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

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

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

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

1. Introduction

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

[illegible]), [illegible] 2000 [illegible] *et al.* 2002 [illegible] *et al.* 2004, 200[illegible] *a*) [illegible]). [illegible] *et al.* 200[illegible] *a,b* [illegible] 2012). [illegible] *et al.* 2003 [illegible] *et al.* 2003 [illegible] *et al.* 200[illegible] *a*) [illegible]

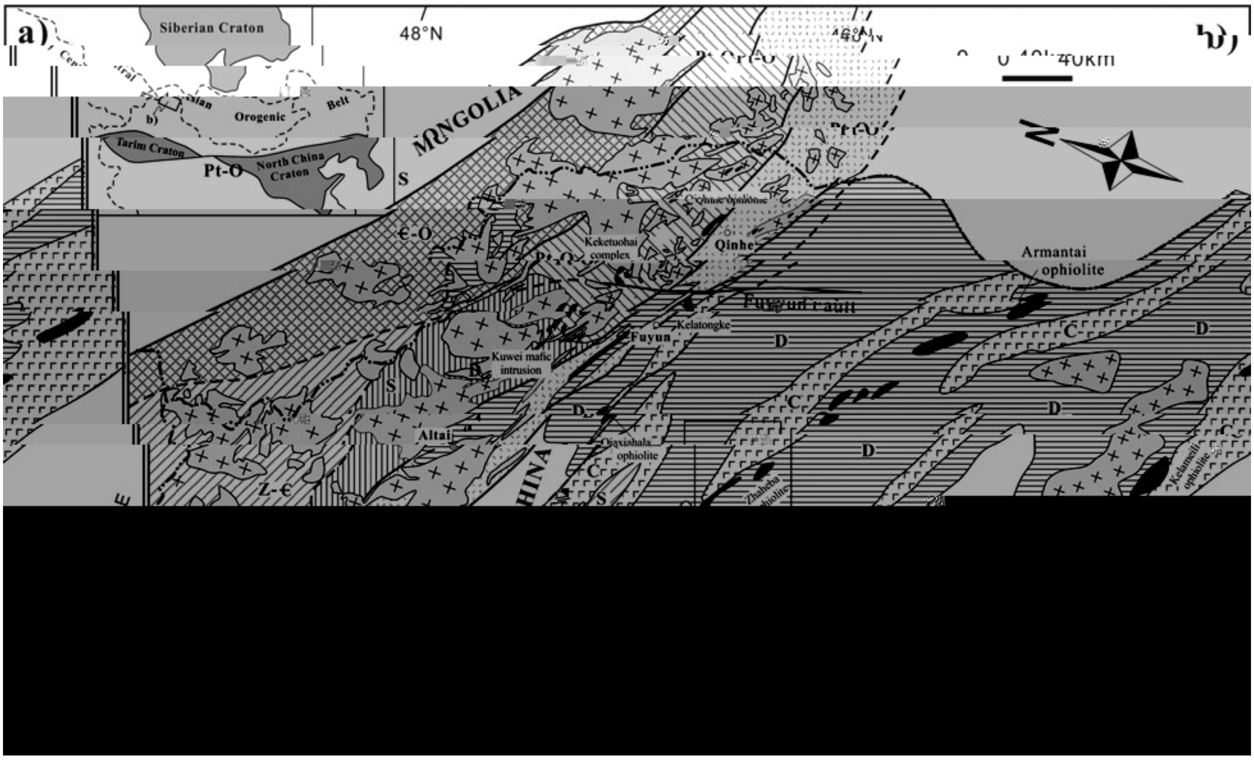


Fig. 1. (a) [illegible] (b) [illegible] *et al.* 200[illegible]).

[illegible] (1) [illegible] (2) [illegible]

2. R[illegible]a[illegible], [illegible]b[illegible]a[illegible]a[illegible]

[illegible] (Fig. 1, 2). [illegible] (Fig. 3) [illegible] 15 [illegible] (Fig. 2, [illegible]). [illegible] 1[illegible] 5[illegible] 1 [illegible]

[illegible] > [illegible]0 % [illegible] (Fig. 3, [illegible]). [illegible] ([illegible] *et al.* 2013). [illegible] (40[illegible]0 %) [illegible] (30[illegible]50 %) [illegible] (5[illegible]10 %) [illegible] (Fig. 3). [illegible] ([illegible]) [illegible] ([illegible]) [illegible] ([illegible]) ([illegible] *et al.* 2006). [illegible] (Fig. 2) [illegible] ([illegible] 1, 3). [illegible]

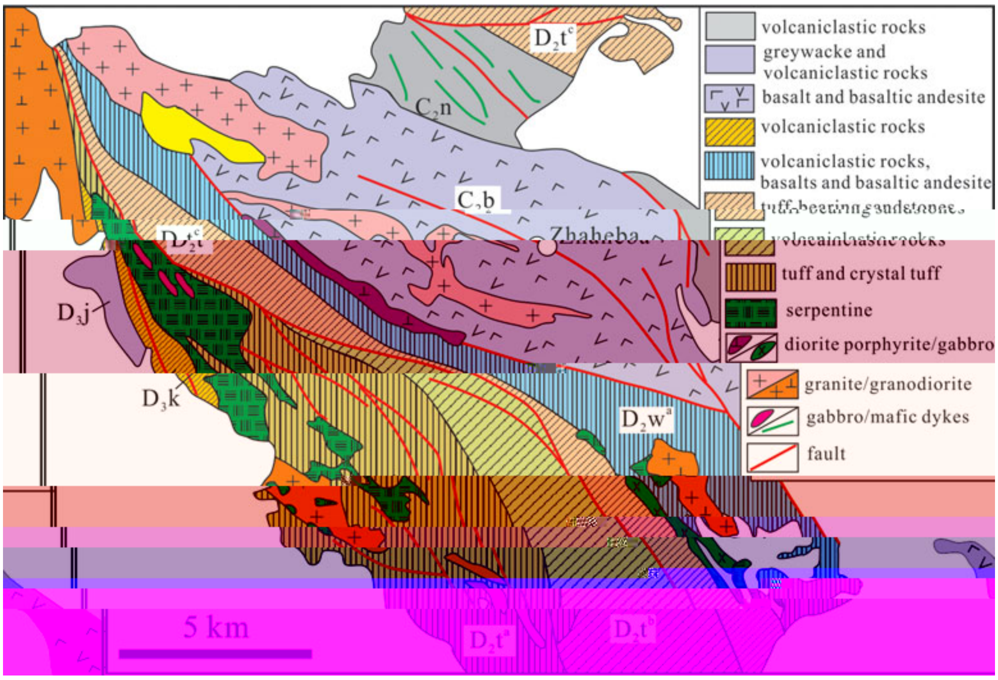
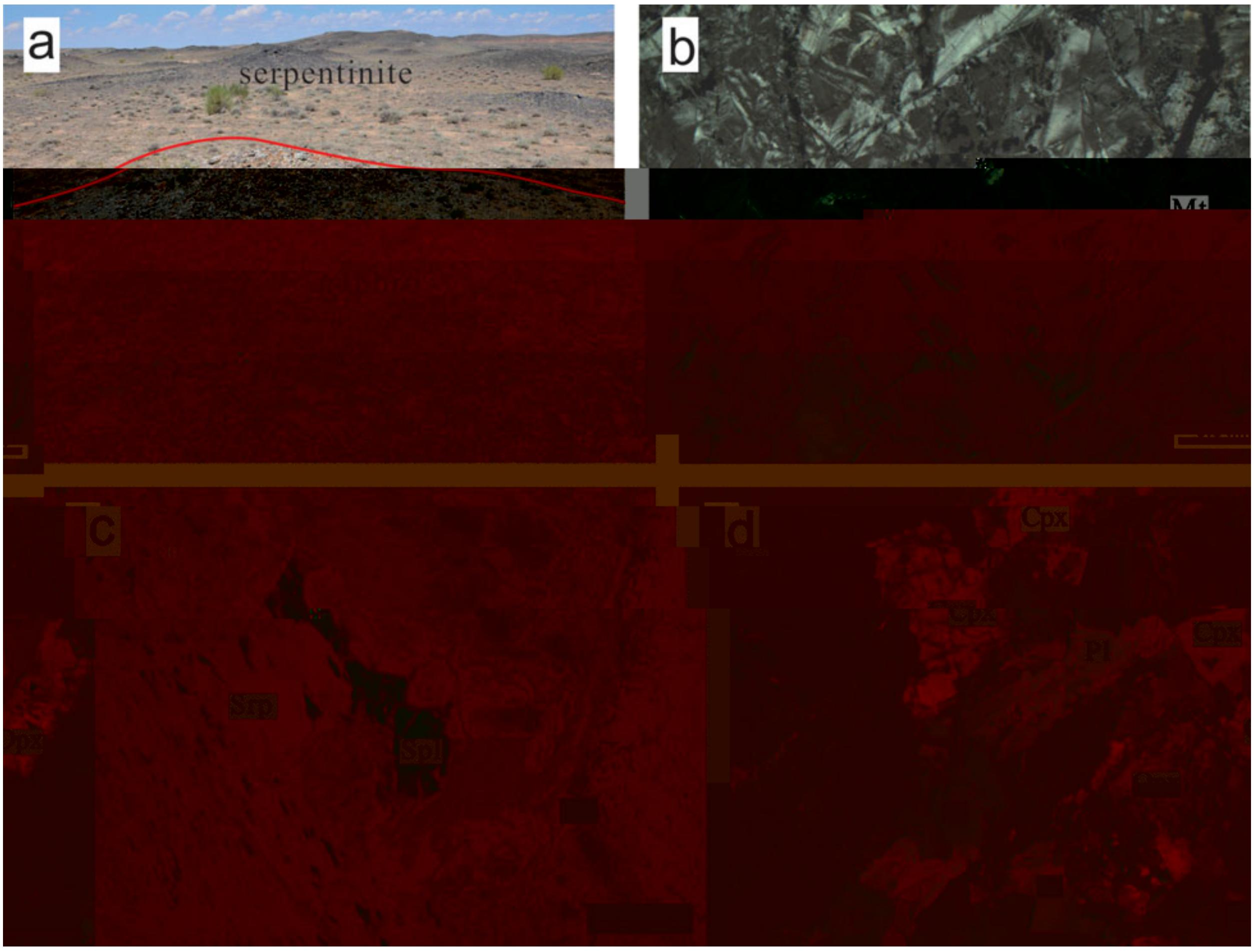


Fig. 2. … *et al.* 200 , 200 … 1 , 3).



3. A a ca c

3.a. Z c U Pb a a H 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 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). / 6 143 /144 6 / = 0.11 4 146 /144 = 0. 21 / 6 0. 102 0. 0506 -1, 143 /144 0.512104 0.5126 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

[illegible] 1. [illegible]

[illegible]	2013[illegible]01-1 [illegible]	2013[illegible]01-3 [illegible]	20132[illegible]01-4 [illegible]	2013[illegible]01-5 [illegible]	2013[illegible]01-6 [illegible]	2013[illegible]01- [illegible]	2013[illegible]01- [illegible]	2013[illegible]01 1 [illegible]	2013[illegible]01 2 [illegible]	2013[illegible]01 4 [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]$_2$[illegible]$_3$	0.61	1. 6	1.04	0.6	0. 0	0. 4	0. 0	1 .2	1 .64	1 .33
[illegible]$_2$[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	0.140	[illegible]		

[illegible] 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] $_2$	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] $_{2}$ $_{3}$	1	1 .5	16.5	16.1	15. 3	15.	16. 6	15.55	15.4	1 .61
[illegible] $_{2}$ $_{3}$	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] $_2$	4. 6	.3	. 2	.3	.00	4.52	.31	4. 0	4.0	.11
[illegible] $_2$	0.13	0.11	0.3	0.31	0.42	2.04	0.33	1.2	2.03	0.1
[illegible] $_2$ $_5$	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

[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 ([illegible] 1)	2013[illegible]03 3 ([illegible] 1)	2013[illegible]03 4 ([illegible] 1)	2013[illegible]03 5 ([illegible] 1)	2013[illegible]01 3 ([illegible] 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.

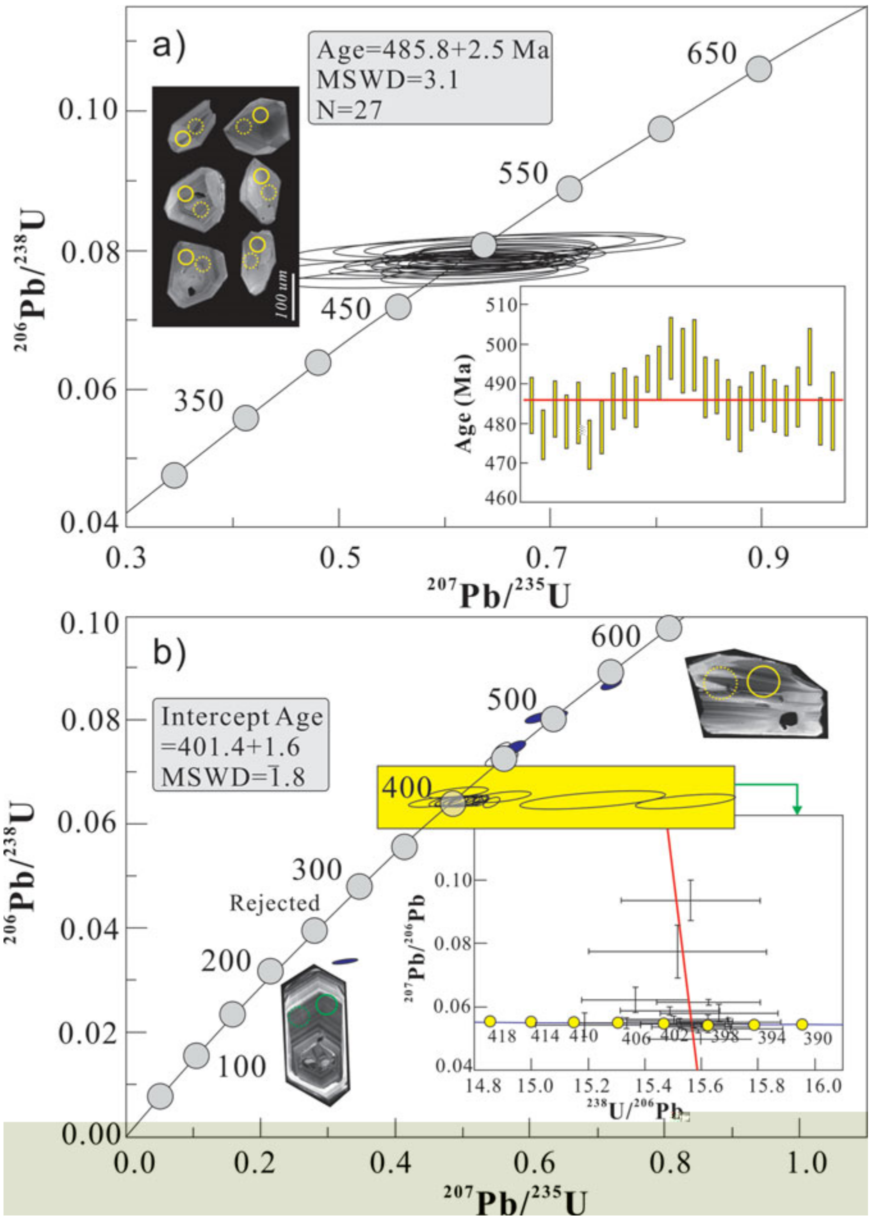
	2013 01 11 (2)	2013 02 1 (2)	2013 02 2 (2)	2013 03 1 (1)	2013 03 6 (1)	2013 01 10 (2)	04 06 (1)	04 24 (1)	04 2 (1)	03 1 (1)
Trace elements (ppm)										
	1 .4	36.	42.4	26.0	32.4	1 .	/	/	/	/
	0.3 5	0.153	0.35	1.1	0. 4	0.46	/	/	/	/
	32.5	33.2	34.5	25.1	26.3	32.1	13.4	20.5	1 .	20.3
	1 4	203	21	33	341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

04 06, 04 26, 04 2 04 1 *et al.* (200 a).

[illegible] 2. [illegible]

[illegible]	[illegible]	( )	( )	/ 6	6 / (1σ)	(/ 6)i	( )	( )	14 / 144	143 / 144 (1σ)	(143 / 144)i	ε (t)
2013 [illegible] 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 [illegible] 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 [illegible] 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 [illegible] 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 [illegible] 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 [illegible] 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

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



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

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

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

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

4.b. M a c

4.b.1. Spinel composition

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

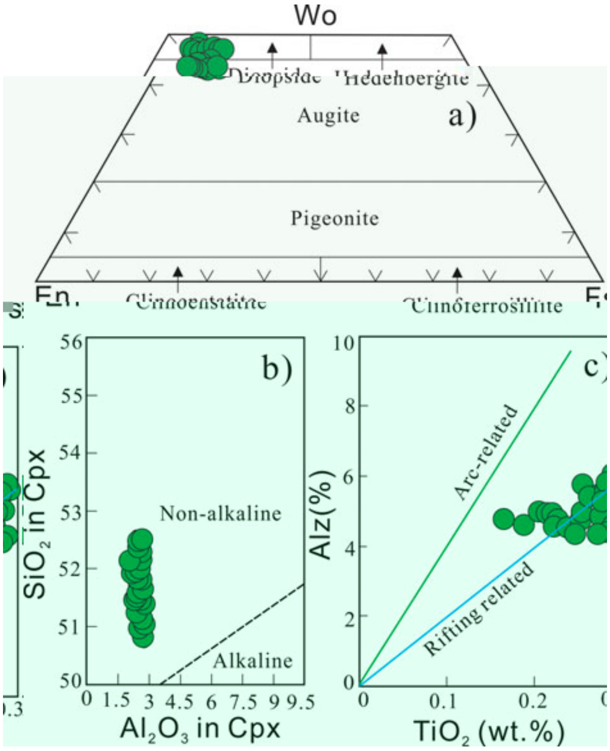
4.b.2. Pyroxene compositions

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

4.c. W - c a c

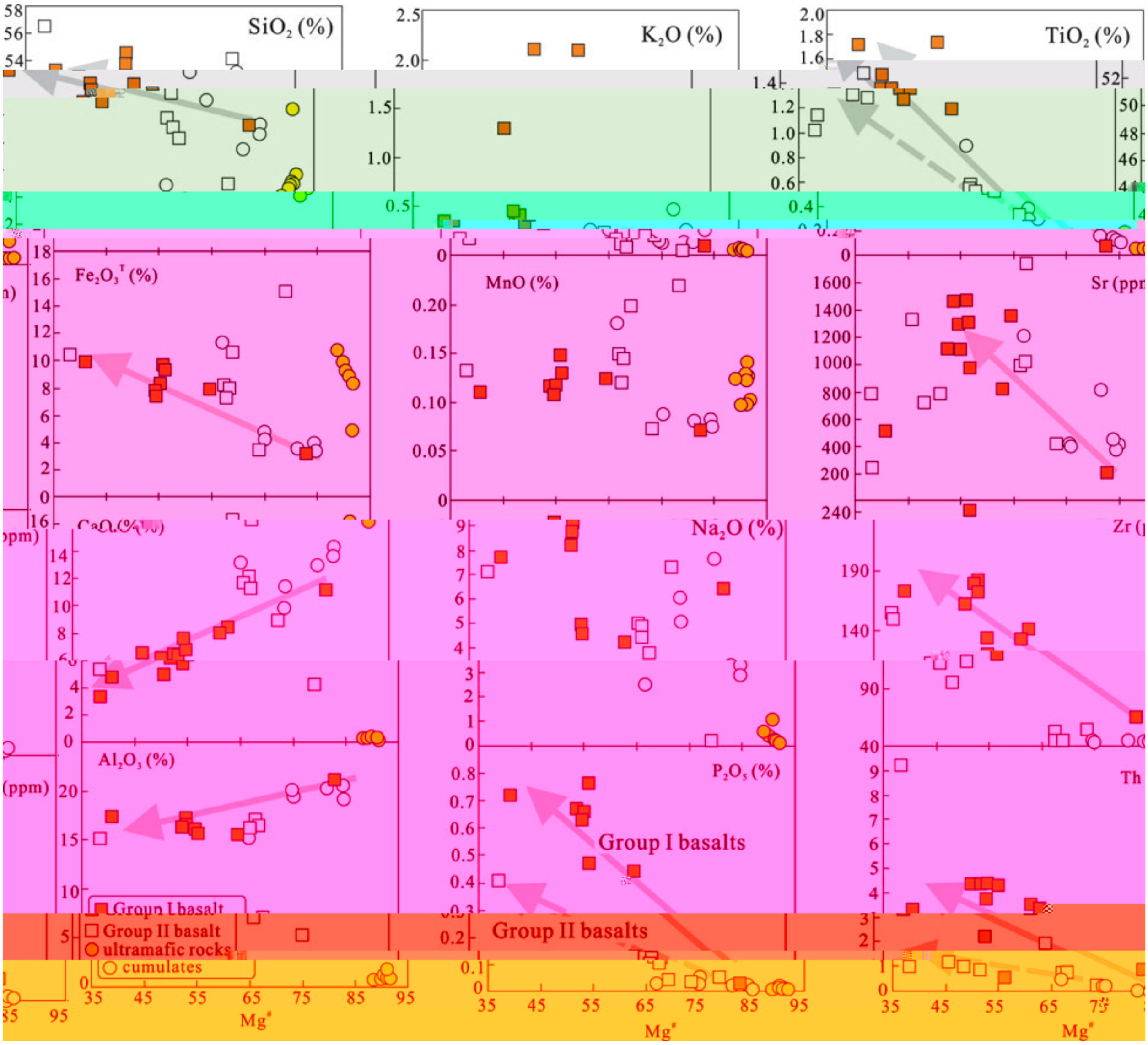
4.c.1. Serpentinites and cumulates

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



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

1 (1). (. 6). (3 103) (5) (1). (> 12 %) 2 , 2 ( ) ( ) ( ). 2 3 2 3 2, ( ) (1). (.), , 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).



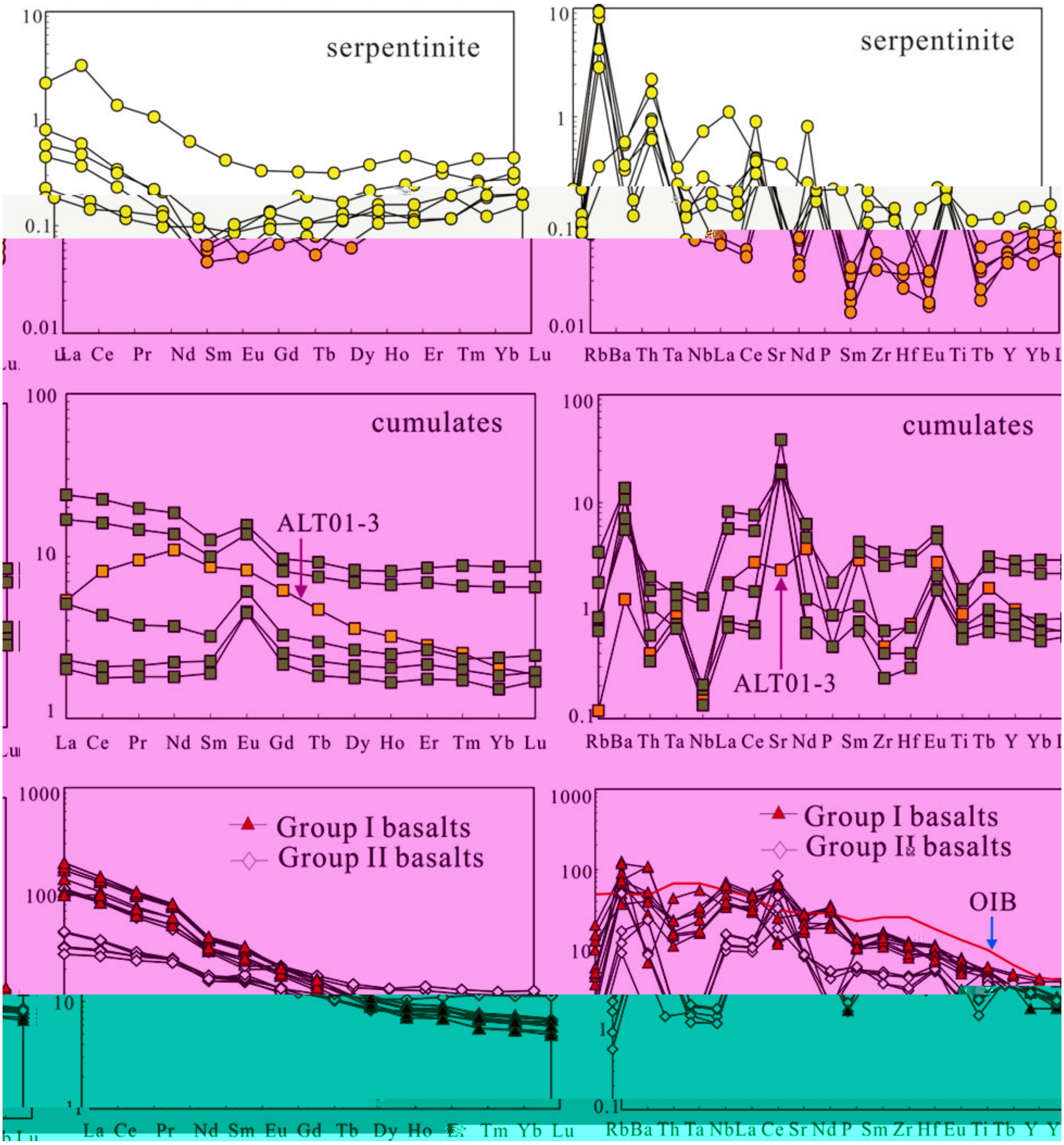
6. ( ) ( ) *et al.* 200).

6). 5 41 ( ) = 1.3 2.) (/ = 1.1 2.2). 2013 01-3 ( ), = 0.2 0.4)

4.c.2. Basalts

43.15 % 5 .65 % (52 %,

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

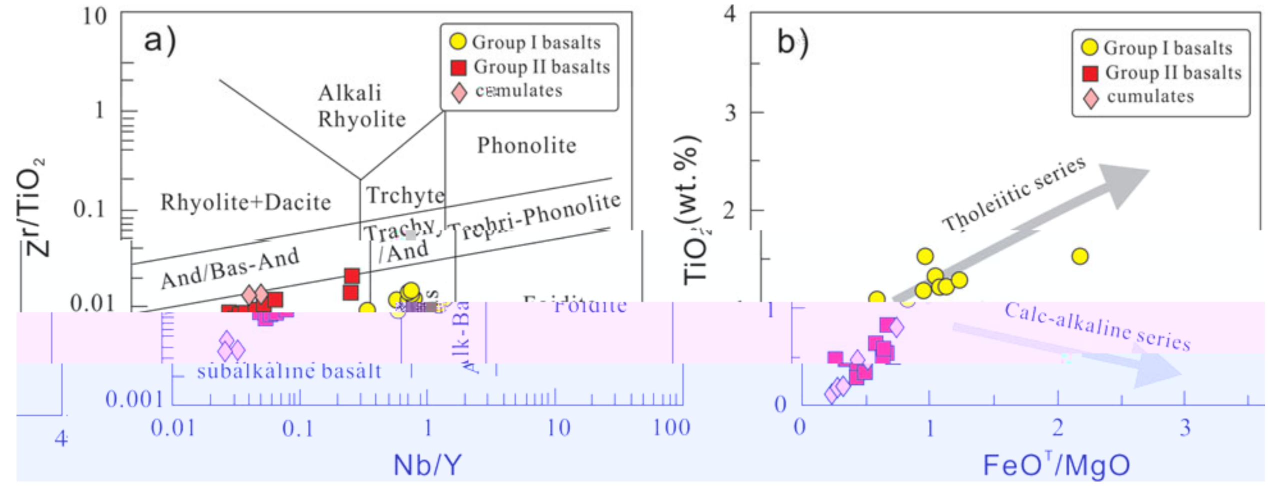


[illegible] (1).

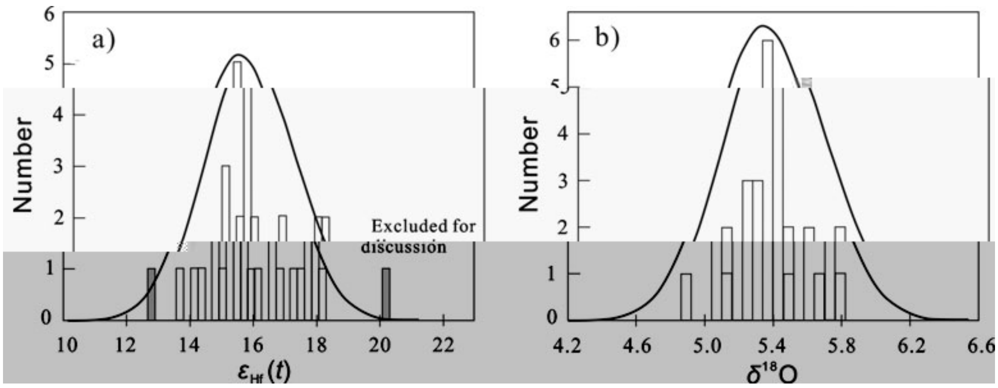
[illegible] (/ = 0. 0 1.14) [illegible] 2 [illegible] 4 6 [illegible] (/ = 1.02 1.21) [illegible] 1 [illegible] 0.44 0. [illegible] 2 [illegible] 1 [illegible] (~0.11) [illegible].

4. . W - c S N a c H [illegible]

[illegible] 2 1 [illegible] 2 [illegible] (0.0024 0.0452) [illegible] (0. 04030 0. 0536), [illegible] (0. 04015 0. 05111, 2013 03 1). [illegible] 14 /144 0.0 0.13 4 143 /144 0.512 0 0.512 3 [illegible] ε (t) +6.3 + .5 (2013 03 1 [illegible] +1.).



[illegible]



[illegible]

[illegible] (2013 [illegible] 01) [illegible] ε [illegible] 13 [illegible] 20. [illegible] ε(t) (> 16) [illegible] ε(t), [illegible] 15. [illegible] 4. 1 ‰ [illegible] 5. 3 ‰, [illegible] 5.3 ± 0.23 ‰ [illegible]

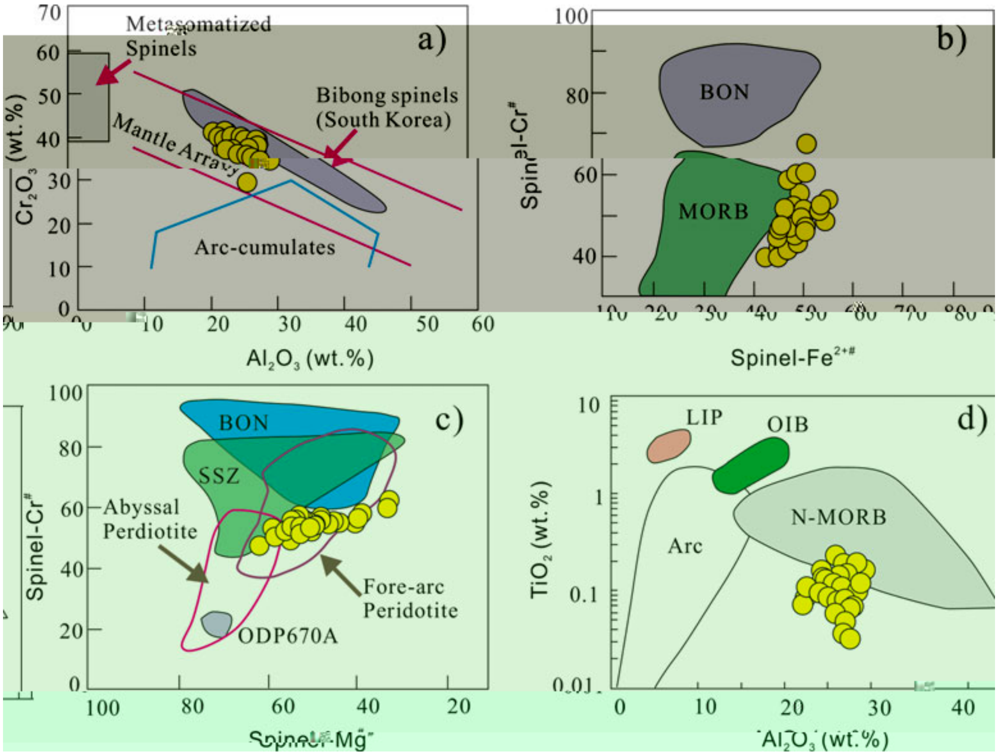
[illegible] ~400 [illegible] ε(t) [illegible] 20 [illegible] *et al.* 200 [illegible]).

5. D c [illegible]

5.a. T [illegible] **Z a ba** [illegible]

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

[illegible]

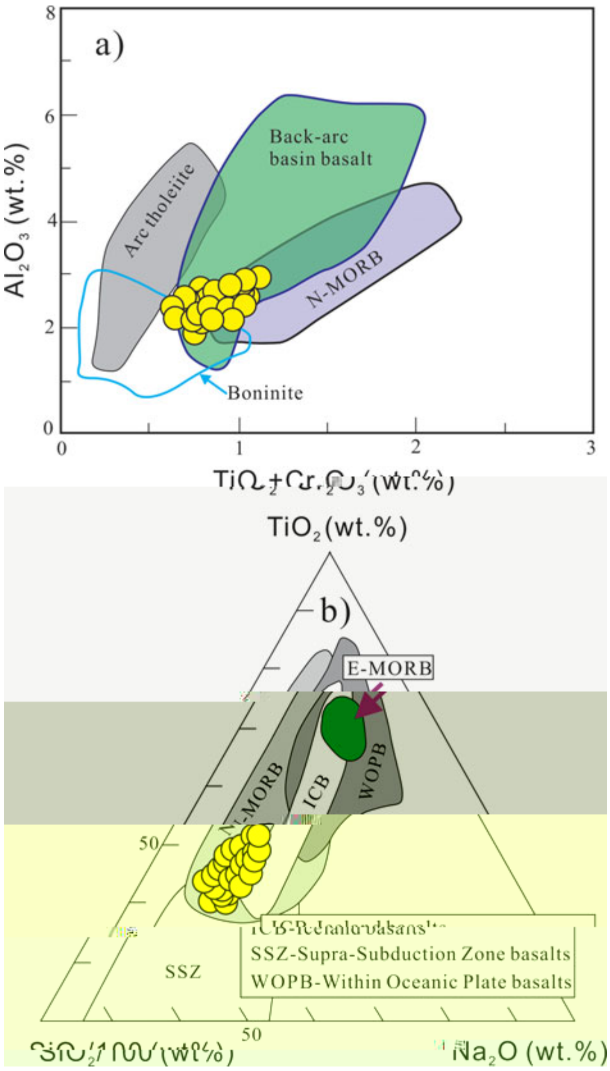


10. ( ) (%) & , 2000). ( ) (100 /(+)) (100 2+/(2+ +)) 1 4 & , 2001). ( ) (100 /(+)) (100 /(+)) et al. 1 5). ( ) & , 2001).

(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. ( ) ( ) 2/100

(. 11). 2/100

(. 11).

(. 12),

(. 12).

et al. (2002)

5.c. P D a ba a

(0.4 0.6 %) (11 24 15, 60)

2001) (. 13).

(1) 2002) (2)

et al. 6).

200 *et al.* 2011).

(0. 04120 0. 06133) (3.44 20.4) (1.51 2.54)

et al. 6). 2000).

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

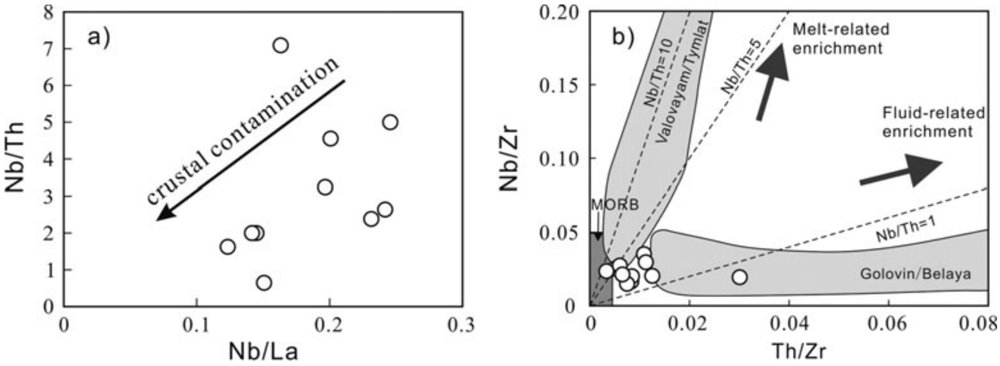


Fig. 12. [illegible]

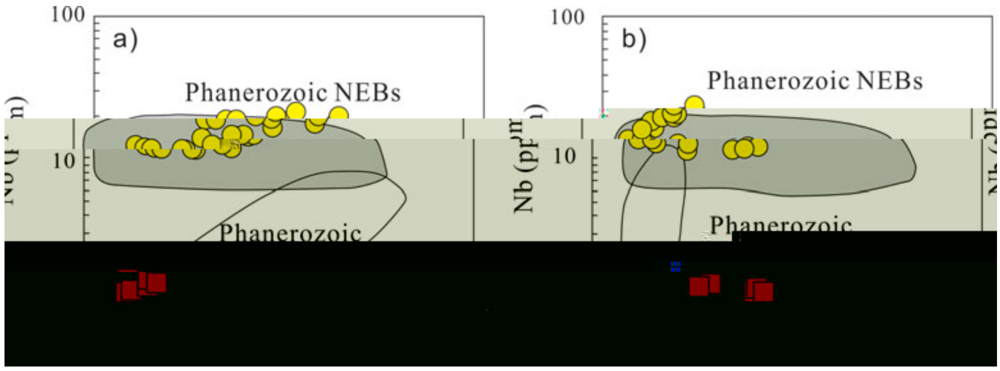


Fig. 13. [illegible]

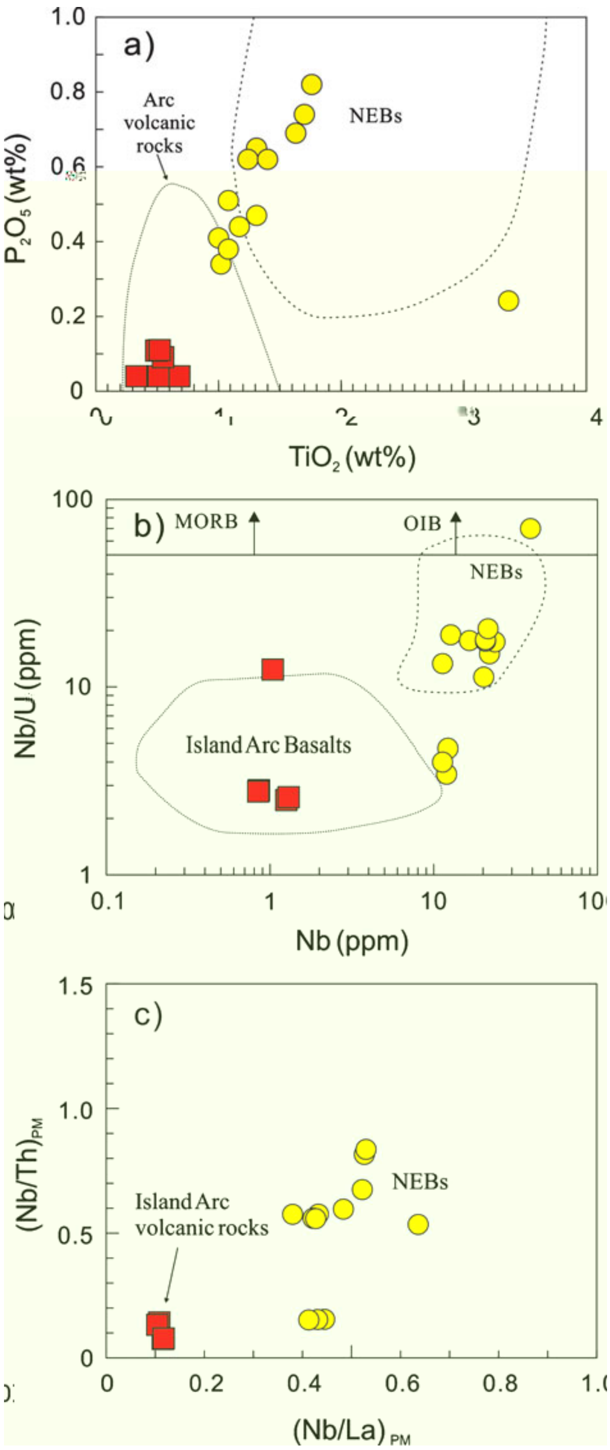
[illegible] ε(t) (1. [illegible] .5) [illegible] (0. 04120 0. 06133) [illegible] 2). [illegible] ε(t) [illegible] (< 0.3), [illegible] 2002). [illegible] (0. 1.0), [illegible] (0.1 0.2) [illegible] (0.6 1.0) [illegible] 6). [illegible] 14). [illegible]

[illegible] 14). [illegible]

5. [illegible]

[illegible] (416 [illegible] *et al.* 2014 [illegible] *et al.* 2015), [illegible] (503 [illegible] *et al.* 2003 [illegible] *et al.* 2015 [illegible] (400 [illegible] *et al.* 2014), [illegible]

[illegible] *et al.* 200 [illegible], 200 a,b [illegible] *et al.* 200 a). [illegible] *et al.* 200 b). [illegible]



14. ( ) ( ) ( ) ( ) ( ) ( ) & (1 2) *et al.* (1 5);

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). (5.), 2

1 , 15). *et al.* (200 , 200 *b*)

(*et al.* 200).

& 1 1 & , 200 *et al.* 2013).

15).

(1) (*c.* 500),

15)

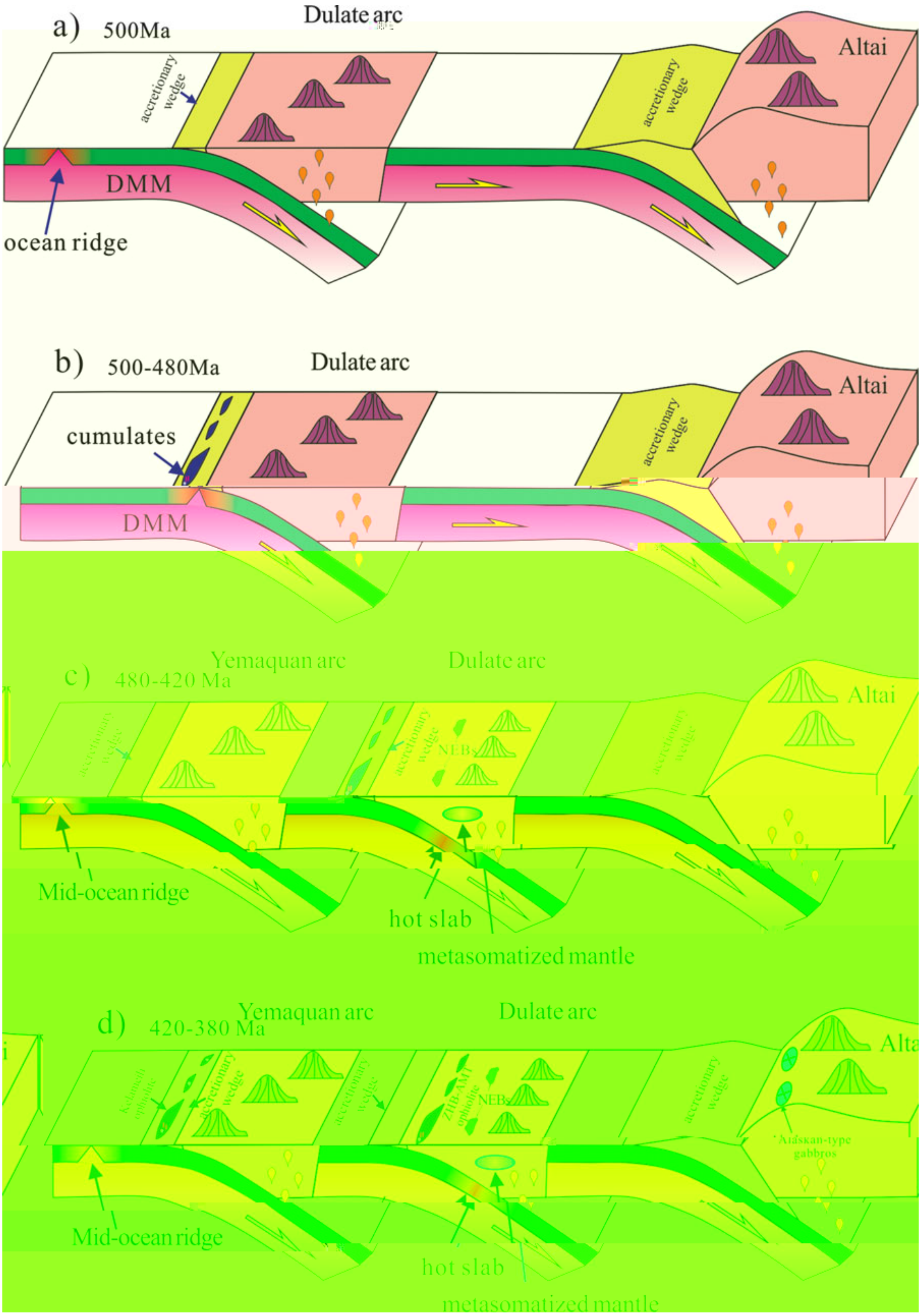
(2) (500 4 0),

15).

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

(440 *et al.* 2014)

15)


a) 500Ma
Dulate arc
accretionary wedge
accretionary wedge
Altai
DMM
ocean ridge
b) 500-480Ma
Dulate arc
cumulates
accretionary wedge
Altai
DMM
c) 480-420 Ma
Yemaquan arc
Dulate arc
accretionary wedge
accretionary wedge
NEBs
accretionary wedge
Altai
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.

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

6. C[illegible]c[illegible]

(1) [illegible] ~4 5 [illegible] *c.* 400 [illegible]

(2) [illegible]

(3) [illegible]

Ac[illegible] [illegible] 305 [illegible] (2011 [illegible] 06 03-01).

S[illegible] a[illegible] a[illegible] a

[illegible] /10.101 [illegible] 0016 56 16000042.

R[illegible]c

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