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Zealandia's Early Paleozoic sandstones: detrital mineralogy of the Greenland and Reefton Groups

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Abstract

New point counts of 13 Buller Terrane sandstones have been made. The results suggest a less quartzose and more lithic rich content of detrital sand grains in the Ordovician Greenland Group than indicated by an earlier published study (average Q:F:L = 58:16:26 and 23% matrix rather than 81:8:11 and 37% matrix). A low grade sedimentary-metasedimentary provenance is indicated. Detrital K-feldspar, previously believed to be absent from the Greenland Group, has been confirmed in at least six sandstones. In contrast to the greywacke-like nature of the Greenland Group, Devonian Reefton Group sandstones are texturally and mineralogically more mature; they are highly quartzose (average Q:F:L 96:2:2, 13% matrix) and generally have better sorted and more rounded grains. The new results indicate a recycled orogen provenance for the Greenland Group and a continental block provenance for the Reefton Group.

Keywords: Greenland Group, Paleozoic, petrography, sandstone, greywacke.

Introduction

The Early Paleozoic Buller Terrane forms the bulk of New Zealand's Western Province west of the Alpine Fault. The purpose of this short paper is to present preliminary new results on the reconnaissance detrital mineralogy of sandstones in two Buller Terrane stratigraphic units, the Ordovician Greenland Group and Devonian Reefton Group. Greenland Group sandstones host important mesothermal gold deposits near Reefton. Prior to this investigation there had been only one published study of the detrital mineralogy of the Greenland Group (Laird, 1972) and none of the Reefton Group. It is hoped this petrological work will be of use in refining correlations of New Zealand's Western Province with specific parts of the Lachlan Orogen of Australia (Cooper and Tulloch, 1992). This paper is a progress report and it is anticipated that a more detailed interpretation of Buller and Takaka Terrane sandstone compositions, including their petrochemistry, will be written up in due course.

Geological Setting

Greenland Group

The Greenland Group (including the former Waiuta Group) is the most voluminous formation in the Buller Terrane (Cooper, 1989; Nathan et al., 2002). The subject of this paper is the eastern part of Greenland Group, exposed in a 450 km long strip in the South Island between Big Bay and Westport (Fig. 1). Greenland Group consists of monotonous, recrystallised, variably cleaved, turbiditic sandstones and mudstones deposited in a submarine fan environment (Laird, 1972; Laird and Shelley, 1974). Unlike the Takaka Terrane and the classic accretionary prism assemblages of New Zealand's Eastern Province Torlesse Rakaia Terrane, the Greenland Group contains no intercalated basalts, cherts or (apart from occasional pebbles and nodules) limestones, and the macroscopic structural style is one of upright folds rather than imbricate thrust sequences. Most Greenland Group sandstones are very fine to fine grained. Conglomerates are known from only three localities at Big Bay (Laird 1986), near Mount Graham (Bell and Fraser, 1906; Laird, 1973) and in Canoe Creek (Fig. 1). Rhyolitic igneous rocks, metamorphosed and deformed along with Greenland Group are known only from Powers Creek (Fig. 1), but whether they are intrusive or extrusive is uncertain. A single fossil locality in the Greenland Group near Reefton has yielded Ordovician (Lancefieldian) graptolites. U-Pb dating of detrital zircons reveals populations with ages of 500-600 Ma, 1000-1200 Ma and c. 1600 Ma (Ireland and Gibson, 1998); Ar-Ar dating of detrital white micas reveals a population with a 490-515 Ma age, with no detrital muscovite ages >550 Ma (Adams and Kelley, 1998).

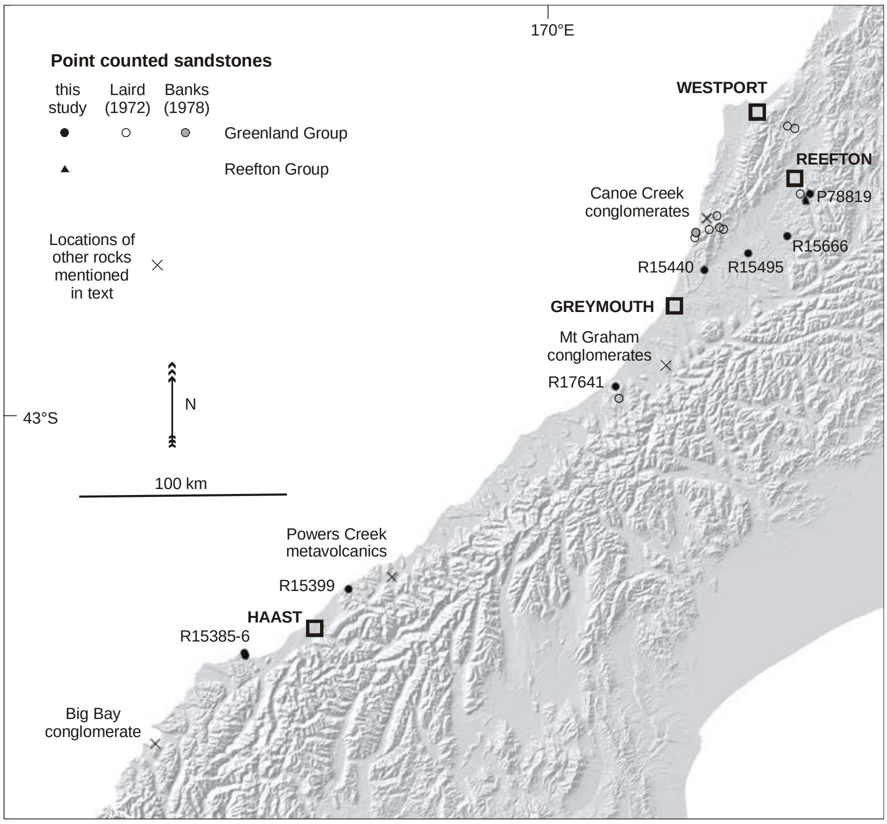

Figure 1. Location of the samples used in this study.

Petrographic studies of 18 Greenland Group samples, mainly from the southern Paparoa Range have been made by Laird (1972) and Banks (1978). Petrochemical studies of Greenland Group sandstones and mudstones have been made by Nathan (1976), Roser et al. (1996) and Roser and Nathan (1997).

Reefton Group

Only two areas of Devonian rocks are known in New Zealand, both in the Western Province. One of these, Reefton Group, is an outlier near Reefton (Fig. 1) entirely surrounded by Greenland Group (Nathan et al., 2002). The most comprehensive account of the geology, and the history of study, of the Reefton Group is given by Bradshaw and Hegan (1983) and Bradshaw (1995). Reefton Group is less recrystallised and cleaved, and more fossiliferous than Greenland Group; limestones are common and indicate a submarine environment. To my knowledge, prior to this study, there have been no published petrographic studies of sandstones from the Reefton Group.

Table 1. Location and sample details of rocks used in this study.

Sample no	Field no	Sheet	Easting	Northing	Site description	Rock description	Point count this study	Avg grain size um	Max grain size um	Sorting	Rounding	Texture ranking
Greenland Group (this study)												
P78818	WR1	L30	2422245	5897328	Waitahu River	Fine grained sandstone	Y	150	500	mod	subang	2
R15385	JB10	E37	2159200	5682300	Jackson Bay road	Fine grained sandstone	Y	150	400	poor	subang	8
R15386	JB11	E37	2158800	5683600	Jackson Bay road	Fine grained sandstone	Y	200	500	poor	subang	6
R15399	WP	F36	2207400	5713200	Whakapohai Bridge	Fine grained sandstone	Y	150	500	poor	subrnd	12
R15440	BRU	K31	2373000	5861800	S.H. 7 near Stillwater	Very fine grained sandstone	Y	100	250	poor	subang	4
R15495	ADNA10	K31	2393400	5869700	Ahaura-2 drillhole	Very fine grained sandstone	Y	100	200	m well	subang	9
R15666	ZW8	L31	2411500	5877700	Snowy River road, near powerhouse	Very fine grained sandstone	Y	80	200	poor	subang	13
R17641	MtG10	J33	2331700	5807600	Donnellys Stream, Ross	Fine grained sandstone	Y	150	400	poor	ang	1
Greenland Group (Laird 1972)												
S31/323	S31/323	L29	2415200	5927900	Rahui, lower Buller River	Very fine grained sandstone	Y	100	300	mod	ang	11
S31/350	S31/350	L29	2411900	5929100	Slaty Creek, lower Buller River	Fine grained sandstone	Y	150	600	poor	ang	3
S37/37	S37/37	K31	2379000	5887200	Headwaters Punakaiki River	Sandy siltstone	Y	30	50	well	subrnd	14
S37/80	S37/80	K31	2380200	5881600	Headwaters Moonlight Creek	Sandstone	-	-	-	-	-	-
S37/81	S37/81	K31	2382000	5881000	Middle reaches Moonlight Creek	Sandstone	-	-	-	-	-	-
S37/82	S37/82	K31	2375300	5880800	Mt Ryall	Sandstone	-	-	-	-	-	-
S38/113	S38/113	L30	2417700	5897300	Blacks Point, Reefton	Very fine grained sandstone	N	75	300	poor	subang	15
S38/114	S38/114	L30	2417700	5897300	Blacks Point, Reefton	Fine grained sandstone	Y	125	400	mod	subang	5
S44/72	S44/72	J31	2368600	5877100	Fourteen Mile Bluff	Sandstone	-					
S44/78	S44/78	J31	2369200	5879400	Seventeen Mile Bluff	Very fine grained sandstone	N	80	400	metaigneous? (NM)		16
S57/84	S57/84	J33	2333400	5802200	Mt Greenland, mine road	Fine grained sandstone	Y	120	400	poor	subang	7
S57/85	S57/85	J33	2333400	5802200	Mt Greenland, mine road	Fine grained sandstone	Y	100	400	poor	subang	10
Reefton Group (this study)												
P73078	SU	L30	2420200	5895200	Stony Creek, near Reefton	Very fine grained sandstone	Y	80	200	well	rnd	-
P73079	Road B	L30	2420094	5894078	Roadcut, SH7 near Reefton	Fine grained sandstone	Y	100	150	v well	subrnd	-
P78819	WR2	L30	2421745	5898271	Waitahu River, 4x3x3m boulder	Very fine grained calcareous ss	Y	80	120	v well	subang	-
P78820	SC1	L30	2420017	5895228	Stony Creek, first 3m waterfall	Very fine grained sandstone	Y	80	300	well	rnd	-
P78822	IR1	L30	2420599	5893746	Bluffs, State Hwy 7 west of Reefton	Fine grained sandstone	Y	150	500	subrnd	well	-
Other												
OU47251-6		J31	2369200	5879400	Seventeen Mile Bluff. Coll. MJ Banks	Sandstones	-	-	-	-	-	-
P45672	85/282	K31	2374160	5885860	Boulder in Canoe Creek. Coll. AJ Tulloch	Conglomerate	-	-	-	-	-	-
P45684	85/294	K31	2374000	5886000	Boulder in Canoe Creek. Coll. AJ Tulloch	Conglomerate band in ss	-	-	-	-	-	-
P49674	p32	G36	2227500	5718900	Power Creek. Coll. S. Nathan	Metarhyolitic rock	-	-	-	-	-	-
		D39	2117300	5641200	Big Bay, field descriptions in Laird (1986)	Metaconglomerate	-	-	-	-	-	-

Texture ranking is a qualitative assessment of the degree of modification of sedimentary textures in the 16 Greenland Group thin sections examined by the author for this study. 1=least recrystallised (most pristine detrital grain boundaries), 16=most recrystallised.

Methods

Thin sections of sandstones were stained for plagioclase and K-feldspar. A total of 300 points were counted at high magnification using a Swift automated stage and a Leica DMR research polarising microscope. Protocols strictly followed the Gazzi-Dickinson method (Dickinson 1970; Ingersoll et al., 1984) in which matrix is defined as grains <0.06 mm in size, and in which mineral grains coarser than this within lithic clasts are counted as individual minerals. Samples prefixed P and R are from GNS Science rock collections and OU from the Otago University rock collection. All location and analytical data can be found in the PETLAB database <http://pet.gns.cri.nz>. Sample locations and basic grain size details are given in Table 1.

Results

New and old point count data are shown in Table 2, and the proportions of detrital quartz, feldspar and total lithics shown in Fig. 2. Eight thin sections from Laird (1972) were examined for this study, six of which were re-point counted.

Greenland Group

All samples show metamorphic recrystallisation of the sedimentary matrix and in more recrystallised samples it is impossible to tell true detrital matrix from lithic grains. Thin sections were ranked in order of textural modification (Table 1), with only the least recrystallised samples being point counted for this study. Images of the least texturally altered Greenland Group sandstone in the dataset, R17641, are shown in Fig. 3.

Table 2. Point count data (%) for Greenland and Reefton Group sandstones.

Sample no	Q	Qm	Qp	P	K	L	Lv	Lvf	Lvm	Lvl	Lm	Ls	musc	biot	D	zirc	tourm	ilm	garn	other	CO3 1	CO3 2	pyr 2	chl	void	matrix	Q/QFL	F/QFL	L/QFL	Lv/L	P/F	%M	%D
Greenland Group (this study)																																	
P78818		48.3	0.0	9.7	1.0			4.0	0.3	0.0	1.0	6.0	1.7	2.3		0.0	0.3	0.7	0.0			4.7	0.0		0.0	20.0	0.69	0.14	0.17	0.38	0.91	5.3	1.3
R15385		37.0	0.0	14.0	1.3			2.7	0.3	0.0	4.7	7.3	1.7	2.3		0.7	0.0	0.0	0.0			7.7	1.3		0.0	19.0	0.55	0.21	0.24	0.20	0.91	5.6	0.9
R15386		44.7	0.0	9.3	1.0			5.7	1.0	0.0	5.0	3.7	1.3	1.7		0.0	0.0	0.0	0.0			8.3	0.7		0.0	17.6	0.64	0.13	0.23	0.43	0.90	4.1	0.0
R15399		29.7	0.0	11.7	0.3			3.3	1.7	0.7	4.3	4.7	2.0	1.3		0.3	0.3	0.0	0.0			11.7	1.0		0.0	27.0	0.53	0.21	0.26	0.39	0.97	5.5	1.1
R15440		29.7	0.3	9.7	0.0			5.3	0.7	0.0	6.0	7.7	2.7	2.7		0.7	0.3	0.7	0.0			0.7	0.0		0.0	32.8	0.51	0.17	0.32	0.31	1.00	8.0	2.5
R15495		32.0	0.7	12.3	0.3			3.0	0.7	0.3	2.7	5.3	3.0	4.7		0.3	0.3	0.7	0.0			6.7	0.0		0.0	27.0	0.57	0.23	0.20	0.33	0.97	11.6	2.0
R15666		32.7	0.0	13.3	0.0			6.0	0.0	0.0	2.0	11.3	2.3	1.3		0.7	0.3	0.0	0.0			2.3	0.7		0.0	27.1	0.50	0.20	0.30	0.31	1.00	5.2	1.4
R17641		46.3	0.0	9.3	4.3			3.3	0.3	0.0	2.3	7.7	3.0	1.3		0.0	0.0	0.7	0.0			3.0	0.0		0.0	18.5	0.63	0.13	0.24	0.27	0.68	5.5	0.8
S31/323		47.3	0.0	7.7	0.0			5.3	0.7	0.0	3.3	4.0	1.3	2.7		0.3	0.7	0.7	0.0		0.0	3.0	1.7			21.3	0.69	0.11	0.20	0.45	1.00	5.4	3.1
S31/350		34.1	1.0	5.0	0.3			5.0	1.0	0.3	7.7	14.7	1.3	1.7		0.7	0.3	0.3	0.3		4.0	1.7	1.3			19.3	0.51	0.08	0.41	0.22	0.94	3.8	3.8
S38/114		40.0	1.0	12.3	3.0			5.0	0.7	0.0	6.0	7.7	0.7	2.0		0.7	0.0	1.3	0.0		0.0	1.3	0.0			18.3	0.54	0.20	0.26	0.29	0.80	3.3	2.5
S37/37		46.1	1.0	11.3	0.0			1.0	0.0	0.0	1.7	1.3	1.3	2.0		0.3	0.0	0.7	0.0		0.0	5.7	0.3			27.3	0.75	0.18	0.07	0.25	1.00	5.0	2.0
S57/84		39.6	1.0	10.0	0.7			6.3	0.3	0.0	8.0	9.7	1.7	2.0		0.7	0.3	0.3	0.0		0.0	0.0	0.7			18.7	0.54	0.14	0.32	0.27	0.94	4.5	2.1
S57/85		36.4	0.0	12.0	0.7			5.7	1.3	0.0	6.7	10.3	1.3	2.0		0.3	0.3	0.3	0.0		0.0	0.0	0.7			22.0	0.50	0.17	0.33	0.29	0.95	4.3	1.7
Greenland Group (Laird 1972)																																	
S31/323	41.8			3.5	0.0		0.0				0.5	0.0								6.2		2.0				46.2	0.91	0.08	0.01	0.00	1.00		
S31/350	41.9			2.8	0.0		0.9				4.4	0.8								7.0		1.0				41.2	0.82	0.06	0.12	0.15	1.00		
S37/37	47.5			3.2	0.0		3.0				5.1	9.1								1.2		10.3				21.0	0.70	0.05	0.25	0.17	1.00		
S37/80	48.9			5.6	0.0		3.6				1.8	5.0								4.6		0.0				30.6	0.75	0.09	0.16	0.35	1.00		
S37/81	44.6			5.0	0.0		6.2				0.8	3.4								3.7		4.6				31.7	0.74	0.08	0.18	0.60	1.00		
S37/82	55.4			5.6	0.0		3.2				4.3	2.4								3.4		0.6				25.1	0.78	0.08	0.14	0.32	1.00		
S38/113	41.5			4.4	0.0		0.4				1.1	0.9								4.9		0.0				46.8	0.86	0.09	0.05	0.17	1.00		
S38/114	49.2			5.9	0.0		0.5				5.2	0.5								2.9		0.2				35.6	0.80	0.10	0.10	0.08	1.00		
S44/72	48.9			5.4	0.0		0.6				1.4	0.2								3.9		1.9				37.7	0.87	0.10	0.03	0.27	1.00		
S44/78	39.1			4.9	0.0		5.7				1.1	3.8								3.6		3.4				38.4	0.72	0.09	0.19	0.54	1.00		
S57/84	47.5			5.2	0.0		0.0				2.0	2.8								3.5		0.0				39.1	0.83	0.09	0.08	0.00	1.00		
S57/85	44.0			4.0	0.0		0.0				0.6	1.1								3.2		0.0				47.1	0.89	0.08	0.03	0.00	1.00		
Greenland Group (Banks 1978)																																	
OU47251	30.2			1.8		5.4							3.4	4.1	0.9							2.5	0.4	12.3		39.0	0.81	0.05	0.14		1.00	8.8	2.0
OU47252	19.0			7.9		11.1							2.0	0.5	1.2							9.3	0.2	1.3		47.5	0.50	0.21	0.29		1.00	2.8	2.9
OU47253	21.2			6.8		10.1							1.3	2.3	1.3							5.4	0.3	2.1		49.2	0.56	0.18	0.26		1.00	3.9	3.0
OU47254	18.4			10.1		6.3							2.3	0.4	0.5							2.3	0.4	2.2		57.1	0.53	0.29	0.18		1.00	2.8	1.3
OU47255	19.7			8.9		8.1							1.3	1.5	0.3							3.2	1.1	0.3		55.6	0.54	0.24	0.22		1.00	2.9	0.8
OU47256	30.8			4.6		15.2							1.5	0.0	0.4							0.0	0.9	0.3		46.3	0.61	0.09	0.30		1.00	1.5	0.8
Reefton Group (this study)																																	
P73078		82.3	0.3	0.3	0.7			0.3	0.0	0.0	0.0	0.0	0.3	0.0		0.7	0.7	0.0	0.3			0.0	0.0		0.0	14.1	0.98	0.01	0.01	1.00	0.33	0.4	1.9
P73079		90.0	0.3	0.3	0.0			1.0	0.0	0.0	0.0	0.0	0.3	0.0		0.3	0.3	0.0	0.0			0.0	0.7		0.0	6.8	0.99	0.01	0.00	1.00	1.00	0.4	0.7
P78819		59.3	0.0	3.7	3.3			0.3	0.0	0.0	0.3	0.7	1.0	0.3		0.0	0.3	0.0	0.3			27.2	1.0		0.0	2.3	0.88	0.05	0.07	0.25	0.52	1.9	1.0
P78820		78.3	0.3	0.7	0.0			0.3	0.0	0.0	0.0	0.3	0.3	0.0		0.7	0.3	0.0	0.7			0.0	0.0		5.0	13.1	0.98	0.01	0.01	0.50	1.00	0.4	2.0
P78822		67.2	0.3	1.0	0.3			1.3	0.0	0.0	0.0	0.0	1.0	0.0		0.7	0.3	0.0	0.3			0.0	0.3		0.0	27.3	0.96	0.02	0.02	1.00	0.75	1.4	1.8

Q=quartz (Qm=monocrystalline, Qp=polycrystalline), P=plagioclase, K=potassium feldspar, L=lithics undifferentiated, Lv=volcanic lithic (Lvf=felsitic, Lvm=microlitic, Lvl=lath texture), Lm=metamorphic lithic, Ls=sedimentary lithic, musc=muscovite, biot=biotite, D=heavy minerals undifferentiated, zirc=zircon, tourm=tourmaline, ilm=ilmenite, garnet, other=other detrital, CO3 1=primary carbonate, CO3 2=secondary carbonate, pyr 2=secondary pyrite, chl=chlorite. Last seven columns are calculated detrital (matrix- and cement-free) parameters after Ingersoll et al. (1984) %M=% mica. %D=% heavies.

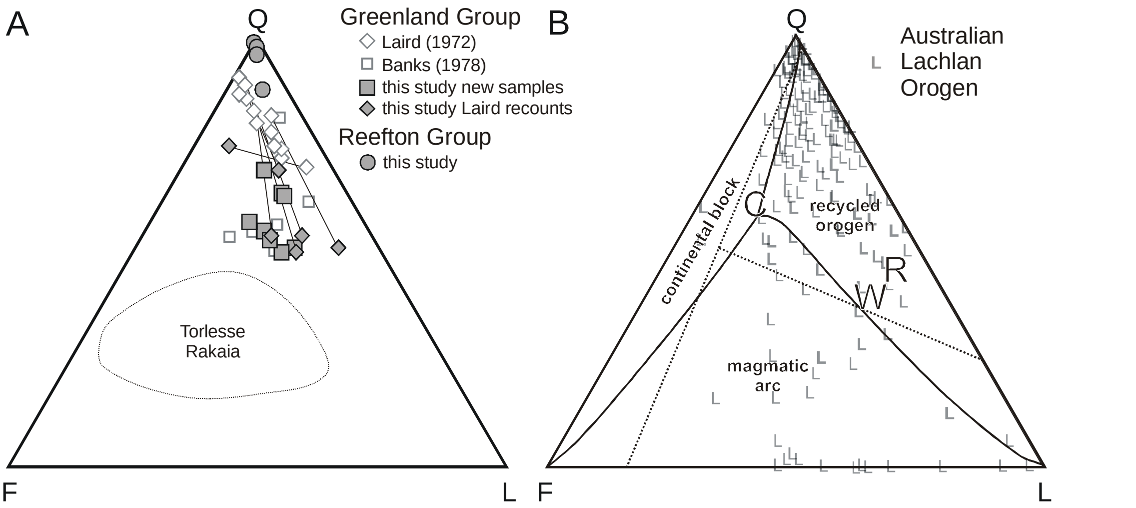

Figure 2. Quartz-Feldspar-Lithics (QFL) ternary plots. **A.** Greenland and Reefton Group sandstones, tie lines connect different counts of same samples. Torlesse Rakaia field from Mortimer (1994). **B.** Lachlan Orogen sandstones (Bhatia, 1981; Colquhoun et al., 1999; Fergusson and Tye, 1999) plotted on a provenance diagram of Dickinson et al. (1983) (solid lines are modifications of Weltje 2006). C, W and R are modern Clutha, Waitaki and Rangitata River sands (eastern South Island, Shapiro et al., 2007); Clutha sediment is mainly sourced from greenschist facies schist, the Waitaki and Rangitata from semischist and greywacke.

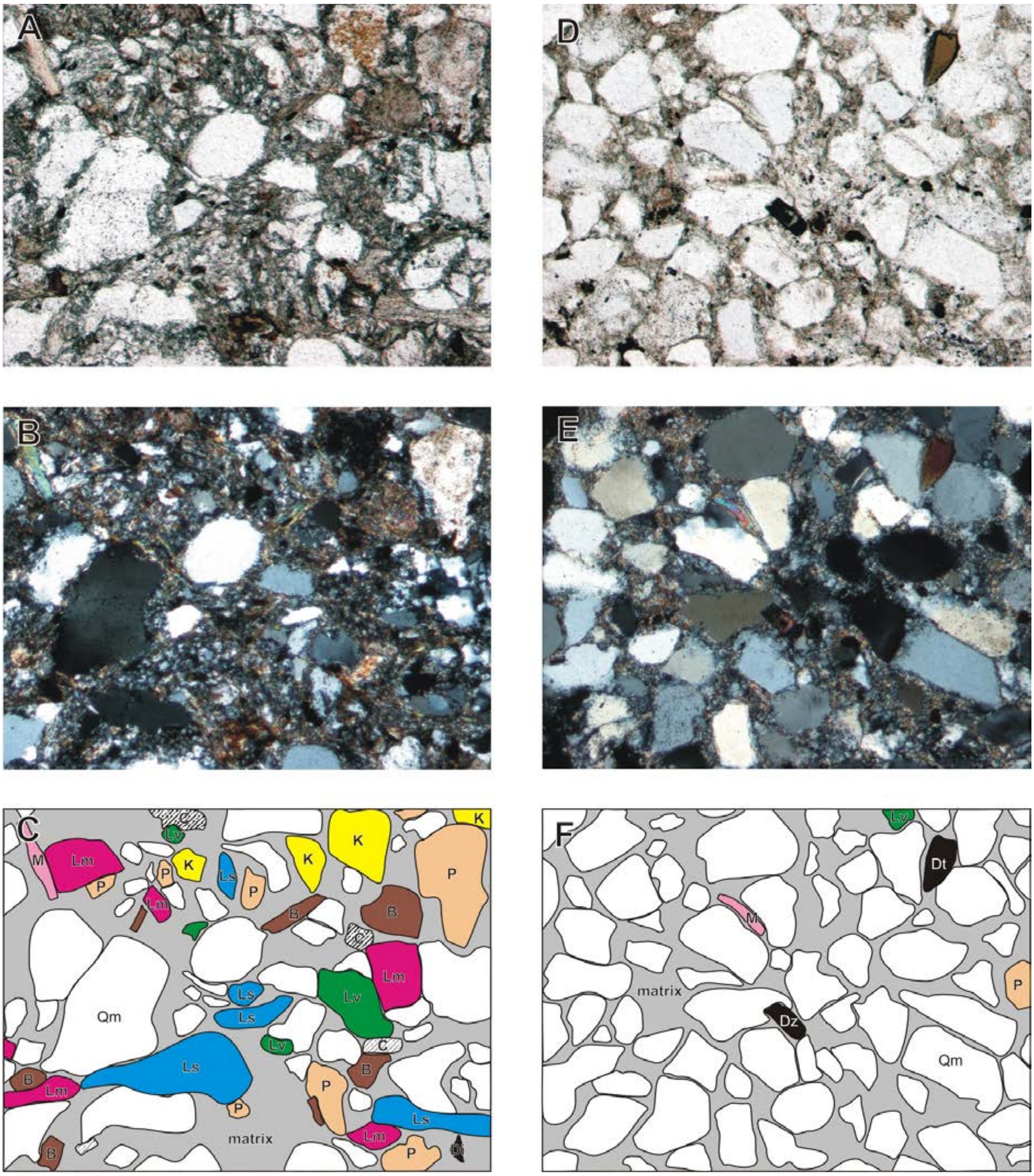

Figure 3. Microscope images, all 1 mm wide. **A, B, C.** R17641, the least recrystallised Greenland Group sandstone in the sample set. **D, E, F.** P78222, the most matrix-rich Reefton Group sandstone in the sample set. The field of view of both sandstones have c. 30% matrix (compared with point counts of 19% for R17641 and 27% for P78222 over their entire thin sections). Top images are plane polarised light, middle images cross polarised light and lower images interpreted detrital grains with Gazzi-Dickinson matrix cutoff of 0.06 mm. Qm=monocrystalline quartz (white in C and F), P=plagioclase, K=potassium feldspar, B=biotite, M=muscovite, Lv=volcanic lithic, Ls=sedimentary lithic, Lm=metamorphic lithic, Dz=zircon, Dt=tourmaline, Di=ilmenite, C=secondary calcite.

Both this study and that of Laird (1972) report a range of 30-55% quartz grains as a total of the whole sandstones. However, my estimates of the percentage of matrix are much less than Laird's and my estimates of the percentage of lithic grains are correspondingly higher (Table 2). This is emphasised by my recounts of six of Laird's samples and their shifted positions on a QFL diagram (Fig. 2). Reasons for these differences are discussed below.

A new discovery in the current study is the confirmation of K-feldspar in several samples, which has previously believed to have been absent from Greenland Group (Laird, 1972; Nathan, 1976). Among the lithic grains, volcanic, metamorphic and sedimentary clasts are generally present in subequal proportions, although sedimentary clasts tend to be more abundant. Most volcanic lithics have felsitic textures indicative of rhyolitic-dacitic volcanism, and most metamorphic clasts are relatively low grade greenschist facies schists and phyllites. Quartz, although point counted as monocrystalline grains >0.06 mm according to Gazzi-Dickinson criteria, typically is strained and sometimes occurs in polycrystalline aggregates suggestive of a vein quartz origin.

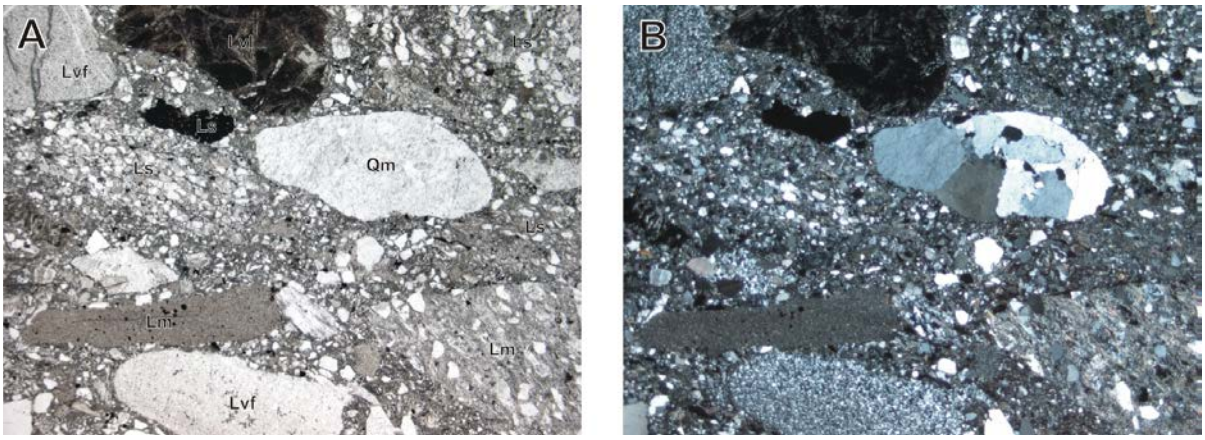

Figure 4. Microscope images of Greenland Group conglomerate P45684. **A.** plane polarised light, **B.** cross polarised light. Both images 8 mm wide. Abbreviations as in Table 2.

A thin section of a rare Greenland Group conglomerate P45684 (Fig. 4) gives confidence that identification of matrix and lithics has been made correctly in the present study of sandstones. The mode for P45684 is, by volume, 11% volcanic lithic pebbles, 24% metamorphic lithic pebbles, 10% sedimentary lithic pebbles, 13% vein quartz-feldspar pebbles and 42% sandy to muddy matrix (note this is not a Gazzi-Dickinson point count and cannot be compared with the sandstone data in Table 2). The conglomerate indicates that abundant lithic clasts were available for disaggregation in the Greenland Group basin.

Reefton Group

Five Reefton Group sandstones belong to a quite different petrofacies from the Greenland Group (Table 2, Fig. 2). One sandstone in the dataset has amounts of matrix comparable to Greenland Group (Fig. 3) but most others are matrix poor. All Reefton sandstones have very high proportions of quartz, and a distinctive heavy mineral assemblage dominated by tourmaline and zircon. Rounding and sorting is generally better than for Greenland Group sandstones.

Discussion

Greenland Group: matrix-rich or lithic-rich?

Laird's (1972) point counts of Greenland Group samples define a tight linear array in QFL space; those from the current study are more scattered but have consistently less detrital quartz on a QFL plot (Fig. 2). At the core of this discrepancy is the recognition of lithic grains versus detrital matrix in recrystallised sandstones. It has long been recognised that apparently higher amounts of matrix in Paleozoic-Mesozoic sandstones as compared to Cenozoic ones, is partly the result of "pseudomatrix", the textural-metamorphic conversion of lithic grains to material indistinguishable from matrix (Dickinson, 1970). This obviously has a major effect on the projection of point count results on a QFL diagram. Also possibly relevant is the grain size cutoff used for matrix. The new thin sections used in the present study are of high quality, well stained, and more parameters were recorded than in previous studies (Tables 1-2). Nowadays there is perhaps greater awareness of the pseudomatrix issue. Whatever its limitations, the new dataset is at least compatible with other GNS datasets (e.g. Mortimer, 1994; Palmer et al., 1995).

The different counts in different studies for the Greenland Group highlight the above problems but, given the recrystallised nature of the rocks, it is difficult to conclusively resolve which is correct. Interestingly, six Greenland Group sandstones point counted by Banks (1978) from Seventeen Mile Bluff (Table 1) gave detrital QFL ratios more consistent with the present study (average Q:F:L 59:18:23) but had up to 49% matrix, more consistent with that of Laird (1972).

Can geochemistry help? Roser et al. (1996) noted that the total range in SiO_2 content in Greenland Group sandstone and mudstones was not exceptional (being broadly similar to the more obviously first-cycle active margin Torlesse clastics) and that they were not particularly geochemically evolved for passive margin sediments. Roser and Nathan (1997) noted a similar cutoff in SiO_2 content between sandstones and mudstones from the Greenland Group and those of the Torlesse Terrane (68-70 anhydrous wt%), further suggesting that the QFL and matrix control on the geochemistry of the two suites may not be that dissimilar (Fig. 2). Integration of Greenland Group point count data with geochemical data may yet provide a test of the lithics vs matrix issue, but is outside the scope of the present study. A full resolution of the problem must await discovery of more unrecrystallised Greenland Group sandstones of a quality suitable for point counting.

Greenland and Reefton Group petrofacies

Irrespective of the correct detrital Q:F:L ratios of the Greenland Group, both the point count data of Laird (1972), Banks (1978) and the present study lie within the (wide) range of Ordovician sandstones from the Lachlan Orogen of Australia (Fig. 2). They thus confirm what has long been said, that the Buller Terrane can be regarded as a correlative of parts of the Lachlan Orogen (e.g. Cooper, 1989; Cooper and Tulloch, 1992; Ireland and Gibson, 1998). More detailed comparison of the Greenland Group petrographic data with individual belts and suites of the Lachlan Orogen is certainly possible, but is outside the scope of this preliminary study. All Greenland Group point counts lie within the recycled orogen provenance field of Dickinson et al. (1983). Some of the most lithic rich points fall into the dissected magmatic arc provenance field as redefined by Weltje (2006), but some gradation between these fields is to be expected. Both Laird (1972) and Nathan (1976) preferred a weathered granitic-gneissic source area for the Greenland Group. Nathan (1976) speculated that a low grade regional metamorphic terrain in the Greenland sand source area may have been partly responsible for the absence of K-feldspar and enrichment of quartz. The abundance of low grade metamorphic clasts, and vein quartz observed in the present study provides tangible evidence of a dominantly low grade metamorphic provenance. A small but significant volcanic lithic supply is also indicated by the presence of K-feldspar and volcanic lithic grains with felsitic textures. On a QFL diagram (Fig. 2) the new Greenland Group data are bracketed by data from modern river sands draining the Mesozoic Rangitata Orogen (Shapiro et al., 2007).

In contrast, the highly quartzose Reefton Group sandstones occupy a small region at the top of the QFL diagram that is more consistent with a craton-derived provenance (Dickinson et al. 1983).

Conclusions

Provisional new point counts of eight Buller Terrane Greenland Group sandstones suggest that, on average, the detrital sand-sized mineralogy of the Greenland Group may be more lithic-rich and not as quartzose or mature as previously interpreted. A typical Q:F:L ratio of 58:16:26 with 23% matrix was obtained in the present study rather than 81:8:11 and 37% matrix in the study of Laird (1972). This reinterpretation is supported by textural observations in the least recrystallised sandstones, and some geochemical considerations. However, more work is needed to fully resolve the differences. In contrast, five Reefton Group sandstones are clearly highly quartzose and reflect a more mature, cratonic provenance than the recycled orogen sandstones of the Greenland Group.

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