Late Triassic metatonalite from the Schwaner Mountains in West Kalimantan and its contribution to sedimentary provenance in the Sundaland

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ABSTRACT

This contribution presents petrography, geochemical characteristicc and LA-ICP-MS U-Pb zircon dating from metatonalites in the Schwaner Mountains of West Kalimantan. The metatonalites mainly consist of plagioclase, biotite, quartz, apatite, muscovite, and titanite with relict clinopyroxene surrounded by hornblende. The geochemical characteristics show that the rocks have calc-alkaline affinities and were derived from subduction-related arc tectonic environment. Some of the metatonalites have adakite signature, which suggests the Schwaner Mountains were not formed by a consecutive subduction system. The result of LA-ICP-MS U-Pb zircon dating reveals that the metatonalite has magmatic age at 233 ± 3 Ma (Late Triassic), which is the oldest magmatic age in the Schwaner Mountains. Therefore, it strongly suggests that the Schwaner Mountains has significantly potential for important sedimentary sources in Sundaland not only from Cretaceous age but also from Triassic age as well as Tin Belt granites from Malay Peninsula.

Keywords: metatonalite, Schwaner Mountains, LA-ICP-MS U-Pb zircon dating, Late Triassic sedimentary provenance, Sundaland.

INTRODUCTION

Schwaner Mountains have been considered as Cretaceous granitoids pluton in the West Kalimantan (Haile et al., 1977; Williams et al., 1988; Amiruddin and Trail, 1993). It has important meaning to the tectonic setting of Sundaland and is considered as main supply of Cretaceous age detrital zircon to the surrounding areas through generated palaeogeography and palaeodrainage during the Late Cretaceous and Early Paleogene (e.g., van Hattum et al., 2006; Clements and Hall, 2008; Clements and Hall, 2011). The Permian to Triassic detrital zircon found in the sedimentary rocks around the Sundaland have always been considered as being derived from Tin Belt granite of Malay Peninsula (e.g., van Hattum et al., 2006; Clements and Hall, 2008; Clements and Hall, 2011).

This contribution reports the existence of metatonalite in the Schwaner Mountains, whose geochemical character can be differentiated from Cretaceous granitoids on the same location. Furthermore, we report LA-ICP-MS U-Pb zircon dating from metatonalite and discuss its correlation to the tectonic setting and contribution to sedimentary provenance in the Sundaland. Mineral abbreviations in this paper follow Whitney and Evans (2010).

GEOLOGICAL BACKGROUND

Western to central parts of Indonesia region, particularly the Sunda Shelf, have low topography, free of seismicity and volcanism. The areas include Thai-Malay peninsula, NE Sumatra, Borneo, and NW Java. This tectonically quiet region forms the continental core of an area called Sundaland (Hamilton, 1979; Hall, 2002; 2009; Metcalfe, 1998).

Borneo Island has a Palaeozoic continental core in western part that is surrounded by ophiolite, island arc, and microcontinental crust accreted during Mesozoic (Hamilton, 1979; Wilson and Moss, 1999; Hall et al., 2008; Figure 1). The NW Kalimantan (Indonesian part of Borneo) domain includes fossiliferous Carboniferous limestones, Permo-triassic granites, Triassic marine shales, ammonite-bearing Jurassic sediments, and Cretaceous mélanges (Williams et al., 1988; Figure 1). NW Kalimantan domain was connected to the Thay-Malay Peninsula, which has a Proterozoic continental basement including tin-bearing Permian to Triassic granites and minor of Cretaceous granites (Hall et al., 2008). Williams and Harahap (1987) considered that NW

Kalimantan domain was allochtonously accreted continental terrane. In SW Kalimantan domain, Palaeozoic units are represented mainly by metamorphic rocks of Carboniferous to Permian age, although Devonian limestones have been found as river boulders in East Kalimantan (Hall et al., 2008; Figure 1). Cretaceous granitoid plutons, which associated with volcanic rocks, intrude the metamorphic rocks in the SW Kalimantan, which known as Schwaner Mountains (Williams et al., 1988; Figure 1). Apatite fission track ages indicate rapid exhumation of the granites in the Late Cretaceous (Sumartadipura, 1976).

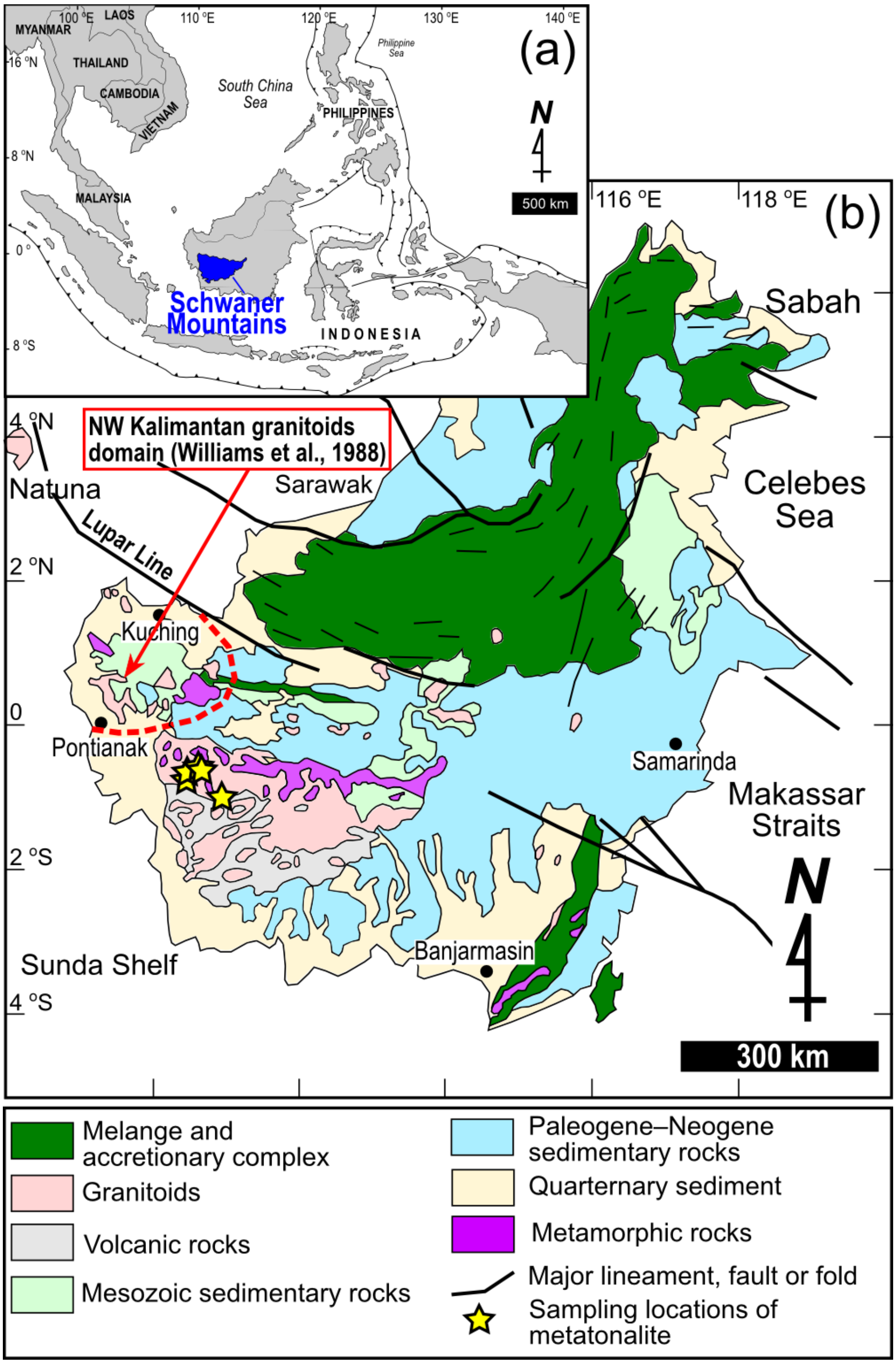

***Figure 1. (a)** Situation map of Indonesia and the location of Schwaner Mountains in Borneo Island. **(b)** Simplified geological map of Borneo Island with the sampling localities of metatonalites. Modified from Wilson and Moss (1999); Hall et al. (2008).*

Schwaner Mountains granitoids are composed of biotite-hornblende tonalite and granodiorite with minor mafic rocks and granite (Haile et al., 1977; Williams et al., 1988; Amiruddin and Trail, 1993). The granitoids formed a belt of 200 km wide and at least 500 km long, extending in an approximately E–W direction (Figure 1). Chemical analyses of typical rocks from the Schwaner Mountains indicate the I-type calc-alkaline nature of the suite (Williams et al., 1988; Amiruddin and Trail, 1993; Amiruddin, 2009). These rocks intruded into the low-grade metamorphic rocks during the Late Jurassic to Early Cretaceous and resulted in contact metamorphism (Williams et al., 1988). The progressive increase in metamorphic grade towards the intrusive contact with the tonalite bodies and the local occurrence of migmatite adjacent to them, indicate that the thermal metamorphism was due to the Early Cretaceous magmatism. The variations of contact metamorphic rocks are cordierite-andalusite-silimanite hornfels, andalusite-biotite hornfels, and andalusite-silimanite hornfels (Setiawan et al., 2013a). Foliations developed in the tonalite that was named as metatonalite (Amiruddin and Trail, 1993; Setiawan et al., 2013a). Strikes of schistosity of the metatonalites generally range from E–W to NE–SW (Amiruddin and Trail, 1993). It might be caused by deformation of the plutonic body after the magmatism (Setiawan et al., 2013a). Williams et al. (1988) particularly described as foliated tonalite.

Southward-directed subduction during Early Jurassic to Early Cretaceous is considered to be represented by granitoid plutons of the Schwaner Mountains (Haile et al., 1977; Williams et al., 1988; Amiruddin and Trail, 1993; Amiruddin, 2009). Furthermore, Zhou et al. (2008) proposed that the Mesozoic subduction belt in the North Kalimantan extends from Natuna Islands south-eastward along the Lupar River to the boundary between Sarawak and Kalimantan, turns eastward along the upper reach of the Kapuas River, and then turns northward in the Adio area of Sabah (Figure 1). The oceanic crust that subducted beneath West Kalimantan terranes, which has completely disappeared, is considered to be beneath proto-South China Sea (Metcalfe, 1998; Zhou et al., 2008).

K-Ar ages of biotite and hornblende from the granitoids in the Schwaner Mountains range from 157 to 77 Ma (Jurassic to Cretaceous), while the northwest Kalimantan block ages are from 320 Ma to 204 Ma (Triassic to Carboniferous) (Haile et al., 1977; Williams et al., 1988; Amiruddin and Trail, 1993).

SAMPLE DESCRIPTIONS

The metatonalites are commonly found in the outer shell of the tonalite body (Figure 2a). Some of the metatonalite bodies are in layer with amphibolite. The rocks are predominantly composed of plagioclase, hornblende, biotite, quartz, apatite, muscovite, and titanite. Foliation texture is recognized from hornblende (0.5–2 mm), biotite (~0.2 mm), plagioclase (0.5–2 mm), and muscovite (~0.2 mm; Figure 2b). Some of the metatonalites have relict clinopyroxene that are surrounded by hornblende (Figure 2c). EPMA analysis confirms that the relict clinopyroxene has augite end-member in composition. Several samples contain numerous apatites.

Whole rock chemistries descriptions of metatonalites from the Schwaner Mountains have been discussed in detail by Setiawan et al. (2013b). Major, trace, and rare-earth elements composition of the metamorphic rock samples were analyzed by X-ray fluorescence spectrometry (XRF) using Rigaku ZSX Primus II and by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) with an Agilent 7500cx quadrupole ICP-MS with a New Wave Research UP-213 laser at Kyushu University, Japan on a fused glass disk (sample:flux ratio 1:2). The detail analytical conditions and procedure are given in Nakano et al. (2012).

Four samples of metatonalites were examined in comparison with Cretaceous granitoids data from Williams et al. (1988; Table 1). Based on the AFM diagram from Irvine and Baragar (1971), Setiawan et al. (2013b) suggested that the metatonalites are classified as calc-alkaline affinities rock similar with Cretaceous granitoids (Figure 3a). The rocks are plotted on the tonalite field in the CIPW normative An-Ab-Or ternary diagram from Barker and Arth (1979), whereas Cretaceous granitoids are scattered in the tonalite, granodiorite and granite fields (Figure 3b). Trace elements patterns (N-MORB norm. Sun and McDonough, 1989) obviously show negative anomalies of Nb and Ti as well as positive anomaly of Pb (Figure 3c), which are usually observed in subduction- and collision-related granitoids, and obviously have different pattern with Cretaceous granitoids. In the Rb versus Yb + Ta discrimination diagram from Pearce et al. (1984), the metatonalite are plotted on the volcanic-arc granite area similar with Cretacous granitoids (Figure 3d). Moreover, Setiawan et al. (2013b) reveals that two samples of metatonalites were plotted on the adakite field using discrimination diagram of Sr/Y versus Y as proposed by Defant and Drummond (1990; Figure 3e). Whereas other metatonalites are plotted on island arc andesite–dacite-rhyolite (ADR) field together with Cretaceous granitoids from Schwaner Mountains (Figure 3f).

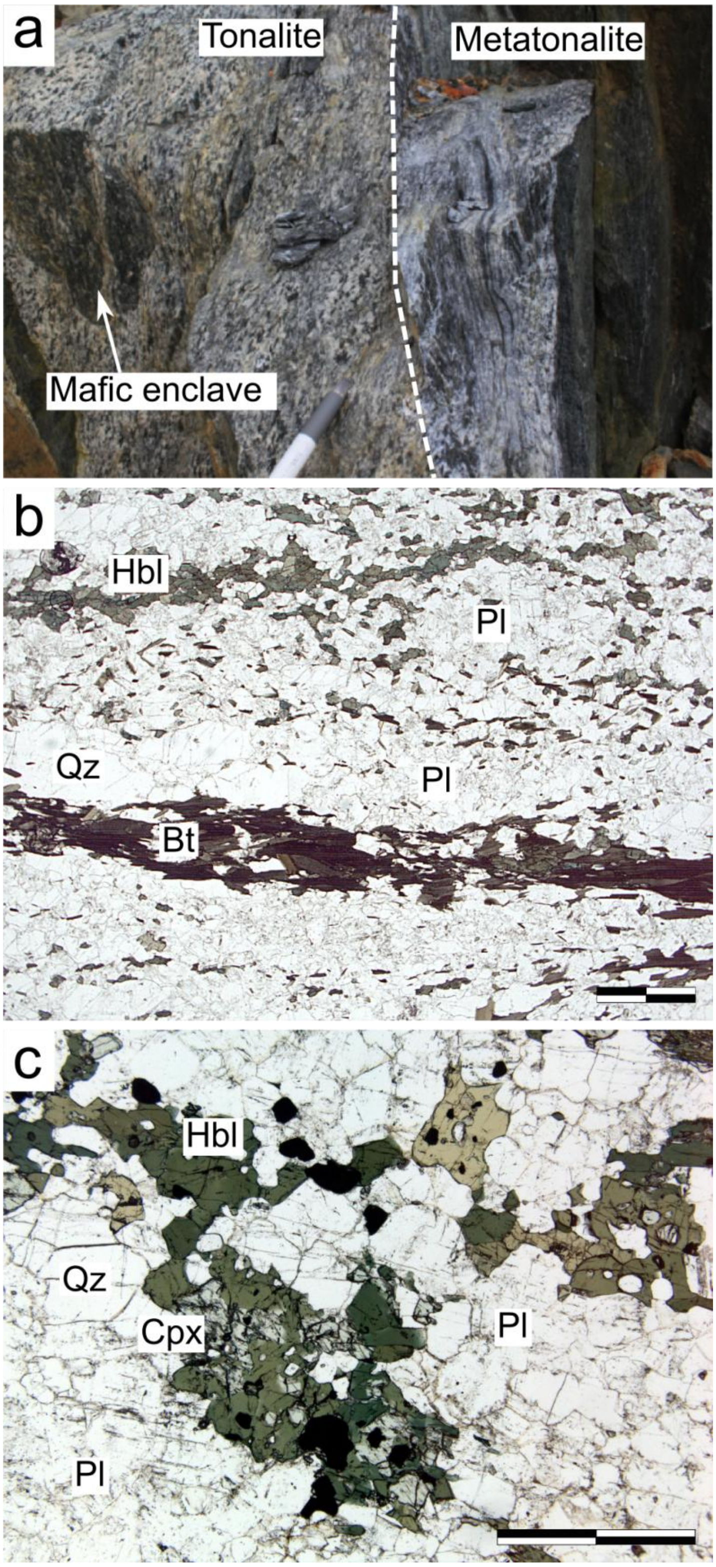

Figure 2. (a) *Mode of occurences of the metatonalite in the field.* ***(b)*** *Foliation of the metatonalite defined by biotite and hornblende.* ***(c)*** *Relict of clinopyroxene surrounded by hornblende. Scale-bars correspond to 1 mm.*

Table 1. *Major (wt%), trace and rare-earth elements (ppm) value of metatonalite and granitoids from Schwaner Mountains of West Kalimantan*

Reference	Setiawan et al. (2013b)				Reference	Williams et al. (1988)											
Rock Type	Metatonalite				Rock Type	Granitoid											
Sample No.	84U221A	84BH236A	84MS89A	0327GM01	Sample No.	83CP115C	83CP1425A	84FK101B	83HZ36A	83HZ34C	84FK89I	84UM110B	84FK89B	84SS104A	84PR177A	84ER165B	84FK130A
SiO_2	59.00	71.12	58.02	60.27	SiO_2	56.20	60.20	72.20	72.70	73.40	60.30	62.90	65.70	69.20	72.50	75.40	76.40
TiO_2	0.90	0.50	0.65	0.66	TiO_2	0.76	0.70	0.26	0.33	0.33	0.84	0.65	0.60	0.37	0.30	0.20	0.09
Al_2O_3	17.47	14.54	18.96	18.00	Al_2O_3	15.30	16.00	13.90	14.00	14.30	16.80	15.90	15.70	14.60	13.20	12.90	12.50
Fe_2O_3*	6.98	3.46	6.30	5.30	Fe_2O_3	1.85	1.35	1.30	0.87	0.24	2.14	2.31	1.48	1.81	1.17	0.60	0.21
					FeO	6.00	5.05	0.90	2.01	2.18	3.00	2.15	2.20	1.05	1.10	0.60	0.70
MnO	0.14	0.06	0.06	0.08	MnO	0.16	0.17	0.08	0.04	0.06	0.11	0.06	0.07	0.05	0.05	0.03	0.04
MgO	2.86	0.90	2.00	1.80	MgO	5.25	3.34	0.65	0.57	0.59	2.10	2.14	1.43	1.00	0.34	0.32	0.08
CaO	7.42	2.75	7.62	6.68	CaO	8.00	6.85	2.06	2.54	3.46	4.12	3.76	3.10	2.36	0.81	1.28	0.54
Na_2O	3.27	4.51	5.18	5.00	Na_2O	2.20	2.72	4.00	3.46	4.06	4.00	3.84	3.64	3.48	3.90	3.24	3.66
K_2O	1.28	1.80	0.96	1.35	K_2O	2.06	1.21	3.68	2.70	0.88	4.68	4.38	4.92	5.15	5.30	4.80	4.88
P_2O_5	0.18	0.11	0.24	0.26	P_2O_5	0.14	0.15	0.11	0.05	0.13	0.26	0.20	0.20	0.11	0.06	0.03	0.02
LOI	0.66	0.72	0.33	0.17													
TOTAL	100.15	100.47	100.33	99.56	TOTAL	99.52	99.15	99.68	99.80	100.21	99.56	100.25	99.93	99.98	99.37	100.30	99.77
Cr	116.36	88.77	70.64	85.79	Cr	10.00	10.00	25.00	0.00	0.00	10.00	15.00	0.00	0.00	0.00	0.00	0.00
Ni	24.49	n.d.	2.23	21.99	Ni	10.00	6.00	34.00	0.00	0.00	8.00	12.00	0.00	6.00	0.00	0.00	0.00
Cu	52.35	7.43	7.23	31.96	Cu	36.00	32.00	4.00	8.00	12.00	25.00	13.00	17.00	9.00	4.00	0.00	0.00
Zn	73.40	31.85	20.87	29.82	Zn	48.00	42.00	25.00	20.00	26.00	54.00	31.00	26.00	24.00	46.00	18.00	16.00
Ga	18.30	14.61	19.66	17.77	Ga	16.00	17.00	13.00	18.00	18.00	19.00	16.00	13.00	12.00	19.00	9.00	12.00
Rb	49.61	51.76	11.30	18.57	Rb	90.00	44.00	125.00	110.00	56.00	190.00	155.00	215.00	230.00	190.00	200.00	240.00
Sr	382.83	228.84	1216.73	873.20	Sr	250.00	310.00	225.00	200.00	235.00	475.00	395.00	390.00	290.00	64.00	125.00	26.00
Y	22.56	24.31	11.94	17.62	Y	18.00	22.00	34.00	30.00	32.00	28.00	24.00	24.00	20.00	76.00	20.00	40.00
Zr	123.17	178.41	70.62	154.20	Zr	76.00	160.00	110.00	185.00	190.00	390.00	200.00	270.00	180.00	375.00	88.00	96.00
Nb	5.77	6.78	5.26	7.72	Nb	4.00	6.00	12.00	6.00	4.00	20.00	10.00	16.00	10.00	14.00	6.00	20.00
Ba	195.10	436.88	608.26	312.31	Ba	260.00	220.00	330.00	520.00	290.00	550.00	570.00	580.00	440.00	640.00	360.00	120.00
La	13.24	19.93	11.49	19.59	La	0.00	0.00	65.00	55.00	45.00	60.00	35.00	40.00	30.00	55.00	0.00	35.00
Pb	21.88	40.49	1.53	8.77	Pb	6.00	6.00	0.00	10.00	16.00	6.00	8.00	0.00	6.00	14.00	0.00	0.00
Th	5.80	10.34	1.39	12.74	Th	10.00	6.00	18.00	8.00	12.00	26.00	16.00	40.00	32.00	22.00	4.00	24.00
Pr	3.71	4.81	3.44	5.44	Pr	0.00	5.00	2.00	0.00	0.00	0.00	13.00	10.00	0.00	6.00	4.00	2.00
Eu	1.22	0.93	1.21	1.33	Eu	0.00	0.00	4.00	0.00	0.00	4.00	4.00	0.00	0.00	0.00	0.00	0.00
Gd	4.12	4.22	3.04	3.83	Gd	0.00	0.00	0.00	0.00	4.00	6.00	6.00	4.00	6.00	6.00	6.00	10.00
Tb	0.65	0.67	0.42	0.54	Tb	6.00	6.00	4.00	4.00	4.00	4.00	6.00	10.00	8.00	0.00	8.00	10.00
Dy	4.04	4.38	2.40	3.22	Dy	7.85	6.40	2.20	2.88	2.42	5.14	4.46	3.68	2.86	2.27	1.20	0.91
Co	233.52	334.39	214.47	174.21													
V	175.51	39.39	101.29	81.19													
Ce	28.59	40.05	25.26	43.54													
Nd	16.15	19.60	15.72	22.36													
Sm	4.00	4.26	3.42	4.48													
Ho	0.82	0.92	0.46	0.64													
Er	2.33	2.79	1.25	1.87													
Tm	0.34	0.43	0.18	0.29													
Yb	2.31	3.00	1.24	2.07													
Lu	0.36	0.48	0.19	0.34													
Hf	3.63	5.86	1.87	4.61													
Ta	0.91	1.31	0.56	1.46													
U	1.80	2.23	0.32	3.59													

Fe_2O_3*, total Fe as Fe_2O_3, LOI and n.d means loss-on-ignition and non detection, respectively.

LA-ICP-MS U-Pb ZIRCON DATING

Analytical method

One sample of metatonalite was examined by LA-ICP-MS U-Pb zircon dating. Zircon grains of analyzed rock were separated from #60 mesh whole-rock powder by panning, magnetic separations, and handpicking techniques. Internal structures of each analyzed zircon grains were observed using SEM (JSM-5310) equipped with cathodo-luminescence (CL) detector. U-Pb zircon dating was performed using Agilent 7500cx quadruple inductively coupled plasma mass spectrometer (ICP-MS), with a New Wave Research UP-213 Nd-YAG UV (213nm) laser ablation system (LA) installed at Kyushu University and with the analytical conditions following Adachi et al. (2012). Data acquisition and calibration of the isotopic ratios of zircon were processed using GLITTER software (Griffin et al., 2008). Data reduction and processing were conducted using the computer program of ISOPLOT version 3.75, provided by K.R. Ludwig at Berkeley Geochemical Center, University of California. Analytical errors shown in this study are 95% confidence levels (2σ error). Analyzed data for zircon grains are shown in Table 2.

Result of LA-ICP-MS U-Pb zircon dating

Zircon grains from metatonalite in Schwaner Mountains are 100–150 µm in size with elongated and subhedral shapes (Figure 4a). The grains show broad oscillatory and sector zoning under the CL images (Figure 4a). Most data are concordant and concentrated at *ca.* 230 Ma from 23 analyses of 11 grains and defined as concordant age of 233 ± 3 Ma (Figure 4b). The core domains (14 analyses from 10 grains) give older age of 246 ± 13 Ma and peak age distribution at *ca.* 235 Ma. The youngest age determined from the rim domain is 202 ± 13 Ma. It is true that oldest age is determined from core domain and youngest age is from rim domain of zircon grains. However, most of the data are overlapping each other regardless of the domain (Figure 4b). Therefore, the data are likely to give magmatic age of this rock at 233 ± 3 Ma (Late Triassic).

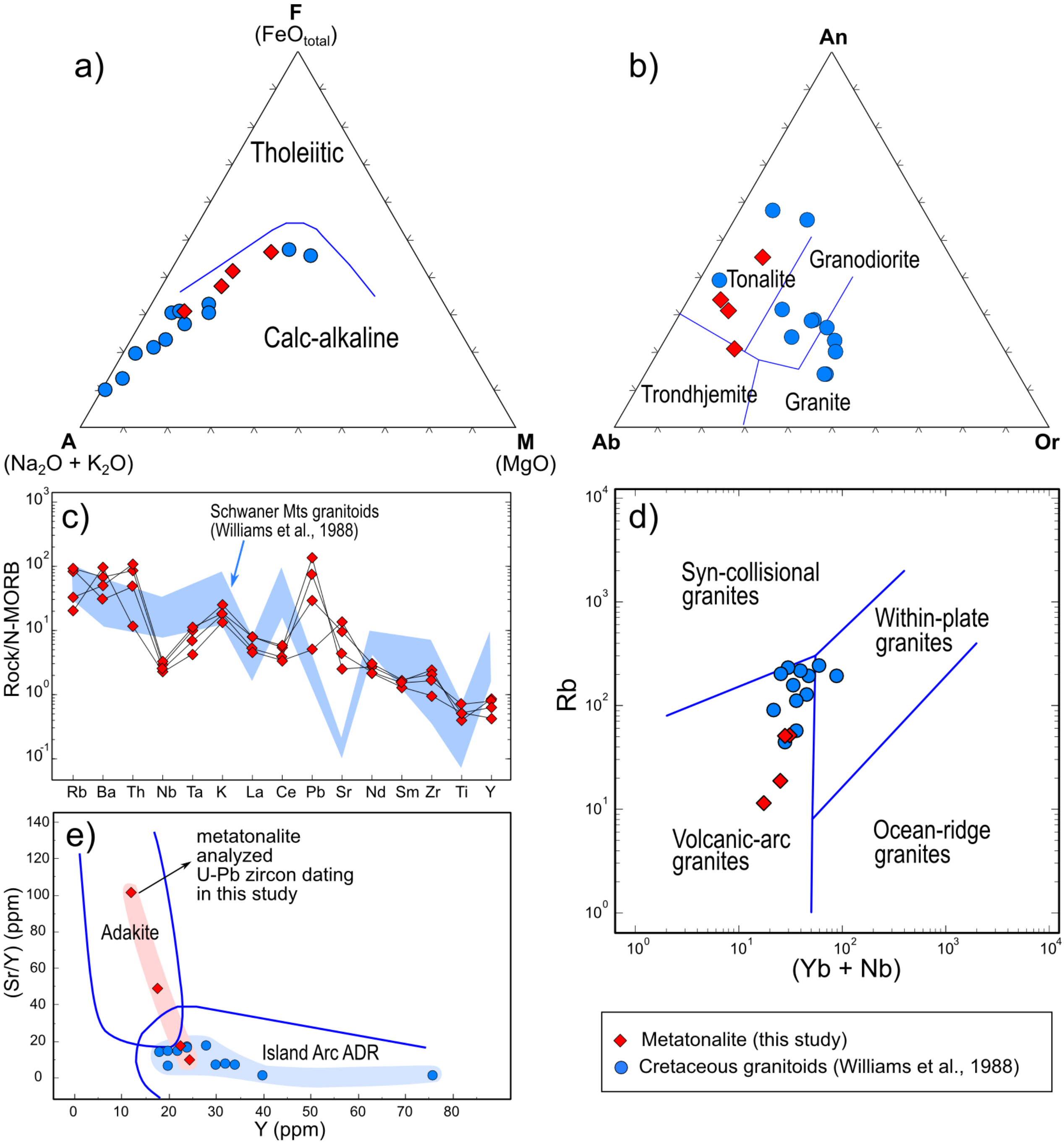

Figure 3. *Geochemical analyses of the metatonalites and their comparison with Cretaceous granitoids (data from Williams et al., 1988) from the Schwaner Mountains (modified after Setiawan et al., 2013b).* ***(a)*** *The metatonalites are plotted on the AFM diagram from Irvine and Baragar (1971).* ***(b)*** *The metatonalites are plotted on the CIPW normative An-Ab-Or classification diagram (Barker and Arth, 1979).* ***(c)*** *N-MORB normalized (Sun and McDonough., 1989) trace element diagram of the metatonalites.* ***(d)*** *Discriminant diagram of Rb vs Yb + Ta (Pearce et al., 1984) for the metatonalites.* ***(e)*** *Two metatonalites fall on the adakite field in the discriminant diagram of Sr/Y vs Y from Defant and Drummond (1990).*

DISCUSSION

Implications for subduction-related felsic magmatism during Mesozoic

The youngest U-Pb age of magmatic zircon in the metatonalite from Schwaner Mountains is 202 ± 13 Ma. This age is older than K-Ar age of granitoids from previous researchers, which ranges from 157 to 77 Ma (Haile et al., 1977; Williams et al., 1988; Amiruddin and Trail, 1993). The magmatic zircon of metatonalite in this study has concordant age of 233 ± 3 Ma. The result gives older age than previous K-Ar granitoids in the Schwaner Mountains (Figure 4c) but in range with the K-Ar ages of granitoids from northwest Kalimantan domain, which ranges from 320 to 204 Ma (Williams et al., 1988; Figure 4c).

Table 2*. LA-ICP-MS U-Pb isotope ratios and calculated ages of zircons*

Samples/	Isotopic ratios and errors (2σ)				Calculated ages and errors (Ma, 2σ)				Th/U	Dis (%)
Analyzes No.	Pb206/U238	error	Pb207/U235	error	Pb206/U238	error	Pb207/U235	error		
N1-1	0.0502	0.0117	0.2476	0.0569	227	11	225	46	0.271	-1
N1-2	0.0520	0.0151	0.2588	0.0741	229	14	234	60	0.638	2
N3-1	0.0494	0.0034	0.2548	0.0174	237	7	231	14	0.683	-3
N3-2	0.0499	0.0131	0.2578	0.0664	237	14	233	54	0.530	-2
N3-3	0.0566	0.0133	0.2720	0.0628	221	12	244	50	0.610	11
N4-1	0.0516	0.0019	0.2424	0.0097	216	6	220	8	1.452	2
N4-2	0.0579	0.0125	0.2952	0.0624	234	14	263	49	0.730	12
N8-1	0.0509	0.0080	0.2640	0.0412	238	10	238	33	0.844	0
N8-2	0.0498	0.0069	0.2395	0.0330	221	8	218	27	0.310	-1
N8-3	0.0479	0.0081	0.2308	0.0385	222	9	211	32	0.180	-5
N9-1	0.0514	0.0124	0.2760	0.0657	246	13	247	52	0.863	0
N9-2	0.0516	0.0058	0.2631	0.0294	234	8	237	24	0.560	1
N10-1	0.0502	0.0111	0.2554	0.0558	234	11	231	45	0.724	-1
N11-1	0.0504	0.0101	0.2582	0.0510	235	11	233	41	0.638	-1
N15-1	0.0517	0.0053	0.2716	0.0273	241	8	244	22	0.193	1
N15-2	0.0481	0.0103	0.2310	0.0489	221	11	211	40	0.169	-4
N15-3	0.0493	0.0113	0.2358	0.0532	220	11	215	44	0.588	-2
N17-1	0.0516	0.0079	0.2590	0.0392	231	10	234	32	0.838	1
N20-1	0.0502	0.0144	0.2203	0.0621	202	13	202	52	0.405	0
N20-2	0.0510	0.0119	0.2586	0.0589	233	13	234	48	0.644	0
N26-1	0.0555	0.0050	0.2813	0.0251	233	8	252	20	0.488	8
N26-2	0.0516	0.0053	0.2682	0.0273	238	8	241	22	0.547	1
N26-3	0.0507	0.0134	0.2424	0.0631	220	12	220	52	0.459	0

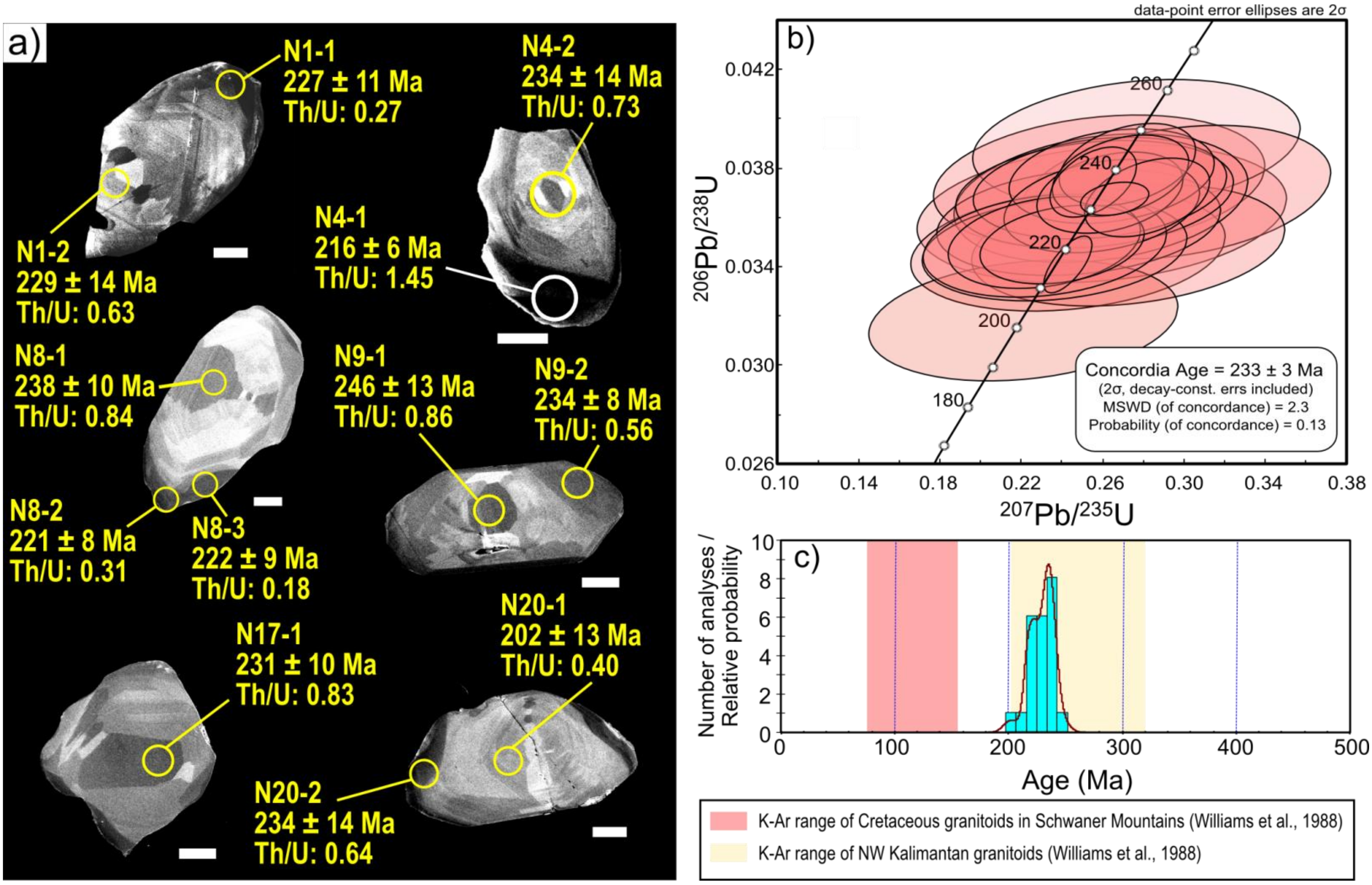

Figure 4. (a) *Cathodoluminescence representative images of magmatic zircon grains in the metatonalite. Circles indicate LA-ICP-MS U-Pb analysis spots. Scale bars indicate 30 µm. (**b**) U-Pb concordia plot for magmatic zircons of the metatonalites. (**c**) Probability distribution diagram of magmatic zircon in the metatonalite in comparison with Cretaceous granitoids from the Schwaner Mountains and NW Kalimantan domains.*

Furthermore, the presence of metatonalite that have adakite signature in the Schwaner Mountains suggests that the Schwaner Mountains was not formed by a consecutive subduction system to build the granitoids because genesis of adakitic magma is different from that of non-adakitic rocks.

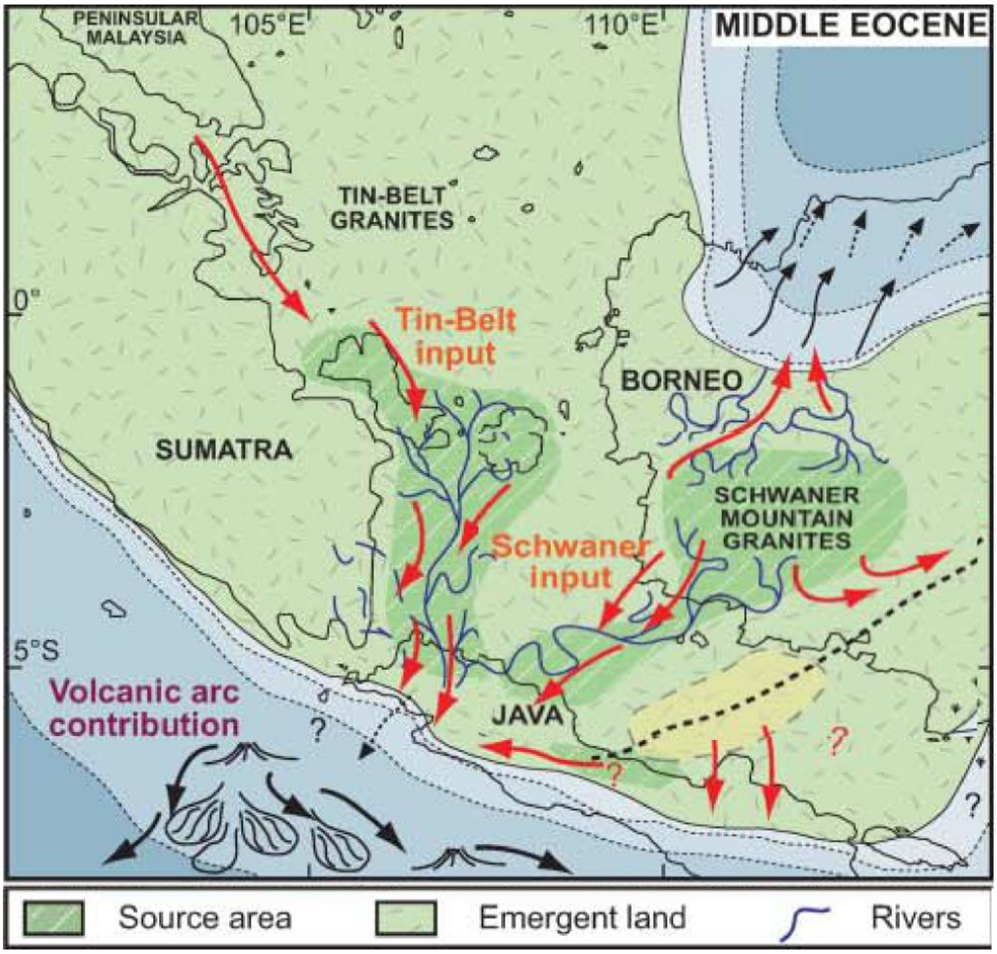

Figure 5*. Suggested Middle Eocene palaeogeographical map of the Sunda Shelf region (modified after Clements and Hall, 2011). Schwaner Mountains might have contributed to sedimentary provenance together with Tin Belt granites from the Malay Peninsula.*

Adakite was introduced by Defant and Drummond (1990) from the specific rock types from Adak Island in Aleutian Islands that are associated with subduction of hot, young (≤ 25 my) oceanic lithosphere. However, the magma genesis of adakite is still controversial and could be any of the following possibilities: slab melting due to the young (hot) oceanic plate; ridge subduction; and magma differentiation (Castillo, 2006).

Newly-found Late Triassic age metatonalite with adakitic signature strongly suggests that the subduction mechanism and felsic magma genesis changed between Early Triassic and Cretaceous. Some of the metatonalites, except adakite rock, show similar signature to Cretaceous granitoids, indicating that the subsequent metamorphism occurred during the Cretaceous subduction system. Metcalfe (1998) and Zhou et al. (2008) proposed that Mesozoic subduction of proto-South China Sea beneath West Kalimantan was responsible to build this formation. The proto-South China Sea has been regarded as a short-lived marginal sea, perhaps related to the backarc extension in Mesotethys domain (Zhou et al., 2008). Hence, the adakitic signature in the metatonalite might be derived from magma as a result of the melting of proto-South China Sea oceanic lithosphere, whose crust was still young (hot) at the time. As the southward-directed subduction of proto-South China Sea was taking place during Cretaceous to form granitoids in the Schwaner Mountains (Lupar-Adio belt; Williams et al., 1988; Amiruddin, 2009), the Indo-Australian plate came from southeast and subducted below southeast Kalimantan forming magmatic events in the Meratus Mountains (Meratus belt; Yuwono et al., 1988; Amiruddin, 2009). However, this double subduction event during Cretaceous in Borneo is still controversial and whether or not the Lupar-Adio belt is connected to the Meratus belt is unknown at present.

Other possibilities are the magmatism of granitoids in several parts of the Schwaner Mountains might be contemporaneous with the granitoids in the northwest Kalimantan domain (K-Ar: 320–204 Ma; Williams et al., 1988) or East Malaya province I-type granitoids (U-Pb: 267–80 Ma; compiled in Searle et al., 2012). This means that the subduction, which generated Triassic granitoids, was eastward below the Indochina or East-Malaya craton (Searle et al., 2012). The occurrence of adakitic magma might imply that the first generation of melting oceanic crust of Paleo-Tethys started from the Schwaner Mountains area and the next generations continued to the northward of Thai-Malay peninsula with or without adakitic signatures. However, detailed studies should be done to confirm the occurrence of adakitic rocks of Triassic age within Indochina or East-Malaya craton and NW Kalimantan domain.

Contributions for the sedimentary provenance in Sundaland

Many publications considered that the Permian–Triassic ages of detrital zircon from Sundaland particularly Borneo Island were supplied from sediment derived from Tin Belt granites in Malay Peninsula (e.g., van Hattum et al., 2006; Clements and Hall, 2008; Clements and Hall, 2011). Clement and Hall (2008; 2011) proposed early Cenozoic palaeogeography and palaeodrainage models in the southern Sundaland based on the study of detrital zircons from West Java. In their models, there is no contribution of sedimentary provenance from the Schwaner Mountains to West Java during Middle Eocene, however they found detrital zircons with Permian to Triassic signature in the Middle

Eocene forearc sandstones. The contribution of Schwaner Mountains as sedimentary provenance in the West Java started in Late Eocene based on the appearance of Mid-Cretaceous detrital zircons in all Upper Eocene and Lower Oligocene formations (Clements and Hall, 2011). Result of LA-ICP-MS U-Pb zircon dating from metatonalite in the Schwaner Mountains in this study reveals the magmatic age of Late Triassic (233 ± 3 Ma). Therefore, it strongly suggests that the Schwaner Mountains has significant potential for important sedimentary sources not only from the Cretaceous age but also from the Triassic age as well as Tin Belt granites from Malay Peninsula (Figure 5).

CONCLUDING REMARKS

1. Schwaner Mountains were not formed by a consecutive Cretaceous subduction system. The subduction mechanism and felsic magma genesis changed between Early Triassic and Cretaceous and subsequent metamorphism occurred during the Cretaceous subduction system.
2. LA-ICP-MS U-Pb zircon dating from metatonalite in the Schwaner Mountains of West Kalimantan reveal magmatic age of Late Triassic (233 ± 3 Ma). It might contribute to the provenance of Triassic age detrital zircon in the Sundaland.

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