1 MUSGRAVE BLOCK SYNTHESIS

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1.1 Executive Summary - Geology

The Musgrave Block is a Palaeo-Mesoproterozoic crystalline basement domain extending across the common borders of South Australia, Western Australia, and the Northern Territory. Exposures are excellent in the main ranges (Birksgate, Tomkinson, Mann, Musgrave and Everard Ranges) but other areas are mostly veneered by sand dunes and sheets of the Great Victoria Desert. The Musgrave Block is flanked by Neoproterozoic and Palaeozoic sedimentary basins: Canning Basin to the northwest, Amadeus Basin to the north, Officer Basin to the south and west, and Warburton Basin to the east. The Mesozoic Eromanga Basin oversteps the latter two from the east onto the Musgrave Block.

The Musgrave Block is subdivided into two tectonic subdomains — the area north of, and structurally below, the Woodroffe Thrust is the Mulga Park Subdomain, whereas the region to the south is the Fregon Subdomain, which is structurally above the thrust. A recent compilation by Major and Conor (1993) simplifies the terminology used in the area. The Olia Gneiss refers to the amphibolite-facies gneisses north of the Woodroffe Thrust (Mulga Park Subdomain); (note that recent dating suggests that only gneiss in areas around Mulga Park is pre-Musgravian Orogeny in age, and that the Olia Gneiss in other areas may be deformed equivalents of the Pottoyu Granitic Complex, i.e., part of the Kulgera Supersuite (N. Duncan, NTGS *pers. comm.* 1996)). The Musgravian Orogeny includes a ~1200 Ma metamorphic event which produced the Birksgate Complex which refers to all the metamorphic rocks (i.e., granulite and amphibolite-facies gneisses) south of the Woodroffe Thrust (Fregon Subdomain). This excludes the Giles Complex, Kulgera Supersuite and mafic dykes. The Bentley Supergroup in the western Musgraves overlies earlier gneisses and the Giles Complex. It includes the Tollu Group, which includes the possibly A-type Smoke Hill Volcanics dated at 1080 Ma.

Only three age groupings of granites have been recognised at this stage. They are the regionally extensive Kulgera Supersuite at ~1185 Ma, a suite of granitoids dated at ~1050 Ma and informally named the Winburn suite in the area of the Giles Complex — Tollu Group, and an age of ~1550 Ma has been obtained from some zircons in felsic gneisses. It must be stressed that this division is tentative, as it is based on a limited geochemical and geochronological dataset, and mapping that was done in pockets rather than throughout the Block. Further, literature descriptions are difficult to interpret. Also, A. Comacho (*pers. comm.*) and J. Sheraton (*pers. comm.*) have indicated that on local scales there is significant variation in the composition of the granites, and that grouping the granites into suites is difficult. It is considered by the author highly likely that further work in the Musgrave Block would substantially change the suites that many of the individual map units are assigned to. This must be borne in mind when considering the metallogenic potential of any of these areas.

Camacho and Fanning (1995) dated felsic gneisses from both the Fregon and Mulga Park subdomains containing zircons that were structured with euhedral centres overgrown by round elongate rims. SHRIMP analyses of the cores gave ages of 1557 ± 24 and 1554 ± 28 Ma respectively, and were interpreted to represent the time of igneous crystallisation. Maboko *et al*. (1992) dated a metagranitoid by the SHRIMP method at 1502 ± 14 Ma. Although this is clear evidence for an old granite event, there are no other data to make an analysis of these granites possible. It is not even clear where these particular granite samples are located, which units they belong to, or how extensive they are. They may represent samples of the Birksgate Complex (see later), or may predate or intrude this Complex. No geochemical analyses are available for these samples, so the granites of this age unfortunately cannot be considered in any more detail.

The Kulgera Supersuite was emplaced during and after high-grade metamorphism of the Musgravian Orogeny, at ~1185 Ma. It is composed of widespread felsic, mainly monzogranitic and charnockitic plutons emplaced predominantly in the Fregon Subdomain. They range in composition from alkali granite to diorite, and include extensive biotite granite gneiss. The hydrous and oxidation states vary, so that orthopyroxene, clinopyroxene, hornblende or biotite can be locally dominant. The granitoids are commonly porphyritic and vary from foliated to massive. The Kulgera Supersuite includes granites of the Kulgera Suite in the northeastern part of the Musgrave Block. It also includes the Pottoyu Granitic Complex and the Olia Gneiss in the northwestern (Petermann Ranges) part of the Block. Granites in the southern part of the Block are thought to be part of the Supersuite, and have been informally grouped as the Southern granites.

The Winburn Suite intruded contemporaneously with the Giles Complex and the Smoke Hill Volcanics at 1080 Ma (Sun *et al.* 1996). It is restricted in occurrence to the western Musgrave Block, in the broad area of the Tomkinson Ranges — Hinkley Ranges. It comprises charnockite, rapakivi granite, megacrystic granite, and biotite granite. Some of the granites are I-types, typical of intracrustal melts, and they have marked Y depletion. Other granites are fluorite-bearing (which is consistent with rapakivi and megacrystic textures), and are suggested as being the intrusive equivalents of the Smoke Hill Volcanics. Some of the granites of this age have back-intrusion relationships with the Giles Complex, and it is suggested that the Winburn Suite and Giles Complex are derived during a single magmatic episode.

The Kulgera Supersuite and Winburn Suite intrude the Birksgate Complex. The only named unit of the complex is the Wataru Gneiss in the Birksgate Range. The Birksgate Complex is composed of more than 90% silicic rocks, with the remainder including pelitic, quartzitic, calc-silicate and intermediate paragneisses, and intermediate, basic and ultrabasic orthogneisses (note that these are common lithologies throughout the Block, meaning that lithological mapping alone cannot provide a stratigraphy). It is granulitic with hornblende + biotite ± orthopyroxene ± clinopyroxene. The bulk of the metamorphic rocks of the Birksgate Complex are suggested to have volcanic precursors, being dominantly felsic orthogneisses, but also including mafic and ultramafic bodies. The presence of peraluminous gneiss, magnetite-rich quartzite and calc-silicate rock indicate that clastic and chemical sedimentary components are widespread.

There appears to be a broad regional pattern in the distribution of metamorphic grade within the Fregon Subdomain, with the Tomkinson, Mann and Musgrave Ranges forming a core characterised by granulite-facies rocks. These possibly pass southwards and eastwards into lower-grade amphibolite-facies rocks. Hornblende-bearing granulites are distributed across the central and southern portions of the subdomain.

1.2 Executive Summary - Metallogenic Potential

The Kulgera Supersuite is strongly oxidised to oxidised, moderately fractionated, has a wide composition range, is strongly metaluminous, and is Sr-depleted, Y-undepleted. Potential hosts which the suite intrude include mafic and ultramafic units of the Birksgate Complex, which have Fe^{2+}-rich minerals (pyroxene, hornblende), and magnetite-rich quartzites. The Kulgera Suite is thought to have moderate potential for gold and possibly copper mineralisation.

The Winburn Suite is not considered to have any significant mineralisation potential, because of its A-type character.

1.3 Methods

Information Sources: Major and Conor (1993) is a useful summary of the part of the Musgrave Block occurring in South Australia. The NGMA mapping carried out in the western part of the Block has also provided useful information and geochemical data and geochronology (Glikson *et al.* 1995; Sheraton and Sun 1995; Sun *et al.* 1996; Glikson *et al.* 1996). However, a large part of the focus of this work was on the mafic and ultramafic units of the Giles Complex, with less information available on the felsic intrusives in the area. Geochemical data are sourced from AGSO's OZCHEM database, and data for the Northern Territory granites were provided by the NTGS.

Classification of Granites: In this synthesis, the granites were tentatively grouped using only limited geochemistry, very brief literature articles, and information from relatively small-scale mapping.

Host Rocks: The country rocks which are thought to be intruded by each suite have been summarised, and classified according to mineralogical characteristics thought to be important in determining the metallogenic potential of a granite intrusive event. Again, the data available for this are limited, and possibly incomplete.

Relating Mineralisation: Very little mineralisation (none of it economic to date) has been found in the Musgrave Block. Minor primary uranium, copper and gold mineralisation has been identified within gneiss and granulite of the Fregon Subdomain.

1.4 References

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1.5 Table 1.1

Chpt #	Grouping (Type)	Age (Ma)	Potential					Confid Level	Pluton
			Cu	Au	Pb/Zn	Sn	Mo/W		
	Unnamed	1550	?	?	?	?	?	???	???
2	Kulgera (Cullen)	1190	Mod	Mod	None	None	None	110	Undivided
3	Winburn (Sybella)	1080	None	None	None	None	None	110	Undivided

2 KULGERA SUPERSUITE

2.1 Timing

1190 -1150 Ma

2.2 Individual Ages

Primary Ages:

1. Ngarinya Adamellite[1]	1186 ± 10 Ma, U-Pb
2. Charnockite[1]	1193 ± 9 Ma, U-Pb
3. Minno augen gneiss[2]	1198 ± 6 Ma, SHRIMP
4. Coarse porphyritic gneissic granite, Pottoyu Granite Complex[3]	1190 Ma, Rb-Sr
5. Leucocratic medium-grained granite, Pottoyu Granite Complex[3]	1150 Ma, Rb-Sr
6. Pottoyu Granitic Complex, Petermann 100K P89/433[4]	1144 ± 12 Ma, U-Pb
7. Pottoyu Granitic Complex, Petermann 100K P88/34[4] (previously mapped as Olia Gneiss)	1192 ± 13 Ma, U-Pb
8. Kulgera Adamellite[5]	1150 ± 12 Ma, SHRIMP
9. Ayers Ranges Adamellite[5]	1152 ± 11 Ma, SHRIMP
10. Ayers Ranges Adamellite[5]	1152 ± 3 Ma, U-Pb
11. Porphyritic suite[5]	1159 ± 20 Ma, SHRIMP

Sources: [1] Maboko *et al.* (1991); [2] Sun *et al.* (1996); [3] P.J. Leggo *in* Forman (1972); [4] Duncan (1997a); [5] Camacho and Fanning (1995).

2.3 Regional Setting

The Kulgera Supersuite was emplaced late in and shortly after the Musgravian Orogeny (Major & Conor 1993). The granites were intruded over approximately 50 Ma, with the oldest granites being significantly deformed, and the younger granites showing little of the deformation of the Musgravian Orogeny. They are widespread throughout the Musgrave Block, and vary greatly in composition from alkali granite to diorite. They are emplaced into, and may be partly derived from, earlier formed basement rocks of the Birksgate Complex.

2.4 Summary

The Kulgera Supersuite is possibly restite-dominated, as it is fractionated at compositions above 70 wt. % SiO_2. It is oxidised, has a broad composition range, and is Sr-depleted, Y-undepleted.

It has been difficult to assign units to this supersuite because of a lack of geochemical data, lack of geochronology, and lack of consistency in mapping across sheet boundaries. Further, the geochemistry of all the felsic rocks in the region is quite similar, possibly implying that the Kulgera Supersuite granites are remelted from rocks of similar composition to those they intrude. This geochemical similarity compounds the difficulty of defining granite suites. As a result, it is expected that further work in the region will significantly improve the understanding of the metallogenic potential of the granites of this supersuite.

Table 2.1 contains a list of all 1:250 000 map units and the suites to which they are assigned in this work.

2.5 Potential

This supersuite is considered to have some metallogenic potential principally because it shows evidence of late-stage fractionation. There is little known mineralisation in the Musgrave Block, due to the low level of exploration which has been carried out in the region and which was concentrated on Giles Complex rocks.

Cu:	**Moderate**
Au:	**Moderate**
Pb/Zn:	**None**
Sn:	**None**
Mo/W:	**None**
Confidence level:	**110**

2.6 Descriptive Data

Location: Granites assigned to the Kulgera Supersuite are found throughout the Musgrave Block.

Dimensions and area: The Kulgera Supersuite, including the Kulgera Suite, the Pottoyu Granitic Complex, the Olia Gneiss, and the Southern granites, has a mapped outcrop area of 9,860 km^2.

2.7 Intrusives

Component plutons: The granites of the Kulgera Supersuite are not named or subdivided in any consistent way across the Block. For this reason, a summary table is given below of the granites occurring on each map sheet. In this work, the Supersuite has been subdivided into four groups, based more on geographical location than geochemistry or geochronology. These are the Kulgera Suite (northeastern part of the Block), the Southern granites (southern part of the Block), the Olia Gneiss, and the Pottoyu Granitic Complex. The latter two occur in the northwestern part of the Block (in the Petermann Ranges particularly), and represent granites intruded early in the Musgravian Orogeny (those parts of the Olia Gneiss thought to be ~1200 Ma), and those intruded largely post-orogeny (Pottoyu Granitic Complex).

Table 2.1: Granitic map units and their assigned suites (of the Kulgera supersuite), Musgrave Block

MAPUNIT	MAPSHEETS	SUITE	COMMENTS
Ayers Range Adamellite (Ᵽ*gc*)	Kulgera	Kulgera Suite	Monzonite and granodiorite
Cartoberinna Granite	Everard	Southern granites?	Equivalent to Illbillie Adamellite?
Charnockite	Woodroffe	Kulgera Suite	Hypersthene monzogranite
Ernabella Charnockite	Alberga	Kulgera Suite	Also known as Ernabella Adamellite
Kulgera Adamellite (Ᵽ*gk*, Ᵽ*gkd*)	Kulgera	Kulgera Suite	Granite, monzogranite + porphyritic microgranite dykes
McNamara Hill adamellite	Woodroffe	Kulgera Suite	Porphyritic gneissic monzogranite
Michel Nob, Maryinna Hill, undifferentiated granites	Woodroffe	Kulgera Suite	Granites & monzogranites
Olia Gneiss, *p€n*	Ayers Rock, Bloods Range, Petermann Ranges, Finke	Olia Gneiss	Subject to syn- & post-magmatic deformation, but same age/composition as Kulgera granites. Some units on Ayers Rock do belong to Birksgate Complex
Ᵽ*bg*	Scott	Kulgera Suite	Banded granitic rocks
Ᵽ*bo*	Scott	Kulgera Suite	Rapakivi granite
Ᵽ*ge*	Cooper	Kulgera Suite	Granite
Ᵽgm_1	Kulgera	Kulgera Suite	Unfoliated
Ᵽgm_2	Kulgera	Kulgera Suite	Foliated
Ᵽ*gn*	Cooper	Kulgera Suite	Granitic gneiss
Ᵽ*gna*, Ᵽ*gnb*	Kulgera	Kulgera Suite	Well layered - similar to Olia Gneiss?
Ᵽ*gp*	Cooper, Scott	Kulgera Suite	Equigranular granite sheets
Ᵽ*gu*	Cooper	Kulgera Suite	Undifferentiated granites
Ᵽγ	Abminga	Kulgera Suite	Porphyritic bio±hbld monzogranite + granite

MAPUNIT	MAPSHEETS	SUITE	COMMENTS
p€g	Bloods Range, Petermann Ranges	Pottoyu Granitic Complex	Metamorphosed - transitional between Olia Gneiss and Pottoyu Granitic Complex?
p€g	Ayers Rock, Finke	Kulgera Suite	Undifferentiated Kulgera Suite
p€m	Bloods Range, Rawlinson	Pottoyu Granitic Complex	Schistose *p€p* on Bloods Range, Rawlinson?
p€p	Bloods Range, Rawlinson	Pottoyu Granitic Complex	Possibly northern extension of Pottoyu?
Pottoyu Granite Complex (*p€o*)	Bloods Range, Petermann Ranges	Pottoyu Granitic Complex	Least deformed and youngest part of Kulgera Supersuite?
Ꝑ*ri*	Scott	Pottoyu Granitic Complex	Equivalent to Pottoyu Granitic Complex?
Ꝑ*rs*	Scott	Pottoyu Granitic Complex	Equivalent to Pottoyu Granitic Complex?
Ampeinna granite	Lindsay	Southern granites	Equivalent to Illbillie & Permano Adamellites
Undifferentiated Birksgate Granitic Complex	Birksgate	Southern granites	Not part of older Birksgate Complex
Illbillie Adamellite	Everard	Southern granites	Equivalent to Permano Adamellite & Ampeinna granite
Permano Adamellite	Birksgate	Southern granites	Equivalent to Illbillie Adamellite and Ampeinna granite
Aplite of Indulkana shear zone	Alberga	Undifferentiated	Assigned to Kulgera Supersuite
Biotite and hornblende monzogranites	Everard	Southern granites	Probably part of Southern granites
Micromonzogranite, microgranite	Alberga	Undifferentiated	Assigned to Kulgera Supersuite

Summary of mapped units assigned to the Kulgare supersuite, by 1:250 000 map sheet.

ABMINGA: Ꝑγ. 1: grey fine to medium-grained biotite granodiorite, 2: pink porphyritic microgranite, 3: reddish coarse-grained granite, 4: medium to coarse-grained hornblende monzogranite and hornblende granite, 5: medium to coarse-grained porphyritic biotite monzogranite with microcline phenocrysts.

ALBERGA: There is a large compositional range in the granites on this sheet, but in the broad scale they include micromonzogranite, microgranite (*red* - on map legend); biotite and hornblende monzogranite (*tan*); hypersthene monzogranites (*orange* - named elsewhere as the Ernabella Adamellite or Charnockite).

AYERS ROCK: Granite (*p€g*), Olia Gneiss (*p€n*). Note that rocks mapped as Olia Gneiss in the Mulga Park area have been dated at ~1550 Ma and are therefore considered to be part of the Birksgate Complex. N. Duncan (*pers. comm.* 1997) defined the Allanah Suite, a complex of thin-sheeted biotite granites.

BIRKSGATE: Birksgate Granitic Complex, Permanno Adamellite.

BLOODS RANGE: Pottoyu Granite Complex (*p€o*), coarse porphyritic granite (*p€g*), quartz-feldspar porphyry (*p€p*), porphyroblastic schists, quartz-feldspar porphyry (*p€m*), Olia Gneiss (*p€n*).

COOPER: Granite (Ꝑ*ge*), undifferentiated granitic rocks partly derived from Ꝑ*nm* and Ꝑ*no* (Ꝑ*gu*), granitic gneiss (Ꝑ*gn*), porphyritic granite (Ꝑ*gp*).

EVERARD: Biotite hornblende gneiss, undifferentiated granitic rocks, Illbillie Adamellite, Cartoberinna Granite.

FINKE: Granite (*p€g*).

KULGERA: Ayers Range Adamellite (Ꝑ*gc*), Kulgera Adamellite (Ꝑ*gk*, Ꝑ*gkd*), type-a gneissic granite & type-b gneissic granite (Ꝑ*gna*, Ꝑ*gnb*), foliated granite (Ꝑgm_1), unfoliated garnet granite (Ꝑgm_2).

PETERMANN RANGES: Olia Gneiss (*p€n*), metamorphosed granite (*p€g*), Pottoyu Granite Complex (*p€o*); coarse porphyritic gneissic granite, leucocratic medium-grained granite.

RAWLINSON: Brown and grey feldspar porphyry (*p€p*).

SCOTT: Acid gneisses (Ꝑ*bg*), rapakivi granite (Ꝑ*bo*), small lath granite, medium-grained granite and porphyritic granite (Ꝑ*gp*), porphyritic microgranite (Ꝑ*ri* ≅ Pottoyu Complex), fine-grained granite with feldspar phenocrysts (Ꝑ*rs* ≅ Pottoyu Complex).

WOODROFFE: McNamara Hill porphyritic gneissic monzogranite; biotite-hornblende adamellitic gneiss north of Ngarinya Rockhole; hornblende monzogranite southwest and northeast of Brock Pass; charnockite and granulite-facies gneiss in the areas of Mount Caroline and Mount Crombie; granite and monzogranite at Michel Nob and Maryinna Hill.

Form: Most exposures of the Kulgera Supersuite granites are bouldery inselbergs with some weathered pavements and ridges.

Metamorphism and Deformation: These granitoids were emplaced during and after high-grade metamorphism of the Musgravian Orogeny. They vary from foliated to massive. Conor (1987) recognised a progressive change from west to east (from approximately the Ernabella Adamellite in the west to the Kulgera Adamellite in the east) in mineral assemblages related to increasing oxidation and hydration. This is seen in the progression from hypersthene → clinopyroxene → clinopyroxene + hornblende → biotite; also (metasedimentary) granulites/ gneisses are magnetite + haematite + ilmenite bearing, where the granites are magnetite-only.

Dominant intrusive rock types: Ranges from alkaline granite to diorite, dominated by monzogranite and charnockite.

Colour: The Ayers Range Adamellite is grey to pale green-grey when fresh. The Kulgera Adamellite is typically red. The colours of other units are not mentioned in the literature.

Veins, Pegmatites, Aplites, Greisens: Some myrmekite is developed in a strongly porphyritic microgranite phase of the Ayers Ranges Adamellite. Some pegmatites occur in the Kulgera area (associated with the Kulgera Adamellite) and form steeply dipping dykes up to 7 km long. The dominant minerals are quartz, K-feldspar, muscovite, biotite and magnetite. Exotic mineral phases such as beryl, garnet and tourmaline are scattered randomly within the dykes in thick pockets of near pure quartz.

Pegmatite, quartz and minor aplite veins intrude all the basement rocks on ABMINGA. They are most abundant in the granites and adjacent gneisses, and were the last intrusive elements to be formed during granitisation (Rogers 1986). Pegmatites consist of quartz, feldspar, biotite, magnetite and minor allanite. Some are up to 2 m wide and are zoned with K-feldspar margins and quartz centers.

Unit *p€g* on FINKE includes dykes of pegmatite, some aplite, and reef quartz.

Distinctive mineralogical characteristics:

ABMINGA: Five varieties of granite occur, but because of poor outcrop they were mapped as one unit (Ꝑγ). Medium to coarse-grained porphyritic biotite monzogranite with microcline phenocrysts is the dominant type. It consists of microcline, plagioclase, quartz, biotite, magnetite and titanite with traces of amphibole, apatite, zircon and allanite. Other types include medium to coarse-grained hornblende monzogranite and hornblende granite, reddish coarse-grained granite, pink porphyritic granite, and grey fine to medium-grained biotite granodiorite. Rogers (1986) notes that in the northern areas of the map sheet, granite occurs as bands within foliated gneiss. Some bands of gneiss pass transitionally northwards into granite of similar composition. The granite bands have flow-oriented feldspar phenocrysts and contain deformed xenoliths of the adjacent gneiss. These features suggest that the granite has formed by melting of the gneisses, with limited mobilisation. Farther north, the granites are massive or irregularly flow-banded, with intrusive contacts and xenoliths of gneiss which cannot be matched with the intruded rock.

On FINKE to the north of ABMINGA, the same unit (Ᵽγ) is mapped as *pЄn*. This includes coarsely foliated medium-grained gneiss and fine-grained granite. Also on FINKE, unit *pЄg* includes porphyritic microgranite, biotite granite, biotite leucogranite, and microgranite; dykes of pegmatite, non-porphyritic microgranite, leucogranite, aplite, and reef quartz.

Units on ALBERGA are not named, but include micromonzogranite and microgranite, biotite and hornblende monzogranites, aplite, and hypersthene monzogranite which elsewhere is referred to as the Ernabella Adamellite or charnockite. Extensive throughout the map area are undifferentiated rocks originally thought to be of Archaean age, including gneissic pyroxene monzogranite, gneissic granite, pyroxene granulite, pyroxene gneiss, and amphibolite. The unnamed biotite and hornblende monzogranites are continuous with the Illbillie Adamellite on EVERARD to the south, and with the Ayers Ranges Adamellite, the Kulgera Adamellite, and Outounya Gneissic unit on KULGERA to the north. The 'Archaean' gneisses are continuous with granulites of the Musgrave-Mann Metamorphics (i.e., Birksgate Complex) on WOODROFFE to the west.

Outcrop of essentially undeformed granite (*pЄg*) on AYERS ROCK is very limited. The Olia Gneiss (*pЄn*) is much more extensive, and is composed of orthogneiss with schist, porphyroblastic schist, amphibolite, migmatite and granite. Duncan *et al* (1997b) suggest that the rocks mapped as *pЄn* in the Mulga Park area on AYERS ROCK make up the Mulga Park Gneiss, which is dated at ~1550 Ma, and may therefore be part of the Birksgate Complex. Duncan (*pers. comm.* 1997) is also defining the Allanah suite, composed of a thin-sheeted complex of biotite granite representing multiple generations and intrusions of variable grain size and ranging progressively from undeformed to highly deformed with a well developed mylonitic fabric. The sheets were synkinematically emplaced during a low-intensity and low-angle shearing associated with the Grenville event (~1200 Ma). The deformed granites grade into orthogneisses, and porphyritic granite is subordinate making up ~10%. The different granitic components of the Allanah suite share the same geochemical signature, and the individual sheets are interpreted as being derived from a single source which has an essentially homogeneous chemistry.

Granites on the BIRKSGATE mapsheet were grouped as the Birksgate Granitic Complex. Note that this is not considered to be equivalent to the Birksgate Complex of Major and Conor (1993). The Permano Adamellite is a coarse-grained porphyritic hornblende biotite gneissic monzogranite, and is probably equivalent to the Illbillie Adamellite (EVERARD) and the Ampeinna granite (LINDSAY). Other granites include coarse-grained porphyritic biotite granite at Beludinna Hill, medium-grained biotite granite with allanite at Tjatamannga Rock Hole, and medium-grained hornblende-biotite monzogranite in Cheesman Peak, Unmoorinna Hill and Yaroona Hill areas.

The Pottoyu Granite Complex (*pЄo*) occurs in the southwest of BLOODS RANGE, and is more extensive on PETERMANN RANGES. It is composed of very coarse-grained porphyritic granite; coarse-grained porphyritic granite; fine, medium and coarse even-grained granite; quartz-feldspar porphyry; gneiss; amphibolite; quartz-epidote rock; schist and quartzite. Two other units mapped out on BLOODS RANGE are included in the Pottoyu Granite Complex on PETERMANN RANGES. These are *pЄm* - porphyroblastic schist and quartz- feldspar porphyry, and *pЄp* - quartz-feldspar porphyry. Unit *pЄg* on BLOODS RANGE comprises coarse porphyritic granite and medium-grained granite. However, the extension of this unit onto the PETERMANN RANGES mapsheet is marked as the Olia Gneiss (*pЄn*). Unit *pЄg* on PETERMANN RANGES is metamorphosed granite, being made up of lineated porphyritic coarse-grained gneissic biotite granite, and coarsely porphyritic gneissic biotite granite.

Units on COOPER assigned to the Kulgera Supersuite include Ᵽ*gn*, Ᵽ*gu*, Ᵽ*ge*, and Ᵽ*gp*. Ᵽ*gp* occurs at Lightning Rocks, Borrows Hill, Blyth Hill and between Bell Rock Range and Mount West, as well as other scattered outcrops. Microcline, plagioclase, quartz and myrmekite are the main constituents of the granite with accessory hornblende, biotite, opaques, apatite and orthite. Ᵽ*gn* is a granitic gneiss, Ᵽ*gu* is an undifferentiated granite, and Ᵽ*ge* is a granite.

Units on EVERARD include the Illbillie Adamellite, Cartoberinna Granite, undifferentiated aplitic granite, and gneiss. The Illbillie Adamellite is equivalent to the Permano Adamellite (BIRKSGATE) and Ampeinna granite (LINDSAY). It is a massive, red-weathering, coarse-grained, porphyritic hornblende monzogranite, and locally contains pyroxene. The Cartoberinna Granite is a massive, medium-grained, biotite-rich granite. The undifferentiated granitic rocks are massive, light red-weathering porphyritic microgranite, gneissic granite porphyry, and massive to slightly gneissic fine and medium-grained granite with suggestions of metamorphic texture. The gneiss is grey, medium-grained, with biotite and hornblende-rich varieties, with rare schist bands and local augen gneiss.

The granites occurring on LINSDAY, BIRKSGATE and EVERARD (i.e., the Illbillie, Permano, Ampeinna, and Cartoberinna Granites and equivalents) have informally been termed the Southern granites here. This is a geographical subdivision only.

Units occurring on KULGERA include the Ayers Range Adamellite, the Kulgera Adamellite, type-a and type-b gneissic granite, unfoliated garnet granite and foliated granite. Rocks of the Ayers Range Adamellite (Ᵽ*gc*) are heterogeneous and grey to pale green-grey when fresh. The mineral assemblage consists of plagioclase, K-feldspar, quartz, amphibole ± clinopyroxene, and biotite. Accessories are apatite, zircon, magnetite, ilmenite, orthopyroxene and epidote. The complex has an inequigranular granoblastic texture, but still preserves a magmatic texture in areas where recrystallisation has been less extensive. Some rocks belonging to the Ayers Range Adamellite do not contain clinopyroxene; this is explained by crystal fractionation and increased water activity in the melt, suggested by textural and geochemical evidence. A strongly porphyritic microgranite phase crops out within the main mass of the Ayers Range Adamellite. The rock consists typically of large crystals (up to 2 cm) of K-feldspar and plagioclase in a fine groundmass of feldspar, quartz and biotite. Myrmekitic textures are developed on grain boundaries in contact with quartz. Other phases are titanite, magnetite, zircon and apatite.

The Kulgera Adamellite (Ᵽ*gk*, Ᵽ*gkd*) is typically red and consists of porphyritic and even-grained granite that have intruded as discrete, elliptically shaped plutons, and constitute the bulk of the Kulgera Adamellite. The even-grained and porphyritic phases have identical mineral assemblages but differ in texture and mineral abundances. The margins of the plutons are strongly porphyritic and contain many xenoliths and tabular black plagioclase crystals. These marginal zones are interpreted as cumulates of refractory and early crystallising phases, concentrated by convection currents in the magma. The cores of the plutons are generally even-grained and relatively poor in xenoliths and black plagioclase. In hand specimen, the equigranular phase is coarse-grained with pink K-feldspars up to 1 cm across, bluish-black and creamy plagioclase, milky quartz and dark aggregates of hornblende, biotite and titanite. The porphyritic phase has a flesh-red colour and is medium to coarse-grained. The rock consists of large crystals of plagioclase and K-feldspar as well as mafic clots, set in a finer granular groundmass of quartz, plagioclase and K-feldspar. The major minerals are K-feldspar, quartz, plagioclase, amphibole, biotite and titanite. Magnetite, apatite, zircon and epidote are accessory phases. Common alteration products are calcite, epidote, sericite and minor chlorite.

Associated linear dykes (Ᵽ*gkd*) of microgranite and pegmatite either radiate from these plutons or form individual dykes within the older gneisses where they are oriented both parallel and perpendicular to the foliation. The dykes form ridges up to 30 m high, and range from flesh-red to bluish-grey. They are fine to medium-grained, and some are weakly porphyritic. They consist of quartz, K-feldspar, plagioclase, biotite and white mica. Accessories are apatite, zircon, magnetite, and monazite.

The dominant minerals of the type-a gneissic granite (Ᵽ*gna*) are plagioclase, quartz and red-brown biotite. Other minerals include K-feldspar, magnetite, zircon, and possibly monazite and apatite.

Type-b granite gneiss (Ᵽ*gnb*) when fresh is white-pink. It has a granoblastic texture with myrmekite textures present where quartz is in contact with plagioclase. The gneiss consists of K-feldspar, quartz, plagioclase, biotite, amphibole and accessory apatite, zircon and opaques in places surrounded by titanite.

Foliated granite (Ᵽgm_1) was intersected only in vertical DDH K-6. It is a grey to pink, medium-grained porphyritic granite with a strong mylonitic fabric. It consists of K-feldspar, plagioclase, quartz, biotite, muscovite, and epidote, with accessory apatite, amphibole and zircon.

Unfoliated garnet granite (Ᵽgm_2) is medium-grained, white, and is intruded by numerous east-west trending pegmatite dykes that range in size from a few centimetres to a few metres. The granite has a granoblastic texture, although some magmatic features such as oscillatory zoning in plagioclase and simple twinning in K-feldspar are still preserved. The rock consists of K-feldspar, plagioclase, quartz, biotite, and muscovite, with accessory magnetite(?), subhedral garnet and zircon.

Unit *p€p* on RAWLINSON is a brown and grey quartz-feldspar porphyry. The extension of this unit onto SCOTT is assigned to unit Ᵽ*ra* - sheared quartz-feldspar porphyry.

Granites assigned to the Kulgera Supersuite on SCOTT include the unnamed units Ᵽ*bo*, Ᵽ*ri*, Ᵽ*rs* and Ᵽ*bg*. Ᵽ*bo* is a rapakivi granite, with large ovoids of K-feldspar and quartz granules in a matrix of biotite granite. Chlorite accompanies some of the biotite. Ᵽ*ri* is a feldspar-phyric microgranite with an abundance of rounded quartz phenocrysts. Ᵽ*rs* is an even-grained fine-grained, red granite with local fist-size ovoid or euhedral K-feldspar phenocrysts. Biotite rich clots are common and rafts of sandstone and basalt of the Kathleen Ranges are present. The peripheral zone is rich in aplite veins, which extend into the sediments and volcanic rocks. Where this granite intrudes the ovoid granite a marginal migmatite zone is present. Ᵽ*bg* may form part of the older basement, as it is composed of banded granitic rocks with metasedimentary remnants.

Granites on WOODROFFE include hypersthene monzogranite (charnokite), granite and monzogranite. The charnockite is massive or weakly foliated, and consists of quartz, orthoclase, perthite and pyroxene rocks. The granite and monzogranite are massive porphyritic microcline-plagioclase-biotite-hornblende-bearing rocks.

Breccias: None noted in literature.

Alteration in the granite: None mentioned in literature.

2.8 Extrusives

Gray (1971) suggested that a continuous volcanic carapace once existed over the Musgrave Block, but has since been largely eroded away. It is not known if this may have been comagmatic with the Kulgera supersuite, although C. Conor (*pers. comm.* 1997) states that it is more likely to be related to the ~1080 Ma magmatism.

2.9 Country Rock

Contact metamorphism: Contacts of Kulgeran granitoids with country-rock gneisses in the Eateringinna 1:100 000 Sheet area (Conor 1987) are both sharply cross-cutting and diffuse. In places there is little sign of alteration whereas at others wide metamorphic aureoles are obvious, indicating profound metamorphic changes. The most obvious mineralogical change in host rocks is the growth of feldspar porphyroblasts which are either disseminated through the rock or else are aggregated into irregular pods and lenses.

Reaction with country rock: Generally, assemblages formed as a result of intrusion of Kulgeran granitoids are: cordierite + opaques; garnet + sillimanite + corundum; cordierite + sillimanite + spinel + sapphirine; biotite + sillimanite + quartz; and K-feldspar + spinel + corundum (Conor 1987).

Units the granite intrudes: The Kulgera Supersuite probably intrudes the Birksgate Complex, although limited outcrop makes mapping difficult. The following is a summary of units on the listed 1:250 000 map sheets, intruded by the Kulgera supersuite:

ABMINGA: Musgrave-Mann Metamorphics (Waratu Gneiss - Ᵽ*mw*, Ᵽ*mm*, Ᵽ*mh*). The Waratu Gneiss is composed of metasedimentary foliated granitic and adamellitic biotite gneiss, augen gneiss, and quartz-feldspar-muscovite schist, intruded by quartz and pegmatite veins. Unit Ᵽ*mm* is composed of foliated feldspar-quartz-biotite and quartz-biotite gneiss of granitic and adamellitic composition. Unit Ᵽ*mh* is composed of hornblende-plagioclase gneiss.

ALBERGA: The gneisses are considered to be equivalent to the Musgrave-Mann Metamorphics (Conor 1987), and are a sequence of metavolcanics with intercalated metasediments, intruded by basic and granitic rocks. Gneiss ie layering was developed at an early stage and folded during two late deformational events in which the earlier mineral assemblages were somewhat modified by changing metamorphic conditions. The gneisses constitute a mineralogically gradational series of rocks which are layered on scales varying from less than one millimetre to a few tens of metres. Mineralogically and chemically the gneisses vary from quartzofeldspathic through to mafic types, and there are aluminous, silicic and calcic variants.

AYERS ROCK: Units mapped as the Olia Gneiss (*p€n*) in the Mulga Park area are in fact older than the Olia Gneiss mapped elsewhere (eg on PETERMANN, dated at ~1190 Ma). These are termed the Mulga Park Gneisses.

BIRKSGATE: Wataru Gneiss. Whereas this unit on ABMINGA is assigned to the Musgrave-Mann Metamorphic complex, on this sheet it is assigned to the Birksgate Granitic Complex. On this sheet it is described as a medium-grained hornblende-biotite granitic gneiss.

BLOODS RANGE: Mount Harris Basalt (*pЄh*)?, Bloods Range Beds (*pЄb*)? The age of these units is not known. The Mount Harris Basalt comprise epidotised amygdaloidal basalt, tuff, agglomerate and quartzite. The Bloods Range Beds comprise sandstone, siltstone, shale, arkose, tuff, agglomerate, basalt, acid porphyry, and metamorphic equivalents.

COOPER: Granulite of igneous origin (Ᵽ*no*) - poorly banded, contain orthoclase; granulite of sedimentary origin (Ᵽ*nm*) - well banded, contains microcline; migmatite of granulite and granitic gneiss (Ᵽ*mg*).

EVERARD: Musgrave-Mann Metamorphics. These consist mainly of brown or grey-brown massive medium to coarse-grained granoblastic or rarely porphyroblastic basic granulite containing orthopyroxene, clinopyroxene, hornblende, biotite, microperthite (and microantiperthite), metamorphosed to hornblende-granulite facies. It also includes quartzo-feldspathic gneisses composed predominantly of quartz and microperthite (and microantiperthite) but with garnet-rich bands and accessory kyanite, spinel, biotite, apatite, zircon, and opaques. Macrolayering is well developed. The rock is massive in hand specimen, and metamorphosed to hornblende-granulite facies.

KULGERA: Calamity gneissic unit (Ᵽ*gn*): tonalitic biotite gneiss, well layered; clinopyroxene-hornblende gneiss; later cross-cutting red granite dykes; metamorphosed to transitional amphibolite-granulite facies. Possible sedimentary or intrusive precursors. Outounya gneissic unit (Ᵽ*gnm*, Ᵽ*gnp*): quartzofeldspathic gneiss + amphibole + garnet; metamorphosed to transitional amphibolite-granulite facies. Extruded or intruded at about the same time as deposition of sediments of Kalamurta gneissic unit. Extrusive acid volcanic and/or intrusive precursor. Kalamurta gneissic unit (Ᵽ*gnc*): cordierite and sillimanite ± garnet; quartzofeldspathic gneiss; minor amphibolite; metamorphosed to transitional amphibolite-granulite facies. Deposited and/or intruded simultaneously with extrusion/intrusion of volcanics/intrusives of Outounya gneissic unit.

LINDSAY: Two types of amphibolite-granulite transitional facies rocks possibly equivalents of the Wataru Gneiss, and amphibolite-facies acid gneiss. (1) Amphibolite-facies acid gneiss of meta-igneous origin. Generally medium-grained dark coloured biotite-hornblende gneiss of granitic or adamellitic composition. Accessory allanite in places. Contains dark coloured xenoliths and minor amphibolite layers. (2) Amphibolite-facies acid gneiss. Generally fine to medium-grained light coloured biotite-hornblende gneiss of adamellitic or granitic composition. Minor amphibolite layers. (3) Amphibolite-granulite transitional facies rocks. Metasediments and basic meta-?igneous rocks locally. Quartzite with clinopyroxene and granulites containing (variously) hornblende, diopside, garnet, quartz and plagioclase. In northwestern part of sheet, granitic and adamellitic gneiss contain orthopyroxene, clinopyroxene, biotite or hornblende.

MANN: Includes the following: quartzite, quartz granulite, quartz-sillimanite granulite; acid granulite - quartz-feldspar granulite and charnockite, quartz-pyroxene granulite, garnet rich in part, associated thin basic bands and bands of calc-silicate marble; intermediate granulite, feldspar-pyroxene granulite, garnet rich in part; basic granulite, pyroxene-feldspar granulite, locally pyroxenite, garnet-pyroxene granulite; anorthositic rocks - coarse-grained, locally discordant, occasional clots and lenticles of pyroxene.

PETERMANN RANGES: Musgrave-Mann Metamorphics (*pЄm*); biotite-garnet-clinopyroxene-hornblende-quartz-feldspar gneiss, quartz-feldspar-garnet-clinopyroxene-orthopyroxene-hornblende gneiss. Feldspar-clinopyroxene-orthopyroxene-garnet rock. ?Bloods Range Beds (*pЄb*); muscovite-quartz schist, quartz-muscovite schist.

RAWLINSON: ?*pЄ*; quartzite, quartz-sericite schist, sericite-quartz schist, quartz-feldspar-sericite schist, slate, phyllite, sheared basalt.

SCOTT: Migmatite and granite with abundant enclaves (Ᵽ*gm*), granulite - well banded, dominantly acid composition, charnockites present, shows flaser structures, migmatisation and complex repeated folding, polymetamorphic (Ᵽ*n*).

WOODROFFE: Musgrave-Mann Metamorphics, including: altered granulite and gneissic granulite — biotite, hornblende, microcline, epidote, etc formed during partial recrystallisation, includes some injection gneisses; granulites — quartz-feldspar-orthopyroxene and/or clinopyroxene-bearing rocks, generally with granulitic textures, foliation marked by linear segregations of mafic minerals; quartz is commonly elongated (forming a lineation); silicic rocks most common with intermediate and basic varieties as interbands; amphibolite, minor anorthosite, minor haematitic metaquartzite and forsterite marble.

Dominant rock types: Metasediments; quartzofeldspathic ± amphibole ± pyroxene granulites and granites; basalts; acid volcanics.

Potential hosts: Calc-silicate marble on MANN could be a suitable host, especially for skarn-type deposits. Elsewhere throughout the Musgrave Block, units with Fe-rich minerals (amphiboles, pyroxene) may be suitable reductants or oxidants.

2.10 Mineralisation

No deposits of significant size are known. Most of the exploration in the region has focused on the Ni + Cr + PGE potential of the mafic-ultramafic Giles Complex.

2.11 Geochemical Data

Data source: Most samples were collected by NTGS and AGSO workers during regional mapping. Other data are from Conor (1987) and Giles (1980).

Data quality: Samples were analysed at AGSO and AMDEL, and are considered to be of good quality.

Are the data representative? Possibly not. Firstly, the samples are not taken evenly across the distribution of the granites. Secondly, the samples are very difficult to assign to groups, mainly because of the inconsistency of the mapping across the area, creating problems with tracing units across map boundaries.

Are the data adequate? Definitely not. Amongst other things, there are too many analyses without trace-element data. A large amount of further work is required to fill in the gaps in the granites database to properly define the granite suites and their metallogenic potential. This includes mapping, geochemistry and geochronology.

SiO_2 range (Fig. 2.1): 51.55 wt% to 78 wt% SiO_2.

Alteration (Fig. 2.2): Some sodic alteration and loss of uranium is evident.

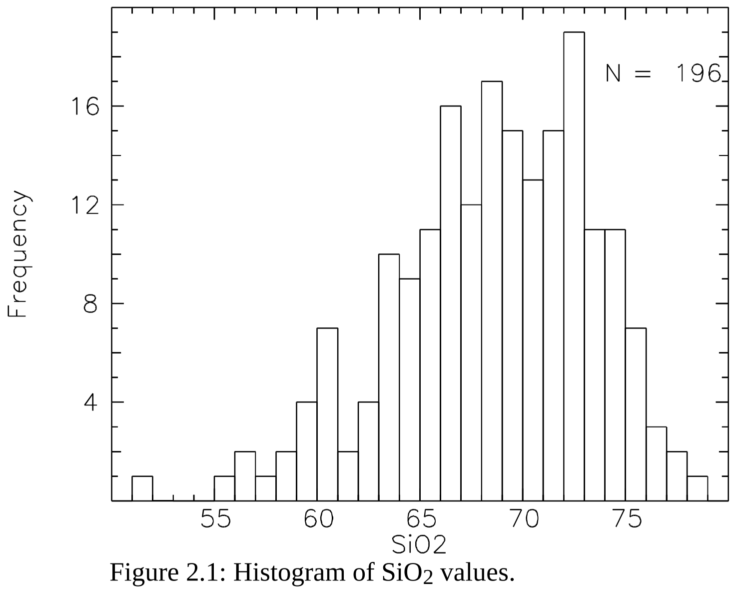

Figure 2.1: Histogram of SiO_2 values.

- ***SiO_2:*** None evident.
- ***K_2O/Na_2O:*** Some sodic alteration has occurred.
- ***Th/U:*** Most samples of the Kulgera Suite have anomalously high values, indicating some alteration.
- ***$Fe_2O_3/(FeO+Fe_2O_3)$:*** There is a broad scattering of oxidation states, but with only a few extreme values which may indicate some alteration or weathering. Some of the variation seen is probably due to the progressive change in oxidation state from west to east in the eastern part of the Musgrave Block (Conor 1987).

Fractionation Plots (Fig. 2.3): This supersuite shows some fractionation in the most felsic samples.

- ***Rb:*** Values range from low to moderately high, increasing with increasing SiO_2.
- ***U:*** Most values are very low to low, with some evidence of exponential increase at higher SiO_2 levels, possibly indicating some fractionation.
- ***Y:*** There is quite a bit of scatter; values range from high to low, decreasing with increasing SiO_2.
- ***P_2O_5:*** Values range from very high to very low, decreasing with increasing SiO_2.
- ***Th:*** There is considerable scatter; values range from very low to very high, generally increasing with increasing SiO_2.
- ***K/Rb:*** Although there is some scatter, there is a definite decreasing trend with increasing SiO_2, indicating that feldspar fractionation has occurred. Values range from moderately high to moderately low.
- ***Rb-Ba-Sr:*** Most values plot in the anomalous granite field, with most of the others plotting in the granite field. Some samples plot in the strongly differentiated field, while others plot in the monzogranite field.
- ***Sr:*** Values range from moderately high to low, and although there is some scatter, they generally decrease with increasing SiO_2.
- ***Rb/Sr:*** Most values are very low (possibly indicating loss of Rb), and increase with SiO_2, with an exponential increase in the most felsic samples.
- ***Ba:*** Values range from very high to low, and although there is some scatter, decrease with increasing SiO_2.
- ***F:*** No data are available.

Metals (Fig. 2.4):

- ***Cu:*** Values range from high to very low, with a large amount of scatter. There is a generally decreasing trend with increasing SiO_2.
- ***Pb:*** Values range from low to high, increasing with increasing SiO_2.
- ***Zn:*** Values range from very high to low, decreasing strongly with increasing SiO_2.
- ***Sn:*** Values are mostly low.

High field strength elements (Fig. 2.5): Values are mostly moderate to high, and all decrease with increasing SiO_2. However, some of the values for Zr are extremely high, and if reliable, represent some of the highest values for Proterozoic granites.

- ***Zr:*** NOTE CHANGE OF SCALE. Values range from extremely high to very low, decreasing with increasing SiO_2. Conor (1987) recognised two groups of granites in the EATERINGINNA area, based on Zr and Ba content.
- ***Nb:*** Values range from moderate to very low, decreasing slightly with increasing SiO_2.
- ***Ce:*** Values range from high to low, decreasing weakly with increasing SiO_2; there is considerable scatter in the data.

Classification (Fig. 2.6): Possibly restite-dominated, becoming fractionated above 70 wt% SiO_2, oxidised, I-type, Sr-depleted Y-undepleted.

- ***The $CaO/Na_2O/K_2O$ plot of White, quoted in Sheraton and Simons (1992):*** Most samples plot in the monzogranite and granite fields, with the rest plotting in the granodiorite field except for a few in the tonalite field.
- ***Zr/Y vs Sr/Sr*:*** Most samples plot along the Zr/Y axis, indicating that they are Sr-depleted, Y-undepleted.
- ***Spidergram:*** The Kulgera Suite is Y-undepleted, Sr-depleted.
- ***Oxidation plot of Champion and Heinemann (1994):*** The majority of samples are oxidised, with some plotting in either the reduced or strongly oxidised fields.
- ***ASI:*** The supersuite shows a clear trend from metaluminous values to slightly peraluminous values with increasing SiO_2, indicating that it is derived from an I-type magma. Some values are peraluminous, and may be the result of alteration or weathering.
- ***A-type plot of Eby (1990):*** The suite shows a range of values, including many in the Palaeozoic A-type field, and a few with very high values. Because there is such a range with only a few samples having high values, it is considered that the suite is not an A-type suite, but rather is a partly enriched suite.

Granite type (Chappell and White 1974; Chappell and Stephens 1988): I-granodiorite.

Australian Proterozoic granite type: Uncertain, possibly transitional between Kalkadoon type (restite dominated, unmineralised) and Cullen type (fractionated, Au-dominant).

2.12 Geophysical Signature

Radiometrics (Fig. 2.7): All units have potassium above the Proterozoic median. The Kulgera Suite has Th slightly higher, and U lower, giving a predicted RGB colour of yellow. The undifferentiated units all have very low U, and mostly low Th, giving a predicted RGB colour of red. There are no Th or U data available for the Pottoyu Granite or Olia Gneiss.

Gravity: In general, the Kulgera Supersuite granites have a gravity signature slightly higher than background.

Magnetics: Units assigned to the Kulgera Suite generally have high magnetic intensity, correlating well with the granites' oxidised nature. The Pottoyu Granite Complex and the Olia Gneiss have less intense magnetic highs.

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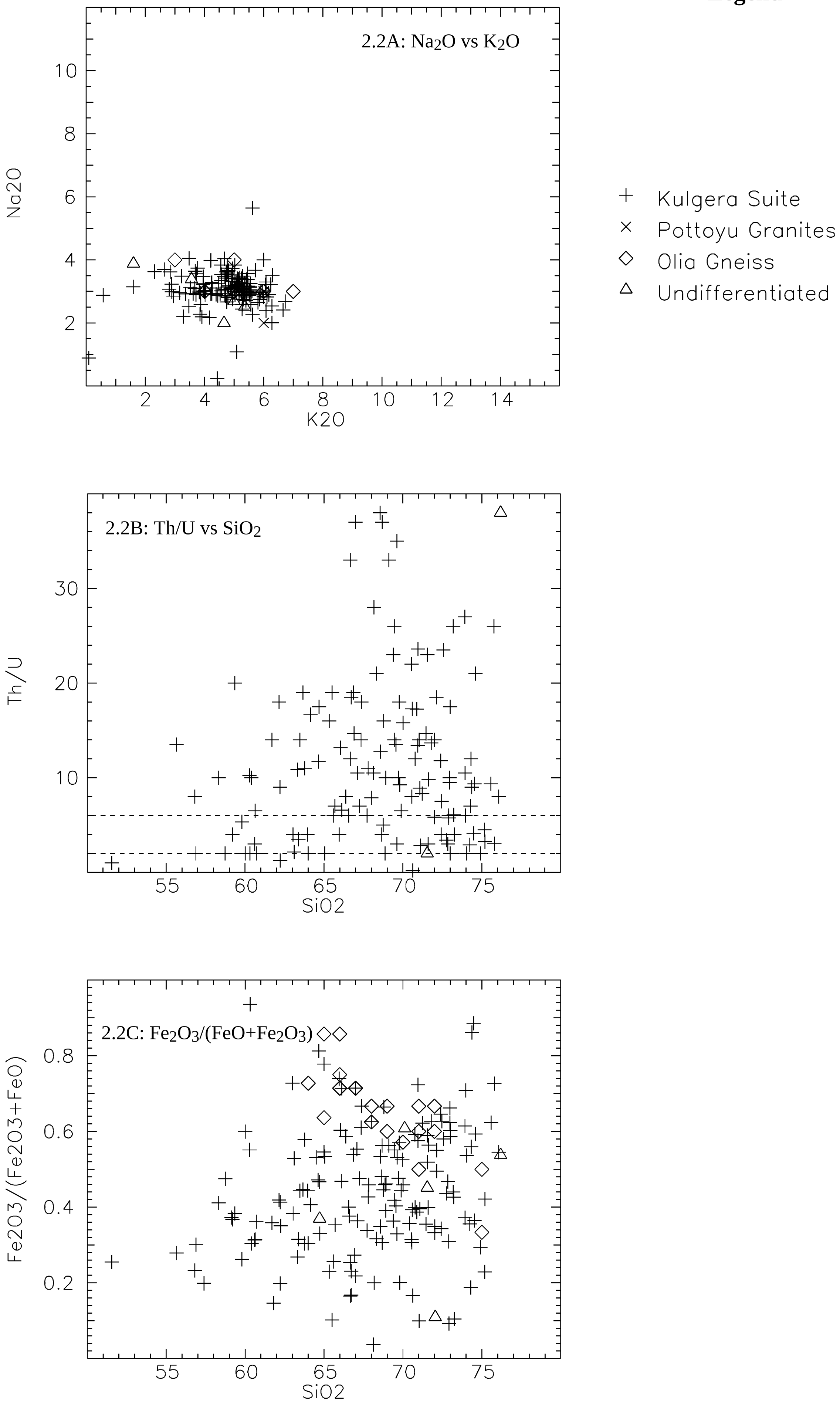
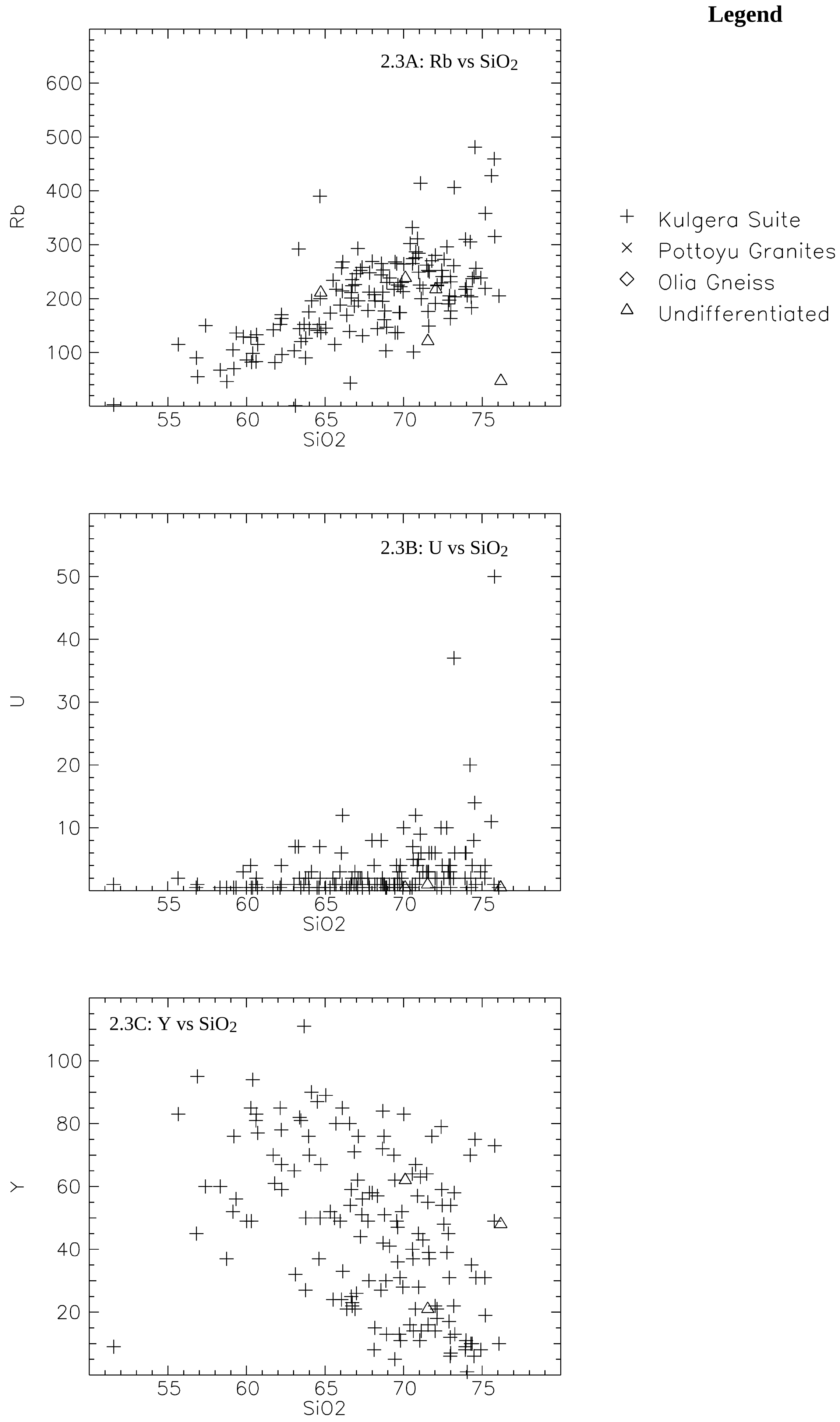
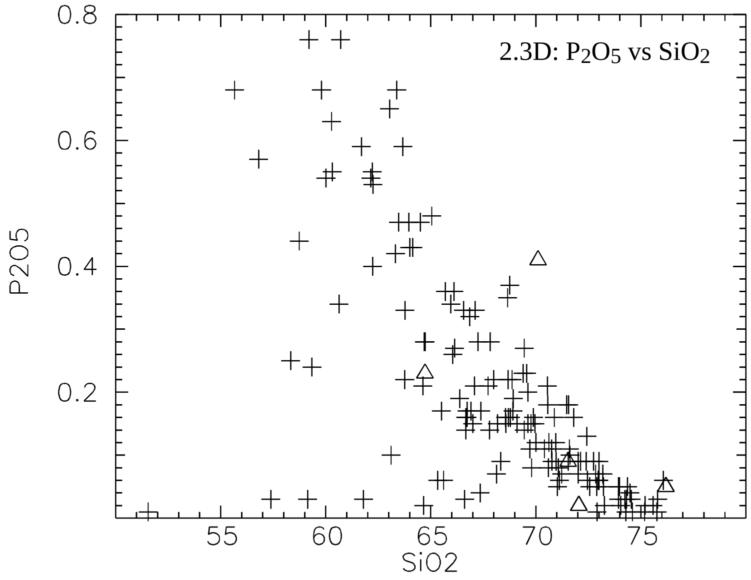
Legend

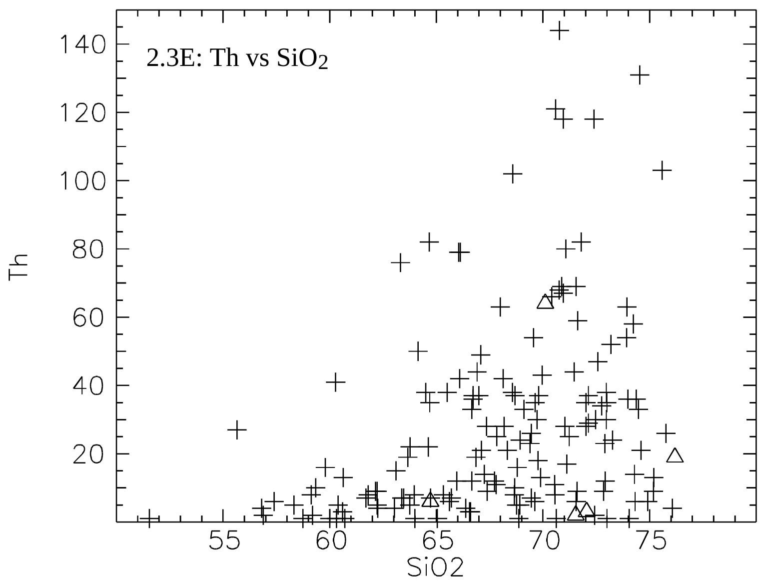

2.2A: Na2O vs K2O
Na2O
K2O
2.2B: Th/U vs SiO2
Th/U
SiO2
2.2C: Fe2O3/(FeO+Fe2O3)
Fe2O3/(Fe2O3+FeO)
SiO2
Kulgera Suite
Pottoyu Granites
Olia Gneiss
Undifferentiated

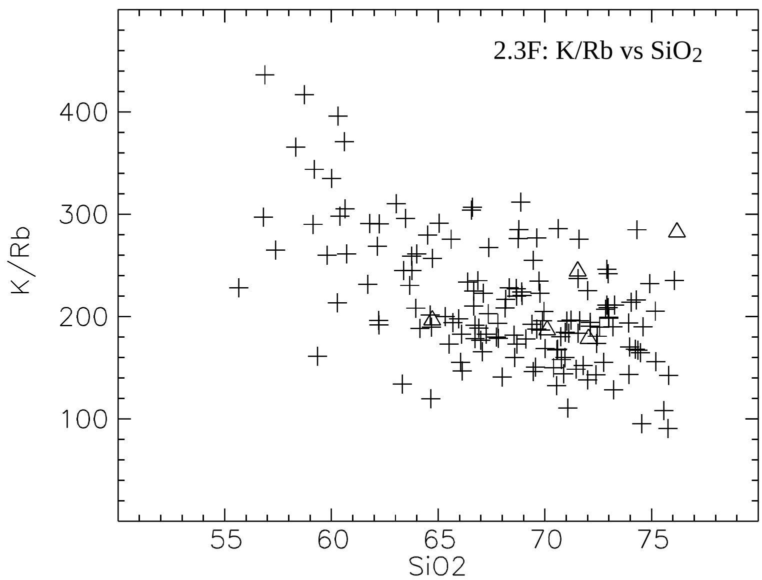

Legend
+ Kulgera Suite
× Pottoyu Granites
◇ Olia Gneiss
△ Undifferentiated
2.3A: Rb vs SiO2
Rb
SiO2
2.3B: U vs SiO2
U
SiO2
2.3C: Y vs SiO2
Y
SiO2

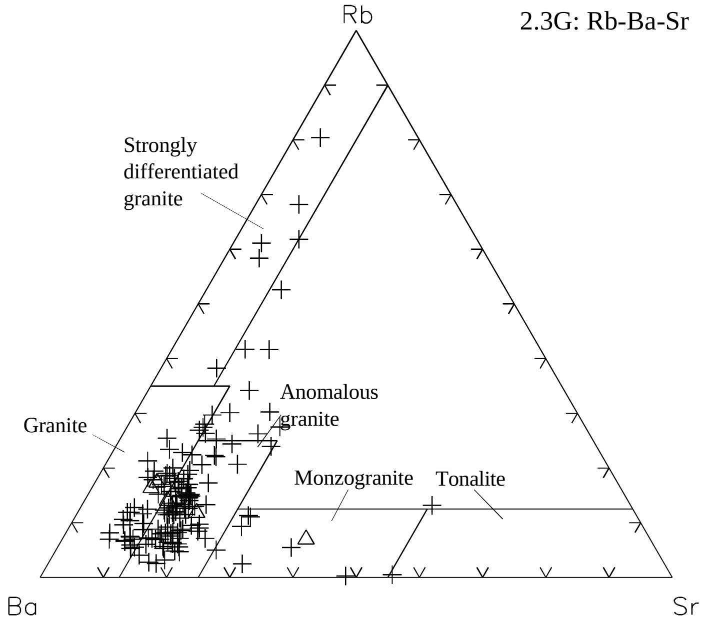


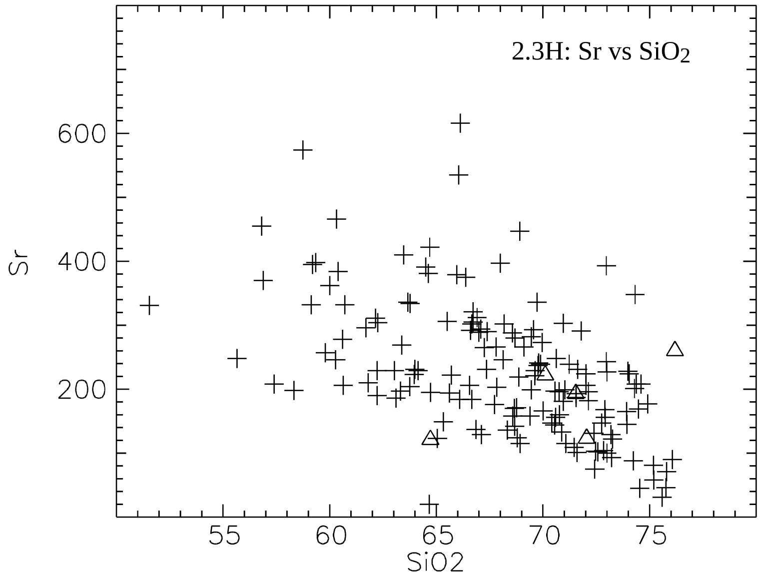
Legend

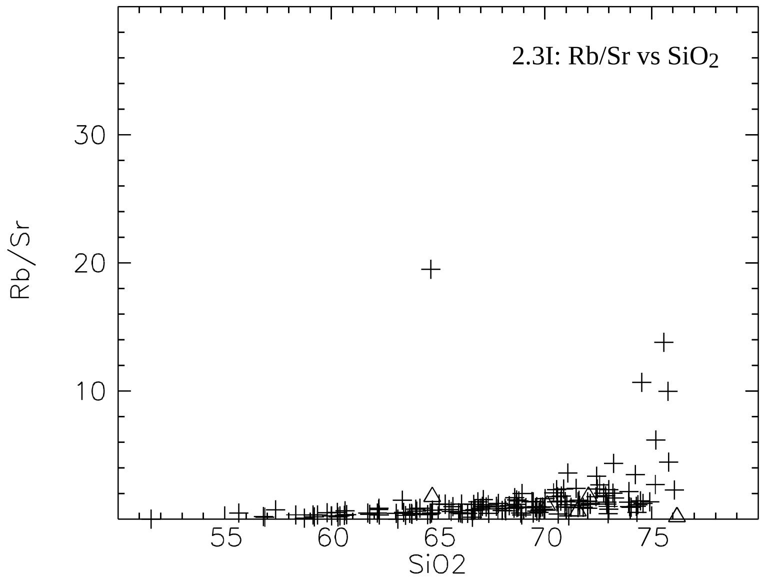
+ Kulgera Suite
× Pottoyu Granites
◇ Olia Gneiss
△ Undifferentiated






2.3G: Rb-Ba-Sr
Rb
Ba
Sr
Strongly differentiated granite
Anomalous granite
Granite
Monzogranite
Tonalite

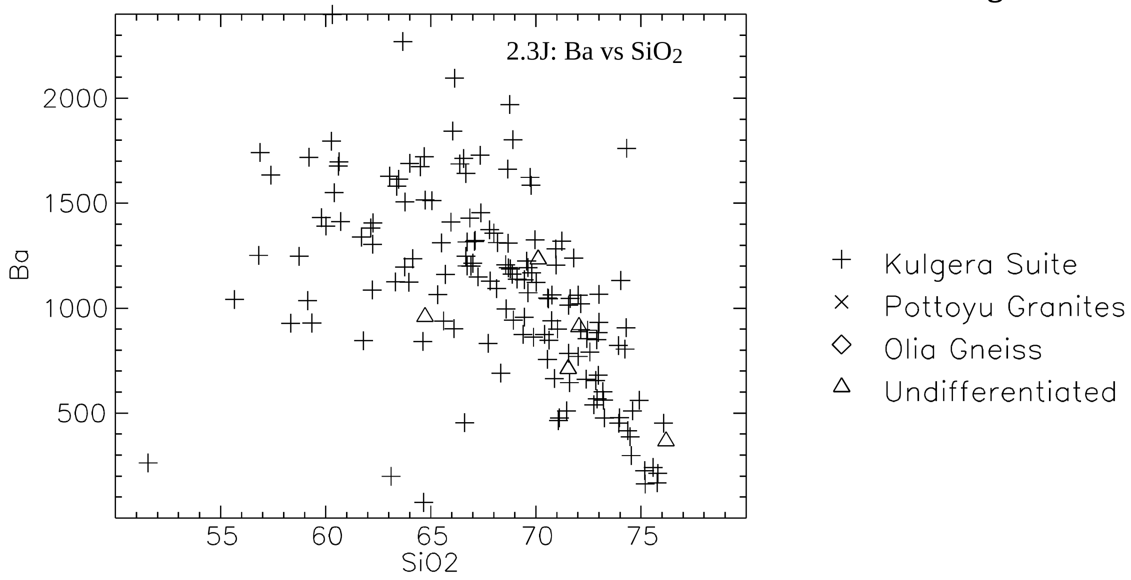

2.3H: Sr vs SiO_2
Sr
600
400
200
55
60
65
70
75
SiO2


2.3I: Rb/Sr vs SiO_2
Rb/Sr
30
20
10
55
60
65
70
75
SiO2

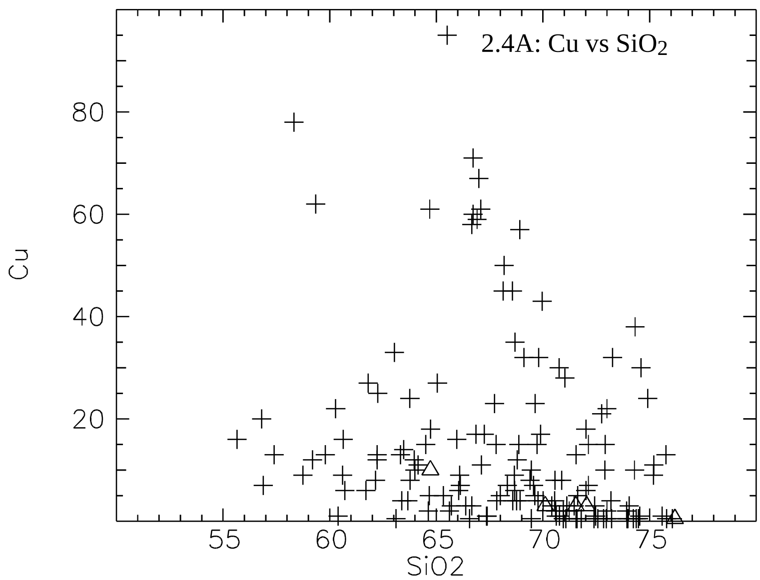
Legend


Kulgera Suite
Pottoyu Granites
Olia Gneiss
Undifferentiated

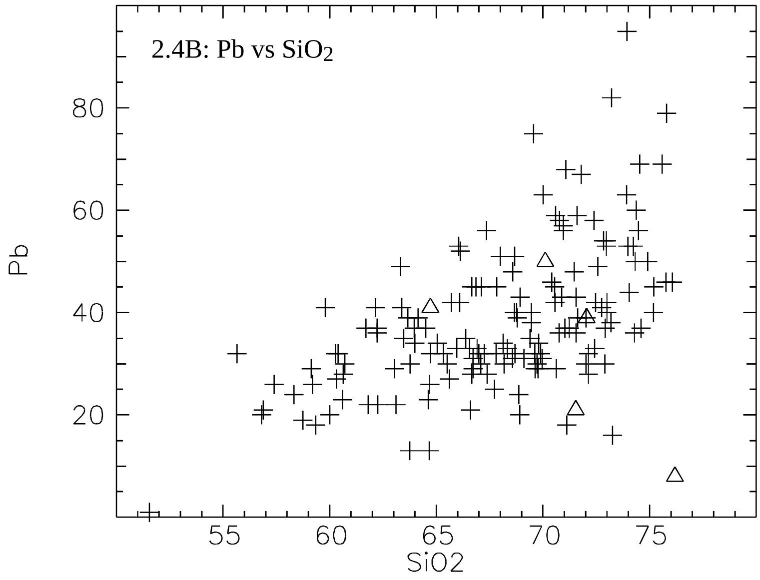
Legend



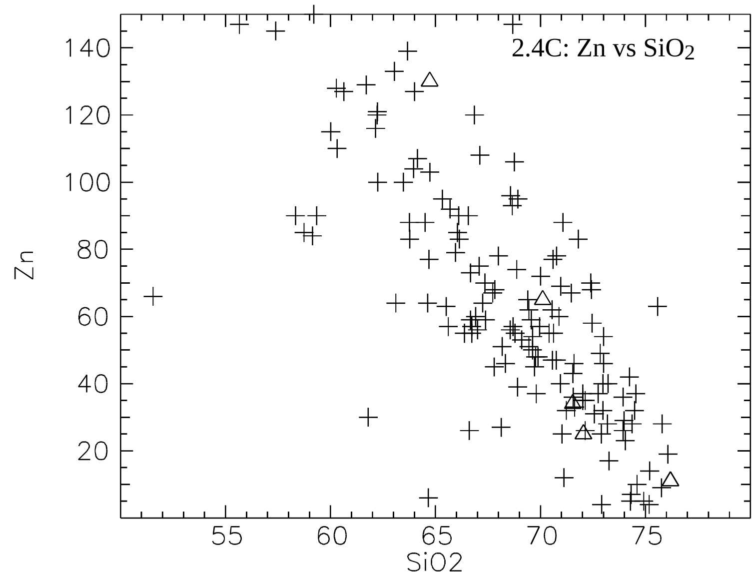
NO FLUORINE DATA AVAILABLE



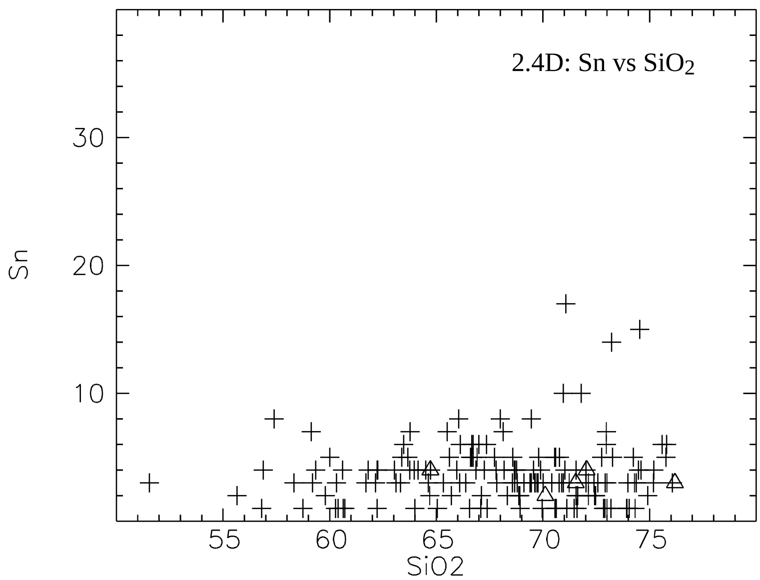
Legend



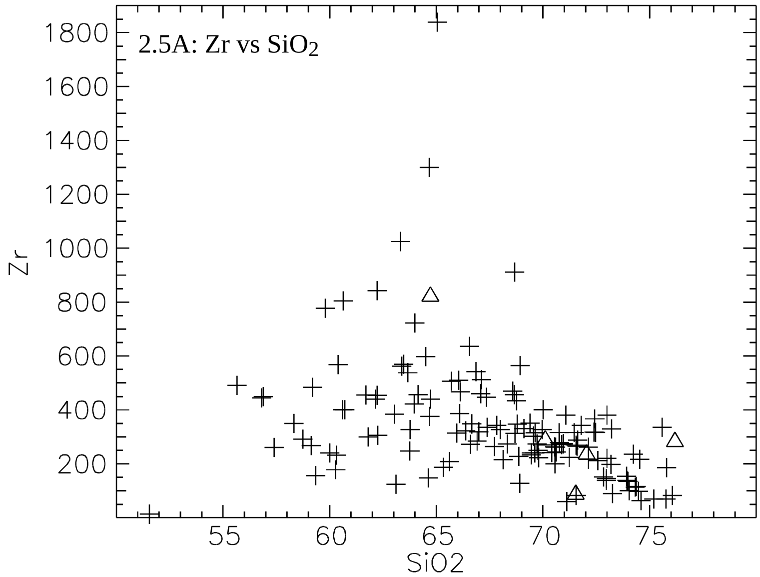
2.4B: Pb vs SiO_2



2.4C: Zn vs SiO_2

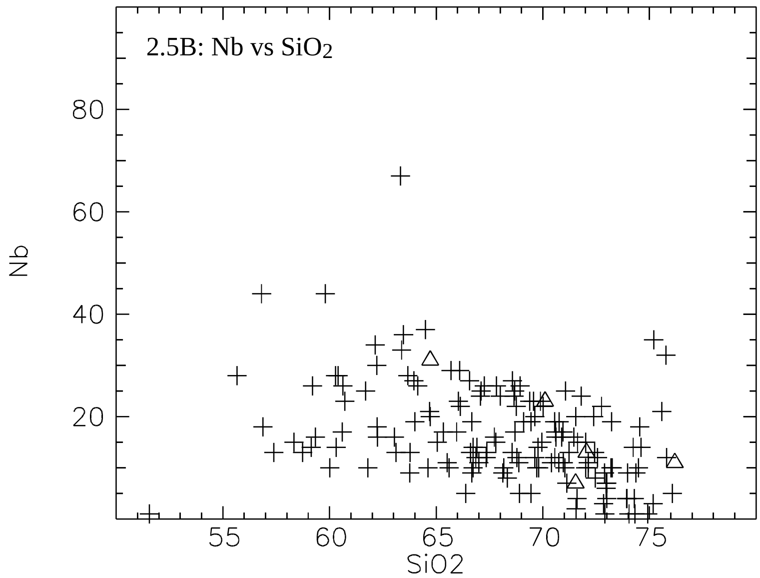


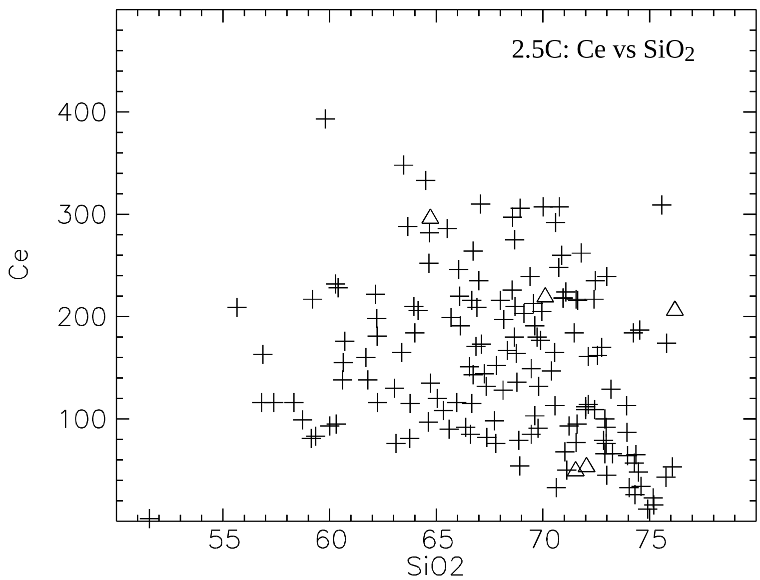
2.4D: Sn vs SiO_2


2.5A: Zr vs SiO2
Zr
1800
1600
1400
1200
1000
800
600
400
200
55
60
65
70
75
SiO2

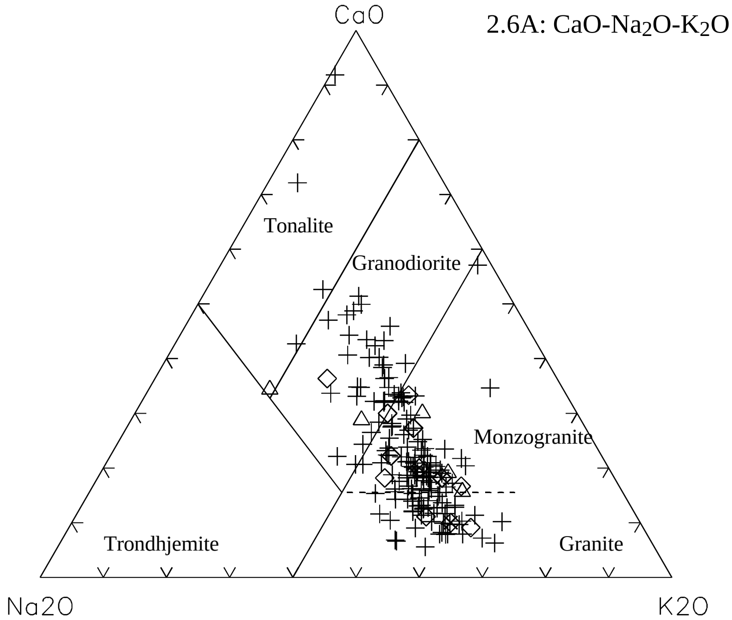
Legend


Kulgera Suite
Pottoyu Granites
Olia Gneiss
Undifferentiated

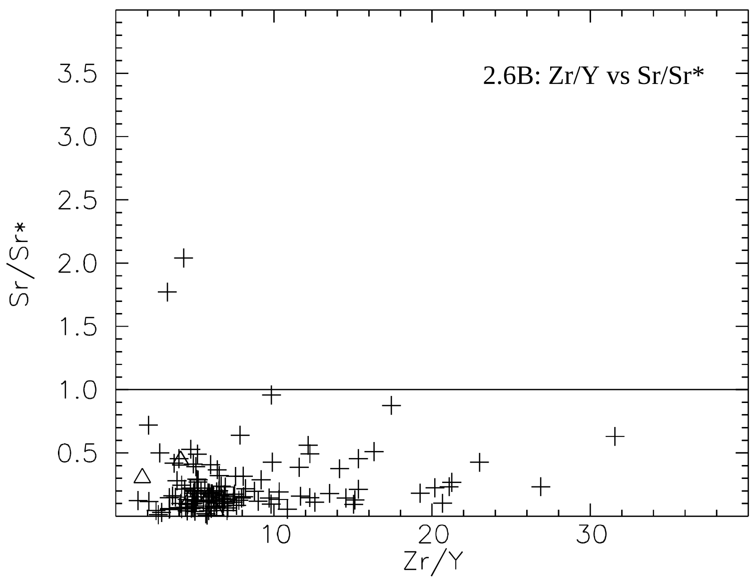

2.5B: Nb vs SiO2
Nb
80
60
40
20
55
60
65
70
75
SiO2

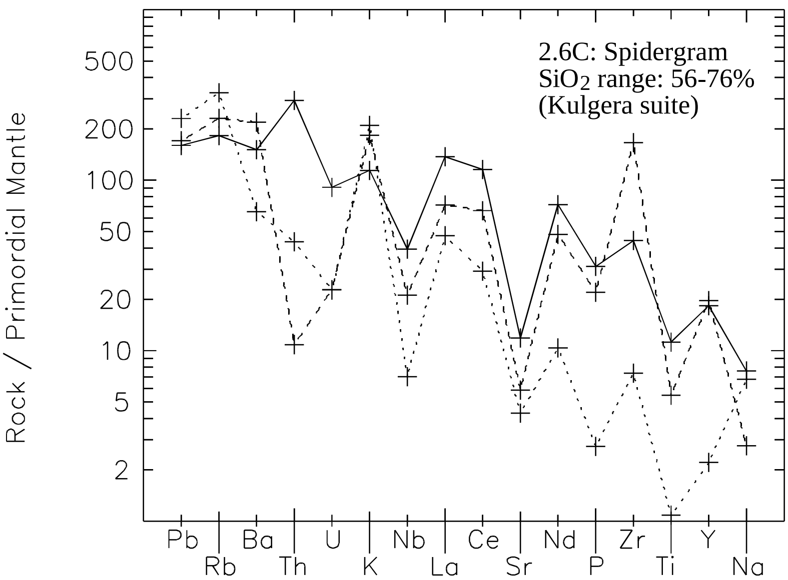

2.5C: Ce vs SiO2
Ce
400
300
200
100
55
60
65
70
75
SiO2

Legend

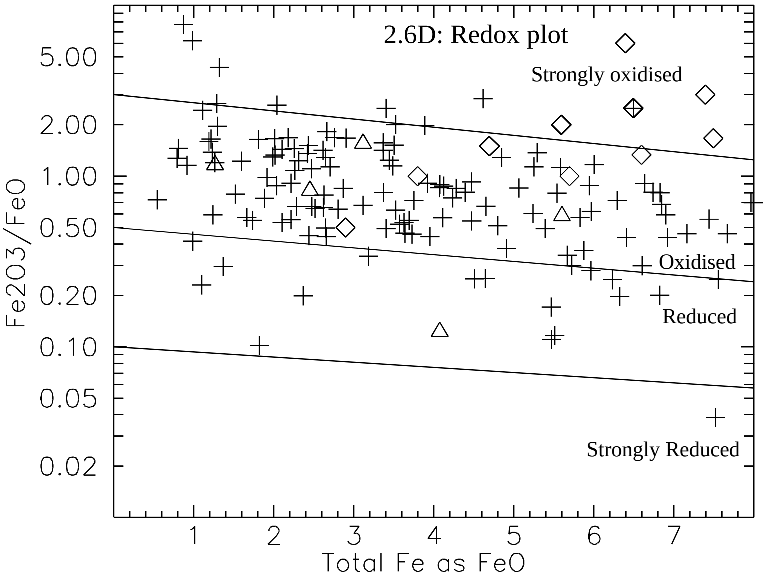

2.6A: CaO-Na2O-K2O
CaO
Na2O
K2O
Tonalite
Granodiorite
Monzogranite
Trondhjemite
Granite


Kulgera Suite
Pottoyu Granites
Olia Gneiss
Undifferentiated

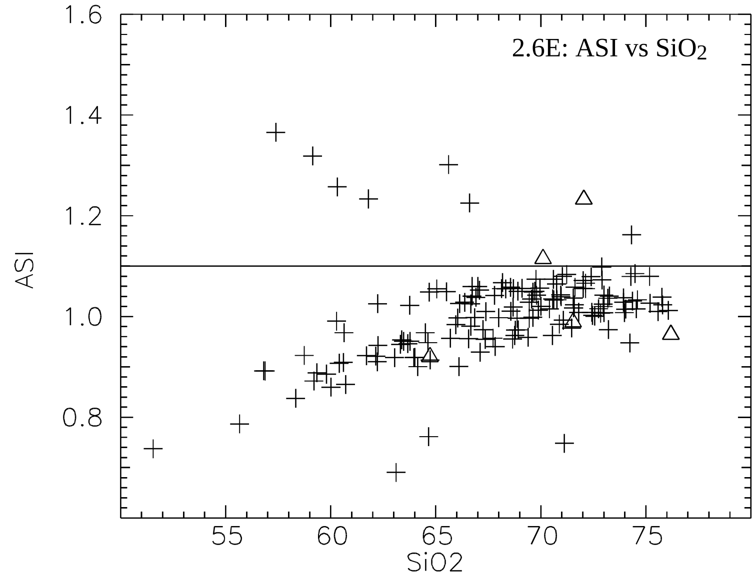

2.6B: Zr/Y vs Sr/Sr*
Sr/Sr*
Zr/Y
3.5
3.0
2.5
2.0
1.5
1.0
0.5
10
20
30

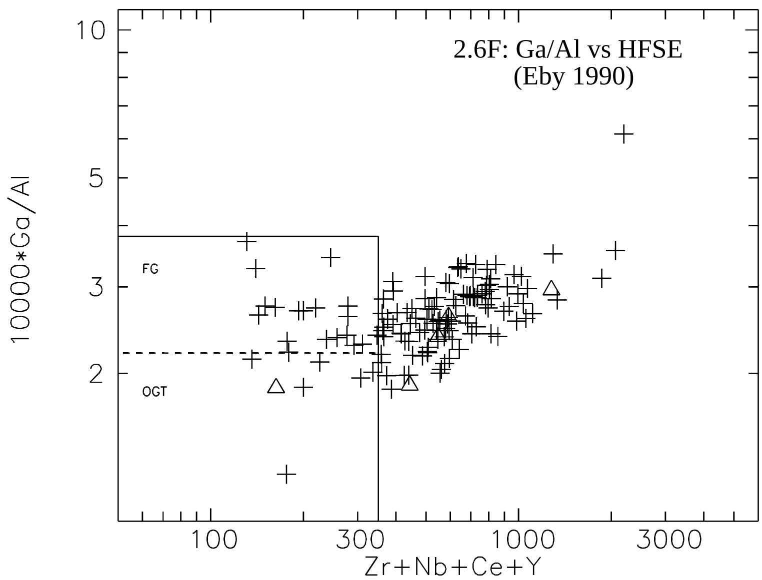

2.6C: Spidergram
SiO2 range: 56-76%
(Kulgera suite)
Rock / Primordial Mantle
500
200
100
50
20
10
5
2
Pb
Rb
Ba
Th
U
K
Nb
La
Ce
Sr
Nd
P
Zr
Ti
Y
Na

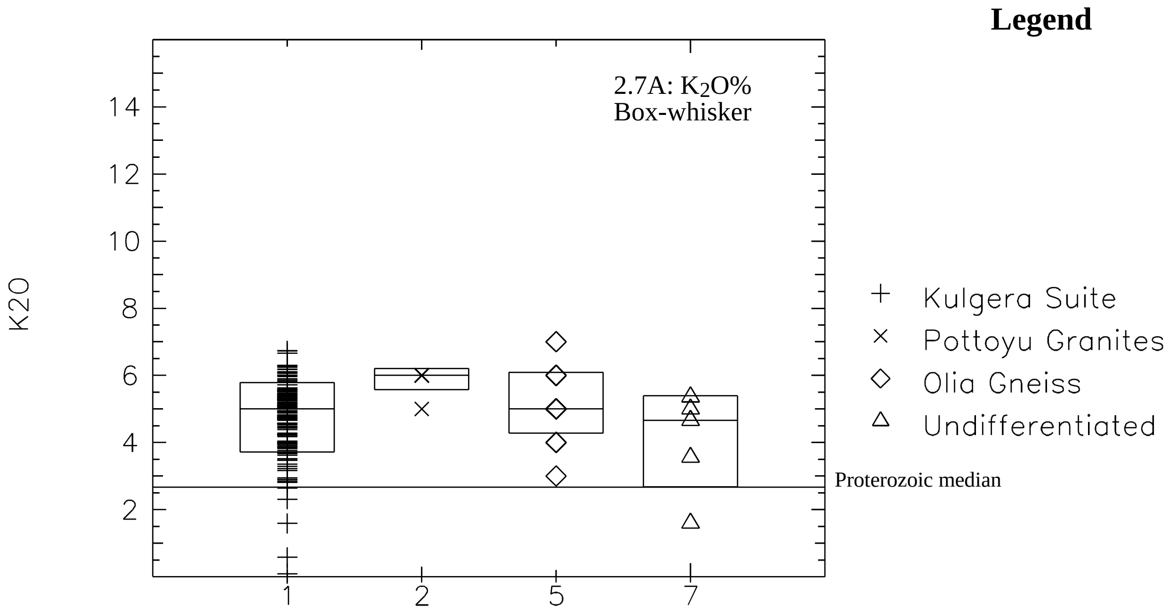
Legend

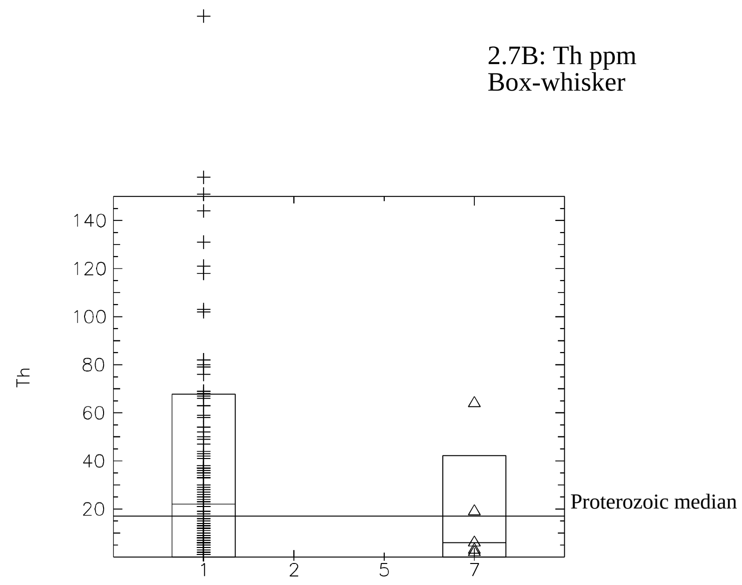

2.6D: Redox plot
Strongly oxidised
Oxidised
Reduced
Strongly Reduced
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
Fe2O3/FeO
1
2
3
4
5
6
7
Total Fe as FeO

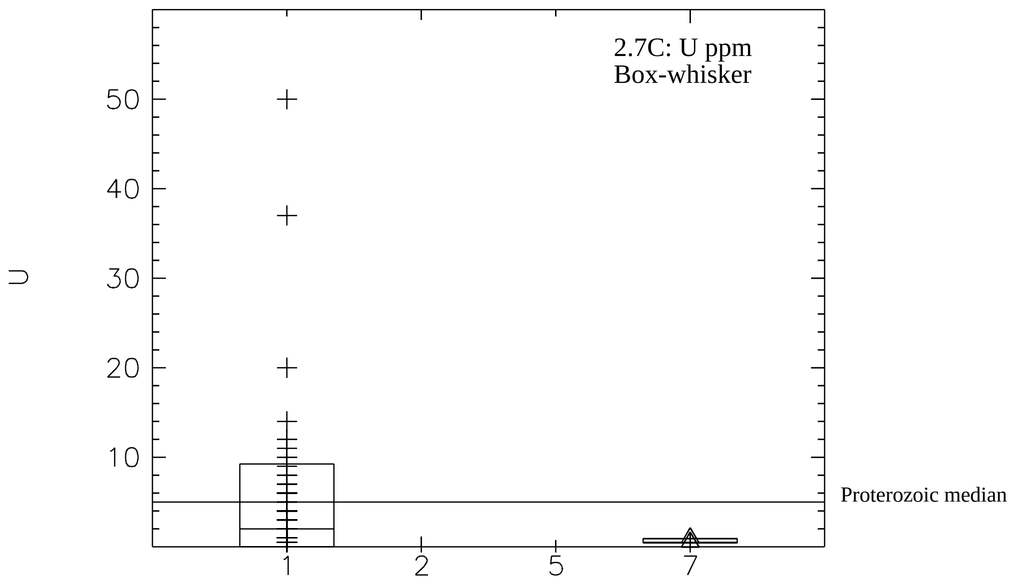

Kulgera Suite
Pottoyu Granites
Olia Gneiss
Undifferentiated


2.6E: ASI vs SiO2
1.6
1.4
1.2
1.0
0.8
ASI
55
60
65
70
75
SiO2


2.6F: Ga/Al vs HFSE
(Eby 1990)
10
5
3
2
10000*Ga/Al
FG
OGT
100
300
1000
3000
Zr+Nb+Ce+Y


Legend
2.7A: K2O%
Box-whisker
K2O
14
12
10
8
6
4
2
1
2
5
7
Kulgera Suite
Pottoyu Granites
Olia Gneiss
Undifferentiated
Proterozoic median


2.7B: Th ppm
Box-whisker
Th
140
120
100
80
60
40
20
1
2
5
7
Proterozoic median


2.7C: U ppm
Box-whisker
U
50
40
30
20
10
1
2
5
7
Proterozoic median

Kulgera Suite

MEANS AND STANDARD DEVIATIONS

Element	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Items
SiO2	67.88	68.66	4.93	51.55	76.07	155
TiO2	0.66	0.52	0.48	0.02	2.38	155
Al2O3	14.28	14.13	1.24	11.61	19.56	155
Fe2O3	1.91	1.53	1.47	0.17	10.84	155
FeO	2.69	2.26	1.9	0.11	7.81	153
MnO	0.08	0.06	0.06	0.01	0.56	151
MgO	0.93	0.74	0.86	0.05	7.89	154
CaO	2.53	2.06	1.59	0.52	11.08	155
Na2O	3.09	3.09	0.55	0.24	5.64	155
K2O	4.75	5	1.03	0.09	6.73	155
P2O5	0.22	0.16	0.22	0.01	1.17	150
LOI	1.06	1	0.32	1	3	97
Ba	1094.03	1124	453.75	75	2399	151
Li	16.89	15	11.1	1	60	151
Rb	203.64	206	82.56	1	481	151
Sr	235.18	221	116.91	20	841	151
Pb	38.68	37	14.27		95	151
Th	31.82	22	36.09		225	151
U	3.45	2	5.82		50	141
Zr	344.58	306	233.26	13	1839	133
Nb	19.19	15	34.22		420	151
Y	50.55	49	34.26	1	225	151
La	80.99	72	48.01		339	151
Ce	161.61	152	92.47		578	151
Pr	15.89	15	9.4		58	151
Nd	62.04	59	37.21		240	151
Co	4.54	5	2.26		8	24
Ni	8.66	5	17.53		195	151
Cu	29.55	9	112.61		1172	151
Zn	69.72	60	42	4	213	151
Sn	4.01	3	3.94		41	151
Mo	1.75		1.37		7	151
Ga	19.74	19	3.93	9	51	151
As	1.49	2	0.81		6	110
Ge	2.31	2	1.15		5	151

Pottoyu Granitic Complex

MEANS AND STANDARD DEVIATIONS

Element	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Items
SiO2	74.89	74	2.15	72	78	9
TiO2	1	1	-	1	1	1
Al2O3	12.33	12	0.71	11	13	9
Fe2O3	2.22	2	0.97	1	4	9
FeO	-	-	-	-	-	-
MnO	-	-	-	-	-	-
MgO	1	1	-	1	1	1
CaO	1.38	1	0.52	1	2	8
Na2O	2.89	3	0.33	2	3	9
K2O	5.89	6	0.33	5	6	9
P2O5	-	-	-	-	-	-
LOI	1	1	-	1	1	6
Ba	-	-	-	-	-	-
Li	-	-	-	-	-	-
Rb	-	-	-	-	-	-
Sr	-	-	-	-	-	-
Pb	-	-	-	-	-	-
Th	-	-	-	-	-	-
U	-	-	-	-	-	-
Zr	-	-	-	-	-	-
Nb	-	-	-	-	-	-
Y	-	-	-	-	-	-
La	-	-	-	-	-	-
Ce	-	-	-	-	-	-
Pr	-	-	-	-	-	-
Nd	-	-	-	-	-	-
Co	-	-	-	-	-	-
Ni	-	-	-	-	-	-
Cu	-	-	-	-	-	-
Zn	-	-	-	-	-	-
Sn	-	-	-	-	-	-
Mo	-	-	-	-	-	-
Ga	-	-	-	-	-	-
As	-	-	-	-	-	-
Ge	-	-	-	-	-	-

Olia Gneiss

MEANS AND STANDARD DEVIATIONS

Element	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Items
SiO2	68.93	69	3.11	64	75	27
TiO2	1	1	-	1	1	16
Al2O3	14.26	14	0.76	13	16	27
Fe2O3	4.33	4	1.64	1	8	27
FeO	2.24	2	0.72	1	4	25
MnO	-	-	-	-	-	-
MgO	1	1	-	1	1	24
CaO	2.22	2	0.85	1	4	27
Na2O	3.07	3	0.27	3	4	27
K2O	5.19	5	0.92	3	7	27
P2O5	-	-	-	-	-	-
LOI	1.24	1	0.54	1	3	21
Ba	-	-	-	-	-	-
Li	-	-	-	-	-	-
Rb	-	-	-	-	-	-
Sr	-	-	-	-	-	-
Pb	-	-	-	-	-	-
Th	-	-	-	-	-	-
U	-	-	-	-	-	-
Zr	-	-	-	-	-	-
Nb	-	-	-	-	-	-
Y	-	-	-	-	-	-
La	-	-	-	-	-	-
Ce	-	-	-	-	-	-
Pr	-	-	-	-	-	-
Nd	-	-	-	-	-	-
Co	-	-	-	-	-	-
Ni	-	-	-	-	-	-
Cu	-	-	-	-	-	-
Zn	-	-	-	-	-	-
Sn	-	-	-	-	-	-
Mo	-	-	-	-	-	-
Ga	-	-	-	-	-	-
As	-	-	-	-	-	-
Ge	-	-	-	-	-	-

Undifferentiated

MEANS AND STANDARD DEVIATIONS

Element	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Items
SiO2	70.92	71.54	4.14	64.72	76.19	5
TiO2	0.52	0.47	0.21	0.31	0.83	5
Al2O3	13.54	13.76	0.64	12.74	14.16	5
Fe2O3	1.3	1.16	0.76	0.45	2.15	5
FeO	2.13	1.41	1.43	0.62	3.67	5
MnO	0.08	0.07	0.05	0.02	0.14	5
MgO	0.99	0.93	0.56	0.27	1.76	5
CaO	2.42	2.81	0.84	1.24	3.3	5
Na2O	2.9	2.69	0.74	2	3.88	5
K2O	4.04	4.66	1.52	1.6	5.36	5
P2O5	0.16	0.09	0.16	0.02	0.41	5
LOI	1	1	-	1	1	3
Ba	836.2	911	321.69	367	1233	5
Li	16.4	15	9.4	4	30	5
Rb	166.8	211	80.61	47	238	5
Sr	183.8	193	61.22	121	260	5
Pb	31.8	39	16.96	8	50	5
Th	18.8	6	26.17	2	64	5
U	0.67		0.29		1	3
Zr	342.6	282	279.61	86	821	5
Nb	17	13	9.8	7	31	5
Y	80.4	62	52.56	21	141	5
La	66.8	68	38.31	27	124	5
Ce	164.6	206	109.27	49	296	5
Pr	15.2	17	10.23	5	30	5
Nd	61	59	53.79	13	148	5
Co	-	-	-	-	-	-
Ni	7.6	5	5.18	3	15	5
Cu	3.9	3	3.58		10	5
Zn	53	34	47.39	11	130	5
Sn	3.2	3	0.84	2	4	5
Mo	1.2		0.45		2	5
Ga	16.8	16	3.7	13	22	5
As	1.5	1.5	0.71	1	2	2
Ge	2.6	3	0.55	2	3	5

3 WINBURN SUITE

3.1 Timing 1050 - 1080 Ma

3.2 Individual Ages

Primary Ages:

1. Granitic dyke	1052 ± 11 Ma, SHRIMP 2
2. Rapakivi-textured dyke	1068 ± 6 Ma, SHRIMP 2
3. Rhyolite, Smoke Hill Volcanics	1078 ± 5 Ma, SHRIMP 2
4. Granophyric pegmatite	1078 ± 3 Ma, SHRIMP 2

Source: Sun *et al*, (1996).

3.3 Regional Setting

The informal name Winburn Suite is given to that group of felsic intrusive and extrusive rocks that are comagmatic with the Giles Mafic-Ultramafic Complex. They occur in the western Musgrave Block. This widespread magmatic event between 1080 and 1050 Ma is a major and separate event from the 1200 Ma Musgravian Orogeny. Emplacement of a large amount of high-temperature (1200 - 1300°C) tholeiitic magma into deep crustal levels is believed to have increased the lithostatic pressure and induced granulite-facies metamorphism and crustal melting, resulting in bimodal mafic and felsic volcanic and hypabyssal igneous activity (Sun *et al.* 1996). The range of initial εNd values (+0.9 to -2.5) and the chemistry of 1080-1050 Ma felsic rocks are consistent with magma generation by various processes, including crustal melting of ~1550 and ~1300 Ma felsic granulite facies country rocks (with εNd of -2.5 to -4.8 at 1070 Ma), and derivation from magic magmas through extensive crustal assimilation coupled with fractional crystallisation.

3.4 Summary

The Winburn Suite comprises various granite, porphyritic microgranite, rapakivi granite, and comagmatic felsic volcanics. Only one sample of the granite is available, however it is considered that the granites and volcanics will be sufficiently similar that the data available will adequately quantify the metallogenic potential of these rocks. The volcanics are weakly fractionated at high silica levels, oxidised, Sr-depleted, Y-undepleted, and markedly enriched. Although fluorine analyses are not available, several of the granites are noted to be fluorite bearing, and it is thought that the suite is a high-fluorine suite.

3.5 Potential

This suite is not considered to have any metallogenic potential, because it is not significantly fractionated, is probably fluorite-bearing, is highly enriched, and has no known association with mineralisation.

Cu:	**None**
Au:	**None**
Pb/Zn:	**None**
Sn:	**None**
Mo/W:	**None**
Confidence level:	**110**

3.6 Descriptive Data

Location: Western Musgrave Block, on the COOPER, TALBOT, SCOTT and BENTLEY 1:250 000 map sheets.

Dimensions and area: The granites and volcanics of this suite outcrop over an area of approximately 200 x 80 km.

3.7 Intrusives

Component plutons: Thought to include the following:

In the Champ de Mars area (COOPER & MANN 1:250 000 map sheets), unnamed porphyritic to even grained granite and rapakivi granite. These intrude the Hinckley Range gabbronorite and Michael Hills gabbro of the Giles Complex.

The Winburn Granite (map symbol Ꝑ*pg* on COOPER, SCOTT and TALBOT map sheets) is intrusive and probably comagmatic with the Palgrave Volcanic Association (Ꝑ*pp* on same map sheets). Unit Ꝑ*pc* (porphyritic microgranite on TALBOT, COOPER and BENTLEY map sheets) is associated with the Winburn Granite. Other intrusives associated with the Palgrave Volcanic Association include Ꝑ*ga* (aplite on TALBOT) and Ꝑ*gr* (COOPER). Unit Ꝑ*sn* (granitic gneiss on TALBOT) is associated with the Scamp Volcanic Association. The Scamp and Palgrave Volcanic Associations, the Skirmish Hill Volcanics, and the Thomas Rhyolite, Hilda Rhyolite and Gombugurra Rhyolite of the Cassidy Group, are all part of the Bentley Supergroup. This Supergroup also includes the Tollu Group.

Form: Generally small sheets, many dyke-like bodies, a few pluton-like intrusions.

Metamorphism and Deformation: None mentioned. However, the Giles Complex which was intruded at the same time as these granites and volcanics is noted to be variably deformed.

Dominant intrusive rock types: Granite, granophyre, rapakivi granite, aplite, porphyritic granite and microgranite.

Colour: Not reported in literature.

Veins, Pegmatites, Aplites, Greisens: None reported in literature.

Distinctive mineralogical characteristics: Granitic rocks intrusive into the Palgrave Volcanic Association form most of the Barrow Range, and are referred to as the Winburn Granite (Ꝑ*pg* on TALBOT, COOPER and SCOTT). They include massive granite with lesser granophyre and porphyritic microgranite. The Winburn Granite is a complex of porphyritic and non-porphyritic varieties of granite and granophyre with a sporadic marginal development of porphyritic microgranite that gradually passes into normal granite over a distance of approximately 20 metres. Typical granite consists of microcline, albite-oligoclase and quartz, with accessory biotite, opaques, fluorite, zircon, titanite, apatite and epidote. Hornblende is also present in some varieties. Phenocrysts in the porphyritic variety consist of microcline perthite and occasional plagioclase. In detail the porphyritic microgranite contacts are transgressive and show numerous minor apophyses extending into the country rocks. The coarse porphyritic character and intrusive nature of these rocks distinguishes them from most of the porphyritic acid volcanics. Sills of porphyritic microgranite, intrusive into the volcanics of Whitby Range, lie outside the Palgrave volcanic association cauldron subsidence area. However, the microgranite resembles the marginal facies of the Winburn Granite, and it is suggested that these sills are genetically related to the main granite mass.

Partial ring dykes of porphyritic microgranite and aplite intrusive into the Palgrave Volcanic Association are probably apophyses from the Winburn Granite, as are sills of porphyritic microgranite intrusive into the Pussy Cat Group (units Ꝑ*ga* and Ꝑ*pc* on TALBOT and COOPER).

Small exposures of a granitic rock intrude the Tollu Group volcanics at Barnard Rocks (Ꝑ*gr* on COOPER). The rock is a potassic granite consisting of quartz and microcline microperthite with very rare plagioclase. Mafic minerals include biotite and a trace of a deep blue-green amphibole. Accessories include zircon, opaques, and epidote.

Breccias: None mentioned.

Alteration in the granite: None mentioned.

3.8 Extrusives

The Winburn Granite and other intrusives of this suite are thought to be comagmatic with volcanics of the Bentley Supergroup, based on field relationships and geochronology. The Winburn Granite intrudes the Palgrave Volcanic Association (TALBOT, BENTLEY & COOPER), and other granites intrude the Scamp Volcanic Association (TALBOT). Other volcanics thought to be comagmatic include the Skirmish Hill Volcanic Association (COOPER), the Smoke Hill Volcanics of the Tollu Group (COOPER), and the Thomas Rhyolite, Hilda Rhyolite, and Gombugurra Rhyolite of the Cassidy Group (TALBOT).

The Palgrave Volcanic Association forms a cauldron subsidence area, and includes porphyritic acid volcanic rocks, feldspathic grey-green tuff, pyritic rhyolite, and agglomerate.

The Scamp volcanic association also forms a cauldron subsidence area, and includes fluorite-bearing porphyritic rhyolite, pyritic rhyolite, felsite, and some basic volcanics.

The Skirmish Hill volcanic association is composed of porphyritic acid volcanic rocks, with minor basic volcanics.

The Smoke Hill Volcanics consist of rhyolite. The Thomas, Hilda and Gombugurra Rhyolites all consist of porphyritic rhyolite.

3.9 Country Rock

Contact metamorphism: None mentioned.

Reaction with country rock: None mentioned.

Units the granite intrudes: These young granites intrude older migmatites and granulites as well as some of the westernmost granites of the Kulgera Suite. They also intrude mafic units of the Giles Complex.

Dominant rock types: Well banded granulites outcrop in areas of the COOPER, SCOTT and MANN map sheets. They are complexly folded and commonly migmatised. The granitic material involved in the migmatisation is generally a leucocratic porphyritic granite with distinctive, bronze-weathering phenocrysts of potash feldspar. A variety of igneous and sedimentary rocks is probably represented in the banded granulites. On the whole the composition is dominantly acid, and basic rocks are rare and confined to narrow bands. The granulites of the northwest portion of the COOPER sheet area are well foliated and lineated quartzofeldspathic rocks with variable amounts of mafics. Their most noticeable field characteristics are a fine banding, well developed flaser structure, and the presence of dark red garnets up to half an inch in diameter. Migmatisation in the region is almost absent and is confined to minor quartz-feldspar-muscovite pods. Individual bands may contain one or more of the following minerals: hypersthene, garnet, sillimanite, spinel, and biotite in addition to quartz, plagioclase, and potash feldspar. Accessories usually include zircon, apatite, and graphite. Several assemblages contain cordierite as a secondary mineral.

This suite is thought to be comagmatic with the Giles Complex. It intrudes several parts of the Complex, in the Michael Hills, Hinkley Range, and Blackstone Range. The Michael Hills Gabbro consists mainly of hypersthene gabbro with several interbanded pyroxenite layers 8 to 20 metres thick in the lower part of the intrusion. Antiperthitic inclusions in the plagioclase are abundant. The Hinckley Range gabbronorite includes olivine norite and olivine-hypersthene gabbro. Ultramafic rocks occur on the northern side of the Range near Wingellina. The Blackstone Range Gabbro refers to the gabbroic rocks forming the Cavenagh, Blackstone and Bell Rock Ranges. It is composed mainly of olivine-bearing rocks with troctolite predominating.

Granites of the Kulgera Suite in the COOPER and SCOTT area include the unnamed units ꓑ*ge*, ꓑ*gu*, ꓑ*gn*, ꓑ*bo*, ꓑ*ri*, ꓑ*rs* and ꓑ*gp*.

Potential hosts: Some of the mafic, iron-rich rocks of both the Giles Complex and the migmatites and graphite in some of the migmatites, may act as reductants.

3.10 Mineralisation

No known ore-grade mineralisation exists in the Musgrave Block.

3.11 Geochemical Data

Data source: About half of the samples were collected during field mapping by AGSO in 1990 and 1991. The remaining samples were collected by Giles (1980).

Data quality: Samples collected by AGSO were analysed at AGSO, and are considered to be of excellent quality. Samples collected by Giles were analysed at the University of Adelaide, and are considered to be adequate.

Are the data representative? No - only one sample comes from the granites - all other samples are of the associated volcanics.

Are the data adequate? No - only one sample of any of the granites, and all other samples are of the associated volcanics.

SiO_2 range (Fig. 3.1): Ranges from 50 to 75 wt.%. Note that 50 wt.% SiO_2 is used as a cutoff value - associated mafic rocks are part of the magma association.

Alteration (Fig. 3.2): Some alteration is evident.

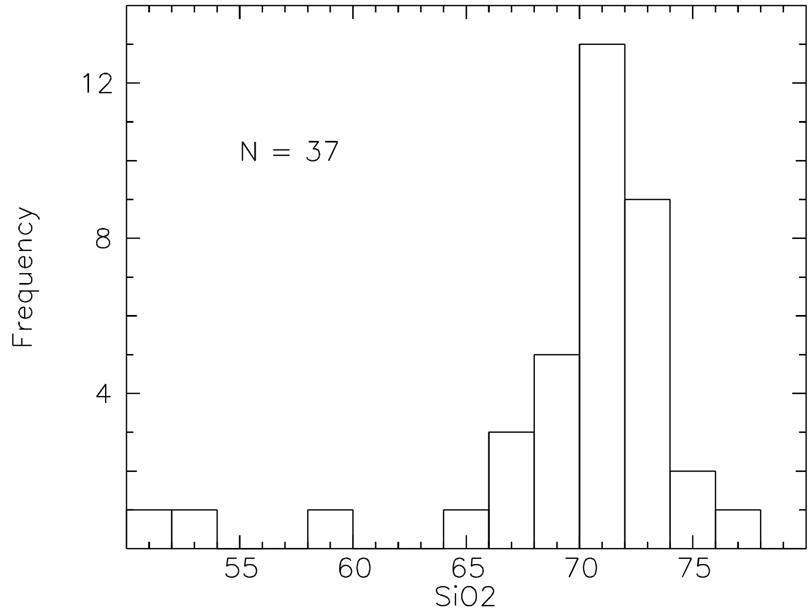


Figure 3.1: Histogram of SiO_2 values.

- ***SiO_2:*** None evident.
- ***K_2O/Na_2O:*** Some sodic alteration has occurred.
- ***Th/U:*** Most samples are slightly above the normal range.
- ***$Fe_2O_3/(FeO+Fe_2O_3)$:*** Samples range from reduced to strongly oxidised, and may indicate some alteration.

Fractionation Plots (Fig. 3.3): Some minor very late-stage fractionation has occurred.

- ***Rb:*** Values range from very low to moderate, increasing with increasing SiO_2.
- ***U:*** All values are low or very low. There are no analyses for the Palgrave and Scamp volcanics, nor for the Winburn Granite and Thomas Rhyolite.
- ***Y:*** Values range from low to very high.
- ***P_2O_5:*** Values range from moderate to very low, decreasing with increasing SiO_2.
- ***Th:*** Values range from very low to high. Most values are moderately low, one value for a granitoid from the Giles Complex is high.
- ***K/Rb:*** Values are mostly moderate, and scattered.
- ***Rb-Ba-Sr:*** Most samples plot in the granite field. Some samples plot in the monzogranite or tonalite fields.
- ***Sr:*** Values range from moderately high to low, decreasing with increasing SiO_2.
- ***Rb/Sr:*** Values range from very low to low, and increase slightly with increasing SiO_2.
- ***Ba:*** Values range from low to high, and there is a lot of scatter.
- ***F:*** No data available.

Metals (Fig. 3.4): Values are mostly moderate and quite scattered.

- ***Cu:*** Values range from moderately low to very low.
- ***Pb:*** Values range from very low to moderately high, increasing with increasing SiO_2.
- ***Zn:*** Values range from very high to low, and are very scattered.
- ***Sn:*** Values range from moderate to low.

High field strength elements (Fig. 3.5): Values range from low to very high (some of the highest in Australian Proterozoic granites), with a lot of scatter.

- ***Zr:*** NOTE CHANGE OF SCALE from 1000 max to 1400 max. Values range from low to extremely high, and decrease strongly with increasing SiO_2. The Smoke Hill Volcanics of the Tollu Group and the Thomas Rhyolite of the Cassidy Group (both of the Bentley Supergroup) have one of the highest Zr values of any Australian Proterozoic felsic intrusive/extrusive.
- ***Nb:*** Values range from very low to very high, with a lot of scatter.
- ***Ce:*** Values range from very low to moderately high, with a lot of scatter.

Classification (Fig. 3.6): Metaluminous, very weakly fractionated, enriched.

- ***The CaO/Na$_2$O/K$_2$O plot of White, quoted in Sheraton and Simons (1992):*** Samples plot mostly in the granite field, with some samples plotting in each of the other fields.
- ***Zr/Y vs Sr/Sr*:*** Samples plot mostly along the Y-undepleted axis.
- ***Spidergram:*** The suite is Sr-depleted, Y-undepleted.
- ***Oxidation plot of Champion and Heinemann (1994):*** The suite is mostly oxidised, with some samples being strongly oxidised.
- ***ASI:*** The suite is strongly metaluminous, but becomes less so with increasing SiO_2.
- ***A-type plot of Eby (1990):*** Only samples from the Smoke Hill Volcanics, felsic intrusives into the Giles Complex, and one undifferentiated sample of the Bentley Supergroup plot. The Smoke Hill Volcanics plot at high HFSE and Ga/Al ratios, and have some of the highest values of any of the Australian Proterozoic felsic intrusives/extrusives.

Granite type (Chappell and White 1974; Chappell and Stephens 1988): I-(granodiorite) type.

Australian Proterozoic granite type: Argylla type.

3.12 Geophysical Signature

Radiometrics (Fig. 3.7): Potassium for most units is above the Proterozoic median. Th and U data are available for only the Smoke Hill Volcanics, the felsic intrusives in the Giles Complex, and one undifferentiated Bentley Supergroup sample. The undifferentiated Bentley Supergroup sample and the Giles Complex intrusives are below the Proterozoic median, while the Smoke Hill Volcanics are significantly above the median for Th, but about the same as the median for U. The predicted RGB colours are: red for the undifferentiated Bentley Supergroup samples, black for the Giles Complex intrusives, and yellow for the Smoke Hill Volcanics.

Gravity: Most Winburn suite granites show a high to above-background gravity signature. This may largely reflect the proximity of the comagmatic intrusives and extrusives of the Giles mafic-ultramafic Complex.

Magnetics: The suite shows a generally high magnetic signature.

3.13 References

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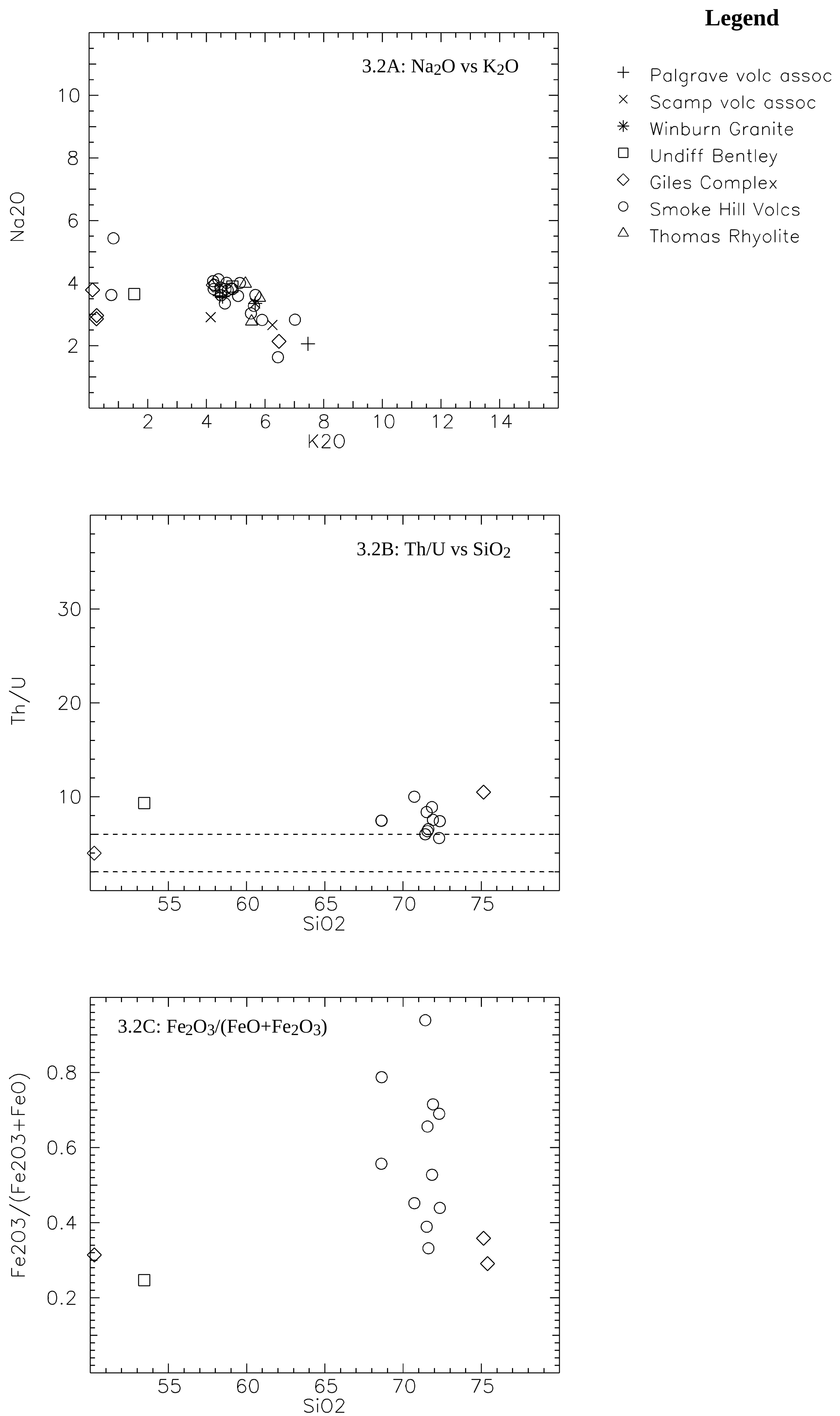
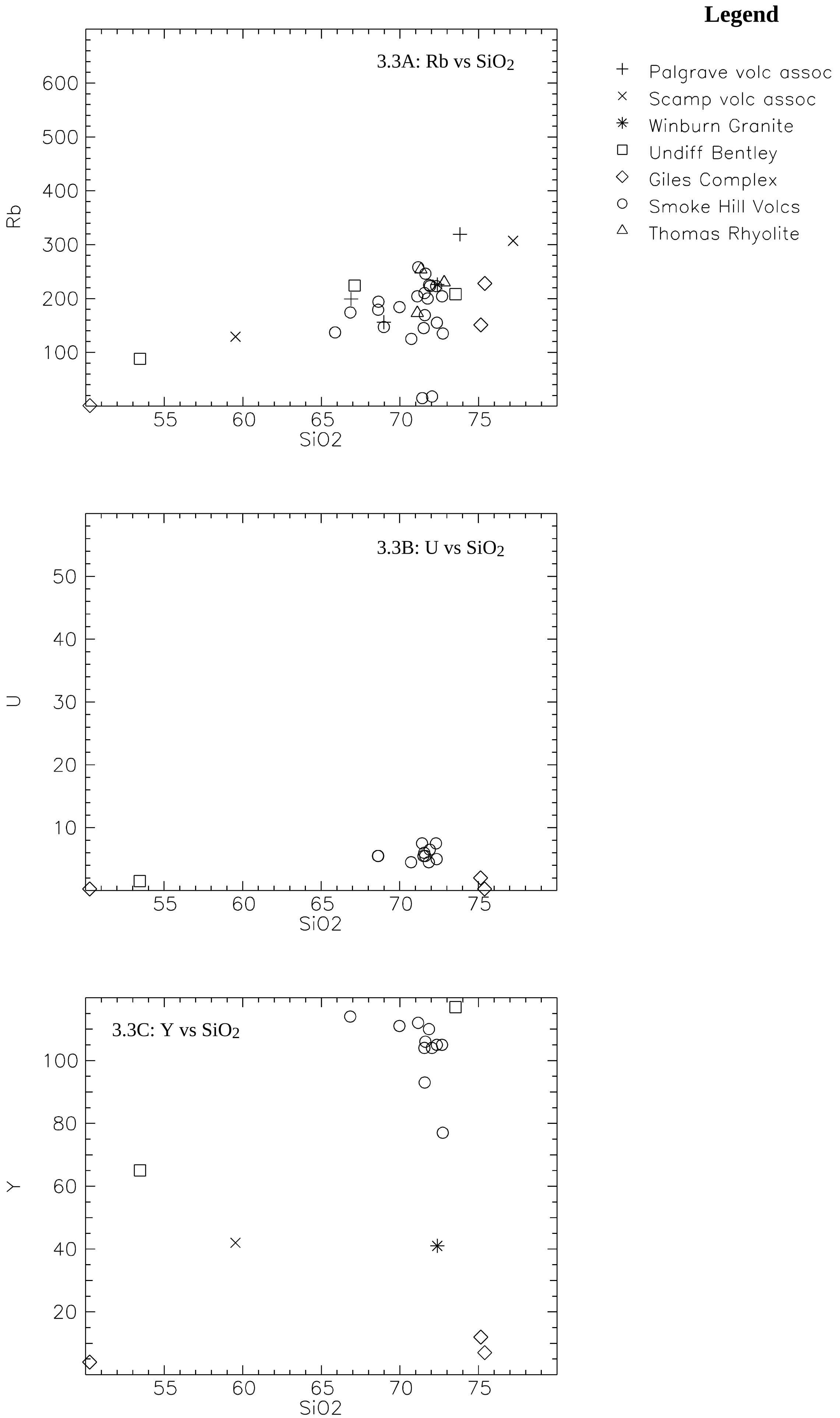
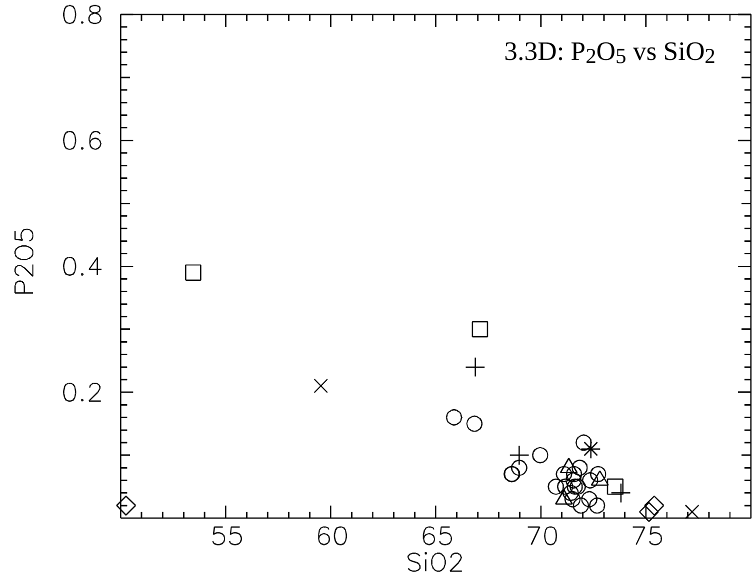
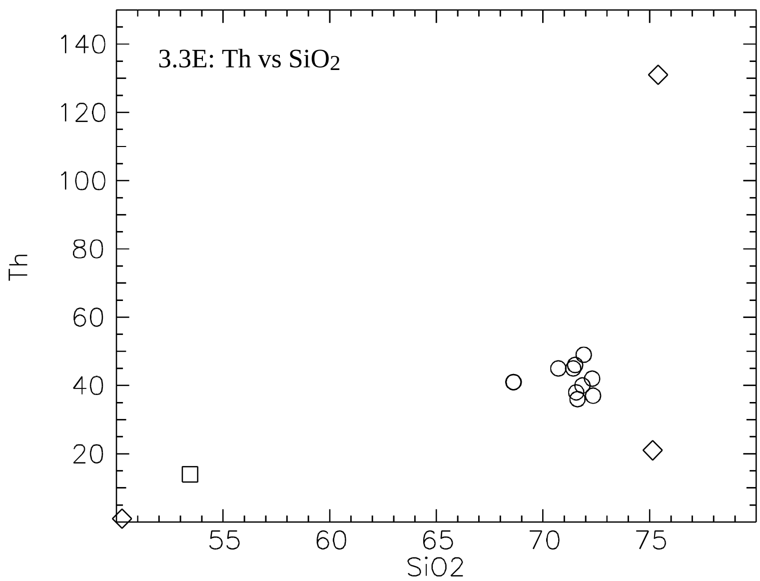

Legend
Palgrave volc assoc
Scamp volc assoc
Winburn Granite
Undiff Bentley
Giles Complex
Smoke Hill Volcs
Thomas Rhyolite
3.2A: Na2O vs K2O
Na2O
K2O
3.2B: Th/U vs SiO2
Th/U
SiO2
3.2C: Fe2O3/(FeO+Fe2O3)
Fe2O3/(Fe2O3+FeO)
SiO2

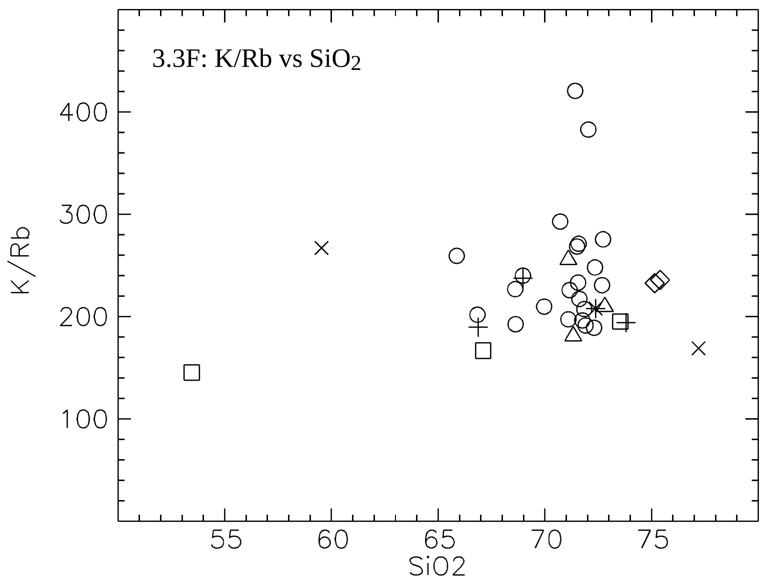

Legend
+ Palgrave volc assoc
× Scamp volc assoc
✳ Winburn Granite
□ Undiff Bentley
◇ Giles Complex
○ Smoke Hill Volcs
△ Thomas Rhyolite
3.3A: Rb vs SiO2
Rb
SiO2
3.3B: U vs SiO2
U
SiO2
3.3C: Y vs SiO2
Y
SiO2

Legend

- + Palgrave volc assoc
- × Scamp volc assoc
- ✳ Winburn Granite
- □ Undiff Bentley
- ◇ Giles Complex
- ○ Smoke Hill Volcs
- △ Thomas Rhyolite







Legend

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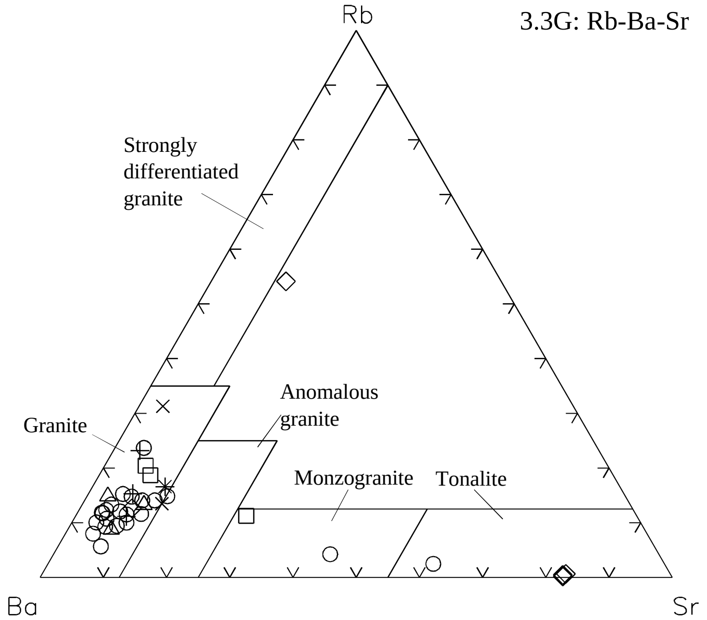
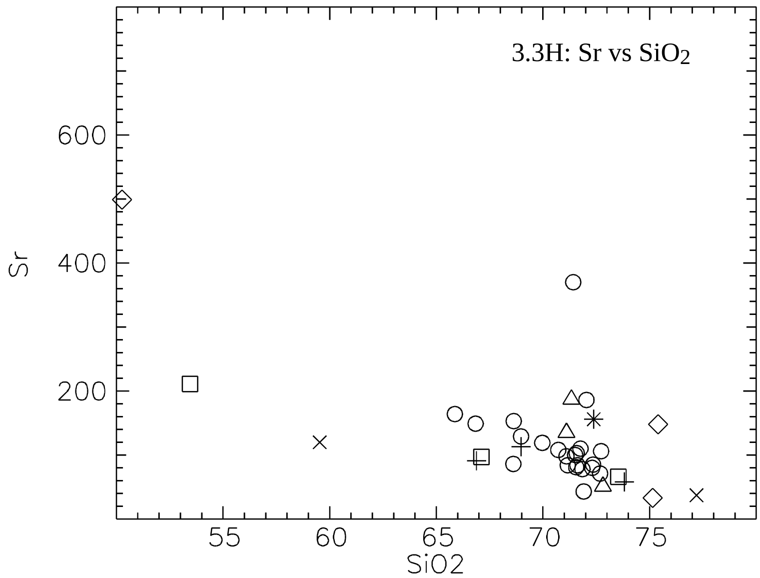
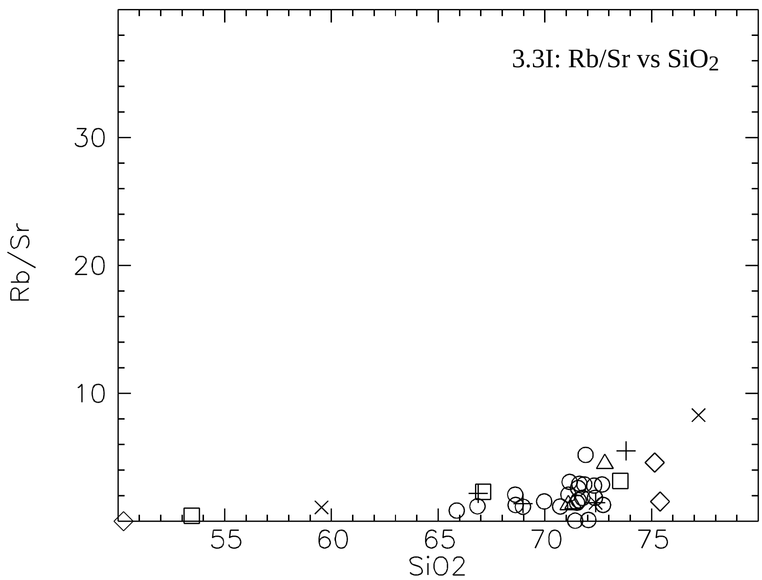
- × Scamp volc assoc
- ✳ Winburn Granite
- □ Undiff Bentley
- ◇ Giles Complex
- ○ Smoke Hill Volcs
- △ Thomas Rhyolite







Legend

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- × Scamp volc assoc
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- □ Undiff Bentley
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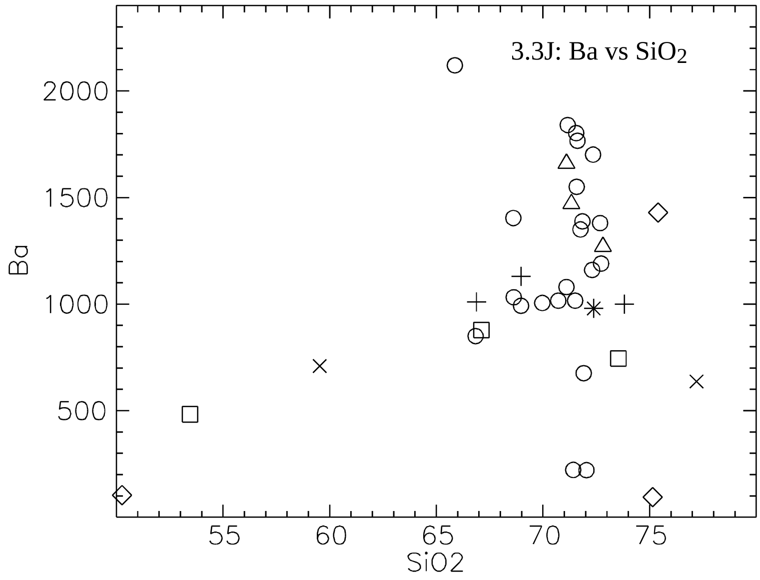
- ○ Smoke Hill Volcs
- △ Thomas Rhyolite



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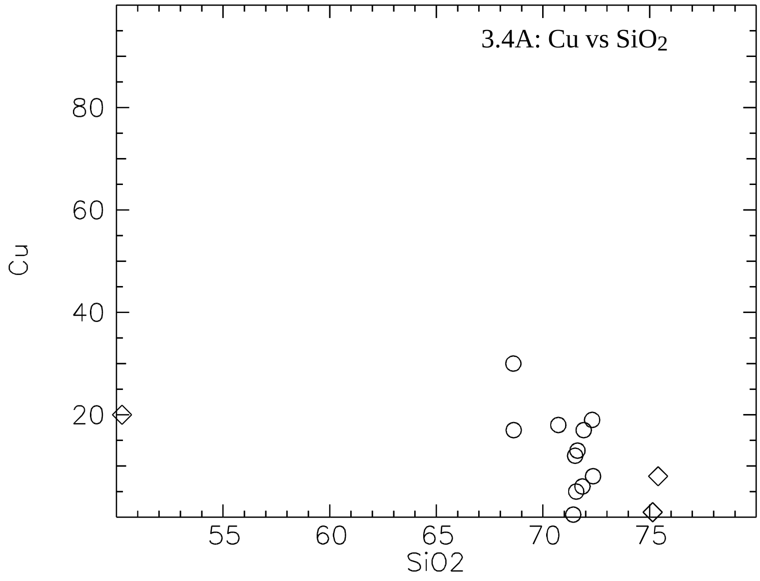

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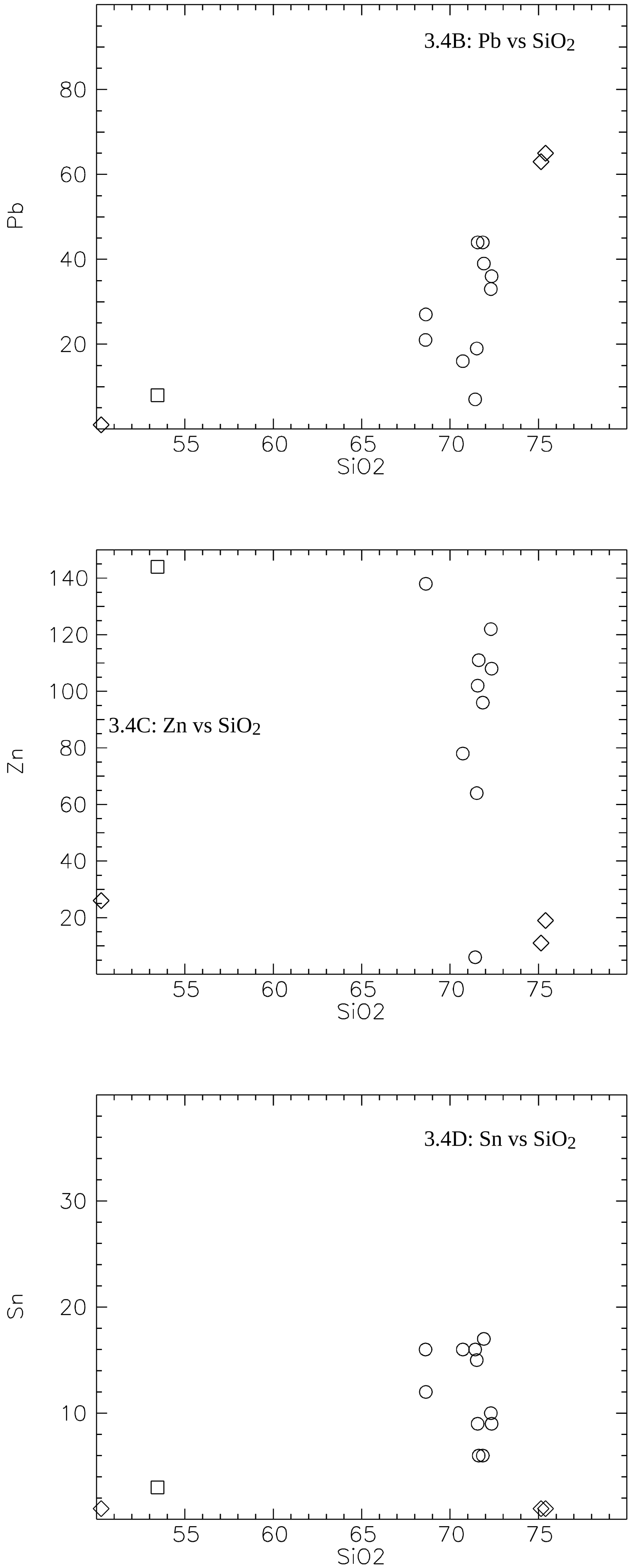
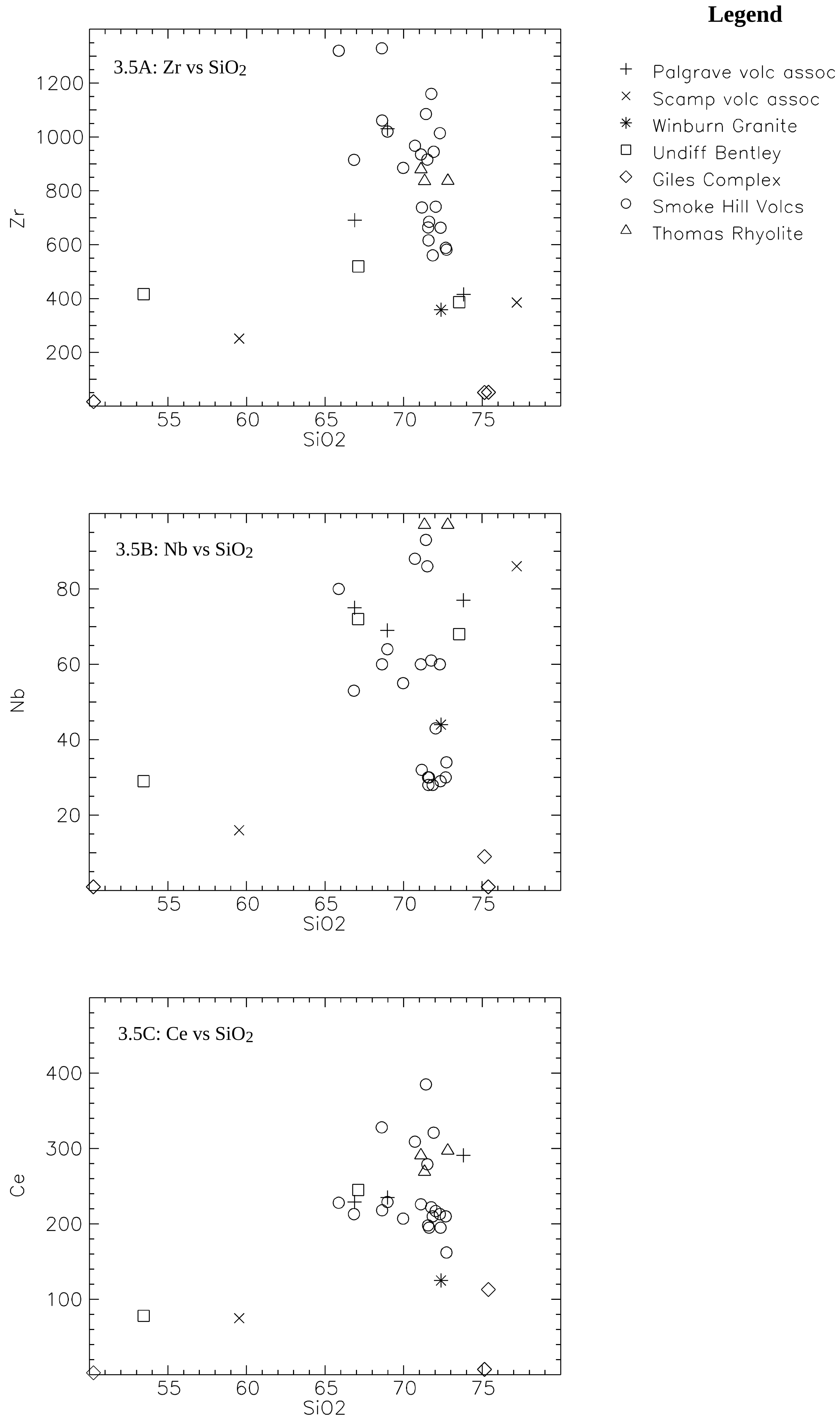
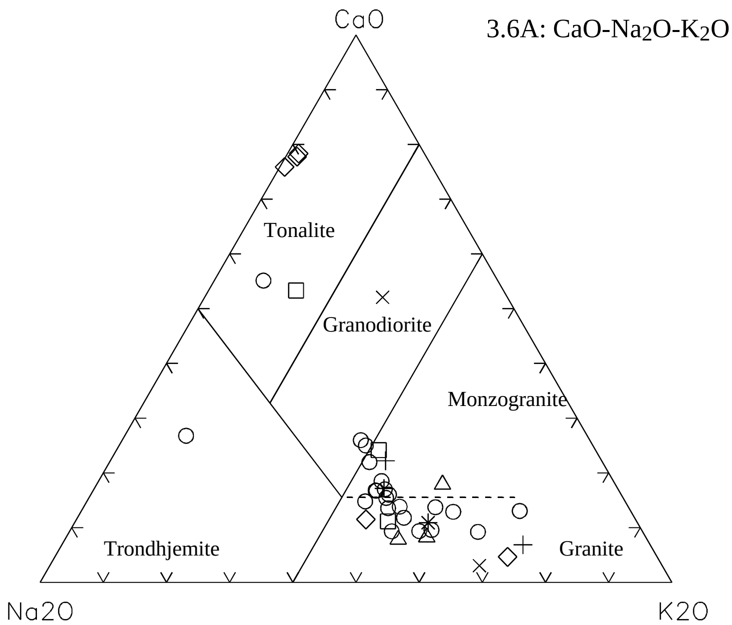
- ○ Smoke Hill Volcs
- △ Thomas Rhyolite

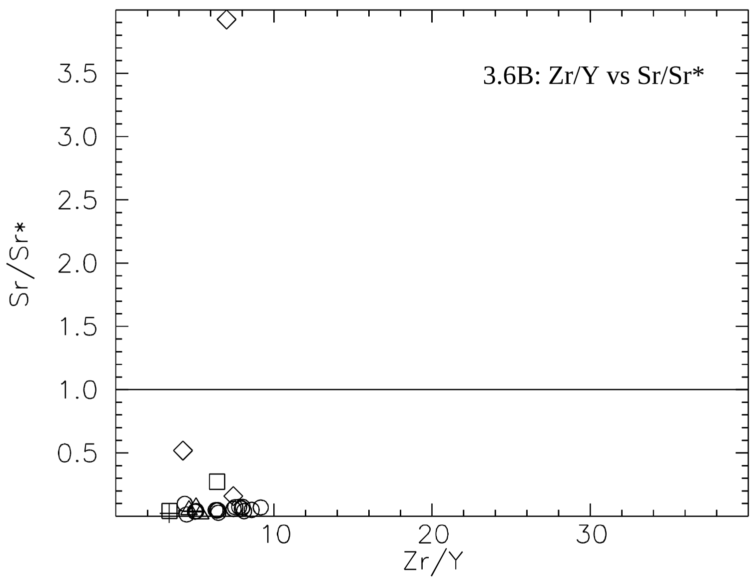


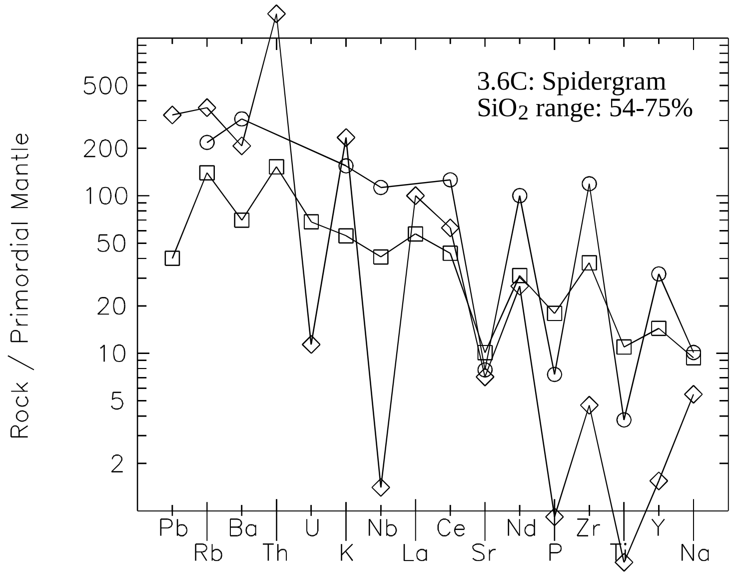

Legend
+ Palgrave volc assoc
× Scamp volc assoc
* Winburn Granite
□ Undiff Bentley
◇ Giles Complex
○ Smoke Hill Volcs
△ Thomas Rhyolite
3.5A: Zr vs SiO2
Zr
1200
1000
800
600
400
200
55
60
65
70
75
SiO2
3.5B: Nb vs SiO2
Nb
80
60
40
20
55
60
65
70
75
SiO2
3.5C: Ce vs SiO2
Ce
400
300
200
100
55
60
65
70
75
SiO2

Legend

- + Palgrave volc assoc
- × Scamp volc assoc
- ✳ Winburn Granite
- □ Undiff Bentley
- ◇ Giles Complex
- ○ Smoke Hill Volcs
- △ Thomas Rhyolite







Legend

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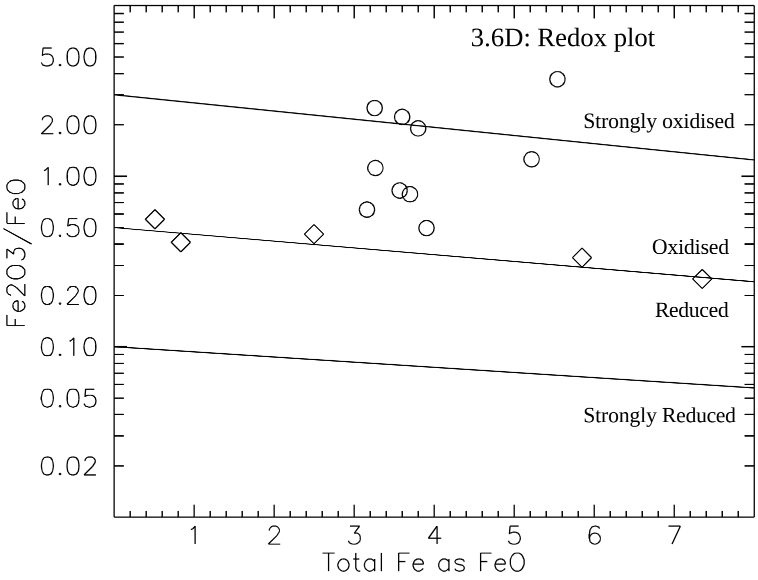
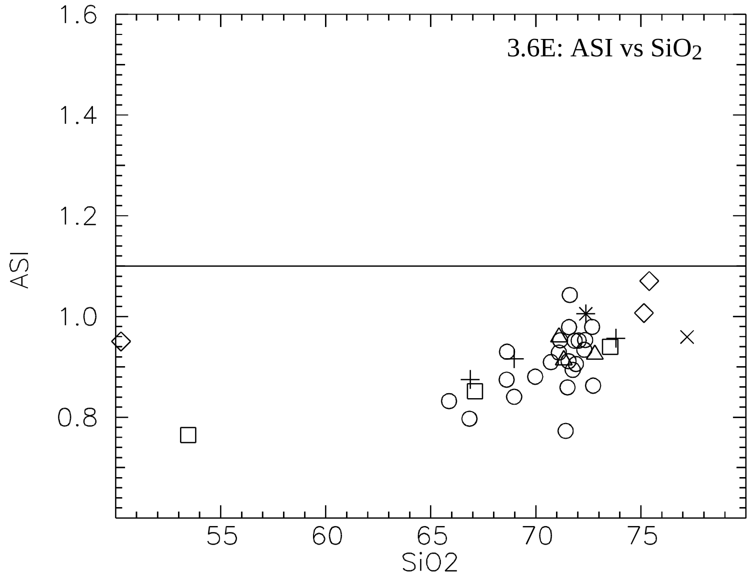
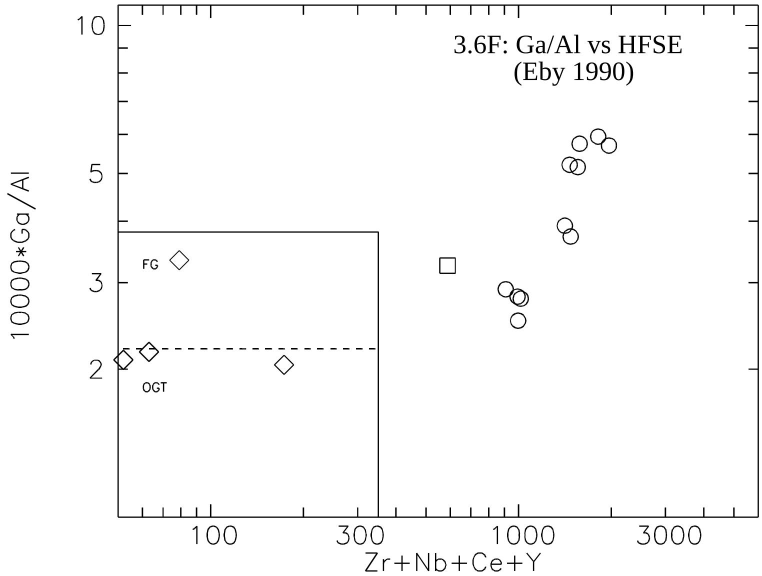
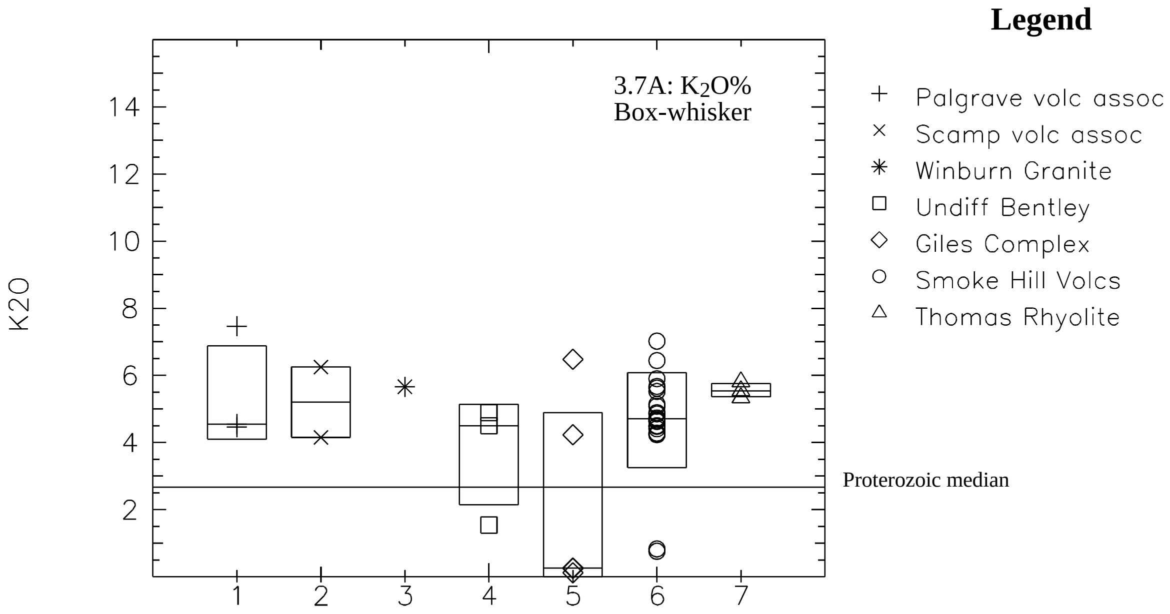
× Scamp volc assoc
✳ Winburn Granite
□ Undiff Bentley
◇ Giles Complex
○ Smoke Hill Volcs
△ Thomas Rhyolite





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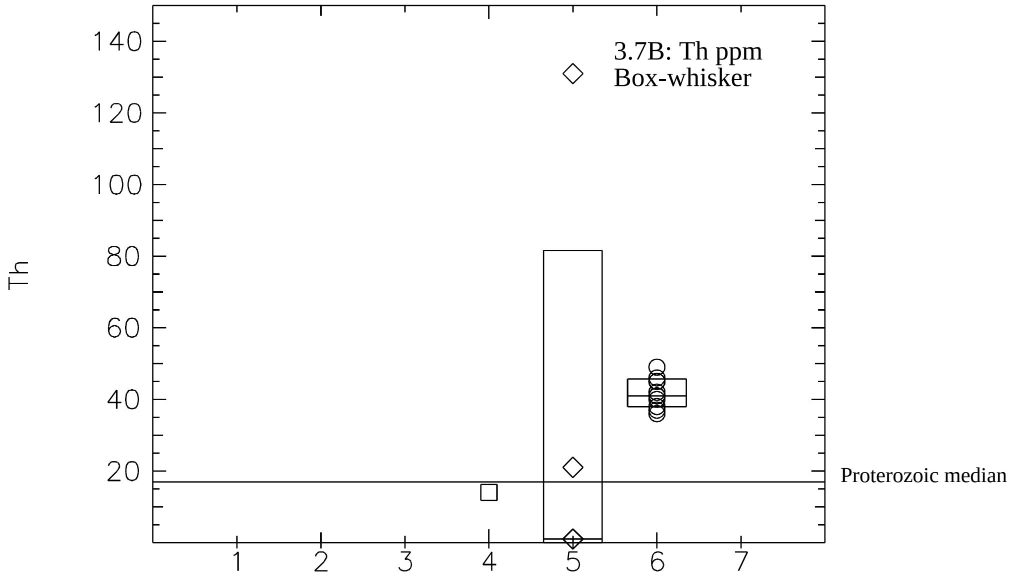
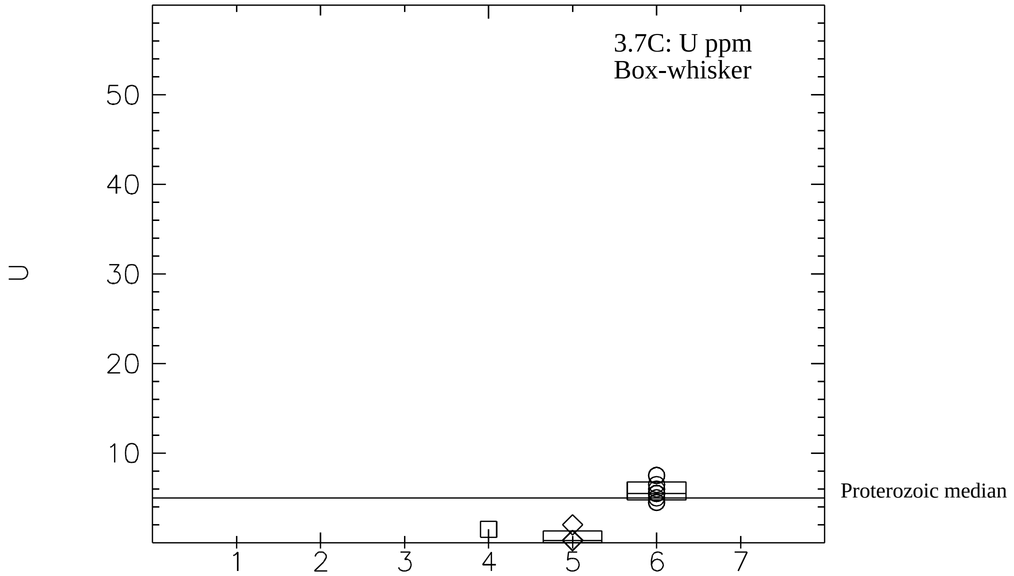
+ Palgrave volc assoc
× Scamp volc assoc
✳ Winburn Granite
□ Undiff Bentley
◇ Giles Complex
○ Smoke Hill Volcs
△ Thomas Rhyolite
3.7A: K_2O%
Box-whisker
K2O
14
12
10
8
6
4
2
1
2
3
4
5
6
7
Proterozoic median


3.7B: Th ppm
Box-whisker
Th
140
120
100
80
60
40
20
1
2
3
4
5
6
7
Proterozoic median


3.7C: U ppm
Box-whisker
U
50
40
30
20
10
1
2
3
4
5
6
7
Proterozoic median

Winburn Granite

MEANS AND STANDARD DEVIATIONS

Element	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Items
SiO2	72.38	72.38	-	72.38	72.38	1
TiO2	0.49	0.49	-	0.49	0.49	1
Al2O3	13.44	13.44	-	13.44	13.44	1
Fe2O3	2.55	2.55	-	2.55	2.55	1
FeO	-	-	-	-	-	-
MnO	0.04	0.04	-	0.04	0.04	1
MgO	0.44	0.44	-	0.44	0.44	1
CaO	1.1	1.1	-	1.1	1.1	1
Na2O	3.35	3.35	-	3.35	3.35	1
K2O	5.66	5.66	-	5.66	5.66	1
P2O5	0.11	0.11	-	0.11	0.11	1
LOI	0.57	0.57	-	0.57	0.57	1
Ba	980	980	-	980	980	1
Li	-	-	-	-	-	-
Rb	226	226	-	226	226	1
Sr	156	156	-	156	156	1
Pb	-	-	-	-	-	-
Th	-	-	-	-	-	-
U	-	-	-	-	-	-
Zr	358	358	-	358	358	1
Nb	44	44	-	44	44	1
Y	41	41	-	41	41	1
La	-	-	-	-	-	-
Ce	125	125	-	125	125	1
Pr	-	-	-	-	-	-
Nd	-	-	-	-	-	-
Sc	4.3	4.3	-	4.3	4.3	1
V	-	-	-	-	-	-
Cr	5.4	5.4	-	5.4	5.4	1
Mn	-	-	-	-	-	-
Ni	-	-	-	-	-	-
Cu	-	-	-	-	-	-
Zn	-	-	-	-	-	-
Sn	-	-	-	-	-	-
Mo	-	-	-	-	-	-
Ga	-	-	-	-	-	-
As	-	-	-	-	-	-
S	-	-	-	-	-	-
Be	-	-	-	-	-	-
Ag	-	-	-	-	-	-
Bi	-	-	-	-	-	-
Hf	-	-	-	-	-	-
Ta	-	-	-	-	-	-
Cs	-	-	-	-	-	-
Ge	-	-	-	-	-	-
Se	-	-	-	-	-	-

Palgrave Volcanic Association

MEANS AND STANDARD DEVIATIONS

Element	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Items
SiO2	69.89	68.97	3.55	66.88	73.81	3
TiO2	0.62	0.52	0.36	0.32	1.02	3
Al2O3	12.38	12.41	0.27	12.09	12.63	3
Fe2O3	5.83	7.06	2.71	2.72	7.71	3
FeO	-	-	-	-	-	-
MnO	0.1	0.09	0.02	0.08	0.12	3
MgO	0.58	0.42	0.38	0.3	1.01	3
CaO	1.56	1.67	0.82	0.7	2.32	3
Na2O	3.08	3.57	0.88	2.06	3.6	3
K2O	5.49	4.55	1.71	4.46	7.46	3
P2O5	0.13	0.1	0.1	0.04	0.24	3
LOI	0.27	0.26	0.08	0.2	0.35	3
Ba	1046.67	1010	72.34	1000	1130	3
Li	-	-	-	-	-	-
Rb	224.67	199	84.48	156	319	3
Sr	87.33	91	27.68	58	113	3
Pb	-	-	-	-	-	-
Th	-	-	-	-	-	-
U	-	-	-	-	-	-
Zr	712	691	308.04	415	1030	3
Nb	73.67	75	4.16	69	77	3
Y	143.33	143	20.5	123	164	3
La	-	-	-	-	-	-
Ce	251.67	235	34.2	229	291	3
Pr	-	-	-	-	-	-
Nd	116.5	116.5	0.71	116	117	2
Sc	8.47	10.4	4.8	3	12	3
V	54	54	-	54	54	1
Cr	6	6	-	6	6	1
Mn	-	-	-	-	-	-
Ni	12	12	-	12	12	1
Cu	-	-	-	-	-	-
Zn	-	-	-	-	-	-
Sn	-	-	-	-	-	-
Mo	-	-	-	-	-	-
Ga	-	-	-	-	-	-
As	-	-	-	-	-	-
S	-	-	-	-	-	-
Be	-	-	-	-	-	-
Ag	-	-	-	-	-	-
Bi	-	-	-	-	-	-
Hf	-	-	-	-	-	-
Ta	-	-	-	-	-	-
Cs	-	-	-	-	-	-
Ge	-	-	-	-	-	-
Se	-	-	-	-	-	-

Scamp Volcanic Association

MEANS AND STANDARD DEVIATIONS

Element	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Items
SiO2	68.36	68.36	12.49	59.53	77.2	2
TiO2	0.58	0.58	0.57	0.18	0.98	2
Al2O3	11.48	11.48	0.46	11.15	11.8	2
Fe2O3	5.5	5.5	4.28	2.47	8.52	2
FeO	-	-	-	-	-	-
MnO	0.09	0.09	0.09	0.02	0.15	2
MgO	2.18	2.18	2.97	0.08	4.28	2
CaO	3.98	3.98	5.23	0.28	7.67	2
Na2O	2.79	2.79	0.18	2.66	2.91	2
K2O	5.2	5.2	1.48	4.15	6.25	2
P2O5	0.11	0.11	0.14	0.01	0.21	2
LOI	0.35	0.35	0.16	0.24	0.46	2
Ba	673	673	50.91	637	709	2
Li	-	-	-	-	-	-
Rb	218	218	125.87	129	307	2
Sr	78.5	78.5	58.69	37	120	2
Pb	-	-	-	-	-	-
Th	-	-	-	-	-	-
U	-	-	-	-	-	-
Zr	318	318	94.75	251	385	2
Nb	51	51	49.5	16	86	2
Y	88.5	88.5	65.76	42	135	2
La	-	-	-	-	-	-
Ce	75	75	-	75	75	1
Pr	-	-	-	-	-	-
Nd	-	-	-	-	-	-
Sc	12.5	12.5	16.26	1	24	2
V	211.5	211.5	62.93	167	256	2
Cr	104	104	-	104	104	1
Mn	-	-	-	-	-	-
Ni	78	78	-	78	78	1
Cu	-	-	-	-	-	-
Zn	-	-	-	-	-	-
Sn	-	-	-	-	-	-
Mo	-	-	-	-	-	-
Ga	-	-	-	-	-	-
As	-	-	-	-	-	-
S	-	-	-	-	-	-
Be	-	-	-	-	-	-
Ag	-	-	-	-	-	-
Bi	-	-	-	-	-	-
Hf	-	-	-	-	-	-
Ta	-	-	-	-	-	-
Cs	-	-	-	-	-	-
Ge	-	-	-	-	-	-
Se	-	-	-	-	-	-

Smoke Hill Volcanics

MEANS AND STANDARD DEVIATIONS

Element	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Items
SiO2	70.78	71.54	1.87	65.87	72.73	22
TiO2	0.45	0.41	0.13	0.31	0.8	22
Al2O3	12.68	12.7	0.38	12.05	13.5	22
Fe2O3	3.85	3.57	1.94	1.28	8.13	22
FeO	1.64	1.63	0.73	0.19	2.7	11
MnO	0.08	0.09	0.03	0.02	0.14	22
MgO	0.22	0.15	0.16	0.04	0.63	22
CaO	1.76	1.51	0.98	0.94	5.38	22
Na2O	3.63	3.79	0.69	1.63	5.43	22
K2O	4.66	4.71	1.45	0.76	7.02	22
P2O5	0.07	0.06	0.04	0.02	0.16	22
LOI	0.53	0.49	0.29	0.1	1.22	22
Ba	1216.41	1175	485.19	221	2120	22
Li	4.1	3	3.63	1	13	10
Rb	171.36	181.5	61.97	15	258	22
Sr	117.59	101.5	65.64	43	370	22
Pb	40	33	39.66	7	154	11
Th	41.82	41	4.07	36	49	11
U	5.77	5.5	1.03	4.5	7.5	11
Zr	881.27	915.5	231.07	560	1329	22
Nb	56.73	57.5	25.63	28	103	22
Y	135.59	119	44.46	77	249	22
La	126.09	114	29.78	93	178	11
Ce	238.25	217.5	56	162	385	20
Pr	27.55	22	8.93	18	43	11
Nd	116.82	106	35.51	69	200	17
Sc	5.81	6	2.34	1	12	22
V	4.92	4	6.46		24	13
Cr	3.53	3	3.44		13	17
Mn	542.3	545.5	242.54	153	862	10
Ni	3	2	4.07		13	13
Cu	13.23	13	8.23		30	11
Zn	110.82	108	57.46	6	234	11
Sn	12	12	4.2	6	17	11
Mo	1.18		0.6		3	11
Ga	28	26	9.38	16	40	11
As	1.5	1.5	0.63	1	3	11
S	118.18	100	69.83	30	200	11
Be	5.45	5	1.92	3	9	11
Ag	1.55	1	0.82	1	3	11
Bi	1.18		0.6		3	11
Hf	22.36	21	5.39	15	34	11
Ta	1.18		0.6		3	11
Cs	13.8	14	2.59	10	17	5
Ge	1.73	1.5	0.47	1	2.5	11
Se	0.55		0.15		1	11

Undifferentiated Bentley

MEANS AND STANDARD DEVIATIONS

Element	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Items
SiO2	64.7	67.11	10.26	53.45	73.54	3
TiO2	1.22	1	1.01	0.33	2.32	3
Al2O3	12.98	12.8	0.36	12.75	13.39	3
Fe2O3	4.28	3.09	2.17	2.97	6.78	3
FeO	9.43	9.43	-	9.43	9.43	1
MnO	0.11	0.12	0.05	0.05	0.15	3
MgO	1.51	0.95	1.53	0.34	3.25	3
CaO	3.22	2.62	2.47	1.1	5.93	3
Na2O	3.75	3.72	0.12	3.65	3.89	3
K2O	3.64	4.5	1.83	1.54	4.89	3
P2O5	0.25	0.3	0.18	0.05	0.39	3
LOI	1.28	0.8	1.14	0.45	2.58	3
Ba	702	745	200.98	483	878	3
Li	4	4	-	4	4	1
Rb	173.33	208	74.33	88	224	3
Sr	124.67	97	76.36	66	211	3
Pb	8	8	-	8	8	1
Th	14	14	-	14	14	1
U	1.5	1.5	-	1.5	1.5	1
Zr	440.33	416	69.76	386	519	3
Nb	56.33	68	23.76	29	72	3
Y	111.67	117	44.24	65	153	3
La	40	40	-	40	40	1
Ce	161.5	161.5	118.09	78	245	2
Pr	11	11	-	11	11	1
Nd	78.5	78.5	51.62	42	115	2
Sc	14	13	11.53	3	26	3
V	247	247	-	247	247	1
Cr	32.5	32.5	37.48	6	59	2
Mn	1336	1336	-	1336	1336	1
Ni	41	41	-	41	41	1
Cu	193	193	-	193	193	1
Zn	144	144	-	144	144	1
Sn	3	3	-	3	3	1
Mo	1		-			1
Ga	23	23	-	23	23	1
As	2	2	-	2	2	1
S	10	10	-	10	10	1
Be	4	4	-	4	4	1
Ag	2	2	-	2	2	1
Bi	1		-			1
Hf	9	9	-	9	9	1
Ta	1		-			1
Cs	10	10	-	10	10	1
Ge	1	1	-	1	1	1
Se	0.5		-			1

Thomas Rhyolite

MEANS AND STANDARD DEVIATIONS

Element	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Items
SiO2	71.75	71.33	0.93	71.1	72.81	3
TiO2	0.37	0.33	0.06	0.33	0.44	3
Al2O3	12.68	12.47	0.38	12.46	13.12	3
Fe2O3	4.33	4.43	0.18	4.13	4.44	3
FeO	-	-	-	-	-	-
MnO	0.1	0.09	0.04	0.07	0.14	3
MgO	0.23	0.2	0.12	0.12	0.36	3
CaO	1.15	0.84	0.58	0.79	1.81	3
Na2O	3.43	3.53	0.61	2.77	3.98	3
K2O	5.56	5.54	0.24	5.33	5.81	3
P2O5	0.06	0.06	0.03	0.03	0.08	3
LOI	0.6	0.54	0.28	0.35	0.91	3
Ba	1466.67	1470	195.02	1270	1660	3
Li	-	-	-	-	-	-
Rb	219	230	41.61	173	254	3
Sr	124.33	135	68.62	51	187	3
Pb	-	-	-	-	-	-
Th	-	-	-	-	-	-
U	-	-	-	-	-	-
Zr	851	837	25.12	836	880	3
Nb	98.67	97	2.89	97	102	3
Y	170.33	165	17.62	156	190	3
La	-	-	-	-	-	-
Ce	285.67	291	14.74	269	297	3
Pr	-	-	-	-	-	-
Nd	135.33	135	2.52	133	138	3
Sc	5.5	5	1.32	4.5	7	3
V	-	-	-	-	-	-
Cr	-	-	-	-	-	-
Mn	-	-	-	-	-	-
Ni	-	-	-	-	-	-
Cu	-	-	-	-	-	-
Zn	-	-	-	-	-	-
Sn	-	-	-	-	-	-
Mo	-	-	-	-	-	-
Ga	-	-	-	-	-	-
As	-	-	-	-	-	-
S	-	-	-	-	-	-
Be	-	-	-	-	-	-
Ag	-	-	-	-	-	-
Bi	-	-	-	-	-	-
Hf	-	-	-	-	-	-
Ta	-	-	-	-	-	-
Cs	-	-	-	-	-	-
Ge	-	-	-	-	-	-
Se	-	-	-	-	-	-

Giles Complex

MEANS AND STANDARD DEVIATIONS

Element	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Items
SiO2	59.43	50.26	14.49	48.09	75.4	5
TiO2	0.38	0.44	0.32	0.05	0.82	5
Al2O3	19.86	22.63	6.89	12.04	27.2	5
Fe2O3	0.85	0.81	0.64	0.19	1.5	5
FeO	2.64	1.77	2.5	0.34	6	5
MnO	0.04	0.03	0.03	0.01	0.09	5
MgO	2.48	1.65	2.36	0.16	5.15	5
CaO	7.26	11.25	5.97	0.42	12.28	5
Na2O	3.14	2.96	0.73	2.14	3.94	5
K2O	2.27	0.26	2.93	0.12	6.48	5
P2O5	0.03	0.02	0.03	0.01	0.07	5
LOI	0.68	0.58	0.22	0.53	1.07	5
Ba	357.2	95	599.81	77	1430	5
Li	6	6	1.58	4	8	5
Rb	77	3	106.25	1	228	5
Sr	290.6	372	192.96	33	499	5
Pb	26.4	2	34.33		65	5
Th	31		56.57		131	5
U	0.6	50	0.78	50	2	5
Zr	39	42	14.51	17	52	5
Nb	3.8	4	3.27		9	5
Y	7.4	7	2.97	4	12	5
La	17.6	5	29.34	3	70	5
Ce	28.1	7	47.56		113	5
Pr	2.4		3.13		8	5
Nd	10.2	4	14.45	3	36	5
Sc	9.5	13	8.19		18	5
V	62.8	88	49.62		114	5
Cr	92.3	31	119.29		273	5
Mn	360.4	316	279.56	64	720	5
Ni	69	39	71.9	3	156	5
Cu	29.8	20	30.07	1	74	5
Zn	32.2	26	19.54	11	57	5
Sn	1.8		1.3		4	5
Mo	2.8	3	1.79		5	5
Ga	23.6	25	6.39	13	29	5
As	0.7	0.5	0.54	50	1.5	5
S	70	d	27.39	d	100	5
Be	1.25	1	0.5	1	2	4
Ag	2	2	1	1	3	5
Bi	1		-			5
Hf	1.6		0.89		3	5
Ta	1.2		0.45		2	5
Cs	2.13		1.25		4	4
Ge	2	1.5	1.17	1	3.5	5
Se	0.9		0.65		2	5