Appendix 2:

Systematic Geochemistry

Part 1: Layout and Nomenclature

INTRODUCTION

The discussion below outlines the present geochemical investigation of the Boggabri Volcanics, and presents a systematic account of their major and trace element geochemistry. This account is illustrated by an extensive suite of diagrams, which compare Boggabri Volcanics with various major geochemical reservoirs, reference compositions and suites of igneous rocks from the region around Boggabri. This broad range of diagrams has been prepared as a basis for assessing the compositional range, source composition, evolutionary trends and geological setting of the Boggabri Volcanics.

DATA PRESENTATION

Tables A1.1, A1.2 and A1.3 in Appendix 1 summarises the major and trace element data for forty five analysed rocks from Boggabri.

Select and Altered Analyses

Of the forty five analysed samples, forty two are from the Boggabri Volcanics. These are divided herein for convenience of discussion into a **select** group ($SFBR_{04}$, SED_{05}, SED_{06}, $SLPR_{08}$, SFA_{09}, SOA_{10}, SOB_{12}, $SLPR_{13}$, SAD_{24}, $SFBR_{25}$, $SLPR_{29}$, SPB_{39}) and a more **altered** group (#1–3, #7, #11, #14–20, #22, #26, #28, #30–38, #40–45). All rhyolitic pitchstones are included in the first group.

Three samples (#21, #23 and #27) are from unassigned volcanic rocks and are discussed separately.

Acronyms

Table A2.1 lists various acronyms used herein.

Diagram Groups

Data for the Boggabri Volcanics are presented below in four groups of diagrams. These groups comprise:

- volatiles;
- variation indices (Si and Cr);
- major elements (Al, Fe, Mg, Ca, Na, K, Ti, P, Mn); and
- trace elements (Ba, Ce, Cu, Cs, Ga, Hf, Nb, Ni, Pb, Rb, Sc, Sr, Th, Ta, V, Y, Zn and Zr).

Diagram Types

The various diagrams presented below comprises:

- histograms, which show the range of each major and trace element;
- relative abundance plots, which show for the range of BV select compositions in order from more mafic to more felsic relative to certain reference compositions for each major and trace element; and
- bivariate diagrams of major and trace elements (plotted against SiO_2 or Cr) which show:
    - * the compositional range of select and altered Boggabri Volcanics;
    - * the Boggabri Volcanics range compared to certain geochemical reservoirs and compositions; and
    - * the Boggabri Volcanics range compared to certain regional igneous suites.

The reference compositions used for the abundance plots are (see Table A2.2): pyrolite (Sun and McDonough, 1989), Primitive MORB (W. McDonough pers. comm., 1996), E-MORB and OIB (McDonough and Sun, 1995), Average Continental Crust (Taylor and McLennan, 1985), Fuji basalt (an indicative arc basalt composition — Sample 85-10-8-4 of Arculus, Gust and Kushiro, 1991), Rindjani basalt (an unusual arc composition chosen for its similarity to SOB_{12} in Cr, Al_2O_3, and P_2O_5 — Sample RINDJ2 of S.M. Eggins, unpublished database, 1997) and Mole Granite (a highly evolved Triassic I-type granitoid of the NEO — Chappell and Bryant, 1994). These compositions are also used to also identify complementary relationships amongst potential source compositions, i.e. pairs of reference compositions that are respectively enriched and depleted compared to the BV mafic rocks and therefore could be mixed to produce the latter.

The geochemical reservoirs and reference compositions used are the representative Arc, Continental (CFB and CRZ) and Oceanic (OFB and OIB) volcanic suites from the Basalt Volcanic Study Project (BVSP, 1981) plus Permian M-type (Clarence River) and I-type (Moonbi and Uralla Plutonic Suites) granitoids from the NEO (Chappell and Bryant, 1994).

The regional igneous suites used are:

- Early Permian volcanic rocks including:
  - the Werrie Basalt from the western margin of the NEO (Vickers, 1991);
  - the Early Permian Halls Peak volcanics (Moody, 1991) from the eastern Nambucca Block; and
  - the Petroi Metabasalt member (Asthana and Leitch, 1985), from the Nambucca Block;
- Permo-Carboniferous intrusives from the central NEO, including:
  - S-type granitoids of the latest Carboniferous Hillgrove Plutonic Suite (Chappell and Bryant, 1994);
  - S-type granitoids of the Early Permian Copeton Plutonic Suite (Chappell and Bryant, 1994), which forms part of the Bundarra Plutonic Suite of other authors; and
  - Early Permian mafic complexes associated with the Hillgrove Plutonic Suite in the central NEO (Chappell and Bryant, 1984);
- Late Carboniferous volcanic rocks and sills from the western NEO:
  - Rhyolitic ignimbrites (McPhie, 1984a), with highlighted average compositions for rhyolitic vitrophyre from Piallaway ignimbrite, and average low-silica and high-silica rhyolitic vitrophyres from Taggarts Mountain Ignimbrite Member;
  - Andesites and rhyolites (Wilkinson, 1971); and
  - Andesitic sills (Dawson, 1992);
- Tertiary and other volcanic rocks:
  - Tertiary volcanic rocks from the Nandewar province (Stolz, 1983); and
  - Unassigned volcanic rocks from Boggabri (this study).

Symbol identification

Fig. A2.1 summarises the various symbols and overprints used in the above diagrams to identify different compositions within the olivine basalt — rhyolite compositional range, different alteration styles and different geochemical reservoirs and reference compositions. Generally, solid symbols designate select BV samples, whereas open symbols indicate more altered BV samples.

Trends

Several **apparent trends** are evident amongst select BV analyses and are also shown on the bivariate plots as a frame of reference and for subsequent evaluation of any evolutionary significance. These are referred to as the 'Main Trend', 'Cross Trend 1', 'Cross Trend 2' and the 'Dyke Trend'.

The 'Main Trend' has two limits and comprises three contiguous segments separated by two inflections:

- a '**Mafic Segment**' projecting through SOB_{12} (245 ppm Cr) and SPB_{39} (123 ppm Cr) to an inferred inflection at 18 ppm Cr;
- an '**Intermediate Segment**' comprising a line projecting from the above inflection through the average of SFA_{09} and SED_{05} to an inferred inflection at the junction with the 'Intermediate Segment';
- an '**Intermediate Segment**' comprising a line projecting from $SLPR_{08}$ (rhyolite pitchstone with the least Zr) through the above inflection towards $SLPR_{13}$ (vitrophyre) and the rhyolite with the most Zr);
- an inferred '**Mafic Inflection**' separating the Mafic Segment and the Intermediate Segment;
- an inferred '**Felsic Inflection**' separating the Intermediate and Felsic Segments;
- a '**Mafic Limit**' representing the high-Cr end of the Mafic Segment, and a Felsic Limit representing the low-Zr end of the Intermediate Segment;
- '**Cross Trend 1**' is defined as a line joining SOB_{12} and the average of SFA_{09} and SED_{05};
- '**Cross Trend 2**' is defined as a line joining SPB_{39} and the average of SFA_{09} and SED_{05}; and
- The '**Dyke Trend**' is defined as the line joining SAD_{24} (vitrophyre from a dyke), to the Main Trend at a silica value equivalent to SED_{05}.

These trends are used throughout for consistency and to provide a frame of reference. However, use of linear projections above in defining the Main Trend is very simplistic because fractionation tends tend to be exponential at very low concentrations, e.g. summary in Rollinson (1993). Currently, there are too few data to attempt to define exponential fractionation trends, and therefore linear trends are used despite their obvious limitations. Problems are most evident amongst highly compatible trace elements such as Ni which project to unrealistically negative values at the Mafic Inflection, or to elements such as Ti, Ca, Mg and Fe which project to low or negative values at the Felsic Inflection. Those parts of trends that lie on the felsic side of any such negative projection have no physical meaning.

Radial Dispersal

Radial dispersal is also indicated on certain bivariate plots involving 'immobile elements' (e.g. TiO_2 v Cr, Al_2O_3 v Cr). This parameter is defined along a radial line projecting from to the origin to a data point and is calculated as the radial distance from the data point to the intersection of the radial line with a trend line expressed as a percentage of the distance from that intersection to the origin (see Stumpfl and Finlow-Bates, 1981; MacLean, 1992 for the underlying concept). Dispersal away from the origin is defined herein as positive (apparent concentration) and towards to origin is negative (apparent dilution).

Table A2.1: Acronyms

ACC	Average Continental Crust
ArcF	Fuji Volcano, Fuji Arc Japan
ArcR	Rindjani Volcano, Lombok, Indonesian Arc
BAB	Back Arc Basalt
BV	Boggabri Volcanics
CAB	Calc-Alkaline Basalt
CFB	Continental Flood Basalts
CRZ	Continental Rift Zone
eM	E-MORB
IAT	Island Arc Tholeiite
IAV	Island Arc Volcanic
LKT	Low-K Tholeiite
mg	Mole Granite
MORB	Mid Ocean Ridge Basalt
NM	Hawaiian Nephelinite Melilitite
OFB	Ocean Floor Basalt
OIA	Ocean Island Alkaline
OIP	Ocean Intraplate
OIT	Ocean Island Tholeiite
pM	Primitive MORB
pyr	Pyrolite
syn-COLG	Syn-Collision
UV	Unassigned volcanic rocks from Boggabri
VAB	Volcanic Arc Basalt
VAG	Volcanic Arc Granite
WP	Within Plate
WPB	Within Plate Basalt
IA & CM	Island Arc and Continental Margin
SCI	Spreading Centre Island
PM	Plate Margin
ACM	Active Continental Margin

Table A2.2: Comparative Analyses

Reference	Rock*	Cs ppm	Rb ppm	Ba ppm	Th ppm	Nb ppm	K_2O %	La ppm	Ce ppm	Pb ppm	Sr ppm	P_2O_5 %	Nd ppm	Na_2O %	Zr ppm	Hf ppm	Sm ppm	Eu ppm
McDonough and Sun (1995)	C1	0.19	2.30	2.41	0.03	0.24	0.07	0.24	0.61	2.47	7.25	0.247	0.457	0.687	3.82	0.103	0.148	0.056
McDonough and Sun (1995)	pyr	0.02	0.60	6.60	0.08	0.66	0.03	0.65	1.68	0.15	19.90	0.021	1.25	0.36	10.50	0.283	0.406	0.154
W. McDonough (pers. comm., 1996)	pM	0.01	0.56	6.30	0.12	2.33	0.07	2.50	7.50	0.30	90	0.12	7.30	2.30	74	2.05	2.63	1.02
Sun and McDonough (1989)	eM	0.06	5.04	57.00	0.60	8.30	0.25	6.30	15	0.60	155	0.142	9		73	2.03	2.60	0.91
Sun and McDonough (1989)	OIB	0.39	31	350	4	48	1.45	37	80	3.20	660	0.619	38.50		280	7.80	10	3
Clague and Frey (1982)	NM	0.80	36	1065	10.10	51	1.29	84	163	6.30	1640	1.24	66	4.82	169	3.60	15	4.53
Arculus, Gust and Kushiro (1991)^	ArcF		17	263	1.39	3.30	0.93	10.15	25.21	6.89	391	0.39	18.84	2.8	115.90	3.23	5.04	1.43
S.M. Eggins (database)#	ArcR	0.23	22	441	6.83	5	1.27	12.60	30.20		497	0.26	17.30	3.02	73	4	4.50	1.30
Taylor and McLennan (1985)	ACC	1	32	250	3.50	11	1.10	16	33	8	260		16	3.10	100	3	3.50	1.10
Chappell and Bryant (1994)	mg		575	51.11	48.9	15	4.97	37.12	100	35.19	13.94	0.03		3.30	122.10			
Pearce and Parkinson (1993)	FMM					0.2									9.20			
McPhie (1984)	Pvt		133	1394	13.33	6.67	2.33			18.67	547.67	0.11		4.34	162.33			
McPhie (1984)	Tmv		215	648	20.50	8.50	3.46			22.50	242.50	0.045		4.01	132			
McPhie (1984)	Tfv		184	542	22.67	7	2.33			26.67	273.67	0.017		4.03	107			

Reference	Rock*	TiO_2 %	Tb ppm	Y ppm	Yb ppm	Lu ppm	Al_2O_3 %	Ga ppm	V ppm	CaO %	Sc ppm	Mn ppm	Fe_2O_3t %	MgO %	Cr ppm	Ni ppm	SiO_2 %
McDonough and Sun (1995)	C1	0.073	0.036	1.57	0.161	0.025	1.625	9.20	56	1.294	5.92	1920	25.84	16	2650	10500	22.78
McDonough and Sun (1995)	pyr	0.201	0.099	4.30	0.441	0.068	4.44	4	82	3.54	16.2	1045	8.94	37.81	2625	1960	44.93
W. McDonough (pers. comm., 1996)	pM	1.27	0.67	28	3.05	0.455	15.30	15.50	290	12.60	43	1200	9.32	10	450	285	49
Sun and McDonough (1989)	eM	1	0.53	22	2.37	0.354											
Sun and McDonough (1989)	OIB	2.87	1.05	29	2.16	0.30											
Clague and Frey (1982)	NM	2.58	1.65	30	1.90	0.28	10.93	17.50	240	12.71	26	1936	14.75	13.54	505	275	37.47
Arculus, Gust and Kushiro (1991)^	ArcF	1.59	0.85	31.55	2.86	0.43	16.21	18	334	9.24	34	1376	12.25	5.64	83	49	50.77
S.M. Eggins (database)*	ArcR	1.29		21	2		18.12		313	10.49	33	1564	8.73	6.66	259	76	49.96
Taylor and McLennan (1985)	ACC	0.90	0.60	20	2.20	0.30	15.90	18	230	7.40	30	1400	10.11	5.30	185	105	57.30
Chappell and Bryant (1994)	mg	0.10		88.83			12.39	20.95	3.04	0.38	7.1	222	1.20	0.1	1.59	1.52	77.36
Pearce and Parkinson (1993)	FMM	0.175		3.90	0.42		3.75	4	78	3.25	15.50	1007	9.77	38.40	2500	2020	
McPhie (1984)	Pvt	0.38		22			14.89	17	25	2.30		361	2.11	0.54	8.67		72.96
McPhie (1984)	Tmv	0.21		31			14.59	17.50	9.50	2.025		465	1.67	0.37	9		73.56
McPhie (1984)	Tfv	0.12		24			12.84	14.67		1.35		310	0.98	0.16	8.33		78.13

* See Table A2.1 for key   Note: Total Fe as Fe_2O_3t ^ = Sample 85-10-8-4   # = Sample RINDJ2

Symbol Definitions

Select Boggabri analyses

- ■ Olivine basalt (SOB$_{12}$)
- ● Olivine-poor basalt (SPB$_{39}$)
- ◆ Olivine-free andesite (SOA$_{10}$)
- ▶ Olivine andesite (SFA$_{09}$)
- ✳ Augite dacite (SAD$_{24}$)
- ◀ Enstatite dacite (SED$_{05}$)
- ▼ Biotite rhyolite lava (SFBR$_{04}$)
- ▲ Pyroxene rhyolite lava (SLPR$_{06}$, SLPR$_{08}$, SLPR$_{29}$)
- ◈ Biotite rhyolite ignimbrite (SFBR$_{25}$)
- ◈ Pyroxene rhyolite ignimbrite (SFBR$_{13}$)

Trend lines

- ---------- Main Trend
- ·········· Cross Trends 1 and 2
- ·········· Dyke Trend

Altered Boggabri rocks

- □ Olivine basalt (#14, #41)
- ○ Basalt (#11, #33, #38, #43, #44, #45)
- ◇ Basaltic andesite (#03)
- ▷ Andesite (#15, #20, #42)
- ◁ Dacite (#07, #16, #17, #18, #19, #26, #30, #35, #36, #40)
- ▽ Biotite rhyolite (#32)
- △ Pyroxene rhyolite #01, #02, #22, #28, #29, #31, #34, #37)

Alteration styles

- ○ Pitchstones (SFBR$_{04}$, SMPR$_{06}$, SLPR$_{08}$, SFBR$_{25}$, SLPR$_{29}$)
- ✕ Carbonated (#03, #07, #11, #44)
- · Al-rich (#33, #40)
- ◇ White rhyolite #28, #32, #34, #37)
- □ Silicified (01, #02, #18, #22, #30, #31, #43, #45)

Abundance diagrams

- · -——— Pyrolite
- ——— Primitive MORB
- - - - - E-MORB
- · · · · OIB
- ·········· Average Continental Crust
- · · · · · Mole Granite
- -·-·-·- Hawaiian Nepheline Melilitite
- - · -◈- · - Select Fuji basalt
- - - -⊕- · - Select Rindjani basalt

Note: ob = olivine basalt, bs = basalt; oa = olivine andesite; an = andesite; ad = augite dacite; ed = enstatite dacite; mrp = melanocratic pyroxene rhyolite; lrp = leucocratic pyroxene rhyolite; rb = biotite rhyolite; * = ignimbrite

Fig. A2.1: Symbols used on diagrams

Symbol Definitions (c'td)

BVSP and Granitoid Reference

- BVSP Reference Arc basalts
- BVSP Reference CRZ basalts
- BVSP Reference CFB basalts
- BVSP Reference OFB basalts
- BVSP Reference OIP basalts
- M-type granitoids (Clarence River Plutonic Suite)
- I-type granitoids (Moonbi Plutonic Suite)
- I-type granitoids (Uralla Plutonic Suite)
- Average Continental Crust
- Mole Granite
- Primitive MORB-Hawaiian Nepheline Melilitite mixing line
- Primitive MORB
- Hawaiian Nepheline Melilitite

Regional Reference

- Werrie Basalt
- Halls Peak volcanics
- Petroi Metabasalt
- Copeton Plutonic Suite
- Hillgrove Plutonic Suite
- Central NEO mafic complexes
- Late Carboniferous volcanics
- Late Carboniferous rhyolites
- Late Carboniferous sills
- Piallaway rhyolite vitrophyre
- Taggarts Mountain low-Si rhyolite vitrophyre
- Taggarts Mountain high-Si rhyolite vitrophyre
- Tertiary volcanics
- Unassigned volcanics from Boggabri

Common overprint

- Main Trend
- Cross Trends
- Select BV
- Altered BV

Fig. A2.1 (cont.): Symbols used on diagrams

Part 2: Volatiles

Volatiles are considered first because analyses are converted to anhydrous basis for interpretation and because the IUGS classification requires special diligence in any application to rocks with > 2% H_2O+ or > 0.5% CO_2 (LeMaitre et al., 1989).

LOI for BV range from 0.46% up to 8.94% (Fig. A2.2a). The distribution is distinctly bimodal, with no values between 5 and 6%. Select basalts, andesites and dacites range from 2 to 4 %, whereas select rhyolites range from 6 to 8% (Fig. A2.2b). In contrast, altered BV (Fig. A2.2c) are highest among carbonated basalts (7 to 9%) and are generally lowest among white rhyolites (0 to 2%). Silicified rocks are highly variable, especially among rhyolites, where the range is 0.46 to 7.6%.

The high water content in most select rhyolites warrants their labelling as 'pitchstones' (cf Johannsen, 1932).

Loss On Ignition

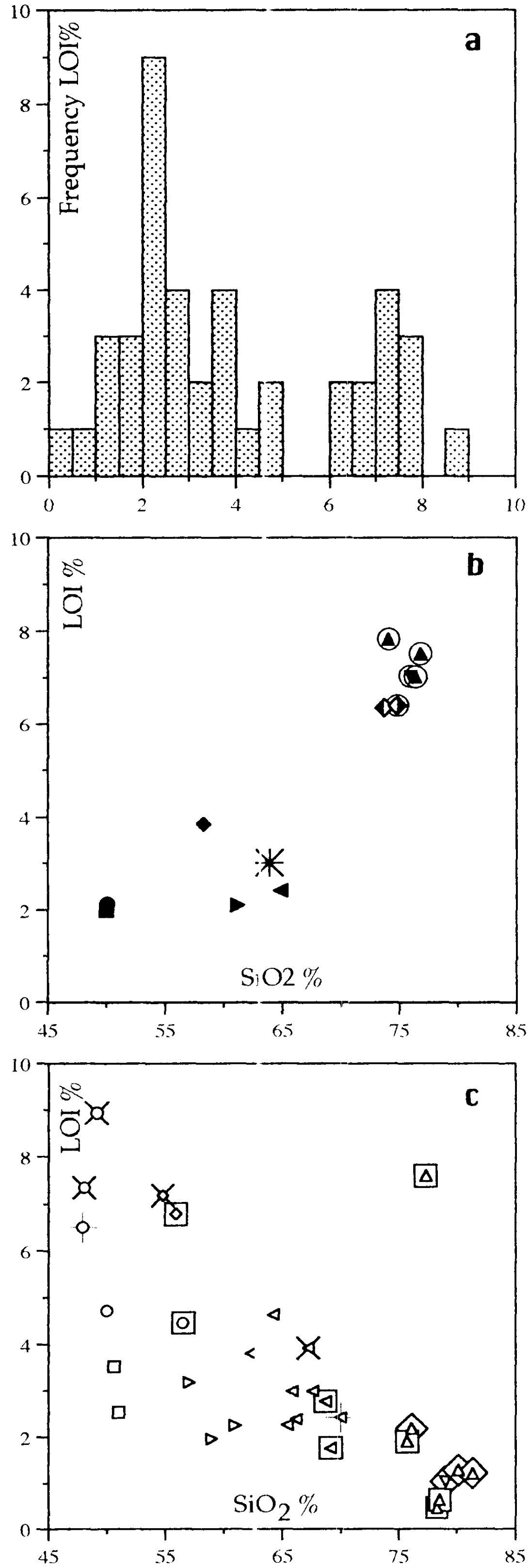

Fig. A2.2 (a–c): Loss on Ignition in Boggabri Volcanics

Part 3: Variation Indices

SiO_2 and Cr are used as variation indices in bivariate plots. The choice of silica follows established practice (e.g. IUGS classification — LeMaitre et al., 1989). Mg, the other element commonly used as a reference in mafic rocks (Wright, 1974), in not used here due to possible effects of alteration. Cr is used instead as a relatively immobile proxy for Mg.

Silica

Silica ranges from to 47.92% to 81.36% (Fig. A2.3a). Select rocks are restricted to the range 50% (SOB_{12} and SPB_{39}) to 73.7% ($SLPR_{13}$) and to 76.8%, including pitchstones ($SFBR_{04}$, $SMPR_{06}$, $SLPR_{08}$, $SFBR_{25}$ and $SLPR_{29}$). This range is within that of common igneous rocks (Si-rich basalt to high-silica rhyolite — cf Wedepohl, 1978). The overall silica range (all analyses) shows notable concentrations in the range ≈ 48 to 51%, ≈ 54 to 70% and 75 to 82%. The three modes correspond approximately (allowing for some alteration) to olivine basalt-basalt basaltic andesite-dacite and rhyolite respectively in the IUGS classification (LeMaitre et al., 1989). This distribution is crudely trimodal and lacks an obvious 'Daly gap' (cf Chayes, 1963). The three samples with < 49.9 % SiO_2 are altered basalt and are either carbonated (#11, #44) or zeolitic (#33). Similarly, rocks in or above the range of high-silica rhyolite (75–77.5% — Mahood and Hildreth, 1983) are strongly altered ('white' rhyolites and silicified rhyolites).

SiO_2 in SOB_{12} and SPB_{39} is depleted relative to Average Continental Crust (0.87x), Fuji basalt (0.98x), but is equal to Rindjani basalt, marginally enriched relative to Primitive MORB (1.02x) and pyrolite (1.11 x), and significantly enriched relative to Hawaiian Nepheline Melilitite (1.33x). Silica abundances patterns (Fig. A2.3c) show a gentle, systematic increase across the BV range to about 1.6x SOB_{12}, marked by a jump from basalt to andesite and another from dacite to rhyolite. The rhyolites show an almost linear increase across the range, with $SLPR_{29}$ and $SLPR_{08}$ have the highest SiO_2 contents. Overall, select BV are enriched relative to Hawaiian Nepheline Melilitite, Primitive MORB, and Rindjani basalt (subequal for basalts). All compositions except basalts are enriched compared to Fuji basalt and Average Continental Crust. All compositions are depleted relative to Mole Granite, although the most felsic rhyolites are sub-equal to Mole Granite. For SOB_{12}, Primitive MORB is complementary to Mole Granite and Average Continental Crust. SOB_{12} is also enriched in silica compared with OIB and E-MORB (Wilson, 1989).

In summary, select rocks display a crudely trimodal silica distribution and a range from silica-rich basalt (≈ 50%) to high-silica rhyolite (≈ 76.8%), i.e. overall enrichment of 1.6x from slightly above Primitive MORB to slightly below Mole Granite. Select andesites, dacites and rhyolites together span the virtually the whole BV silica range, whereas select basalts represent only a fraction of the range. The silica range of select BV and the abundance of rhyolites together distinguish BV from most type and regional comparative data sets (except some alkalic basalts have significantly lower silica). Altered rocks display a slightly greater silica range than select rocks, especially among white and silicified rhyolites.

Chromium

Cr ranges from 245 ppm to 1 ppm (Fig. A2.3b). The BV range is within that of common igneous rocks (typically x00 ppm, less commonly x0 ppm — Wedepohl, 1978). The great majority of BV values, including most andesites, dacites and rhyolites are below 20 ppm. Only basalts and olivine basalt contain more than 100 ppm Cr.

SOB_{12} is depleted relative to pyrolite (≈ 0.09x), Hawaiian Nepheline Melilitite (0.48x), Primitive MORB (≈ 0.54x), and Rindjani basalt (0.95x) but is enriched relative to Average Continental Crust (≈ 1.3x), and Fuji basalt (2.95x). Cr abundance patterns (Fig. A2.3d) show a systematic, decrease across the BV range to about 0.01x SOB_{12} in the most felsic rhyolite, marked by a small step down from SOA_{10} to SFA_{09} and by a significant peak at $SFBR_{25}$ (an ignimbrite), and a trough at $SFBR_{04}$. Overall, select BV are depleted relative to Hawaiian Nepheline Melilitite and Primitive MORB, most (except SOB_{12}) are depleted relative to Rindjani basalt and Average Continental Crust, all except basalts are depleted relative to Fuji basalt, but all are enriched relative to Mole Granite. For SOB_{12}, Primitive MORB are complementary to Mole Granite and Average Continental Crust.

In summary, select BV exhibit about a hundred-fold decrease in Cr from SOB_{12} to high-silica rhyolite with most of the decrease being in the basalt range. SOB_{12} has less Cr than Primitive MORB (0.54x) but more than Mole Granite and Average Continental Crust. Cr values in select BV are generally lower at equivalent silica than those of most geological settings, except for some oceanic islands and some of continental affinity. Altered rocks do not display obvious Cr mobility, except for #01 (a silicified rhyolite) which has anomalously high Cr.

Cr v SiO_2

On **Cr v SiO_2** (Fig. A2.3e), the Main Trend shows a steep, nearly vertical Mafic Segment characterised by virtually constant SiO_2 (50%) over a Cr range of 250 ppm to 18 ppm (inferred Mafic Inflection) and nearly horizontal, essentially colinear Intermediate and Felsic Segments characterised by low Cr (< 20 ppm) over a silica range of 54.77 to 76.8%. SOA_{10} plots close to Cross Trend 2. SFA_{09}, SED_{05} and SAD_{24} plot along the Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites cluster at the end of the felsic trend. Most altered samples (Fig. A2.3f) lie along or close to the Main Trend except for a silicified basalt (#43), a silicified basaltic andesite (#45), a carbonated basaltic andesite (#03) and one silicified rhyolite (#01). The silicified basalt and basaltic andesite plot along Cross Trend 1 and contain about 6% more silica than their Main Trend equivalents based on Cr content and mineralogy. The carbonated basaltic andesite plots close to Cross Trend 2. The silicified rhyolite contains about 10x the Cr content (34 ppm) of the Intermediate Segment equivalent.

Cr v SiO_2 (Fig. A2.3g–m) shows that the BV range largely overlaps that of the BVSP Reference CRZ basalts (although some of the latter have higher Cr at intermediate Si) and select M-type granitoids, whereas higher Cr generally distinguishes select I-type granitoids. The Mafic Segment partly overlaps the BVSP Reference Arc basalt and Continental Flood Basalt data, but the latter ranges to about twice the Cr content. Similarly the Mafic Segment only overlaps lower extreme of the range of BVSP Reference Oceanic basalts. Regional comparisons show that the BV range largely overlaps that of the ranges of the Werrie Basalt, Halls Peak volcanics, most Late Carboniferous volcanic rocks and unassigned volcanic rocks from Boggabri. There is also partial overlap of the Hillgrove and Copeton granitoid ranges, but the former especially exhibits a tendency to higher Cr among mafic granitoids. However, higher Cr distinguishes most Early Permian central NEO mafic complexes. Tertiary volcanic rocks largely follow the Main Trend, apart from a lower Si at similar Cr among basalts.

In summary, **Cr v SiO_2** contrasts Cr depletion at nearly constant SiO_2 in the Mafic Segment with SiO_2 depletion and slight Cr depletion in the intermediate trend. It also distinguishes BV rocks by limited Cr range among basalts compared to BVSP reference Arc, CFB and Oceanic rocks, among mafic to intermediate rocks compared to Early Permian central NEO mafic complexes and among dacites compared to select I-type granitoids.

Variation Indices

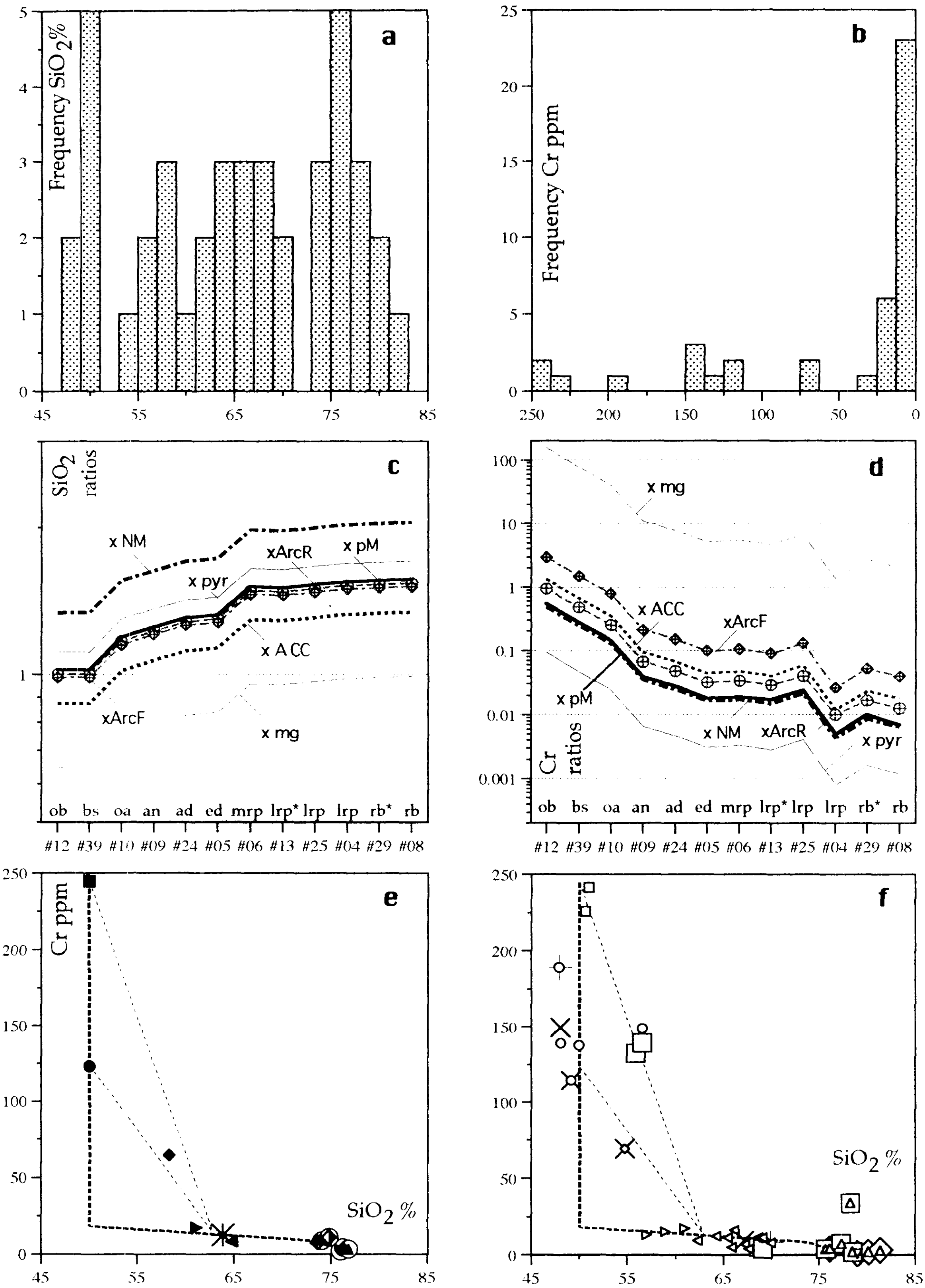

Fig. A2.3 (a–f): Variation Indicies in Boggabri Volcanics

Variation Indices (cont.)

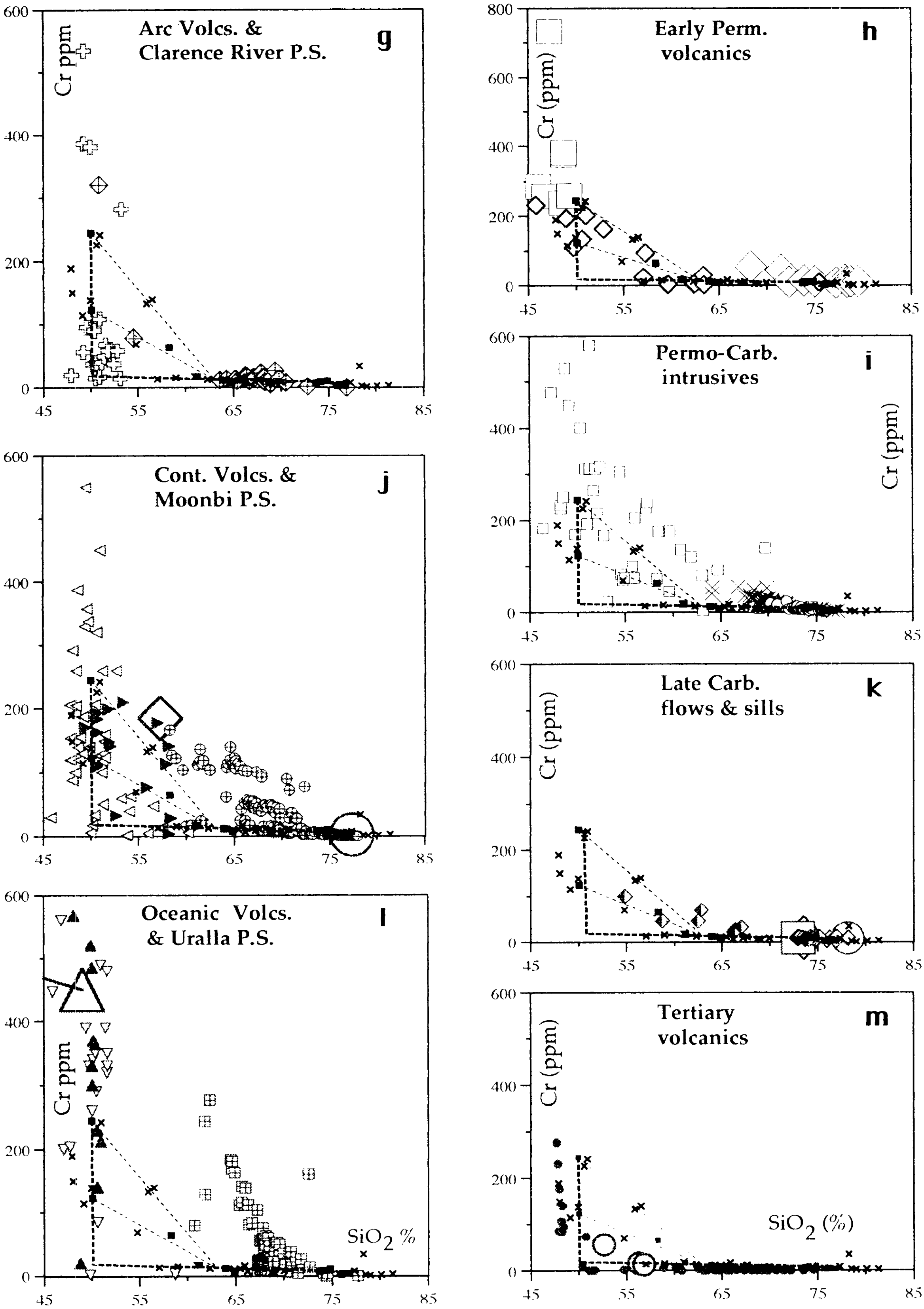

Fig. A2.3 (g–m): Variation Indicies in Boggabri Volcanics

Part 4:
Other Major Elements

Alumina

Al_2O_3 ranges from 20.5 % to 11.3% with the distribution symmetrical around a median value of 16.3% (Fig. A2.4a). There is a notable gap among low-Si rhyolites and a less obvious one between basalts and andesites. Select rocks range from 18% (SOB_{12}) to 15% ($SLPR_{13}$), extending to 13.6% including the rhyolitic pitchstones. The BV range is within that of common igneous rocks (typically 5% to 24% and up to 26% in anorthosites — Wedepohl, 1978). BV basalts contain >17% Al_2O_3 and therefore warrant the label 'high-alumina' (criterion of LeMaitre et al., 1989, rather than Kuno, 1966, which relates to aphyric compositions).

Al_2O_3 in SOB_{12} is enriched 1.11x Fuji basalt, 1.12x Average Continental Crust, 1.17x Primitive MORB, 1.63x Hawaiian Nepheline Melilitite and 4x pyrolite, but depleted relative to Rindjani basalt (0.99x). Abundance patterns (Fig. A2.4b) exhibit a gradual depletion across the BV range from a slight peak at SPB_{39}, with select rhyolites typically being about 0.8x SOB_{12}. Only minor fluctuations affect this decline, the most notable being a small but significant depletion from the dacites to the rhyolites and a slight peak at $SLPR_{13}$ (ignimbrite). $SLPR_{29}$ and $SLPR_{08}$ have the lowest Al_2O_3 contents. Overall, all rocks are depleted relative to Rindjani basalts, but are enriched compared to Mole Granite and Hawaiian Nepheline Melilitite. Rhyolites are depleted compared to Primitive MORB, Fuji basalt and Average Continental Crust, but the basalt-dacite range is mostly enriched compared to other reference compositions except. For SOB_{12}, Rindjani basalt is subequal and there are no complementary relationships.

On **Al_2O_3 v SiO_2** (Fig. A2.4c), select rocks shows a Main Trend composed of a very short, vertical, positive-slope in the Mafic Segment, an inclined, negative slope in the Intermediate Segment and a short, more steeply negative slope in the Intermediate Segment. SOA_{10} plots slightly above the Main Trend and distinctly above Cross Trend 2. SFA_{09}, SED_{05} and SAD_{24} plots close to the Intermediate Segments and the Dyke Trend is indistinct. Select rhyolites cluster tightly along the Intermediate Segment. Altered rocks (Fig. A2.4e) show an overall decline from highest Al_2O_3 amongst basaltic rocks (20.45 %)

to lowest values amongst rhyolites (11.25%). Most plot within 2% Al_2O_3 of the Main Trend. There is a distinct gap in the rhyolite field. Those rocks with <13% Al_2O_3 (white and silicified rhyolites) also have highest silica content and form a distinct cluster along a trend projecting to 100% SiO_2.

Al_2O_3 v SiO_2 (Fig. A2.4g,i,k) shows that the BV mafic rocks overlap the mid range of BVSP Reference Arc basalts but have distinctly higher Al_2O_3 than BVSP Reference Oceanic and Continental basalts and Average Continental Crust, most I-type granitoids and Mole Granite. BV intermediate rocks have slightly lower Al_2O_3 than most select M-type granitoids, but significantly more Al_2O_3 than Primitive MORB and Hawaiian Nepheline Melilitite. Regional comparisons (Fig. A2.4m,o,q,s) show that the BV have similar Al_2O_3 contents at equivalent SiO_2 to the Werrie Basalt, the middle of the Petroi Metabasalt range, Late Carboniferous volcanic rocks, most Tertiary volcanic rocks (except basalts) and the unassigned volcanic rocks from Boggabri. However, they have slightly higher Al_2O_3 contents than most Hillgrove and Copeton Plutonic Suite granitoids, most Early Permian central NEO mafic complexes and the Halls Peak volcanic rocks.

On **Al_2O_3 v Cr** (Fig. A2.4d) the Main Trend shows a nearly flat Mafic Segment (at ≈ 18% Al_2O_3) and steep, negative, nearly colinear Intermediate and Felsic Segments (alumina range 18.2% to 13.8%). SOA_{10} plots beside Cross Trend 2. SFA_{09}, SED_{05} and SAD_{24} virtually coincide on the Intermediate Segments and the Dyke Trend is indistinct. S elect rhyolites cluster tightly along the Intermediate Segment. Numerous altered rocks (Fig. A2.4f) coincide with the Intermediate and Felsic Segments of the Main Trend. A few analyses coincide with the Mafic Segment, whereas most plot at higher Al_2O_3. These include the zeolitised basalt (#33) and carbonated basalts (#11 and #44) which have distinctly higher Al_2O_3 than the Mafic Segment of the Main Trend. Radial dispersal relative to the mafic trend is up to +34% (#33) but typically ≈ ±13% (other altered basalts). In addition, most white rhyolites and silicified basalts have distinctly lower Al_2O_3 than the felsic trend.

Al_2O_3 v Cr (Fig. A2.4h,j,l) largely distinguishes the BV from BVSP Reference Oceanic and Continental basalts (slight overlap with the latter), select I-type granitoids, Average Continental Crust, Primitive MORB and Hawaiian Nepheline Melilitite. The BV overlap the lower Cr range of BVSP Reference Arc basalts and overlaps the range of select M-type granitoids. Mole Granite plots on the projection of the Intermediate Segment to lower Al_2O_3. Regional comparisons (Fig. A2.4n,p,r,t) indicate similarity to the Werrie Basalt and Late Carboniferous volcanic rocks, intermediate to felsic Tertiary volcanic rocks and unassigned volcanic rocks from Boggabri. The BV are also similar to the Halls Peak volcanics, the Hillgrove and Copeton Plutonic Suites, but those suites (especially the Hillgrove granitoids) display a tendency towards high Cr among mafic granitoids.

However, lower Cr at similar Al_2O_3 distinguishes the BV from the Petroi Metabasalt, higher Al_2O_3 at similar Cr distinguishes the BV from Tertiary basalts and higher Cr at lower Al distinguishes most Early Permian central NEO mafic complexes.

In summary, select BV exhibit a very slight enrichment in the Mafic Segment (to 1.02x SOB_{12}) then a progressive depletion with only minor inflections across the compositional range to about 0.8x SOB_{12} among rhyolites. Basalts are high-alumina types with high (Arc-like) Al_2O_3 contents, similar to Rindjani but less (0.86x) than Fuji Basalt. SOB_{12} contains more Al_2O_3 than Mole Granite, Primitive MORB (1.17x), Hawaiian Nepheline Melilitite and Average Continental Crust. At equivalent Si and/or Cr, select BV have similar Al_2O_3 to Werrie Basalt, Late Carboniferous volcanic rocks, unassigned Boggabri Volcanics and most Tertiary Nandewar volcanic rocks (except basalts), higher Al_2O_3 than BVSP Continental and Oceanic volcanic rocks, most I-type and S-type granitoids, Early Permian central NEO mafic complexes, Mole Granite and Tertiary Nandewar basalts. M-type granitoids overlap the BV range at similar Cr but not at similar SiO_2. Altered BV analyses display a range of 9%, or about 3x that of select BV analyses. White rhyolites plot along a trend towards 100% SiO_2.

Iron Oxide

Fe_2O_3t ranges (Fig. A2.5a) from 0.2% to 11.7%, with 4 samples in the range 0.2% to 1.7% (rhyolite), 13 samples in the range 2.6 % to 6% (dacite) and 11 samples in the range 7.5% to 10.2% (andesite to olivine basalt). Select rocks are in the range 0.9% ($SLPR_{08}$) to 9.9% (SPB_{39}). The BV range is within that of common igneous rocks (up to 20% — Wedepohl, 1978). BV basalts contain <12% Fe_2O_3t and are well below the 'high-iron' range (cf BVSP, 1981).

Fe_2O_3t abundance in SOB_{12} is depleted relative to Hawaiian Nepheline Melilitite (0.6x), Fuji basalt (0.72x), Average Continental Crust (0.87x) and Primitive MORB (0.95x), but is enriched relative to Rindjani basalt (1.01x). Relative to SOB_{12}, Fe_2O_3t abundance patterns (Fig. A2.5b) show an enrichment to about 1.12x in SPB_{39} then a gradual depletion in the andesite-dacite range. The rhyolite range is notably lower (0.1 to 0.2x SOB_{12}) and displays minor variation, including a minor peak at $SLPR_{25}$. Overall, Fe_2O_3t is depleted relative to Hawaiian Nepheline Melilitite and Average Continental Crust for all compositions and is depleted relative to Primitive MORB except for minor enrichment in SPB_{39}, and to Fuji and Rindjani basalts except for SOB_{12} and SPB_{39}. However, Fe_2O_3t is enriched relative to Mole Granite for all compositions, except rhyolites which are sub-equal to Mole Granite. For SOB_{12}, Mole Granite is complementary to Hawaiian Nepheline Melilitite, Average Continental Crust and Primitive MORB.

On **Fe_2O_3t v SiO_2** (Fig. A2.5c), BV select data exhibit a Main Trend with a short, positive, near-vertical Mafic Segment rising to a Mafic Inflection at 10.82 %, followed by a moderately negative sloping Intermediate Segment and a slightly flatter negative slope in the Intermediate Segment. SOA_{10} plots slightly above the Intermediate Segment and distinctly above Cross Trend 2. SFA_{09}, SED_{05} and SAD_{24} plot along the Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites cluster along the Intermediate Segment. Altered rocks exhibit an overall decline in Fe_2O_3t from about 11% at 48% SiO_2 to virtually zero at ≈ 80% SiO_2 (Fig. A2.5e). Most samples plot close to the Main Trend (within 1.5% Fe_2O_3t). Only one silicified basalt and a carbonated basaltic andesite depart significantly from the Main Trend. At higher silica contents, white rhyolites are offset from the Main Trend towards 100% SiO_2. Silicified rhyolites have a slightly higher Fe_2O_3t (average ≈ 1.1 %) than white rhyolites (average ≈ 0.3 %).

Fe_2O_3t v SiO_2 (Fig. A2.5g,i,k) shows that BV mafic rocks overlaps the lower half of BVSP Reference Arc and Ocean Floor basalt ranges and Mole Granite, but have distinctly lower Fe_2O_3t than BVSP Reference Ocean Island basalts, Hawaiian Nepheline Melilitite and Average Continental Crust. BVSP Reference Continental basalts mainly have higher Fe_2O_3t contents than BV mafic rocks. Most importantly, the BV Main Trend lacks the Fe_2O_3t range (enrichment) that characterises tholeiitic rocks of CFB and OFB affinities. The BV intermediate and felsic trends overlap the I-type granitoid ranges, but is marginally higher in Fe_2O_3t than select M-type granitoids. Regional comparisons (Fig. A2.5m,o,q,s) show that BV rocks are similar to most comparative data sets apart from lower Fe_2O_3t in some Early Permian central NEO mafic complexes and slightly higher Fe_2O_3t at lower SiO_2 among Tertiary basalts.

On **Fe_2O_3t v Cr** (Fig. A2.5d), the Main Trend comprises a Mafic Segment with a slight positive slope and well defined, virtually colinear, negative slopes in the Intermediate and Felsic Segments. SOA_{10} plots slightly above Cross Trend 2. SFA_{09}, SED_{05} and SAD_{24} plot along the Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites cluster along the end of the Intermediate Segment. Many altered intermediate to felsic rocks closely follow the Main Trend, apart from silicified and white rhyolites which cluster along the projection of the felsic trend to lower Fe_2O_3t values and #01 with anomalously high Cr (Fig. A2.5f). However, basaltic rocks exhibit considerably greater scatter relative to the Main Trend. The carbonated basaltic andesite (#03) has very low Fe_2O_3t compared to the Main Trend equivalent and even plots below the two cross trends.

Fe_2O_3t v Cr (Fig. A2.5h,j,l) shows that BV mafics overlap the low-Cr range of BVSP Reference Arc basalts, overlap the low-Fe_2O_3t margin of the range of BVSP Reference Continental rocks but have distinctly lower Fe_2O_3t and/or Cr than BVSP Reference

Oceanic rocks and Hawaiian Nepheline Melilitite and slightly lower Fe_2O_3t than Average Continental Crust. BV felsic to intermediate rocks overlap select M-type granitoids and Mole Granite but lack the Cr enrichment of the more mafic I-type granitoids. Regional comparisons (Fig. A2.5n,p,r,t) indicate that the BV substantially overlap comparative data sets. Notable exceptions are the Petroi Metabasalt (similar Fe_2O_3t at higher Cr), Early Permian intrusives (mostly higher Cr at equivalent Fe_2O_3t, or slightly lower Fe_2O_3t at equivalent Cr) and Tertiary basalts (higher Fe_2O_3t at equivalent Cr). Hillgrove granitoids and some Halls Peak volcanics also tend to higher Cr at equivalent Fe_2O_3t.

In summary, select BV exhibit minor (12% relative) Fe-enrichment from SOB_{12} to SPB_{39} and 23% enrichment to the Mafic Inflection, then a progressive depletion in Fe_2O_3t to dacite with a significant drop to 0.1 to 0 2x SOB_{12} among rhyolites. SOB_{12} has more Fe_2O_3t than Mole Granite, but less than Primitive MORB (0.98x), Hawaiian Nepheline Melilitite and Average Continental Crust. Most rocks are depleted relative to Fuji and Rindjani basalts, except for basalts which are marginally enriched. The Fe_2O_3t range is well below the 'high-Fe range' of common igneous rocks. Si-Cr-Fe systematics indicate that select BV have similar Fe_2O_3t to BVSP Arc basalts, most Primitive OFB basalts, as well as I-type granitoids, Petroi Metabasalt, Halls Peak volcanics, Late Carboniferous volcanic rocks, unassigned Boggabri Volcanics and Tertiary Nandewar volcanic rocks (excluding basalts), but more Fe_2O_3t than M-type granitoids and many Early Permian central NEO mafic complexes and less than in BVSP OIP basalts, most BVSP Continental and evolved OFB basalts and Tertiary Nandewar basalts.

Calcium Oxide

CaO ranges from 0.2% to 14.4%, but most values are in the lower part of the range and only thirteen above 5.5% and only four are above 9.9% (Fig. A2.6a). Select rocks range from 9.2% (SOB_{12}) to 1.7% ($SLPR_{13}$), extending down to 1.2% to include the rhyolitic pitchstones. The histogram lacks an obvious Daly gap (cf Chayes, 1963). The BV range is within that of common igneous rocks (from < 1% in granites with >70% SiO_2 to over 12% in some gabbros — Wedepohl, 1978). The BV range (9.2% in SOB_{12}, 9% in SPB_{39}) is typical of olivine-rich alkali basalts, but is less than typical tholeiitic basalts and gabbros (Wedepohl, 1978). The BV basalt range is also low compared to most basalts used in early melting experiments (cf Ringwood, 1975), but is high compared to many ophiolitic basalts (cf Coleman, 1977).

CaO in SOB_{12} is depleted relative to Hawaiian Nepheline Melilitite (0.72x), Primitive MORB (0.73x), Rindjani basalt (0.88x) and Fuji basalt (0.99x), but is enriched 1.24x Average Continental Crust, and 2.6x pyrolite. Abundances patterns (fig 5b) exhibit a smooth depletion across the BV range apart from a significant peak at $SFBR_{04}$.

Overall, the BV range is entirely depleted in CaO relative to Primitive MORB, Hawaiian Nepheline Melilitite and Fuji and Rindjani basalts, but is entirely enriched relative to Mole Granite. The range is enriched in the olivine basalt-basalt range and depleted in the andesite-rhyolite range relative to Average Continental Crust and is enriched in the olivine basalt-dacite range. Select rhyolites are about 3.5x to 7.2x Mole Granite. For SOB_{12}, Primitive MORB, Hawaiian Nepheline Melilitite, Fuji and Rindjani basalts are complementary to Average Continental Crust and Mole Granite.

On **CaO v SiO_2** (Fig. A2.6c), the Main Trend comprises a near vertical, negative slope in the main Mafic Segment (possibly statistically insignificant), a long, declining Intermediate Segment and a short positive slope in the Intermediate Segment. SOA_{10} plots distinctly above the Intermediate Segment and the cross trends. SFA_{09}, SED_{05} and SAD_{24} plot along the Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites form a distinct cluster at and above the end of the Intermediate Segment. Altered rocks (Fig. A2.6e) generally display a well defined array within 1% CaO of the Main Trend throughout the basalt-dacite range. Notable exceptions are carbonated rocks (basalts, basaltic andesite and dacite) which contain from 3 to 6% more CaO than the Main Trend. Altered olivine basalts are slightly enriched and the zeolitised basalt (#33) is slightly depleted in CaO compared to the Main Trend at equivalent SiO_2. White rhyolites and silicified rhyolites contain least CaO and most contain notably less CaO than rhyolite pitchstones. White rhyolites plot on an array trending to 100% SiO_2.

CaO v SiO_2 (Fig. A2.6g,i,k) shows that BV mafic rocks overlap the mid range BVSP Reference Continental basalts, but only overlap the lower margin of the BVSP Reference Arc and Oceanic basalts, have slightly less CaO than Average Continental Crust, and significantly less CaO than Hawaiian Nepheline Melilitite and Primitive MORB. The limited CaO range in the BV Mafic Segment contrasts with the far greater range of the other data sets. The BV intermediate trend parallels that of the three granitoid suites, but at distinctly lower CaO than select M-type granitoids and marginally lower CaO than select I-type granitoids at equivalent SiO_2. The BV felsic trend is oblique to the trend of the I- and M-type granitoids and does not overlap Mole Granite. Select rhyolites partly overlap the range of select I-type granitoids, but plot separately from select M-type granitoids. Regional comparisons (Fig. A2.6m,o,q,s) indicate the BV range overlaps that of the Werrie Basalt, Hillgrove and Copeton granitoids and overlaps the somewhat scattered ranges of the Petroi Metabasalt, Halls Peak volcanics, Late Carboniferous volcanic rocks and the unassigned Boggabri Volcanics. The Early Permian central NEO mafic complexes generally have distinctly higher CaO for equivalent SiO_2, whereas Tertiary volcanic rocks have distinctly lower CaO and/or SiO_2.

On **CaO v Cr** (Fig. A2.6d) the Main Trend comprises a nearly flat Mafic Segment, a negative, nearly vertical slope in the Intermediate Segment and a short positive slope in the Intermediate Segment. SOA_{10} plots beside Cross Trend 2. SFA_{09}, SED_{05} and SAD_{24} plot along the Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites form a distinct cluster overlapping the end of the Intermediate and Felsic Segments. Altered rocks (Fig. A2.6f) display modest scatter, most notably among basaltic types. Carbonated basalts and basaltic andesites containing about 3 to 6 % more CaO than the trend estimate. Lesser scatter is evident among other mafic rocks. The zeolitized basalt (#33) is depleted in CaO relative to the Main Trend as are two silicified basalts. Silicified rhyolites and white rhyolites contain significantly less CaO than rhyolite pitchstones and vitrophyres.

CaO v Cr (Fig. A2.6h,j,l) distinguishes BV mafic rocks from most BVSP Reference Arc and Oceanic basalts (higher CaO, greater Cr range in the latter), as well as from Hawaiian Nepheline Melilitite and Primitive MORB (greater CaO in both). BVSP Reference CFB's overlap the BV mafic range, but extend to higher Cr and higher CaO values. Select M-type granitoids and BVSP Reference CRZ basalts overlap the BV range. Select I-type granitoids are generally distinguished by higher Cr for equivalent CaO. Average Continental Crust has lower CaO for BV with equivalent Cr (i.e. basalts). Regional comparisons (Fig. A2.6n,p,r,t) show that the BV range overlaps that of the Werrie Basalt, Late Carboniferous volcanic rocks, Tertiary volcanic rocks, unassigned Boggabri Volcanics. However, higher Cr at equivalent CaO distinguishes the Petroi Metabasalt and higher Cr and/or higher CaO distinguishes most Early Permian central NEO mafic complexes (some overlap the BV trends). The BV felsic and intermediate trends overlap the ranges of the Halls Peak volcanics and parts of the Hillgrove and Copeton granitoids, but all show some tendency to higher Cr at equivalent CaO.

In summary, select BV exhibit a progressive decline in CaO from SOB_{12} (9.91%) to lowest values among select rhyolites (0.13 to 0.24 x SOB_{12}). SOB_{12} contains more CaO than Mole Granite and Average Continental Crust, but less than Primitive MORB (0.73x), Hawaiian Nepheline Melilitite and Fuji and Rindjani basalts. Si-Cr-Ca systematics for select BV indicate similar CaO levels to BVSP Continental basalts, Werrie Basalt, Petroi Metabasalt Late Carboniferous volcanic rocks and Halls Peak volcanics, but less SiO_2 than BVSP OIP alkalic basalts and Tertiary Nandewar basalts, less CaO than most BVSP Arc basalts, tholeiitic Oceanic basalts and Early Permian central NEO mafic complexes, and less Cr than I-type and S-type granitoids. Altered BV exhibit a greater CaO range with carbonated basalts containing up to 14.44% CaO (i.e. 1.5x SOB_{12}).

Magnesia

MgO ranges from < 0.1% in white rhyolites to 9.2% in SOB_{12}. There is a gap between 3.5 and 5% and only 6 analyses contain > 5% MgO (Fig. A2.7a). $SLPR_{13}$ contains 0.3% MgO and rhyolite pitchstones range down to 0.2%. The BV range is within that of common igneous rocks (< 1% to > 12% — Wedepohl, 1978). SOB_{12} (9.2% MgO) contains >8.5% MgO and is therefore within the range of Archean 'magnesian' basalts (BVSP, 1981).

MgO in SOB_{12} is depleted relative to pyrolite (0.24x), Hawaiian Nepheline Melilitite (0.68x) and Primitive MORB (0.92 x), but is enriched 1.38x Rindjani basalt, 1.63x Fuji basalt, and 1.73x Average Continental Crust. Abundances patterns (Fig. A2.7b) exhibit a significant depletion across the olivine basalt-dacite range to SED_{05} at 0.13x SOB_{12}, with a notable low at SOA_{10}. Select rhyolites continue this decline at a lower level (0.025x to 0.04x SOB_{12}), but with $SLPR_{29}$ and $SLPR_{08}$ marginally enriched compared to biotite rhyolites. Overall, the BV range is depleted relative to Primitive MORB and Hawaiian Nepheline Melilitite, depleted relative to Average Continental Crust and Fuji basalt except for SPB_{39} and SOB_{12}, and depleted relative to Rindjani basalt except for SOB_{12}. However, the range is enriched relative to Mole Granite, the enrichment for select rhyolites being is 1.6 to 3.6x Mole Granite. For SOB_{12}, Mole Granite, Average Continental Crust and Fuji and Rindjani basalts are complementary to Primitive MORB.

On **MgO v SiO_2** (Fig. A2.7c), select rocks display a long, near-vertical negative slope for the Mafic Segment, and a moderate negative slope in the Intermediate Segment. The Felsic Inflection is negative and therefore unrealistic, and the rest of the Main Trend is meaningless. SOA_{10} has 2 and 3 % less MgO than cross trends 1 and 2 respectively. SFA_{09}, SED_{05} and SAD_{24} plot along the Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites plot in an elongate cluster adjacent to the end of the Intermediate Segment. Altered basaltic to dacitic rocks fall into two groups (Fig. A2.7e). A few plot very close to the Main Trend. Most plot well below it, defining a negative sloping array declining from about 2% MgO at about 49% SiO_2 to almost zero MgO among the rhyolites. Silicified and white rhyolites form an elongate cluster that overlaps the rhyolitic pitchstones and extends towards 100% SiO_2.

MgO v SiO_2 (Fig. A2.7g,i,k) shows that the BV Mafic Segment largely overlaps the range of BVSP Reference Arc, Continental and Oceanic ranges, although all extend to higher Mg and Continental data extend to higher SiO_2 (overlapping the cross trends and Intermediate Segment). Primitive MORB and Average Continental Crust have slightly higher MgO and Hawaiian Nepheline Melilitite has distinctly higher MgO. Select I- and M-type granitoids (especially more mafic rocks amongst the latter) tend to have marginally higher Mg at equivalent SiO_2. Regional comparisons (Fig. A2.7m,o,q,s) show that the BV have a similar range to many comparative data, especially the Werrie Basalt and Late

Carboniferous rhyolites. However, the Petroi Metabasalt and Halls Peak volcanics display a larger MgO range, Tertiary volcanic rocks and unassigned Boggabri Volcanics tend to have marginally lower Mg and/or lower SiO_2. In addition, Hillgrove and Copeton granitoids tend to have marginally higher MgO for equivalent SiO_2.

On **MgO v Cr** (Fig. A2.7d) the Main Trend shows a moderate, negative slope through the Mafic Segment, a steep negative slope in the Intermediate Segment to an unrealistic negative Felsic Inflection and the Main Trend is thereafter undefined. SOA_{10} has 2 and 3 % less MgO than cross trends 1 and 2 respectively. SFA_{09}, SED_{05} and SAD_{24} plot along the Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites plot in a cluster that overlaps the end of the felsic and Intermediate Segments. Altered mafic rocks systematically plot 2 to 6% MgO below the Mafic Segment of the Main Trend (Fig. A2.7f). In contrast, altered andesitic to rhyolitic rocks generally cluster along the Main Trend (#01 excepted).

MgO v Cr (Fig. A2.7h,j,l) for the BV Mafic Segment partly overlaps the range of BVSP Reference Arc and Continental basalts. However, the Arc and CFB basalts range to higher Cr at similar Mg and CRZ basalts range to lower MgO at equivalent Cr. BVSP Reference Oceanic basalts are mainly distinct, having higher Cr and/or lower Mg. Hawaiian Nepheline Melilitite is notable for having distinctly higher MgO at distinctly higher Cr. BV trends tend to be steeper than for BVSP data. Select M-type granitoids closely overlap the BV felsic to Intermediate Segments, but Average Continental Crust and most select I-type granitoids have far higher Cr for equivalent Mg. Regional comparisons (Fig. A2.7n,p,r,t) show that the Late Carboniferous volcanic rocks and Tertiary and unassigned Boggabri Volcanics are indistinguishable on **MgO v Cr**. However, the Petroi Metabasalt is distinct (higher Cr at equivalent Mg) and the Werrie Basalt tends to have marginally lower MgO at equivalent Cr. The Early Permian mafic intrusives partly overlap the BV trends, but range to substantially higher Cr at similar or slightly higher Mg.

In summary, select BV exhibit a progressive decline in MgO from marginally magnesian levels for SOB_{12} (9.19%) to ≈ 0.25 to 0.4x SOB_{12} for select rhyolites. SOB_{12} contains more MgO than Fuji and Rindjani basalts, and Average Continental Crust, but less than Primitive MORB (0.92x) and Hawaiian Nepheline Melilitite. Si-Cr-Mg systematics for select BV indicate similar levels of MgO to most BVSP Arc, Continental and Oceanic basalts (excluding Primitive OFBs), Early Permian central NEO mafic complexes, Late Carboniferous volcanic rocks, but distinguish Tertiary Nandewar volcanic rocks (lower Si and/or Mg) as well as Average Continental Crust, I-type granitoids, S-type granitoids (marginally) and many Halls Peak volcanics (high MgO v SiO_2, low MgO v Cr) and M-type granitoids (high MgO v SiO_2). Altered rocks are generally depleted in MgO, some by over 50 %.

Sodium Oxide

Na_2O ranges from 0.9 to 6.9% (Fig. A2.8a). Both the lowest and highest values occur in silicified rhyolite. Select rocks range from 2.9% in SOB_{12} to 5.3% in rhyolitic ignimbrite vitrophyre ($SLPR_{13}$) and 5.5% in $SMPR_{06}$ but some pitchstones are anomalously low in Na_2O (1.7 % in $SLPR_{08}$). The BV range is within that of common igneous rocks (generally 2 –9% — Wedepohl, 1978).

Na_2O in SOB_{12} is depleted relative to Hawaiian Nepheline Melilitite (0.61x), Average Continental Crust (0.95x) and Rindjani basalt (0.97x) but is enriched relative to Fuji basalt (1.05x), Primitive MORB (1.27x) and, pyrolite (8.14x). Abundances patterns (Fig. A2.8b) show a modest, systematic increase in the olivine basalt-basaltic andesite range and a lesser increase in the andesite-dacite range. Some rhyolites ($SLPR_{13}$ and $SMPR_{06}$) extend this trend, but the leucocratic rhyolite lavas (especially $SLPR_{08}$) are notably depleted, with most sub-equal to or depleted relative to SOB_{12}. The BV range is enriched relative to most compositions except for a slight depletion in olivine basalt relative to Mole Granite and Average Continental Crust and depletion in most rhyolites relative to Mole Granite, Average Continental Crust and Hawaiian Nepheline Melilitite. For SOB_{12}, Hawaiian Nepheline Melilitite, Mole Granite and Average Continental Crust are complementary to Primitive MORB.

On **Na_2O v SiO_2** (Fig. A2.8c) the Main Trend exhibits a steep (nearly vertical) positive slope in the Mafic Segment, a gentle positive slope in the Intermediate Segment and a steep negative slope in the Intermediate Segment. SOA_{10} plots adjacent to the Intermediate Segment and to Cross Trend 2. SFA_{09}, SED_{05} and SAD_{24} plot along the Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites are scattered along the Intermediate Segment, but mainly towards the low-Na end. Altered rocks (Fig. A2.8e) show considerable scatter relative to the Main Trend. Basaltic to dacitic rocks occupy a broad band adjacent to the Main Trend, but lack a Mafic Inflection. Two silicified rhyolites (#01 and #22) have anomalously high Na_2O (up to 6.94%) whereas a third (#02), a rhyolitic ignimbrite, has the lowest Na_2O (0.92 %). White rhyolites have Na_2O values in the mid range of the Intermediate Segment (slightly higher than most rhyolitic pitchstones) and are offset from the Intermediate Segment towards 100% SiO_2.

Na_2O v SiO_2 (Fig. A2.8g,i,k) shows that the BV Mafic Segment overlaps the upper half of the range of BVSP Reference Arc and Continental basalts. Tholeiitic OIB basalt have lower Na_2O, whereas Hawaiian Nepheline Melilitite and alkalic OIB volcanic rocks have significantly higher Na_2O and/or lower SiO_2. Average Continental Crust, select M- and I-type granitoids and Mole Granite all plot well below the Intermediate Segment of the Main Trend. Regional comparisons (Fig. A2.8m,o,q,s) show that the BV range substantially overlaps that of the Werrie Basalt and parts of the scattered Halls Peak volcanics. The BV range has significantly higher Na_2O than most Permo-Carboniferous intrusives and Late Carboniferous volcanic rocks, although Late Carboniferous rhyolites overlap the Felsic Segment. The Petroi Metabasalt and Tertiary volcanic rocks ranges are marginal to but largely distinct from the BV range. Unassigned Boggabri Volcanics have marginally higher Na_2O.

On **Na_2O v Cr** (Fig. A2.8d) the Mafic Segment of the Main Trend shows a gentle positive slope, the Intermediate Segment is a short, positive slope and steeper and the Intermediate Segment has a long, near-vertical, negative trend. SOA_{10} plots slightly above the Mafic Segment and the cross trends. SFA_{09}, SED_{05} and SAD_{24} plot along the short Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites are scattered along the elongate Intermediate Segment. Most plot towards the low-Na end, but one ($SMPR_{06}$) plot at the other end. Altered rocks (Fig. A2.8f) tend to plot close to the Main Trend, although there is considerable scatter especially along the Mafic Segment. Two silicified rhyolites (#1 and #22) have anomalously high Na_2O as does one zeolitised basalt (#33). White rhyolites have higher Na_2O that do most pitchstones.

Na_2O v Cr (Fig. A2.8h,j,l) distinguishes the BV range from most BVSP Reference Arc, Continental and Oceanic tholeiitic data, Hawaiian Nepheline Melilitite and select I-type granitoids by a combination of higher Na_2O and/or a lesser Cr range in the BV. Only M-type granitoids and Mole Granite overlap the BV Main Trend systematically, and Average Continental Crust plots adjacent. Regional comparisons (Fig. A2.8n,p,r,t) distinguish the BV from the Petroi Metabasalt (higher Cr and similar to higher Na_2O) and the Early Permian central NEO mafic complexes (higher Cr range and lower Na_2O). Late Carboniferous andesites have lower Na_2O and/or higher Cr than the BV. Unassigned Boggabri Volcanics have marginally higher Na_2O.

In summary, select BV displays a significant enrichment in Na_2O among select basalts, high-Na and modest, progressive enrichment in the andesite-dacite-low-Si rhyolite range to ≈ 1.86x SOB_{12}, and a large decrease in high-Si rhyolites (all leucocratic pitchstones) to 0.57x SOB_{12}. SOB_{12} contains more Na_2O than Primitive MORB (0.92x), but less than Average Continental Crust, Mole Granite, Hawaiian Nepheline Melilitite, and Fuji and Rindjani basalts. Si-Cr-Na systematics for select BV indicate similar levels of Na_2O to many Werrie Basalt rocks, Petroi Metabasalt rocks, Tertiary Nandewar basalts and unassigned Boggabri Volcanics, but more Na_2O than most BVSP Arc, Continental and Oceanic basalts (except alkalic OIP basalts), M-, I- and S-type granitoids, Early Permian central NEO mafic complexes, more Na at equivalent SiO_2 than Average Continental Crust, and less Na_2O than Tertiary Nandewar intermediate volcanic rocks, BVSP alkalic Oceanic volcanic rocks and Hawaiian Nepheline Melilitite. Altered BV have similar or slightly lower Na_2O compared with select rocks, except for two silicified rhyolites which are significantly enriched in Na_2O.

Potassium Oxide

K_2O ranges from 0.4 to 5% (Fig. A2.9a). The lowest value in a select rocks is 0.6% in SOB_{12}. Most rhyolites regardless of alteration contain between 4 and 5%, but the select rhyolite ($SLPR_{13}$ — rhyolite ignimbritic vitrophyre) is anomalous in containing only 2.1% K_2O and one pitchstone ($SMPR_{06}$) contains only 1.1% K_2O. The BV range is within that of common igneous rocks (typically ≈ 0.3% to ≈ 6% and increasing with differentiation — Wedepohl, 1978).

K_2O in SOB_{12} is depleted relative to OIB (0.41x), Hawaiian Nepheline Melilitite (0.46x), Rindjani basalt (0.46x), Average Continental Crust (0.54x) and Fuji basalt (0.63x) but is enriched relative to E-MORB (2.3x), Primitive MORB (8.2x) and pyrolite (20x). Abundances patterns (Fig. A2.9b) show no change in the olivine basalt-basalt range, then an increase to SOA_{10} (2.4x SOB_{12}) followed by a gradual increase in the andesite-dacite range (to 4.55x SOB_{12}). Leucocratic rhyolites generally exhibit high values (8 to 8.5x SOB_{12}), but $SMPR_{06}$ is notable depleted relative to other rhyolites, and $SLPR_{13}$ (an ignimbrite) has levels similar to $SMPR_{06}$. Overall, the BV range is generally depleted relative to the Mole Granite (except for marginal enrichment in $SLPR_{13}$), but is systematically enriched relative to Primitive MORB, E-MORB and Fuji basalt. The range is generally enriched relative to OIB, Hawaiian Nepheline Melilitite, Rindjani basalt and Average Continental Crust, but SOB_{12} and SPB_{39} are depleted relative to all four, and one rhyolite ($SMPR_{06}$) is marginally depleted relative to OIB, Hawaiian Nepheline Melilitite and Rindjani basalt. For SOB_{12}, Primitive MORB, E-MORB and Fuji basalt are complementary to OIB, Hawaiian Nepheline Melilitite, Rindjani basalt, Average Continental Crust and Mole Granite.

On **K2O v SiO_2** (Fig. A2.9c) the Main Trend for select rocks shows a short, indistinct, mafic trend, a moderate positive slope in the Intermediate Segment and a short steep positive slope in the Intermediate Segment. The cross trends virtually coincide with the Main Trend. SOA_{10} plots just below the Main Trend. SFA_{09}, SED_{05} and SAD_{24} plot distinctly off the Intermediate Segment and the Dyke Trend is short but distinct. Select rhyolites are mainly scattered near the high-K end of the Intermediate Segment, but one pitchstone ($SMPR_{06}$) and one ignimbritic vitrophyre ($SLPR_{13}$) contain significantly less K_2O and plot well off trend. Altered rocks (Fig. A2.9e) display considerable scatter, but generally plot in a broad band parallel to the Main Trend. Obvious exceptions are #16 (a dacite with about 2% excess K_2O), one silicified basalt (#43 with about 1% K_2O

deficit) and two silicified rhyolites (#01 and #22) which plot close to $SMPR_{06}$ and the white rhyolites which are offset from the Main Trend towards 100% SiO_2.

K2O v SiO_2 (Fig. A2.9g,i,k) for the BV Mafic Segment falls within the range of BVSP Reference Arc, Continental and Oceanic tholeiitic basalts, but Continental basalts range to higher K_2O and Oceanic alkalic analyses and Hawaiian Nepheline Melilitite have systematically higher K_2O at the same SiO_2. The BV Main Trend generally has lower K_2O than select I-type granitoids, except for limited overlap at the felsic end of the trend (close to Mole Granite). Select M-type granitoids generally and Average Continental Crust have slightly lower K_2O than the BV. Regional comparisons (Fig. A2.9m,o,q,s) indicate that the BV range overlaps that of the Werrie Basalt and most Early Permian central NEO mafic complexes. The Hillgrove and Copeton granitoid generally have higher K_2O, apart from limited overlap at the felsic end of Main Trend. The BV range also partly overlaps that of the Petroi Metabasalt, Halls Peak volcanics and Late Carboniferous volcanic rocks but very scattered data inhibit detailed comparison. Tertiary volcanic rocks generally have higher K_2O than the BV, whereas unassigned Boggabri Volcanics overlap the BV range.

On **K2O v Cr** (Fig. A2.9d), the Main Trend comprises a flat Mafic Segment and positive, near vertical, Intermediate and Felsic Segments which are essentially colinear. SOA_{10} plots along Cross Trend 2. SFA_{09}, SED_{05} and SAD_{24} plot along the Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites are mainly scattered near the high-K end of the Intermediate Segment, but two ($SLPR_{13}$ and $SMPR_{06}$) have lower K_2O and plot along the Intermediate Segment among the mafic dacites. Altered rocks (Fig. A2.9f) also plot as scattered points adjacent to the Main Trend. Two silicified rhyolites are obviously anomalous: one because of high Cr (#01), and another (#22) because of very low K_2O.

K2O v Cr (Fig. A2.9h,j,l) distinguishes the BV range from BVSP Reference OFB analyses (lower K_2O, greater Cr range), from Hawaiian Nepheline Melilitite (lower K_2O, greater Cr) and from most select I-type granitoids (higher K_2O and higher Cr range). However, the BV range overlaps that of select M-type granitoids, BVSP Reference CRZ basalts, Mole Granite and the lower Cr range of BVSP Reference CFB and Arc analyses. Average Continental Crust is poorly distinguished. Regional comparisons (Fig. A2.9n,p,r,t) show that the BV range overlaps that of the Werrie Basalt, Halls Peak volcanics, Late Carboniferous volcanic rocks, Tertiary intermediate and felsic volcanic rocks (basalts have higher K_2O) and unassigned Boggabri Volcanics. Central NEO Early Permian mafic intrusives partly overlap the BV range, but extends to higher Cr and higher Cr also distinguishes the Petroi Metabasalt. Hillgrove and Copeton granitoids overlap the Intermediate Segment, but most tend to have slightly higher Cr at equivalent K_2O.

In summary, select BV display progressive enrichment from SOB_{12} (0.59% or medium-K) to felsic rhyolite (up to 8.5x SOB_{12} or high-K) with a notable jump from basalt to andesite and from dacite to rhyolite (apart from two anomalous sample). SOB_{12} contains more K_2O than Primitive MORB (8.2x), E-MORB and Fuji basalt but less than Average Continental Crust, OIB, Hawaiian Nepheline Melilitite, Rindjani basalt and Mole Granite. Si-Cr-K systematics for select BV indicate similar levels of K_2O to BVSP Arc basalts and OIP tholeiites and some Continental basalts, but more K_2O than BVSP OFB basalts, less K_2O than BVSP OIP alkalic basalts, Hawaiian Nepheline Melilitite, most BVSP Continental basalts, Tertiary Nandewar volcanic rocks and I- and S-type granitoids. M-type granitoids are distinguished on K_2O v Regional comparisons (Fig. A2. only.

Titania

TiO_2 ranges from 0.2 (white rhyolite) to 1.6% (SPB_{39}). TiO_2 values show a distinct gap between 0.4 and 0.7 %, i.e. between rhyolite and dacite (Fig. A2.10a). The lowest value in select samples is 0.4% TiO_2 in $SLPR_{13}$ or 0.3 % in pitchstone ($SFBR_{04}$). The BV range is within that of common igneous rocks (0.2% to 4.2% — Wedepohl, 1978). BV basalts are less than 1.8% and thus within the Circumoceanic rather than oceanic group (Chayes, 1964). However, the Mafic Inflection is at 2 12% and thus within the 'oceanic' range.

TiO_2 in SOB_{12} is slightly depleted relative to OIB (0.36x), Hawaiian Nepheline Melilitite (0.4x), Fuji basalt (0.65x), Rindjani basalt (0.80x) and Primitive MORB (0.82x) but is enriched 1.04x E-MORB, 1.16x Average Continental Crust, and 5.17x pyrolite (Fig. A2.10b). Relative to SOB_{12}, these abundance patterns show a slight enrichment of 1.56x in basalt followed by a gradual depletion through andesite and dacite to 0.98x SOB_{12}, followed by a drop to about 0.4x to 0.25x SOB_{12} among rhyolite. Overall, the BV range is enriched relative to Mole Granite (2.7x to 4.1x in the select rhyolites) and depleted relative to OIB and Hawaiian Nepheline Melilitite. Relative to Average Continental Crust, E-MORB, Primitive MORB and Fuji and Rindjani basalt, the BV range is enriched in the rhyolite range, but exhibits varied behaviour in the basalt-dacite range. For SOB_{12}, OIB, Hawaiian Nepheline Melilitite and Primitive MORB are complementary to E-MORB, Average Continental Crust and Mole Granite.

On **TiO_2 v SiO_2** (Fig. A2.10c), the Main Trend consists of a near-vertical, positive slope in the Mafic Segment, a moderately negative slope in the Intermediate Segment and a short, slightly flatter Felsic Segment. The Mafic Inflection in the Main Trend occurs at a TiO_2 content of about 2.1%, which is well above the TiO_2 content of select basalts and andesites. SOA_{10} plots close to Cross Trend 1 and well below Cross Trend 2 and the Intermediate Segment. SFA_{09}, SED_{05} and SAD_{24} plot close to the Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites cluster along the end of the segment. Altered rocks (Fig. A2.10e) generally plot close to the Main Trend, except for a silicified basalt and silicified and carbonated basaltic andesites which plot between the two cross trends and well away from the Main Trend. White rhyolites plot adjacent to rhyolitic pitchstones, but slightly offset towards 100% SiO_2.

TiO_2 v SiO_2 (Fig. A2.10g,i,k) shows that the BV Mafic Segment largely overlaps the range of BVSP Reference CRZ and OFB data and falls within the lower range of BVSP Reference CFB analyses and within the upper range of BVSP Reference Arc basalts. The Main Trend has distinctly higher TiO_2 than Average Continental Crust, select I-type granitoids and most select M-type granitoids, and slightly higher TiO_2 than Mole Granite. Hawaiian Nepheline Melilitite and most BVSP Reference OIB have higher TiO_2 and lower SiO_2. Regional comparisons (Fig. A2.10m,o,q,s) show that the BV range overlaps that of most Werrie basalt data, the Halls Peak volcanics and unassigned Boggabri Volcanics, and marginally overlaps the Hillgrove and Copeton granitoid ranges, and Late Carboniferous felsic volcanic rocks. In contrast, the BV range is distinct from that of the Petroi Metabasalt (slightly lower SiO_2 and ranges to higher TiO_2), most Early Permian central NEO mafic complexes (lower TiO_2, but a subgroup overlaps the BV range) and Late Carboniferous intermediate volcanic rocks (lower TiO_2). Tertiary volcanic rocks range from higher TiO_2 among basalts to lower TiO_2 among dacites and rhyolites and only overlaps the BV range close to the Mafic Inflection.

TiO_2 v Cr (Fig. A2.10d) exhibits a moderately steep, positive trending Mafic Segment and near-vertical, negative slope in the, nearly colinear intermediate and felsic trends. SOA_{10} plots on Cross Trend 1 and well below Cross Trend 2 and the Main Trend. SFA_{09}, SED_{05} and SAD_{24} plot along the Intermediate Segment and the Dyke Trend is indistinct. Select rhyolites cluster tightly at the low-Ti end of the felsic trend. Altered intermediate to felsic rocks generally follow the Main Trend, except for #22 with high Cr (Fig. A2.10f). However, zeolitic basalt, carbonated basalts, silicified basalt and silicified basaltic andesite generally plot slightly off the Mafic Segment of the Main Trend. Radial dispersal relative to this trend is up to about 15% (e.g. #33).

TiO_2 v Cr (Fig. A2.10h,j,l,n,p,r,t) distinguishes the BV range from BVSP Reference Oceanic basalts, Hawaiian Nepheline Melilitite, most CFB rocks and select I-type granitoids, Average Continental Crust, Petroi Metabasalt, most Early Permian central NEO mafic complexes and Tertiary Nandewar basalts. In contrast, BV on **TiO_2 v Cr** overlap the range of M-type granitoids, the Werrie Basalt, Tertiary intermediate to felsic volcanic rocks and unassigned Boggabri Volcanics. The Halls Peak volcanics, Hillgrove and Copeton granitoids and Late Carboniferous volcanic rocks all partly overlap the BV intermediate to felsic range but tend to higher Cr especially among more mafic compositions.

In summary, select BV display a modest increase in the basalt range from SOB_{12} to the Mafic Inflection (≈ 2x SOB_{12}), followed by a steady decline in the andesite-dacite range and a significant decrease to the rhyolite range (0.25 to 0.4x SOB_{12}). TiO_2 in BV are in the lower range of common igneous rocks. SOB_{12} contains more TiO_2 than Mole Granite, Average Continental Crust, Fuji basalt and E-MORB but less than Primitive MORB (0.82x), Hawaiian Nepheline Melilitite, Rindjani basalt and OIB. Si-Cr-Ti systematics for select BV indicate similar levels of TiO_2 to BVSP CRZ and evolved OFB basalts, most Petroi Metabasalt, Werrie Basalt, Halls Peak volcanics, unassigned Boggabri Volcanics, S-type granitoids and some intermediate Tertiary Nandewar volcanic rocks, but more TiO_2 than most BVSP Arc basalts, Early Permian central NEO volcanic rocks, I-type granitoids, and Late Carboniferous volcanic rocks, and less TiO_2 than evolved BVSP CFB and Oceanic basalts, Hawaiian Nepheline Melilitite and evolved Tertiary Nandewar basalts. Low MgO v SiO_2 distinguish primitive OFBs and felsic Tertiary Nandewar volcanic rocks.

Phosphorus Pentoxide

P_2O_5 ranges from virtually 0 to 0.5%. The highest values are in altered basalt and andesite (Fig. A2.11a). The highest values in select samples are 0.4% in SFA_{09}, whereas the lowest value in select rock is <0.1% in rhyolites. The BV range is within that of common igneous rocks (0 to 2%, more commonly x00 to 5000 ppm — Wedepohl, 1978).

P_2O_5 in SOB_{12} (Fig. A2.11b) is depleted relative to Hawaiian Nepheline Melilitite (0.22x) and OIB (0.44x), Fuji basalt (0.69x), but is subequal to Rindjani basalt (1.03x) and enriched 1.9x E-MORB, 2.25x Primitive MORB, and 12.9x pyrolite. Relative to SOB_{12}, these abundance patterns show a slight gradual enrichment of up to 1.48x in SFA_{09} followed by a gradual depletion to 1.11x SOB_{12} in SED_{05}. Rhyolites have significantly lower levels which decline further across the range, except for an anomalously high value in $SLPR_{08}$. Overall, the BV range is depleted relative to OIB and Hawaiian Nepheline Melilitite and enriched relative to Mole Granite (except for $SLPR_{29}$). The basalt-dacite range is enriched and the rhyolites depleted relative to Primitive MORB, E-MORB, Rindjani and Fuji basalts. For SOB_{12}, OIB and Hawaiian Nepheline Melilitite are complementary to Primitive MORB, E-MORB, Fuji basalt and Mole Granite, whereas Rindjani basalt is subequal to SOB_{12}.

On **P_2O_5 v SiO_2** (Fig. A2.11c), the Main Trend consists of a near vertical, positive slope in the mafic trend, a slightly negative slope in the intermediate trend and a steeply negative slope in the felsic trend. SOA_{10} plots on Cross Trend 1 and well below Cross

Trend 2 and the Intermediate Segment. SFA_{09} and SED_{05} plot well away from the Intermediate Segment. SAD_{24} plots close to SED_{05}, but well below the Main Trend and the Dyke Trend is distinct and nearly normal to the Main Trend. Most select rhyolites form a cluster distinctly offset from the low-P end of the Intermediate Segment. Altered rocks (Fig. A2.11e) exhibits considerable scatter, but overall form a poorly defined negative slope that trends distinctly oblique to the various segments of the Main Trend. Silicified and white rhyolites plot separately from dacites and are slightly offset from the pitchstones towards 100% SiO_2. Overall, the calculated Intermediate and Felsic Segments provide a poor approximations to the distribution of data points. A better approximation would be provided by a single line projecting from the end of the Intermediate Segment through SFA_{09} and SED_{05} to an intersection with an upward projection of the Mafic Segment. Most select and altered andesitic to dacitic analyses would lie close to this alternative trend.

P_2O_5 v SiO_2 (Fig. A2.11g,i,k) for the BV Mafic Segment falls in the middle of BVSP Reference Continental analyses, in the uppermost range of BVSP Reference Arc basalts and is marginal to the upper limit of BVSP Reference Oceanic tholeiitic analyses. BVSP OIP alkalic volcanic rocks range to considerably higher values (comparable to Hawaiian Nepheline Melilitite) than select BV. Select I- and M-type granitoid data overlap many of the BV intermediate and felsic rocks, but are quite distinct from the calculated intermediate and felsic trends. Regional comparisons (Fig. A2.11m,o,q,s) distinguish BV from to most Early Permian central NEO mafic complexes and Tertiary volcanic rocks, Late Carboniferous sills and the Petroi Metabasalt. The Werrie Basalt partly overlaps the BV, but shows a much greater range. Other comparisons are complicated by problems with the calculated Main Trend. For example, the Halls Peak volcanics, Hillgrove and Copeton granitoids, Late Carboniferous rhyolites overlap felsic and intermediate BV but not the Intermediate and Felsic Segments of the Main Trend.

On **P_2O_5 v Cr** (Fig. A2.11d) the BV Main Trend comprises a gentle positive slope in the Mafic Segment of the Main Trend, a short, moderately steep, negative slope in the intermediate trend and a steep negative slope in the Intermediate Segment of the Main Trend. SOA_{10} plots slightly below Cross Trend 1 and well below Cross Trend 2 and the Main Trend. SFA_{09} and SED_{05} plot close to the projection of the Intermediate Segment. SAD_{24} plots close to SED_{05}, but off the Intermediate Segment and the Dyke Trend is distinct. Select rhyolites cluster at the low-P end of the Intermediate Segment. Altered intermediate to felsic rocks (Fig. A2.11f) mainly mimic the Main Trend, apart from two altered andesites that plot at higher P_2O_5 than the Mafic Inflection. Mafic rocks display considerable departure from the Main Trend, the majority plotting at higher P_2O_5. Radial scatter relative to the Mafic Segment is up to 25%.

P_2O_5 v Cr (Fig. A2.11h,j,l) distinguishes BV range from most BVSP Reference Arc and Oceanic analyses, from Hawaiian Nepheline Melilitite and from many select I-type granitoids. In contrast BV data overlap the BVSP Reference Continental range and select M-type granitoids. Regional comparisons (Fig. A2.11n,p,r,t) indicate the distinctiveness of BV range compared to the Petroi Metabasalt, Early Permian central NEO mafic complexes, Late Carboniferous andesites and Tertiary basalts. Other suites partly overlap the BV range, but are also partly distinctive.

In summary, P_2O_5 exhibits a range from 1.48 x SOB_{12} in andesites to 0.07 to 0.26x SOB_{12} in rhyolites that is poorly modelled by the Main Trend. SOB_{12} contains more P_2O_5 than Mole Granite, Fuji basalt, Primitive MORB (2.25x) and E-MORB, less than OIB and Hawaiian Nepheline Melilitite, and about the same as Rindjani basalt. Si-Cr-P systematics for select BV indicate similar levels of P_2O_5 to some BVSP Continental basalts, more P_2O_5 than most BVSP Arc and Oceanic tholeiitic basalts, Early Permian central NEO volcanic rocks, I- and S-type granitoids, Late Carboniferous volcanic rocks and felsic Tertiary Nandewar volcanic rocks, but less P_2O_5 than many BVSP Continental basalts, Tertiary Nandewar basalts, some Petroi metabasalts, BVSP OIP alkalic rocks, Hawaiian Nepheline Melilitite and some Werrie Basalts. Low P_2O_5 v SiO_2 distinguishes M-type granitoids.

Manganese Oxide

MnO ranges from virtually zero to 0.3% (Fig. A2.12a). The highest values are in carbonated rocks and the highest value in select rocks is 0.2% in basalt (SPB_{39}). The lowest values in select rocks are < 0.1% in $SLPR_{13}$ and $SLPR_{08}$. The BV range is within that of common igneous rocks (typically 800 to 2000 ppm for basaltic and ultramafic compositions and significantly less among granites and varying with $Fe2^{+}$ — Wedepohl, 1978).

MnO in SOB_{12} is depleted relative to Hawaiian Nepheline Melilitite (0.53x), Rindjani basalt (0.66x), Average Continental Crust (0.74x), Fuji basalt (0.75x), Primitive MORB (0.86x) and to pyrolite (0.99x). Relative to SOB_{12}, these abundance patterns show a slight enrichment of 1.3x in basalt followed by a gradual depletion through andesite ($\approx$ SOB_{12}) and a more varied range among dacites and rhyolites (0.55x to 1.22x SOB_{12}), before dropping to 0.08x in $SLPR_{08}$ (Fig. A2.12b). Overall, the BV range is enriched relative to Mole Granite except for some highly depleted rhyolites, and is depleted relative to Hawaiian Nepheline Melilitite. The range is subequal to or slightly depleted among the basalt-dacite range and strongly depleted among the rhyolites relative to Primitive MORB and Average Continental Crust. For SOB_{12}, Mole Granite is complementary to Primitive MORB, Hawaiian Nepheline Melilitite and Average

Continental Crust.

On **MnO v SiO_2** (Fig. A2.12c), the Main Trend shows a steep positively trending mafic trend, a moderately negative slope in the Intermediate Segment and a steep negative slope in the felsic trend. SOA_{10} plots slightly below Cross Trend 1 and well below Cross Trend 2 and the Main Trend. SFA_{09} and SED_{05} plot close to the Intermediate Segment. SAD_{24} plots significantly below the Main Trend and the Dyke Trend is distinct and nearly normal to the Main Trend. Select rhyolites exhibit considerable dispersal along the felsic trend. Altered rocks (Fig. A2.12e) generally form a broad band declining from about 0.2% MnO at about 49% SiO_2 to almost zero MnO at 80% SiO_2. The carbonated basaltic andesite plots well above that band. White rhyolites are offset towards 100% SiO_2 from rhyolitic pitchstones.

MnO v SiO_2 (Fig. A2.12g,i,k) shows the BV Mafic Segment overlapping the range of BVSP Reference Arc, Continental and Oceanic analyses. Felsic to intermediate BV analyses overlap I- and M-type granitoids even though they plot below the Intermediate Segment, and nearly overlap Average Continental Crust and Mole Granite. Hawaiian Nepheline Melilitite has higher MnO than select BV basalts. Regional comparisons (Fig. A2.12m,o,q,s) also indicate similarity between the BV range and the Werrie Basalt, Halls Peak intrusives, Early Permian mafic intrusives, Hillgrove and Copeton granitoids, Late Carboniferous volcanic rocks, Tertiary volcanic rocks and unassigned Boggabri Volcanics. However, some of these suites plot at marginally lower MnO that the BV range.

MnO v Cr (Fig. A2.12d) exhibits a Main Trend with a gently positive slope in the Mafic Segment and essentially colinear, negative slope in the Intermediate and Felsic Segments. SOA_{10} plots slightly below Cross Trend 1 and well below Cross Trend 2 and the Main Trend. SFA_{09} and SED_{05} plot close to the Intermediate Segment. SAD_{24} plots significantly away from the Intermediate Segment and the Dyke Trend is distinct. Select rhyolites exhibit considerable scatter along the felsic trend. Altered felsic to intermediate rocks (Fig. A2.12f) closely mimic the Main Trend (#01 with high Cr excepted), but altered mafic rocks display considerable scatter. The zeolitized basalt (#33), one carbonated basalt (#44) and the carbonated basaltic andesite (#03) are notably enriched in MnO relative to this trend.

MnO v Cr (Fig. A2.12h,j,l) distinguishes the BVSP Reference Oceanic basalts, Average Continental Crust, I-type granitoid, Petroi Metabasalt (higher Cr), Hawaiian Nepheline Melilitite (distinctly lower MnO) and some Early Permian central NEO mafic complexes. Mole Granite and other regional suites are not distinguished (Fig. A2.12n,p,r,t). The BV range also partly overlaps the lower Cr range of BVSP Reference Arc and Continental basalts.

In summary, select BV display a range from SPB_{39} (1.3x SOB_{12}) and an inferred peak at the Mafic Inflection (1.6x SOB_{12}) to about 0.08 to 0.55x SOB_{12} among rhyolite pitchstones. SOB_{12} contains more MnO than Mole Granite but less than other reference compositions. Si-Cr-Mn systematics for select BV indicate similar MnO values to BVSP Arc, Continental and many Oceanic basalts, Petroi Metabasalts, Early Permian central NEO mafic complexes, Halls Peak volcanics and unassigned Boggabri Volcanics, but distinguish most select M-, I- and S-type granitoids and some Late Carboniferous volcanic rocks (low MnO) and Hawaiian Nepheline Melilitite (high MnO).

Alumina

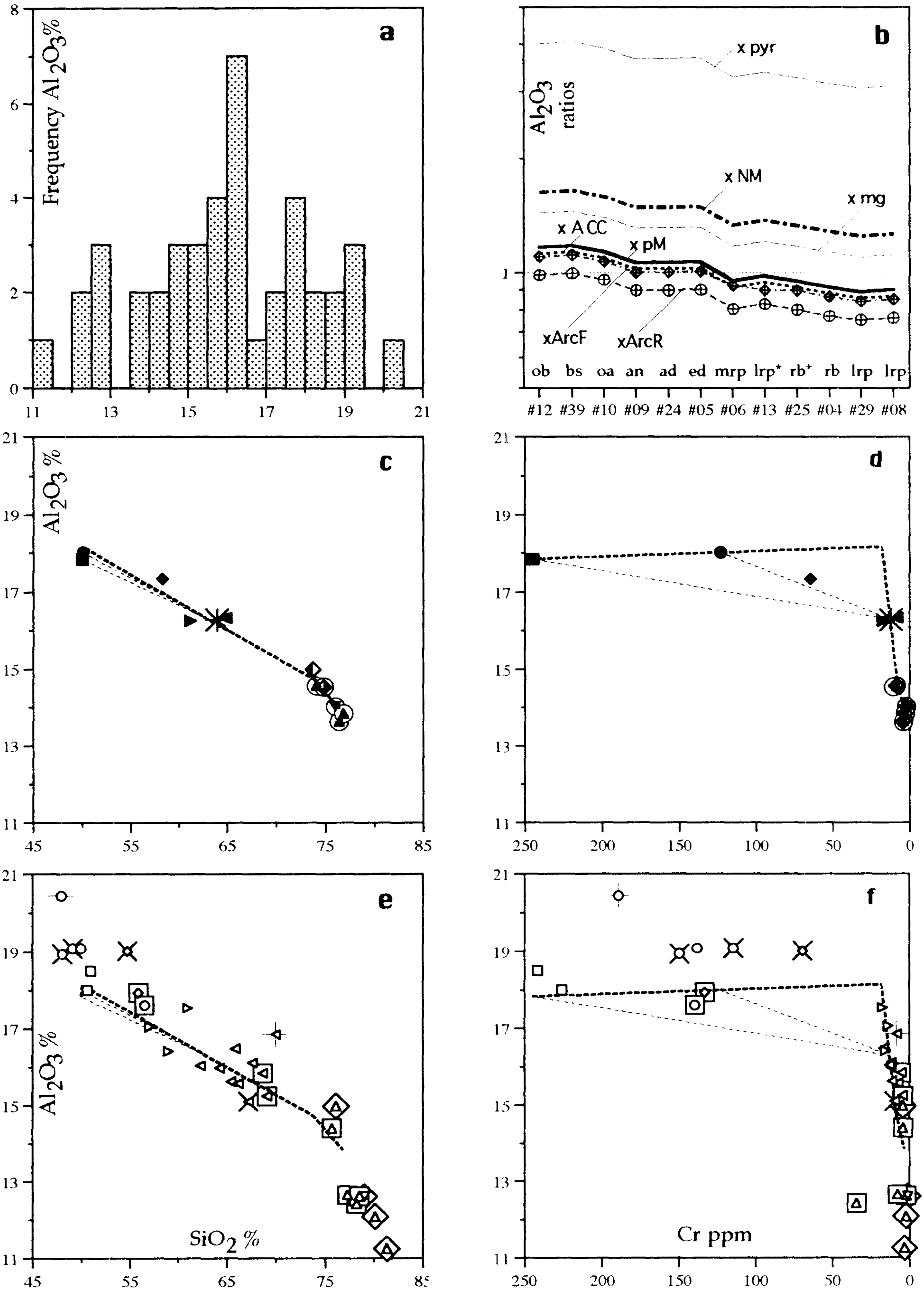

Fig. A2.4 (a–f): Al_2O_3 in Boggabri Volcanics — histogram for all BV, relative abundance plot for Select BV, and variation in Select and altered BV compared to SiO_2 and Cr (see Fig. A2.1 for legend, and text for explanation)

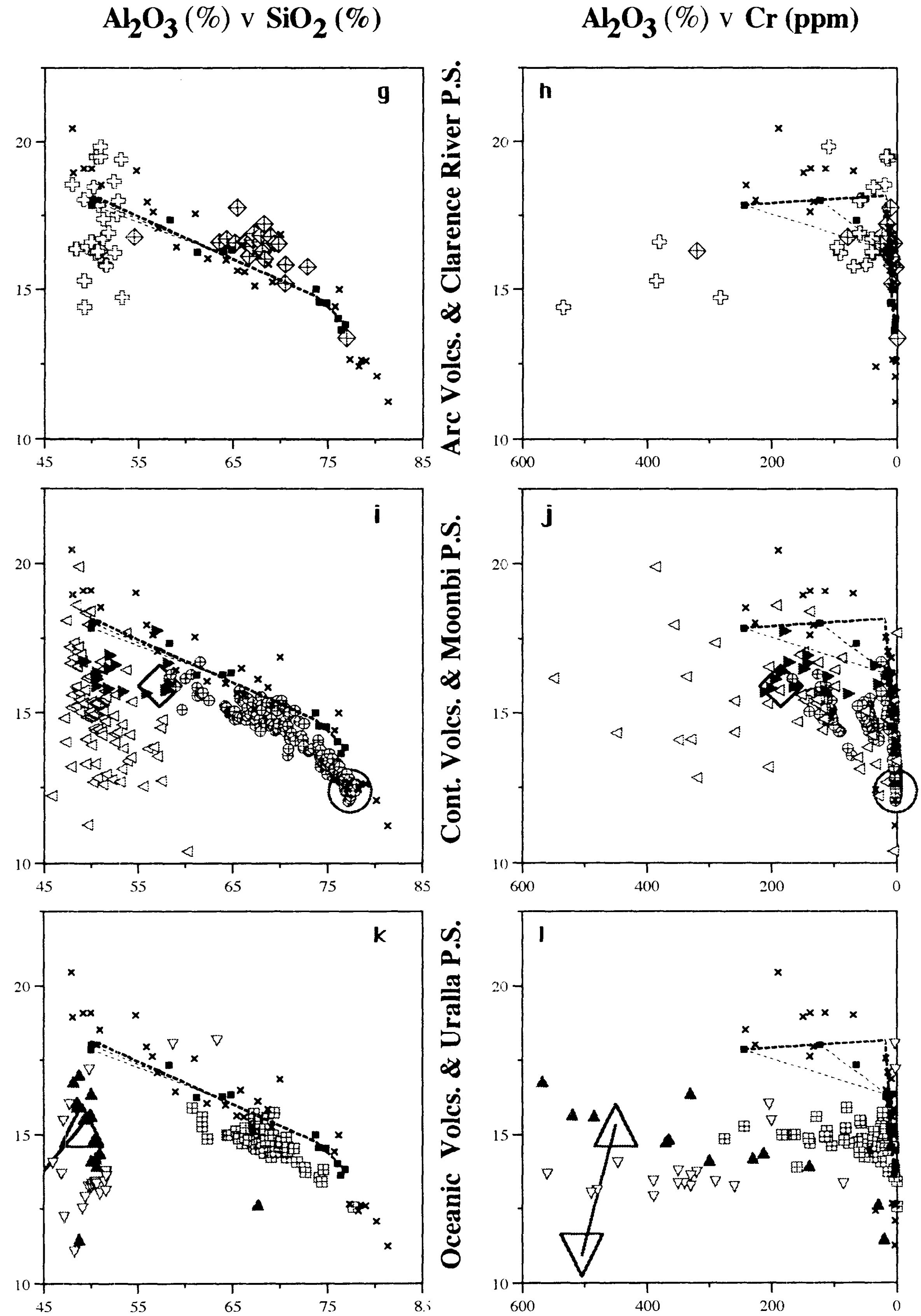

Fig. A2.4 (g–l): Al_2O_3 in Boggabri Volcanics — comparison with major geochemical reservoirs and select volcanic rocks and granitoid suites

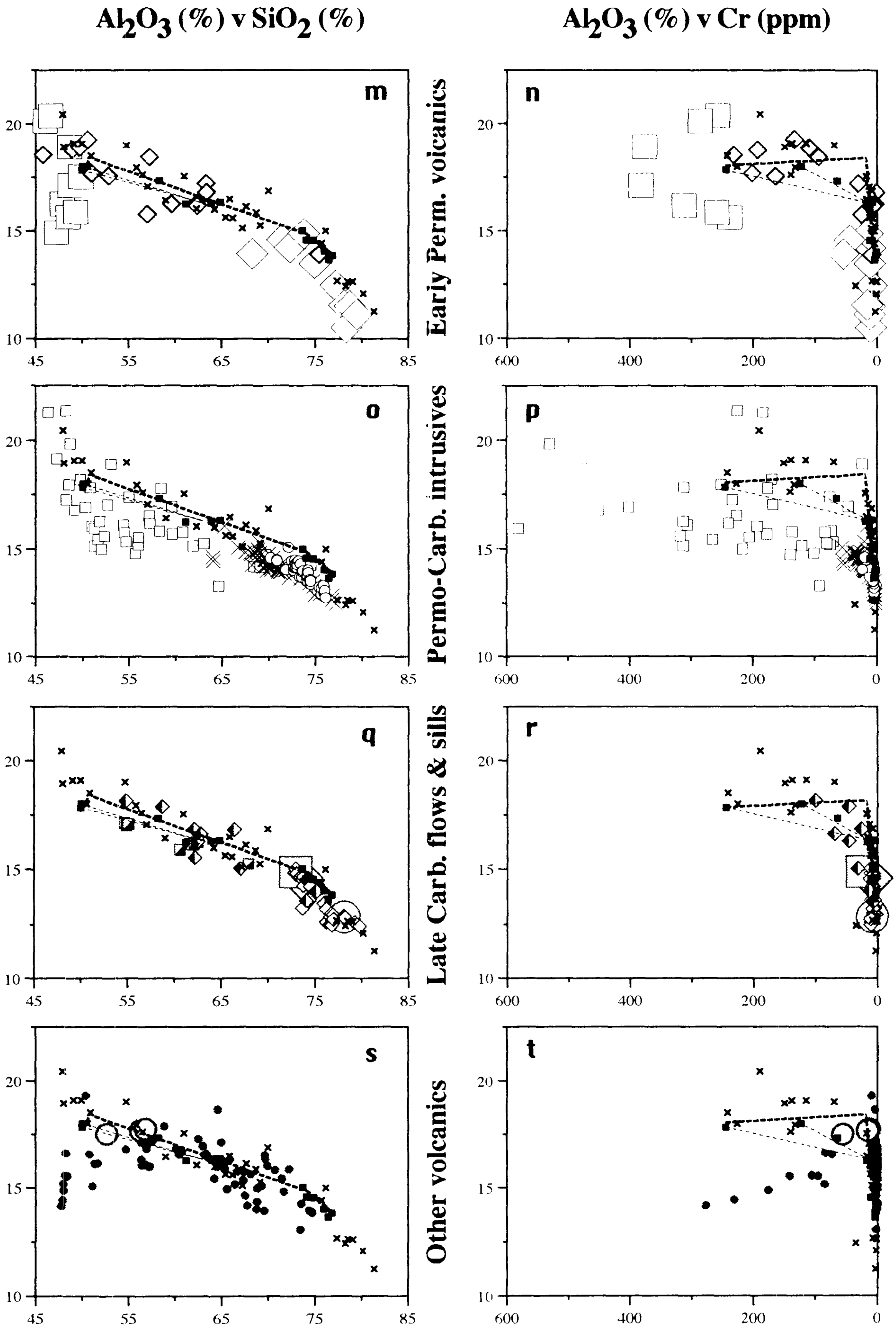

Fig. A2.4 (m–t): Al_2O_3 in Boggabri Volcanics — regional comparisons

Iron Oxide

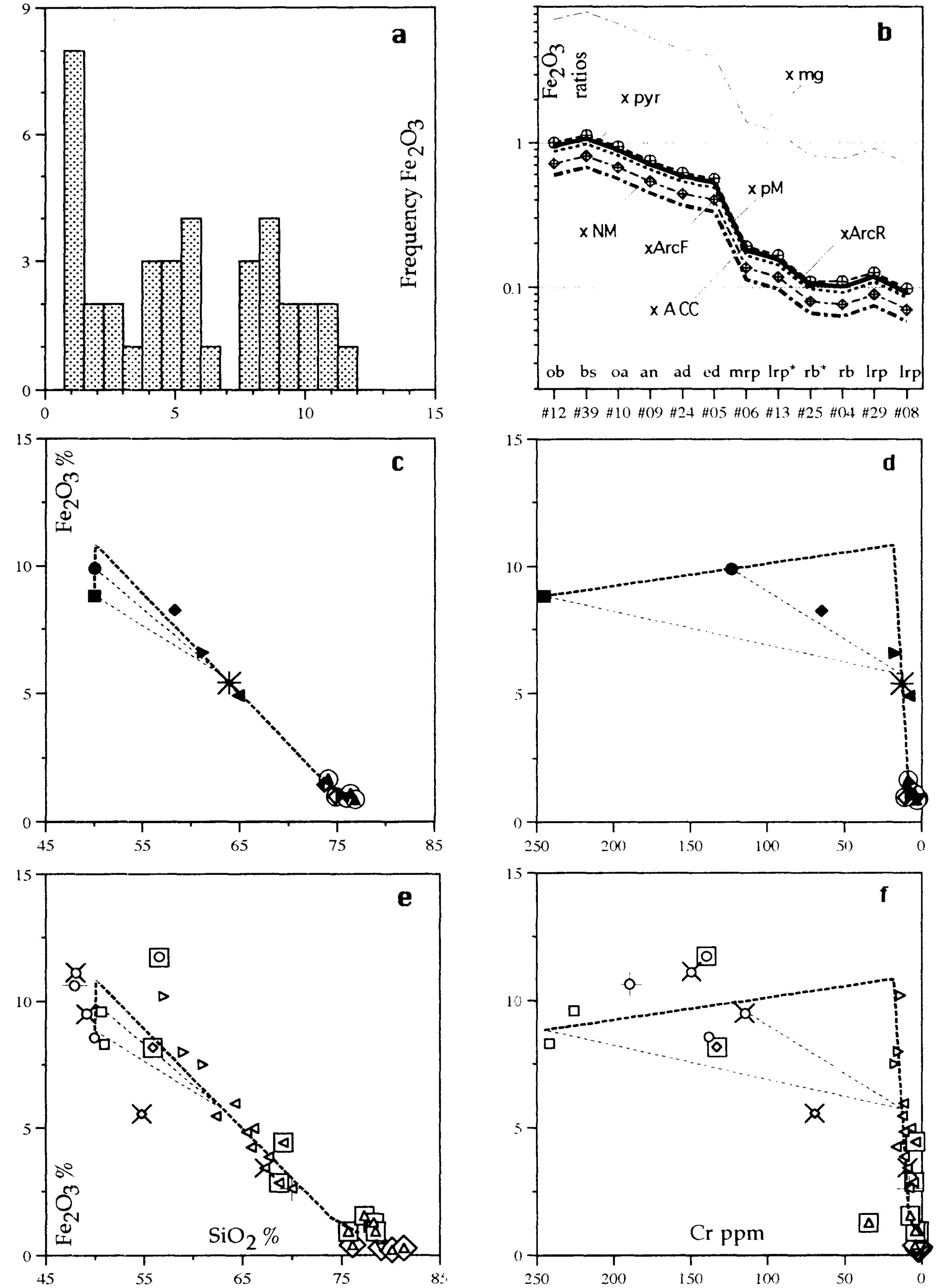

Fig. A2.5 (a–f): Fe_2O_{3t} in Boggabri Volcanics — histogram for all BV, relative abundance plot for Select BV, and variation in Select and altered BV compared to SiO_2 and Cr (see Fig. A2.1 for legend, and text for explanation)

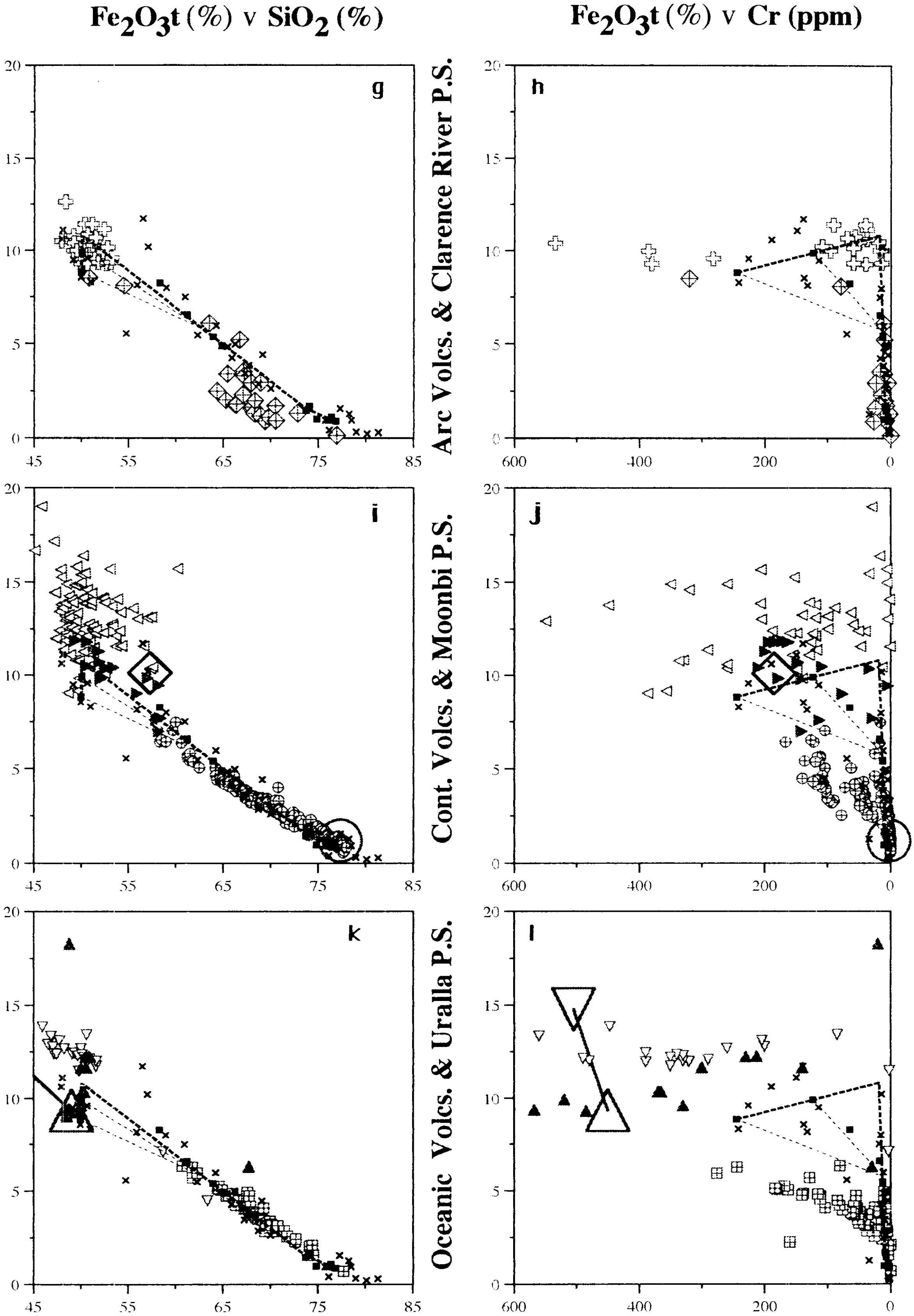

Fig. A2.5 (g–l): Fe_2O_3t in Boggabri Volcanics — comparison with major geochemical reservoirs and select volcanic rocks and granitoid suites

Fe_2O_3t (%) v SiO_2 (%) **Fe_2O_3t (%) v Cr (ppm)**

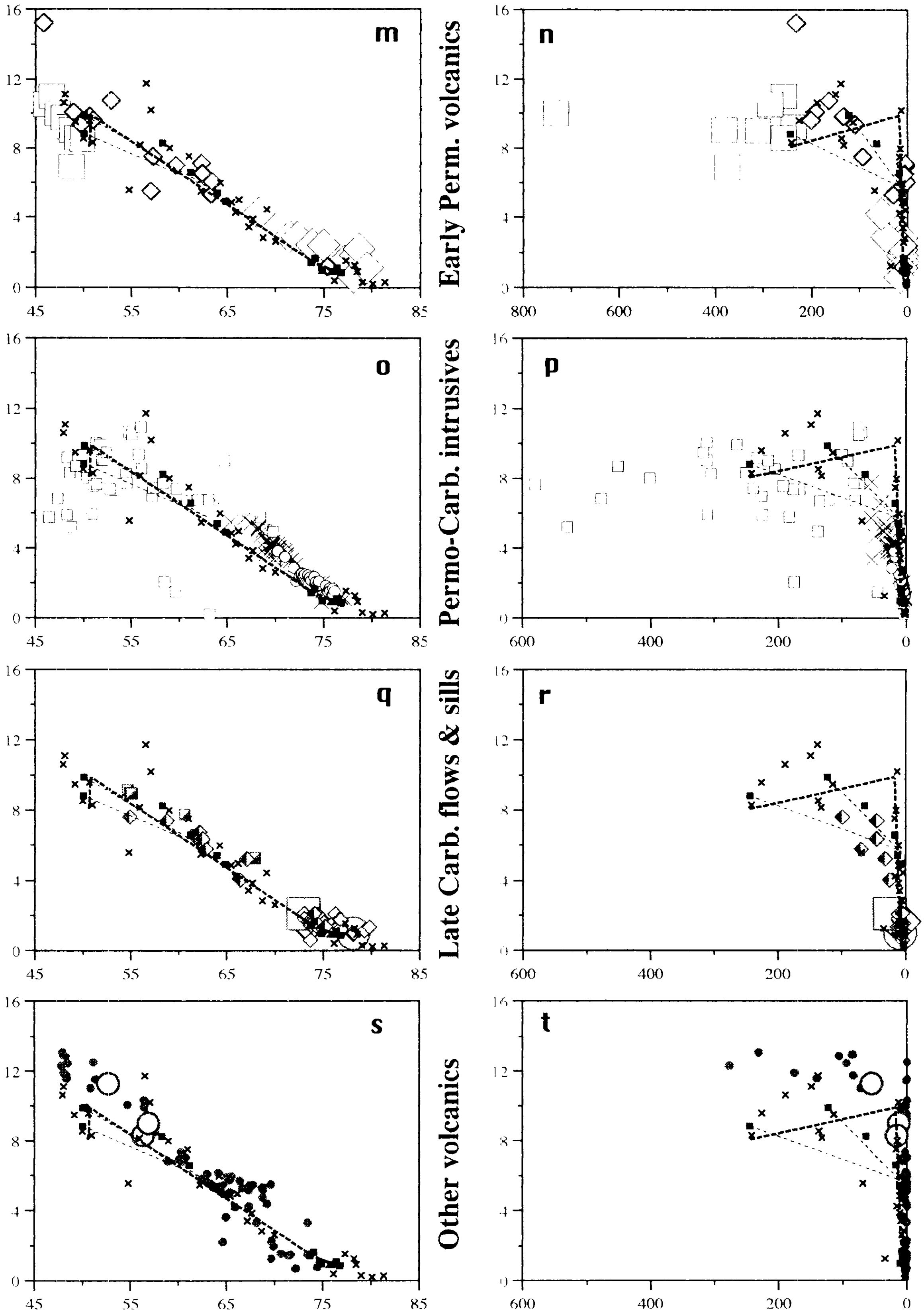

Fig. A2.5 (m–t): Fe_2O_3t in Boggabri Volcanics — regional comparisons

Calcium Oxide

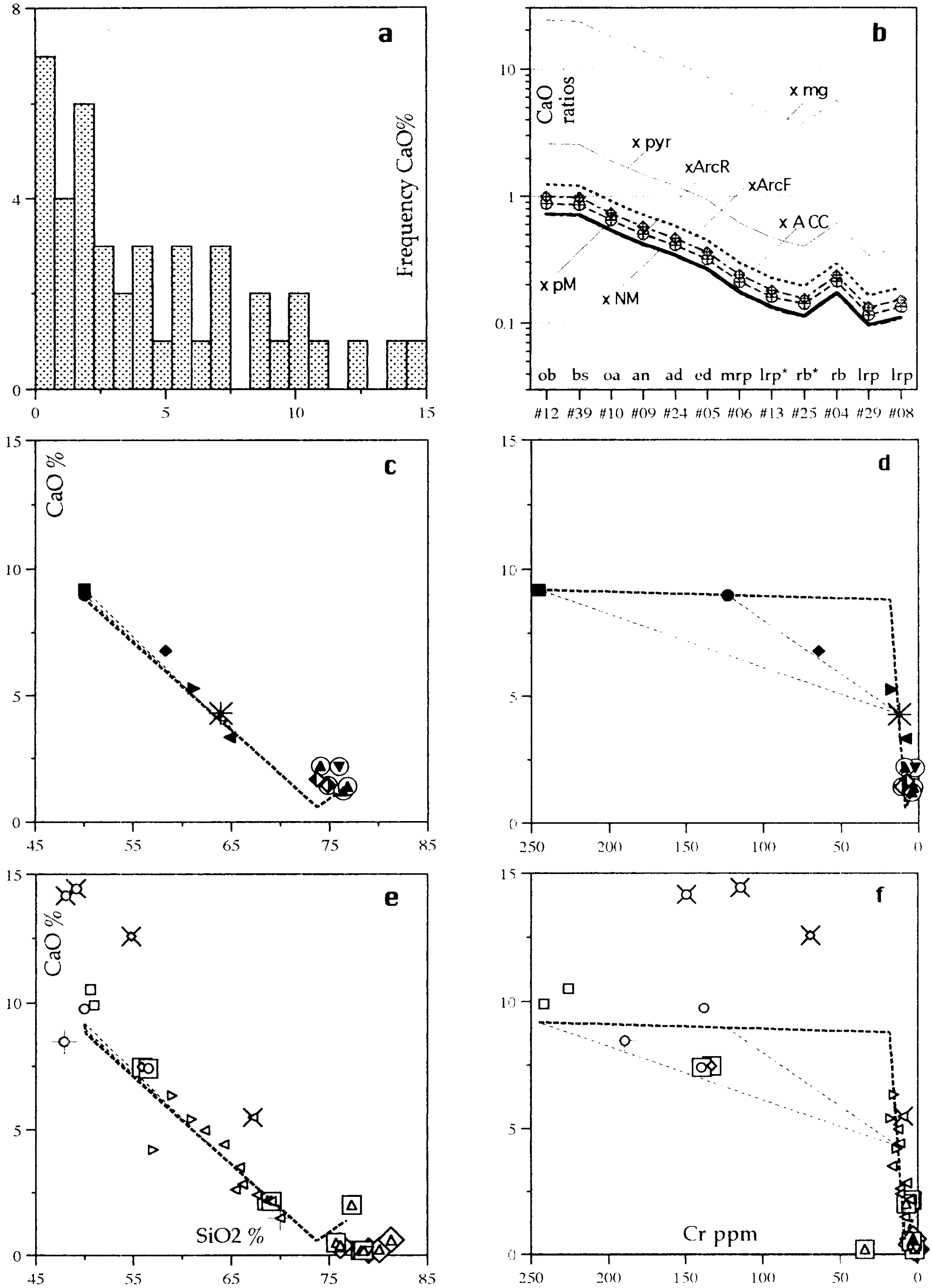

Fig. A2.6 (a–f): CaO in Boggabri Volcanics — histogram for all BV, relative abundance plot for Select BV, and variation in Select and altered BV compared to SiO_2 and Cr (see Fig. A2.1 for legend, and text for explanation)

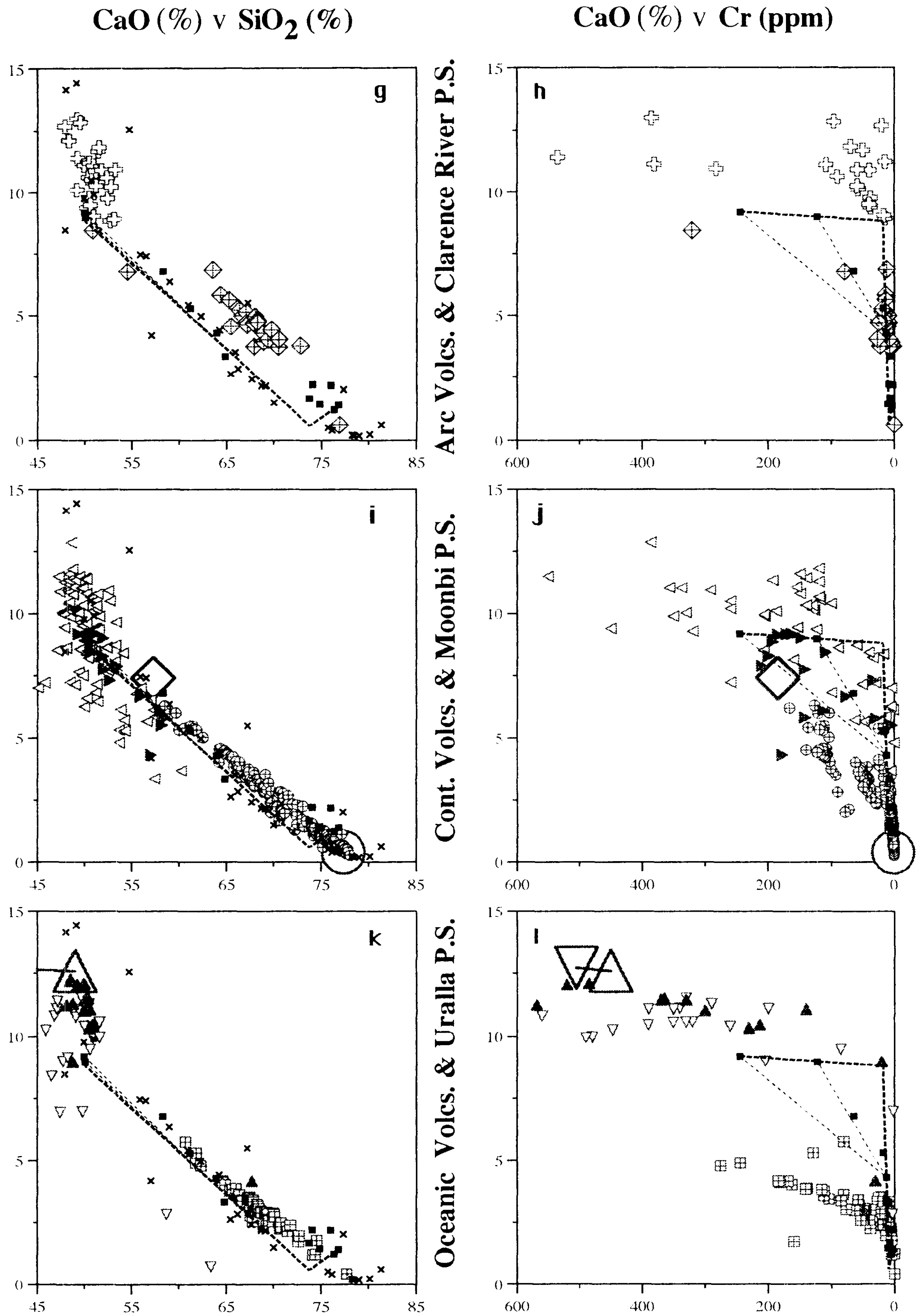

Fig. A2.6 (g–l): CaO in Boggabri Volcanics — comparison with major geochemical reservoirs and select volcanic rocks and granitoid suites

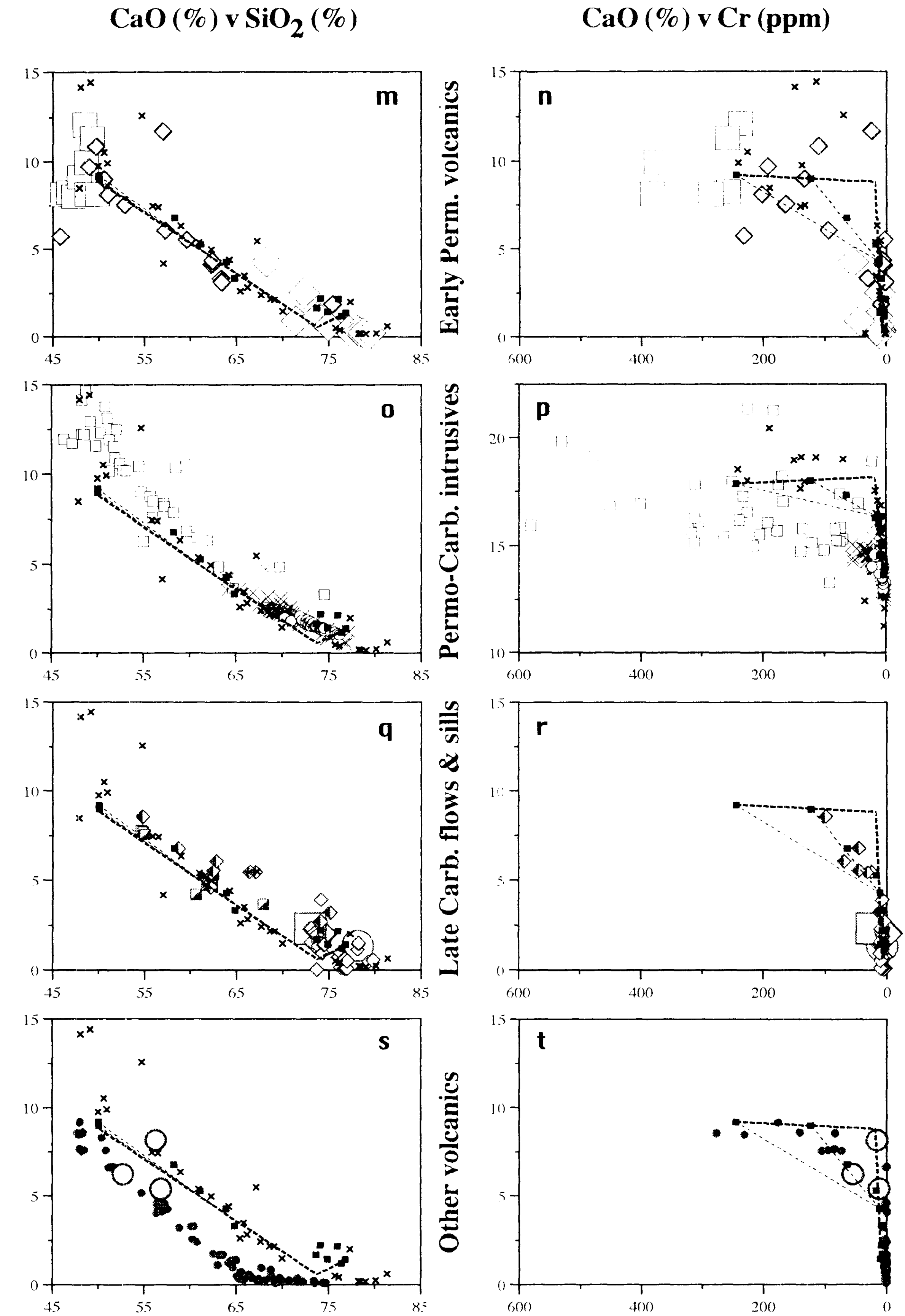

Fig. A2.6 (m–t): CaO in Boggabri Volcanics — regional comparisons

Magnesia

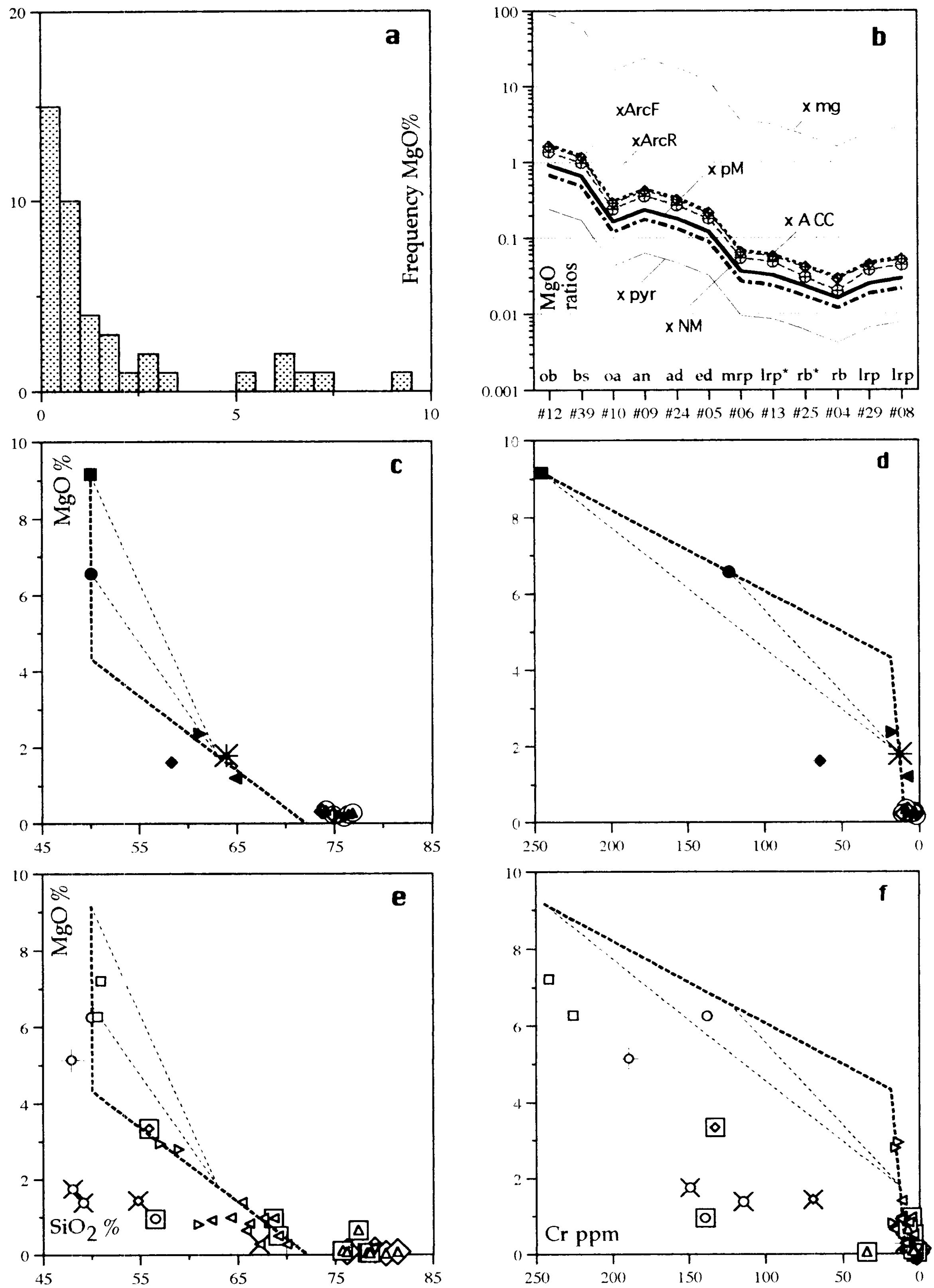

Fig. A2.7 (a–f): MgO in Boggabri Volcanics — histogram for all BV, relative abundance plot for Select BV, and variation in Select and altered BV compared to SiO_2 and Cr (see Fig. A2.1 for legend, and text for explanation)

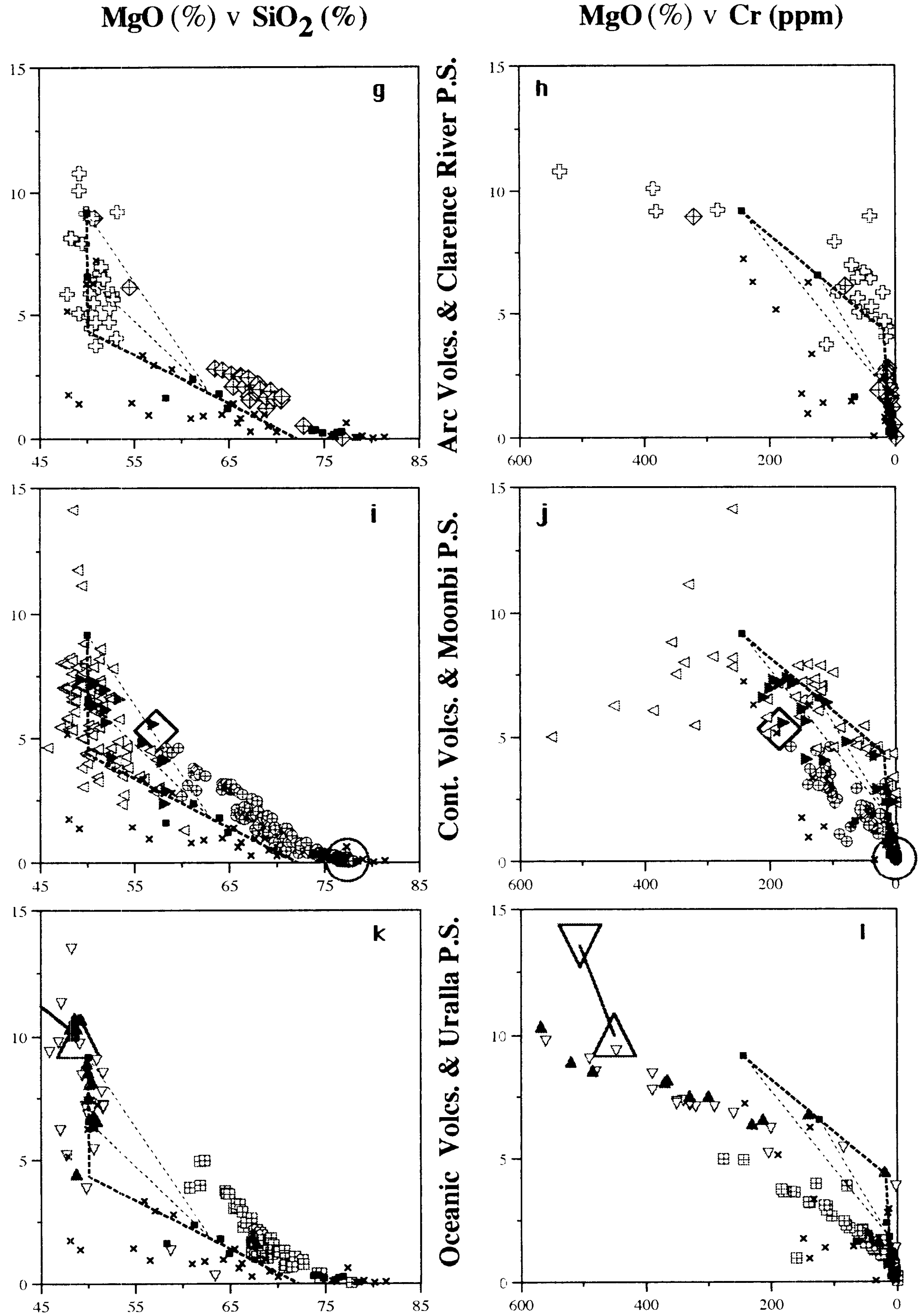

Fig. A2.7 (g–l): MgO in Boggabri Volcanics — comparison with major geochemical reservoirs and select volcanic rocks and granitoid suites

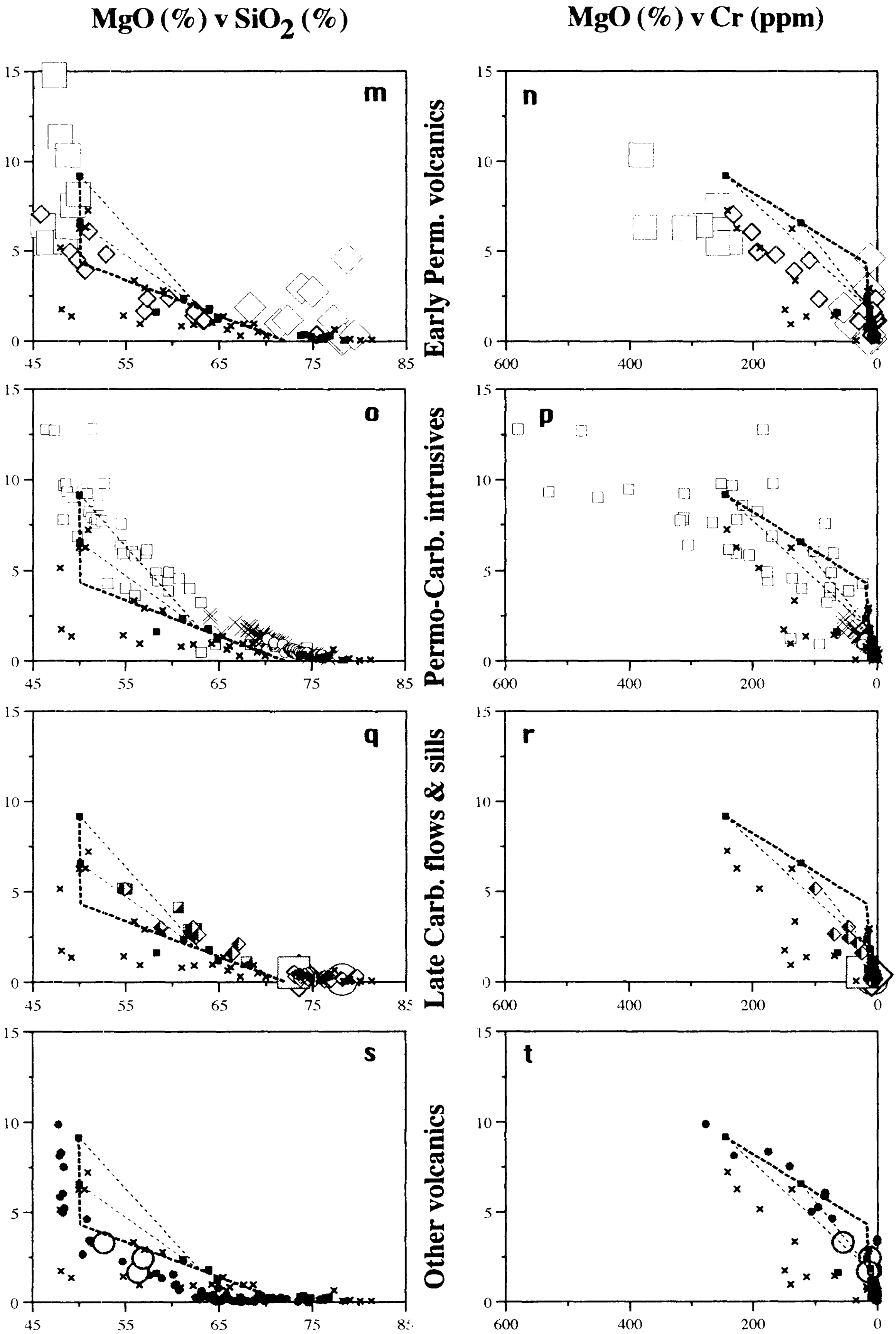

Fig. A2.7 (m–t): MgO in Boggabri Volcanics — regional comparisons

Sodium Oxide

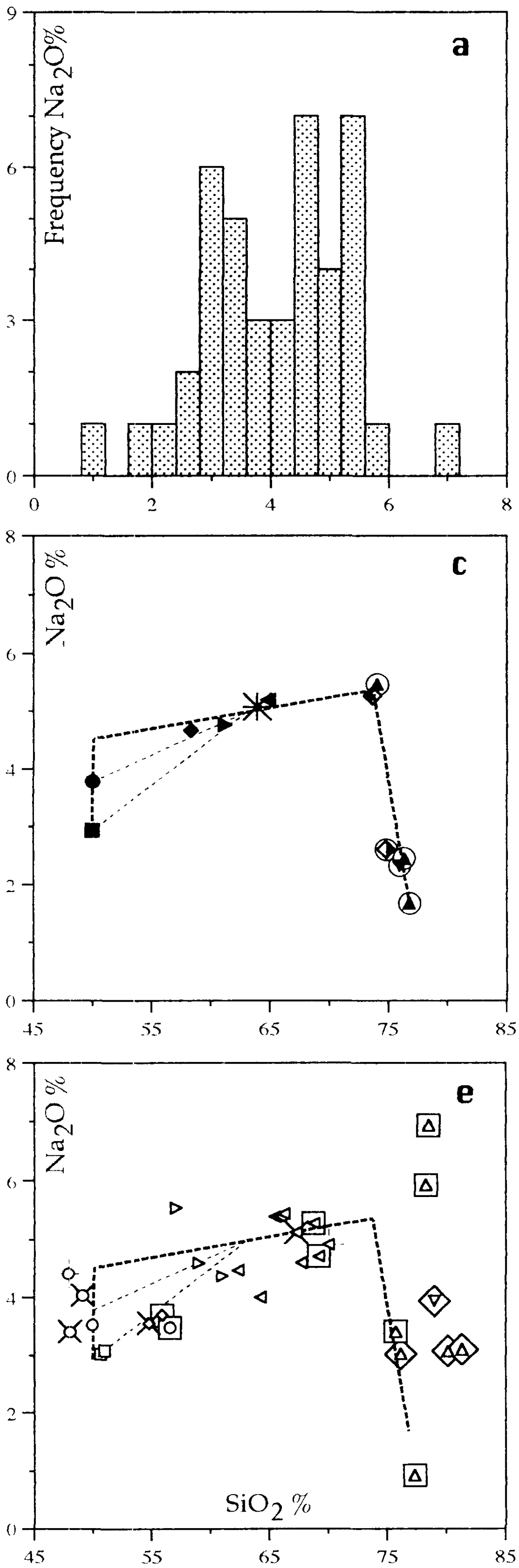

Fig. A2.8 (a–f): Na_2O in Boggabri Volcanics — histogram for all BV, relative abundance plot for Select BV, and variation in Select and altered BV compared to SiO_2 and Cr (see Fig. A2.1 for legend, and text for explanation)

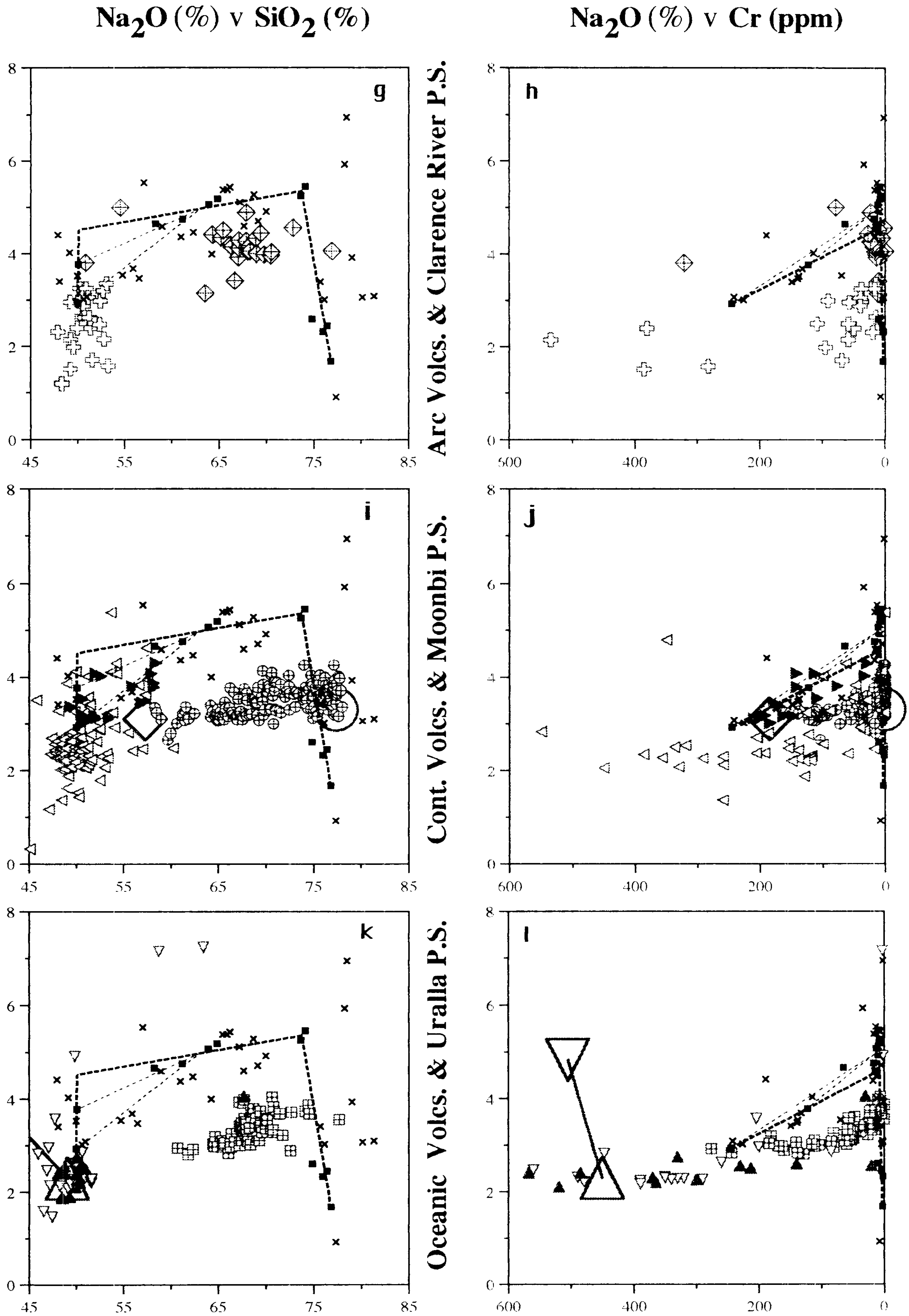

Fig. A2.8 (g–l): Na_2O in Boggabri Volcanics — comparison with major geochemical reservoirs and select volcanic rocks and granitoid suites

Na_2O (%) v SiO_2 (%) **Na_2O (%) v Cr (ppm)**

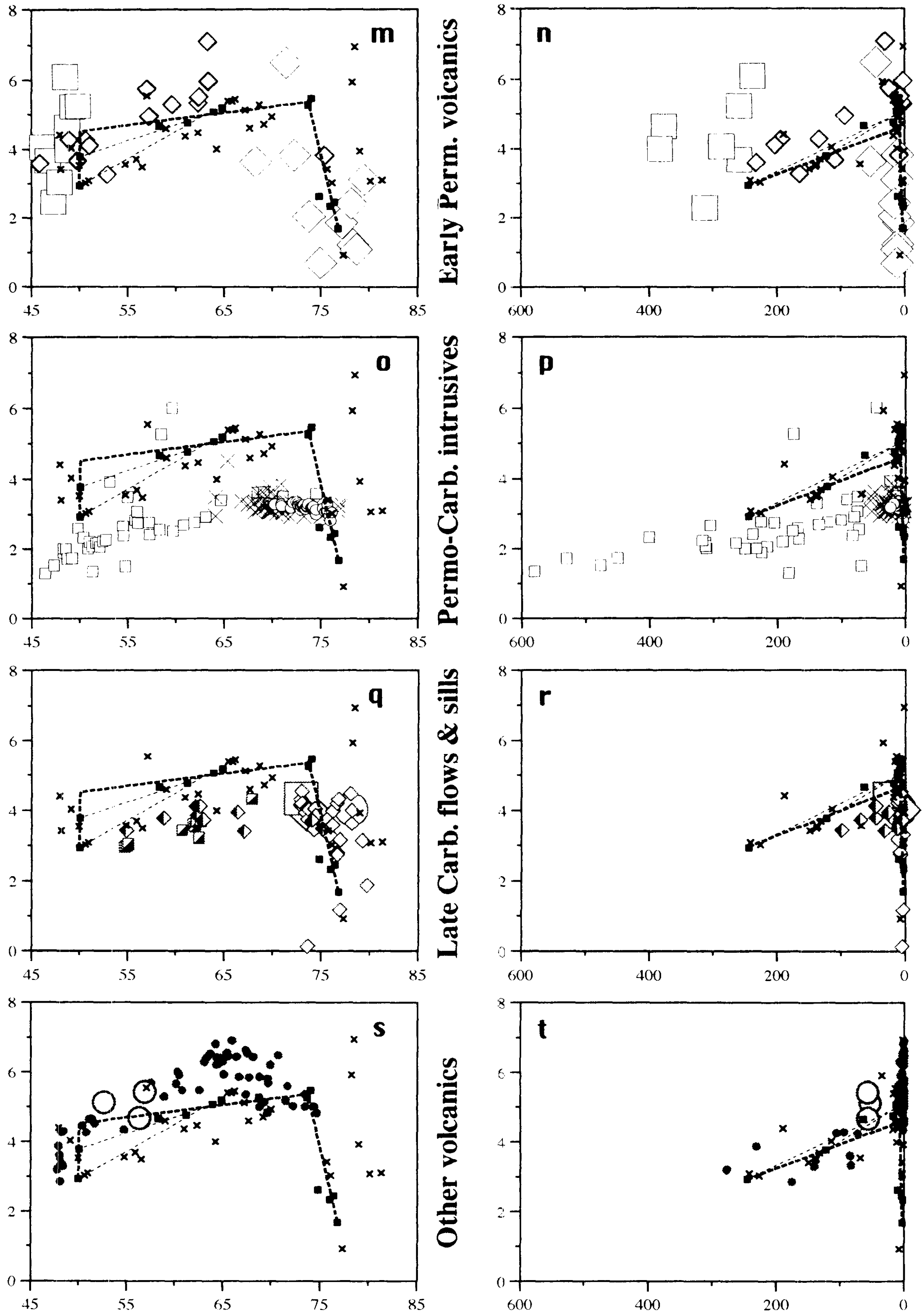

Fig. A2.8 (m–t): Na_2O in Boggabri Volcanics — regional comparisons

Potassium Oxide

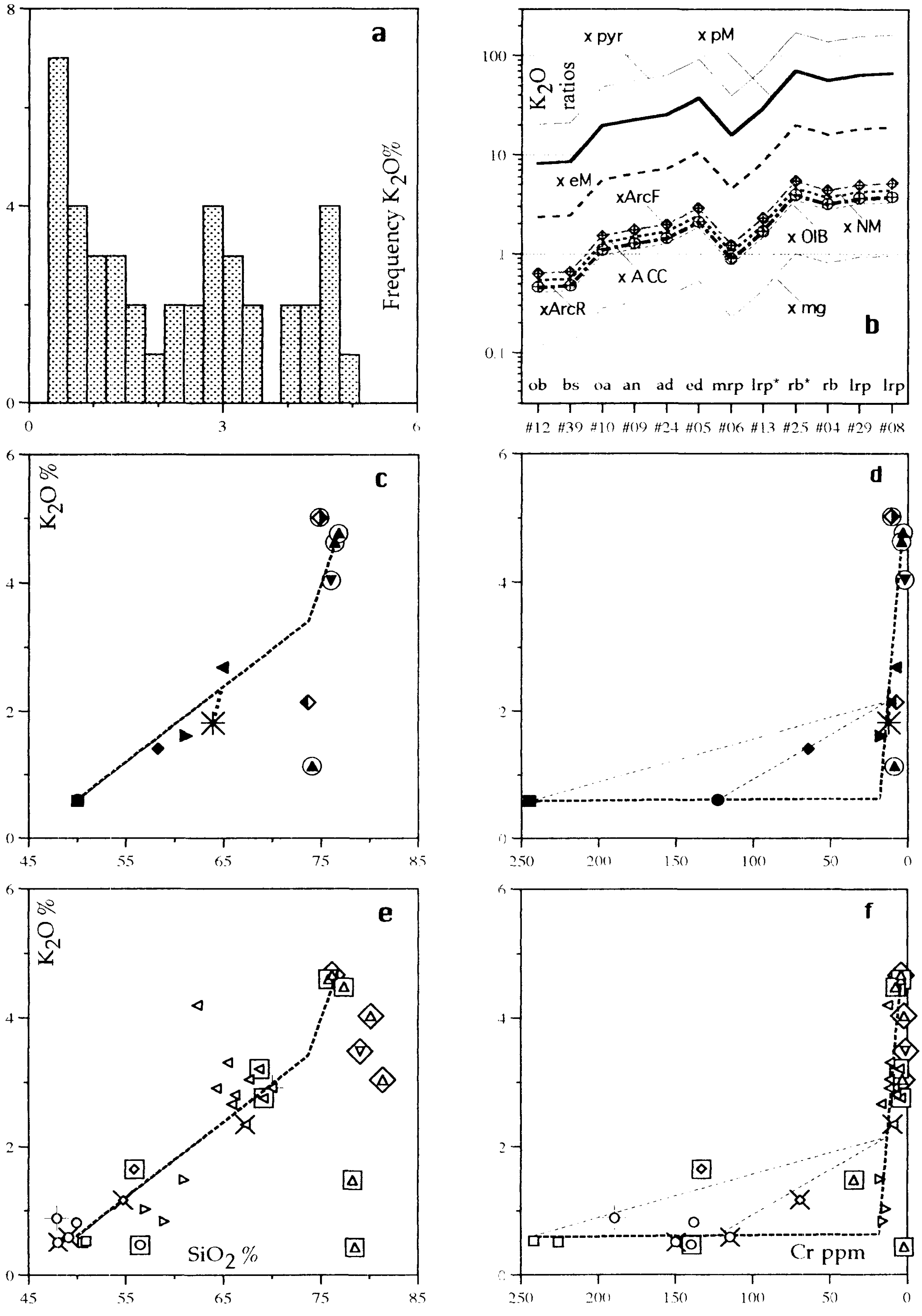

Fig. A2.9 (a–f): K_2O in Boggabri Volcanics — histogram for all BV, relative abundance plot for Select BV, and variation in Select and altered BV compared to SiO_2 and Cr (see Fig. A2.1 for legend, and text for explanation)

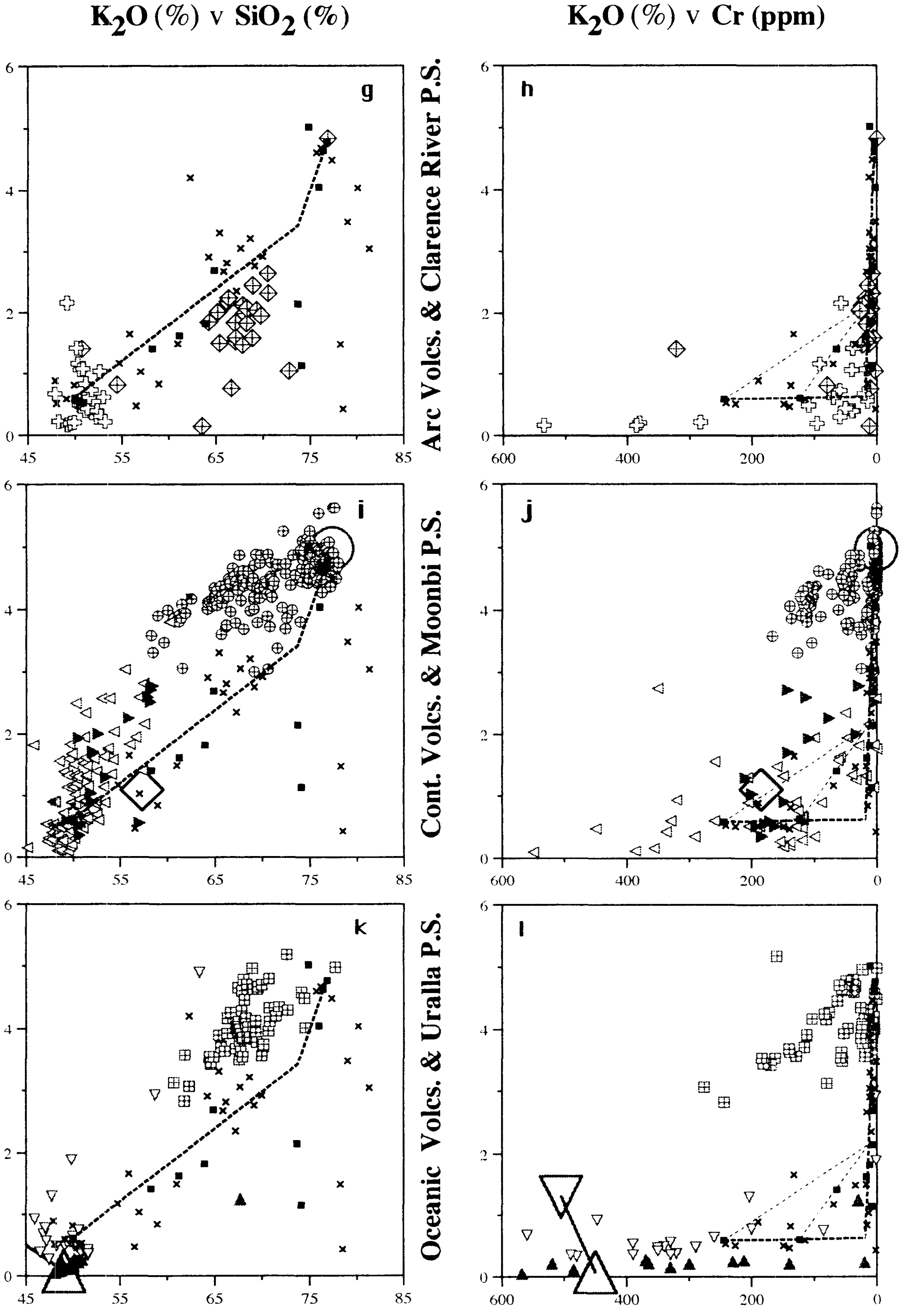

Fig. A2.9 (g–l): K_2O in Boggabri Volcanics — comparison with major geochemical reservoirs and select volcanic rocks and granitoid suites

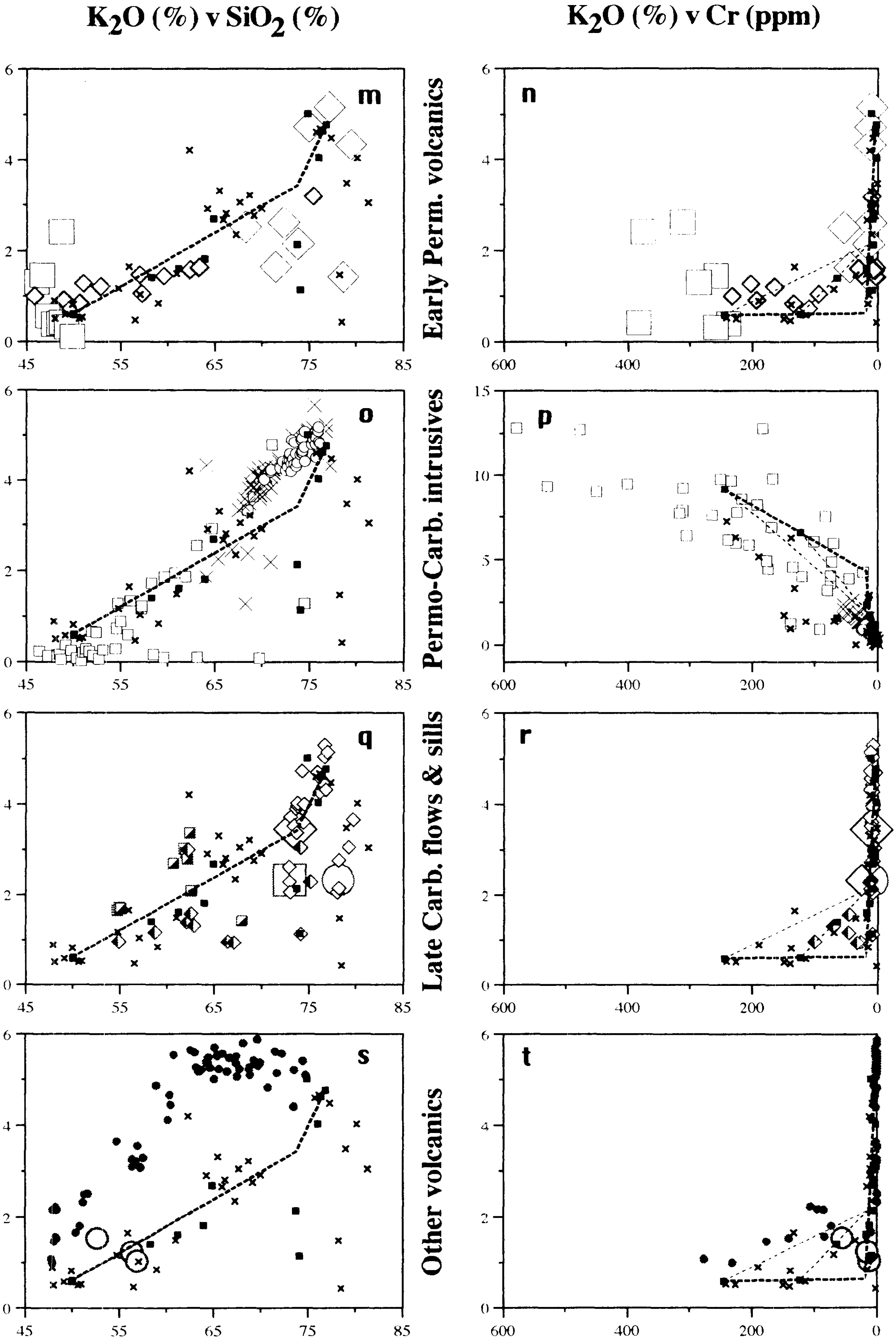

Fig. A2.9 (m–t): K_2O in Boggabri Volcanics — regional comparisons

Titania

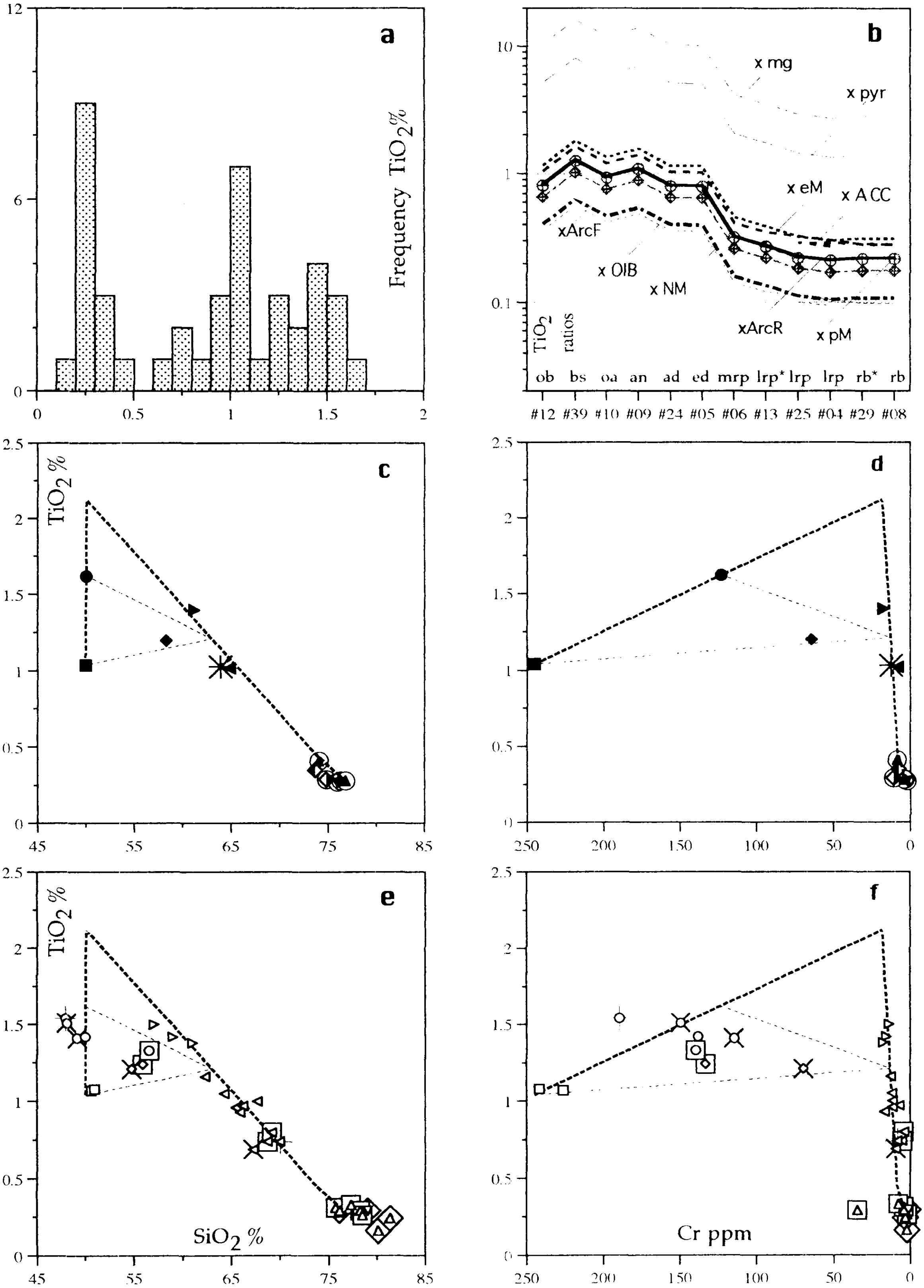

Fig. A2.10 (a–f): TiO_2 in Boggabri Volcanics — histogram for all BV, relative abundance plot for Select BV, and variation in Select and altered BV compared to SiO_2 and Cr (see Fig. A2.1 for legend, and text for explanation)

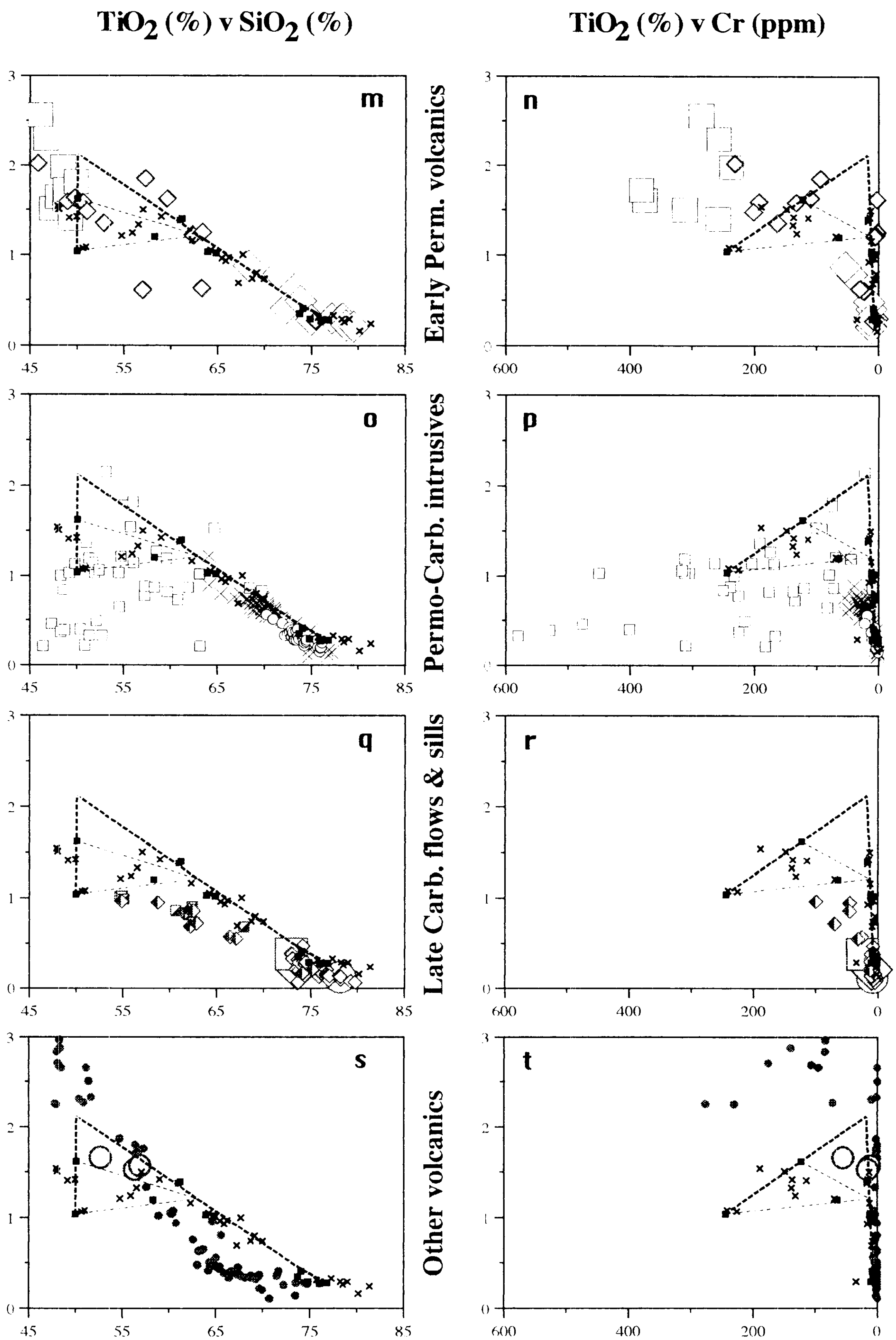

Fig. A2.10 (m–t): TiO_2 in Boggabri Volcanics — regional comparisons

Phosphorus Pentoxide

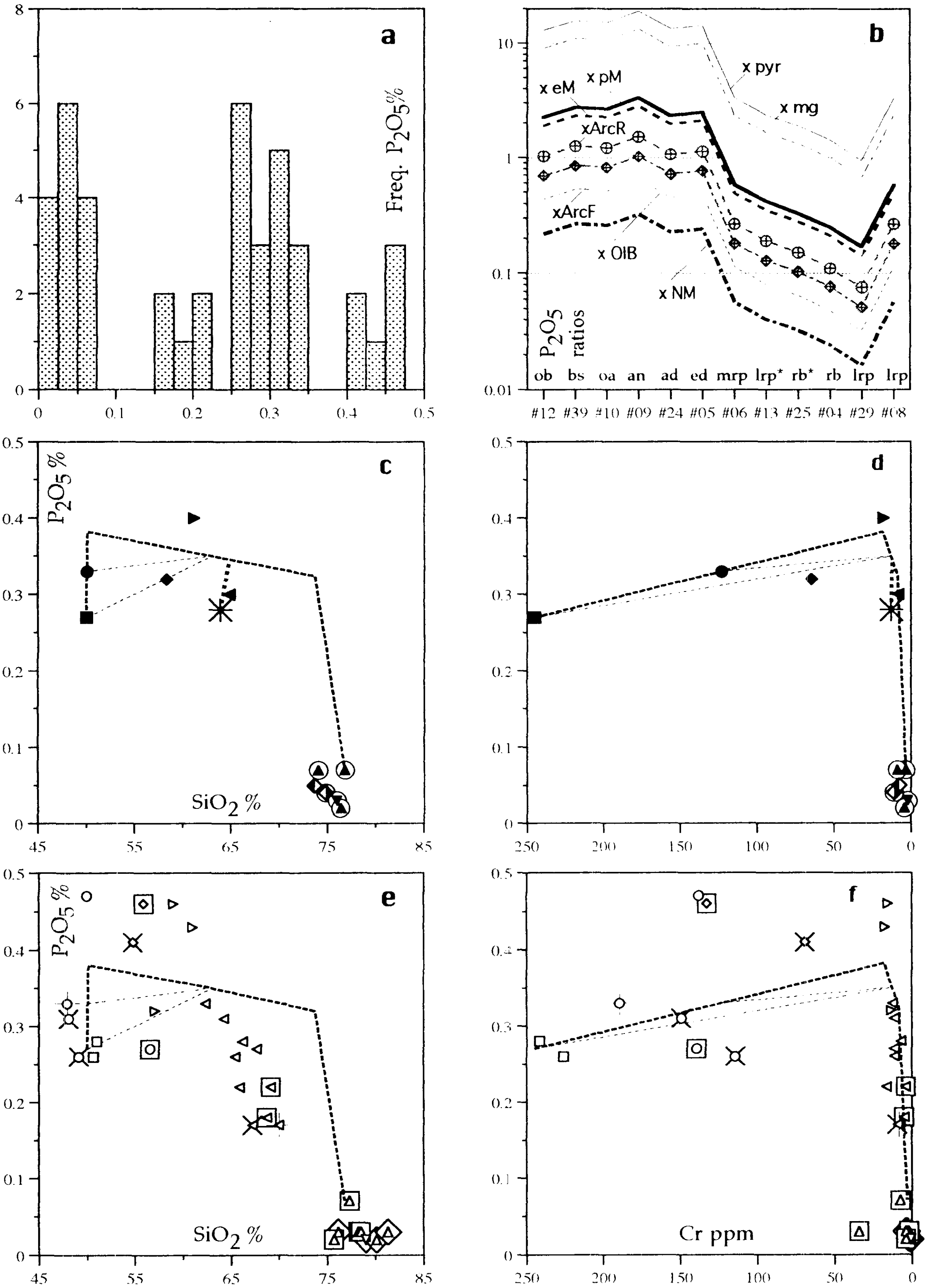

Fig. A2.11 (a–f): P_2O_5 in Boggabri Volcanics — histogram for all BV, relative abundance plot for Select BV, and variation in Select and altered BV compared to SiO_2 and Cr (see Fig. A2.1 for legend, and text for explanation)

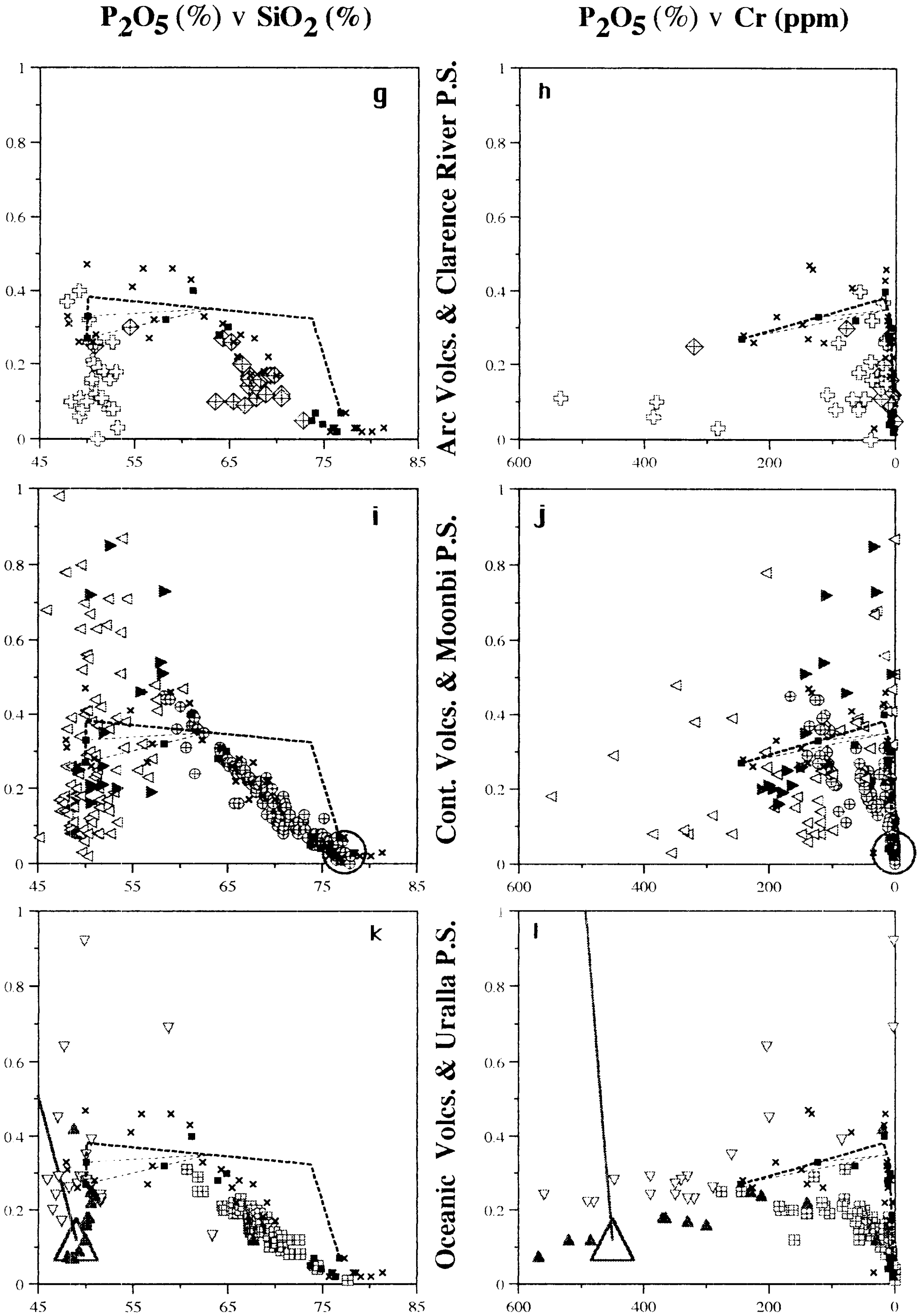

Fig. A2.11 (g–l): P_2O_5 in Boggabri Volcanics — comparison with major geochemical reservoirs and select volcanic rocks and granitoid suites

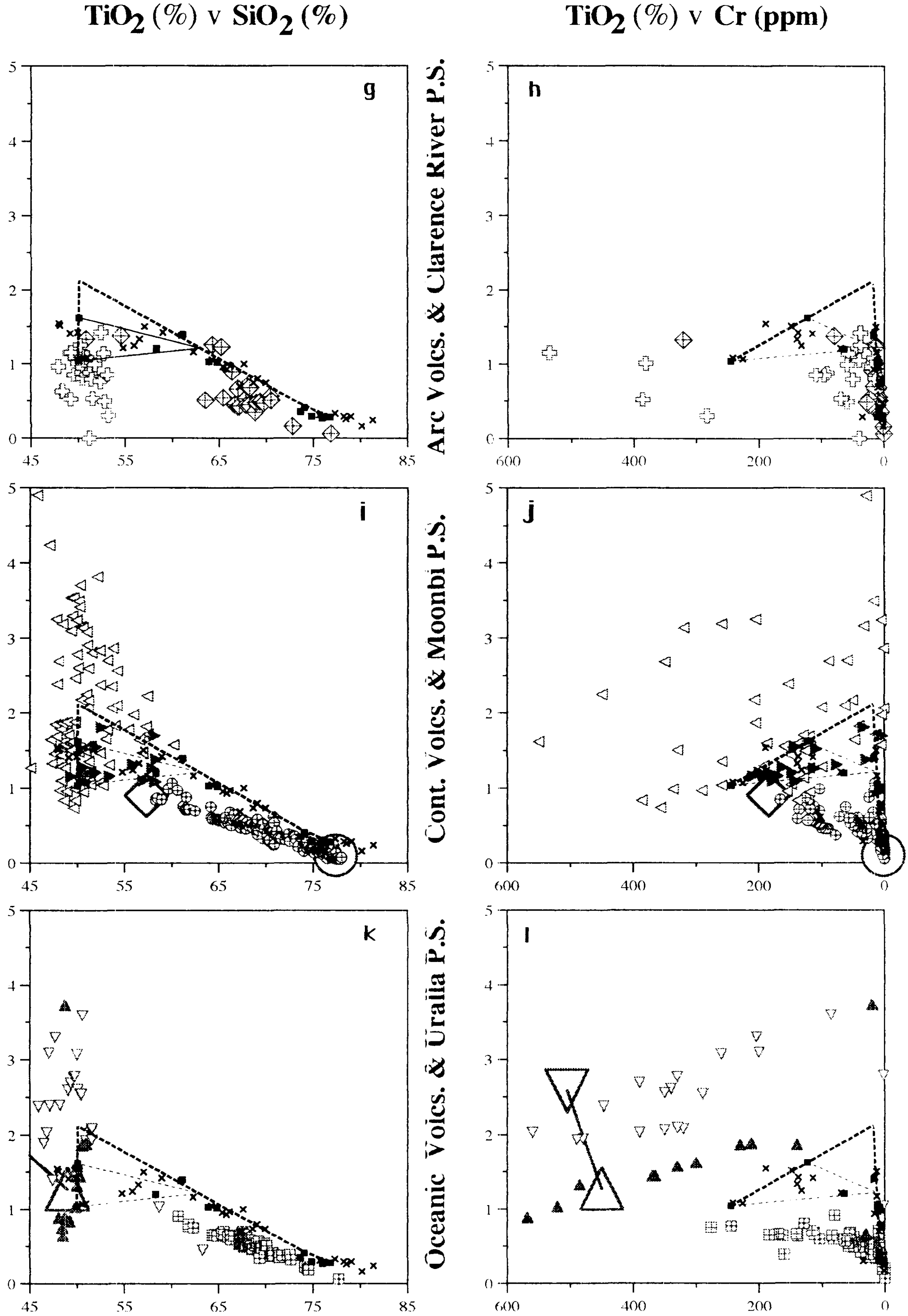

Fig. A2.10 (g–l): TiO_2 in Boggabri Volcanics — comparison with major geochemical reservoirs and select volcanic rocks and granitoid suites

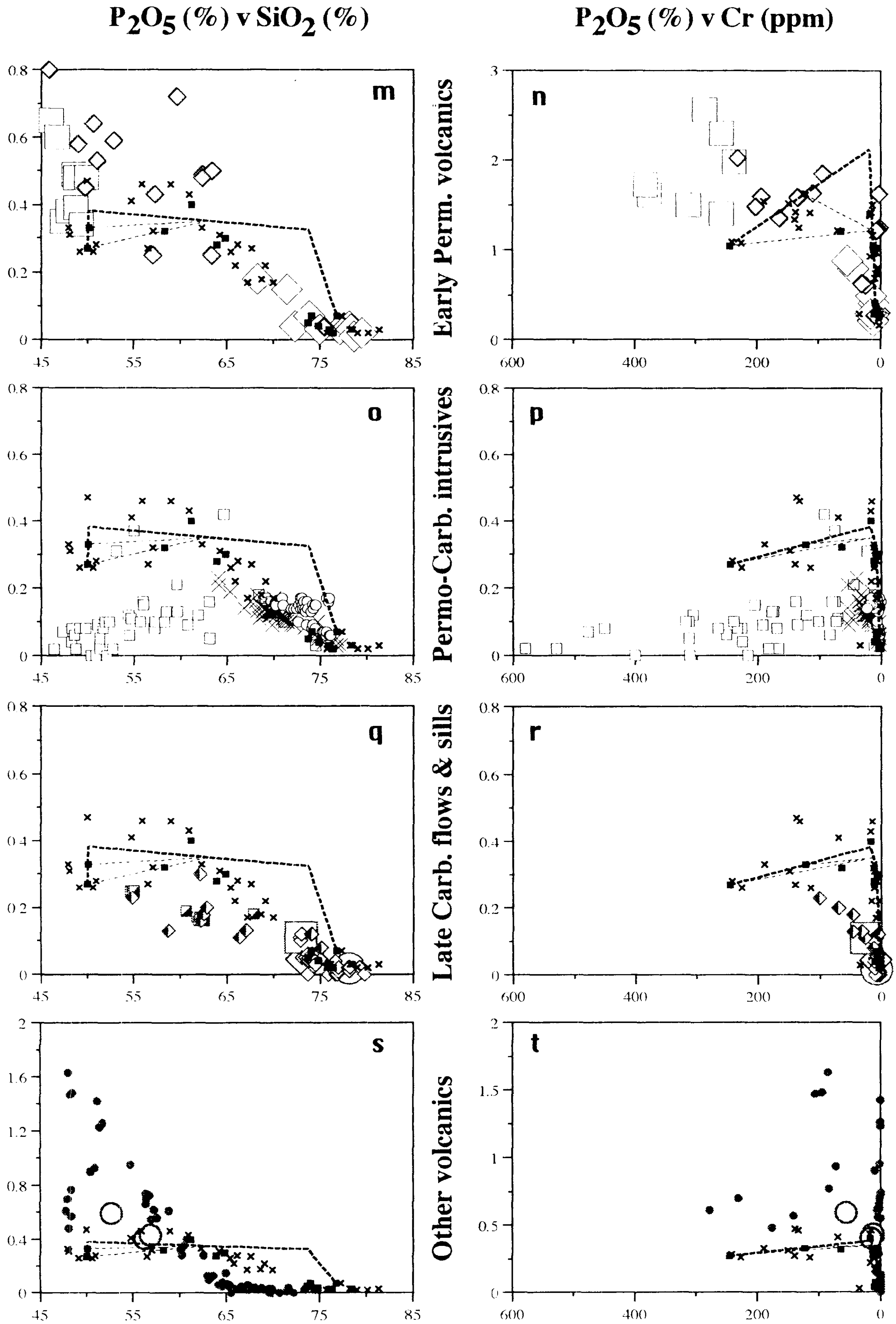

Fig. A2.11 (m–t): P_2O_5 in Boggabri Volcanics — regional comparisons

Manganese Oxide

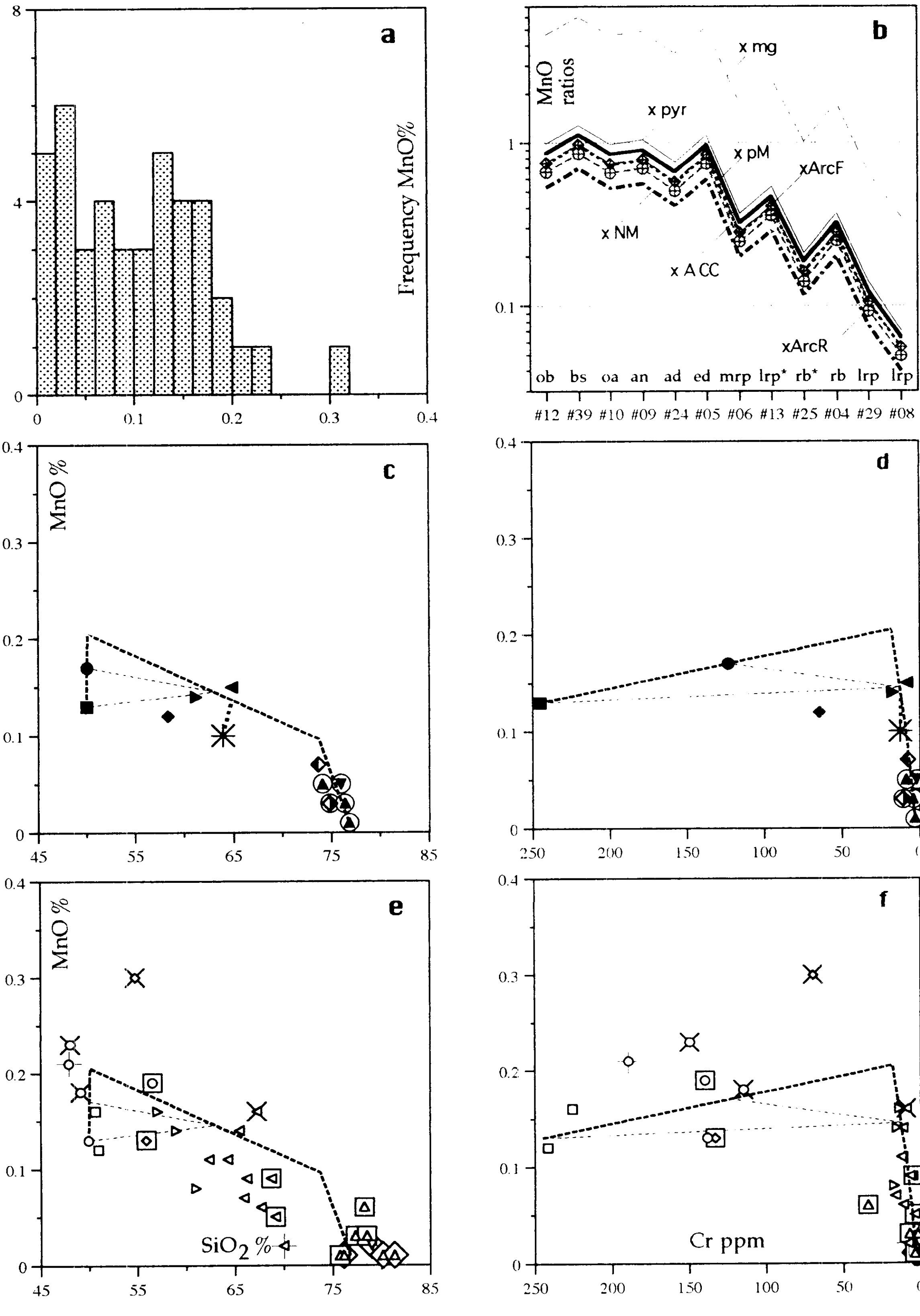

Fig. A2.12 (a–f): MnO in Boggabri Volcanics — histogram for all BV, relative abundance plot for Select BV, and variation in Select and altered BV compared to SiO_2 and Cr (see Fig. A2.1 for legend, and text for explanation)

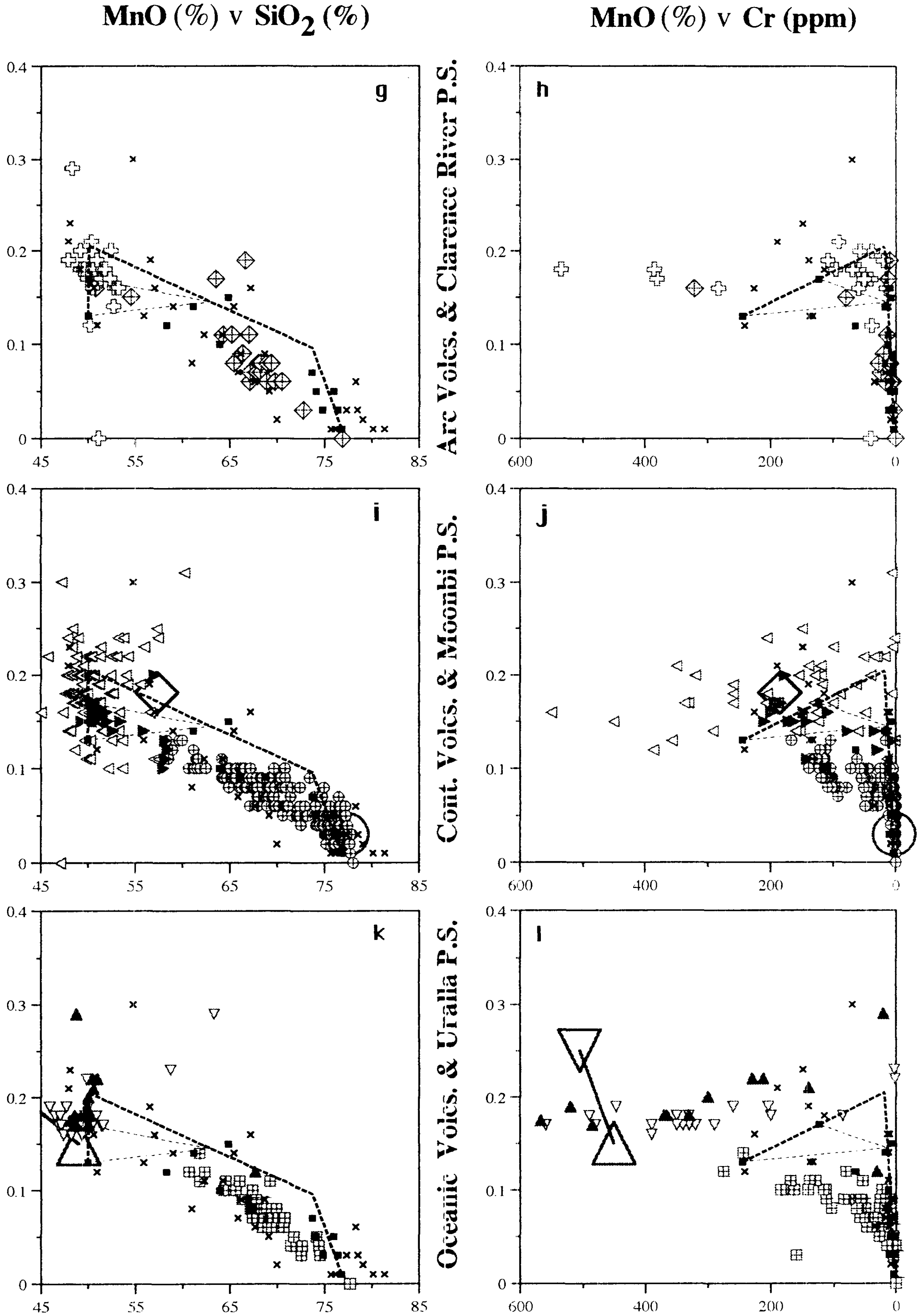

Fig. A2.12 (g–l): MnO in Boggabri Volcanics — comparison with major geochemical reservoirs and select volcanic rocks and granitoid suites

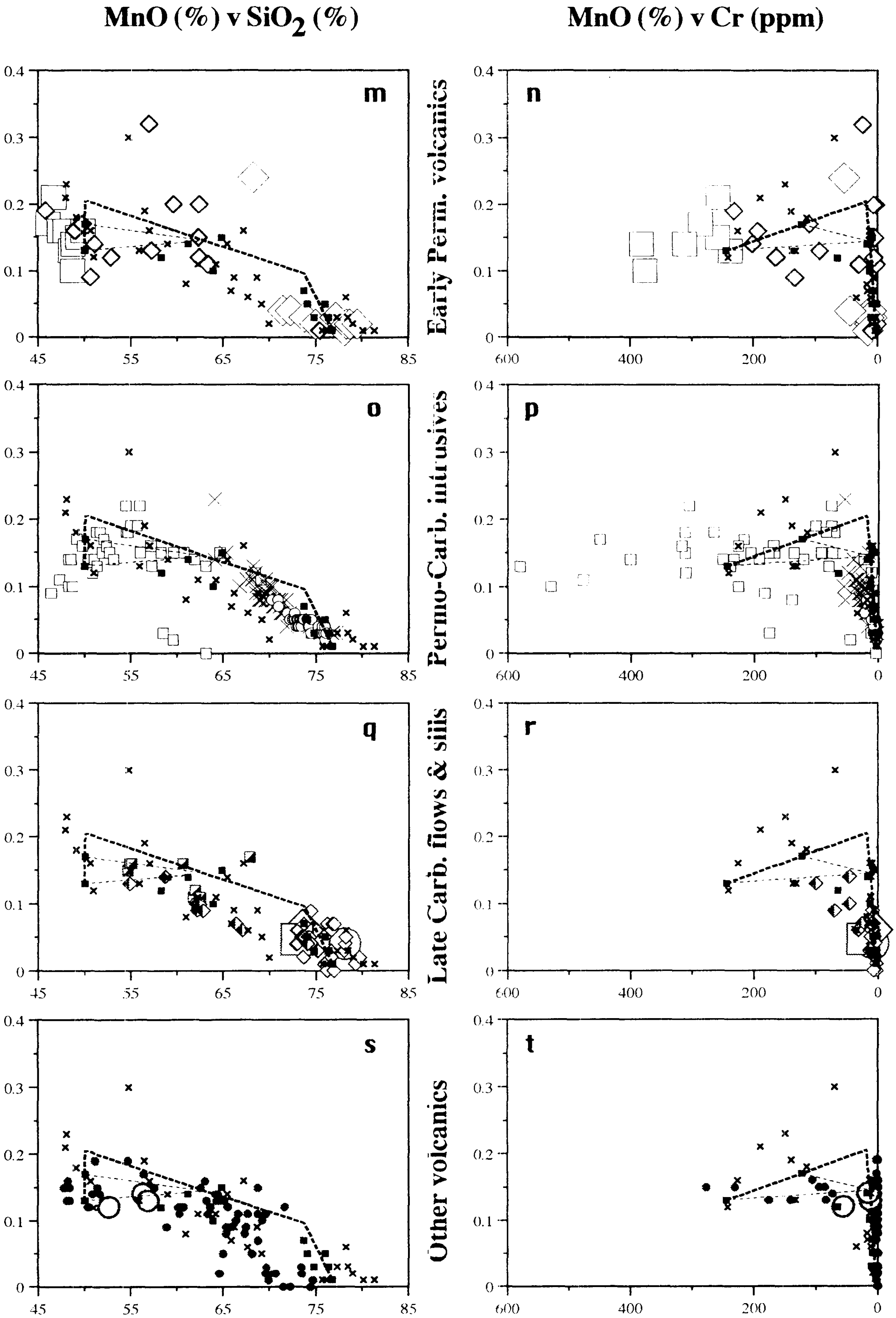

Fig. A2.12 (m–t): MnO in Boggab i Volcanics — regional comparisons