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Alkali feldspar granite clasts from Jurassic conglomerate, Murihiku Terrane, South Island, New Zealand

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ABSTRACT

We newly discovered rift-related alkali feldspar granite clasts consisting of perthitic alkali feldspar, quartz, arfvedsonite and/or aegirine from Jurassic conglomerate beds in the Murihiku Terrane, New Zealand. The alkali feldspar granite clasts are rare (ca. 1–2% of total clasts) and occur together with various volcanic and plutonic clasts. This discovery provides a possible key to reconstruct paleogeographic and paleotectonic settings of the 'volcanic arc-related' Murihiku Terrane in the eastern margin of Gondwanaland. We describe here new occurrence, geochemical and geochronological data about alkali feldspar granite clasts.

Their chemical features are characterized by 'A-type' granite such as high value of Nb, Ga, and Y and high ratio of Ga/Al. Geochronological results (156±8 Ma and 212±11 Ma) by K-Ar whole-rock dating method indicate that a possibility of two distinct batholiths existed as sources of the alkali feldspar granite clasts. The clast ages suggest a tectonic link between the Murihiku Terrane, the Median Batholith (Median Tectonic Zone) and West Antarctica. They are important clues to reveal the tectonics of the Mesozoic Gondwanaland margin.

INTRODUCTION

The Murihiku Terrane (Campbell and Coombs, 1966) is fault-bounded and the relationship among surrounding terranes is still unclear (Balance and Campbell, 1993). The Murihiku sequence has a long span for its depositional duration from Permian (?) to Late Jurassic, which is overlapped by some active periods of the Median Batholith (Campbell et al., 1999; Tulloch et al., 1999; Mortimer et al., 1999). The sediments are predominantly volcanic-derived and have been interpreted as arc-related basin deposits (forearc basin: Coombs et al., 1976; Ballance and Campbell, 1993; Bradshaw, 1994 or backarc basin: Coombs et al., 1996) along the Mesozoic Gondwanaland margin. It is, however, unknown where the provenance of huge volcaniclastics is located. Conglomerate clasts contain direct information about their provenances. Studying of conglomerate clasts is an essential method to understand the relationship between the Murihiku and surrounding terranes.

Conglomerates of the Murihiku Terrane in South Island have been studied by several researchers. Mackie (1935) was the first to report granitic clasts from the Triassic and Jurassic conglomerate beds. He noted that the plutonic rocks were highly sodic and some clasts were strained. Watters (1952) reported granophyre pebbles and pointed out that strain effects were common in granitoid clasts of Jurassic conglomerate. Wood (1956) recorded granite and granite porphyry pebbles in the Diamond Peak Group of Early Jurassic age. Speden (1971) noticed the occurrence of metamorphic clasts, mainly hornfels pebbles, in addition to granite and granophyre pebbles. Boles (1974) studied petrology of Triassic conglomerate in detail and discussed the source direction and area. All these studies have been restricted to conventional petrographical analyses, and no detailed chemistry and age data of pebbles have been reported. A recent paper by Graham and Korsch (1990) has dealt with age and chemistry of granitoid clasts in the Moeatoa Conglomerate in the Kawhia Syncline, North Island. The granitoid clasts are regarded as having been derived from the Permian-Triassic Brook Street magmatic arc (Graham and Korsch, 1990). Noda et al. (1999) revealed that clasts in the Jurassic conglomerate at the Waikawa district of the Murihiku Terrane were transported from southeast on the basis of clast imbrication.

This paper is the first to document the existence of alkali feldspar granite clasts having sodic amphibole and/or clinopyroxene from Jurassic conglomerate beds in the Murihiku Terrane. We present the petrological, geochemical and geochronological data of the alkali feldspar granite clasts and discuss their origin.

GEOLOGICAL SETTING

The Murihiku Terrane has a synclinal belt of volcanic sandstone, siltstone and conglomerate deposits containing interbedded tuff beds. It lies between the Brook Street and the Dun Mountain-Maitai Terranes with fault contacts (Ballance and Campbell, 1993; Fig. 1). An asymmetrical structure is characterized by a steeply dipping north limb and a gently folded south limb. The strata in the north limb consist mainly of Middle Triassic to Middle Jurassic deposits (Boles, 1974; Carter, 1979). On the other hand, correlative strata on the south limb are composed of Early to Middle Jurassic shelf-nonmarine sediments (Speden, 1971; Carter et al., 1978) with minor Permian strata (Campbell et al., 1999). A general tendency for strata to become thinner and finer towards east and northeast is recognized (Bishop and Turnbull, 1996).

Sedimentary sequences are well exposed along the coast at the Waikawa district where they are characterized by stacked, sheet-like bodies of conglomerate that alternate with sandstone, siltstone and minor coal seams (Fig. 2). One regional syncline, the Waikawa Syncline (Watters et al., 1968), dominates geological and geographical features in this area.

Depositional age is not clear due to sparse marine fossils. *Neocrassina* sp. (Temaikan) is obtained at one locality (identified by Campbell, personal communication, 1999). Suggate et al. (1978) showed that the Waikawa sequence was of Temaikan (Bajocian-Bathonian) age on the basis of *Hibolithes* sp., Macrocepdhalitid ammonoids and *Tancredia allani*. *Cladophlebis indica* is obtained at some localities with respect to flora. Fossil forest at Curio Bay, west of Waikawa, indicates Middle Jurassic age (Park, 1887; Arber, 1917). Palynological data, however, suggests Bathonian-Callovian (Upper Temaikan Stage; Pole, 1999). A precise age and duration of sedimentation are currently still uncertain.

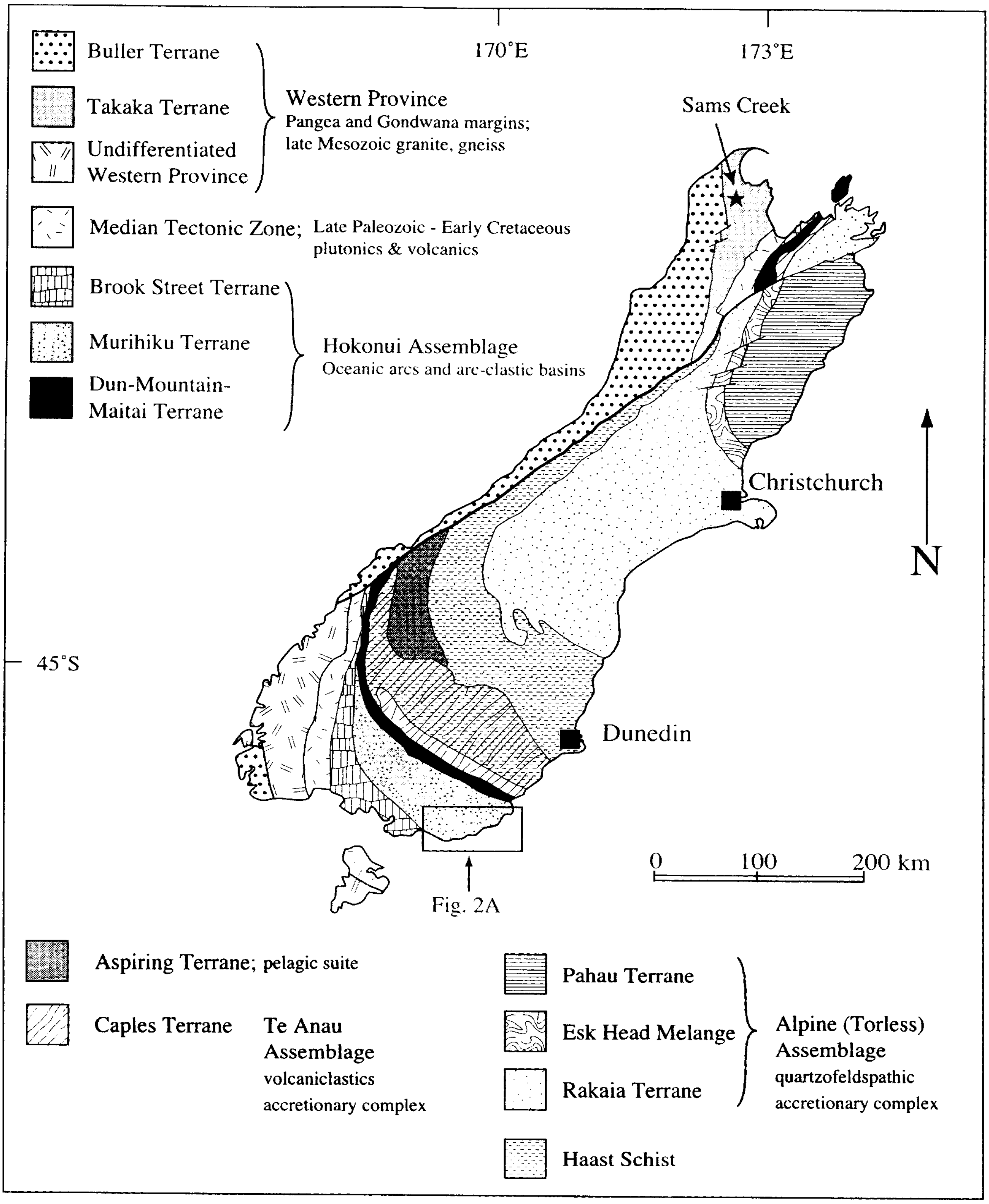

Fig. 1. Tectonostratigraphic terrane map, South Island, New Zealand (after Landis et al., 1999).

OCCURRENCE OF CONGLOMERATE

Two localities (NZMS260 grid reference: G47/152903 and G47/120908) where the clasts have been collected are shown in Fig. 2. This area is widely underlain by thick fluvial-deltaic deposits (Noda et al., 1999). The conglomerate beds are ten to twenty meters thick, clast-supported and interbedded with relatively thin, lenticular sandstone

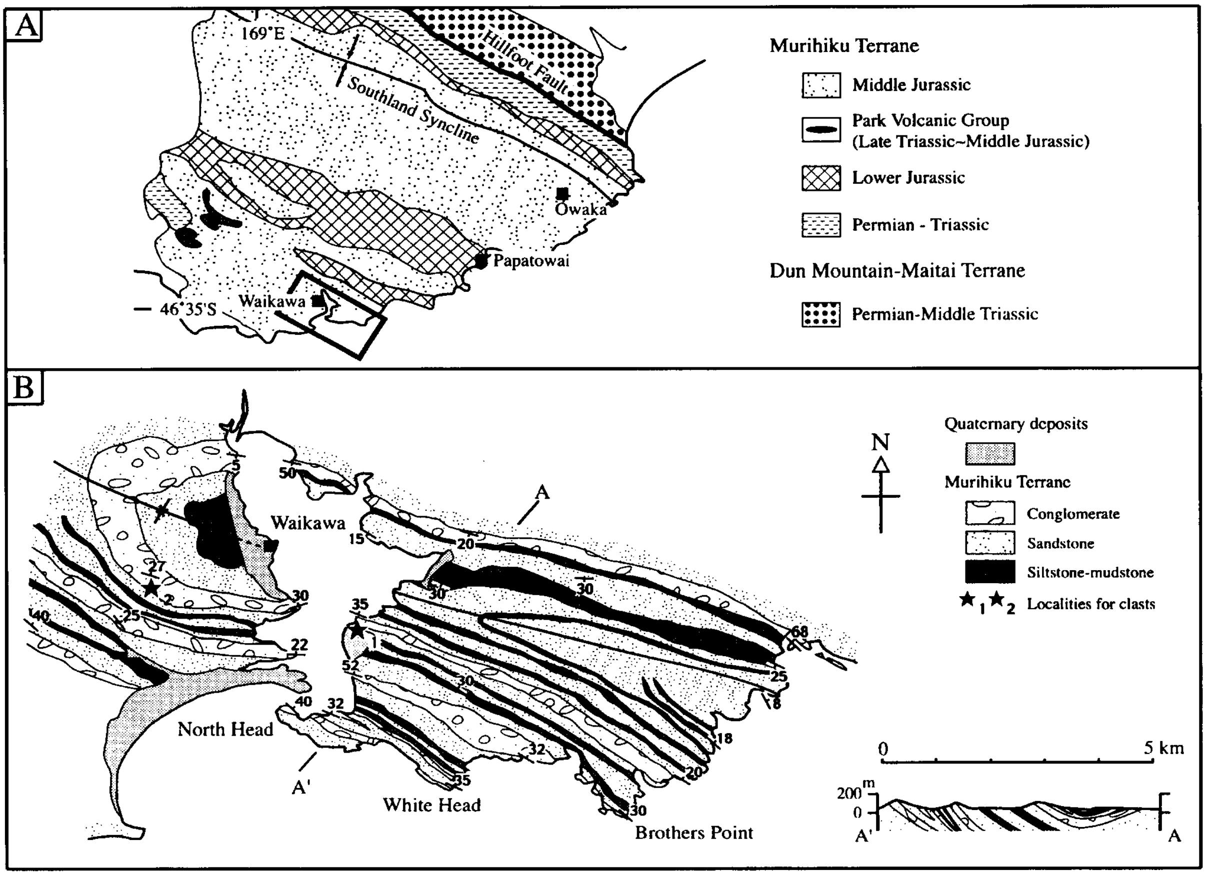

Fig. 2. (A) Geological map of Southland region of the Murihiku Terrane and study area. Modified from Watters et al. (1968), McKellar (1966) and Wood (1966). (B) Geological map of the Waikawa district and cross section. Solid stars show localities for alkali feldspar granite clasts.

beds. The matrix is coarse-grained lithic wacke and consists of volcanic lithic fragments. Well-rounded to rounded and spherical clasts are predominant. Discoidal clasts are less commonly present. Average clast diameter is 5 cm and the maximum is 30 cm. Clast imbrication indicates derivation from the southeast (Noda et al., 1999).

The conglomerate is composed mainly of volcanic lithofacies with plutonic and minor metamorphic components (Table 1). Volcanic clasts include rhyolite, dacite and andesite. Rhyolitic welded tuff and andesitic tuff breccia are also present. Plutonic clasts are chiefly of granite including alkali feldspar granite (1–2% of total clasts) and less commonly diorite and hornblende gabbro. Minor hornfels and mylonite clasts are also present as metamorphic clasts.

METHODOLOGY

Seven alkali feldspar granite clasts were petrographically, geochemically and geochronologically analyzed. Samples 1 to 6 were obtained from the east of Waikawa Harbour (Star 1 in Fig. 2), Sample 7 was from the west (Star 2). Modal analyses are taken by point counting (1000 points) on thin sections; all sections were stained for K-feldspar. Major and trace element compositions of clasts were determined by XRF

Table 1. Average clast composition at two conglomerate localities in Fig. 2.

Rhyolite-dacite	40.5 (%)
Quartz porphyry-granite porphyry	12.8
Andesite-basalt	14.6
Welded tuff & tuff breccia	11.4
Granitoids (including alkali feldspar granite)	4.9
Diorite-gabbro	8.3
Metamorphic rocks	7.2
Sedimentary rocks	0.3

(number of measured clasts = 775)

spectrometry at Nagoya University using a Shimadzu SXF-1200 spectrometer.

Chemical compositions of constituent minerals of the clasts were analyzed at Nagoya University on a JEOL JXA-8800 electron probe microanalyzer. The operating conditions were: an accelerating voltage of 15 kV, beam current of 0.12 μA, beam diameter of 5 μm, and maximum count times of 20 s. Since Fe^{3+} has not been analyzed for amphiboles, the amphibole chemistry has been calculated by (Fe^{2+}+Mg+Mn+Fe^{3+}+Al+Ti+Cr+Si) = 13 for O = 23. For clinopyroxene chemistry, Fe^{3+} has been calculated on the basis of total cation = 4 for O = 6. The nomenclature of amphibole and pyroxene is based on Leake (1978) and Morimoto (1988), respectively.

Two of the clasts (Samples 2 and 7) were determined their radiometric age by K-Ar whole rock dating due to fine-grained and graphic texture. The K-Ar ages were calculated using the physical constants, $\lambda_e = 0.581 \times 10^{-10}$/y, $\lambda_\beta = 4.962 \times 10^{-10}$/y, isotopic abundance ^{40}K/K = 1.167×10^{-2} atom% (Steiger and Jäger, 1977). The minimum error assigned to age determination is ±5%.

RESULTS

Petrology

The alkali feldspar granite clasts are pinkish to light gray (Fig. 3A), and are 5 cm to 15 cm in size. The clasts show graphic structure under the microscope (Fig. 3B). They consist of anhedral phenocrysts of perthitic alkali feldspar (up to 5 mm across) and quartz with ca. 5% sodic amphibole and clinopyroxene (Table 2). Discrete plagioclase grains are rarely observed. Clinopyroxene, where present, is commonly associated with amphibole (Fig. 3C). Zircon, apatite and opaque oxides occur as accessory minerals. No strain effect and little alteration is recognized under the microscope.

Alkali amphibole grains showing deep-blue, pale-green, yellow-green and yellow pleochroism occur as euhedral to subhedral grains (Fig. 3C). Some glomeroporphyritic grains are also present. Because ΣA values for all grains are over 0.5 (Leake, 1978), almost amphibole grains are arfvedsonite (some grains are manganoan-arfvedsonite; Fig. 4).

Clinopyroxene showing yellow to yellow-green pleochroism forms subhedral to euhedral grains that occur closely with alkali amphibole (Fig. 3C). The chemical compositions show aegirine (Morimoto, 1988; Table 3).

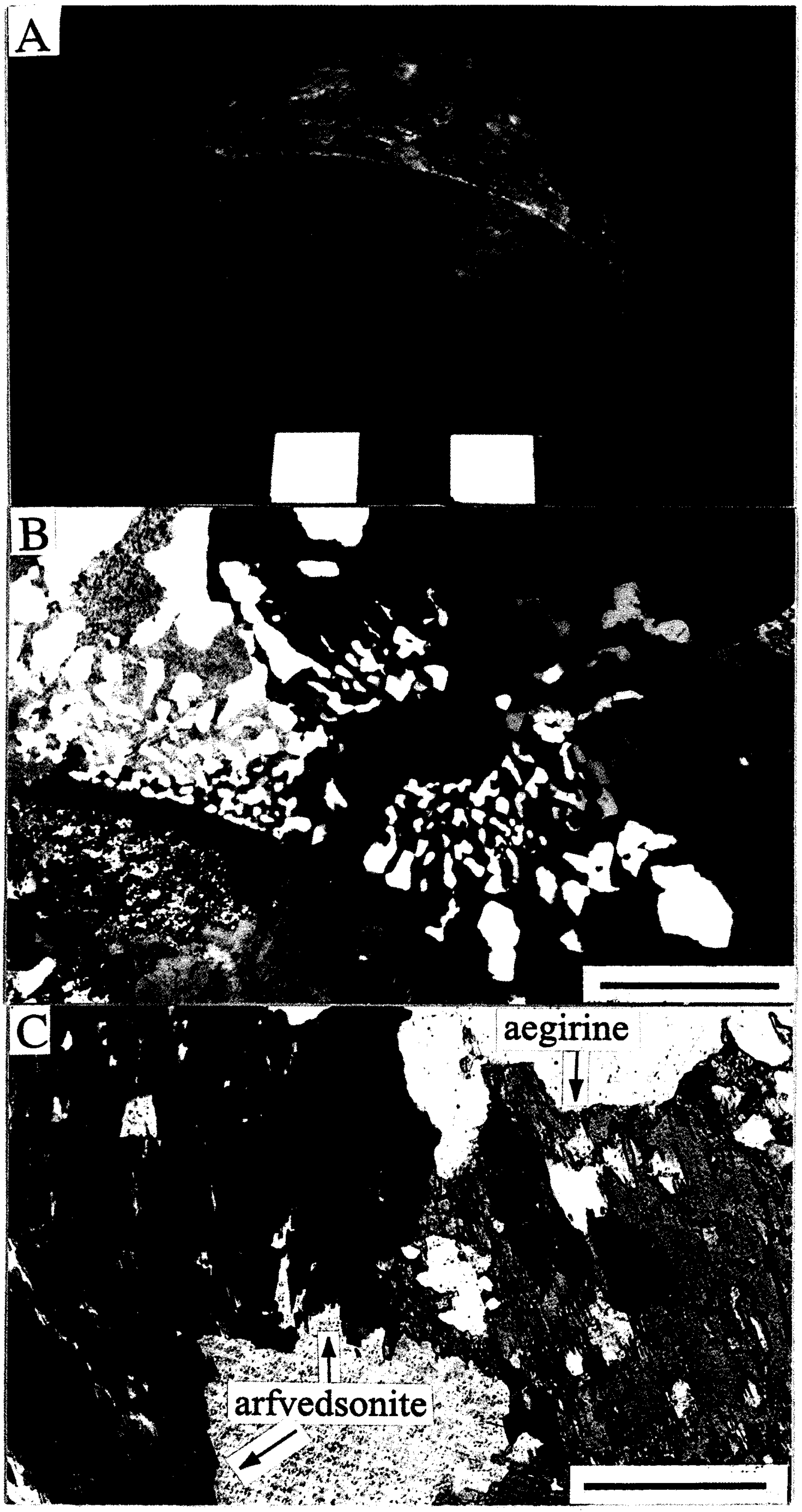

Fig. 3. (A) Hand specimen of an alkali feldspar granite clast obtained from east side of Waikawa Harbour. Scale bar is 50 mm. (B) Photomicrograph showing graphic structure of quartz and perthite. Crossed polars. Scale bar is 0.5 mm. (C) Photomicrograph of arfvedsonite and aegirine. One polar. Scale bar is 0.2 mm.

Table 2. Whole-rock chemical and modal compositions of the alkali feldspar granite clasts from Middle Jurassic conglomerate beds.

Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Major elements							
SiO_2	77.81	76.94	77.25	75.86	77.09	76.74	76.64
TiO_2	0.13	0.22	0.13	0.22	0.16	0.13	0.17
Al_2O_3	11.53	11.85	11.80	11.58	11.74	11.28	11.99
FeO*	1.74	1.83	1.32	1.66	1.40	1.67	1.18
CaO	0.08	0.06	0.10	0.13	0.10	0.11	0.10
MnO	0.04	0.02	0.03	0.03	0.04	0.06	0.02
MgO	0.04	0.05	0.05	0.04	0.06	0.06	0.05
Na_2O	4.46	5.20	4.75	5.16	4.73	4.48	5.04
K_2O	3.97	3.28	3.54	3.32	3.44	3.75	3.52
P_2O_5	0.02	0.01	0.02	0.01	0.03	0.02	0.02
Total	100.00	99.66	99.14	98.19	98.94	98.49	98.86
Trace elements (in ppm)							
Ba	110	350	280	330	320	150	230
Rb	160	120	140	120	130	150	120
Sr	9	12	16	11	29	11	18
Pb	20	15	22	27	21	30	30
Th	23	6	24	13	29	22	13
Zr	540	280	980	320	1000	670	650
Nb	26	11	32	15	35	31	29
Y	48	32	96	29	89	57	87
Co	11	6	11	5	8	8	5
Cu	9	3	7	-	8	7	0
Zn	73	34	49	32	50	104	40
Ga	21	n.d.	19	26	20	21	n.d.
*Norms***							
Qz	35.8	33.5	35.6	33.5	36.0	36.0	33.7
Co	0.0	0.0	>0.0	0.0	0.1	0.0	0.0
Or	23.5	19.4	21.1	20.0	20.6	22.5	21.1
Ab	37.2	42.8	40.5	41.8	40.4	37.7	42.5
An	0.0	0.0	0.4	0.0	0.3	0.0	0.0
Ac	0.5	1.2	0.0	1.8	0.0	0.7	0.6
Ns	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Di	0.2	0.2	0.0	0.5	0.0	0.4	0.3
Hy	1.8	2.0	1.4	1.8	1.4	1.8	1.1
Mt	0.7	0.4	0.7	0.0	0.8	0.6	0.4
Il	0.2	0.4	0.2	0.4	0.3	0.2	0.3
Ap	>0.0	>0.0	>0.0	>0.0	>0.1	>0.0	>0.1
Modal analyses							
Qtz	30.7	20.9	29.8	24.5	33.0	31.1	26.4
Kf	64.0	75.2	65.3	71.3	63.1	65.5	70.1
Pl	-	0.2	-	-	-	-	0.8
A. Amph	2.5	0.3	4.7	0.6	3.7	3.0	-
Cpx	2.5	1.9	-	2.0	-	0.1	2.1
Bt	-	-	-	-	-	-	-
Others	0.4	1.5	0.2	1.6	0.2	0.3	0.6

Analysts: M. Tsuboi & A. Noda

FeO* as total iron. Norms** are calculated on the basis of Fe_2O_3/FeO = 0.5. n.d. = not determined. Abbreviations: Qtz; quartz, Pl; plagioclase, Kf; alkali feldspar, A. Amph; alkali amphibole, Cpx, clinopyroxene, Bt; biotite. Others include zircon, apatite, and opaque oxides.

Alkali feldspar appears to be slightly altered under the microscope. Its chemical composition shows pure alkali feldspar with little calcium (Table 3).

Geochemistry

Major and trace element analyses show narrow variety of the values among the clasts analyzed (Table 2). The clasts are peralkaline to weakly peraluminous (Fig. 4). Remarkable features are high SiO_2 (>75 wt%), high total alkali (>8 wt%) and low CaO (<0.13 wt%) contents as is typical of A-type granites (Whalen et al., 1987). Na_2O/K_2O ratios are > 1. All samples are acmite normative except Samples 3 and 5 that are corundum normative.

In trace element chemistry, the clasts show low values of Ba and Sr and high values of Zr, Nb, Y, Zn and Ga, and high ratio of Ga/Al (Table 2). On the discriminant diagram

Table 3. Selected microprobe analyses of alkali amphibole, aegirine and alkali feldspar.

Sample	**1**	**2**	**3**	**1**	**2**		**1**	**2**	**3**
	Arfvedsonite			Aegirine			Alkali feldspar		
SiO_2	50.7	46.9	48.7	52.3	51.6		63.6	67.5	67.0
TiO_2	0.96	1.61	1.63	0.99	0.49		0.01	-	-
Al_2O_3	0.95	1.15	1.04	1.08	0.21		18.0	18.6	18.5
FeO*	29.3	33.5	33.0	28.6	29.9		0.83	0.93	0.62
MnO	1.92	1.55	1.82	0.04	0.74		0.04	-	0.02
MgO	2.92	0.93	0.78	0.08	0.11		-	-	-
CaO	1.28	2.75	1.56	0.01	2.21		0.01	-	-
Na_2O	8.16	6.71	7.65	13.8	12.2		0.18	9.50	11.8
K_2O	1.22	1.11	1.24	0.02	-		15.2	4.07	0.55
Cr_2O_3	-	-	-	-	-		-	-	-
Total	97.41	96.21	97.42	96.92	97.46		97.87	100.60	98.49
Cations	**(23 oxygens)**			**(6 oxygens)**			**(32 oxygens)**		
Si	7.93	7.61	7.78	1.99	1.99		12.09	11.87	11.88
Al^{IV}	0.06	0.22	0.20	0.01	-		4.02	3.85	3.86
Al^{VI}	0.11	-	-	0.04	-		-	-	-
Ti	0.11	0.20	0.20	0.03	0.01		-	-	-
Fe^{3+}	0.57	0.89	0.70	0.91	0.90		0.01	0.65	0.81
Fe^{2+}	3.27	3.65	3.69	-	0.07		0.13	0.14	0.09
Mn	0.25	0.21	0.25	-	0.02		0.01	-	-
Mg	0.68	0.22	0.19	-	0.01		-	-	-
Ca	0.22	0.48	0.27	-	0.09		-	-	-
Na	2.48	2.11	2.37	1.02	0.91		0.05	2.59	3.23
K	0.24	0.23	0.25	-	-		3.68	0.91	0.13
Total	16.11	16.03	16.08	4.00	4.00		20.00	20.00	20.00
$\frac{100 \times Mg}{(Mg+Fe^{**})}$	15.08	4.71	4.06	0.47	0.65	ΣZ	16.26	16.50	16.64
ΣA	0.94	0.81	0.89			ΣX	4.02	3.85	3.86
						Or/Ab	0.99	0.26	0.39

Analyst: A. Noda.

Amphibole Fe^{2+}/Fe^{3+} are calculated by IMA-approved scheme (Leake, 1978).
FeO* as total iron.
Fe** as total cation of iron.
ΣA is excess Na plus all K cations.
ΣZ and ΣX are summations for Si, Al and Fe^{3+} and Na, K and Ca, respectively.

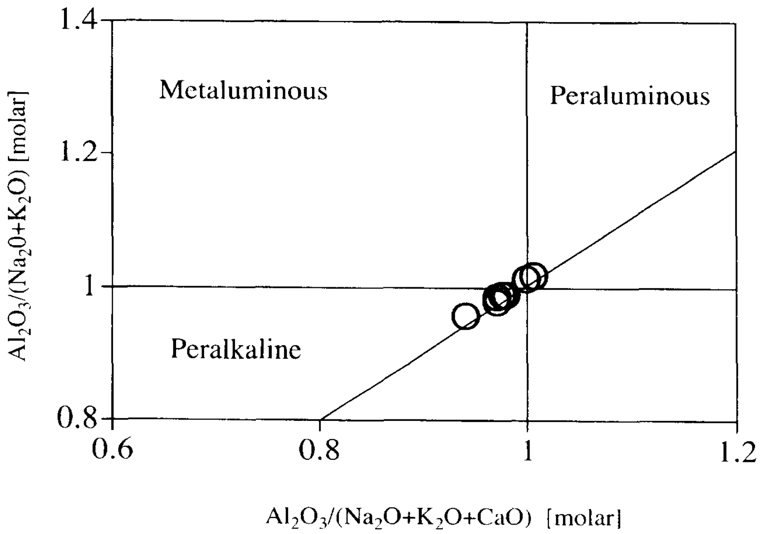

Fig. 4. Illustration of the Shand Index for the alkali feldspar granite clasts, showing slightly peraluminous to peralkaline.

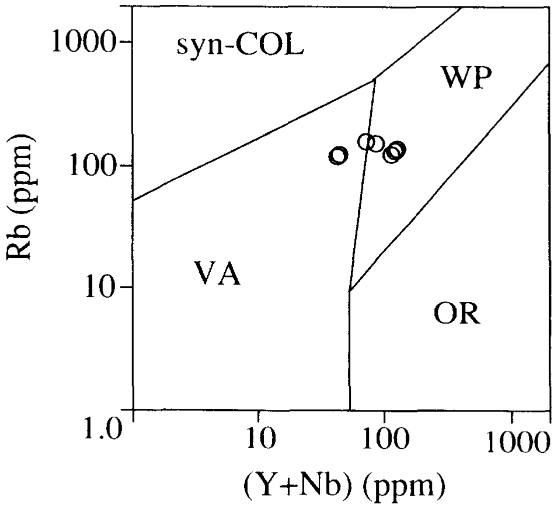

Fig. 5. Rb-(Y+Nb) discriminant diagrams for the alkali granite clasts. Abbreviations; syn-COL: syn-collision, VA: volcanic arc, WP: within plate, and OR: normal and anomalous ocean ridge granite (Pearce et al., 1984).

of Rb-(Y+Nb) the clasts straddle the boundary within-plate granite and volcanic-arc granite (Pearce et al., 1984; Fig. 4). Samples 2 and 4 are, however, plotted in the field of volcanic arc (VA) granite due to their low contents of Y and Nb.

Geochronology

Two radiometric ages (Sample 2: 156±8 Ma and Sample 7: 212±11 Ma) by K-Ar whole-rock dating are given in Table 4. High ratio of radiogenic ^{40}Ar/total ^{40}Ar enhances the reliability of the age data. Although the two clasts show similar results of petrographical and major element analyses each other, two age data show a large gap (ca. 50 m.y.). On trace element analysis, contents of Zr, Y and Nb are different between the two dated clasts (Table 2).

Table 4. K-Ar whole-rock age data for alkali feldspar granite clasts.

Sample	K (wt%)	^{40}Ar (radiogenic) (scc/g x 10^{-5})	^{40}Ar (radiogenic) (% total)	Isotopic age (Ma)
2	2.88	1.76	97.1	156 ± 8
	2.90	1.89	97.3	
7	2.77	2.43	97.8	212 ± 11
	2.75	2.40	97.8	

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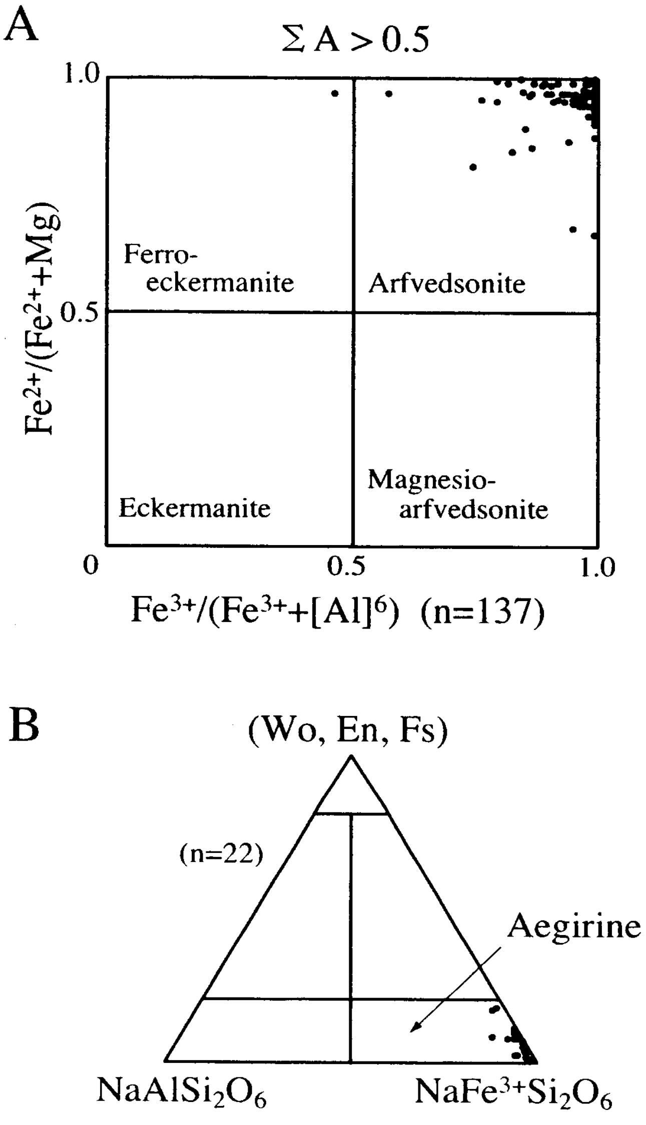

Fig. 6. Chemical compositions of alkali amphibole and clinopyroxene. (A) alkali amphibole (ΣA > 0.5) in the alkali feldspar granite clasts. (B) Clinopyroxene in the alkali feldspar granite clasts. Abbreviations; Wo: wollastonite, En: enstatite, Fs: ferrosilite.

DISCUSSION

Depositional age of the Waikawa sequence

Ages for the clasts constrain the maximum depositional age of the Waikawa sequence, which is restricted by the clast age (156±8 Ma; Late Jurassic). On the other hand, the minimum age is not constrained by such as an intrusion. Previous macroplant and palynological fossils indicate that the sediments around the Waikawa district are of Middle Jurassic age (see Geological Setting section). If the depositional age of the Waikawa sequence is Oxfordian (157–155 Ma) or later, the Waikawa sequence is younger than the New Haven Group (Callovian, 161–157 Ma, Harland et al., 1989; Speden, 1971). It means the Waikawa sequence is the youngest strata in the Murihiku Terrane of South Island. From a view point of sedimentary facies, terrestrial facies as upper part of the Waikawa sequence (Noda et al., 1999) has similarity to that of the False Islet Formation (New Haven Group) in Papatowai Subdivision (Speden, 1971). Sedimentary facies of Late Jurassic Huriwai braidplain delta in North Island (Balance, 1988) also resemble that of the Waikawa on the fan-deltaic system. The latest sedimentary environment of the Murihiku Terrane in South Island may have been fluvial before it uplifted and eroded.

Possible provenance of the clasts

Conglomerate beds in the Waikawa sequence are dominated by felsic to intermediate volcanic and plutonic clasts (Table 1). The source area inferred from petrology in conglomerate and sandstone is magmatic arc or active continental margin as mixed volcanic-plutonic-metamorphic sources (Landis et al., 1999; Tulloch et al., 1999). Murihiku sediments geochemically indicated that the deposition occurred near the Gondwanaland margin (Kimbrough et al., 1984; Frost and Coombs, 1989). Possible provenances of the clasts are the Brook Street Terrane, the Median Batholith, the Western Province, East Australia, and West Antarctica in terms of paleogeographic and paleomagnetic data (Grindley et al., 1980; Grindley and Davey, 1982).

The Brook Street Terrane that consists of marine volcanic and volcaniclastic strata (Bradshaw, 1994) may be discounted as the provenance on the basis of the Permian age and an intra-oceanic arc origin (Frost and Coombs, 1989; Houghton and Landis, 1989). In the Western Province, Sams Creek peralkaline granite, west of Takaka (Fig. 1), is of Triassic age (Tulloch, 1992). It shows close age (226±1.1 Ma) and petrography to the clasts in this study. There might be some relationship of magmatic activity between the Sams Creek granite and the source batholith of the clasts. However, the geographic distance between Sams Creek and Waikawa is a problem as a provenance of the clasts.

The Median Batholith represents the manifestation of a continental margin arc that was active in two main periods: ca. 228–195 Ma and ca. 170–130 Ma (Kimbrough et al., 1994; Tulloch et al., 1999). The periods are overlapped by the sedimentation span of the Murihiku basin (until Late Jurassic) and contain the two ages dated in this study. This is the most likely source of the clasts and huge volcanic-derived detritus in the Murihiku basin. Alkali feldspar granite in the Median Batholith is reported only from the Freds Camp Granite that is, however, of Carboniferous age (Allibone and Tulloch, 1997; Tulloch et al., 1998). It is difficult for the Freds Camp Granite to consider as a provenance of the clasts due to the age gap. It seems unlikely that Median Batholith as presently exposed was a major source for the alkali feldspar granite clasts. We suggest that the source of the clasts was dissected or unexposed presently in the Median Batholith.

West Antarctica should be also regarded as a provenance of the clasts. Marie Byrd Land can be considered to be relics of a succession of arcs that developed along the Gondwanaland margin (Bradshaw et al., 1997). Mesozoic magmatism is abundant in Marie Byrd Land and predominantly Jurassic ('I'-type granitoids) and Cretaceous (calc-alkaline 'I'- and younger break-up related 'A'-type granitoids) in age (Pankhurst et al., 1993). Their lithologies are closely related to the Median Batholith (Bradshaw et al., 1997; Pankhurst et al., 1998). There is, however, also no Triassic-Jurassic rift-related batholith in Marie Byrd Land as well as the Median Batholith. Marie Byrd Land is not admissible as another candidate for a presently exposed provenance of the alkali feldspar granite clasts in the Murihiku Terrane.

CONCLUSIONS

The alkali feldspar granite clasts from the Jurassic conglomerate in the Murihiku Terrane are newly found and described in this study. The 'A'-type characteristics are extraordinary in detritus of the the Murihiku Terrane strata. There is presently no outcrop of undoubted source in present New Zealand and West Antarctica. However, the Median Batholith or Marie Byrd Land is permissible as a possible provenance of the clasts due to their huge Mesozoic felsic plutonic batholiths. This indicates that the tectonic setting of the Murihiku Terrane is foreland basin of the Gondwana continental margin. The suggestion is the Murihiku sedimentation occurred adjacent to an arc with continental underpinnings that included rift-related magmas.

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