Geol. Mag. **154** (3), 2017, pp. 419–440. © Cambridge University Press 2016 41[illegible]
10.101[illegible] / 0016[illegible]56[illegible]16000042

[illegible]

[illegible]
, 10003 ,
210016,
, 36[illegible] 4[illegible] -5305,

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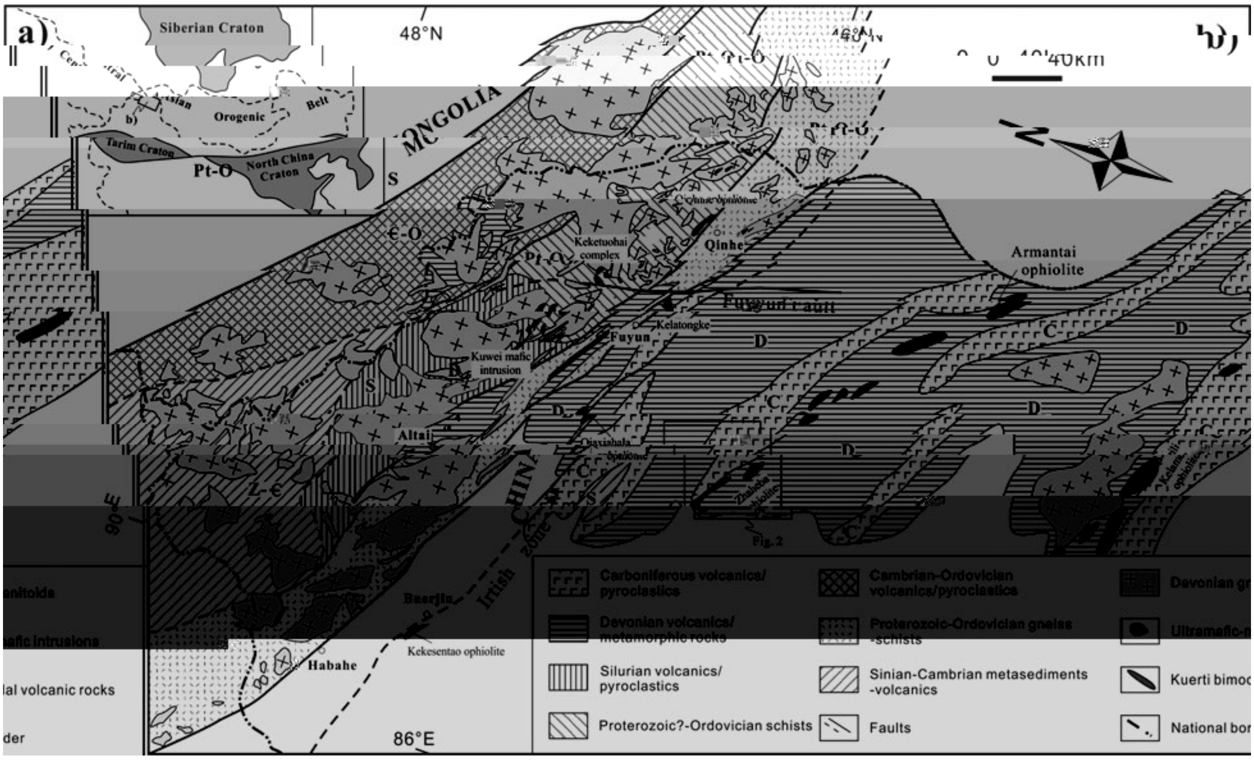
Abstract [illegible] ~4[illegible]5 [illegible] ~400 [illegible] ε(t) (13[illegible]20) [illegible] δ[illegible] (+5.3[illegible]‰) [illegible]

1. Introduction

[illegible] (et al. 200[illegible] & [illegible], 200[illegible]; et al. 2012; et al. 2012, 2013; et al. 2013), [illegible] 1[illegible]; et al. 200[illegible]; et al. 200[illegible]a). [illegible] (1[illegible] 2000; 1[illegible]; 1[illegible]3; et al. 2000; & [illegible], 2003; et al. 200[illegible], 2014). [illegible] & [illegible] (2011) [illegible] (2014) [illegible]

[illegible] (2[illegible]), [illegible] & [illegible], 2000; 1[illegible]3; & [illegible], 2000; et al. 2002; et al. 2004, 200[illegible]a) ([illegible] 1[illegible]). [illegible] (et al. 200[illegible]a,b; & [illegible], 2012). [illegible] (1[illegible]3; et al. 2003; et al. 2003; et al. 200[illegible]a) ([illegible] 1[illegible]). [illegible]

[illegible] 1[illegible]6 [illegible]



1. ( ) … *et al.* 200).

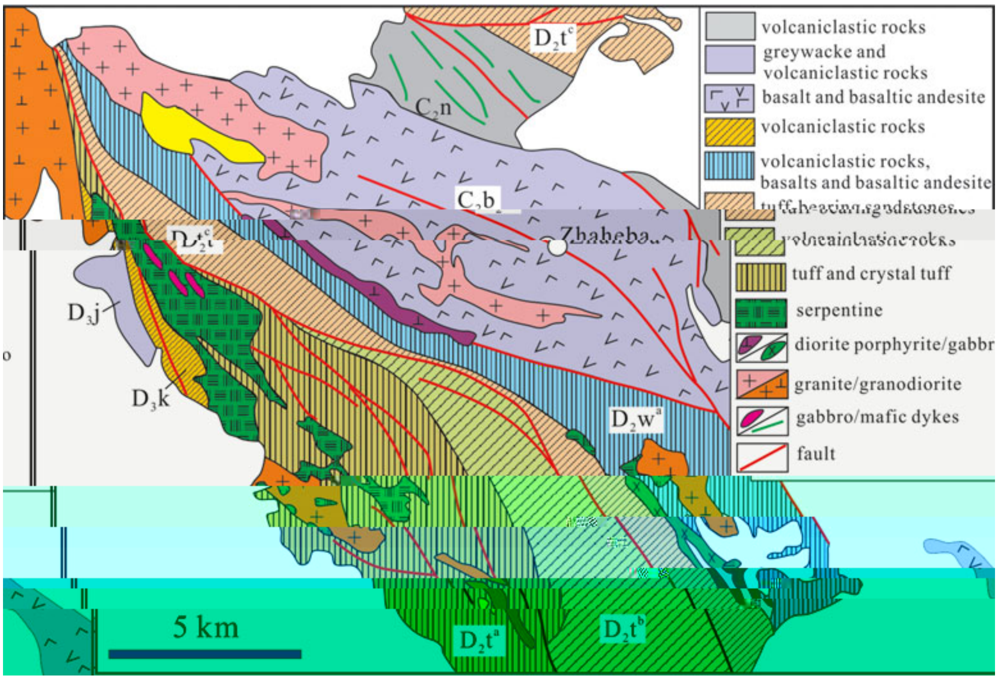
… > 0 % … (. 3 ,). … *et al.* 2013) … (40 0 %) … (30 50 %) … (5 10 %) … (. 3) …

… (1) … (2) …

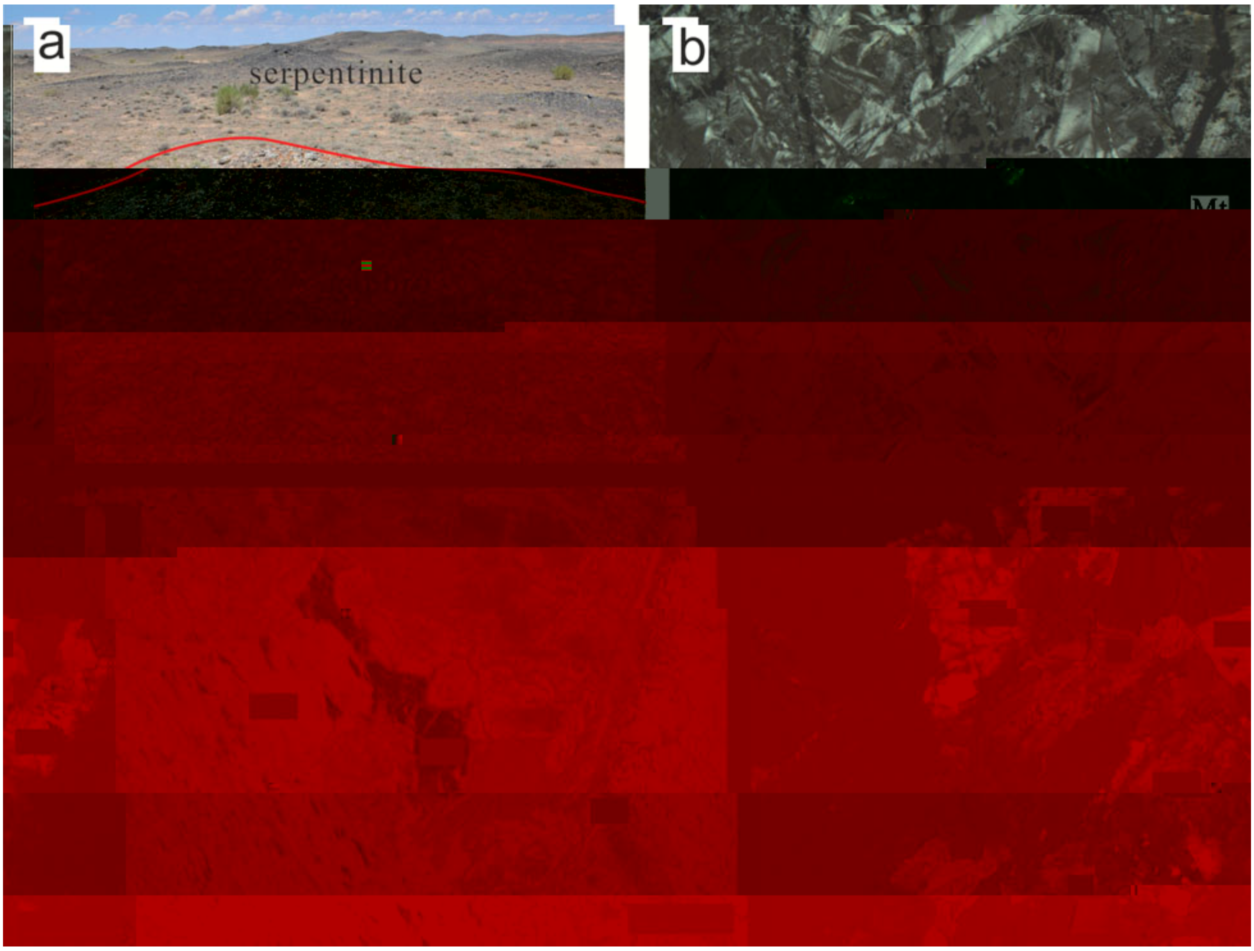
2. R a , b a a t a

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

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



2. (...) ... (... *et al.* 200 , 200 *a* ... , 1 , 3).



3. (...) ... ( ) ... (,) ... > 0% ... ( ) ...

3. A a t ca c

3.a. Z c U Pb a a Hf O t 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*).

= 0.0020052),

( ) δ 5.31 ‰ (*et al.* 2010*b*).

δ 5.44 ± 0.21 ‰ (2), 5.4 ± 0.2 ‰ (*et al.* 2013). 3

3.b. M a 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. 21

0. 102

0. 0506 -1,

143/144 0.512104

0.5126 1 -1.

2.

4. A a t ca t

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

[illegible] 1. [illegible]

[illegible]	2013 [illegible] 01-1	2013 [illegible] 01-3	20132 [illegible] 01-4	2013 [illegible] 01-5	2013 [illegible] 01-6	2013 [illegible] 01-	2013 [illegible] 01-	2013 [illegible] 0[illegible] 1	2013 [illegible] 0[illegible] 2	2013 [illegible] 0[illegible] 4
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] 3	0.61	1. 6	1.04	0.6	0. 0	0. 4	0. 0	1 .2	1 .64	1 .33
[illegible] 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	0.142	[illegible]	[illegible]	[illegible]

13.2.1(.1. (3 .21)-55307 1) 4-5 11 --6030.1(3[illegible])-

0(0.11)- (.0) 10 5. - .1431 ( ) 0 5.4 5 3.53 4.1(.12) 42.5 5 4.3

[illegible] 1. [illegible]

[illegible]	2013 01-1	2013 01-3	20132 01-4	2013 01-5	2013 01-6	2013 01-	2013 01-	2013 0 1	2013 0 2	2013 0 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 0 5	2013 0 6	2013 0 (1)	2013 0 (1)	2013 0 (1)	2013 03 2 (1)	2013 03 3 (1)	2013 03 4 (1)	2013 03 5 (1)	2013 0 3 (2)
Major elements (%)										
[illegible] 2	4 .1	45.	4 .	53.1	51. 1	50.40	50.54	50.52	51.22	52.3
[illegible] 2	0.34	0.15	1.40	1.24	1.31	1. 0	1.63	1.31	1.1	0.33
[illegible] 3	1	1 .5	16.5	16.1	15. 3	15.	16. 6	15.55	15.4	1 .61
[illegible] 3	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] 5	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	1	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

1.

	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)
	3.	1.20	3 .60	46. 0	4 .30	23.40	43.00	25.20	32. 0	6.56

23.40 .1 .1 23.40 6.540 .1 25.20 .1 605 5 ( )-250

1.

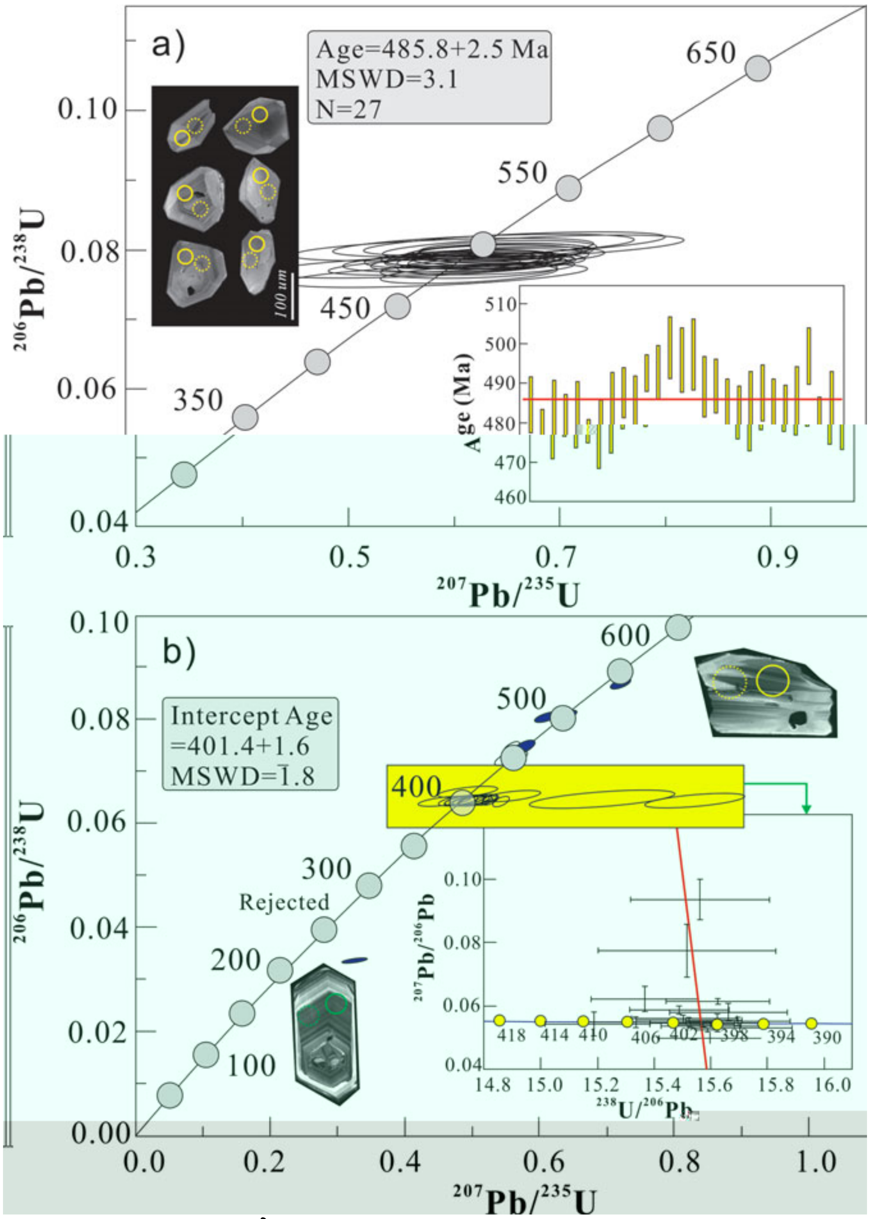
[illegible]	2013 01 11 (2)	2013 02 1 (2)	2013 02 2 (2)	2013 03 1 (1)	2013 03 6 (1)	2013 01 10 (2)	04 06 (1)	04 24 (1)	04 2 (1)	03 1 (1)
				Trace elements (ppm)						
[illegible]	1 .4	36.	42.4	26.0	32.4	1 .	/	/	/	/
[illegible]	0.3 5	0.153	0.35	1.1	0. 4	0.46	/	/	/	/
[illegible]	32.5	33.2	34.5	25.1	26.3	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*).

2. [illegible]

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

(t) = 10 000((143 /144) (t)/(143 /144) (t) − 1) (t) (/ 6) [illegible] 401 [illegible]



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

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

[illegible] 1. 3. [illegible] 1 (1) [illegible] 0% [illegible] (2) [illegible]

(2, ... 4). ... 2 ... 450 ... 500 ... 21 ... 1 ... 206 ... 23 ... 401 ± 2 (= 3.3) ... 206 ... 23 ... 20 ... 235 ... 401.4 ± 1.6 (= 1.) ... 206 ... 23 ... . 4), ... 1 . 3).

4.b. M a c t

4.b.1. Spinel composition

(. 3). ... 100 ... 300 μ ... 4 ...) ... 3 ... 3 ... 2 ... (100 /(+)) ... 44 ... 60 ... (100 /(+)) ... 25 ... 61. ... *et al.* 2010). ... ( ) ... (*et al.* 2013).

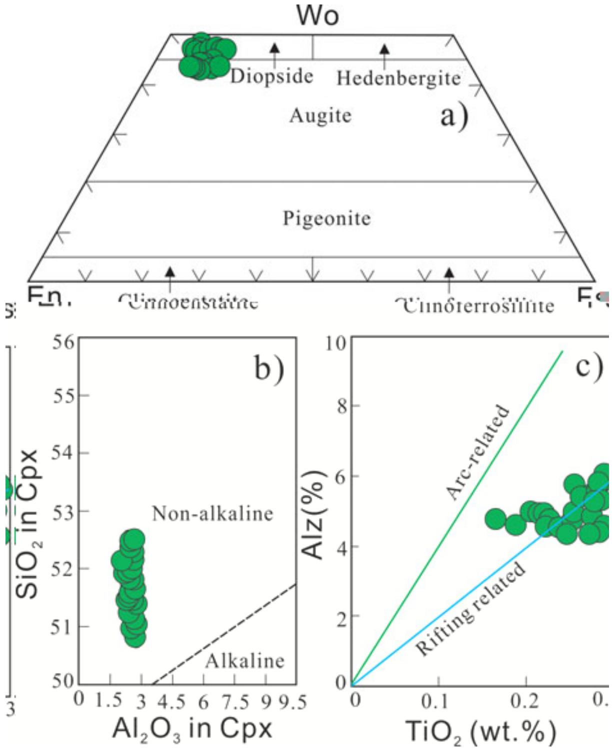
4.b.2. Pyroxene compositions

(= 4 6). ... 2 ... (0.5 %) ... 5 ...). ... 41 4 ... , 46 55 ... 1 ... (. 5). ... 3, ... 2 ... 2 ... (. 5 ;).

4.c. W - c t a c t

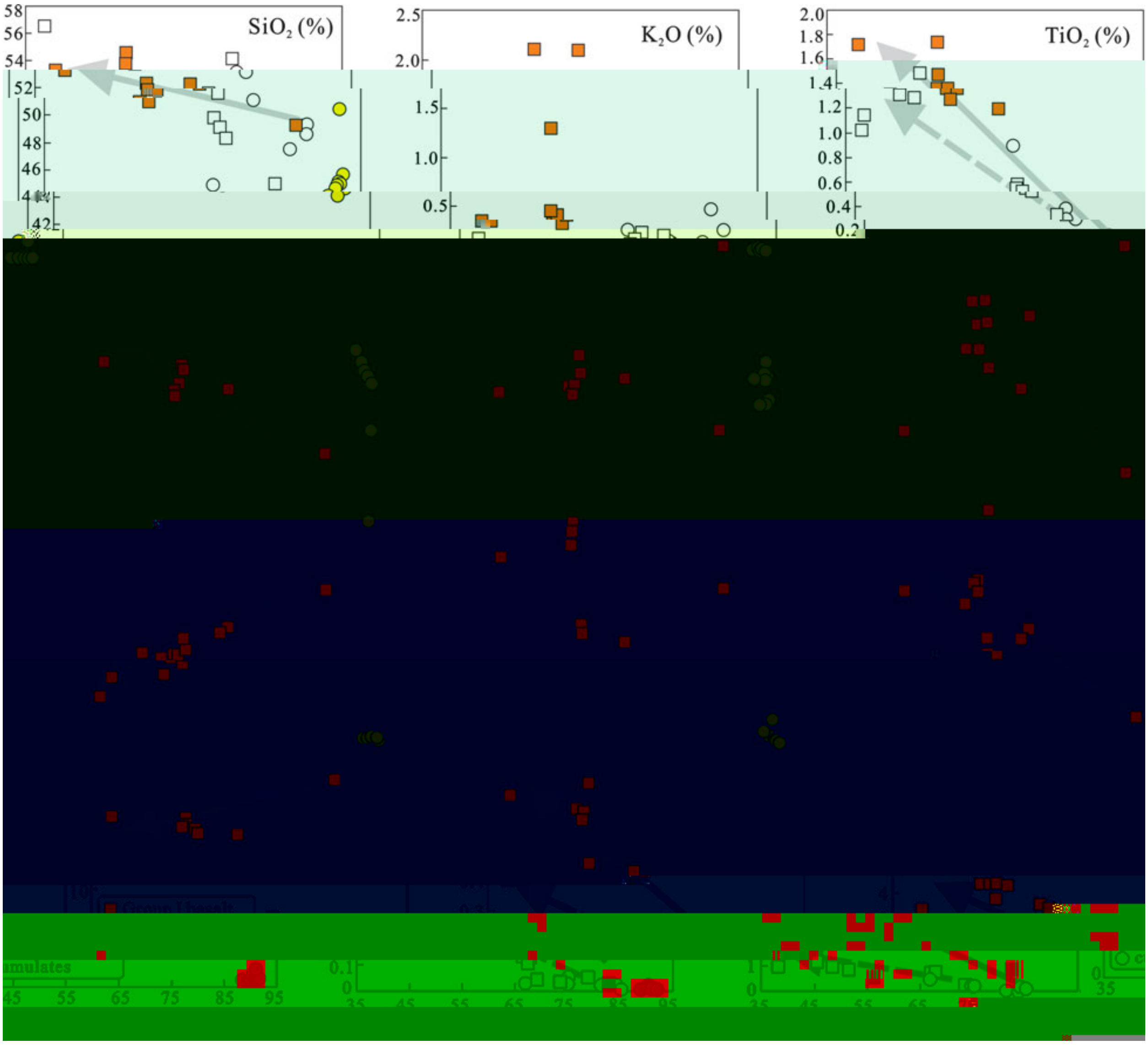
4.c.1. Serpentinites and cumulates

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

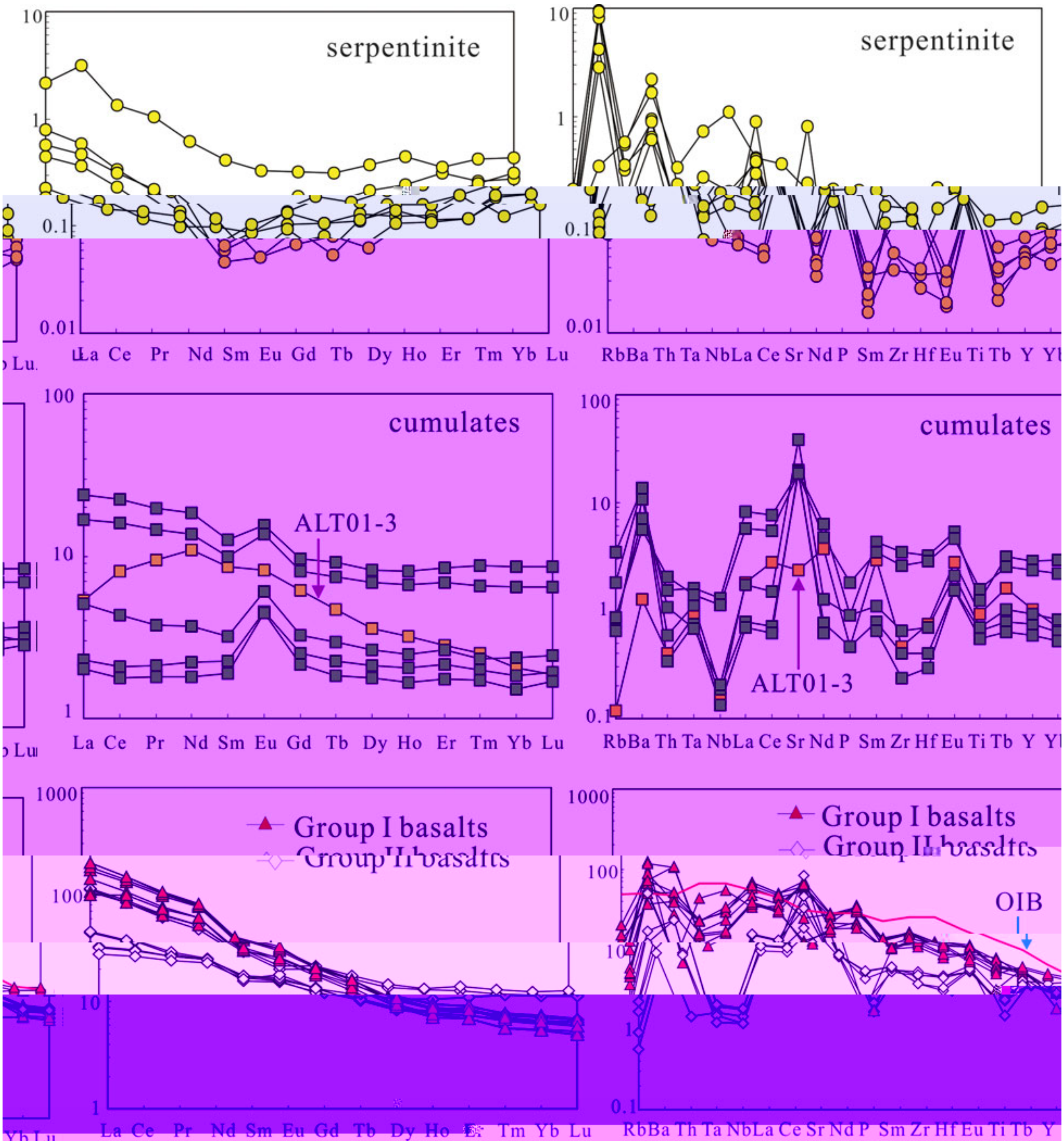


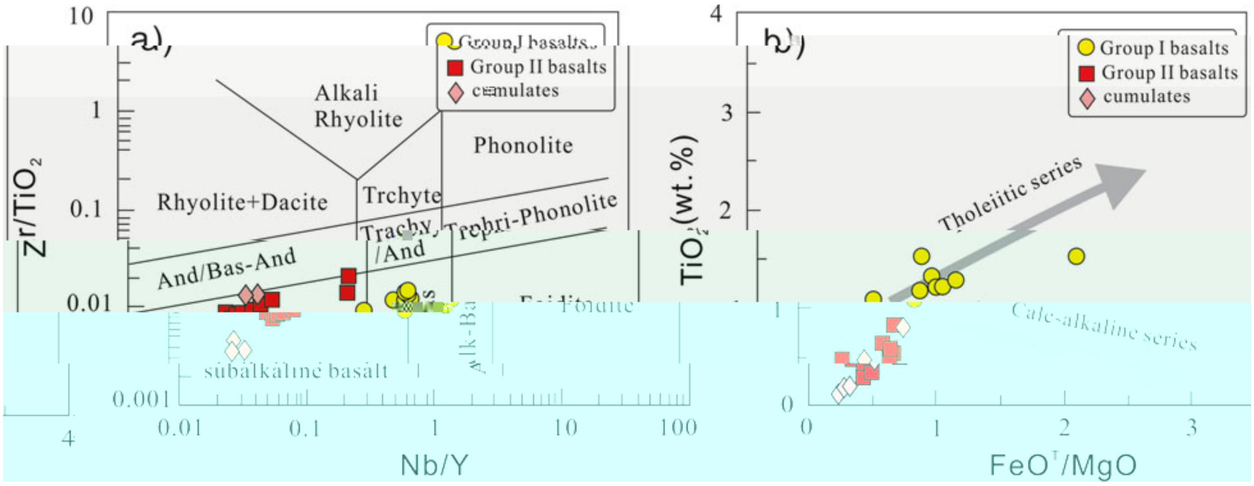
5. ( ) ( ) ... . ( ) 2 (%) ... 3 (%) ... ( ) ... ( ) ... 2 (%) ...

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

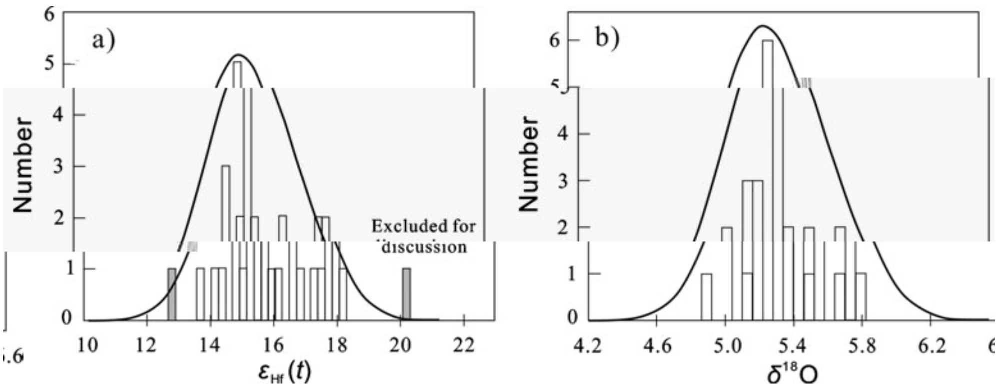


4.c.2. Basalts


serpentinite
serpentinite
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Rb Ba Th Ta Nb La Ce Sr Nd P Sm Zr Hf Eu Ti Tb Y Yb
cumulates
cumulates
ALT01-3
ALT01-3
Group I basalts
Group II basalts
Group I basalts
Group II basalts
OIB



( ). ( ) (4).



( ) ε (t) ( )

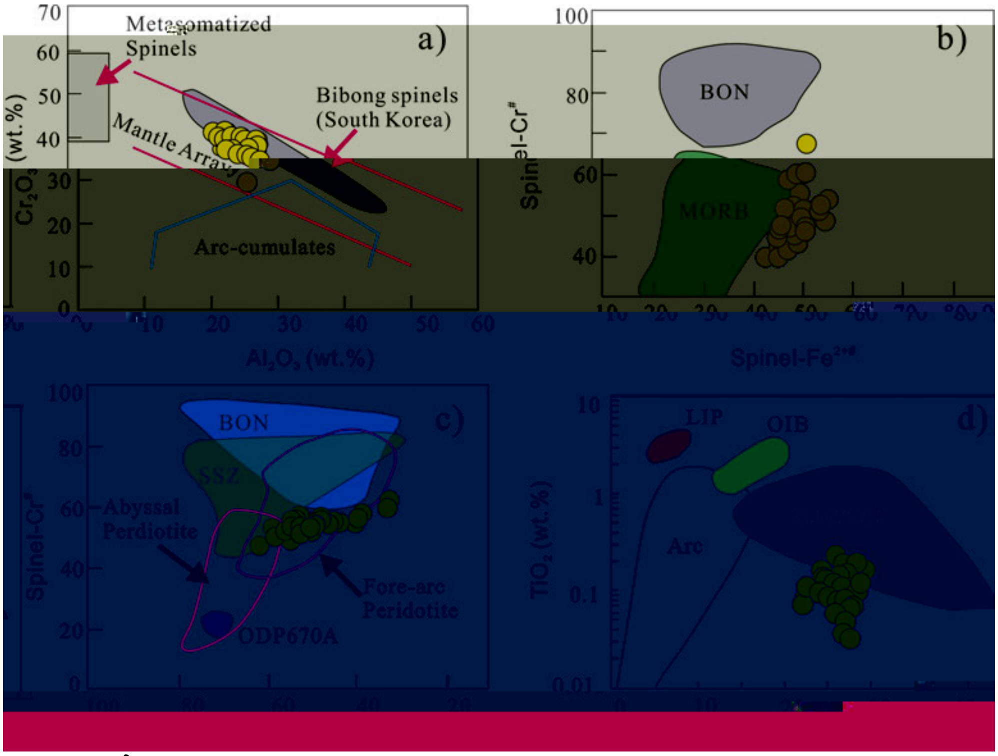
(2013 01) 2), ε (t = 4 5) 13 20. 2 5 5 ε (t) (> 16) ε (t), 15. δ 4. 1 ‰ 5. 3 ‰, ( ). δ 5.3 ± 0.23 ‰ ( ).

~400 ε (t) 1.4 .2 6 0 20 (*et al.* 200).

5. D c

5.a. T a b t Z a ba t

c. 4 6 401 (503 ±) (416 ± 3) *et al.* 2012 *et al.* 200 b, 1). (401) (4 6) (1 3). (1),

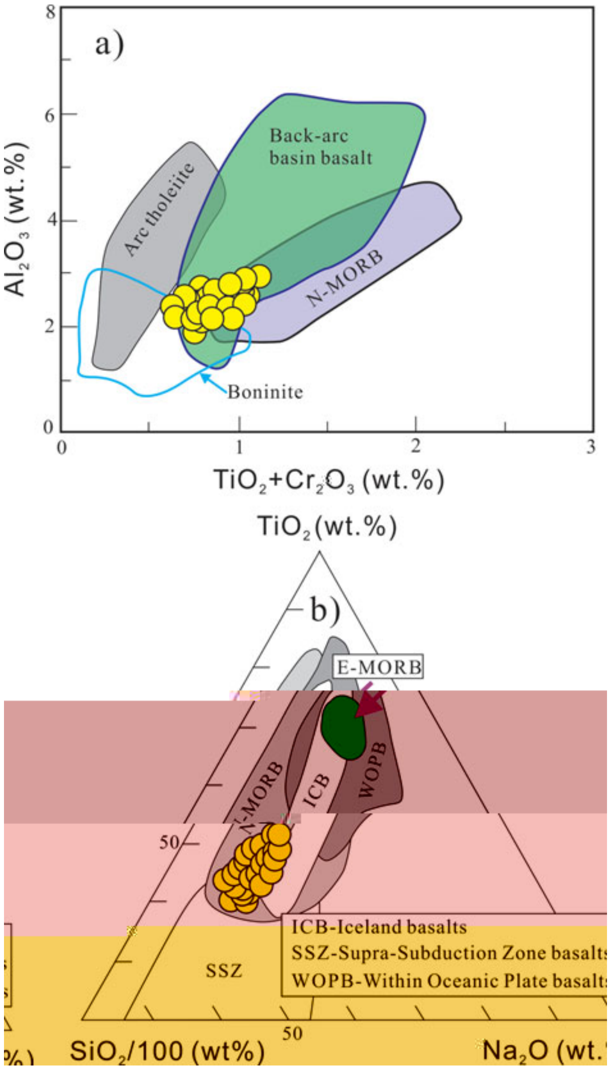


10. (...) ... ( ) ... (%) ... & ... 2000). ( ) ... (100 ... /(... + ...)) ... $^{2+}$ ... (100 ... $^{2+}$/(... $^{2+}$ + ...)) ... & ... 2001). ( ) ... (100 ... /(... + ...)) ... (100 ... /(... + ...)) ... *et al.* ... 5). ( ) ... $_2$ ... $_3$ ... & ... 2001).

... (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 ... t ... t a c ... a

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



11. ( ) ( ) $_3$ $_2$+ $_3$ ( ) $_2$ $_2$/100

5 $_3$ $_2$+ $_3$

(. 11) $_2$/100 $_2$

(. 11)

(. 12),

(. 12).

et al. (2002)

5.c. P t D a ba at

(11 24 ,
2. 1. 15), $_5$ (0.4 0.6 %)
(11 15, 60)

2001) (. 13).

(1)

, 2002) (2)

et al. 1 6).

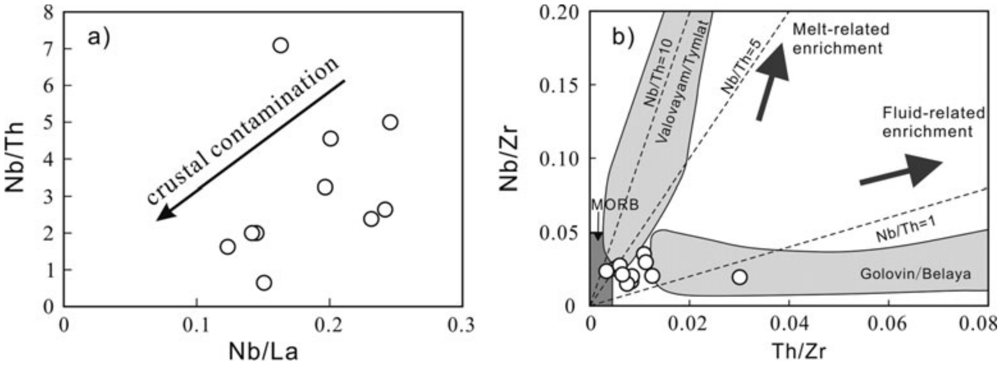
1.

, 200 *et al.*
2011)
(0. 04120 0. 06133) (t)
(+1. + .5).
(3.44 20.4)
(1.51 2.54)
1 6).

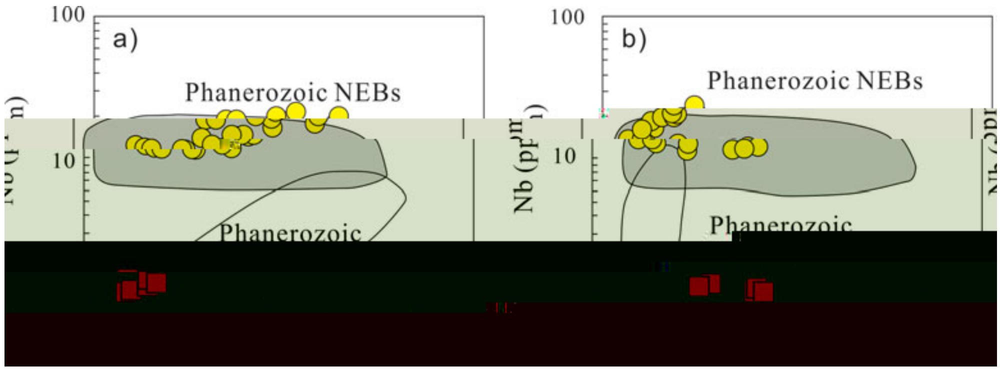
et al.
1 6 1 6).

2000).

et al. 1 6). *et al.*
(200



12. [illegible]



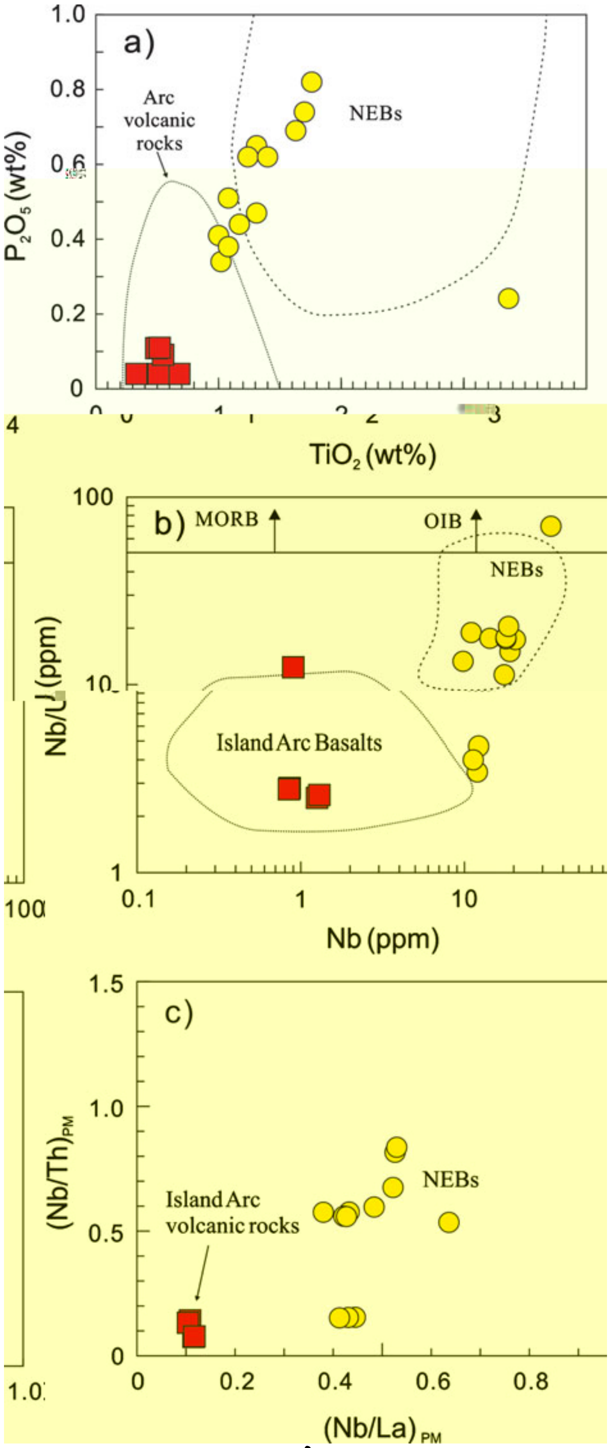
13. [illegible]

[illegible] (t) (1. [illegible] .5) [illegible] (0. 04120 0. 06133) [illegible] 2). [illegible] (t) [illegible] 1. [illegible] 2. [illegible] (< 0.3) [illegible] 2002). [illegible] 2. [illegible] (0. [illegible] 1.0), [illegible] (0.1 0.2) [illegible] (0.6 1.0) [illegible] 2. [illegible] 6). [illegible] 2. [illegible] 14). [illegible]

[illegible] 14). [illegible] 2. [illegible] 1 [illegible] 2. [illegible]

5. [illegible]

[illegible] (416 [illegible] *et al.* 2014 [illegible] *et al.* 2015), [illegible] (503 [illegible] 4 5 [illegible] *et al.* 2003 [illegible] *et al.* 2015 [illegible] (400 [illegible] *et al.* 2014), [illegible] *et al.* 200 [illegible], 200 [illegible] *a*,*b* [illegible] *et al.* 200 [illegible] *a*). [illegible] *et al.* 200 [illegible] *b*). [illegible]


a)
1.0
0.8
0.6
0.4
0.2
0
P_2O_5 (wt%)
Arc volcanic rocks
NEBs
0
1
2
3
TiO_2 (wt%)
b)
MORB
OIB
NEBs
Island Arc Basalts
100
10
1
Nb/La (ppm)
0.1
1
10
Nb (ppm)
c)
1.5
1.0
0.5
0
$(Nb/Th)_{PM}$
Island Arc volcanic rocks
NEBs
0
0.2
0.4
0.6
0.8
$(Nb/La)_{PM}$

14.

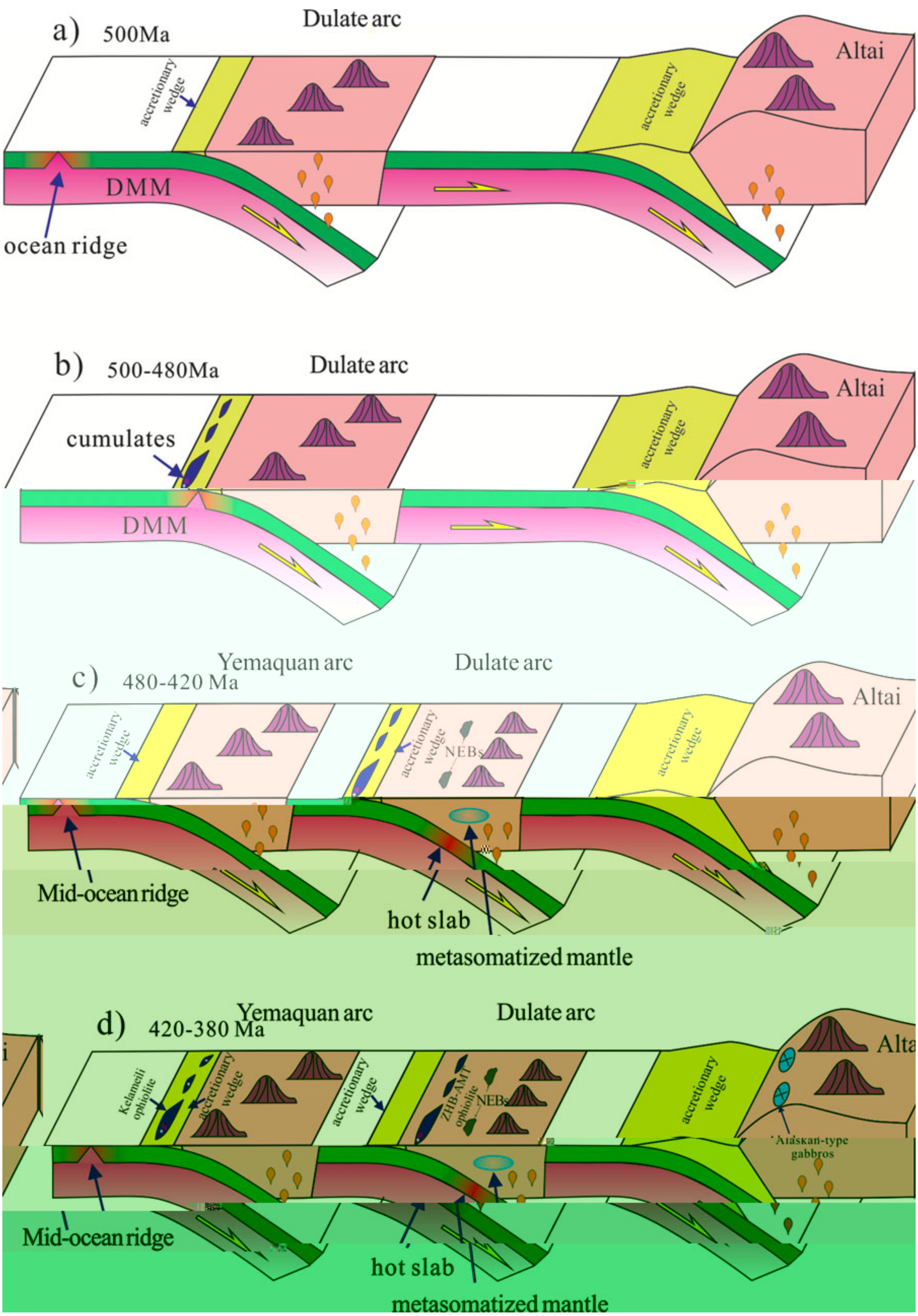

a) 500Ma
Dulate arc
Altai
accretionary wedge
accretionary wedge
DMM
ocean ridge
b) 500-480Ma
Dulate arc
Altai
cumulates
accretionary wedge
DMM
c) 480-420 Ma
Yemaquan arc
Dulate arc
Altai
accretionary wedge
accretionary wedge
NEBs
accretionary wedge
Mid-ocean ridge
hot slab
metasomatized mantle
d) 420-380 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

Fig. 15. [illegible]

(4) ... (420 ... 3 ... 0 ...) (... *et al.* 2014 ... *et al.* 2015). ... 1 ... 2 ... (... 15). ... (400 ... 3 ... 0 ...).

6. C... c...

(1) ... ~4 ... 5 ... *c.* 400 ...

(2) ...

(3) ...

Ac... ... 305 ... (2011 ... 06 ... 03-01).

S... ... t a ... a ... a

... /10.101 ... / 0016 ... 56 ... 16000042.

R... c...

... 1 ... 4. ... *Chemical Geology* **113**, 1 ... 1 ... 204.

... & ... 2001. ... *Journal of Petrology* **42**, 22 ... 302.

... & ... 200 ... *Lithos* **97**, 2 ... 1 ...

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... & ... 2002. ... *Geological Magazine* **139**, 1 ... 13.

... 1 ... 3. ... *Geological Society of America Bulletin* **105**, ... 15 ... 3 ...

... 1 ... *Ophiolites.* ... 220

... & ... 1 ... 3. ... *Geology* **21**, 54 ... 50.

... & ... 1 ... 2. ... *Journal of Geological Society, London* **149**, 56 ...

... & ... 1 ... 4. ... *Contributions to Mineralogy and Petrology* **86**, 54 ... 6.

... & ... 2003. ... (2) ... *Ophiolites in Earth History* (... & ...), ... 43 ... 6 ... 21 ...

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... & ... 2015. ... *Chinese Journal of Geology* **50**, 140 ... 54 ...

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... & ... 1 ... 1. ... *Lithos* **27**, 25 ...

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