Geol. Mag. **154** (3), 2017, pp. 419–440. © Cambridge University Press 2016

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&

, 100037,

‡ 210016,

, 36 4 -5305,

(*Received* 1 2015; *accepted* 2016; *first published online* 1 2016)

Abstract

~4 5

~400

ε (*t*) (13 20) δ (+5.37‰)

),

1. I

(*et al.* 200 & 200 *et al.* 2012 *et al.* 2012, 2013 *et al.* 2013),

(1 *et al.* 200 *et al.* 200 a).

(1 1 3 *et al.* 2000 & , 2003 *et al.* 200 , 2014).

& (2011)

( ),

(2014)

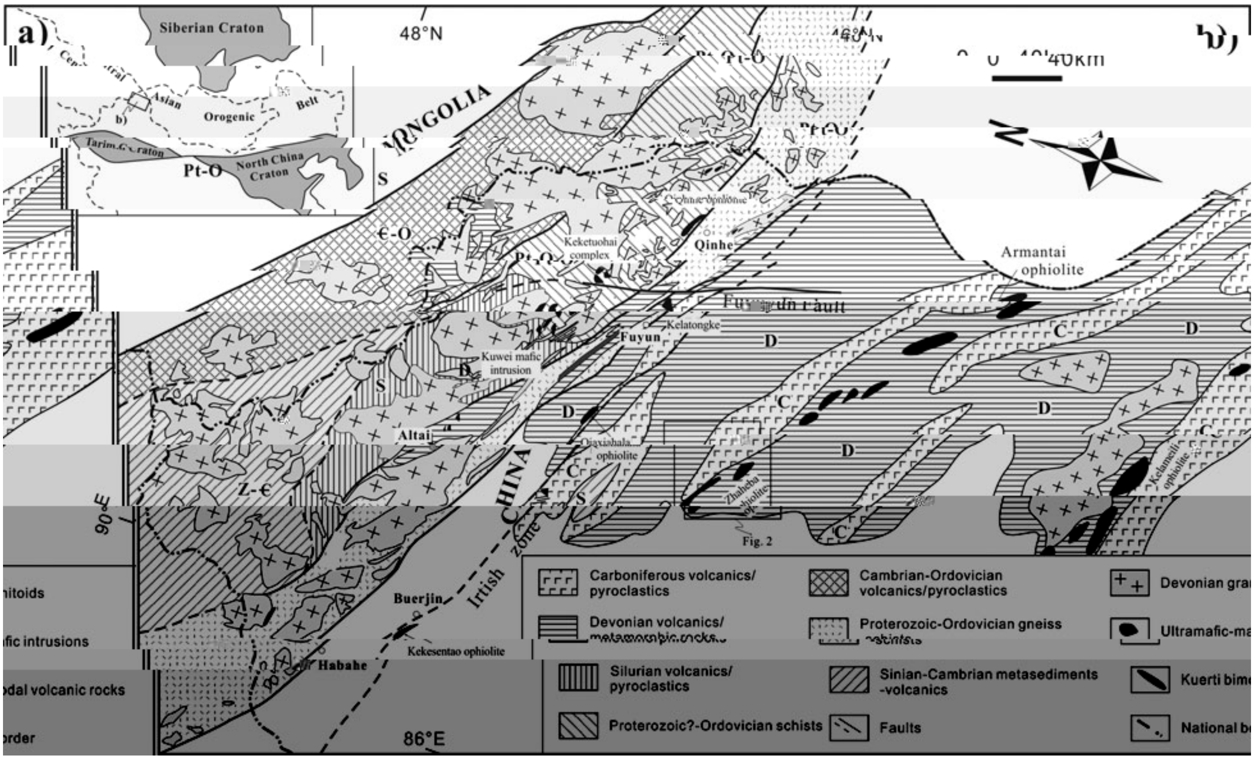
1 6

( ),

(& 1 3 & , 2000 *et al.* 2002 *et al.* 2004, 200 a) (. 1).

(*et al.* 200 a,b & , 2012).

(1 3 *et al.* 2003 *et al.* 2003 *et al.* 200 a) (. 1).



1. ( ) ( ) ( ) *et al.* 200).

(1) (2)

> 0 % (. 3 ,). (. *et al.* 2013). (40 70 %) (30 50 %) (5 10 %) (. 3).

2. R a , b a a

(. 1 , 2). (. 3). 15 (. 2,). 1 5 1

( ) ( ) ( ) (*et al.* 2006). (. 2) (1, 3).

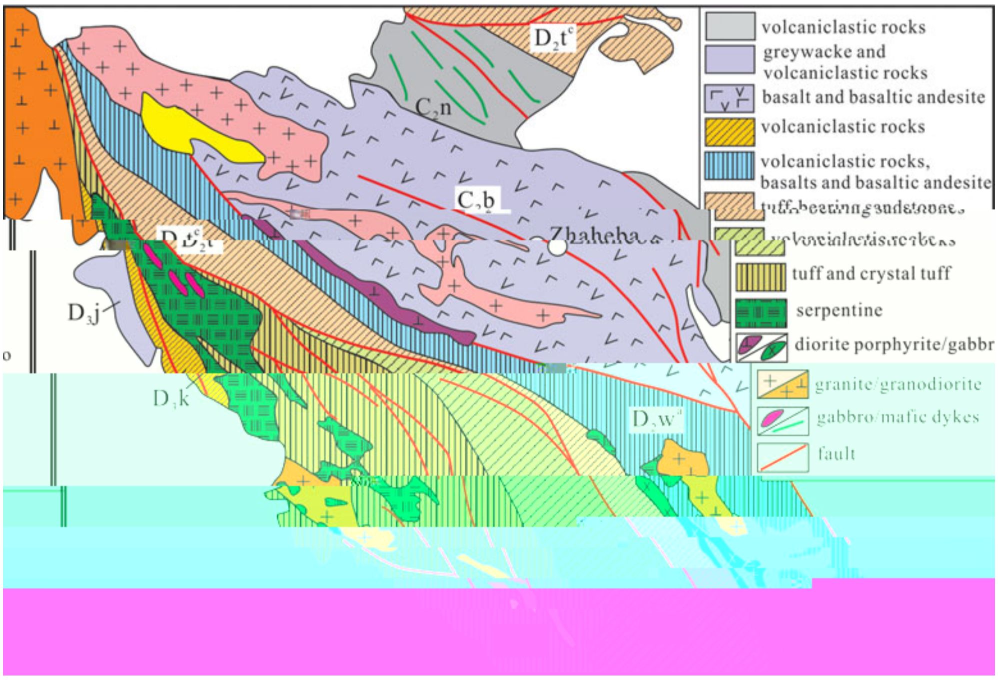


Fig. 2. [illegible] *et al.* 2007, 200[illegible] [illegible] 1, 3).

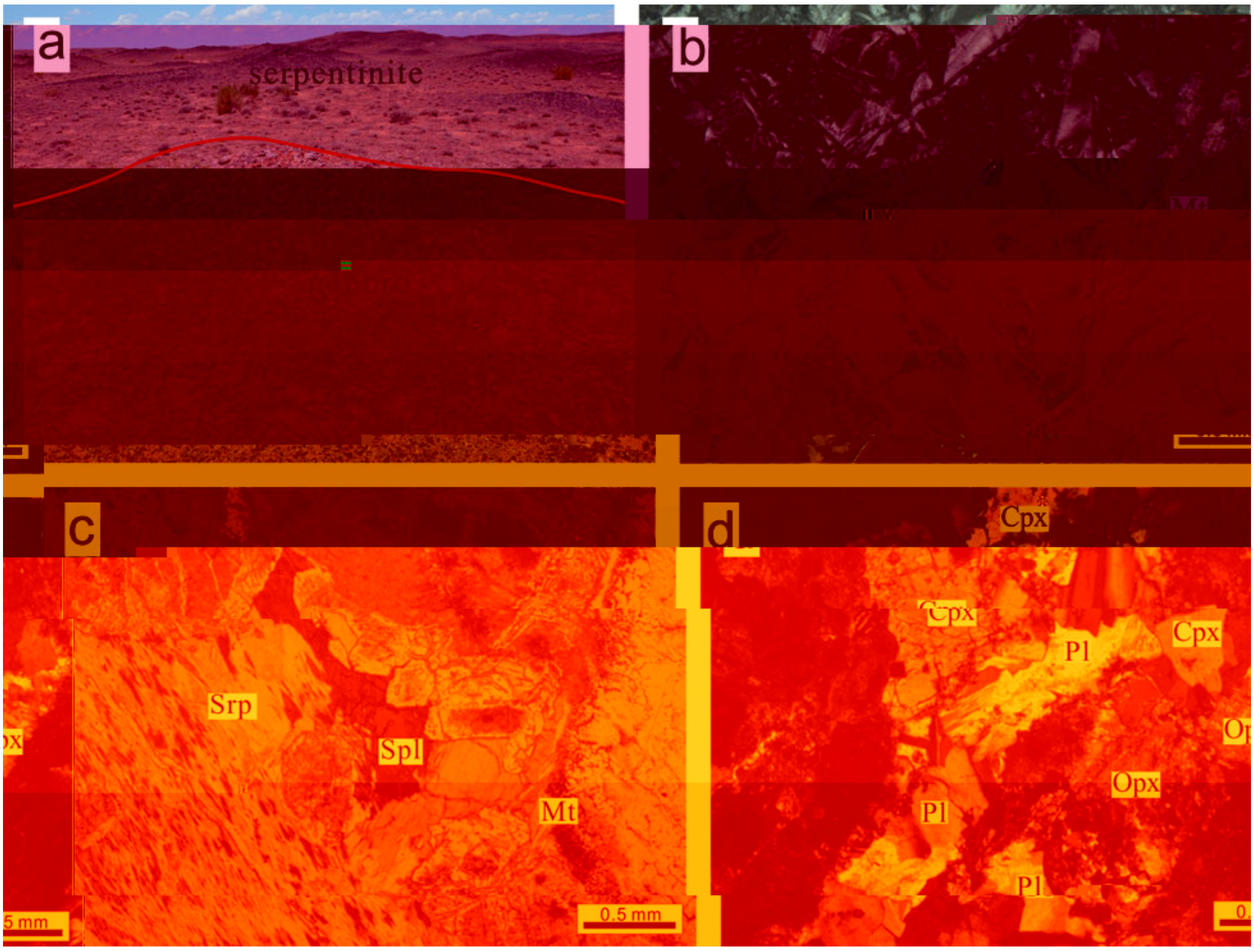


Fig. 3. [illegible] 0% [illegible]

3. A a ca c

3.a. Z c U Pb a a H O a a

(2013 01, 46° 32′ 51 , ° 2′ 4)
(2013 02, 46° 33′ 2 , ° 2′ 36.)

( )

( )

et al. (2011).

et al. 2010) (, 2003).
5 %

1
2,

12 0

et al. (2010*a*).
1 /16

(/ , 1 /16 ± 0.0020052),
( ) δ1 5.31 ‰ (*et al.* 2010*b*).
δ1 5.44 ± 0.21 ‰ (2), 5.4 ± 0.2 ‰
(*et al.* 2013).
3

3.b. M a a

00
15 15

20
4 5

3.c. W - c a a

100 *et al.*
(2004).
2 %.
6000
et al. (2004). 50
+ 3
1, -2 -2,
-1
3,
3 5 %.
1.
+ 3

et al. (2004).
143 /144 /
0.11 4 146 /144 = 0.721
0.7102
0.70506 -1,
143 /144 0.512104
0.51267 1 -1.
2.

4. A a ca

4.a. Z c U Pb a

100 150 μ
1 1 2 1.
(. 4).
(22 123) (
5) 0.4
0.
30
4 5. ± 2.5

1. [illegible]

[illegible]	2013 01-1	2013 01-3	20132 01-4	2013 01-5	2013 01-6	2013 01-	2013 01-	2013 01 1	2013 01 2	2013 01 4
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Major elements (%)										
[illegible] 2	3 .0	4 .20	3 .41	3 .62	3 .22	3 . 2	3 .05	4 .22	46.4	51.2
[illegible] 2	0.05	0.20	0.05	0.05	0.04	0.05	0.04	0.14	0.12	0.2
[illegible] 2 3	0.61	1. 6	1.04	0.6	0. 0	0.4	0. 0	1 .2	1 .64	1 .33
[illegible] 2 3	44	4.6	.	.36	.5	.16	. 4	3.6	3.24	3.
[illegible]	0.0	0.10	0.11	0.11	0.11	0.0	0.11	0.0	0.0	0.0
[illegible]	3 .21	24.5	3 . 2	3.	3 .0	3 .31	3 .44	10.04	.03	5.
[illegible]	0.12	15.42	0.15	0.14	0.2	0.10	0.1421	.0	0.0	

13.2.1(.1. (3 .21)-5530. 1) 4-5 10.425 6

2 --6030

1. [illegible]

[illegible]	2013 01-1	2013 01-3	20132 01-4	2013 01-5	2013 01-6	2013 01-	2013 01-	2013 01 1	2013 01 2	2013 01 4
[illegible]	0.005	0.064	0.00	0.005	0.00	0.003	0.003	0.051	0.044	0.222
[illegible]	0.021	0.34	0.044	0.042	0.0 2	0.031	0.033	0.310	0.25	1.450
[illegible]	0.004	0.04	0.00	0.00	0.011	0.005	0.005	0.04	0.043	0.21
[illegible]	0.011	0.232	0.036	0.044	0.012	0.034	0.00	0.123	0.0 0	0. 3
[illegible]	0.0 0	0.036	0.03	0.03	0.06	0.026	0.025	0.046	0.031	0.06
[illegible]	0.26	1. 10	6.600	1. 0	0. 3	0.233	1.150	1.5 0	0.516	0.1 5
[illegible]	0.406	0.0 2	0.12	0.112	0.0	0.1	0.054	0.16	0.1 1	0.6 5
[illegible]	0.046	0.034	0.014	0.02	0.050	0.030	0.010	0.050	0.02	0.130
[illegible]	0.1 1	0.144	0.203	0.364	0.042	0.0 4	0.0	0.066	0.042	0.0 3
[illegible]	2013 01 5	2013 01 6	2013 01 (1)	2013 01 (1)	2013 01 (1)	2013 03 2 (1)	2013 03 3 (1)	2013 03 4 (1)	2013 03 5 (1)	2013 01 3 (2)
					Major elements (%)					
[illegible]	4 .1	45.	4 .	53.1	51. 1	50.40	50.54	50.52	51.22	52.3
[illegible]	0.34	0.15	1.40	1.24	1.31	1. 0	1.63	1.31	1.1	0.33
[illegible]	1	1 .5	16.5	16.1	15. 3	15.	16. 6	15.55	15.4	1 .61
[illegible]	4.52	3.34	.	.11	.43	.0	.50	.42	. 2	3.44
[illegible]	0.0	0.0	0.11	0.10	0.11	0.13	0.11	0.14	0.12	0.0
[illegible]	6.	.42	4. 0	4.2	4.41	5.	3.2	6.06	.14	4.
[illegible]	11.03	12.61	6.22	5. 5	6.3	6. 5	4.52	.4	.26	. 0
[illegible]	4. 6	.3	.2	.3	.00	4.52	.31	4. 0	4.0	.11
[illegible]	0.13	0.11	0.3	0.31	0.42	2.04	0.33	1.2	2.03	0.1
[illegible]	0.04	0.02	0.62	0.62	0.65	0. 4	0.6	0.4	0.44	0.04
[illegible]	3. 2	3.26	4.24	2.54	2. 3	2.2	5.14	2.65	1. 3	2.
[illegible]	. 5	. 2	. 6	. 0	.4	.40	. 1	.6	.6	.1
[illegible]	4.	.4	.11	.0	.42	6.56	.64	6.0	6.11	.2
[illegible] #	5	[illegible]	55	54	54	56	41	56	64	4
					Trace elements (ppm)					
[illegible]	.0	4. 5	1.16	1.12	1.4	.0	40.4	5.2	6. 2	5. 1
[illegible]	0.22	0.135	1.2 4	1.6 3	1.316	1. 53	1.034	1.100	0.5 5	0.62
[illegible]	25.0	23.	1 .6	1 .5	1 .5	.5	1 .2	25.2	1	1 .0
[illegible]	11	3.	1 6	166	1 2	22	22	254	1	5.
[illegible]	34.	163	60.5	62.6	64.1	116	1	0.	203	23.
[illegible]	24.2	21.6	26.	23.6	24.6	2.	2 .5	2 .0	2 .0	16.4
[illegible]	4.	1 5	63.6	50.	51.4	6.	2.	5 .3	132	1.1

[illegible] 1. [illegible]

[illegible]	2013[illegible]01 5	2013[illegible]01 6	2013[illegible]01 [illegible] (1)	2013[illegible]01 [illegible] (1)	2013[illegible]01 [illegible] (1)	2013[illegible]03 2 (1)	2013[illegible]03 3 (1)	2013[illegible]03 4 (1)	2013[illegible]03 5 (1)	2013[illegible]01 3 (2)
[illegible]	3[illegible]	1.20	3[illegible].60	46.[illegible]0	4[illegible].30	23.40	43.00	25.20	32.[illegible]0	6.56

1. [illegible]

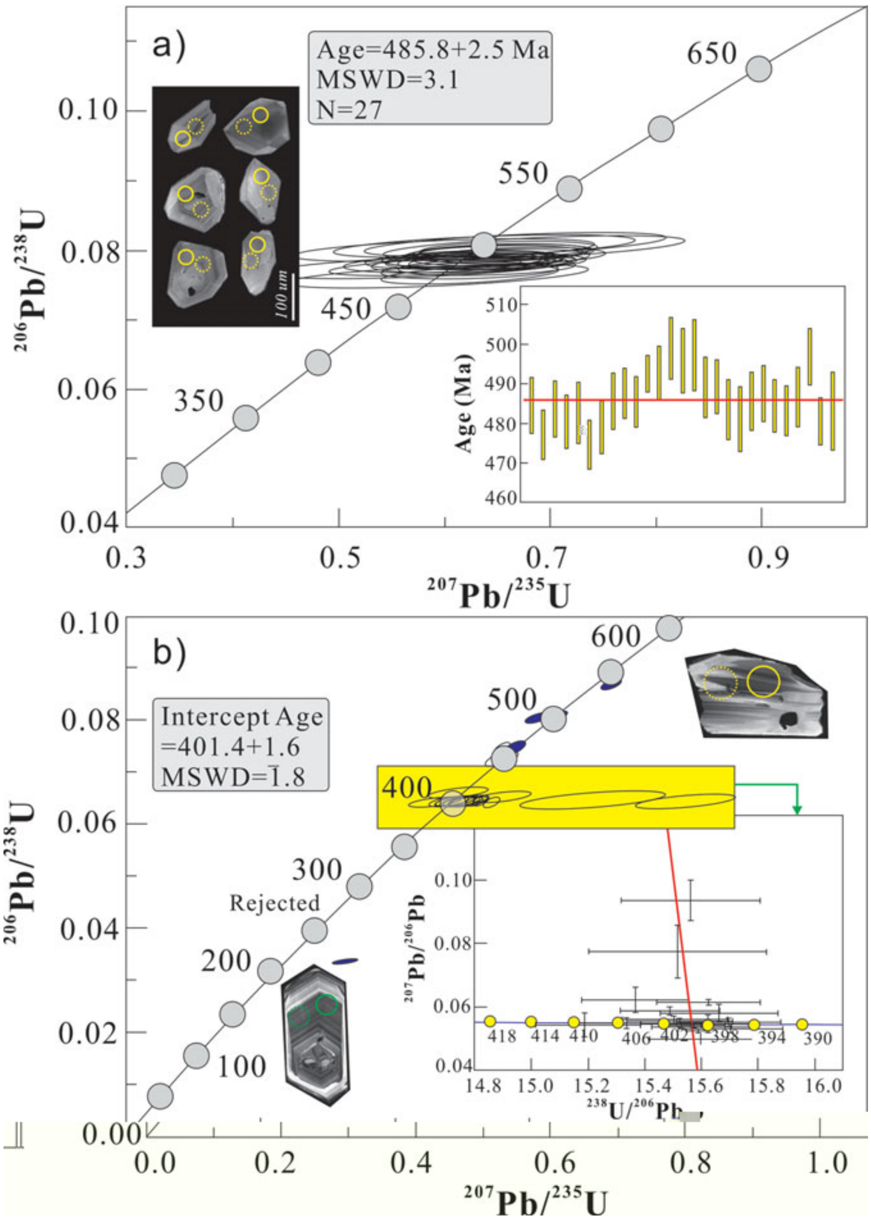
[illegible]	2013 01 11 (2)	2013 02 1 (2)	2013 02 2 (2)	2013 03 1 (1)	2013 03 6 (1)	2013 01 10 (2)	04 06 (1)	04 24 (1)	04 2 (1)	03 1▼ (1)
					Trace elements (ppm)					
[illegible]	1 .4	36.	42.4	26.0	32.4	1▼.	/	/	/	/
[illegible]	0.3 5	0.153	0.35	1.1	0. 4▼	0.46	/	/	/	/
[illegible]	32.5	33.2	34.5	25.1	26.3	32.1	13.4	20.5	1▼.▼	20.3
[illegible]	1 4	203	21▼	33▼	341	1 5	144	1 4	214	265
[illegible]	56.5	44.2	4▼.	1 .	22.2	53.	15	162	214	265
[illegible]	34.▼	3▼.5	3 .3	23.1	24.	33.	20.6	30.	2 .	20.2
[illegible]	66.4	4.6	▼6.4	25.4	2▼.1	66.6	.1	114	▼5.5	▼.02
[illegible]	6.4	236.4	256.▼	205.4	20	114.20	/	/	/	/
[illegible]	4 .0	44.1	4 .0	4.	103	44.1	/	/	/	/
[illegible]	12.0	11.1	11.2	14.▼	13.6	12.0	/	/	/	/
[illegible]	0.5	1.420	1.0▼0	3.130	3.2▼0	0.5 3	4.	1 .1	22.0	1▼.2
[illegible]	▼1	1▼50	5	2▼0	24	6 6	▼1	31	111	▼▼6
[illegible]	13.0	13.0	13.2	21.1	22.	12.5	13.2	13.2	14.▼	20.1
[illegible]	54.	42.3	41.5	144	154	52.	243	133	164	151
[illegible]	1.2	0. 4▼	0. 55	11.315	11. 5	1.25▼	20.2	12.▼	21.	12.2
[illegible]	0.025	0.030	0.02▼	0.051	0.052	0.02	/	/	/	/
[illegible]	0.3 1	0.2 6	0.32	1.560	1.450	0.360	/	/	/	/
[illegible]	0.2	1.▼20	1.030	0.365	0.406	0.336	/	/	/	/
[illegible]	11▼	3▼2	346	25	50▼	4.3	/	/	/	/
[illegible]	10.▼0	▼. 40	▼.610	26.40	26. 0	10.50	30.6	32.2	40.1	26.4
[illegible]	23.00	1 . 0	1 .40	51.50	54.▼0	22.30	5▼.	62.	2.3	52.5
[illegible]	2.▼▼0	2.520	2.510	5.▼50	6.1 0	2.6▼0	6. ▼	▼. 4	10.5	6.4
[illegible]	11. 0	11.▼0	11.60	22.30	24.30	11.60	2▼.5	31.2	43.1	24.4
[illegible]	2.540	2.▼00	2.6 0	4.4 0	4.▼00	2.3▼0	4.5	5.2	6.	4. 5
[illegible]	0. 6	0. 1	0. ▼0	1.163	1.25▼	0. 3	1.45	1.5	2.0▼	1.03
[illegible]	2.4 0	2. 13	2.▼54	4.14	4.46	2.522	3.56	4.01	5.35	4.23
[illegible]	0.3 6	0.3	0.3 ▼	0.612	0.660	0.3 4	0.4	0.54	0.64	0.63
[illegible]	2.1 0	2.150	2.220	3.420	3.6 0	2.130	2.5▼	2.▼▼	3.24	3.▼5
[illegible]	0.46	0.446	0.444	0.▼2	0.▼5	0.46	0.4	0.52	0.5	0.▼
[illegible]	1.350	1.230	1.240	2.120	2.2 0	1.310	1.32	1.3▼	1.45	2.25
[illegible]	0.1 0	0.16	0.1▼5	0.304	0.32	0.1 4	0.1	0.2	0.2	0.34
[illegible]	1.210	1.050	1.120	1. 60	2.110	1.210	1.25	1.23	1.24	2.13
[illegible]	0.1▼4	0.164	0.165	0.2 1	0.323	0.1▼3	0.20	0.1▼	0.1▼	0.34
[illegible]	1.3 0	0. 41	1.040	3.2 0	3.510	1.460	5.3▼	3.2▼	4.16	3.▼2
[illegible]	0.0 4	0.062	0.051	0.5 ▼	0.644	0.0▼	1.35	0.6	1.16	0.6
[illegible]	0.151	2.0	1.50	2.▼5	1.	0.33	/	/	/	/
[illegible]	0.3 4	0.206	0.200	45.20	35.10	0.41▼	.13	.0▼	4.1	21.06
[illegible]	1. 0	0.▼61	0.▼1▼	. 60	.2 0	1. 0	4.50	2.63	3.20	.41
[illegible]	0.500	0.304	0.302	2. 30	3.4 0	0.501	1.▼	0.6▼	1.46	2.5

[illegible] 04 06, 04 26, 04 2 [illegible] 04 1▼ [illegible] *et al.* (200 *a*).

[illegible] 2. [illegible]

[illegible]	[illegible]	([illegible])	([illegible])	[illegible]/[illegible]	[illegible]/[illegible] (1σ)	([illegible]/[illegible])	([illegible])	([illegible])	[illegible]/144	143/144 (1σ)	(143/144)	ε (t)
2013[illegible]01 3	[illegible] (2)	0.36	3[illegible]2	0.002[illegible]	0.[illegible]04030(2[illegible])	0.[illegible]04015	2.4	10.[illegible]	0.13[illegible]4	0.512[illegible]3[illegible](40)	0.5124[illegible]4	6.[illegible]
2013[illegible]01 10	[illegible] (2)	0.5	6[illegible]6	0.0024	0.[illegible]04[illegible]5 (23)	0.[illegible]04[illegible]45	2.3[illegible]	11.6	0.1235	0.512[illegible]0 (43)	0.5124[illegible]6	[illegible].1
2013[illegible]03 1	[illegible] (1)	3.13	2[illegible]0	0.0335	0.[illegible]06324(20)	0.[illegible]06133	4.4	22.3	0.121[illegible]	0.512533(4[illegible])	0.512214	1.[illegible]
2013[illegible]03 2	[illegible] (1)	2.[illegible]	1320	0.0063	0.[illegible]042[illegible] (20)	0.[illegible]04255	4.[illegible]5	2[illegible].6	0.1046	0.512[illegible]1 (51)	0.512445	6.3
2013[illegible]03 3	[illegible] (1)	[illegible].06	516	0.0452	0.[illegible]0536 (43)	0.[illegible]05111	5.[illegible]	36.[illegible]	0.0[illegible]	0.512[illegible]0[illegible](30)	0.512450	6.4
2013[illegible]03 4	[illegible] (1)	[illegible].65	14[illegible]0	0.01[illegible]	0.[illegible]0422[illegible](51)	0.[illegible]04120	4.55	24.5	0.1123	0.512[illegible]03(53)	0.51250[illegible]	[illegible].5

ε (t) = 10 000((143/144)(t)/(143/144)(t) − 1) ε (t) ([illegible]) [illegible] 401 [illegible]



[illegible] 4. [illegible] 1σ [illegible] 2σ [illegible]

[illegible] 4 [illegible] = 2[illegible], [illegible] = 3.1). [illegible] 4[illegible] ± 4 [illegible] ([illegible] *et al.* 2003). [illegible] 100 [illegible] 200 μ[illegible]

[illegible] 1 3[illegible] [illegible] 1 ([illegible] 1) [illegible] 10 % [illegible] ([illegible] 2) [illegible]

(2, Fig. 4).
2
450
500
21
^{206} ^{23}
401 ± 2 (= 3.3).
^{206} ^{23} ^{207} ^{235}
401.4 ± 1.6 (= 1.) (^{206}
^{23} Fig. 4),
(1, 3).

4.b. M a c

4.b.1. Spinel composition

(Fig. 3). 100 300 μ
4
$_{2}$ $_{3}$ $_{2}$ $_{3}$
$_{2}$
(100 /(+))
44 60 (100 /(+))
25 61.
(et al. 2010).
et al. 2013).

4.b.2. Pyroxene compositions

(= 4 6).
$_{2}$
0.5 %)
5
).
41 4 46 55 1
(Fig. 5).
$_{2}$ $_{3}$ $_{2}$ $_{2}$
(Fig. 5 ,).

4.c. W c a c

4.c.1. Serpentinites and cumulates

(> 12 %,
$_{2}$ (40 %) $_{2}$ $_{3}$ (
1.0 %), $_{2}$ (0.03 0.06 %), $_{2}$ (0.04
0. 2 %) $_{2}$ (0.04 0.05 %). $_{2}$ $_{3}$

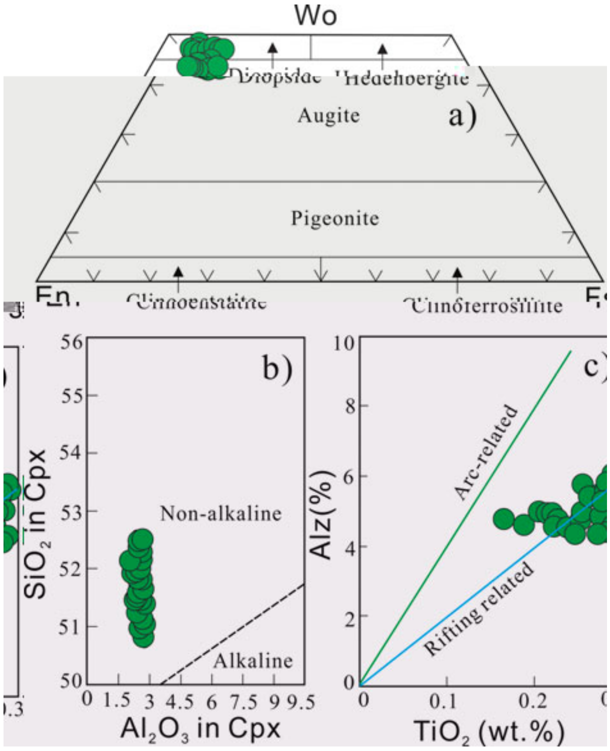
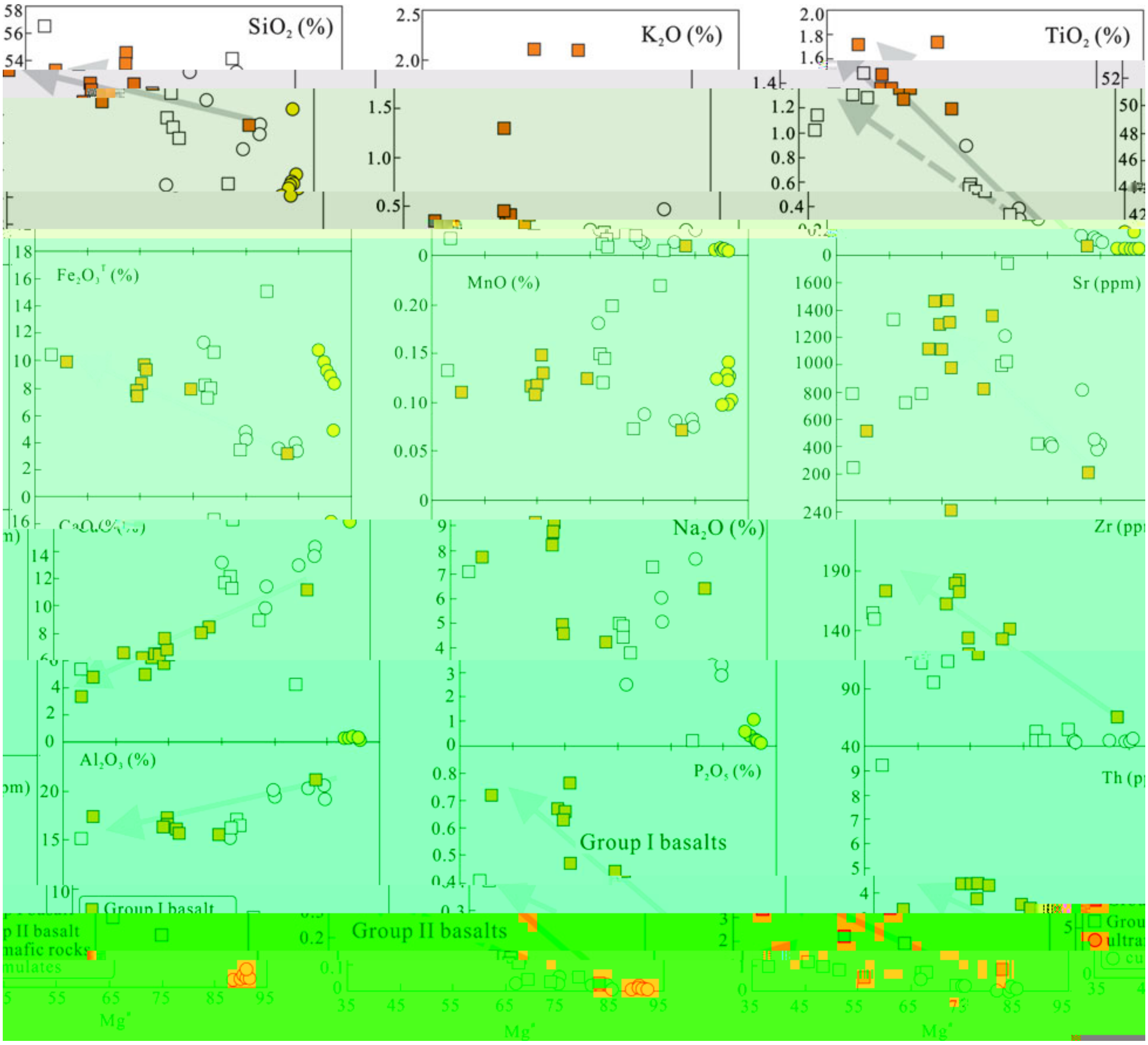


Figure 5. ( ) ( ) $_{2}$ (%) $_{2}$ $_{3}$ (%) $_{2}$ (%)

1 (1).
(Fig. 6).
(3 103)
(5) (1). (> 12 %)
$_{2}$ $_{2}$
).
$_{2}$ $_{3}$ $_{2}$ $_{3}$ $_{2}$,
(1).
(Fig. 7),
, 2014
&
(1).
45. % 51.2 %,
$_{2}$ $_{3}$ (3.24 4.6 %), $_{2}$ $_{3}$ (1 .3 1 .6 %,
2013 01-3), (.54 15.42 %), $_{2}$
(0.12 0.34 %), $_{2}$ (2. 1 .3 %,
2013 01-3) $_{2}$ (0.11 0.46 %)
(1).



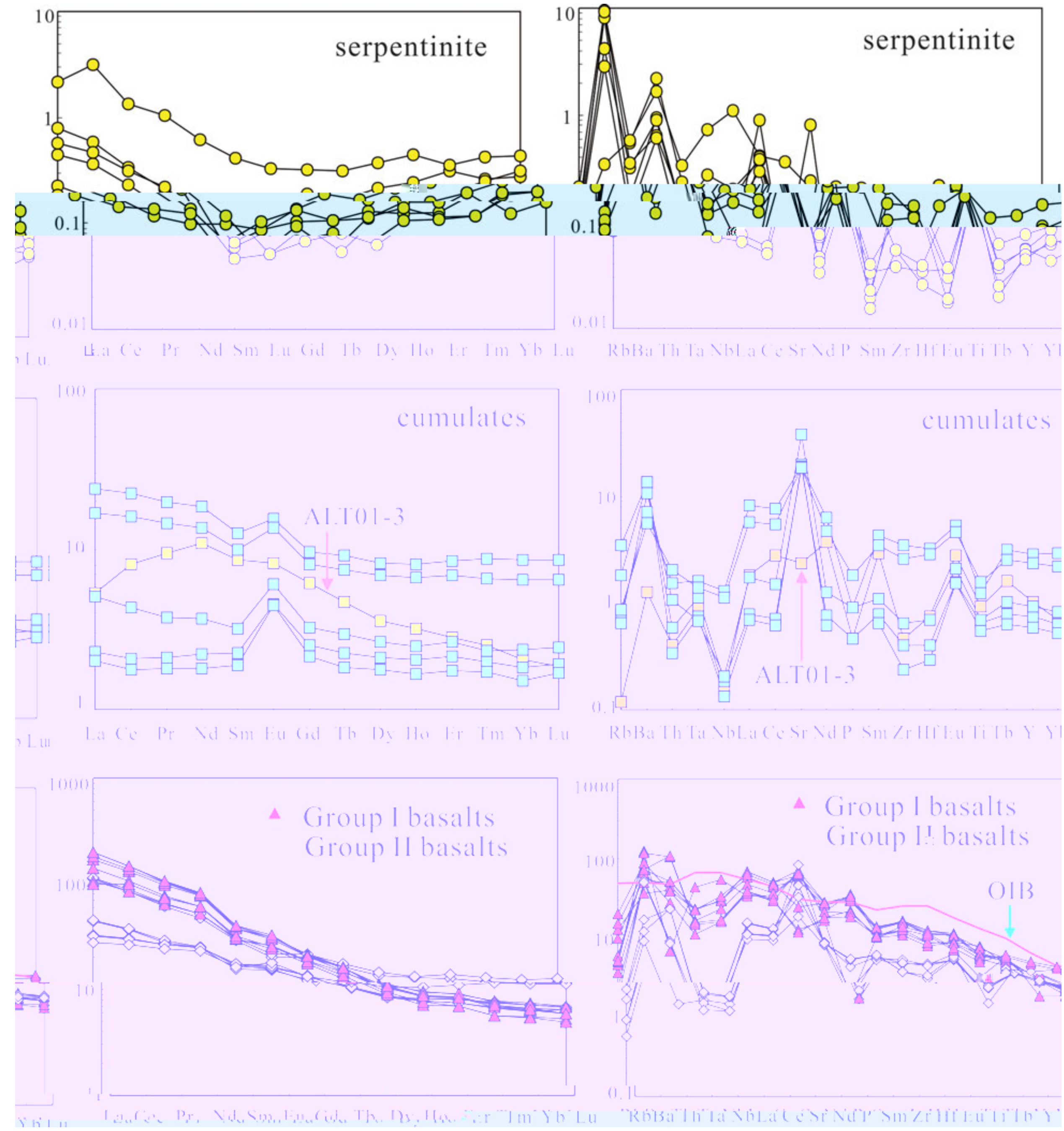
6. (...) ... *et al.* 200 ...

... 6). ... 41 ... = 1.3 2.2 ... = 1.1 2.2). ... 2013 ... 01-3 ... = 0.2 0.4) ...

4.c.2. Basalts

... 43.15 % ... 51.65 % ... 52 %, ...

1). ... 1 (1) ... 2 (2). ... 6). ... 124 ... 205 ... 50 ... 60 ... 10 ... 30 (... 20) ...

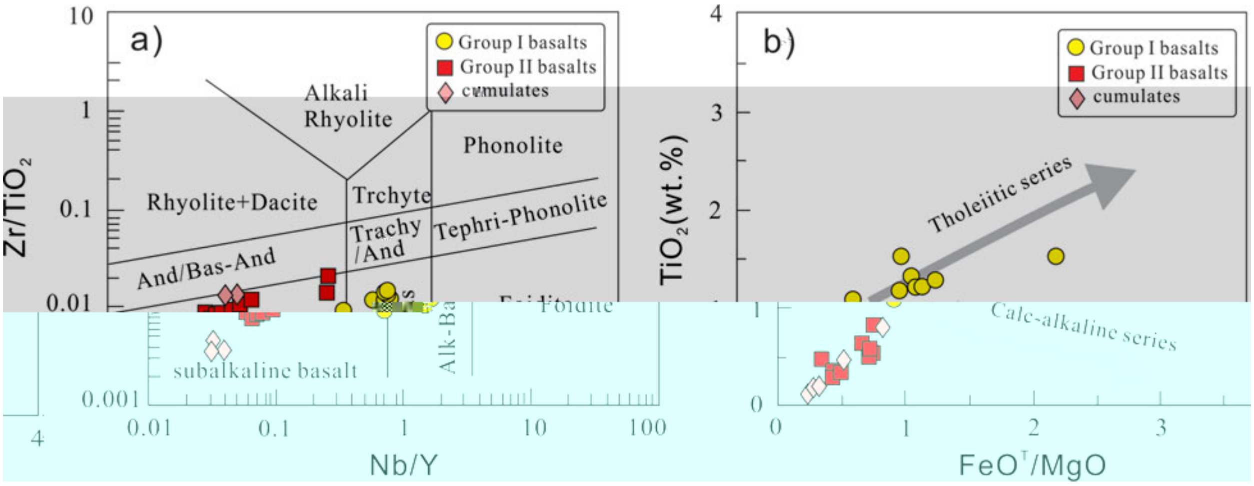


[illegible] (1 [illegible]).

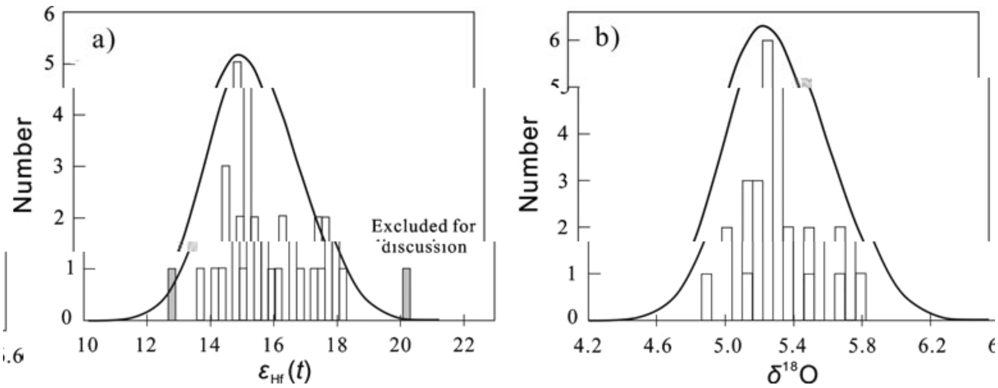
[illegible] (0.[illegible]0 1.14) [illegible] 2 [illegible] 4 [illegible] 6 [illegible] 1.02 [illegible] 1.21) [illegible]. [illegible] 1 [illegible] 0.44 [illegible] 0.[illegible] [illegible] 2 [illegible] 1 [illegible] (~0.11) [illegible].

4. [illegible]

[illegible] 2 [illegible] 1 [illegible] 2 [illegible] (0.0024 [illegible] 0.0452) [illegible] (0.[illegible]04030 [illegible] 0.[illegible]0536 [illegible]), [illegible] (0.[illegible]04015 [illegible] 0.[illegible]05111, [illegible] 2013 [illegible] 03 [illegible] 1). [illegible] 0.0[illegible] [illegible] 0.13[illegible]4 [illegible] 0.512[illegible]0 [illegible] 0.512[illegible]3 [illegible] ε [illegible] (t) [illegible] +6.3 [illegible] +[illegible].5 ([illegible] 2013 [illegible] 03 [illegible] 1 [illegible] +1.[illegible]).


a)
Group I basalts
Group II basalts
cumulates
Alkali Rhyolite
Phonolite
Rhyolite+Dacite
Trchyte
Trachy /And
Tephri-Phonolite
And/Bas-And
subalkaline basalt
Alk-Ba
Zr/TiO2
Nb/Y
0.001
0.01
0.1
1
10
100
b)
Tholeiitic series
Calc-alkaline series
TiO2(wt.%)
FeOT/MgO
0
1
2
3
4

[illegible]


a)
Number
Excluded for discussion
εHf(t)
10
12
14
16
18
20
22
0
1
2
3
4
5
6
b)
δ18O
4.2
4.6
5.0
5.4
5.8
6.2

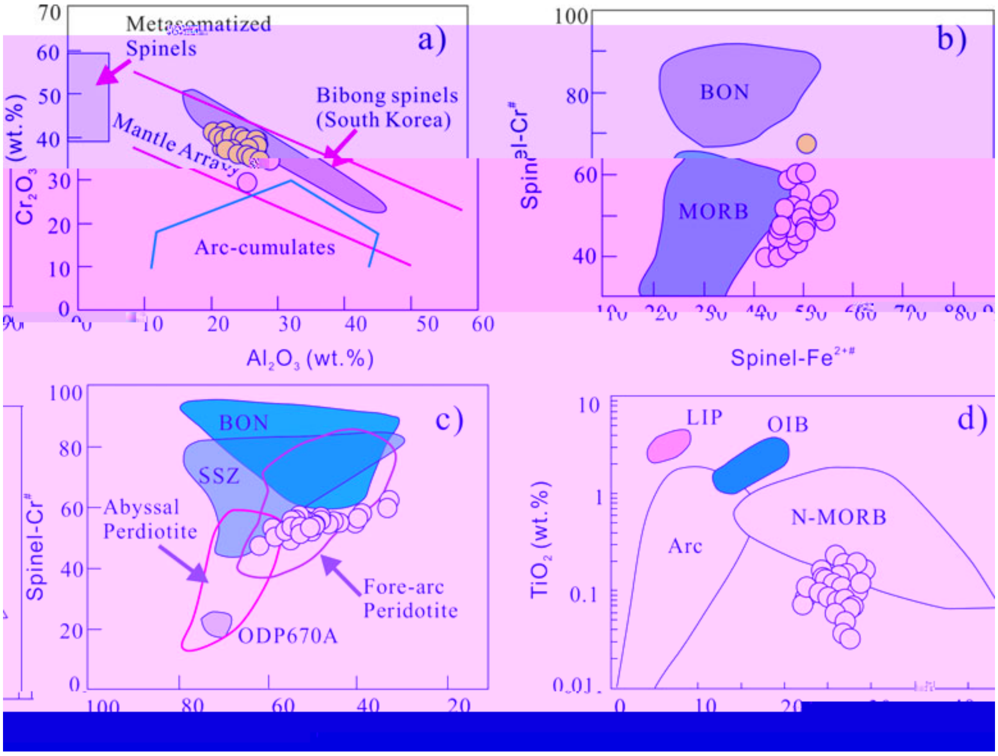
[illegible]

[illegible]

5. D[illegible]

5.a. T[illegible]

[illegible]

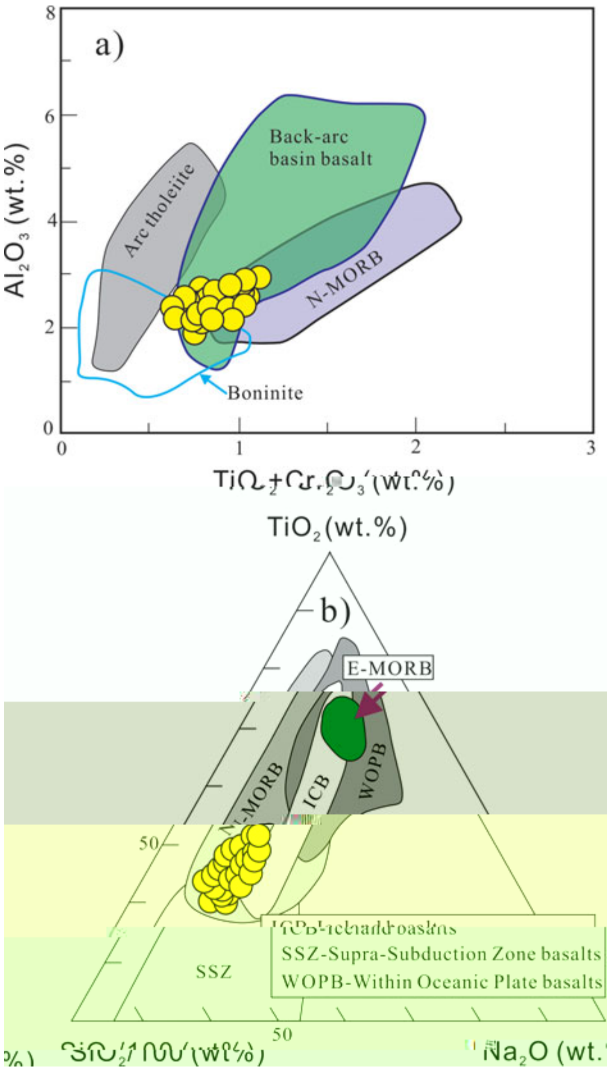


10. ( ) ... ( ) ... $_2$ ... $_3$ ... $_2$ $_3$ (%) ... (... & ... , 2000). ( ) ... (100 ... /(... + ...)) ... $^{2+}$ ... (100 ... $^{2+}$/(... $^{2+}$ + ...)) ... (... 1 ... 4 ... & ... , 2001). ( ) ... (100 ... /(... + ...)) ... (100 ... /(... + ...)) ... (... *et al.* 1 ... 5). ( ) ... $_2$ ... $_2$ $_3$ ... (... , ... & ... , 2001).

... (500 4 0 ...) (... *et al.* 2003 ... *et al.* 2015 ...), ... (430 400 ...) (... *et al.* 200 ... b, 2014 ...) ... (3 0 350 ...) (... *et al.* 2003 ... *et al.* 2006).

5.b. O ...

... (... & ... , 2002 ... *et al.* 2010 ...



11. ([illegible]) ( ) Al_2O_3 [illegible] TiO_2 + Cr_2O_3 [illegible] TiO_2/100 [illegible]

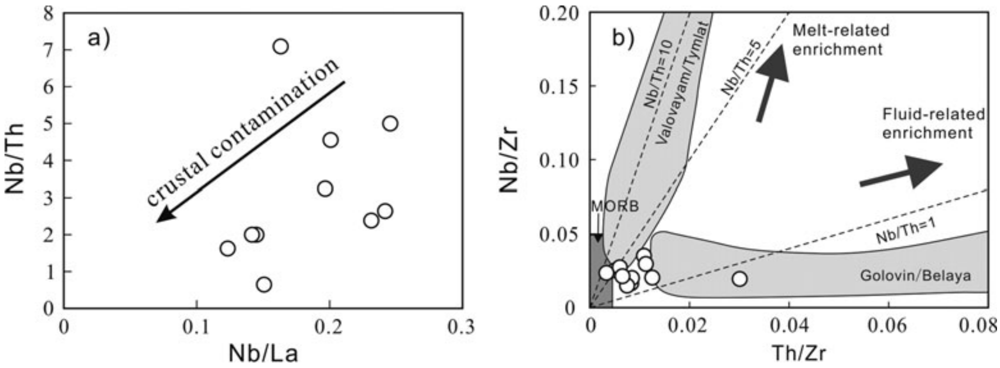
[illegible] (Fig. 11) [illegible] TiO_2/100 [illegible] (Fig. 11) [illegible]

[illegible] (Fig. 12) [illegible] (Fig. 12) [illegible] et al. (2002) [illegible]

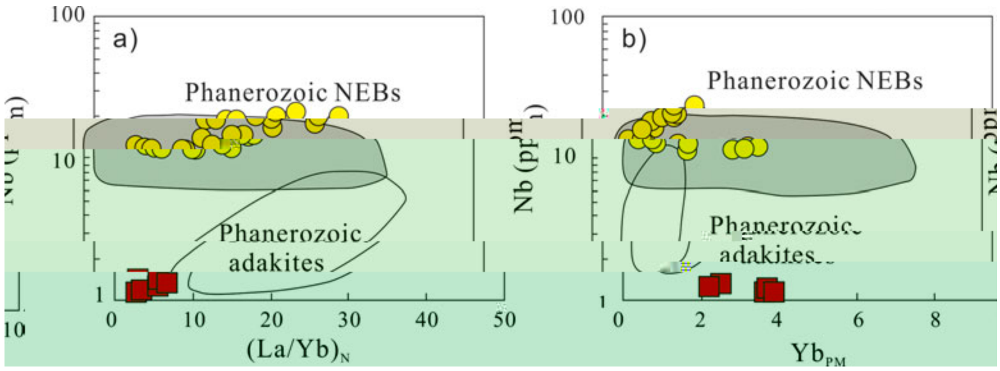
5.c. P[illegible] D[illegible] a ba[illegible]

[illegible] (0.4 0.6 %) [illegible] (11 15, [illegible] 60) [illegible] 2001) (Fig. 13) [illegible] (1) [illegible] 2002) (2) [illegible] et al. [illegible]

[illegible] 2011). [illegible] (0.704120 0.706133) [illegible] ε(t) [illegible] (3.44 20.4) [illegible] (1.51 2.54) [illegible] 2000). [illegible] et al. [illegible] et al. (200[illegible]



12. ( ) ( )



13. ( ) ( ) ( ) ( ).

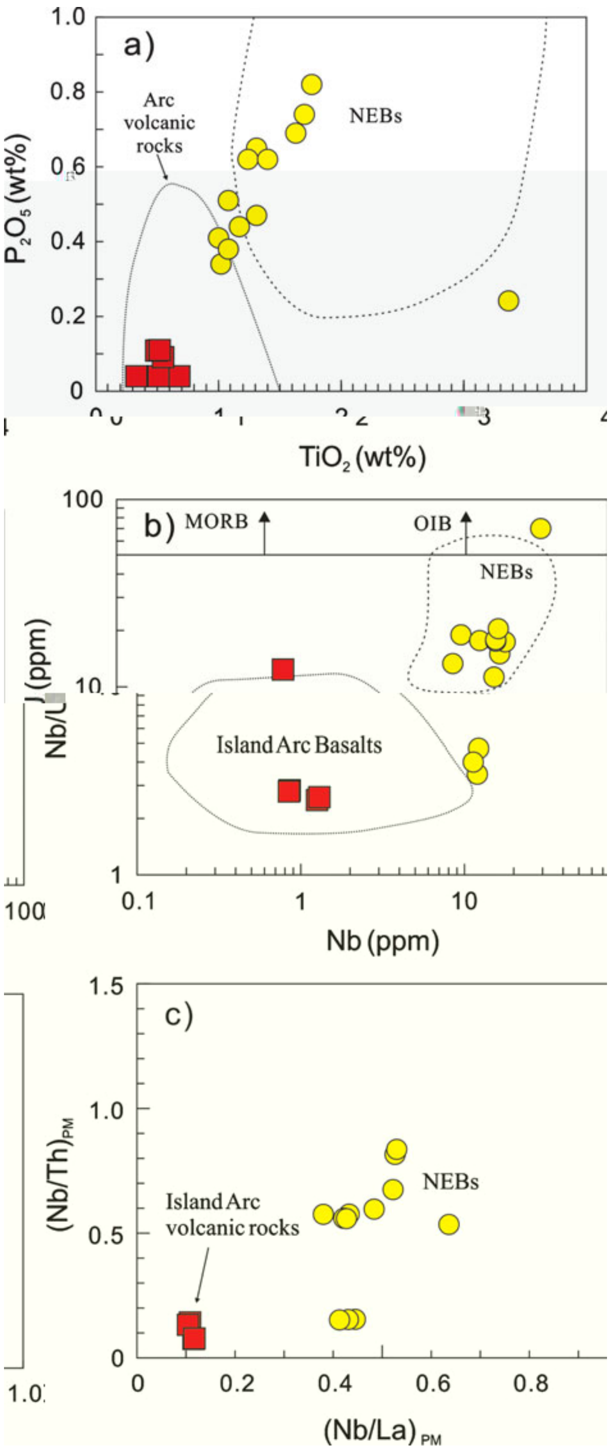
ε(t) (1. .5) (0.704120 0.706133) (2). ε(t) 1 2 (< 0.3), ( ), 1 1 2002). 2 (0.1 1.0), (0.1 0.2) (0.6 1.0) 2 (& 1 6). 1 2 ( ) 1 14).

(. 14). 2 1 2

5. . I ca Pa a z c acc c a J7 a

J (416 et al. 2014 et al. 2015), (503 4 5 et al. 2003 et al. 2015) (400) (. 1) (et al. 2014),

(et al. 2007, 200 a,b et al. 200 a). (et al. 200 b).



14.

et al. (2015)

400 3 0

460 3 5 *c.* 400 *et al.* 2006, 200 *et al.* 200 *et al.* 200 *et al.* 200 , 200 *et al.* 2012 *et al.* 2015).

2002 *et al.* 200).

(*et al.* 2015).

et al. (200 , 200 *b*)

(*et al.* 200).

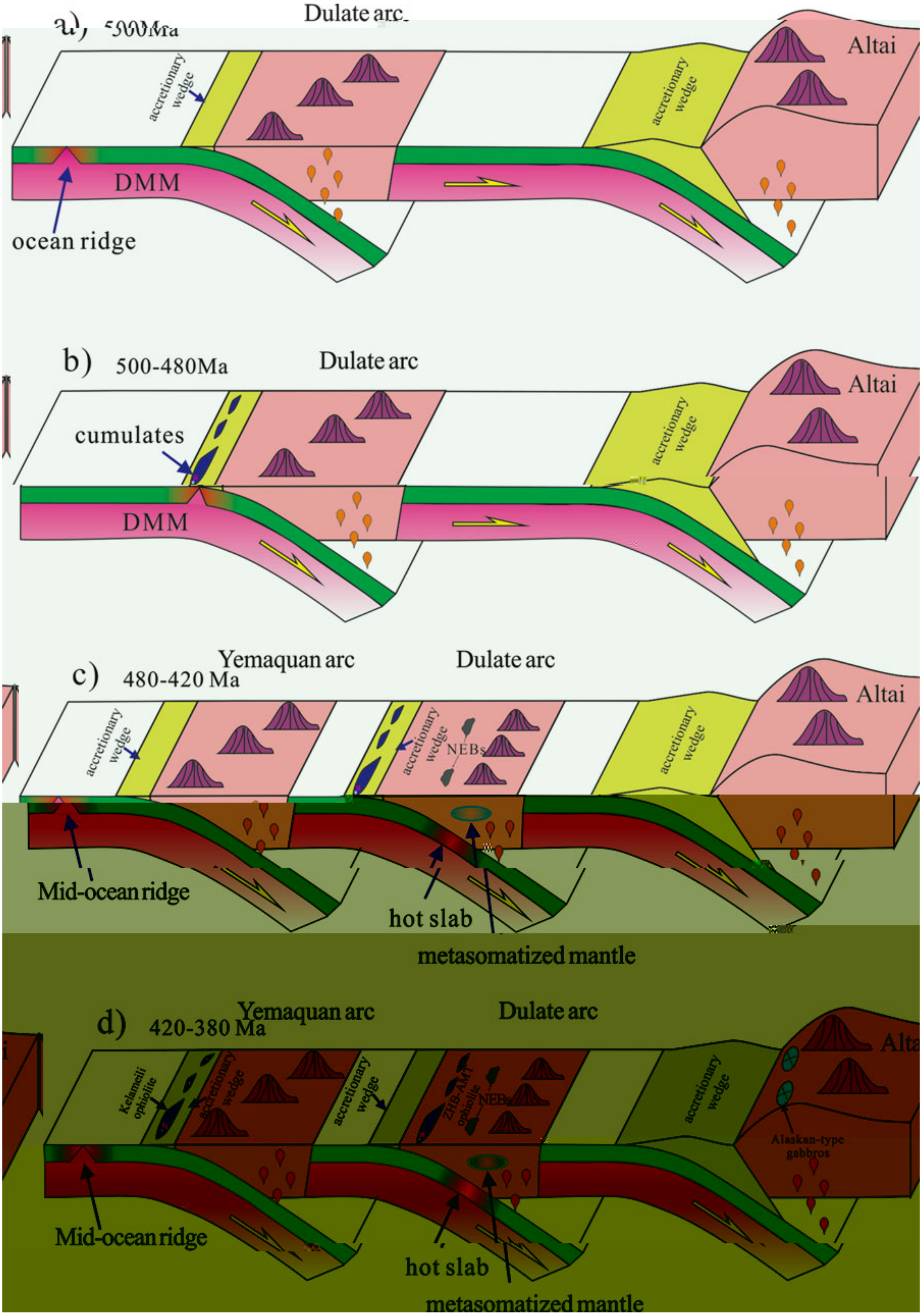
200 *et al.* 2013).

(1) (*c.* 500),

(2) (500 4 0),

(3) (4 0 420), (45 *et al.* 2015)

(440 *et al.* 2014)



a)
Dulate arc
Altai
accretionary wedge
accretionary wedge
DMM
ocean ridge
b) 500-480Ma
Dulate arc
Altai
cumulates
accretionary wedge
DMM
c) 480-420 Ma
Yemaquan arc
Dulate arc
Altai
accretionary wedge
accretionary wedge
NEBs
accretionary wedge
Mid-ocean ridge
hot slab
metasomatized mantle
d) 420-380 Ma
Yemaquan arc
Dulate arc
Kelameili ophiolite
accretionary wedge
accretionary wedge
ZHB-AMT ophiolite
NEBs
accretionary wedge
Alaskan-type gabbros
Mid-ocean ridge
hot slab
metasomatized mantle

15. ([illegible]) [illegible]

(4) J (420 3 0) (*et al.* 2014 *et al.* 2015).

1 ( ) 2

15).

(400 3 0).

6. C

(1) ~4 5 *c.* 400

(2)

(3)

Ac

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2002. *Geology* **30**, 0 10.

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3. *Geology* **21**, 54 50.

2. *Journal of Geological Society, London* **149**, 56

4. *Contributions to Mineralogy and Petrology* **86**, 54 6.

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