these features are the controlling structures for the emplacement of mineralisation at the Browns Creek deposit.

Few northeast oriented structures are observed within the open-cut and underground workings. The majority of these are minor joints, fractures and small-scale shears. Stereographic projection of such structures gives a preferred dip/dip direction of 81°/315° and strike of 045° (figure 4.9). These structures show no obvious signs of movement and appear to be post-mineralisation. Detailed mapping performed by Wilkins (1998) shows some northeast trending structures in the uppermost levels of the underground workings. However, there is a northeast foliation within the skarn observed as a preferential mineral orientation. There is another form of foliation within the skarnified marble that has developed post-marble formation. The skarning fluids have infiltrated the protolith via fracture and joint sets, where they metasomatise the surrounding rock, eventually obliterating evidence of their channelways. Towards the edges of the ore zone, the fluids have not infiltrated to as great an extent as in the central part of the ore zone. This is evident as their original orientation can still be observed. As such openings have now been healed, a distinct measurement cannot be taken. However, they are oriented in a NNE direction.

Mapping of the upper levels of the underground workings (Wilkins, 1998) shows that there is a preferential NNE to northeast orientation of sub-vertical basalt dykes. These levels are no longer accessible. The basalt dykes, placed in a tensional

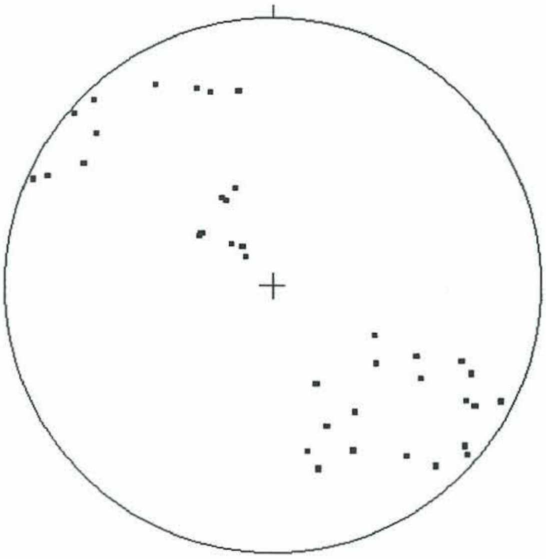
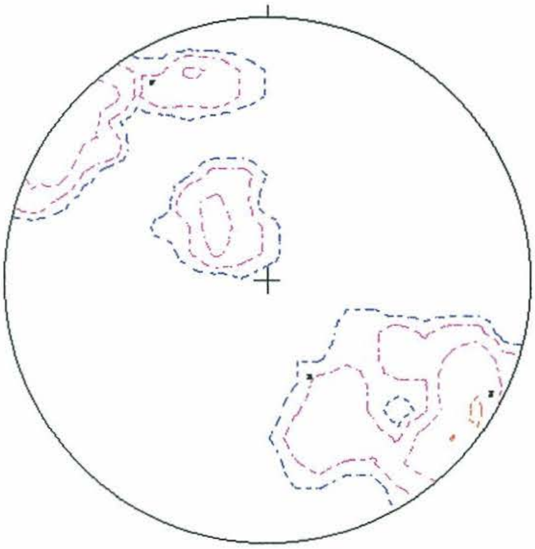
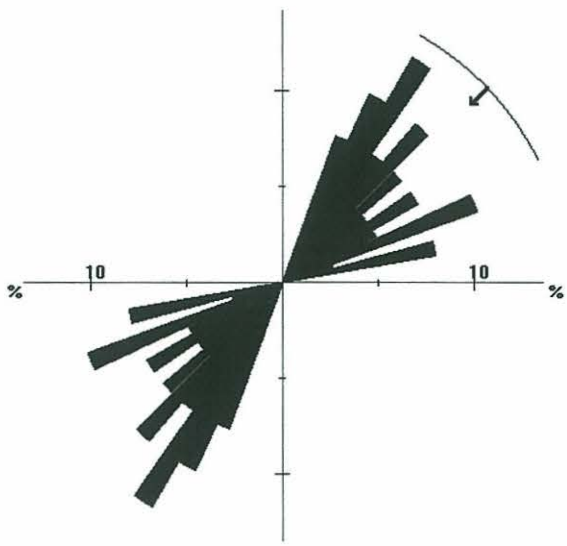


Figure 4.9 (a) Equal area projection - Northeast Structural Trend. Preferred direction = 81°/315°. All structures measured by author in underground exposures.



(b) Contour of equal angle projection - Northeast Structural Trend

• 1 point (2.70%)
3%
6%
12%
24%
(max. = 27.03%)



(c) Rose diagram - Northeast Structural Trend.
Vector mean = 047°
(5° sector size)

position, are interpreted as having been subsequently skarnified and mineralised. Thus, the NNE to northeast orientation has been active pre-mineralisation.

Drilling intersected a fault in the hangingwall in the southern part of the orebody that is interpreted to have a northeast trend. Although the core through this area has not been oriented, the same interpretation can be made on the 10285mRL, 10265mRL and 10250mRL levels. The development did not continue to these southern-most extents as the bulk of the ore has been cut by a late dioritic intrusion, that leaves only a thin sliver that is not economic to mine.

Another steep northeast trending fault is interpreted to the north of the current development in the lowest-most levels of the mine striking northeast (24850mN, 4000mE). A distinct northeasterly trending truncation of the orebody is observed when viewing a three dimensional solid of the ore zone in plan view (figure 4.10). The lower levels of the mine do not extend this far north, thus detailed mapping of the upper levels by Wilkins (1998) was reviewed. On these levels (10652mRL to 10530mRL), Wilkins mapped northeast, dextral structures matching the location of the interpreted structural zone. He interprets this as a releasing bend on the 4000E Fault, where it shifts to the west. His interpretation does not have the structures continuing east of the 4000E Fault. The lack of substantial drilling and development in this area has meant that there is little to no information regarding the continuity of such structures beyond the 4000E Fault. However, the swing in the 4000E Fault is real. This change in direction has most likely occurred along a pre-existing northeasterly fault plane. This plane is the same one that can be observed in the three dimensional solid and upper levels.

There appears to be two steep northeast trending faults at either end of the orebody, located some 200m apart. Between these is a development of skarn that has formed by the infiltration of fluids along small northeast oriented fractures. The location of the faults coincides with those that have been interpreted and projected at depth by Hargraves Resources N.L. exploration personnel in the vicinity of the mine. The

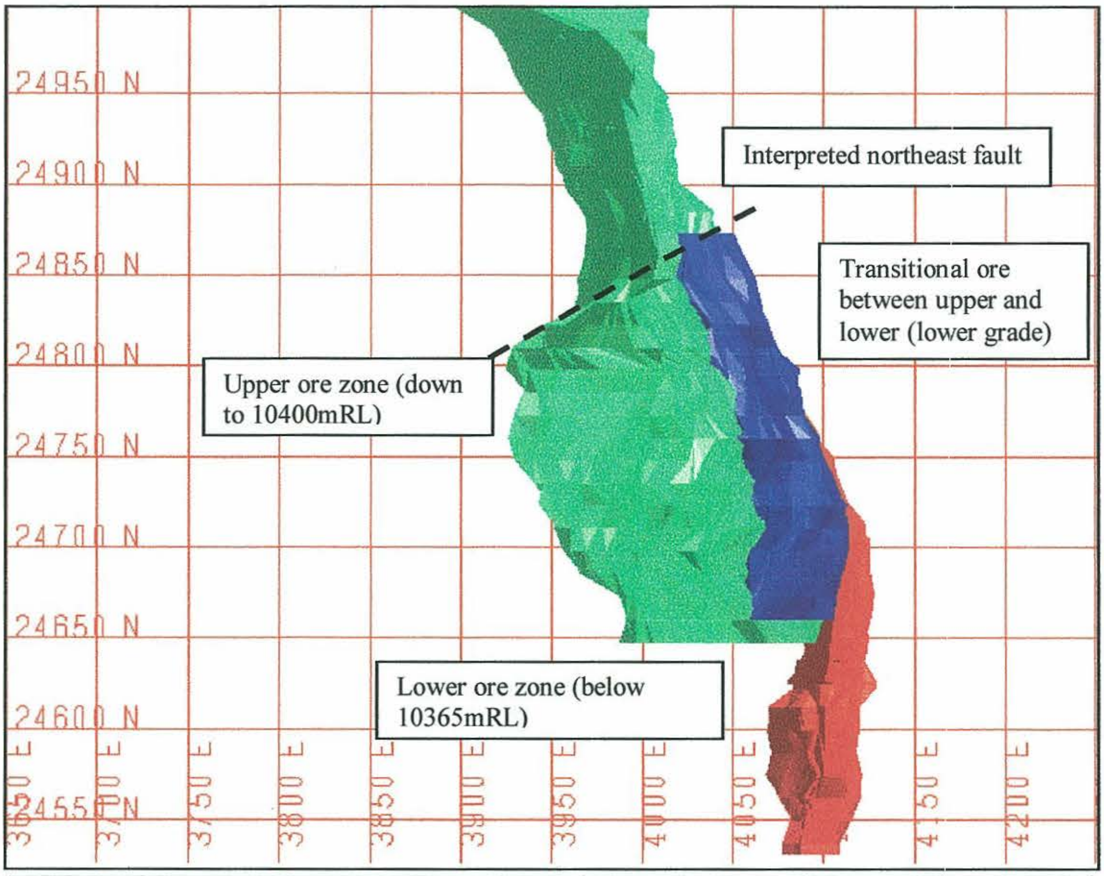


Figure 4.10 – Three dimensional solid of the orebody as of December 1999. Dashed line represents a possible northeast fault controlling ore location. Ore to the north of this fault occurs above it.

faulting in question appears to terminate the economic mineralisation to the north and south. This relation of NNE to northeast oriented structures is not unique to the Browns Creek deposit. Further to the southeast of the mine is the Millners prospect, where the mineralisation is constrained by northeast oriented structures, with an interaction of northwest structures.

Stereonet plots of northeast structural measurements (see figure 4.9) indicate that there are two groups of northeast structures - a steep to moderate northwest dipping group (with a mean dip/dip direction of 75°/303°) and a flat-lying southeast dipping group (with a mean dip/dip direction of 24°/131°). This has not been identified by previous researchers of the Browns Creek deposit. The flat-lying structures were observed and measured from a variety of levels throughout the mine (located within the ore zone and the Carcoar Granodiorite). The structures observed included minor shears, minor faults, joints and veins. The lack of substantial evidence of this flat-lying northeast group implies that it is only a minor structural feature of the Browns Creek orebody. It is most likely not involved in the formation of the orebody and is likely to have occurred post-mineralisation. Alternatively, the lack of examples of these structures may be a factor of the sub-parallel development of the drives. Thus, they cannot be overlooked.

4.6 East-West Structural Trend

This group of structures are oriented around east-west (around 280° AMG) have often been misinterpreted as the *Cadia Trend* or the *Lachlan River Lineament*. These other regional structures are oriented 300° AMG, different to the east-west structures in the mine. The *Cadia Trend* refers to the orientation of structures that host the gold-copper veins at the Cadia/Ridgeway deposits that are located to the west of the Browns Creek deposit. The *Lachlan River Lineament* stems from several magnetic lineaments interpreted from regional airborne magnetic data (AGSO). These lineaments appear to transgress all known geological units and formations, regardless of age.

While the east-west structures have some regional importance, they are rarely observed in relation to the Browns Creek deposit, with the exception of the pit. A set of moderately to shallow south to SSW-dipping fault planes can be readily observed within the Carcoar Granodiorite, on the western wall of the open-cut (figure 4.11). Rangott and Bird (1994) report a variation in strike (approximately 070° to 110°) of these structures, with the majority of measurements at 100°. The structures are described as generally chloritic and commonly oxidised where open. The relative sense of movement could not be determined however, the authors report a probable local reverse sense of movement. This is confirmed by the observations made in this report. The contact of the Carcoar Granodiorite in the northern limits of the pit has been offset by moderately dipping broadly east-west trending structures that have offset the margin of the granite with an apparent reverse movement.

Figure 4.11 – Photo of western end of open pit showing east-west trending faults (dipping to the left) offsetting the granodiorite (left of photo) contact.

The east-west trend also manifests itself as a series of joints within the Carcoar Granodiorite and the marble in the open-cut (preferred dip/dip direction from steroegraphic projection 56°/189° and strike of 279°, figure 4.12). These joint planes generally have a shallow dip (down to 5° to 15° in the marble, Rangott and Bird, 1994) to the north to NNE. The timing of the east-west structural trend in the pit by Rangott and Bird (op. cit) indicates that they occurred prior to the north-south structural trend. The authors state that the east-west trend is observed within blocks that are bounded by major north-south structures.

The east-west trend is rarely observed in the underground workings. There have been no major structures intersected by the development or drillcore. However, as the core has not been oriented, this is not a certainty. There have been several measurements taken of minor joint sets and other fractures that have a mean strike of 268° (figure 4.12). These occur within the ore zone and have little lateral extent (generally less than one metre). Their surfaces are generally undulating and rough.

The other example of the east-west trend in the underground workings is the intrusion of the only recorded example of the Post-Mineralisation Intrusive, occurring on levels below 10285mRL (see plan 2). Such rounded bodies tend to cut perpendicularly across the ore zone. No structures were observed in relation to these intrusives and as such, there may not be a structural relation to the intrusion of these

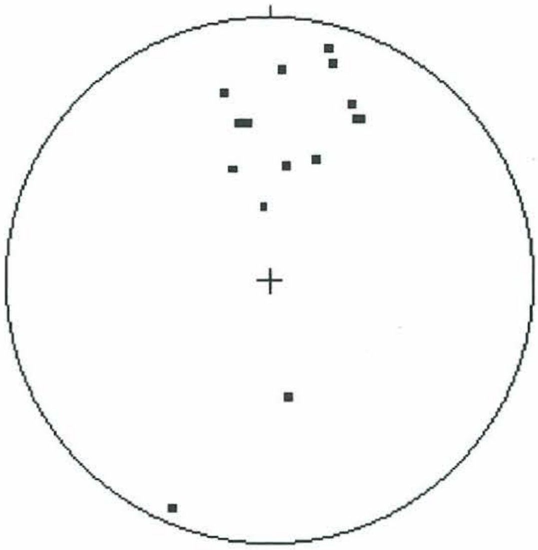
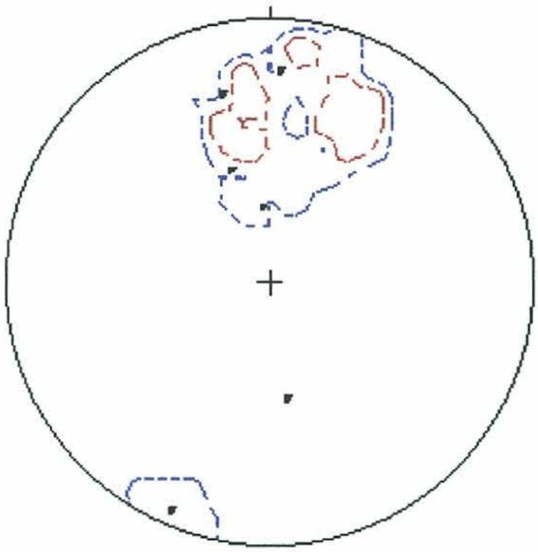
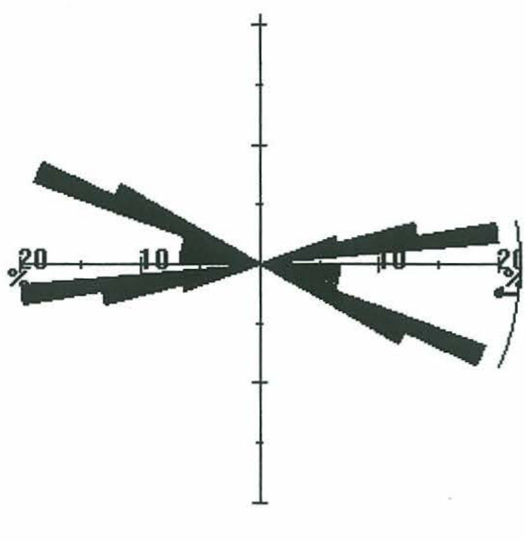


Figure 4.12 (a) Equal area projection - East-west Structural Trend. Preferred direction = 56°/189°. All structures measured by author in underground exposures.



(b) Contour of equal angle projection - East-west Structural Trend



(c) Rose diagram - East-west Structural Trend. Vector mean = 097° (5° sector size)

bodies. Alternatively, they may represent a zone of extension at the time of emplacement.

4.7 Synthesis

All of the structural orientations described here have been active over an extended period of time, most of which occurred prior to the formation of the orebody. Each played a role in the mineralisation process, some directly and others involved in the preparation of the ground. In comparison to the structural activity prior to mineralisation, there has been comparatively little activity post-ore formation, despite the large amount of tectonic activity in the region that has occurred after the formation of this orebody (for example the Mount Canobolas volcanism). However, it is difficult to comprehend the view of Bogacz (1999) that there has been no movement on any of these structural sets after the ore was formed. Utilising the knowledge of the region by the Hargraves Resources N.L. exploration personnel, the following is a synthesis of the structural history of the Browns Creek orebody.

- The north-south oriented structures are interpreted as the earliest structures occurring in the vicinity of the Browns Creek deposit. The most notable occurrence is the Carcoar Break that may have a displacement in the order of tens of kilometres. Such a regional event would result in the formation of a variety of lower order structures of similar orientation. The 4000E Fault or the mylonite zone may have propagated at this stage but were later reactivated.

- The northwest trending structures (such as the Mount David Shear Zone) appear to be the next oldest structural trend at the Browns Creek deposit. This structural trend is offset by all other known structural orientations. Its importance to the formation of ore at the Browns Creek deposit is paramount. The Mount David Shear Zone truncates the Carcoar Granodiorite/Blayney Volcanics package alongside the Cowriga Limestone Member. This forms a locally significant contact zone extending to the Millners Prospect.

- Following the movement on the northwest trending structures, the northeast trend was activated. These structures are observed to cut and offset the Carcoar Break and the Mount David Shear Zone. They are readily observed on all airborne magnetic images and have a very regular distribution.

- Following this, the north-south structural trend is thought to have been reactivated. This has been crucial in the formation of the present-day relationship between the 4000E Fault and the mylonite zone in the marble. At this stage, one of these structures was pre-existing. The other formed as a result of transposition of stress across the northeasterly offset. This has resulted in the formation of converging sub-parallel north-south trending structures within the mine environment. In between these structures is a range of smaller scale structures. This has produced dilation in a northeast orientation and shearing in a northwest orientation, which indicates dextral movement along the north-south oriented faults. This is consistent with observations of dextral displacement taken along the Carcoar Break. The fluids responsible for skarn formation would have infiltrated at this time.

- The next period of activity is postulated as being crucial to the formation of ore at the Browns Creek deposit. While the north-south and the northwest structural trends were responsible for more substantial structural deformation in the area, the northeast trend was more pervasive. The northeast trend was reactivated, causing opening of north-south oriented structures. This facilitated the formation of a dilatant zone required for the formation of the orebody. This zone also hosted the intrusion of the granite into the "Ore Zone Package". For such dilational zones to occur, there would have to be a component of dextral lateral movement on the northeast faults.

- The north-south trend was reactivated post-ore formation. This late movement has been responsible for the formation of the sheeted veins and late shearing.

The paragenetic sequencing of the east-west trend is unknown. This is due to the lack of observed cross-cutting relationships. It is a rarely seen and subordinate structural trend that has had little impact on the formation of the ore or post-ore deformation. Due to the absence of later cross-cutting structures, this trend is thought to have formed post-ore.

The activation and reactivation of all of these separate structural trends has resulted in a very unique setting. This dilatant environment and the specific combination of lithologies are prime factors in the formation of the Browns Creek deposit.

Structure	Example	Other
North-south	Carcoar Break; pre-cursor to the 4000E Fault	Intrusion of Carcoar Granodiorite
Northwest	Mount David Shear Zone	
Northeast	Minor structures offsetting Carcoar Break and Mount David Shear Zone	
North-south	4000E Fault and/or mylonite zone	Skarn formation
Northeast	Dilation of north-south structures; Ore Zone Package	Intrusion of Mine Dyke Group; ore formation
North-south	Sheeted veins; post-ore shearing and reactivation of pre-existing structures	?Post-Mineralisation Intrusive
?East-west	Minor structures	

Table 4.1 – Summary table of structural history of the Browns Creek deposit.

5. Mineralisation

The Browns Creek Mine is a gold and copper deposit that is hosted within calcium metasomatised volcanics and limestone. Mineralisation is composed dominantly of bornite and chalcopyrite, with lesser amounts of pyrrhotite, magnetite, arsenopyrite, molybdenite, sphalerite, tellurides, electrum and occasional visible gold and native copper. For many years, the mineralisation was thought to be retrograde skarn. However, recent research has revealed that the mineralisation is magmatic derived and the economic grade of gold and copper was deposited after the skarn was formed. It is proposed that the mineralisation is not only magmatically derived but that it is also related to the intrusion of the Mine Dyke Group of the Browns Creek Intrusive Complex.

5.1 Ore Mineralogy

The ore at the Browns Creek Mine is dominated by the presence of chalcopyrite and bornite. These ore minerals typically occur within the skarn although rare specks are identified in the Mine Dyke Group and Carcoar Granodiorite. The grains vary in size and tend to occur in patches that can vary up to several centimetres wide. There is no distinct difference in the appearance of chalcopyrite from the marble skarn to the volcanics skarn. However, bornite is generally elongate and fine-grained within the marble skarn due to the presence of bladed and fibrous wollastonite (figure 5.1), and tends to be more 'blebby' within the volcanics skarn. The copper sulfides are dominantly located within veins, fracture infill and disseminated. They are also located within fault zones and shear zones. These two minerals are dominantly found to coincide and their presence is associated with the highest gold grades.

Visible gold is a feature of the Browns Creek deposit (figure 5.2). It was readily observed in ore definition drillcore. This was particularly the case with the lower ore zone of the mine. An example was the 10305mRL ore definition drilling where visible gold was observed within a number of 12.5m spaced drillholes. The visible gold is typically of pinhead size and is mostly located within the wollastonite-rich skarn with bornite and minor chalcopyrite. However, rare specks were also observed within the sheeted vein ore.

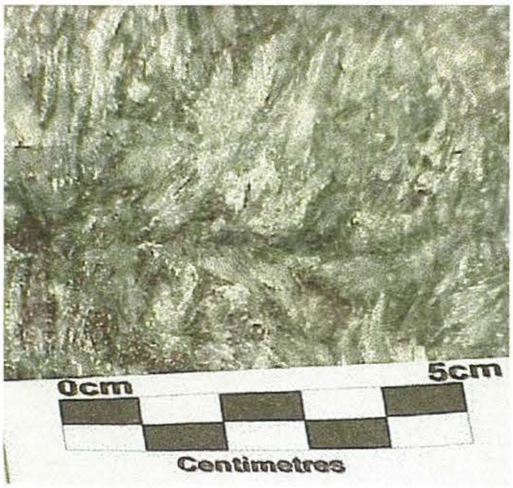


Figure 5.1 – Photo of bornite in bladed wollastonite (sample courtesy of G. Kovacs).

Figure 5.2 – Photo of gold in skarn altered marble (sample #NH66, hole #30515, 2.36m).

Microscopically, gold occurs by itself and in association with other minerals. However, it is almost always spatially associated with sulfides, mostly copper sulfides, especially chalcopyrite and bornite, also with other ore minerals. Creelman *et al* (1990) state that in the open cut the gold was intimately associated with hessite (Ag_2Te). They add that the gold contained tellurium that confirms its telluride association. To support the association of gold with silver, Barron (1999) reported the presence of electrum in the ore samples.

Arsenopyrite occurs throughout the ore and is also observed within late shears and fractures with quartz. Petrological examination (Barron, 1999) found that it hosts gold. The gold occurs as small inclusions within the arsenopyrite and along its grain boundaries. Arsenopyrite also contains small inclusions of pyrrhotite and chalcopyrite.

Pyrrhotite occurs in small quantities throughout the ore (figure 5.3). However, large accumulations of fine-grained pyrrhotite occur with magnetite, an example of skarn alteration. The most extensive zone of this skarn occurs in the lower parts of the orebody (10285mRL and below). It occurs immediately west of the ore zone, dominantly within the Blayney Volcanics. The zone ranges up to one metre wide and it can be traced along strike for an increasing distance (up to several metres) with depth. Where pyrrhotite is the dominant constituent within these zones, anomalous gold grades are common (around 30g/t). This skarn appears to have occurred after the prograde skarn. This zone is discussed in further detail in the later part of this chapter (section 5.4). Apart from this zone, there is only a minor amount of magnetite occurring within the ore. Rare grains were also observed in thin sections of the mine-related intrusives.

Figure 5.3 – Photo of pyrrhotite in late quartz-calcite vein (sample #NH76).

Molybdenite has been identified sporadically throughout the deposit. In underground exposures, molybdenite was found to occur within narrow milky quartz veins (figure 5.4). The grains are clearly visible in hand specimen and are around two millimetres wide. These veins were usually located outside of the main ore zone within the Carcoar Granodiorite. However, rare veins were located within the ore zone. These veins have formed after the skarn as they clearly cross cut it.

Figure 5.4 – Photo of molybdenite in quartz vein (sample #NH75).

Sphalerite has been reported within the ore however, this study showed only small grains present within the intrusive phases. Barron (1999) reported its presence within a calc-silicate skarn rock. The sphalerite observed is an iron-poor variant, based on its light colour.

There is a noticeable lack of pyrite within the Browns Creek deposit. Small grains of pyrite can be found within the intrusive phases however, it is rare in the ore zone. The exception is within late-stage shear and fault zones. Petrology reports by Barron (1999) state only minor amounts of pyrite located within the ore. However, an earlier report by Taylor (1983) of the ore within the open cut reveals a greater abundance of pyrite than the deeper ore zones. A greater abundance of pyrite within the open pit may suggest a greater interaction with meteoric fluids, indicating a more oxidised environment.

Taylor (1983) continues that there are two types of ore present within the open pit at the Browns Creek Mine - stratabound skarn and vein skarn. The stratabound skarn consists of three ore mineral assemblages, representing increasing metamorphism/ metasomatism:-

(i) pyrite - chalcopyrite

(ii) pyrrhotite - pyrite - chalcopyrite with retrograde pyrite and marcasite

(iii) banded arsenopyrite - chalcopyrite - pyrrhotite - (tennantite - gold)

The vein skarn (sub-vertical mineralised fractures) also consists of three ore mineral assemblages:-

(i) bornite - chalcopyrite - pyrite - chalcocite - covellite

(ii) chalcopyrite - bornite - chalcocite - pyrite - gold

(iii) supergene enrichment in fault gouge (pyrite - chalcocite - chalcopyrite - bornite - covellite - copper oxides - native copper - gold)

As these assemblages relate to the early ore that was mined in the open cut, Taylor's findings cannot be substantiated. However, rare native copper was also identified within shear zones in the lower ore zones. Another mineral that was reported by Creelman *et al.* (1990) to occur in the open pit was the bismuth telluride, hedleyite, located within chalcopyrite veins. The presence of appreciable amounts of bismuth is a geochemical characteristic of the Browns Creek Mine. However, little has been reported on the presence of bismuth minerals and they were not observed as part of this research.

5.2 Styles of Mineralisation

There are several different styles of mineralisation at the Browns Creek Mine. However, the majority of mineralisation occurs as microfracture infill and veins, or is finely disseminated throughout the skarn and other host lithologies. It overprints the pre-existing prograde and retrograde skarn mineralogy, indicating that the main mineralisation may not be related to the silicate-skarn formation (see figure 5.6). This has been clearly observed in underground exposures, hand specimen and by previous petrological reports. Such reports have found that the gold and copper mineralisation is frequently observed along microfractures through pre-existing minerals, including garnet porphyroblasts. Thus the bulk of mineralisation has been introduced by a late fluid which has deposited the ore minerals within microfractures and along grain boundaries.

Sheeted vein mineralisation is also present at the Browns Creek Mine (figure 5.5). As previously discussed (Chapter 4), these quartz veins form a north-south trending parallel vein set. The veins have formed late in the evolution of the Browns Creek deposit and are dominantly located within the Blayney Volcanics. However, it is only the sheeted veins within the upper levels of the mine that contain significant mineralisation. Other sheeted quartz veins were intersected within the lower levels of the mine, which were barren or contained only sub-economic grades.

The sheeted veins are composed of quartz - calcite - epidote - prehnite - chlorite - sericite - gold - chalcopyrite - bornite. This represents lower temperature retrograde ore skarn assemblages (Smart and Wilkins, 1997). The veins were host to very high

Figure 5.5 – Sheeted quartz veins in drillcore (hole #HD7B, 326.6m). Au values are 37 – 41ppm (Rangott & Bird, 1994).

gold grades in these upper levels of the underground workings, reaching up to 40g/t. Barron (1999) identified other minerals within the veins:- chalcocite exsolved from bornite, tellurides, arsenopyrite with blebs of silver and electrum.

Petrological observation by Barron (1999) has revealed that the sheeted veins cut both the skarn and the Mine Dyke Group. However, sample NH43 was taken from a dyke that clearly cut through the sheeted vein mineralisation. This indicates that the formation of the sheeted veins is closely linked, and possibly syngenetic with, the intrusion of the dykes. This also suggests a relation in the source of vein material and the intrusives.

5.3 Metal Associations

Throughout the deposit, gold grade has always been closely related to copper grade. The ratio between the two metals has been consistently around 1:1000. However, what has changed is the style of gold crystallisation and the form of the copper mineralisation. There is a decrease in the abundance of bornite relative to chalcopyrite with depth. This may be an indication of metal zonation within the system. It may also relate to changing temperatures and hence proximity to a source. In addition to the changing copper sulfides, the gold has decreased in overall grade but has concentrated in places, giving the indication in ore reserve calculations that it is more "nuggetty". Thus the ratio of gold to copper has remained the same as the decrease in bornite (Cu_5FeS_4 with 63 weight % Cu, compared with chalcopyrite – $CuFeS_2$ with 34 weight % Cu) crystallisation is matched by a decrease in the overall gold grade.

While a metal zonation is not obvious, it has yet to be investigated. The gold grades have decreased with depth, averaging around 4.5 g/t gold as opposed to the upper levels where grades averaged around 7 g/t gold. The form of the copper sulfide has also changed from bornite to chalcopyrite. Apart form these changes, a slight increase in molybdenite occurs at depth. This may indicate that the system is getting closer to a magmatic source. An alternative suggestion is that the system is becoming slightly more reduced at depth. This is consistent with the increased pyrrhotite content.

5.4 Pyrrhotite - Magnetite Skarn

Massive magnetite and pyrrhotite zones occur sporadically throughout the deposit. These zones have become more frequent with depth and extend over several metres, with an average width of up to one metre. They host very high gold grades of up to 30 g/t but little copper. The zones have formed by replacement of the protolith and are forms of skarn alteration.

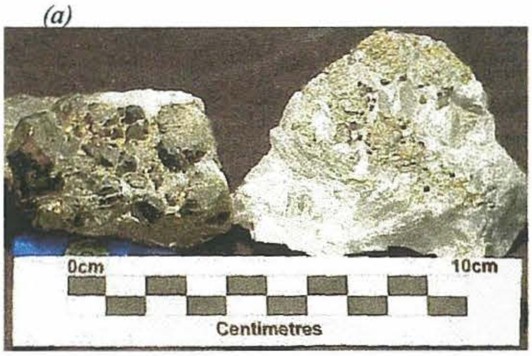
The pyrrhotite and magnetite zones occur at the contact of the ore zone with the surrounding Blayney Volcanics. The zone has been cut by the Post-Mineralisation Intrusive of the Browns Creek Intrusive Complex. Thus, they have formed between the hornfelsing of the volcanics unit and the intrusion of the Post-Mineralisation Intrusive. There are two possible origins for this style of mineralisation:- either it has formed as a skarn due to the intrusion of the Carcoar Granodiorite or it is related to the intrusion of the Mine Dyke Group which has been responsible for the bulk of the mineralisation.

Unfortunately, this pyrrhotite-magnetite zone has not been investigated in detail due to lack of development and drilling through it. The zone was given little importance in mine and drilling planning by previous mine personnel due to the low gold grades associated with it in the upper levels of the underground mine. Thus any conclusion beyond this would be highly speculative. The exception is Corbett (1997) who makes mention of them briefly and describes them as a distal skarn, formed at the time of prograde skarn. His conceptual cross-section shows the magnetite skarn as occurring along the eastern-most margins of the orebody, along the volcanic/marble contact. The presence of pyrrhotite indicates a reduced fluid has been responsible for the mineralisation and also that the fluids have not cooled significantly. In addition, the presence of magnetite indicates the proximity of a magmatic source. It is suggested that the pyrrhotite-magnetite zones are related to the initial skarn alteration of the host lithologies that was caused by the intrusion of the Carcoar Granodiorite. The gold present within these zones is suggested to be part of the later main mineralisation event. It is also noted that magnetite skarn is also located within the Milners area.

5.5 Implications from Mineralisation

The nature of the mineralisation indicates a magmatic source that is post-silicate skarn formation. There are several key features that support this. Petrography shows that the mineralisation is replacing the pre-existing skarn mineral assemblage. The ore minerals are found to occur dominantly within microfractures and veinlets that clearly crosscut the skarn mineral assemblage (figure 5.6). Smart and Wilkins (1997, after Meldrum, 1995) state that the mineralisation is related to the retrograde gangue mineral assemblage of calcite - quartz - sericite - chlorite - epidote - amphibole - biotite (figure 5.7). They add that this has formed from the infiltration of hydrothermal fluids as the system has decreased in temperature.

(a)



(b)

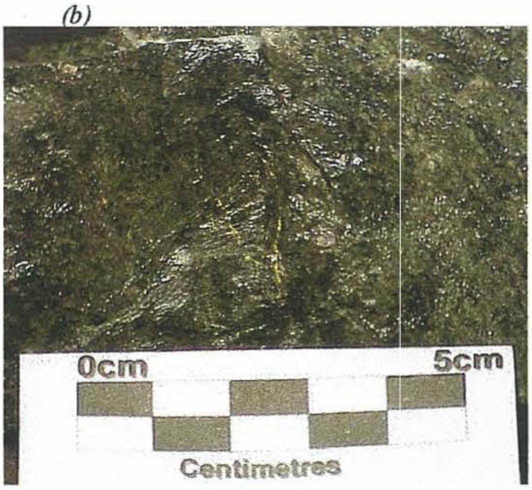


Figure 5.6 – Photos displaying late crystallisation of chalcopyrite. (a) Overprinting euhedral garnet (sample courtesy of G. Kovacs). (b) In hornfelsed volcanics (sample #NH68).

Creelman *et al.* (1990) revealed that bornite present in this system is particularly rich in sulphur. Sulphur-rich bornite is indicative of low temperature sulfide formation due to direct precipitation or supergene reactions (Yund and Kullerud, 1966 and Dutrizac *et al.*, 1970, in Creelman *et al.*, 1990). To support this finding, the presence of hessite with gold also indicates low formation temperatures (approximately 200°C) (Vaughan and Craig, 1978, in Creelman *et al.*, 1990).

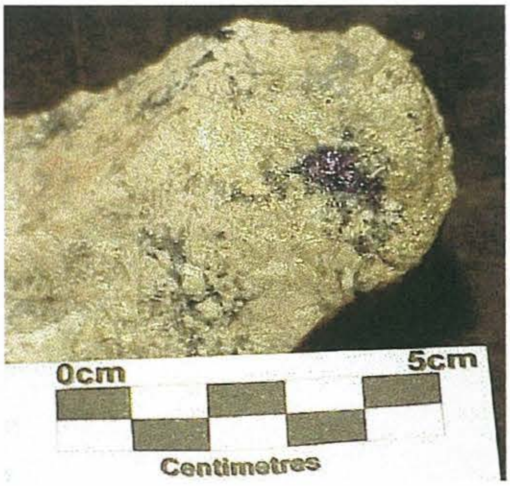


Figure 5.7 – Photo of bornite within epidote alteration (sample #NH73).

There is petrological evidence to support a magmatic source of the mineralisation. Magnetite has been identified in thin section in minor amounts within the ore. In her petrological report, Barron (1999) observed that minute blebs of bornite were located within igneous quartz grains in a late-stage crosscutting quartz monzonite.

Barron states that this in association with the copper sulfides comprising the mineralisation, resembles assemblages located proximal to an intrusive porphyry. In addition, the presence of arsenopyrite with gold/electrum is suggested to indicate formation from the mixing of a hot porphyry-related fluid with a meteoric fluid in a distal vein system.

6. Igneous Geochemistry

The focus of this thesis is the intrusive activity that is prominent in the Browns Creek deposit and its relation to mineralisation. The key to deciphering the relation of the respective intrusive bodies with the mineralisation dominantly lies in the geochemistry of each phase and each one's relationship with the ore zone. Five objectives were defined for the geochemical observations.

1- Derive the connection between the Long Hill Phase and the Carcoar Phase of the Carcoar Granodiorite.
2- Derive the relation, if any, of the Mine Dyke Group with the Carcoar Granodiorite.
3- Place the Post-Mineralisation Intrusive into the Browns Creek Intrusive Complex.
4- Compare the intrusives located within the orebody to others in the area which may also be related to mineralisation.
5- Aim to establish the intrusive phase that is most likely to be related to mineralisation.

Through these objectives, it was revealed that these intrusive bodies located throughout the deposit are geochemically related. Their geochemical signatures identified an evolving magmatic source producing several different intrusive phases. These were the Long Hill Phase (previously known as the *Long Hill Diorite*) and the Carcoar Phase of the Carcoar Granodiorite Pluton, the Mine Dyke Group (previously known as the *Monzonites*) and the Post-Mineralisation Intrusive (previously known as the *Late Diorite*).

The Mine Dyke Group of intrusives is conspicuous with respect to the mineralisation. This phase of intrusive activity is predominantly located within the ore zone and is rare on either side of it, as has been discussed in Chapter 3. This became the focal point of the study, as it had not been investigated in any great detail by previous researchers of the area. The most obvious intrusive phase that is also looked at is the Carcoar Granodiorite as it occurs to the immediate west of the ore zone and was thought to be related to the mineralisation. The data has been obtained from a variety of sources including Hargraves Resources N.L., A.G.S.O. and previous researchers in the area. While there are more data available, many were not included due to the uncertainty of their sample location and nomenclature.

6.1 Previous Geochemical Studies

While there have been plenty of whole-rock geochemical analyses performed on igneous rocks of this area, very little has been written about the results and any geochemical relations between the intrusive phases. Meldrum (1995) has performed whole-rock geochemical analyses on a variety of rocks but has not discussed these results in any great detail, except for the purposes of classification. Kjolle (1997) has also performed geochemical analysis on a variety of rock types form the Browns Creek deposit. However, the geochemical relationship between the intrusives has not been investigated. Trzebski *et al* (1999) and Lennox *et al* (1998) have studied regional relationships between the Carcoar Granodiorite and the Barry Granite and Sunset Hills Granite (Neville Granite). However, these studies have focused on structural relations between these intrusives and have also included geochronology. Whole rock analyses of several of the intrusives studied are also included in various databases regarding intrusives in the Lachlan Fold Belt. However, no detailed comparisons are made of the intrusives associated with the Browns Creek orebody. Finally, Lawrie *et al* (1998) studied intrusive phases associated with the Bald Hill Prospect, also owned by Hargraves Resources N.L. and included brief details about this in their abstract. The analyses that were collected for this study are located in Appendix 2.

6.2 The Long Hill Phase and the Carcoar Phase of the Carcoar Granodiorite

The Carcoar Phase is a new term introduced to refer to the granodioritic compositions within the Carcoar Granodiorite pluton. The Long Hill Phase refers to those more mafic portions which represent cumulates of the Carcoar Granodiorite. Such mafic portions have historically been referred to as the *Long Hill Diorite*, an intrusive that was reported to occur on the northwest corner of the Carcoar Granodiorite (figure 6.1). The Long Hill Phase is not a separate intrusive body that has formed from a separate magmatic event. This is supported by the definition given by Wyborn in the Bathurst Sheet Explanatory Notes (Pogson and Watkins, 1998). In addition, other examples of these types of intrusives have been identified throughout the mine. Thus, the terminology of Long Hill Phase is utilised to refer to all those mafic (cumulate) phases of the Browns Creek Intrusive Complex.

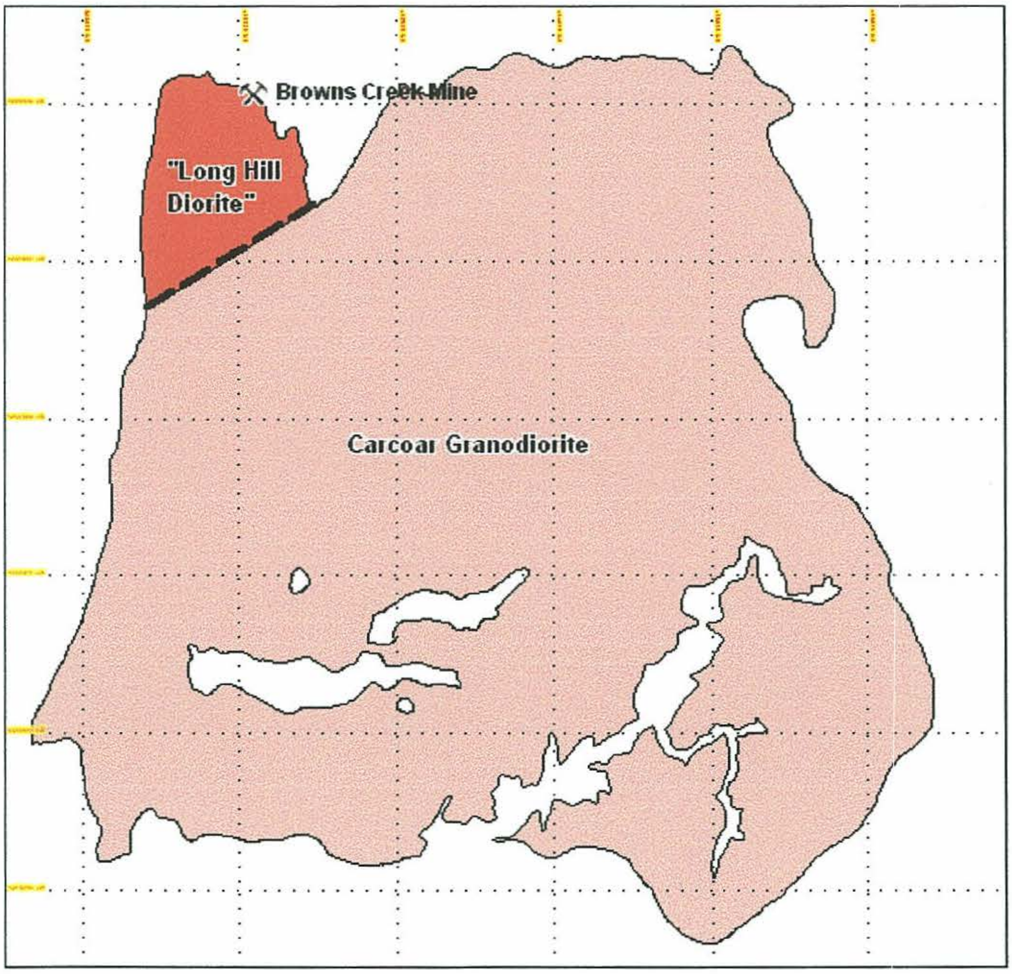


Figure 6.1 – The Carcoar Granodiorite with the previously interpreted "Long Hill Diorite". The intrusives were inferred to be fault bounded, as marked (modified after AGSO Bathurst 1:250,000 sheet – refer to figure 2.2).

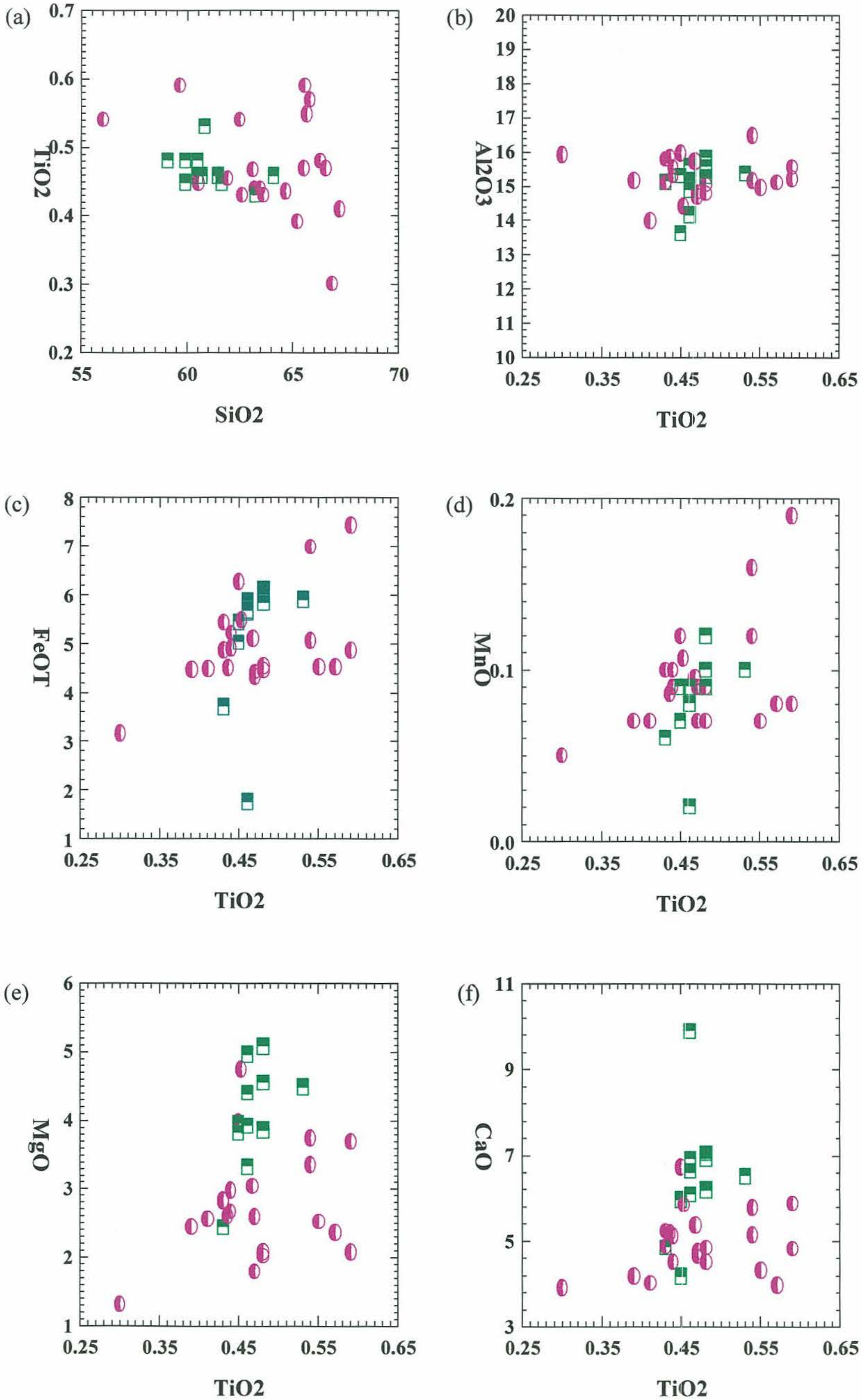
There is an alternative suggestion that while the Long Hill Phase and the Carcoar Phase are part of the same plutonic body, they represent different levels of emplacement. It has been suggested that the *Long Hill Diorite* is an uplifted block of the Carcoar Granodiorite. The movement is thought to have occurred along an interpreted northeast structure that was postulated as being the boundary between the two intrusives.

Kjolle (1991) classified the *Long Hill Diorite* by modal mineralogy on a QAP diagram. This gives a range of compositions from granodiorite and tonalite to quartz-diorite. Kjolle also classified the *Carcoar Granite* as granodiorite. The petrographic observations in this study support this nomenclature.

The Long Hill Phase and the Carcoar Granodiorite are similar in texture and overall hand sample appearance, indicating a possible connection in their origin. However, the Long Hill Phase is more mafic in appearance. This is consistent with its higher amphibole content relative to the Carcoar Phase. In addition, there is a lower amount of plagioclase in the Long Hill Phase. The reader is referred to Chapter 3 for more detailed descriptions of the Long Hill Phase within the Carcoar Granodiorite.

The geochemistry of the Long Hill Phase and the Carcoar Phase is consistent with the petrographic observations (figure 6.2 (a) - (i)). A plot of total FeO* against TiO_2 shows that the Long Hill Phase occurs on a linear trend that is slightly above the trend of the Carcoar Phase samples. When MgO is plotted against TiO_2, the Long Hill Phase also plots as a higher cluster. The plot of FeO* + MgO shows that the Long Hill Phase is clearly higher than the Carcoar Phase samples. These observations are consistent with the increased amphibole content. The indication from this is that the Long Hill Phase may represent a cumulate phase of the Carcoar Granodiorite.

The plot of Al_2O_3 shows an overlap of values for the Long Hill Phase relative to the Carcoar Phase. However, the Long Hill Phase is also notably


(a)
TiO2
SiO2
0.2
0.3
0.4
0.5
0.6
0.7
55
60
65
70
(b)
Al2O3
TiO2
10
11
12
13
14
15
16
17
18
19
20
0.25
0.35
0.45
0.55
0.65
(c)
FeOT
TiO2
1
2
3
4
5
6
7
8
0.25
0.35
0.45
0.55
0.65
(d)
MnO
TiO2
0.0
0.1
0.2
0.25
0.35
0.45
0.55
0.65
(e)
MgO
TiO2
1
2
3
4
5
6
0.25
0.35
0.45
0.55
0.65
(f)
CaO
TiO2
3
5
7
9
11
0.25
0.35
0.45
0.55
0.65

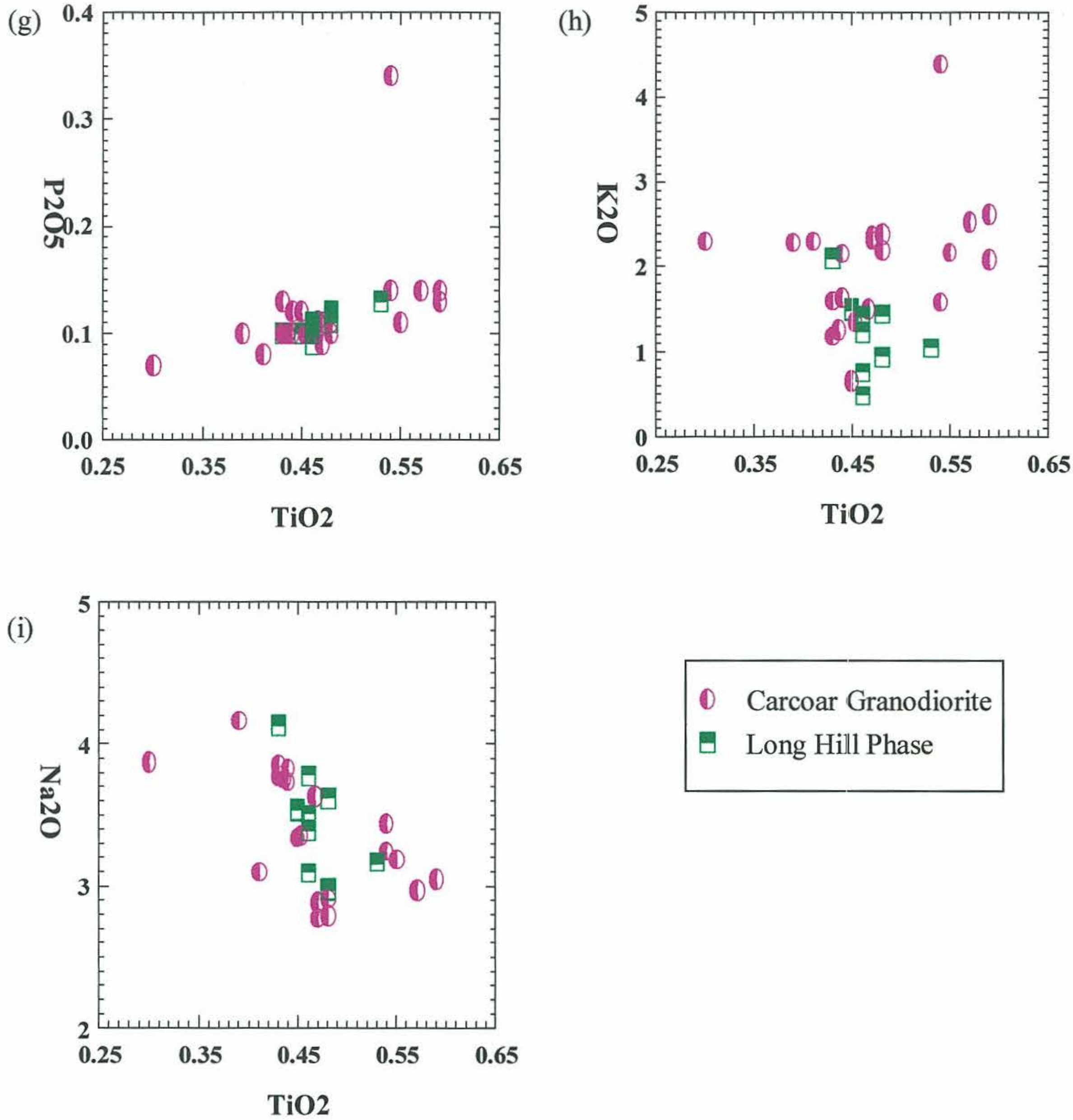


Figure 6.2 (a)-(i) - Variation diagrams for the Cacoar Granodiorite and Long Hill Phase

lower in K_2O content with respect to the Carcoar Phase. This is consistent with the former intrusive having lower alkali feldspar content or that they are more calcic as shown by the CaO versus TiO_2 plot.

The other major elements show an overlap between the Long Hill Phase and the Carcoar Phase. This suggests that the two intrusive groups have been sourced from the same parent magma. Drill core and underground observations also confirm this, as zones of more mafic material were frequently observed throughout the rest of the Carcoar Granodiorite. These zones have somewhat diffuse margins with the host intrusive, as opposed to distinct contacts that may indicate that they are xenoliths or that they represent discrete intrusions. One possibility for their formation is that the mafic zones (of which the Long Hill Phase represents) are accumulations of early precipitating minerals from the melt. Such accumulations may have broken away from larger accumulations that may have formed on the outer edges of the pluton. The location of the *Long Hill Diorite* is consistent with this as it occurs on the northwestern corner of the Carcoar Granodiorite.

Thus, it is concluded that the Long Hill Phase represents cumulate-rich portions of the Carcoar Granodiorite. The majority of samples sourced from the Carcoar Granodiorite represent the more felsic Carcoar Phase. From this, it would be incorrect to classify the Long Hill Phase as being a separate and distinct intrusive phase to the Carcoar Granodiorite. In addition, there is no geochemical evidence to substantiate the idea that the *Long Hill Diorite* represents a deeper level of the Carcoar Granodiorite.

6.3 The Mine Dyke Group and the Carcoar Granodiorite

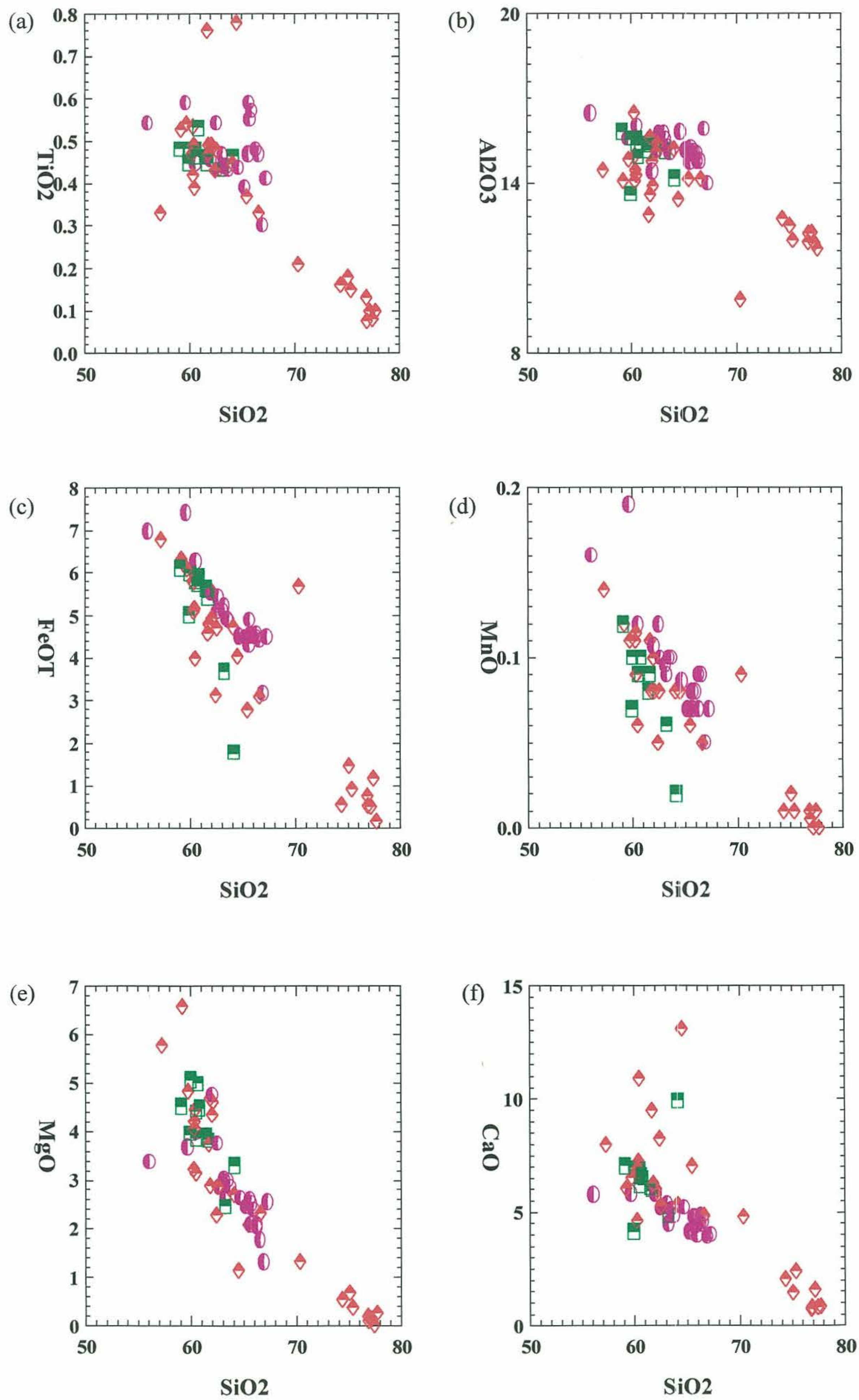
The Mine Dyke Group refers to the intrusive dykes that occur throughout the mine environment. As these dykes have a variety of compositions and textural features, composition or textural characteristics cannot easily classify them. Their method and timing of emplacement are the only common features that link this group of intrusives. As many of the dykes are similar in appearance to the Carcoar Granodiorite and occur proximal to it, they were originally thought to be apophyses of that pluton. However, geochemical analysis in conjunction with petrography of the Mine Dyke Group indicates otherwise.

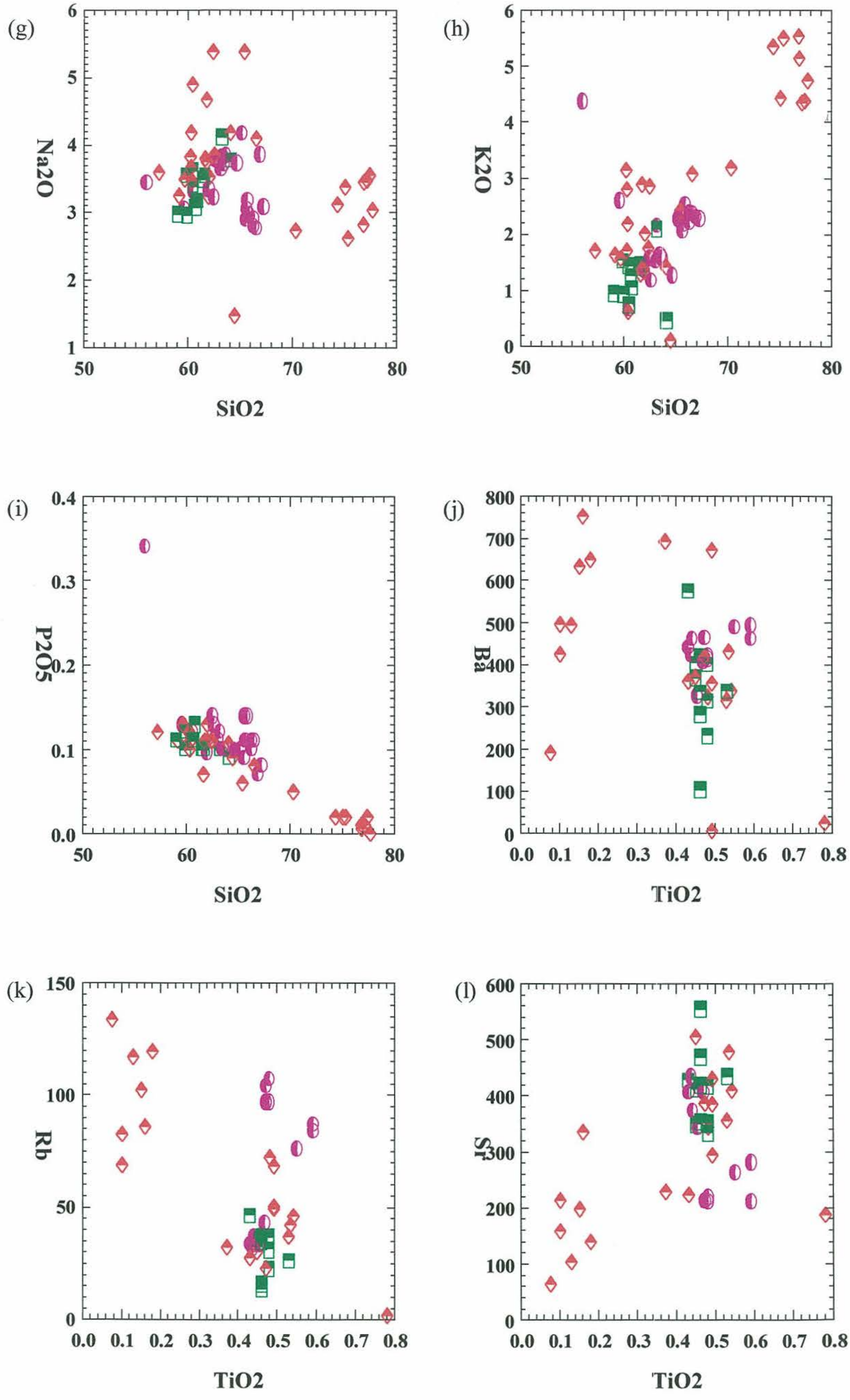
The most notable pattern among all the variation plots is the considerable amount of overlap of the Mine Dyke Group with the two phases of the Carcoar Granodiorite. This is believed to be the result of poor sample nomenclature. The historical practice within the mine was to classify any intrusive that occurred away from the main body of Carcoar Granodiorite as *monzonite*. The lithology coding left no option to log or map according to the dykes' real composition.

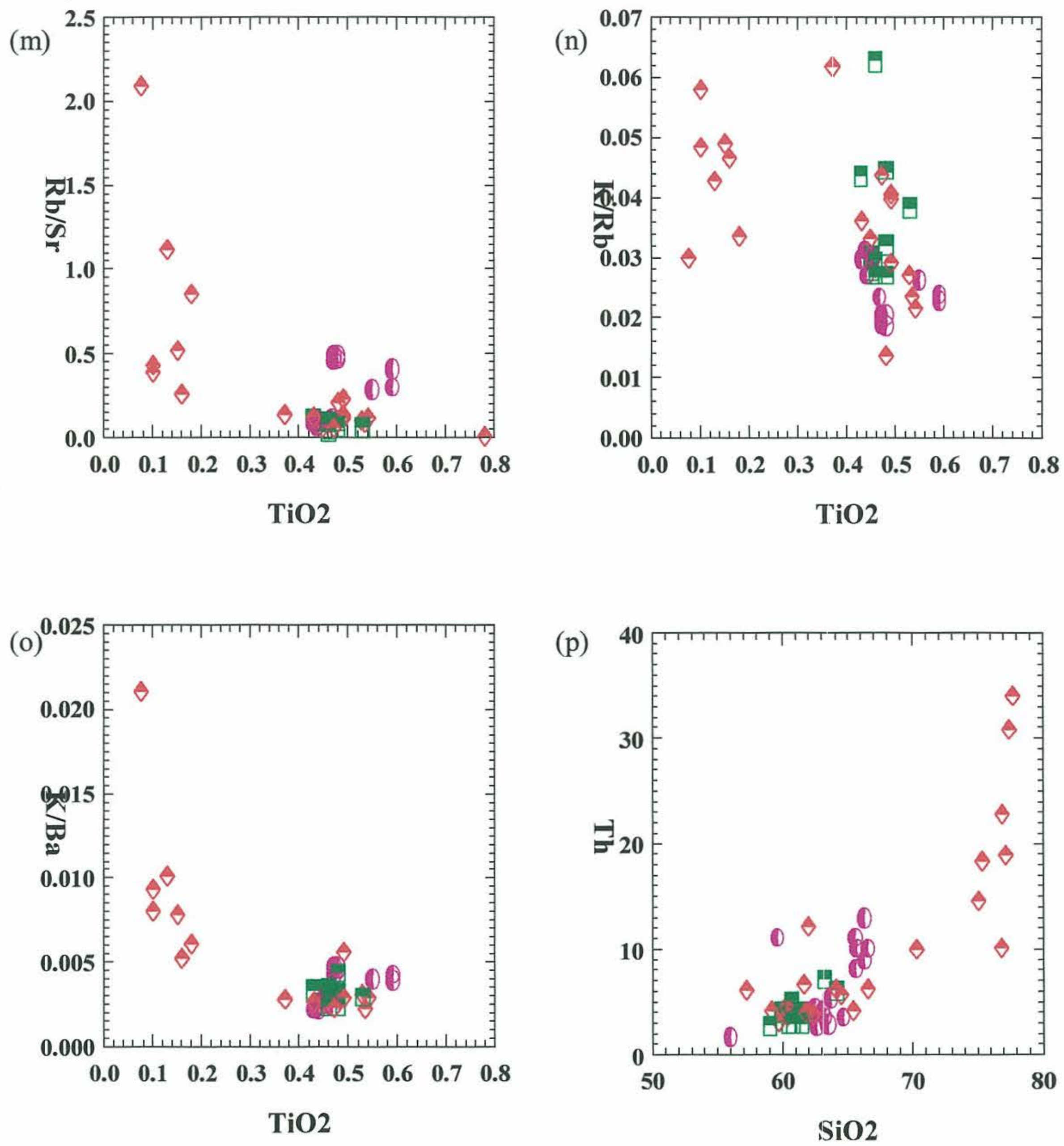
However, not all of the overlapping samples are the result of poor classification. As discussed Chapter 3, one of the more noteworthy characteristics of the Mine Dyke Group is the wide variety of textures and compositions they can have. Textures range from equigranular and granitic to aplitic and pegmatitic. Their compositions range also from quartz monzonite to granite to quartz-feldspar dykes (see figure 3.1). Some of these variations take place along a strike length of several metres within a single dyke. These characteristics are mentioned in this section as they are used to support the geochemical signature of the Mine Dyke Group. And likewise the textures can be explained by the geochemistry.

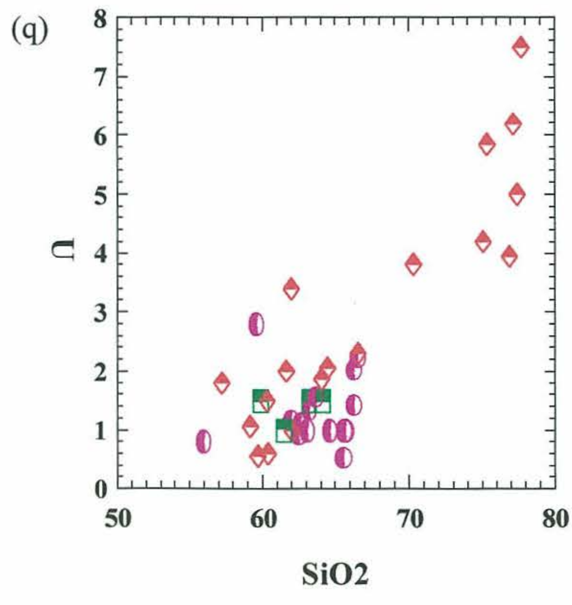
The Mine Dyke Group occupies a wide range of silica values, from 56 to 78 weight percent SiO_2 (figure 6.3 (a) – (q)). There is a gap in the Mine Dyke Group that occurs at 70 to 74 weight percent SiO_2. It is noted that this is a common feature of felsic intrusives that are related to mineralisation. This gap in silica values corresponds to points of inflection in various plots. On such plots, this is interpreted as the change in crystallisation methods within this suite of co-genetic intrusive phases. Mine Dyke Group samples that have lower silica values are likened to the formation of the Long Hill Phase of the Carcoar Granodiorite. Those samples that have higher silica values show a greater amount of fractionation.

Of the major elements, few show any real distinction between the Mine Dyke


(a)
TiO2
SiO2
(b)
Al2O3
SiO2
(c)
FeOT
SiO2
(d)
MnO
SiO2
(e)
MgO
SiO2
(f)
CaO
SiO2


(g)
Na2O
SiO2
(h)
K2O
SiO2
(i)
P2O5
SiO2
(j)
Ba
TiO2
(k)
Rb
TiO2
(l)
Sr
TiO2





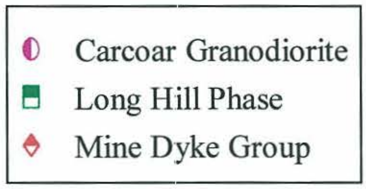


Figure 6.3 (a)-(q) - Variation diagrams for the Carcoar Granodiorite, Long Hill Phase and the Mine Dyke Group

Group and the Carcoar Granodiorite phases. As with the comparison between the Long Hill Phase and the Carcoar Phase, there appears to be a cumulate component to the lower silica Mine Dyke Group samples. Such samples have higher amounts of MgO and FeO* compared to the Carcoar Granodiorite. The plot of Al_2O_3 and SiO_2 shows that the low-SiO_2 samples of the Mine Dyke Group plot below the Carcoar Granodiorite trend. This also supports a cumulate component to the Mine Dyke Group. The Mine Dyke Group is also notably higher in K_2O and Na_2O. This is consistent with the higher amount of feldspars in these intrusives relative to the Carcoar Granodiorite.

When comparing the petrography of the Mine Dyke Group with the Carcoar Granodiorite, one of the characteristics of the dykes is the earlier crystallisation of alkali feldspar, commonly with a later crystallising phase. This is not observed within the Carcoar Granodiorite where alkali feldspar tends to occur only as a late interstitial mineral (Carcoar Phase). The crystallisation of alkali feldspar in this case is important when determining the relation between the different intrusive phases and understanding the crystallisation history of them.

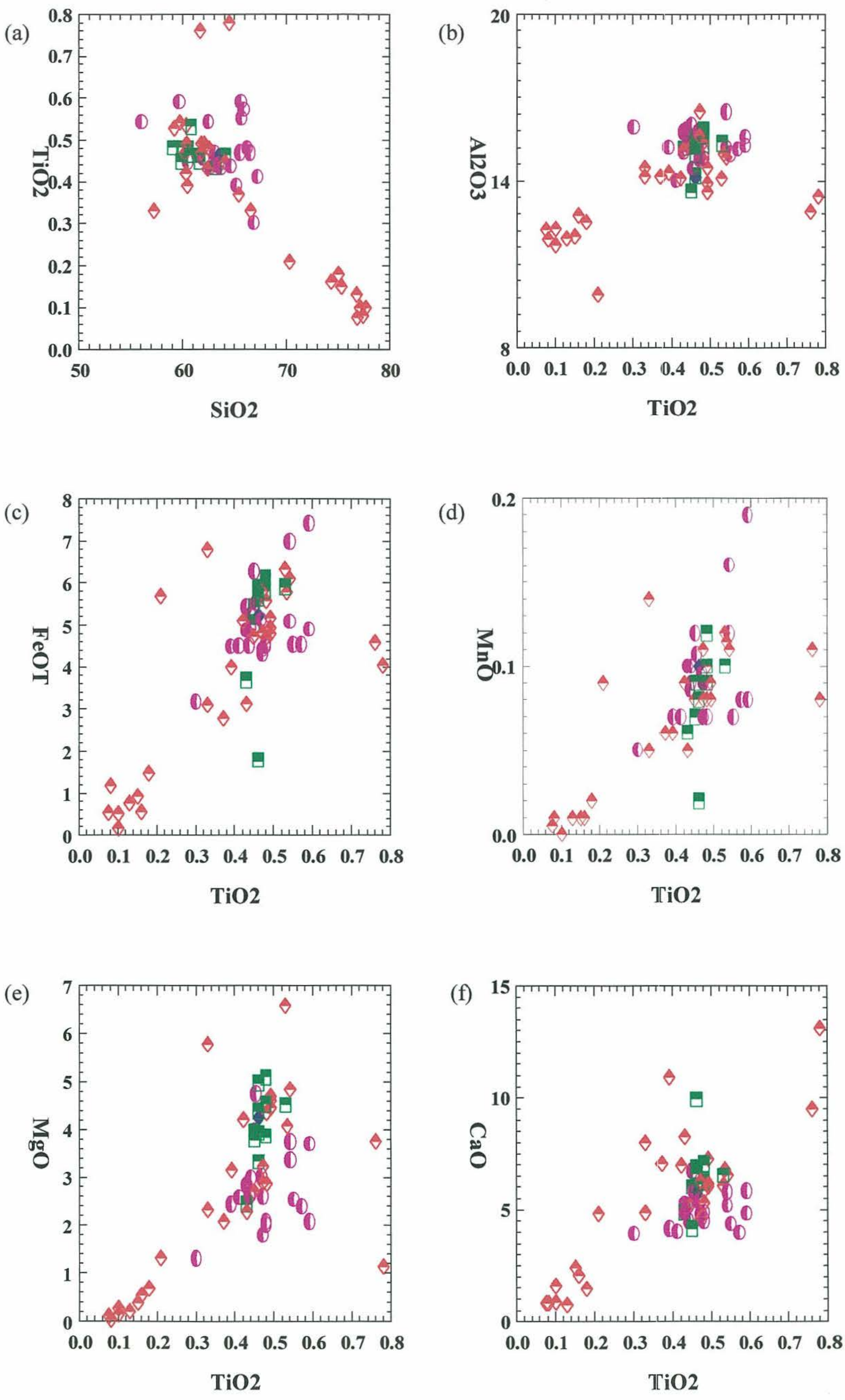
The plot of Ba against TiO_2 for the Mine Dyke Group shows a sharply increasing trend with decreasing TiO_2, till it reaches a slight plateau (at TiO_2 = 0.2 - 0.35 weight percent) then sharply decreases. The sharply increasing section can be explained by the late crystallisation of alkali feldspar. This is observed in the Carcoar Granodiorite phases. The plateau section shows the saturation of alkali feldspar in the melt. The sharply decreasing section shows the early crystallisation of alkali feldspar as phenocrysts. This would remove any Ba that would be in the melt.

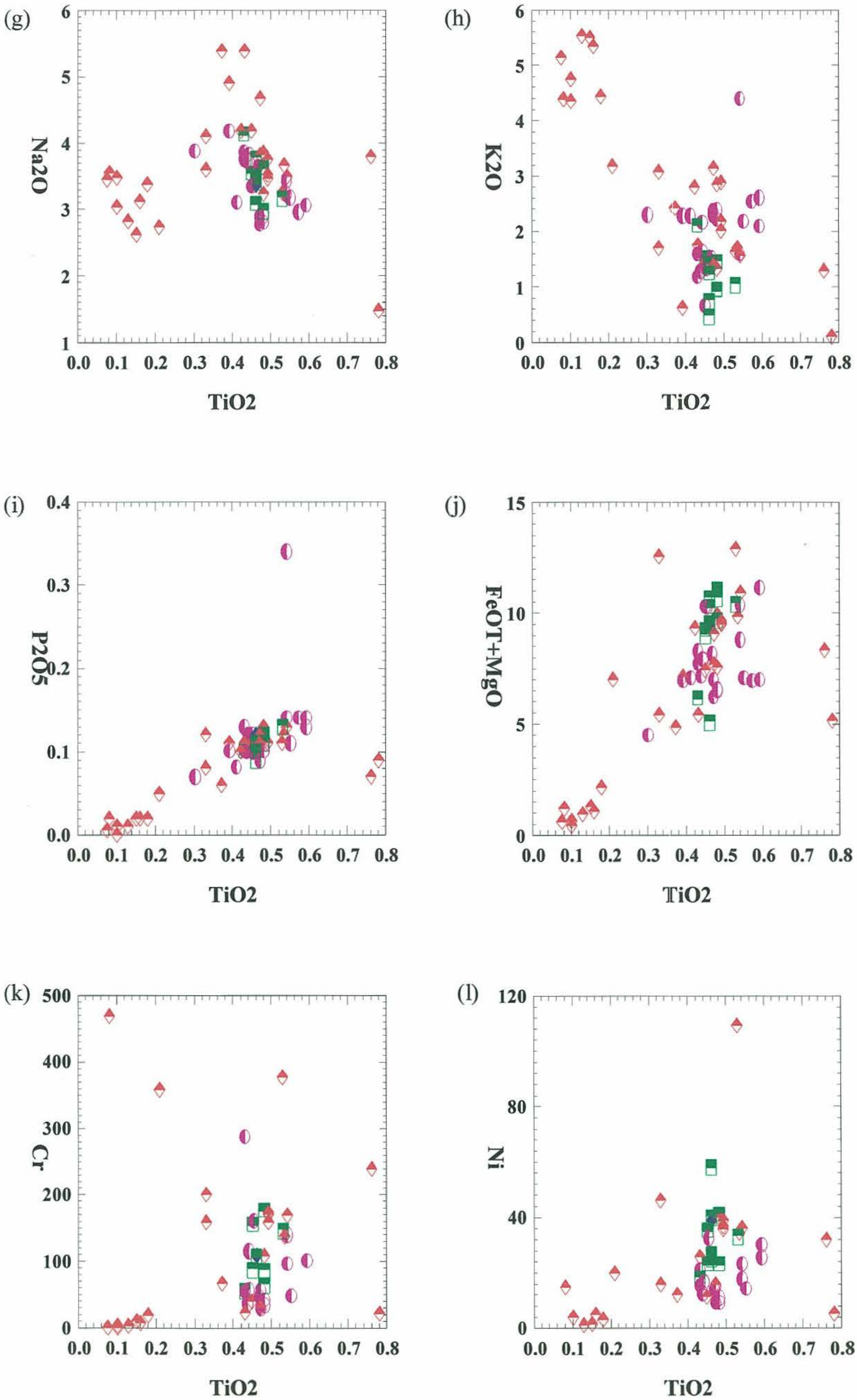
When Sr is plotted against TiO_2, this shows a general decrease in Sr with decreasing TiO_2. This is consistent with the lower amount of plagioclase that is observed in the Mine Dyke Group. The ratio of Rb/Sr was plotted against TiO_2. This showed an increase with decreasing TiO_2. This is also consistent with feldspar fractionation. As the feldspar crystallises, they are removing Sr and thus leave the remaining melt with higher amounts of Rb relative to Sr. If this is the case, the plot of the ratio of K/Rb against TiO_2 should also show a sharp decrease with the crystallisation of alkali feldspar as an early phase. This is arguably the case and supports the findings of previous plots. The conclusion from these plots is that the felsic end members of this intrusive suite represent fractional crystallisation. While not as convincing, the plot of the ratio of K/Ba also shows a sharp increase with decreasing TiO_2 as Ba is preferentially removed with the crystallisation of alkali feldspar.

The conclusion from the geochemical analysis of the Mine Dyke Group is that they represent a more evolved magma source that has an overall increase in incompatible elements. However, it has the same source as the Carcoar Granodiorite and its cumulate, the Long Hill Phase, as there is clearly an overall continuum of magmatic trends. There is an indication that the Mine Dyke Group has formed due to rapid crystallisation, as can be observed in the textural variation of their petrography. The rapid crystallisation of the mineral phases present is most likely caused by the rapid loss of heat due to the loss of a volatile phase from the magma, most likely gas charged. Again the diverse assemblage of textures in the Mine Dyke Group supports this.

6.4 The Post-Mineralisation Intrusive

The intrusive classified as the Post-Mineralisation Intrusive was only found and mapped within the last few weeks before the mine's closure. As such, there were no samples obtained for petrographic observations. The field terminology of *Late Diorite* was used to distinguish it from the Mine Dyke Group that is generally more felsic. In addition, it has clearly intruded after the mineralising event as it cross-cuts the ore boundaries. However, classification by hand specimen identification of several samples places it in the field of granodiorite to quartz monzodiorite (see figure 3.1). The geochemical analysis of the group gives it a classification of quartz diorite to diorite. However, this has been determined from only one analysis. As such, the following results are speculative and would be enhanced by further sampling if possible.


(a)
TiO2
SiO2
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
50 60 70 80
(b)
Al2O3
TiO2
8 14 20
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
(c)
FeOT
TiO2
0 1 2 3 4 5 6 7 8
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
(d)
MnO
TiO2
0.0 0.1 0.2
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
(e)
MgO
TiO2
0 1 2 3 4 5 6 7
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
(f)
CaO
TiO2
0 5 10 15
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8


(g)
Na2O
TiO2
(h)
K2O
TiO2
(i)
P2O5
TiO2
(j)
FeOT+MgO
TiO2
(k)
Cr
TiO2
(l)
Ni
TiO2

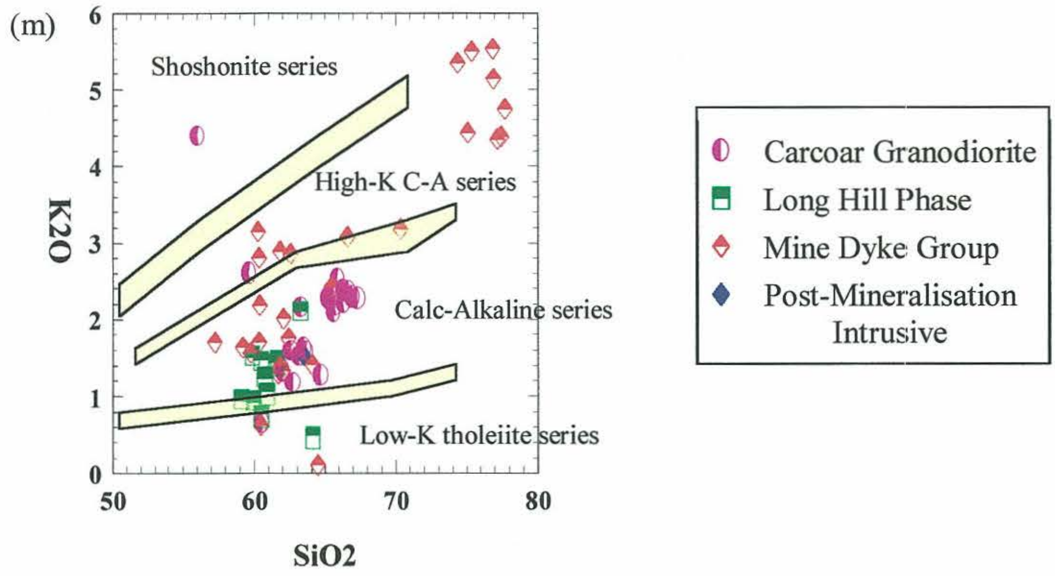


Figure 6.4 (a)-(m) - Variation diagrams for all members of the Browns Creek Intrusive Complex. (m) K_2O versus SiO_2 diagram for the Browns Creek Intrusive Complex with calc-alkaline classification of Rickwood (1988, in Rollinson, 1998)

When observing plots of major elements, the geochemistry of the Post-Mineralisation Intrusive has a great similarity to the Carcoar Granodiorite and particularly the Long Hill Phase (figure 6.4 (a) – (m)). It is chemically different to the Mine Dyke Group. It can be argued that it is a protrusion of either the Carcoar Granodiorite or specifically the cumulate Long Hill Phase. However, it clearly has intruded post-mineralisation, while the Carcoar Granodiorite (and hence the Long Hill Phase) has intruded prior to the mineralisation. Rather, there appears to have been a resurgence of the mafic end of the Browns Creek Intrusive Complex after the somewhat rapid intrusion of the Mine Dyke Group. It appears that this resurgence comprises a phase that has a cumulate component.

The Post-Mineralisation Intrusive is higher in MgO than the Carcoar Phase and the majority of the Mine Dyke Group samples, as was the Long Hill Phase. However, when FeO* was compared, there was little distinguishing the late intrusive with the granodiorite. The plot of iron plus magnesium versus titanium clearly shows the increase in the Post-Mineralisation Intrusive compared to the others. However, this is mainly caused by the difference in the MgO values.

As with the Long Hill Phase, the Post-Mineralisation Intrusive contains less Al_2O_3 than the Carcoar Phase of the Carcoar Granodiorite and the majority of the Mine Dyke Group samples. The same can arguably be observed with the plot of K_2O. These findings are consistent with the Post-Mineralisation Intrusive representing another cumulate-rich phase of the Browns Creek Intrusive Complex, like the Long Hill Phase. Elevated values of Cr and Ni support this, as they are consistent with cumulate ferromagnesian minerals.

The Post-Mineralisation Intrusive is clearly more mafic than the Carcoar Granodiorite. In this way, it has similarities with the cumulate Long Hill Phase. This less felsic magma may represent an intrusion that was sourced from a less evolved part of the magma chamber. Each intrusive phase of the Browns Creek Intrusive Complex has tapped different levels/zones of the magma chamber.

6.5 The Browns Creek Intrusive Complex and Other Intrusives in the Area

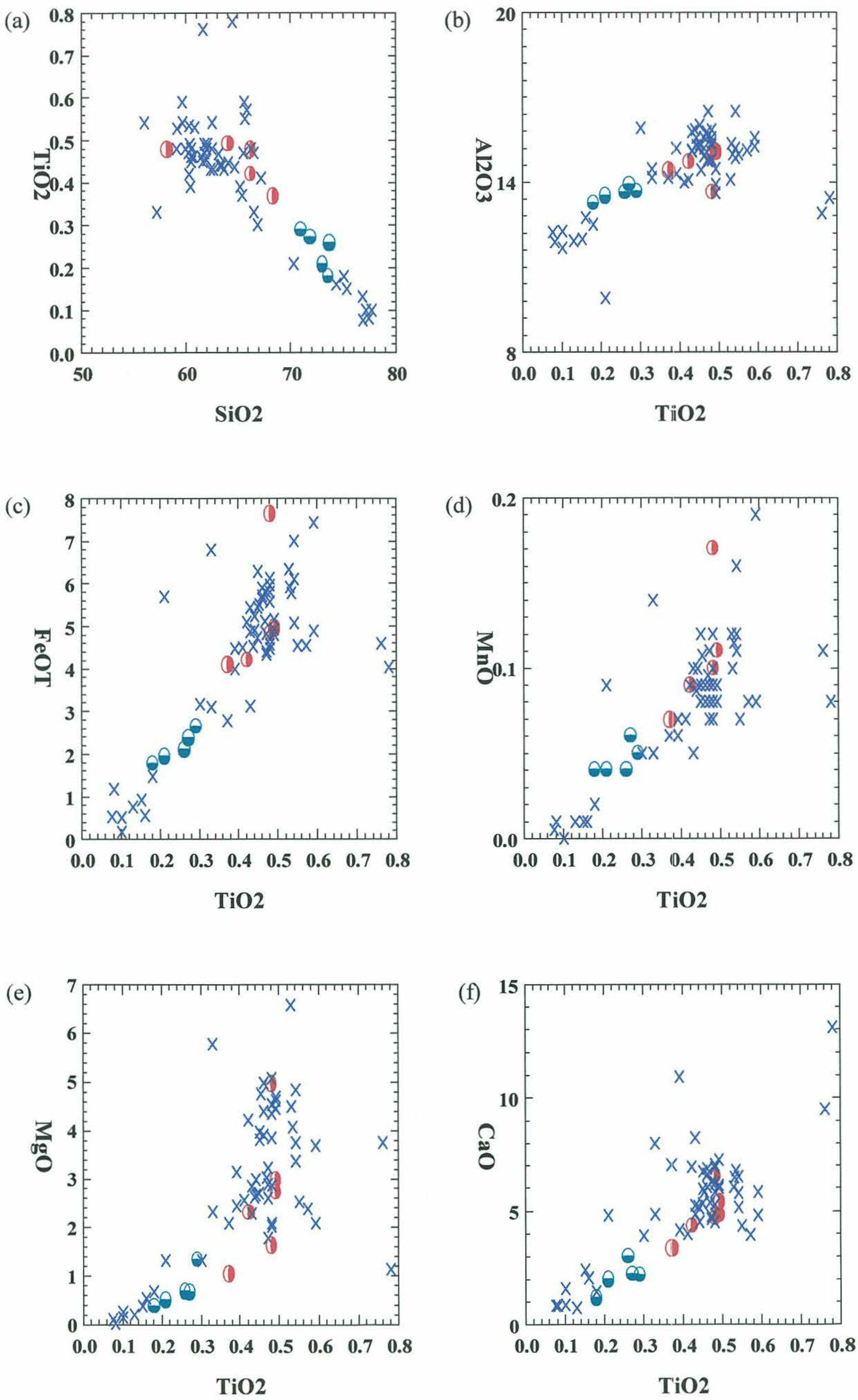
Other intrusive phases in the local vicinity of the mine were included in this study to investigate any possible relation between them and the Browns Creek Intrusive Complex. If any relation can be proven, this may aid future exploration in the area. If similar intrusive phases can be identified, they may also be associated with mineralisation. The other intrusives that were used for comparison were:-

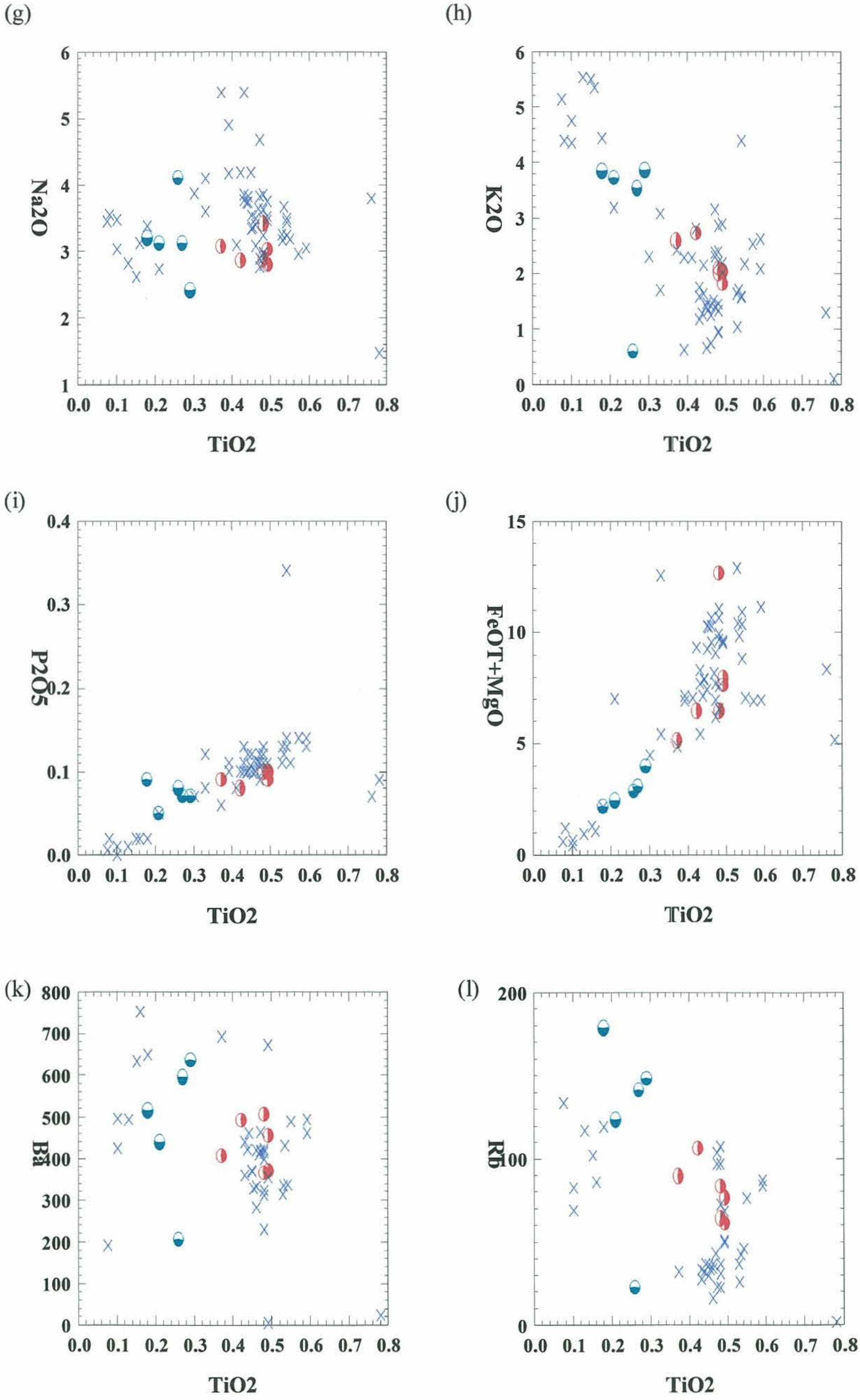
Barry Granite
Neville Granite (also referred to as the Sunset Hills Granite)
Diorite (Stokehill Metagabbro and diorite from Millner's Prospect)
Monzodiorite (various dykes from drill core and open cut)
Porphyritic Monzonite (deep mine exploration drillholes, Carramar Prospect, North of Glen Ayr Syenite, Dirt Hole)
Various tonalite samples (from the mine and Millner's Prospect)
Errowan Monzonite
Glen Ayr Syenite
Halls Road Intrusives (micro-quartz syenite, syenite)
Tallwood Monzonite

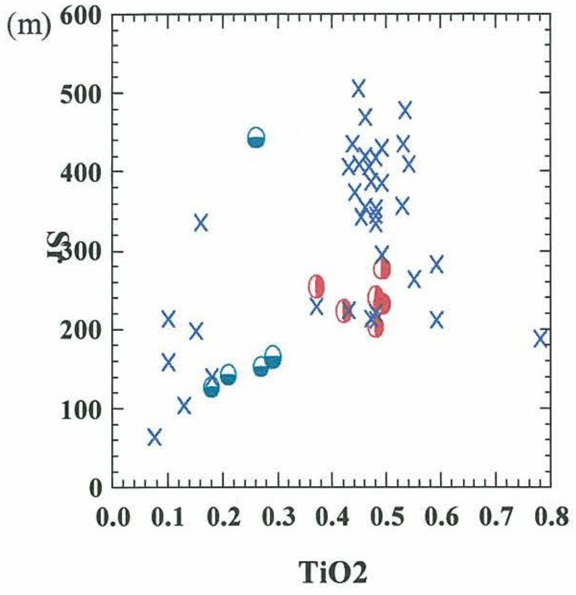
The whole-rock geochemical data utilised for these intrusives has been obtained from other sources. The vast majority of data is from Hargraves Resources N.L..

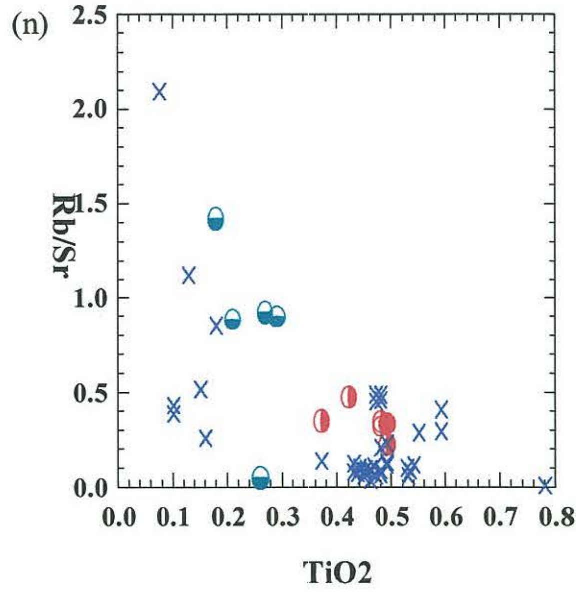
6.5.1 Barry and Neville Granites

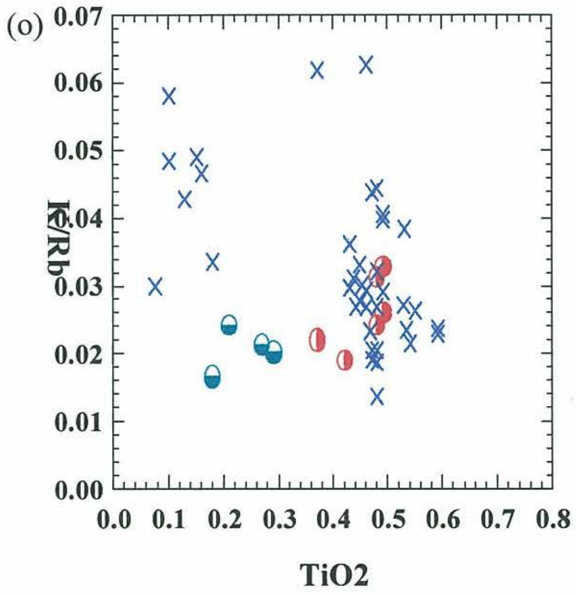
The Barry and Neville Granites are two north-trending, elongate granitic masses that occur approximately 10-15km to the southeast of the Carcoar Granodiorite. The dimensions of both intrusives are 3- 5km by 23- 24km. They are believed to have intruded contemporaneously with the Carcoar Granodiorite (Lennox *et al*, 1998). However, the two granites are quite distinct as the Barry Granite is of I-

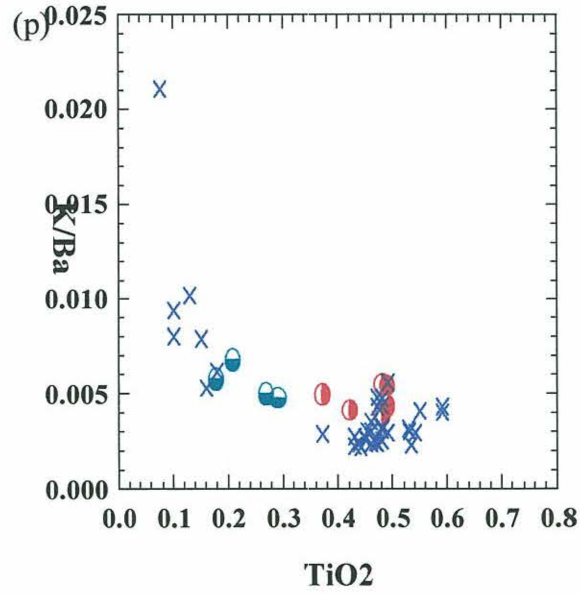

(a)
TiO2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
50
60
70
80
SiO2
(b)
Al2O3
8
14
20
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
TiO2
(c)
FeOT
0
1
2
3
4
5
6
7
8
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
TiO2
(d)
MnO
0.0
0.1
0.2
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
TiO2
(e)
MgO
0
1
2
3
4
5
6
7
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
TiO2
(f)
CaO
0
5
10
15
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
TiO2

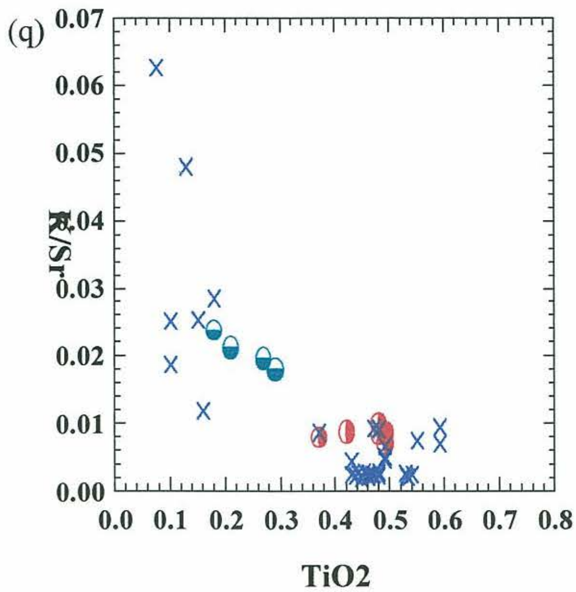

(g)
Na2O
TiO2
(h)
K2O
TiO2
(i)
P2O5
TiO2
(j)
FeOT+MgO
TiO2
(k)
Ba
TiO2
(l)
Rb
TiO2











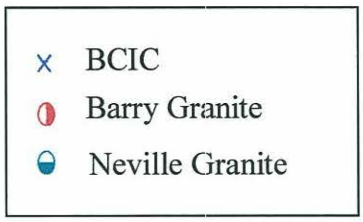


Figure 6.5 (a)-(q) - Variation diagrams for the Browns Creek Intrusive Complex (BCIC), Barry Granite and Neville Granite

type affinity and the Neville Granite is of S-type affinity (Pogson and Watkins, 1998).

The Barry Granite has a similar SiO_2 and TiO_2 range to the Carcoar Granodiorite. The Neville Granite has higher SiO_2 and lower TiO_2 contents than the Carcoar Granodiorite. Both granites have similar amounts of FeO*, FeO* + MgO, CaO and K_2O to the granodiorite. However, the plot of MgO versus TiO_2 shows that the Barry and Neville Granites tend to plot on a lower sub-parallel trend. A slight decrease can also be observed in the Al_2O_3 plot.

Few trace elements have been analysed in the Barry and Neville Granite samples. However, while the major oxides showed an overall similarity in the composition of the granites with the Carcoar Granodiorite, the trace element data shows variation between the three intrusives. The plot of Ba against TiO_2 shows that the Barry Granite clusters with the granodiorite. However, the Neville Granite clearly plots away from the Browns Creek Intrusive Complex cluster. The Neville Granite also has a strong decline in its Ba content with respect to decreasing values of TiO_2 which may represent a fractionated and more evolved intrusive. As it is of S-type affinity, it would be expected that its source would be different to that of the Barry Granite and the Carcoar Granodiorite and hence the Browns Creek Intrusive Complex.

The plot of Rb supports these findings. This plot shows the Barry Granite with higher amounts of Rb than the majority of the Carcoar Granodiorite. However, there are a few outliers of the granodiorite that plot with the granite. This supports a common melt history of the Barry Granite and the Carcoar Granodiorite. The Neville Granite shows a sharp increase in Rb contents with decreasing TiO_2, like the Mine Dyke Group of the Browns Creek Intrusive Complex. However, this increase is clearly in a different pattern to that of the Mine Dyke Group. The plot of Rb/Sr versus TiO_2 also shows similar trends. The plots of the ratios of K/Ba and K/Sr show no deviation of the granites from the Browns Creek Intrusive Complex.

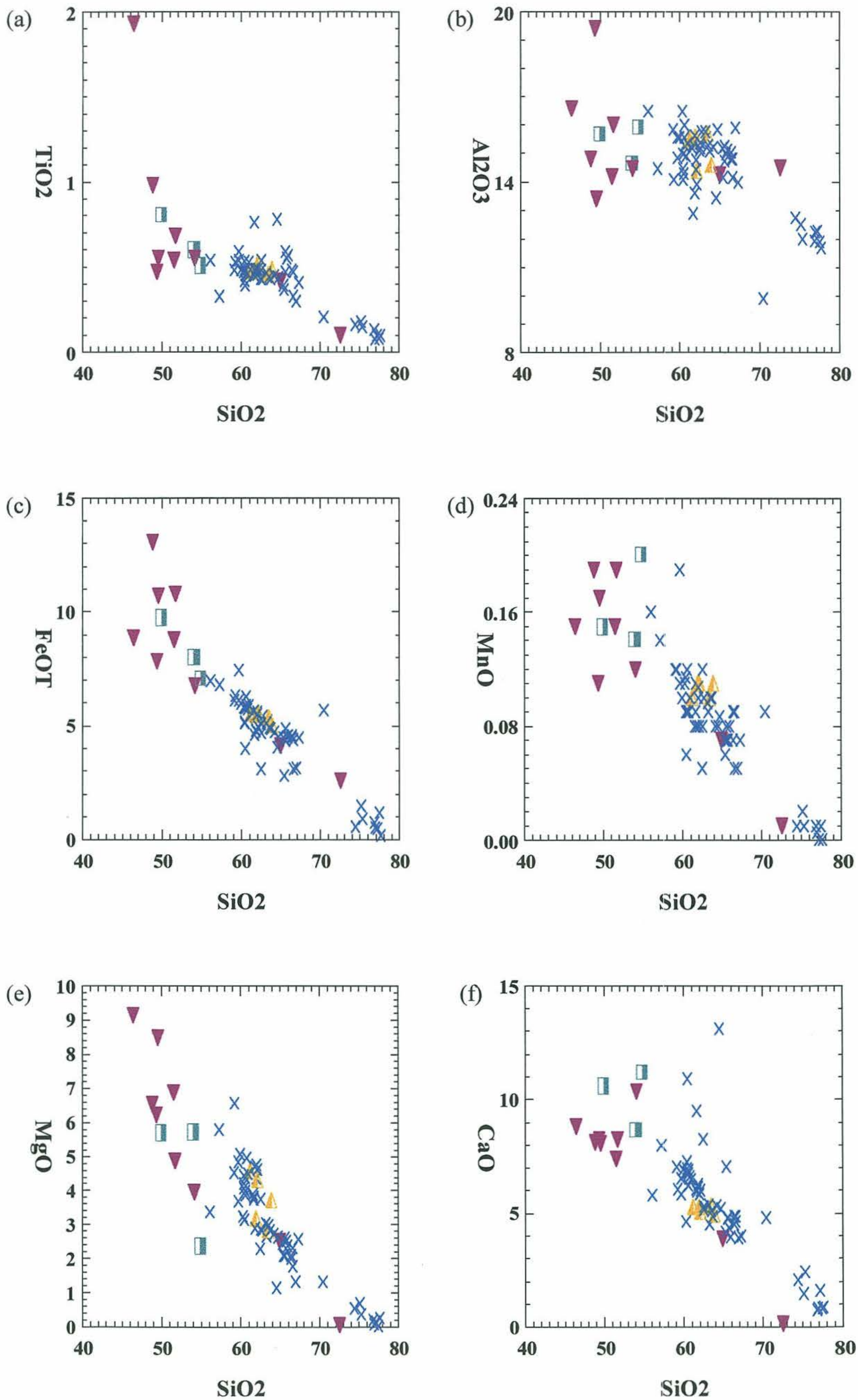
The plot of the ratio of K/Rb versus TiO2 again shows that the Barry Granite plots with the Carcoar Granodiorite. However, the Neville Granite tends to cluster at a relatively low ratio, not showing a rapidly decreasing trend, typical of the Browns Creek Intrusive Complex and Barry Granite.

From comparing the geochemistry of the Barry and Neville Granites with the Carcoar Granodiorite and the rest of the Browns Creek Intrusive Complex, several conclusions can be made. The Barry Granite and the Carcoar Granodiorite are very similar in their appearance, suggested age of emplacement and also their geochemistry. The magmas have most likely been sourced from the same parent magma but have had different ascent paths and hence slightly different crystal fractionation patterns. The Neville Granite is of S-type affinity and hence from a different magma source to both the Barry Granite and the Carcoar Granodiorite. However, it does have some affinities with the high SiO_2 members of the Mine Dyke Group.

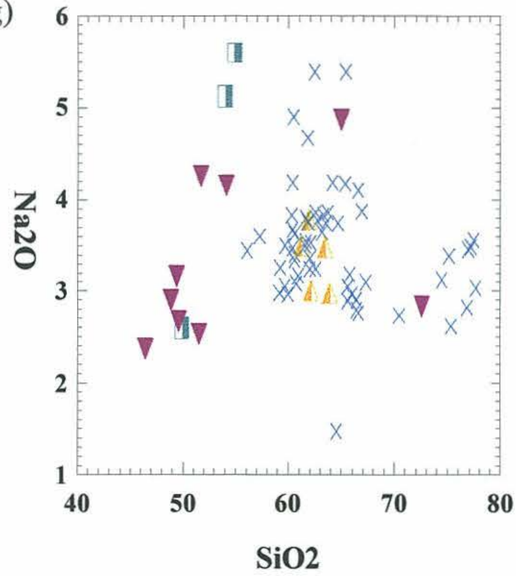
6.5.2 Diorite, Monzodiorite and Tonalite Samples

These three regional intrusive phases are considered together as they often have the same geochemical properties when compared to the Carcoar Granodiorite and the rest of the Browns Creek Intrusive Complex. While the monzodiorite and some tonalite samples were sourced from a close proximity to the mineralisation, the diorite and the other tonalite samples have come from prospects located up to 8km from the Browns Creek deposit. Those samples that were sourced from the pit highlight the inconsistency in sampling terminology. They would be better classified as part of the Mine Dyke Group, and their geochemistry supports this. The monzodiorite and diorite samples represent the more mafic intrusive phases and as such have lower SiO_2 and higher TiO_2 contents. The tonalite samples tend to have similar amounts to the Carcoar Granodiorite, making comparisons easier to observe.

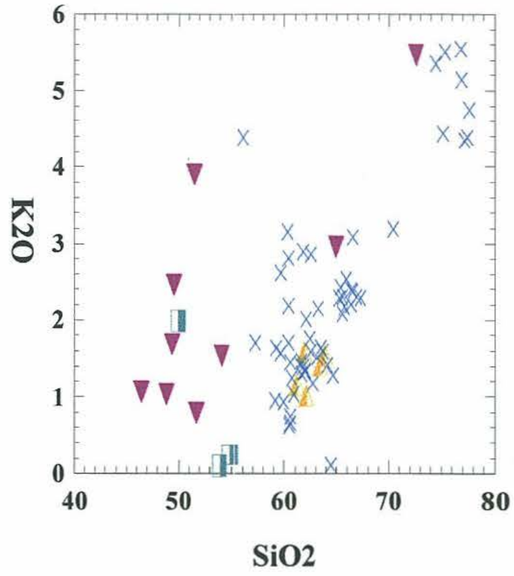
The most obvious feature that can be observed with these intrusive phases is the considerable amount of scatter of the monzodiorite samples (figure 6.6 (a) – (n)). This can especially be observed in the plots of Al_2O_3 and K_2O. As the


(a)
TiO2
SiO2
(b)
Al2O3
SiO2
(c)
FeOT
SiO2
(d)
MnO
SiO2
(e)
MgO
SiO2
(f)
CaO
SiO2

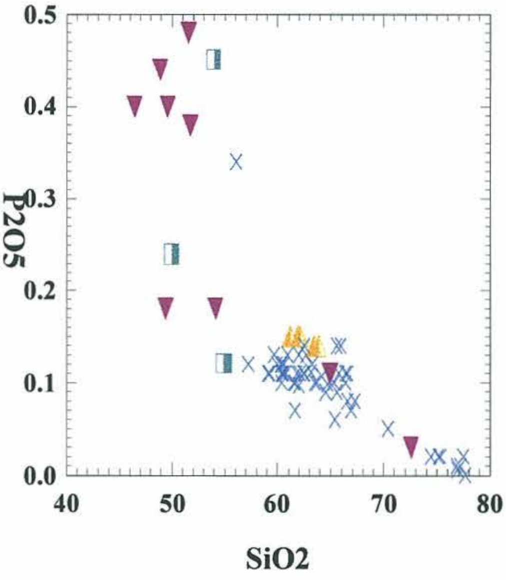
(g)


Na2O
1
2
3
4
5
6
40
50
60
70
80
SiO2

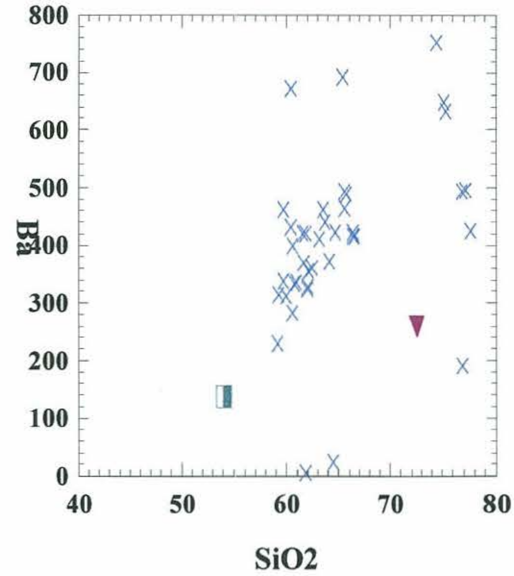
(h)


K2O
0
1
2
3
4
5
6
40
50
60
70
80
SiO2

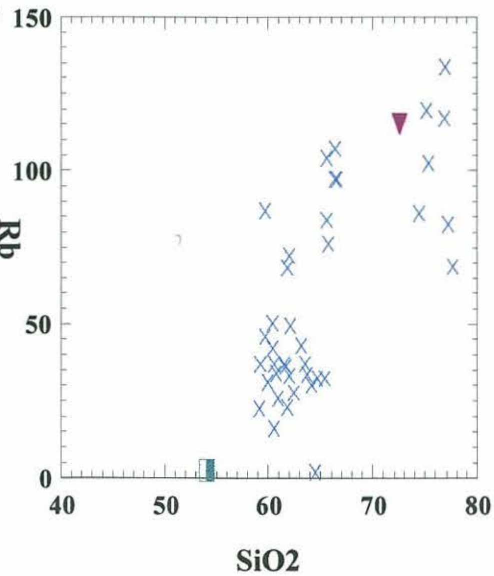
(i)


P2O5
0.0
0.1
0.2
0.3
0.4
0.5
40
50
60
70
80
SiO2

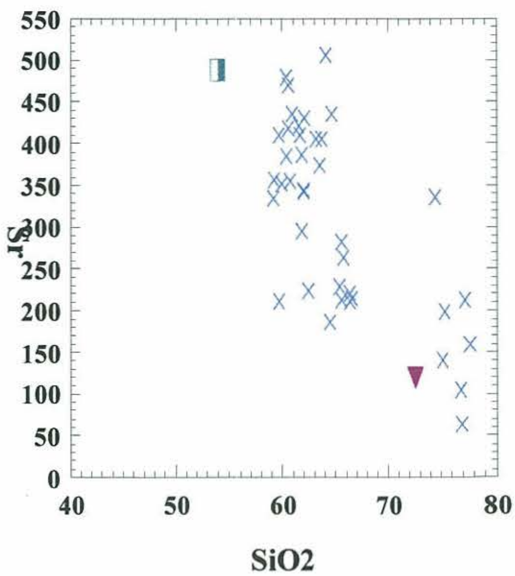
(j)


Ba
0
100
200
300
400
500
600
700
800
40
50
60
70
80
SiO2

(k)


Rb
0
50
100
150
40
50
60
70
80
SiO2

(l)


Sr
0
50
100
150
200
250
300
350
400
450
500
550
40
50
60
70
80
SiO2

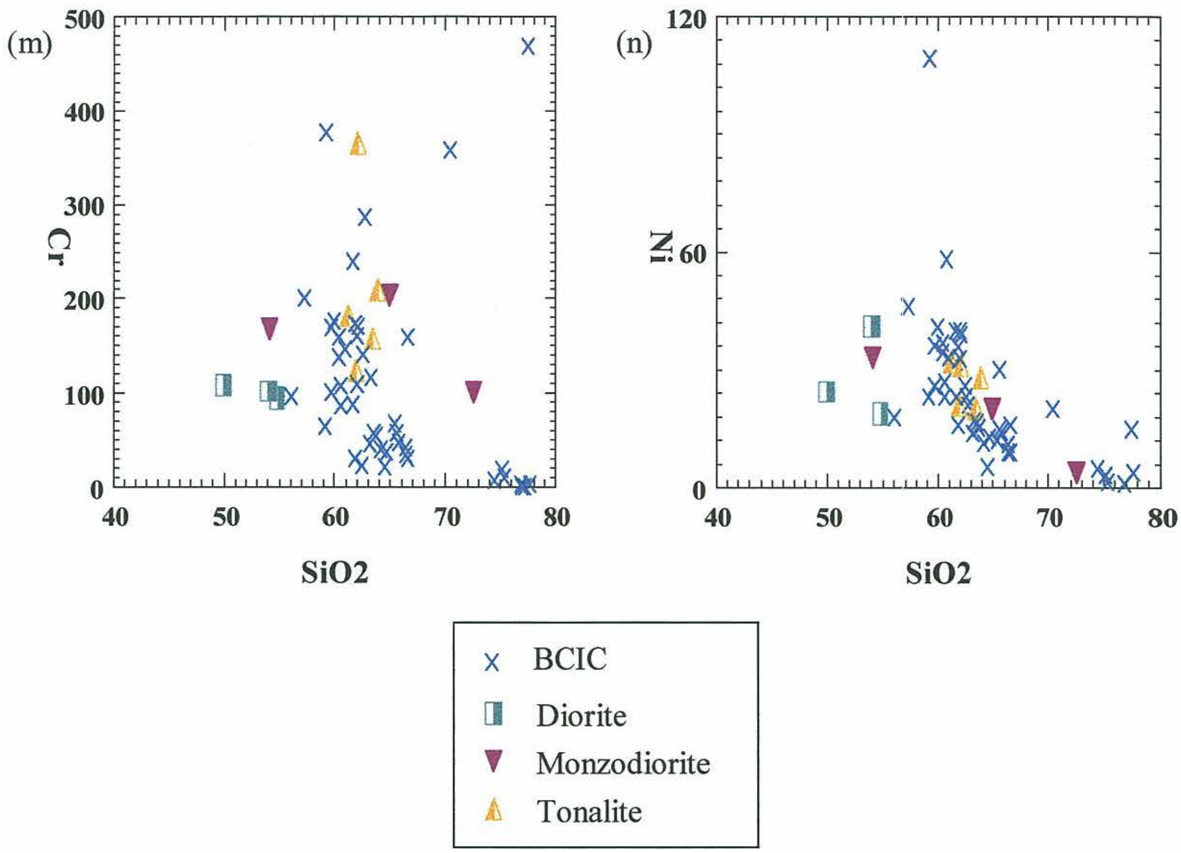


Figure 6.6 (a)-(n) - Variation diagrams for the Browns Creek Intrusive Complex and various diorites, monzodiorites and tonalites

monzodiorite samples have been sourced from various dykes from around the mine area, it is suggested here that this scatter is a misnomer due to poor sample terminology, similar to the scatter within the Mine Dyke Group. However, the major elements show some distinguishing features of this group of intrusive phases when compared to the Carcoar Granodiorite and other phases within the Browns Creek Intrusive Complex.

The plot of Al_2O_3 against TiO_2 shows only a small degree of variation between the groups. The diorite and monzodiorite values are slightly lower than for the Carcoar Granodiorite samples, and the tonalite tends to plot with the granodiorite. This may indicate that the more mafic phases may be likened to the Long Hill Phase of the Carcoar Granodiorite, and represent a cumulate. The plots of FeO* and MgO clearly support this, as they show that the monzodiorite and the diorite samples are higher in these elements. This plot also shows that the tonalite samples are slightly enriched in MgO with respect to the Carcoar Granodiorite. The CaO plot also shows that the mafic phases are more enriched than the granodiorite, whereas the tonalite again plots with it.

Of the trace elements, the plots of Cr and Ni support the findings of the major element variation diagrams. The more mafic phases of the diorite and the monzodiorite are enriched in these elements with respect to the Carcoar Granodiorite. This is consistent with these intrusives representing a more cumulate-rich phase of the same source as the granodiorite. However, the Cr content of the tonalite samples are also higher than those in the Carcoar Granodiorite.

Unfortunately only one diorite and one monzodiorite sample were analysed for the contents of Ba, Sr and Rb. However, these two samples did not stray from the trends that have previously been discussed in Section 6.3.

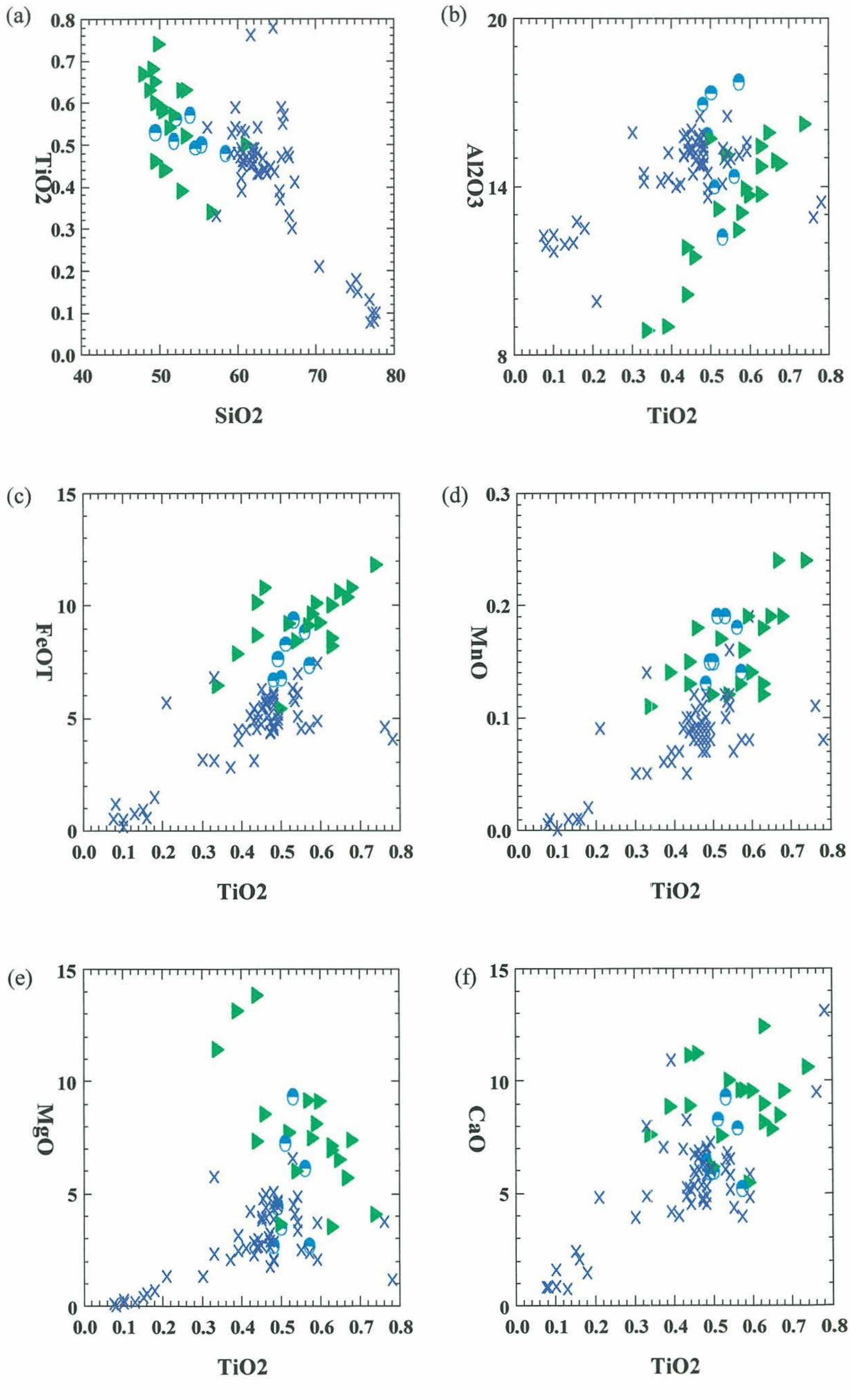
The conclusion from this is that these intrusive phases are related to the Browns Creek Intrusive Complex. The more mafic samples are most likely representative of the cumulate phases of the Carcoar Granodiorite, which is consistent with the Long Hill Phase. The scatter in the monzodiorite samples and their frequent overlapping with the Mine Dyke Group, indicates that they are most likely affiliated with this group. The difference in nomenclature has been sourced from the difference in work practices over the years. The monzodiorite samples were sourced from dykes in the open cut and from drill core. Thus, they are consistent with the characteristics of the Mine Dyke Group.

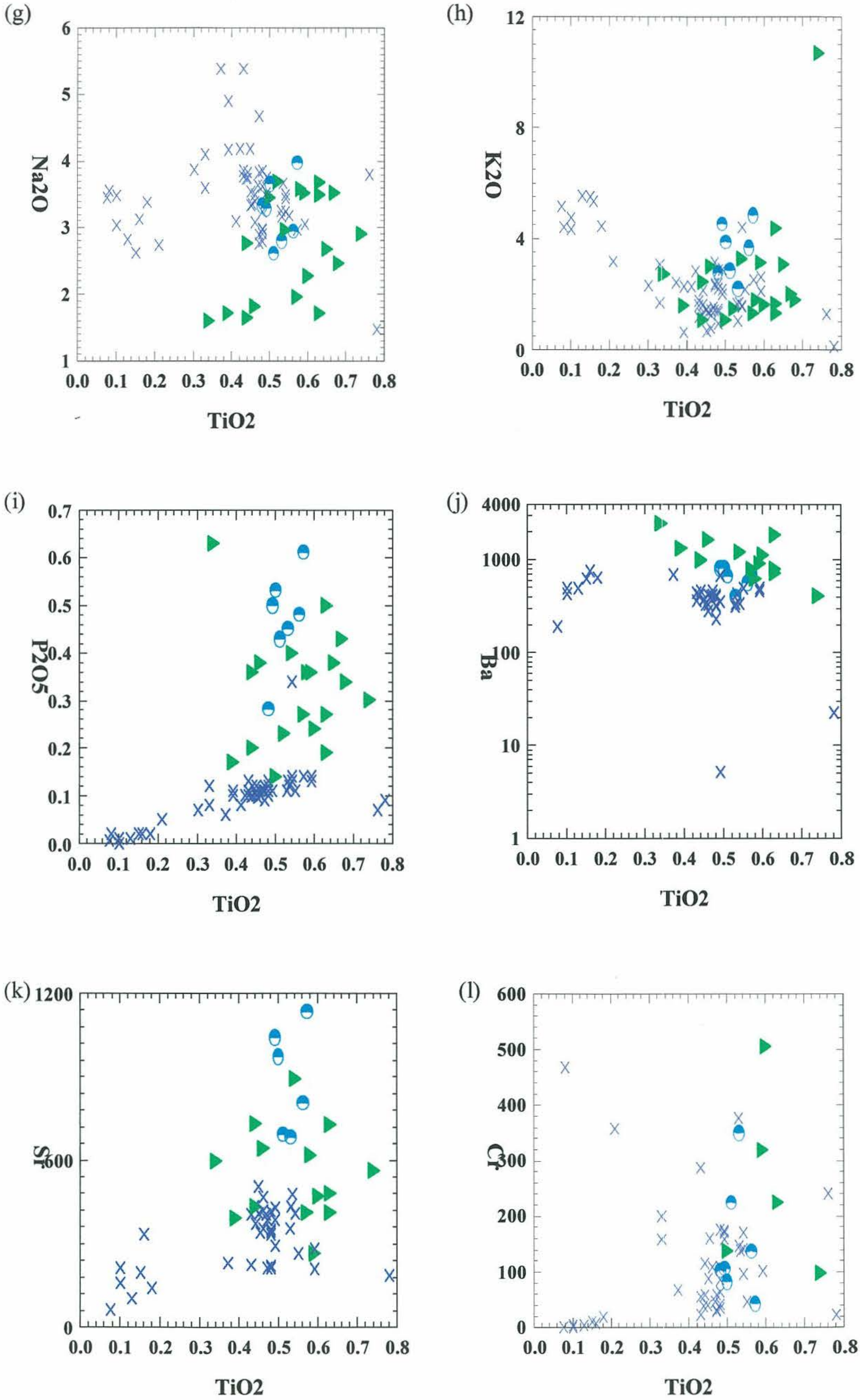
6.5.3 Porphyritic Monzonite

As discussed in Chapter 3, the porphyritic monzonite is quite distinct and different to the other intrusives within the mine. Due to the texture and mafic nature of the porphyritic monzonite, it was anticipated that they were not related to the Carcoar Granodiorite but possibly the volcanics. As such, the Blayney Volcanics have been included in these comparisons.

The porphyritic monzonite samples have a silica range from 48 to 58 weight percent, which places these intrusives on the mafic side of the Carcoar Granodiorite and other phases of the Browns Creek Intrusive Complex (figure 6.7 (a) – (n)). The major element plots also enhance these differences. The plot of Al_2O_3 shows a range of values within the monzonite. However, the majority of values are greater than those of the Browns Creek Intrusive Complex. This is consistent with the greater amount of feldspars that are observed in the monzonite. The plot of K_2O supports this finding with the majority of feldspars being alkali in their nature. The sample of Blayney Volcanics with approximately 11% K_2O has most likely been hydrothermally altered.

The plots of FeO* and MgO versus TiO_2 show that the porphyritic monzonite is also relatively enriched in these elements when compared with the other intrusive phases. For FeO* versus TiO_2, the monzonite samples plot with the Blayney Volcanic samples on a sub-parallel trend above that of the other intrusives in FeO*. For the MgO plot, the volcanics and monzonite show descreasing MgO with increasing TiO_2. The greater concentration of these elements is consistent with the greater amount of clinopyroxene that is contained in the monzonite as phenocrysts and in the groundmass fraction. This also explains the relative


(a)
TiO2
SiO2
(b)
Al2O3
TiO2
(c)
FeOT
TiO2
(d)
MnO
TiO2
(e)
MgO
TiO2
(f)
CaO
TiO2


(g)
Na2O
TiO2
(h)
K2O
TiO2
(i)
P2O5
TiO2
(j)
Ba
TiO2
(k)
Sr
TiO2
(l)
Cr
TiO2

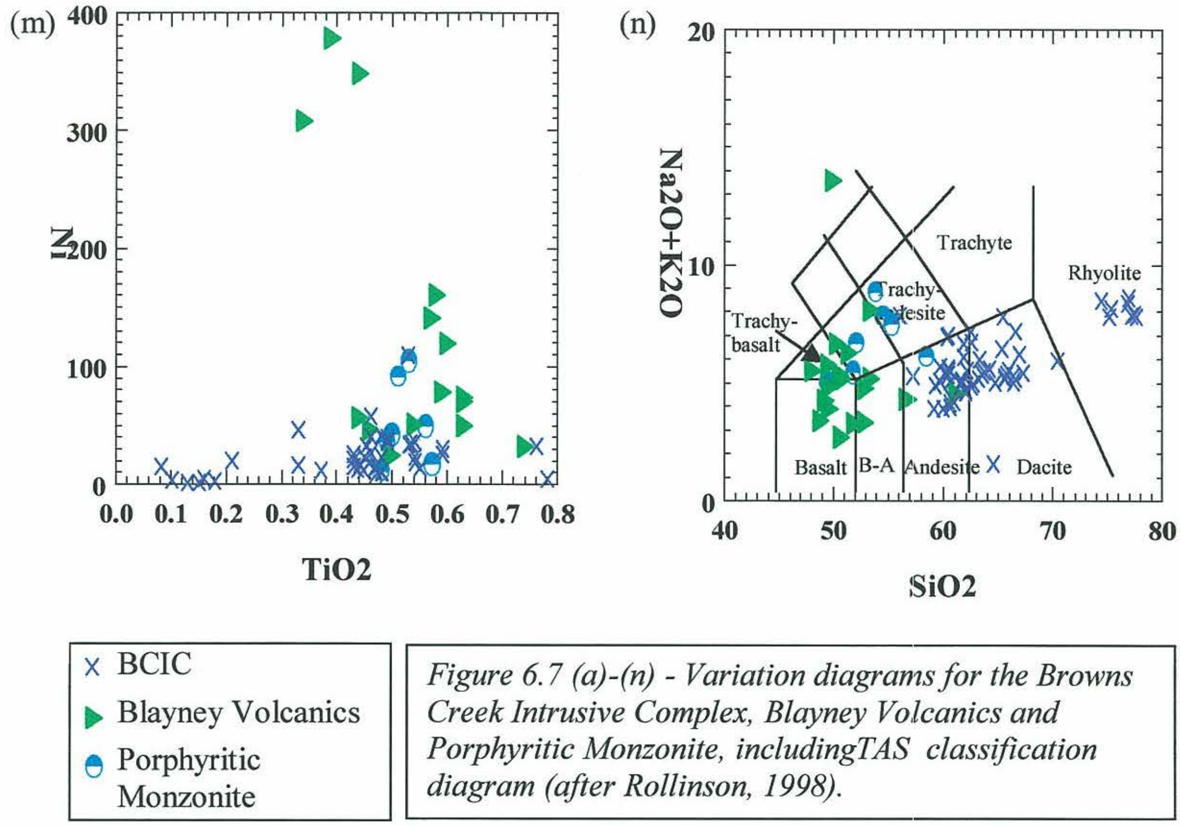


Figure 6.7 (a)-(n) - Variation diagrams for the Browns Creek Intrusive Complex, Blayney Volcanics and Porphyritic Monzonite, includingTAS classification diagram (after Rollinson, 1998).

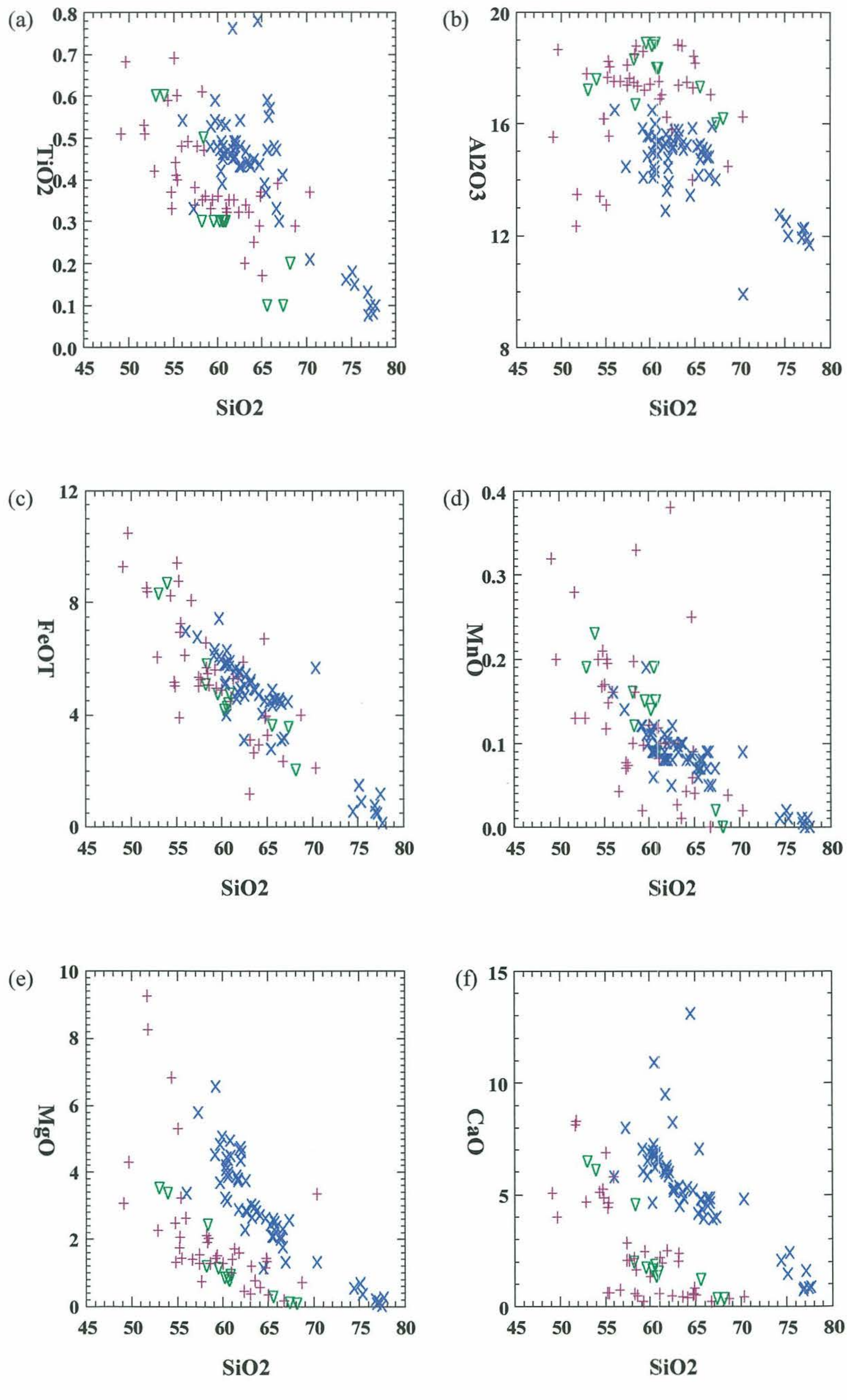
enrichment of CaO in these intrusives. The other major elements tend to be greater in the monzonite than the Carcoar Granodiorite. The exception is Na_2O that shows a slight decrease in the monzonite samples. More importantly the enrichment of MgO indicates that the porphyritic monzonite, and the Blayney Volcanics, represent a less evolved magma source.

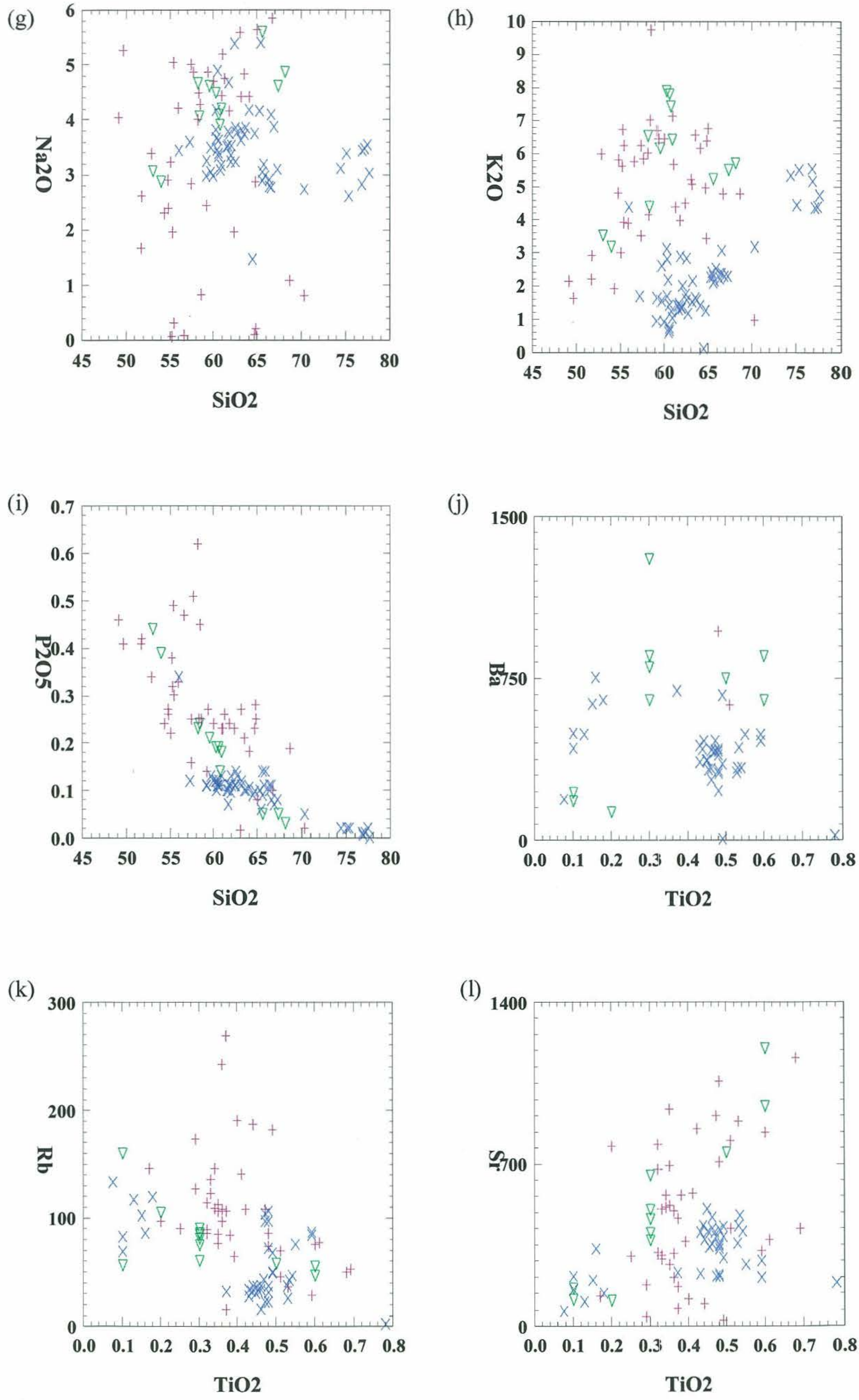
The trace element plots also indicate that the porphyritic monzonite is from a less evolved magma source. They are noticeably higher in their Ni and Cr contents. The high amounts of Ba in the monzonite and Blayney Volcanics is consistent with the high abundance of alkali feldspar within the mineralogy. The enriched Sr is a reflection of the plagioclase content of the monzonite. The relative enrichment of V, Cr, Ni and Ti may be related to the greater abundance of ferromagnesium, Ti and oxide mineral phases in these samples.

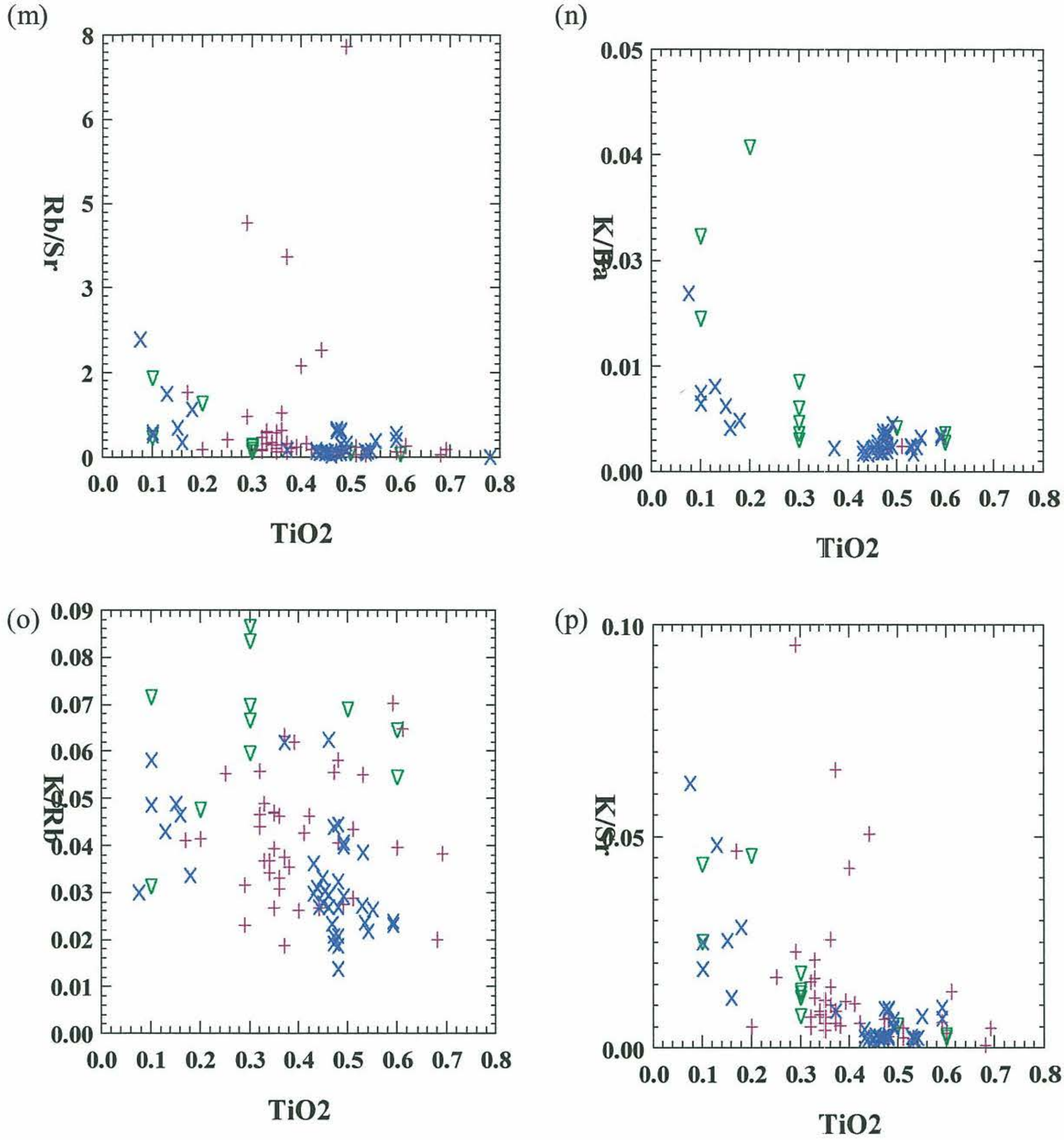
The porphyritic monzonite has come from a less evolved, unfractionated parent magma. The high amounts of clinopyroxene and feldspars in their mineralogy is consistent with the geochemical characteristics displayed by the variation diagrams. Their relation to the other intrusives at the Browns Creek deposit is unclear. It appears that they are geochemically related to the Blayney Volcanics, which were erupted prior to the intrusion of the Carcoar Granodiorite and hence the other intrusive phases of the Browns Creek Intrusive Complex. The petrography and geochemistry of the monzonite point to it representing the high-level intrusion of the same magma source as the Blayney Volcanics.

6.5.4 Errowan Monzonite, Glen Ayr Syenite, Carramar Syenite and Halls Road Intrusives

While these intrusives are geochemically distinct from each other, they all generally plot away from the Browns Creek Intrusive Complex in a similar fashion (figure 6.8 (a) – (p)). They have been included in this comparison as they are among the larger intrusive bodies that are in close proximity to the mine. As discussed in Chapter 2, the age of the Errowan Monzonite (450 ±10 Ma, Pogson and Watkins, 1998) is also comparable to other mineralisation in the area, such


(a)
TiO2
SiO2
(b)
Al2O3
SiO2
(c)
FeOT
SiO2
(d)
MnO
SiO2
(e)
MgO
SiO2
(f)
CaO
SiO2


(g)
Na2O
SiO2
(h)
K2O
SiO2
(i)
P2O5
SiO2
(j)
Ba
TiO2
(k)
Rb
TiO2
(l)
Sr
TiO2



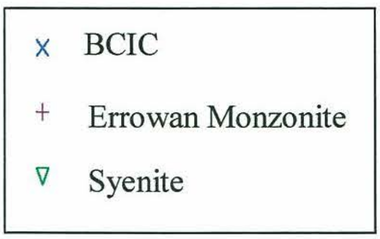


Figure 6.8 (a)-(p) - Variation diagrams for the Browns Creek Intrusive Complex, the Errowan Monzonite and various syenites

as the Cadia deposit. The Halls Road intrusives are also related to local mineralisation. Due to geochemical similarities, the Glen Ayr Syenite, Carramar Syenite and the Halls Road intrusives are referred to here as the *syenite group*.

The Errowan Monzonite and the syenite group have a range of silica values similar to the Browns Creek Intrusive Complex, from approximately 48 to 70 weight percent. However apart from this, these intrusives are quite distinct from the Browns Creek Intrusive Complex. The Al_2O_3 and FeO* variation diagrams clearly show that apart from a few outliers, the samples plot on sub-parallel trends above that of the Carcoar Granodiorite and other members of the Browns Creek Intrusive Complex. The plot of MgO shows more scatter particularly within the Errowan Monzonite and are below the trend of the Browns Creek Intrusive Complex. The scatter within the Errowan Monzonite samples is also evident within the plots of K_2O and CaO. In the K_2O plot, the monzonite and the syenite group plot well above the Browns Creek Intrusive Complex while on the plot of CaO, they are scattered below.

While the syenite group has Ba levels similar to the Browns Creek Intrusive Complex, the plot of Ba against TiO_2 shows the difference between the syenites. The Carramar Syenite most likely resembles an unfractionated magma source. The Glen Ayr Syenite is more evolved than the Carramar Syenite. The evolved Halls Road intrusives represent a fractionated magma source. However, there is no continuum between the three. There is a lack of trace element analyses for the Errowan Monzonite and as such it cannot be placed in this process.

When comparing the above process with the Browns Creek Intrusive Complex, there is little deviation of the trace element plots of the Glen Ayr Syenite, Carramar Syenite and the Halls Road intrusives. In both cases, there is a series of intrusive phases that range from true melts to fractionated magmas. However, as there is no continuum of magmas in the latter series of intrusives, it cannot be stated that they represent a single source, as is the case with the Browns Creek Intrusive Complex.

The plot of Rb supports the findings of the barium plot regarding the syenite group. However, the addition of the Errowan Monzonite to the data enables a comparison to be made with it. Like most plots, the monzonite is quite scattered but an overall increasing trend can be identified with decreasing titanium. This trend plots above that of the Browns Creek Intrusive Complex. The Sr plot on the other hand has the syenite group plotting on a sub-parallel decreasing trend that is slightly above that of the Browns Creek deposit intrusives. The Errowan Monzonite samples are scattered above this again.

Plots of the ratios of the trace elements show inconsistencies between the syenite group and the Errowan Monzonite with the Browns Creek Intrusive Complex. Rubidium over strontium shows overlapping trends with the Browns Creek deposit intrusives. However, the plot of K/Rb shows a high amount of scatter of both the Errowan Monzonite and the syenite group which generally plot above the Browns Creek deposit intrusives. This plot does not show the same degree of differentiation of the syenite group as the previous plot. Potassium over strontium ratios are similar between the two groups of intrusives, with the monzonite and the syenites showing steadily increasing trends as with the Browns Creek deposit intrusives. As there is a lack of Ba analyses for the Errowan Monzonite, the plot of K/Ba is only useful for the comparison of the syenite group with the Browns Creek deposit group. Both tend to overlap and show steadily increasing trends.

The geochemistry alone of the Errowan Monzonite and the syenite group shows that there are dramatic compositional differences between them and the Browns Creek Intrusive Complex. The monzonite and syenites would most likely comprise a higher proportion of feldspars in their mineralogy. However, as their petrography was not available, this is speculative. While they also represent a variation of crystallisation histories, the continuum that is observed within the Browns Creek Intrusive Complex is not seen. The considerable amount of scatter within the Errowan Monzonite samples may indicate its complex crystallisation history or be an artifact of alteration. There is differentiation within the syenite group as well. They represent a different magma source to the Browns Creek Intrusive Complex, most likely older. Any mineralisation that may be related to these intrusives is concluded to be unrelated to that that is associated with the

Browns Creek Intrusive Complex.

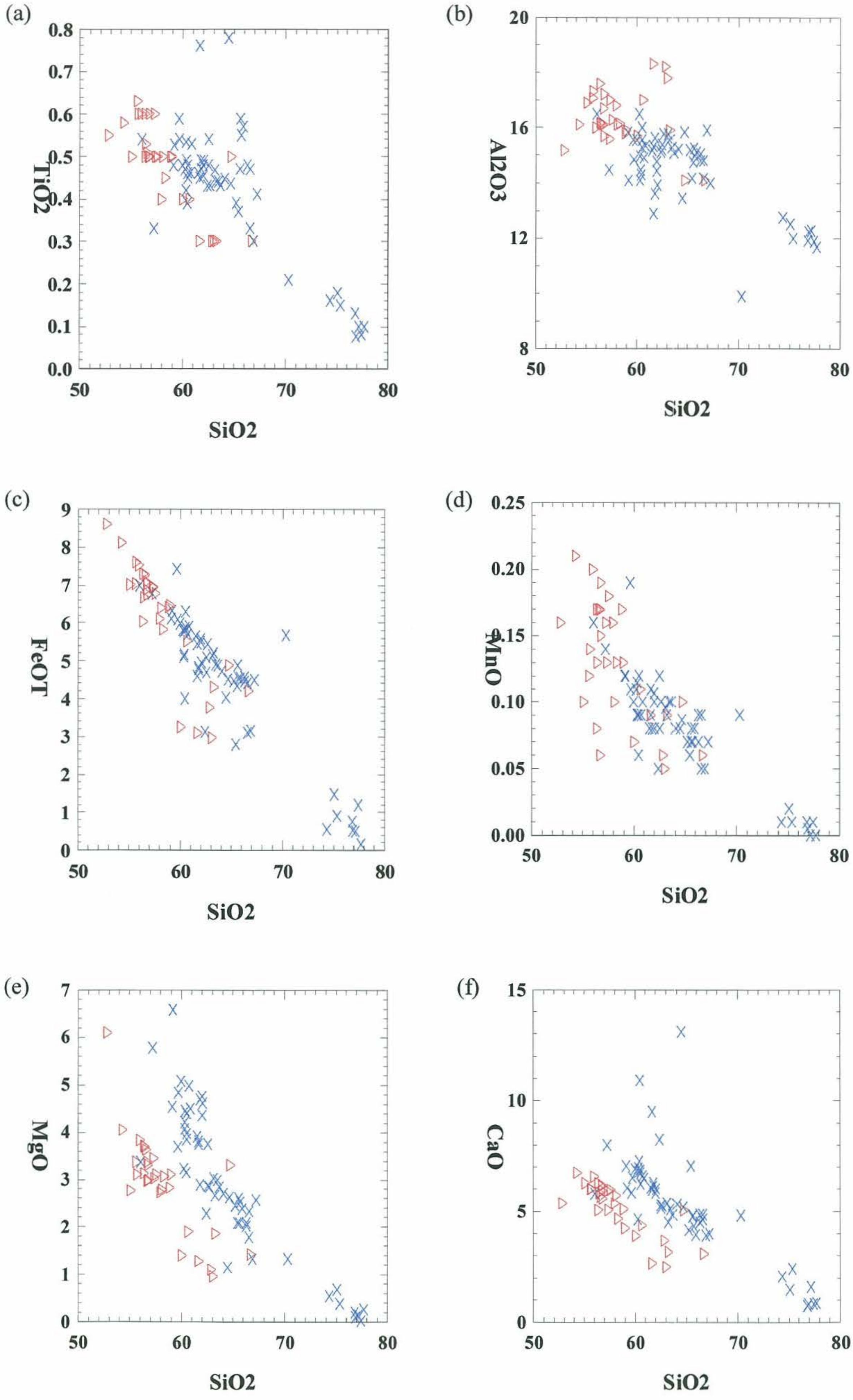
6.5.5 Tallwood Monzonite

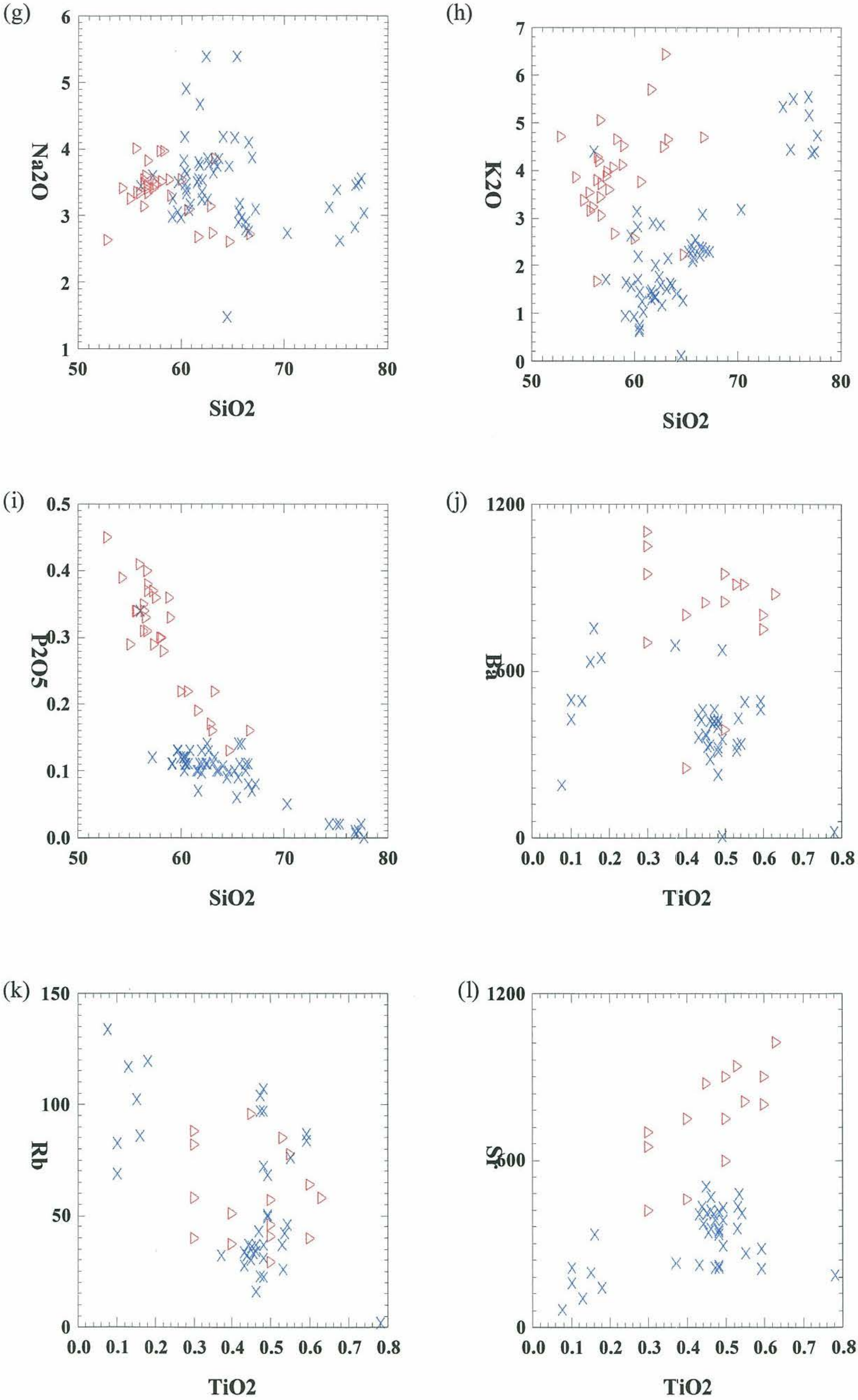
The Tallwood Monzonite was also compared with the Browns Creek Intrusive Complex. The Tallwood Monzonite is thought to be of late Late Ordovician age (Pogson and Watkins, 1998), older than the Browns Creek Intrusive Complex. While the major elements showed some overlap on variation diagrams, the monzonite clearly plots differently to the Browns Creek Intrusive Complex in others (figure 6.9 (a) – (l)). The silica range of the monzonite is similar to that of the Carcoar Granodiorite, from 53 to 66 weight percent SiO_2.

The variation plot of Al_2O_3 versus SiO2 shows that the Tallwood Monzonite samples tend to be slightly higher in Al_2O_3 than the Browns Creek deposit intrusives. They also display a slight increase in $Al_2O_3$with respect to decreasing TiO_2. Regarding the FeO* plot, there is little distinguishing the monzonite from the Browns Creek Intrusive Complex. It can be argued that the Tallwood samples may be slightly higher in iron than the latter group. The MgO and CaO levels of the monzonite plot on a lower parallel trend and the K_2O levels in the monzonite are obviously higher relative to most of the Browns Creek Intrusive Complex. The plot of P_2O_5 also shows considerably higher amounts of P_2O_5 in the monzonite samples.

The Ba plot does not show that same trend in the Tallwood Monzonite samples as the concave trend of the Browns Creek deposit intrusives. Rather, the monzonite samples are slightly higher in Ba and tend to scatter on a linear trend. The plot of Sr also shows higher concentrations of this trace element in the monzonite. The plot of Rb however, shows a similar level in the monzonite and the Browns Creek deposit intrusives. The plots of the trace element ratios for the monzonite samples are also similar to the Browns Creek deposit samples.

The Tallwood Monzonite is clearly different intrusive to the members of the Browns Creek Intrusive Complex. It has lower amounts of MgO and CaO and


(a)
TiO2
SiO2
(b)
Al2O3
SiO2
(c)
FeOT
SiO2
(d)
MnO
SiO2
(e)
MgO
SiO2
(f)
CaO
SiO2


(g)
Na2O
SiO2
(h)
K2O
SiO2
(i)
P2O5
SiO2
(j)
Ba
TiO2
(k)
Rb
TiO2
(l)
Sr
TiO2

x BCIC
▷ Tallwood Monzonite

Figure 6.9 (a)-(l) - Variation diagrams for the Browns Creek Intrusive Complex and the Tallwood Monzonite

dramatically different amounts of K_2O, P_2O_5, Ba and Sr. It is anticipated that the monzonite most likely contains a greater amount of alkali feldspar in its mineralogy, which may just be an artifact of alteration. This would be consistent with the increase in Ba and the noticeable increase in K in the monzonite. Again, as the petrography of the Tallwood Monzonite was not available, this is speculative. The age of the Tallwood Monzonite is thought to be older than that of even the new age determinations for the Carcoar Granodiorite. As such, the two intrusives are not thought to be related. The Tallwood Monzonite may be more closely related to the porphyritic monzonite and this would be the topic of further study of the intrusives of this area.

6.6 Mineralisation and Intrusive Phases

The intrusion of the Mine Dyke Group represents the main magmatic metal surge of the Browns Creek Intrusive Complex. While each phase has an associated fluid that has caused local metasomatism of the country rock, the fluids associated with the Mine Dyke Group are interpreted as responsible for the widespread mineralisation at the Browns Creek deposit.

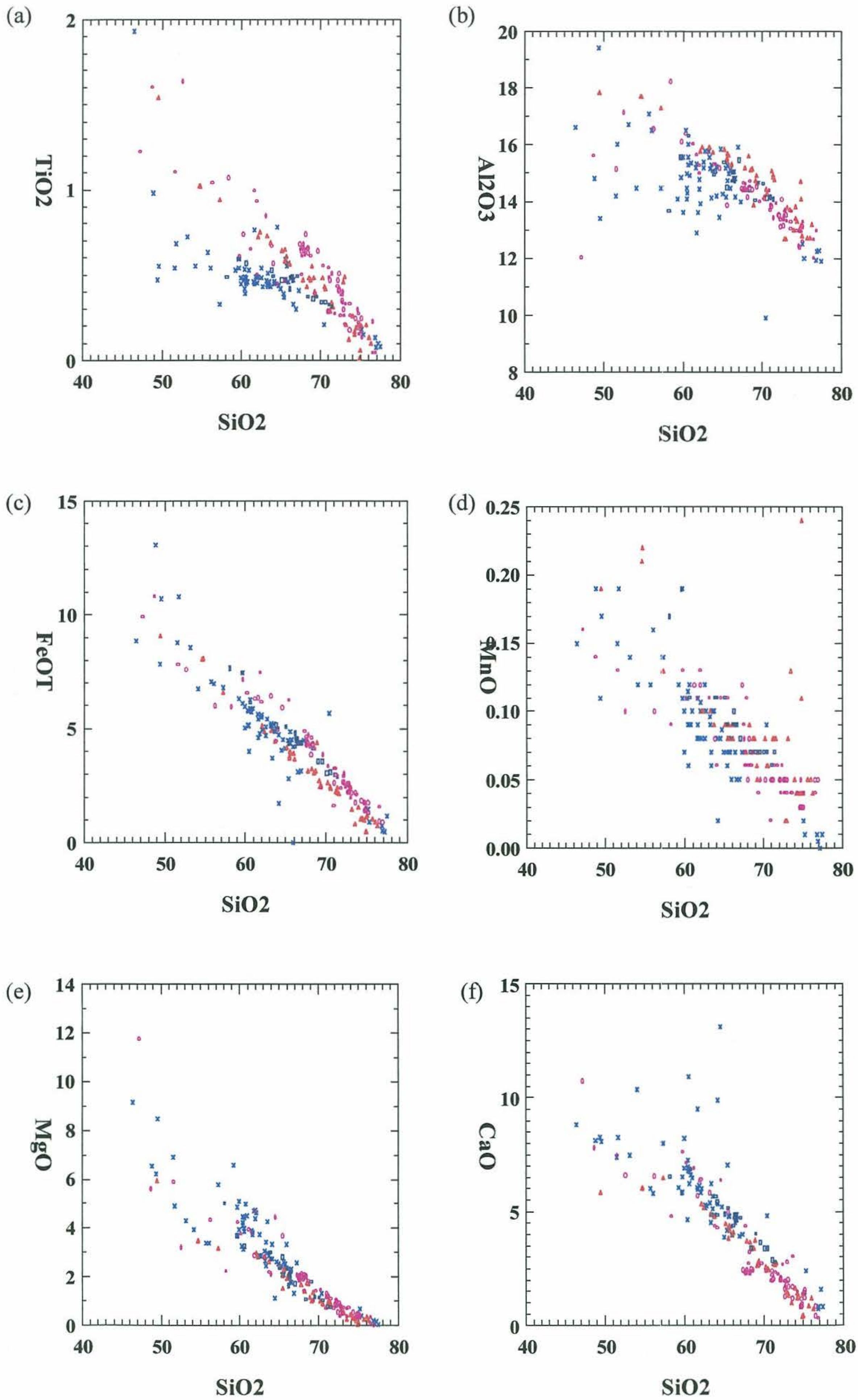
Geochemical analysis, together with petrographic observations, has shown that the Mine Dyke Group represents disequilibrium crystallisation. The dykes are most likely associated with a volatile phase that has caused the rapid loss of heat from the intruding material. This is readily observed in the range of textures in the Mine Dyke Group, dominantly the presence of graphic intergrowth of feldspars and quartz. The whole-rock geochemistry of the Mine Dyke Group has shown that some members of the group are a more compositionally evolved than most of the Browns Creek Intrusive Complex and have increased contents of incompatible elements such as LREE, U and Th. If they are carrying these elements then they are capable of carrying other incompatible elements such as gold and copper. This supports the Mine Dyke Group being responsible for the mineralisation at the Browns Creek deposit.

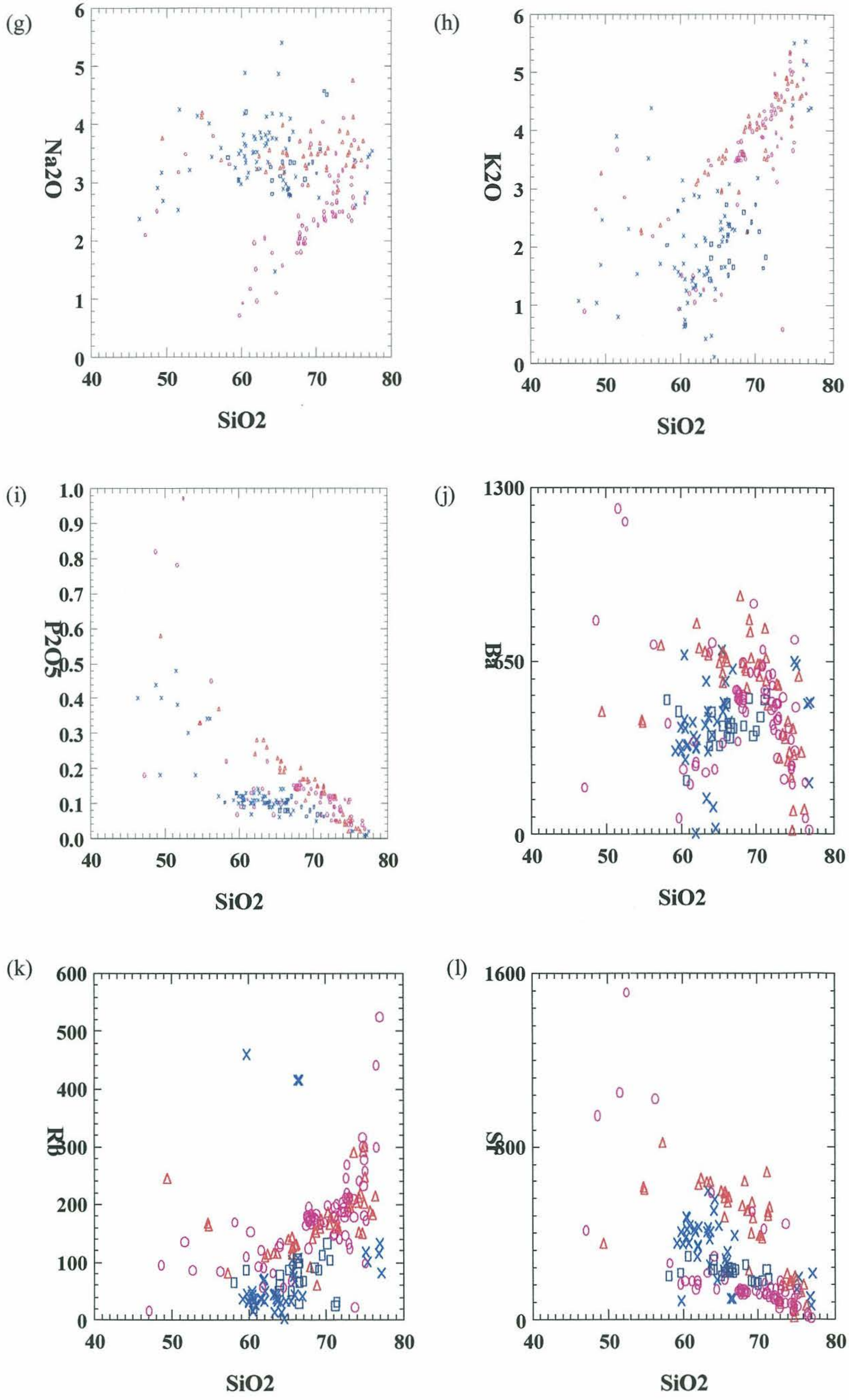
The dykes are concentrated within the ore zone at the Browns Creek deposit. Within this zone, cross-cutting relationships indicate that the dykes range from pre-mineralisation to post-mineralisation. If the mineralisation were to be a direct result of the intrusion of the dykes then this would explain the discrepancies in the relative timing of the dykes and the mineralisation. This supports the previous findings of the relationship between the Mine Dyke Group and the mineralisation.

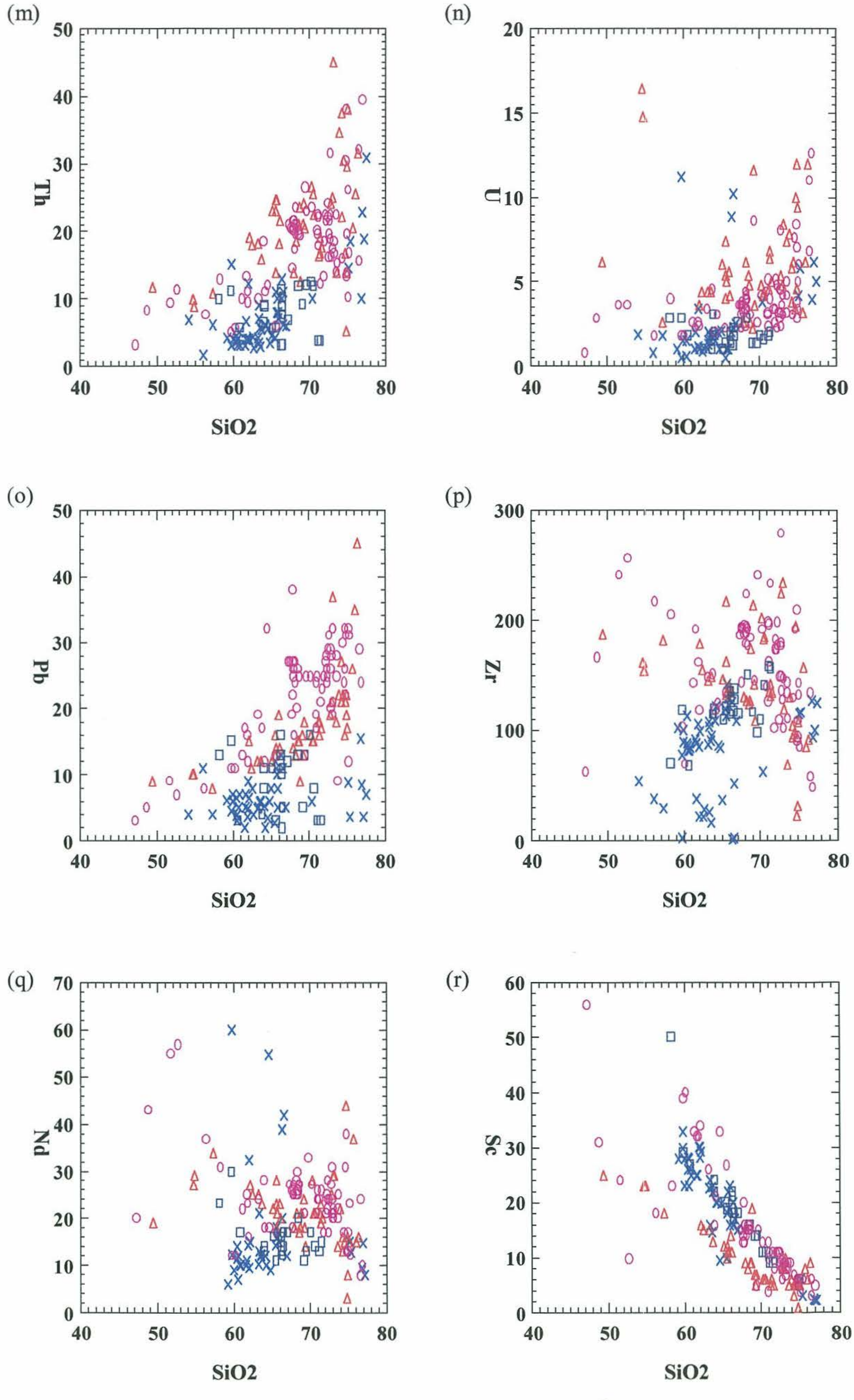
6.7 Regional Intrusives

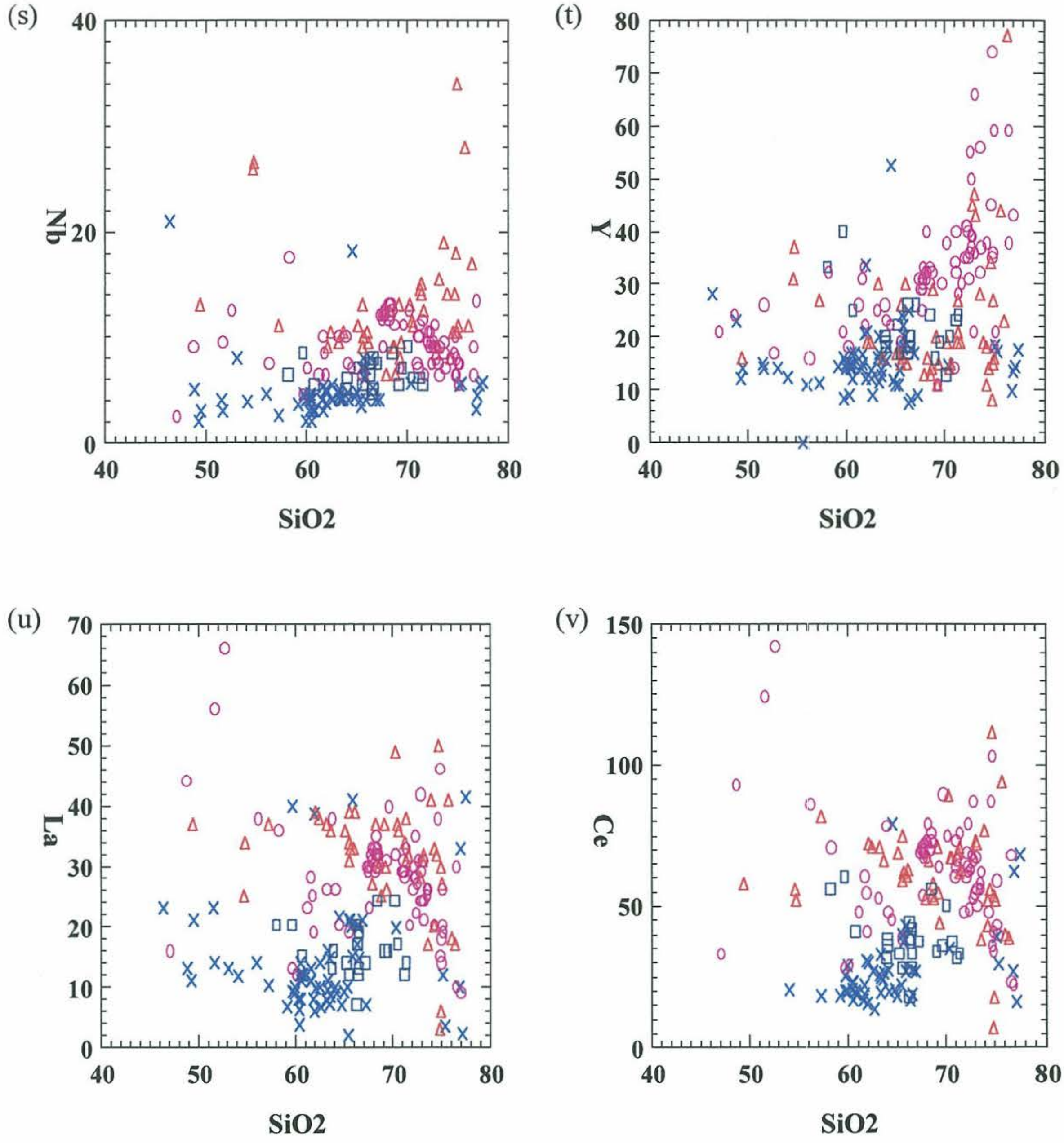
The relation of the Browns Creek Intrusive Complex with the Barry Granite warranted further investigation into its relation with other intrusives in the region. As the Carcoar Granodiorite has been proven to be considerably older than previously thought (Chapter 7), near the Ordovician/Silurian boundary, granites of the Bathurst 1:250,000 sheet were compared (B. Chappell, unpubl. data). During this investigation, it was noted that several Silurian intrusives were consistently plotting as outliers to the rest of the Silurian intrusives on variation diagrams (figure 6.10 (a) – (v)). These outliers were lower in TiO_2, P_2O_5, MgO, K_2O, Ba, Rb, Th, U, Pb, Zr, V, Nb, Nd, La, Ce and Sr. They were also higher in abundance of FeO*, Na_2O, CaO and Sc. This may indicate that these outliers are geochemically less evolved. These intrusives were three members of the Wyangala Batholith (Swan Ponds Tonalite, Garland Granodiorite, Grants Corner Granodiorite), the Barry Granite and the Carcoar Granodiorite. Together, they are referred to as the S1 Intrusives.

A noteworthy feature of the S1 Intrusives is that their geochemical signature is more consistent with Carboniferous intrusives. It would be expected that considering the Carcoar Granodiorite is close to the Ordovician boundary that its geochemical signature and that of the other S1 Intrusives, would be similar to the


(a)
TiO2
SiO2
(b)
Al2O3
SiO2
(c)
FeOT
SiO2
(d)
MnO
SiO2
(e)
MgO
SiO2
(f)
CaO
SiO2


(g)
Na2O
SiO2
(h)
K2O
SiO2
(i)
P2O5
SiO2
(j)
Ba
SiO2
(k)
Rb
SiO2
(l)
Sr
SiO2


(m)
Th
SiO2
(n)
U
SiO2
(o)
Pb
SiO2
(p)
Zr
SiO2
(q)
Nd
SiO2
(r)
Sc
SiO2



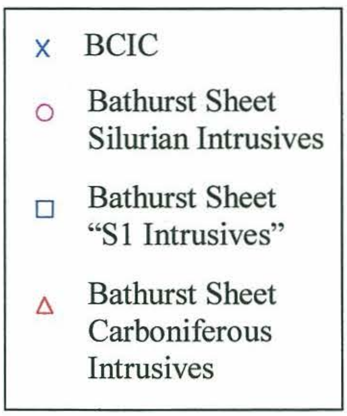


Figure 6.10 (a)-(v) - Variation diagrams for the Browns Creek Intrusive Complexand intrusives of the Bathurst 1:250,000 sheet

earlier Silurian intrusives. On several variation diagrams, the S1 Intrusives plot on similar trends to the Carboniferous intrusives, in particular the plots of Na_2O, CaO and possibly Y. This feature needs to be further investigated to substantiate if there is a genetic connection between the S1 Intrusives and the Carboniferous intrusives. No further conclusions can be made at this stage.