Preliminary study of the sandstones in the Torlesse terrane, New Zealand(MEMORIAL VOLUME TO THE LATE PROFESSOR TERUHIKO SAMESHIMA)

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Preliminary study of the sandstones in the Torlesse terrane, New Zealand

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Abstract Heavy fractions of minerals in the sandstones from the Torlesse terrane are composed mainly of metamorphic minerals such as epidote, titanite and pumpellyite with subordinate amounts of detrital minerals such as zircon, garnet, apatite and ilmenite. Although metamorphism has been considered to be continuous within the Torlesse terrane, modal proportions of metamorphic minerals, especially pumpellyite and epidote, are depleted in the central region.

Compositions of detrital garnets vary consistently with the geological age of their host sandstones. Jurassic-Cretaceous sandstones contain garnets with a wide compositional range, whereas garnets in Triassic rocks have a narrow compositional range. Rocks of both ages contain Mg-rich and Ca-rich garnets, whereas Permian garnets are usually rich in Mn. Although dissolution of garnets is common in the sandstones due to diagenesis and metamorphism, the difference of the garnet composition reflects compositional differences in the source rocks. Garnets in the Permian rocks were predominantly derived from granitic rocks, whereas those in the Triassic to Cretaceous rocks were derived from garnet amphibolite and gneiss which should be lower in metamorphic grade than metamorphic rocks in the eastern Antarctic.

Key words: sandstone, heavy mineral, Torlesse terrane, New Zealand

INTRODUCTION

The Torlesse terrane is an extensive accretional prism composed mostly of quartz-feldspathic, submarine-fan deposits ranging in age from Permian to Early Cretaceous. It is often inferred to represent an accreted subduction complex (e.g., MacKinnon 1983), but exotic blocks derived from the oceanic plate, such as basalt, chert and limestone, occur only sporadically throughout the terrane. The Torlesse terrane is divided into the Older and Younger subterranes by the Esk Head mélange (e.g., Frost & Coombs 1989; Silberling *et al.* 1988). Age of sedimentation of the Older subterrane is Triassic to Permian and that of the the Younger one is Late Jurassic to Early Cretaceous. Reconstructions of the South New Zealand by Bradshaw (1989) shows that the submarine fan deposits were formed at the continental margin of the Antarctic and were present at the north of the Marie Byrd Land of the Antarctic before the Middle Cretaceous.

Many detailed paleontological and petrological studies of the Torlesse terrane have been published (e.g., Landis & Coombs 1967; MacKinnon 1983; Silberling *et al.* 1988). However, there have been few studies of detrital minerals in the terrane (e.g., MacKinnon 1988). As a preliminary study of the sandstones in the Torlesse terrane, the auther obtained the modal proportions of minerals in heavy and light fractions and analysed detrital garnets to discuss the provenance of the constituent minerals.

COLLECTED SAMPLES AND MINERAL SEPARATION:

Thirty one sandstones were collected from the Torlesse terrane which was metamorphosed mostly under the prehnite-pumpellyite facies conditions (Fig. 1). Rocks of the zeolite facies occur

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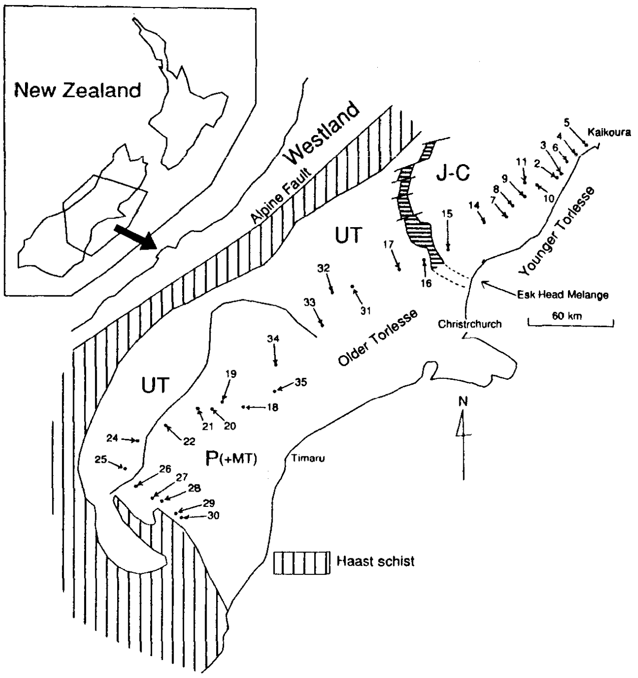

Fig. 1 Locality map of the sandstones in the Torlesse terrane. Tectonic framework and paleontological data are after Silberling *et al.* (1988) and MacKinnon (1983), respectively. P(+MT): Permian region with local occurrences of Middle Triassic rocks. UT:Upper Triassic region. J-C: Late Jurassic to Early Cretaceous region.

locally in the Younger subterrane (Landis & Coombs 1967; Landis & Bishop 1972). The Haast schist occurring to the west is the high grade equivalent of the Torlesse terrane rocks and is exposed locally in the Older subterrane.

The sandstones, highly consolidated, were crushed in a stainless steel morter. The following procedures of mineral separation were carried out, as described by Yokoyama *et al.* (1990). The specific gravity of the liquid, methylene iodide, was reduced to 2.82 in order to recover composite grains and aggregates of heavy and light minerals. All the minerals in the heavy and light fractions were identified by means of profiles obtained from a Link Systems energy dispersive spectrometer (EDS). The numbers of heavy minerals counted in each sample are listed in Table 1. As rutile, anatase and brookite are not distinguished by the EDS profile, they were counted collectively as TiO_2 polymorphs. Chlorite, micaceous minerals and carbonate minerals are present in both the heavy and light fractions. Therefore, these minerals were not included in the mineral counts. Magnetic fractions were removed before the separation. Magnetite and maghemite were rarely observed in the Younger subterrane.

HEAVY AND LIGHT MINERALS

A number of heavy mineral species are listed in Table 1. Epidote group minerals and titanite are the most abundant, followed by zircon, garnet, ilmenite, apatite and pumpellyite (Fig. 2). Among the listed heavy minerals, garnet and zircon are clearly detrital. Other detrital grains include apatite, ilmenite, tourmaline, hornblende, clinopyroxene, monazite and thorite. Metamorphic minerals include epidote, pumpellyite and titanite in the heavy fractions, as discussed in a subsequent section.

Garnet is well preserved in the Younger subterrane and the eastern part of the Older subterrane, whereas it is locally replaced by chlorite in the western part of the Older subterrane (Fig. 3a). Euhedral zircon is common, and often contains apatite and rounded inclusion (glass?) (Fig. 3b). Pyroxenes and amphibole are extremely etched and skeletal due to replacement by chlorite, carbonate and rarely laumontite. Epidote occurs commonly as aggregate at the grain boundaries of quartz and feldspar (Fig. 3c), whereas zoisite and clinozoisite are major components produced by the breakdown of plagioclase. Pumpellyite occurs usually as aggregates of fine-grained euhedral crystals and is commonly associated with epidote (Fig. 3c & d). Both pumpellyite and epidote are abundant in the Younger subterrane, but less common in the eastern part of the Older subterrane (Fig. 2). Titanite is replacing ilmenite and TiO_2 polymorphs.

In the light fractions, the modal proportion of quartz is approximately 40%. Plagioclase commonly is replaced by albite and epidote-group minerals and occasionally by zeolite. Prehnite is not common in spite of the metamorphism of the prehnite-pumpellyite facies. It is restricted to the Older subterrane. K-feldspar is common in the eastern part, but is highly decomposed into muscovite in the area close to the greenschist facies terrane. Laumontite occurs most commonly as a vein mineral and rarely as a replacement of plagioclase and hornblende. It is abundant in the area to the east of the Esk Head mélange, consistent with the zeolite zone of Landis & Coombs (1967). However, laumontite occurs sporadically also in the Older subterrane, in the the prehnite-pumpellyite facies zone.

GARNET COMPOSITION

The EDS data of garnet were plotted in two serial diagrams: Mn-Ca-(Fe+Mg) and Ca-Fe-Mg diagrams (Fig. 4). The plots are divided into three fields based on geological age: Permian with Middle Triassic in part, Upper Triassic and Late Jurassic to Early Cretaceous. Clear differences among the three groups of garnets are observed.

Table 1 Heavy and light minerals in the sandstones from the Torlesse terrane.

	Heavy minerals													light minerals				
	gar	zir	apa	tou	spi	epi	pum	sph	Ti	gro	all	ilm	others	qz	ab	pl	kf	others
NZ-5	12	17	1	2		105	4	55	8	3	5	1		55	31	3	11	lm
NZ-4	28	50	3			44	6	38	6	1	9	21		42	31	6	21	lm
NZ-6	12	12	3			99	22	58	10	3	2	3		51	27	9	13	
NZ-3	9	20	1	1	1	108	13	27	11	4	2	15	mo(1)	54	21	8	17	
NZ-2	9	5	3		1	109	19	20	8	4	1	15		53	21	12	21	
NZ-10	28	17	5	2	1	98	4	34	14	2		4		55	24	8	13	
NZ-11	11	12	5	1		125	8	37	4	1	1	12	st(1)cp(1)	44	35	9	15	lm
NZ-9	39	7	5			87	22	37	4			1		48	47		5	lm
NZ-8	33	10	2	2		97	10	45	4	1			mo(1)	55	38	1	6	lm
NZ-7	9	7	5			115	15	35	10			4		54	33	2	12	lm
NZ-14	36	8	3		1	104	19	41	4	1		11		40	39	3	18	lm
NZ-15	6	15	2			111	13	44	17	1		1		47	24	5	24	
NZ-16	64	72	2	3	2	18		23	22	6				63	22	8	7	
NZ-17	18	16	24	1		49	1	96	5	1	4	16		35	42		23	lm
NZ-31	28	25	12		1	72		56	8	4	5	21	hb(7)th(1)	42	39	7	15	lm,pr
NZ-32	11	24	23			51	3	81	7	3	6	2	th(1)	45	47	1	7	pr
NZ-33	25	58	13		1	55	1	50	8	5	4	5		28	53	6	13	
NZ-34		12	5			150	5	31	1		1	2		62	37	1		
NZ-35	8	37	8			51	1	69	1		1	53	hb(7)cp(3)	33	42	9	16	lm
NZ-18	7	18	4			61	10	68	3	1	2	38	hb(1)	48	30	3	19	
NZ-19		8	2			118		28	1		1	3	ac(48)	54	45	1		
NZ-20		8	3			108	43	30	3			5		53	47			
NZ-21	1	4	9			103	28	42	3		4	18		31	60	2	7	pr
NZ-22	1	3				102	42	44	6		1	2		60	40			pr
NZ-24	4	7	9			110	11	50	5	1	2	2	hb(2)	53	42	5		
NZ-25	2	2	1			155	17	18	2		3			42	57	1		
NZ-26	10	17	13			96	4	70	8	1	3	3		44	37	19		lm
NZ-27		15	21			62	61	40	4			1		34	66			
NZ-28		5	4			127	46	21	1					59	41			
NZ-29	1	5	6			60	2	22	2	2		9		48	24	14	14	pr
NZ-30	3	8	3			76	7	76	12	1	3	20		41	44		15	pr

Mineral abbreviations; gar=garnet,zir=zircon,apa=apatite,tou=tourmaline,spi=spinel,epi=epidote,pum=pumpellyite, sph=titanite,Ti=TiO_2 polymorphs,gro=Ca-rich garnet,all=allanite,ilm=ilmenite,mo=monazite,st=staurolite, cp=clinopyroxene,hb=hornblende,th=thorite,ac=actinolite,qz=quartz,ab=albite,pl=calcic plagioclase,kf=K-feldspar, lm=laumontite, pr=prehnite. Each number is counted one in the heavy and light fractions

Garnets from the first group, Permian to Middle Triassic, are usually rich in MnO and poor in CaO. They are similar to garnets from granitic rocks in Westland (Fig. 4). In the Ca-Fe-Mg diagram, Upper Triassic garnets are similar to those from the Permian, but the Mn-Ca-(Fe+Mg) diagram shows that they are clearly depleted in MnO. On the other hand, garnets from the Jurassic to Cretaceous sandstones have a wide compositional range in both diagrams. Garnets in all the groups have pyrope content less than 35% and commonly plot on the Fe-rich side of the Ca-Mg-Fe diagram. The compositional features shown above are different from those of the high grade rocks in the Antarctic and of the Frazer gneiss in South Islands (Fig. 4).

DISCUSSION

Heavy minerals in sediments frequently have been used in studies of their provenance (e.g., Morton 1985). However, they are also sensitive to diagenesis, suffering from dissolution processes after deposition. Besides the dissolution, minerals in the Torlesse terrane were metamorphosed under the prehnite-pumpellyite or under the zeolite facies conditions, causing difficulties in discrimination between detrital and metamorphic minerals.

Morton (1984) summarized the order of dissolution of detrital minerals in deeply varied sediments. In deep marine sediments, zircon, tourmaline, garnet and apatite are resistant minerals, whereas pyroxenes, amphibole, epidote and titanite are decomposed at the shallower levels than the former. In the Shimanto and Mino belts, Japan, which represent typical subduction complexes, epidote, pumpellyite and titanite have not been

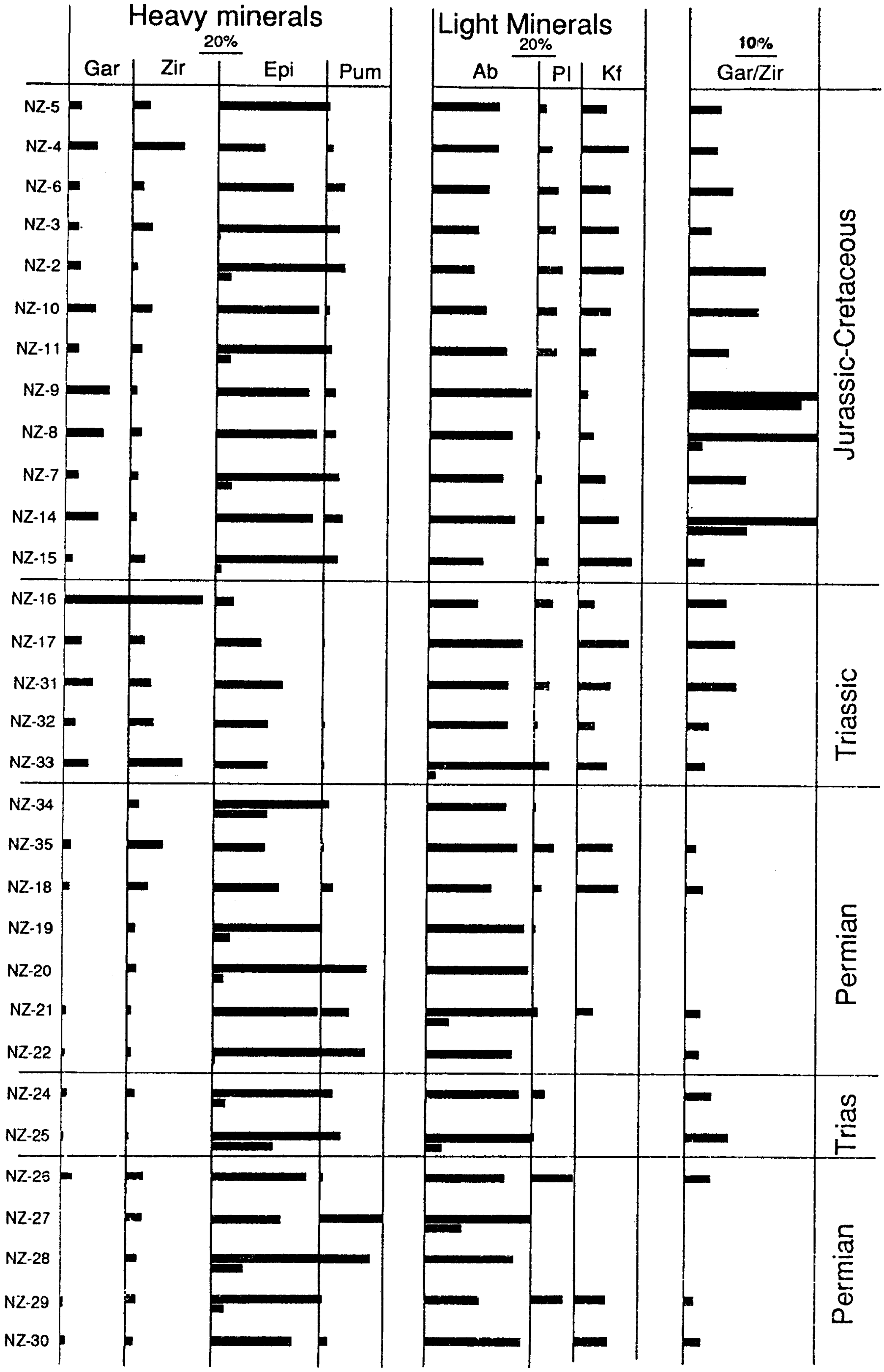

Fig. 2 Modal proportion of representative heavy and light minerals in the sandstones from the Torlesse terrane. Mineral abbreviations are the same as in Table 1.

found as a detrital minerals (Yokoyama unpublished). Since the Torlesse terrane should have been deposited in somewhat deep marine conditions as a deep sea deposit, epidote, pumpellyite and titanite may have already been decomposed before the weak metamorphism. Accordingly, among the major heavy minerals, detrital minerals are garnet, zircon, apatite and ilmenite, while epidote, pumpellyite, and titanite are metamorphic. In the Paleogene sandstones from the McKee

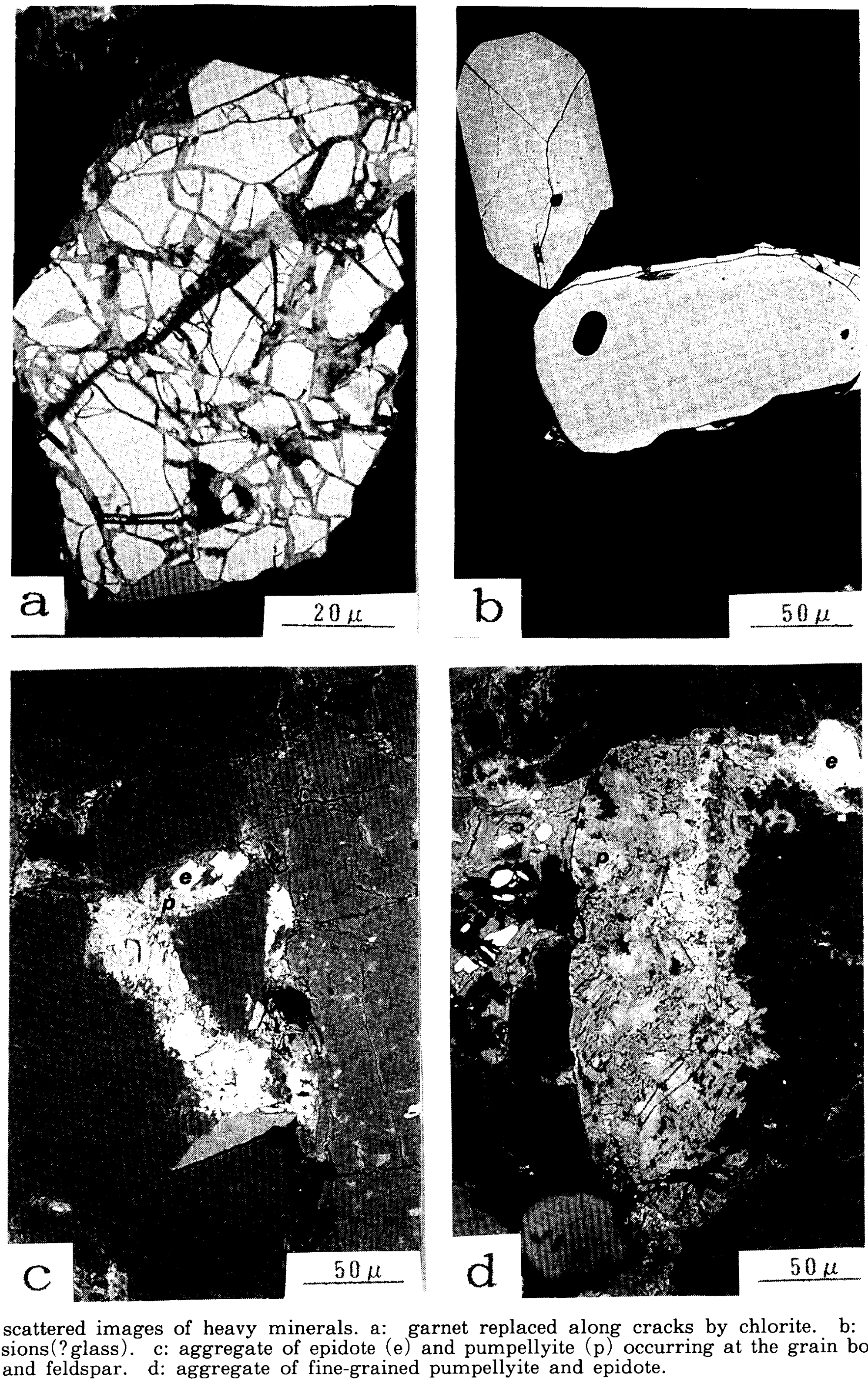

Fig. 3 Back scattered images of heavy minerals. a: garnet replaced along cracks by chlorite. b: zircons with rounded inclusions(?glass). c: aggregate of epidote (e) and pumpellyite (p) occurring at the grain boundaries between quartz and feldspar. d: aggregate of fine-grained pumpellyite and epidote.

Formation, northeast of Palmaston North, New Zealand, garnet, zircon, tourmaline, apatite and TiO_2 polymorphs are preserved (Smale & Morton 1987). Epidote and amphibole are scarcely preserved. Rare preservation of hornblende in the Torlesse terrane, therefore, indicates the possibility that epidote and titanite grains in this terrane have also been rarely preserved as detrital minerals.

Among the studied samples, one sample, NZ19 from the greenschist facies, contains abundant actinolite (Table 1). Other samples are from

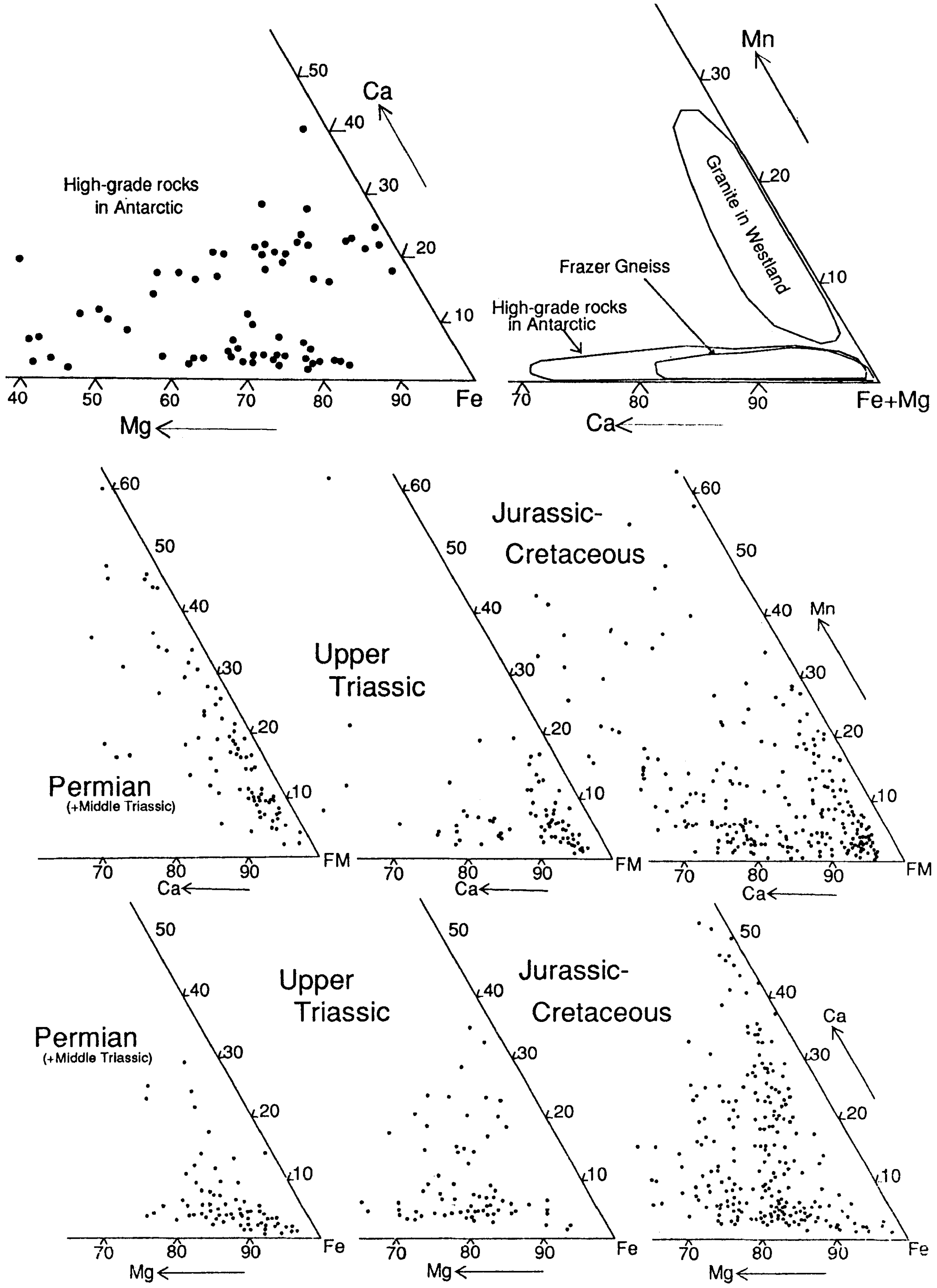

Fig. 4 Garnet compositions plotted in Ca-Fe-Mg and Mn-Ca-(Fe+Mg) diagrams. Garnet compositions from Antarctic, Frazer Gneiss and granite in Westland are summarised in the top diagrams. Data from Antarctic: Asami *et al.*(1990), Matsubara & Motoyoshi (1985) and others. Data from Frazer gneiss and granite: Mason (1981) and Smale & Morton (1987).

the prehnite-pumpellyite or zeolite facies according to Landis & Coombs (1967) and Landis & Bishop (1972). Metamorphic grade is considered to be continuous from the Older to Younger subterranes. However, modal proportions of metamorphic minerals are largely different between the

Older and Younger subterranes. As shown in Fig. 2 and Table 1, epidote content is low and pumpellyite is rare in the eastern part of the Older terranes. Prehnite is observed in the prehnite-pumpellyite zone of Landis & Coombs (1967), but in this area it occurs only as a vein mineral. Laumontite is not restricted to the Younger subterrane. It also occurs sporadically in the Older subterrane. Such occurrences of metamorphic minerals may be explained due to differences in bulk chemical compositions or retrogressive metamorphism. Although further regional work is required to confirm whether such low modal proportion of metamorphic minerals in the eastern region of the Older subterrane is widespread, it is likely that the metamorphism was not continuous from the Younger to Older Torlesse terranes.

The ratio of garnet to zircon is mostly higher than 1.0 in the Younger Torlesse and is less than 0.5 in the Permian sandstones in the Older Torlesse (Fig. 2). Such a difference is either due to an effect of provenance, reflecting the scarcity of garnets in the provenance of the Permian rocks, and/or that of dissolution or replacement of garnets by chlorite during diagenesis and metamorphism. Garnets are commonly surrounded by chlorite in some Permian rocks, but other Permian samples do not show such replacement or dissolution texture. Even though Ca-rich garnet were decomposed selectively during diagenesis, Ca-poor garnets are preserved in such condition as well as Mn-rich ones (Smale & Morton 1987). Garnets in the Permian rocks are clearly different in composition from those in the Triassic and Late Jurassic to Early Cretaceous rocks (Fig. 4). Therefore, it is probable that the difference in the ratio is due to the provenance effect of the sandstones rather than the dissolution and replacement.

The compositional variation of garnet from the Permian sandstones cannot be explained by preferential decomposition of garnets similar to those in the Jurassic-Cretaceous and Triassic terranes and the East Antarctic. Garnets from the Permian rocks have spessartine component up to 60% (Fig. 4), similar to those from the McKee Formation (Smale & Morton 1987). As discussed for Mn-rich garnets by Smale & Morton (1987), garnet from the Permian rocks are simply explained to be derivatives from granitic rocks. It is also clear that the Triassic-Cretaceous garnets were not derived from the Antarctic and were not reworked grains from the Permian rocks. Wide compositional variation of garnets from Jurassic to Cretaceous rocks shows that they were derived from various types of metamorphic and granitic rocks. The restricted compositional range of the Triassic garnets is due to lesser degree of contribution from granitic rocks.

Ireland (1991) obtained isotope ages of detrital zircons in a sandstone from the Permian region. Distribution of the ages has a strong peak at 250 Ma and a weak peak at 530 Ma. On the basis of the age analysis of each zircon grain in the sandstones, Ireland (1991) discussed the provenance of the constituent in the Torlesse sandstones. Present analyses of detrital garnets could not designate the source rocks of detrital minerals in the Torlesse sandstones. Further work should be concentrated on the age analyses of detrital zircons in sandstones as did Ireland (1991).

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