

UPORABA SLEDNIH PRVIN

ZA INTERPRETACIJO
MAGMATSKIH KAMNIN

- Posebne skupine prvin.
 - Prvine redkih zemelj - REE
 - Spider diagrami – normalizirani multielementni diagrami nezdružljivih prvin
 - Prvine skupine platine – PGE
 - Prehodne prvine
- Bivariatni grafi.
- Grafi obogatitve/izgube
- Modeliranje magmatskih procesov
- Določanje tektonskega okolja.

REE

- Kemizem REE ali lantanidov - www.ptable.com/
- Izolirane iz redkih, neobičajnih mineralov.

Rare Earth Elements

La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------

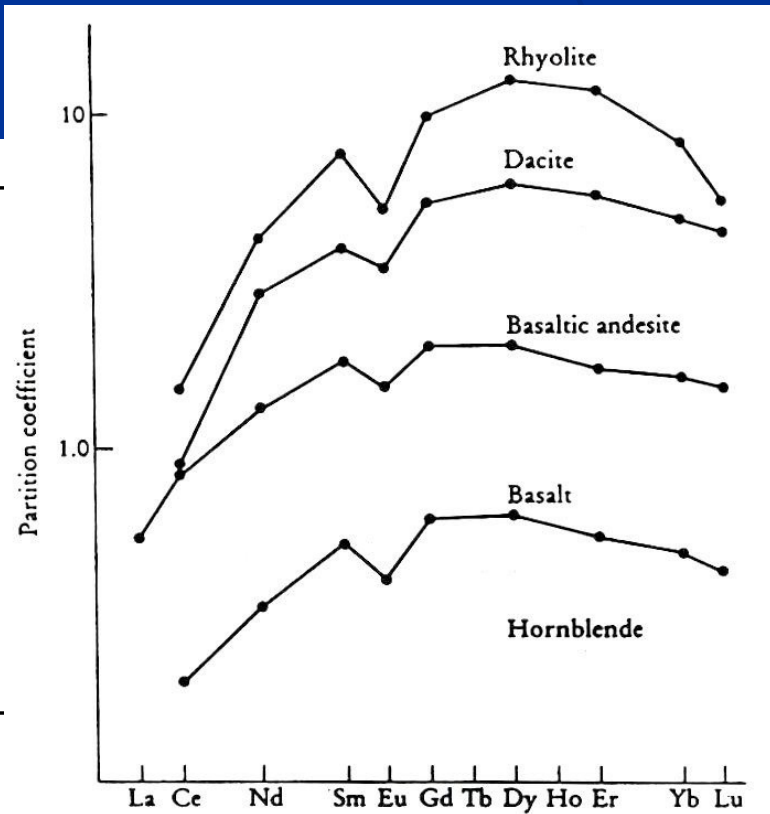
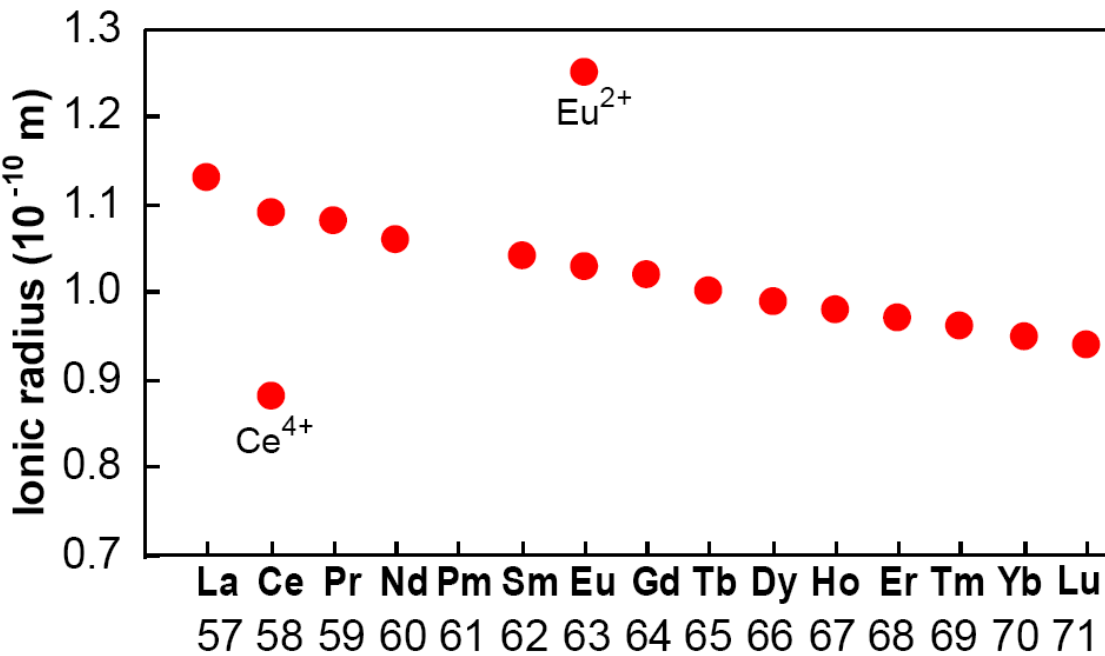
Lanthanides

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	An	Lr														

Z	Symbol	Name	Etymology	Selected Usages
70	Yb	Ytterbium	for the village of Ytterby, Sweden.	Infrared Laser, chemical reducing agent, High-temperature superconductors (YBCO)
69	Tm	Thulium	for the mythological land of Thule.	Portable X-ray machine
65	Tb	Terbium	for the village of Ytterby, Sweden, where the first rare earth ore was discovered.	Green phosphors, laser, fluorescent lamp
62	Sm	Samarium	for Vasili Samarsky-Bykhovets, who discovered the rare earth ore samarskite.	Rare-earth magnets, Laser, neutron capture, maser
59	Pr	Praseodymium	from the Greek "praso," meaning <i>leek-green</i> , and "didymos," meaning <i>twin</i> .	Rare-earth magnets, laser, green colors in glass and ceramics, flint
61	Pm	Promethium	for the Titan Prometheus, who brought fire to mortals.	Nuclear battery
60	Nd	Neodymium	from the Greek "neo," meaning <i>new-one</i> , and "didymos," meaning <i>twin</i> .	Rare-earth magnets, laser, violet colors in glass and ceramics, ceramic capacitor
71	Lu	Lutetium	for Lutetia, the city which later became Paris.	
57	La	Lanthanum	from the Greek "lanthanon," meaning <i>I am hidden</i> .	High refractive index glass, flint, hydrogen storage, battery-electrode, camera lens
67	Ho	Holmium	for Stockholm (in Latin, "Holmia"), native city of one of its discoverers.	Laser
64	Gd	Gadolinium	for Johan Gadolin (1760–1852), to honor his investigation of rare earths.	Rare-earth magnets, high refractive index glass or garnets, laser, x-ray tube, computer memory, neutron capture
63	Eu	Europium	for the continent of Europe.	Red and blue phosphors, laser, mercury-vapor lamp
68	Er	Erbium	for the village of Ytterby, Sweden.	Laser, vanadium steel
66	Dy	Dysprosium	from the Greek "dysprositos," meaning <i>hard to get</i> .	Rare-earth magnets, laser,
58	Ce	Cerium	for the Roman deity of fertility Ceres.	chemical oxidising agent, polishing powder, yellow colors in glass and ceramics, catalyst for Self-cleaning oven etc.

- Zelo podobne kemijske in fizikalne lastnosti.
 - Lahke redke zemlje LREE so La – Sm.
 - Težke redke zemlje HREE so Gd – Yb oz Eu - Lu.
 - Srednje redke zemlje MREE.
- Stabilni 3+ ioni. Izjemi sta europij, ki je lahko tudi 2+ in cerij, ki je 4+.
- Postopno manjšanje radija – lantanidsko krčenje.
- V magmatskih sistemih se Eu^{2+} zaradi večjega radija, ki mu omogoča nadomeščanje s Ca^{2+} v plagioklazih, obnaša anomalno.
- Podobno velja za Ce^{4+} v sedimentih.

- Majhne razlike v velikosti in obnašanju so vzrok, da se v petroloških procesih med seboj frakcionirajo
- Inkompatibilne v bazičnih talinah, z napredujočo diferenciacijo pa postajajo kompatibilne.

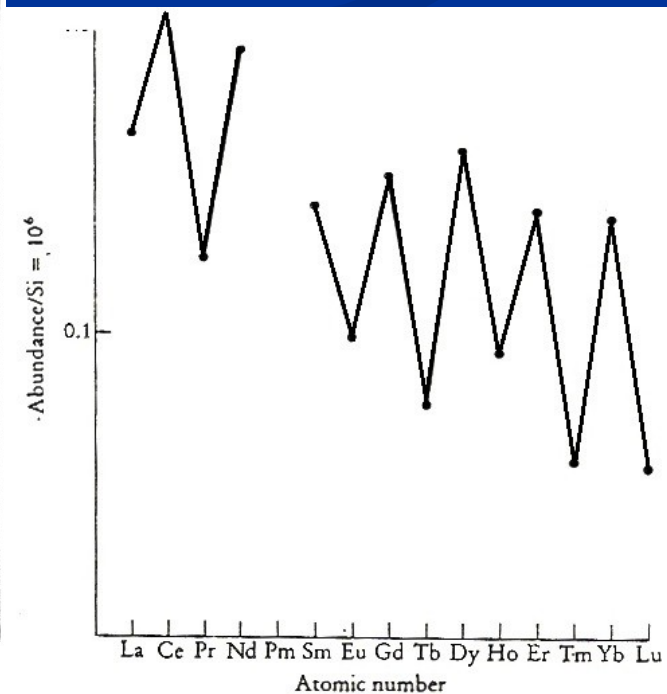
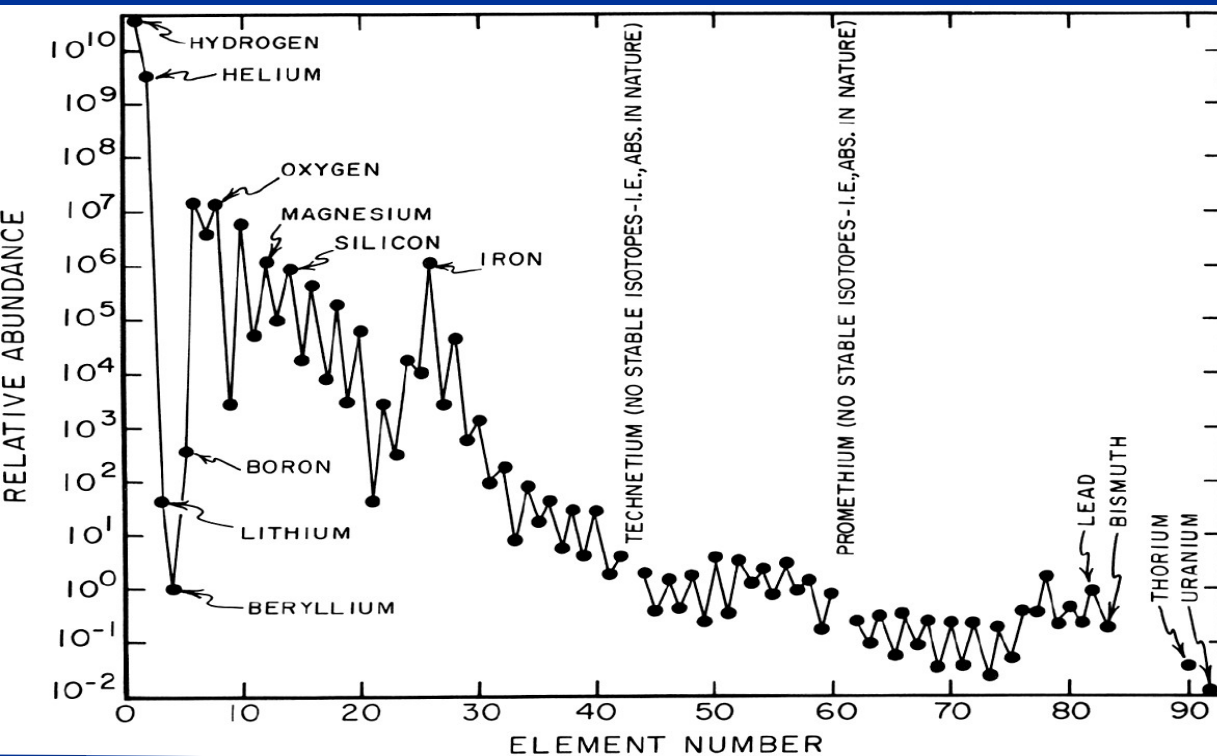


Predstavljanje REE

- REE normaliziramo, zato da

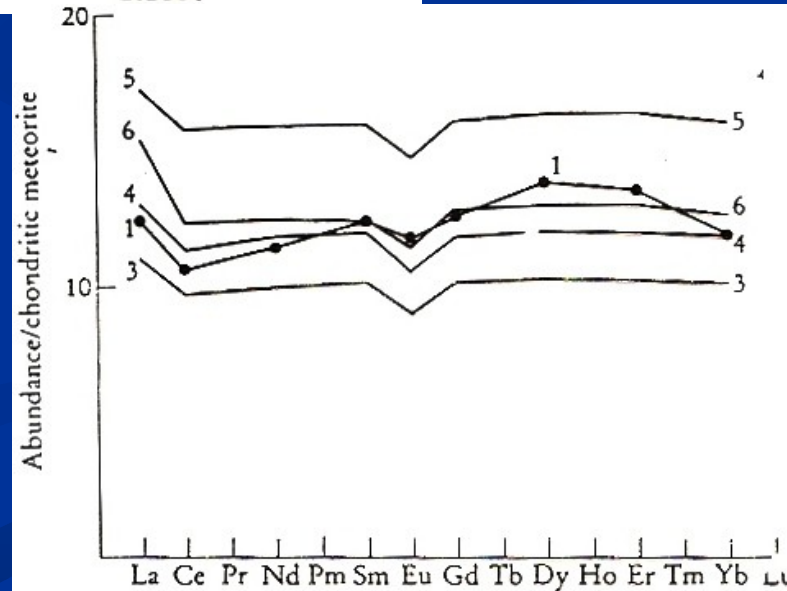
- Odpravimo učinek Oddo Harkinsovega pravila (prvine s sodim atomskim številom so obilnejše, ker so stabilnejše).

- Lažje vidimo, koliko se je proučevana snov diferencirala



- Za normalizacijo uporabimo:
 - Hondrit
 - Ena analiza hondrita
 - Povprečje več analiz enega hondrita.
 - Kompozit več hondritov.
 - Prvotni plašč (hipotetični plašč iz katerega se še ni diferencirala skorja).
 - Najmanj diferencirano kamnino raziskovanega kompleksa.
 - Za sedimente uporabimo severno ameriški kompozit glinavca (NASC).
- Normalizirane vrednosti označujemo z N ob imenu prvine (Eu_N).
- Vedno prikazujemo celoten niz REE in navedemo,

Analytical method	Wakita	Haskin	Masuda	Nakamura	Evensen	Boynton	T & M	Primitive mantle value
Chondrite(s) analysed: (Ref.)	Composite (1)	Composite (2)	Leedeey (3)	Composite (4)	Avg.CI (5)	Avg.CI (6)	Avg. CI (7)	(8)
La	0.340	0.330	0.3780	0.3290	0.244 60	0.3100	0.3670	0.7080
Ce	0.910	0.880	0.9760	0.8650	0.637 90	0.8080	0.9570	1.8330
Pr	0.121	0.112			0.096 37	0.1220	0.1370	0.2780
Nd	0.640	0.600	0.7160	0.6300	0.473 80	0.6000	0.7110	1.3660
Sm	0.195	0.181	0.2300	0.2030	0.154 00	0.1950	0.2210	0.4440
Eu	0.073	0.069	0.0866	0.0770	0.058 02	0.0735	0.0870	0.1680
Gd	0.260	0.249	0.3110	0.2760	0.204 30	0.2590	0.3060	0.5950
Tb	0.047	0.047			0.037 45	0.0474	0.0580	0.1080
Dy	0.300		0.3900	0.3430	0.254 10	0.3220	0.3810	0.7370
Ho	0.078	0.070			0.056 70	0.0718	0.0851	0.1630
Er	0.020	0.200	0.2550	0.2250	0.166 00	0.2100	0.2490	0.4790
Tm	0.032	0.030			0.025 61	0.0324	0.0356	0.0740
Yb	0.220	0.200	0.2490	0.2200	0.016 51	0.2090	0.2480	0.3480
Lu	0.034	0.034	0.0387	0.0339	0.025 39	0.0322	0.0381	0.0737
Y							2.1000	



Interpretacija REE

- Ugotavljamo prisotnost in velikost Eu anomalije.

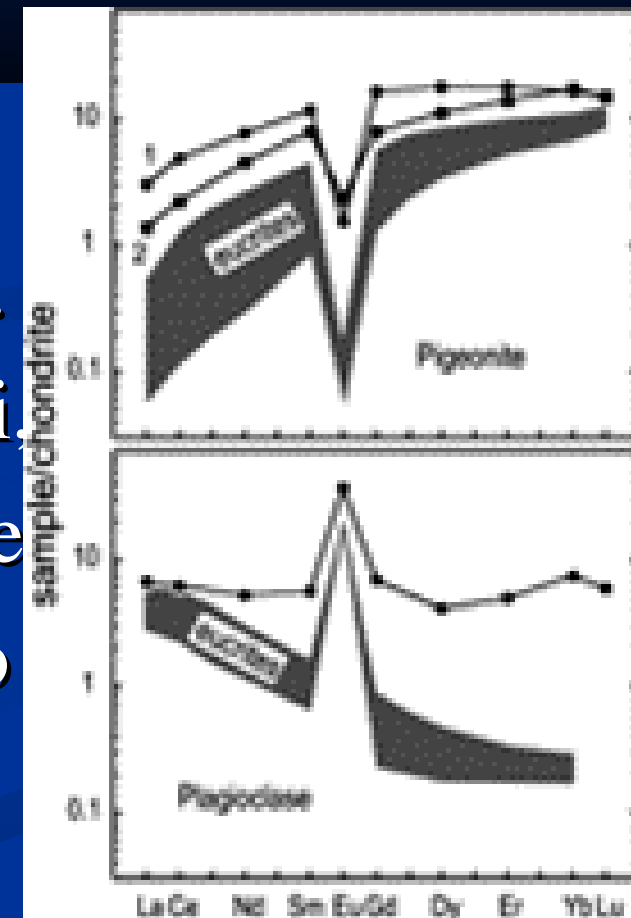
- $Eu/Eu^* = Eu_N / \sqrt{(Sm_N - Gd_N)}$

- $Eu/Eu^* > 1$ pozitivna

- $Eu/Eu^* < 1$ negativna

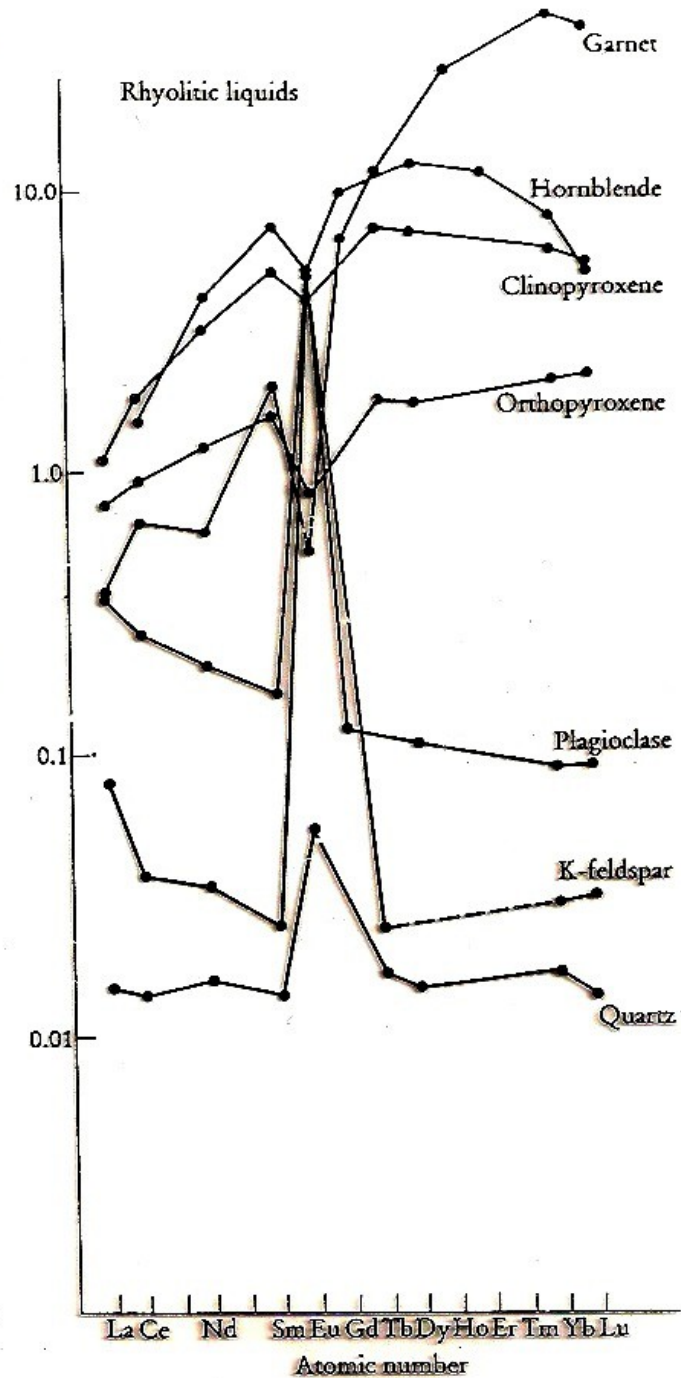
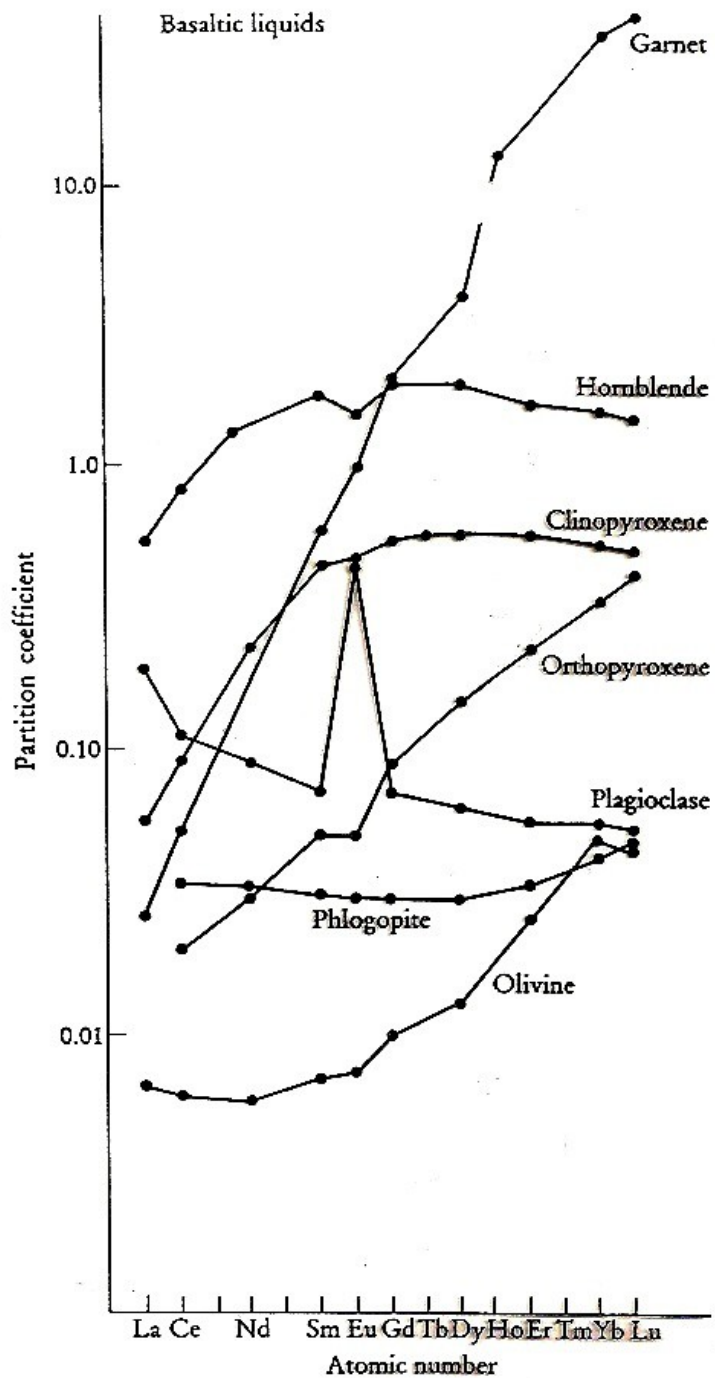
- Kar pove, kateri minerali so bili udeleženi pri kristalizaciji/taljenju.

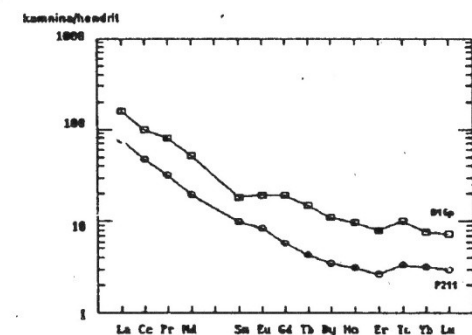
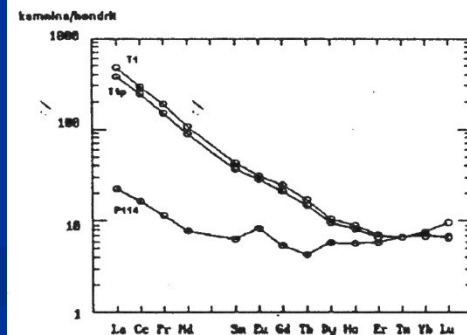
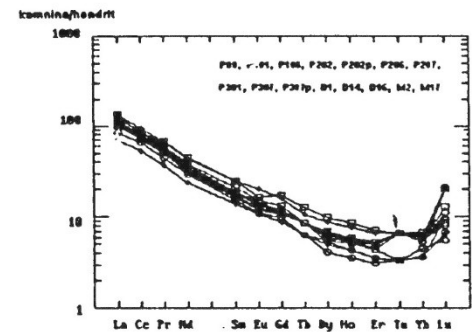
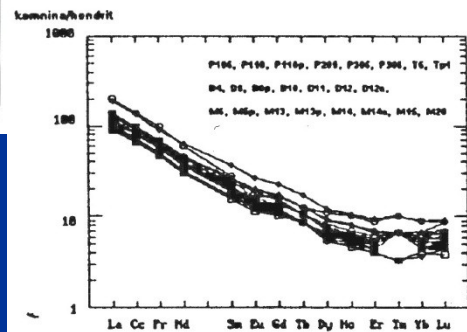
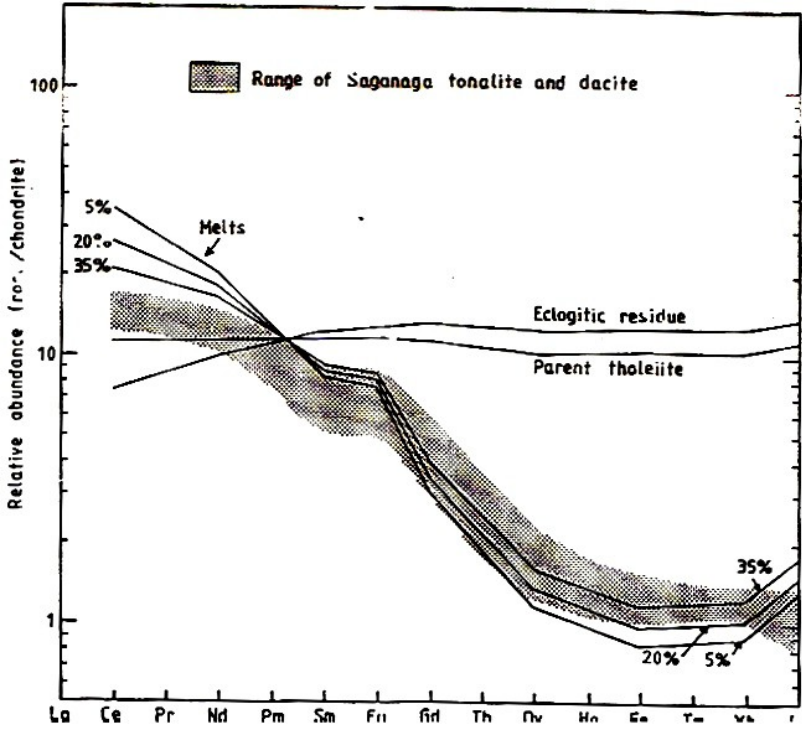
- Odsotnost anomalije lahko pomeni, da je kristaliziralo takšno razmerje mineralov s pozitivno in negativno anomalijo, da se je učinek izničil.



- Na osi y razberemokoliko je diferenciacije glede na material s katerim smo REE normalizirali.
- Glede na vzorec REE ugotavljamo, kolikšna je stopnja frakcionacije med njimi.
 - $(\text{La/Yb})_N/\text{Ce}_N$ ali $(\text{La/Yb})_N/\text{Yb}_N$
- Ugotavljamo, ali je bila za vse (LREE, HREE, MREE) enaka.
 - $(\text{La/Sm})_N/\text{Sm}_N$ za LREE
 - $(\text{Gd/Yb})_N/\text{Yb}_N$ za HREE

- REE so zelo kompatibilne v nekaterih akcesornih mineralih (cirkon, ortit, monacit...) in že majhna količina teh mineralov močno oblikuje vzorec REE.
- V mineralih bo:
 - Pozitivna Eu anomalija – glinenci.
 - Negativna Eu anomalija – rogovača, sfen, pirokseni, granati.
 - Obogatitev z MREE – rogovača, deloma pirokseni in sfen.
 - Obogatitev z HREE – granat, olivin.
- V preostali talini so REE osiromašene, glede na mineral, ki je iz taline kristaliziral.
- Vzorec REE v kamnini je torej zrcalna slika vzorca





Spider diagrami

■ Normalizirani multielementni diagrami, glede na plašč, nezdružljivih prvin.

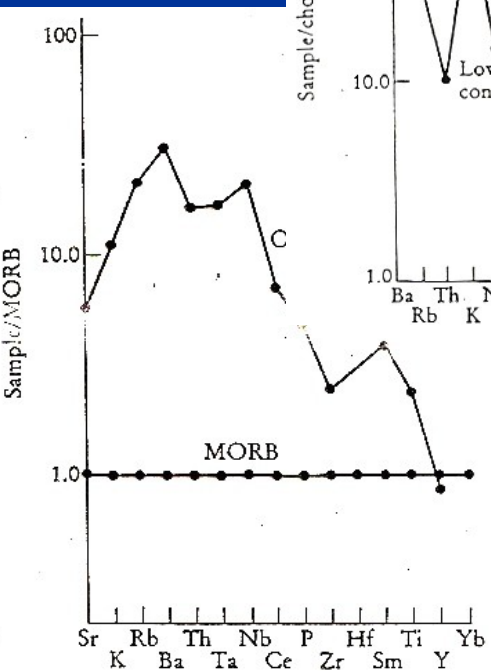
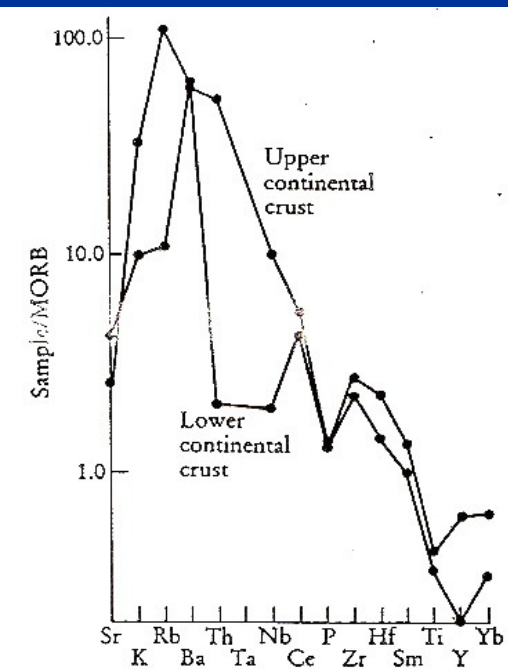
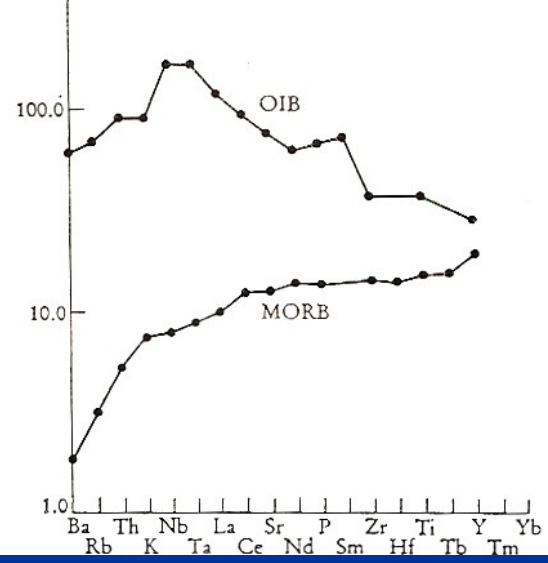
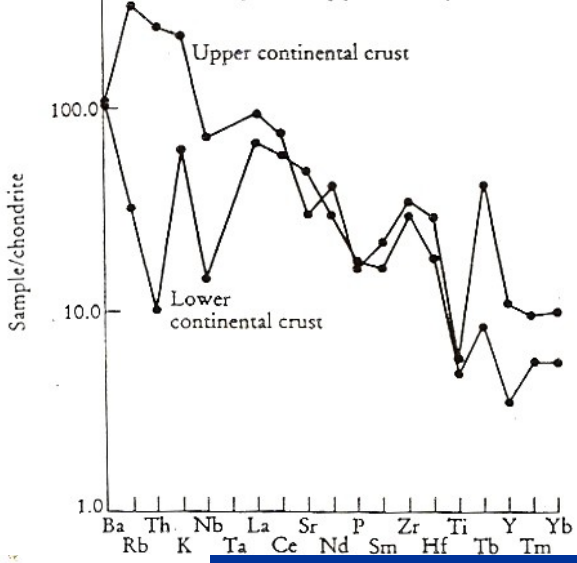
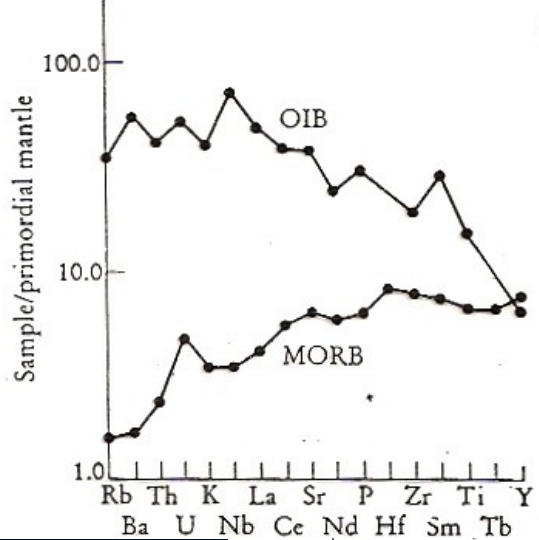
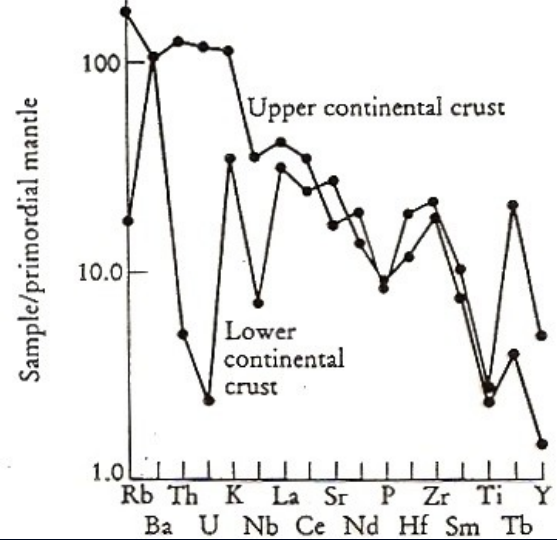
1 H 1.008																	2 He 4.00
3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.0	45 Rh 102.9	46 Pd 106.4	47 Ag 107.8	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.7	52 Te 127.6	53 I 126.9	54 Xe 131.2
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.1	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr 223.0	88 Ra 226.0	89 Ac 227.0	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 Ds (281)	111 Rg (272)	112 Uub (285)	113 Uut (284)	114 Uuq (289)	115 Uup (288)	116 Uuh (292)		

58 Ce 140.1	59 Pr 141.0	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 153.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np (237)	94 Pu (240)	95 Am (243)	96 Cm (247)	97 Bk (248)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (257)	102 No (259)	103 Lr (262)

- Uporabne zlasti za bazalte.

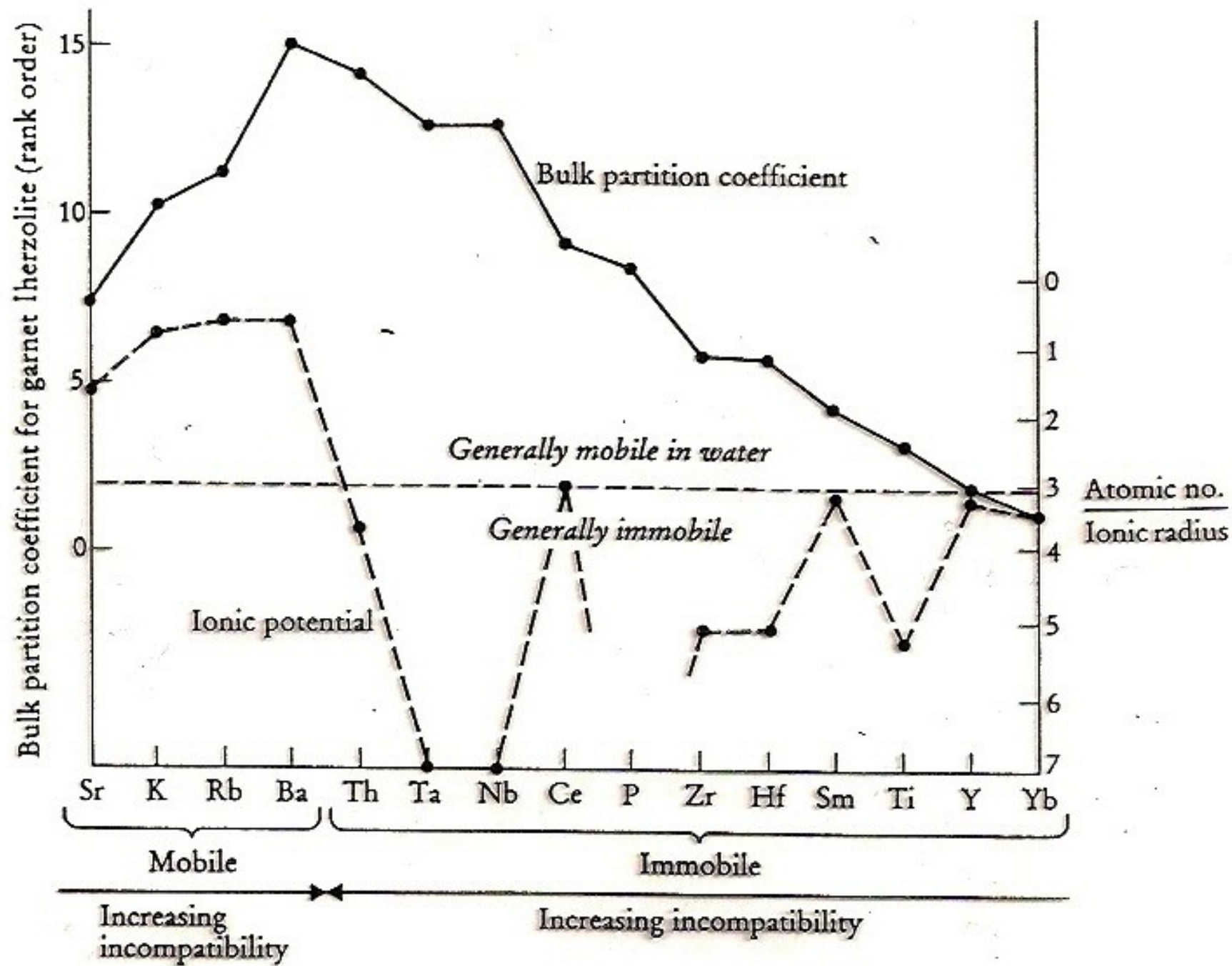
- Normalizacija glede na prvotni plašč, hondrit ali MORB (Mid Ocean Ridge Basalt).

(Ref.)	Primordial mantle					Chondrite					MORB normalization					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)					
Cs	0.019	0.017		0.023	0.018					Cs	0.012	0.188				
Rb	0.860	0.660	0.810	0.635	0.550	Ba	6.900	Rb	1.880	Pb	0.120	2.470	Sr	120	Rb	1.00
Ba	7.560		6.900	6.990	5.100	Rb	0.350	K	850	Rb	0.350	2.320	K ₂ O (%)	0.15	Ba	12.00
Th	0.096		0.094	0.084	0.064	Th	0.042	Th	0.040	Ba	3.800	2.410	Rb	2.00	K ₂ O (%)	0.15
U	0.027		0.026	0.021	0.018	K	120	Ta	0.022	Th	0.050	0.029	Ba	20.00	Th	0.20
K	252.0	230.0	260.0	240.0	180	Nb	0.350	Nb	0.560	U	0.013	0.008	Th	0.20	Ta	0.17
Ta	0.043		0.040	0.041	0.040	Ta	0.020	Ba	3.600	Ta	0.020	0.014	Ta	0.18	Sr	136
Nb	0.620		0.900	0.713	0.560	La	0.329	La	0.328	Nb	0.350	0.746	Nb	3.50	La	3.00
La	0.710		0.630	0.708	0.551	Ce	0.865	Ce	0.865	K	120	545	Ce	10.00	Ce	10.00
Ce	1.900			1.833	1.436	Sr	11.800	Sr	10.500	La	0.315	0.237	P ₂ O ₅ (%)	0.12	Nb	2.50
Sr	23.000		28.000	21.100	17.800	Nd	0.630	Hf	0.190	Ce	0.813	0.612	Zr	90.00	Nd	8.00
Nd	1.290			1.366	1.067	P	46.000	Zr	9.000	Sr	11.000	7.260	Hf	2.40	P ₂ O ₅ (%)	0.12
P	90.400	92.000				Sm	0.203	P	500	Nd	0.597	0.467	Sm	3.30	Hf	2.50
Hf	0.350		0.350	0.309	0.270	Zr	6.840	Ti	610	P	46.000	1220	TiO ₂ (%)	1.50	Zr	88.00
Zr	11.000		11.000	11.200	8.300	Hf	0.200	Sm	0.203	Sm	0.192	0.153	Y	30.00	Eu	1.20
Sm	0.385		0.380	0.444	0.347	Ti	620	Y	2.000	Zr	5.600	3.870	Yb	3.40	TiO ₂ (%)	1.50
Ti	1200	1300	1300	1280	960	Tb	0.052	Lu	0.034	Ti	620	445	Sc	40.00	Tb	0.71
Tb	0.099			0.108	0.087	Y	2.000	Sc	5.210	Y	2.000	1.570	Cr	250.0	Y	35.00
Y	4.870		4.600	4.550	3.400	Tm	0.034	V	49.000						Yb	3.50
Pb				0.071		Yb	0.220	Mn	1720						Ni	138
								Fe	265000						Cr	290
								Cr	2300							
								Co	470							
								Ni	9500							



- Interpretacija:
 - Ugotavljanje vpliva kristalizacije določenih mineralov
 - Zr – cirkon
 - P – apatit
 - Sr – plagioklaz
 - Ti, Nb, Ta - ilmenit
 - Ugotavljanje udeležnosti skorje - Nb, LILE

- Problemi:
 - Izbira normalizacije
 - Izbira prvin
 - Izbira zaporedja nanašanja prvin na diagram
 - Različna mobilnost (LILE bolj kot HFSE) prvin.
 - Različna inkompatibilnost prvin.



Prvine skupine platine - PGE

H																			He
Li	Be											B	C	N	O	F	Ne		
Na	Mg											Al	Si	P	S	Cl	Ar		
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe		
Cs	Ba	La *	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn		
Fr	Ra	Ac **	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn								

* Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu

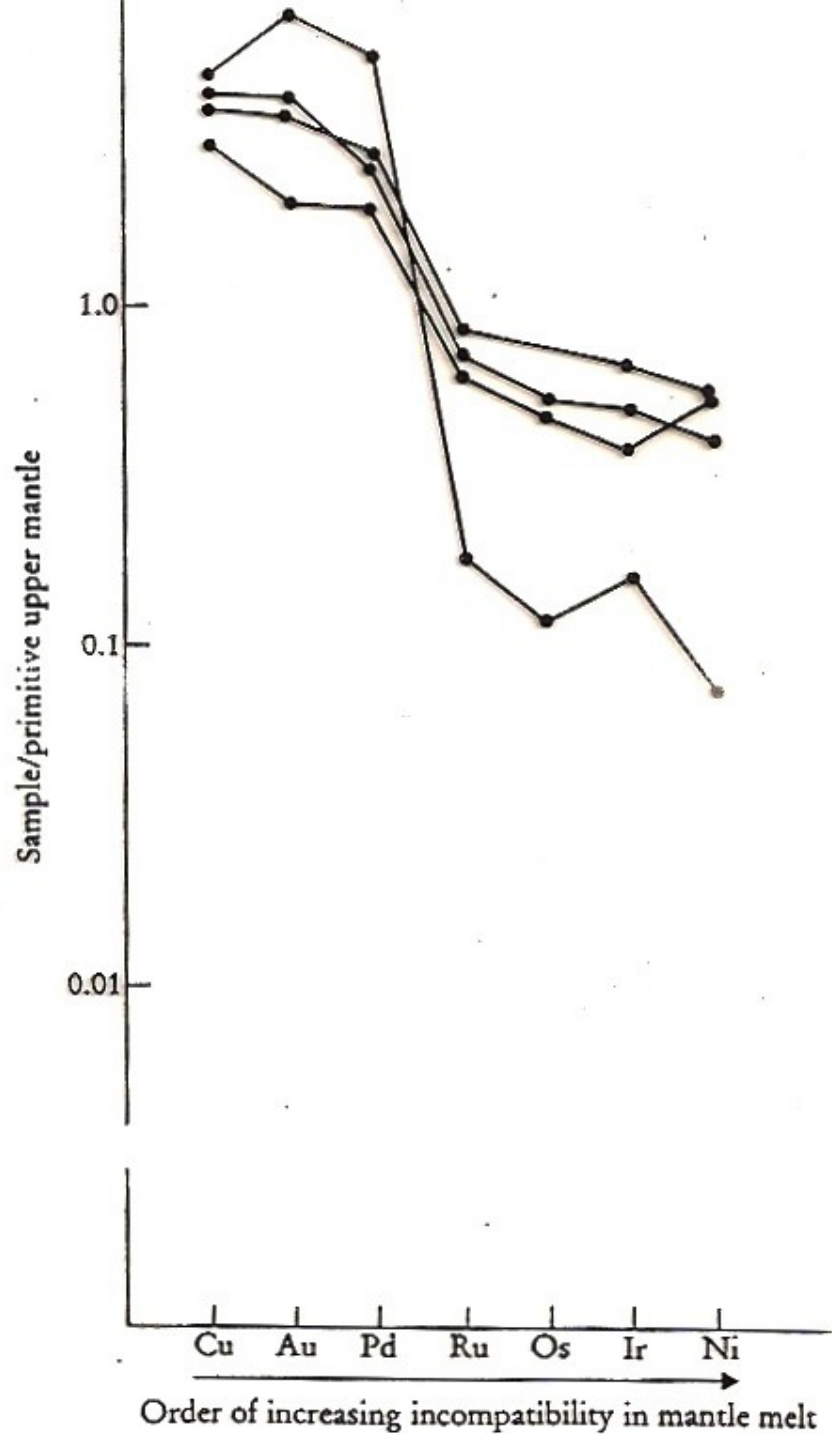
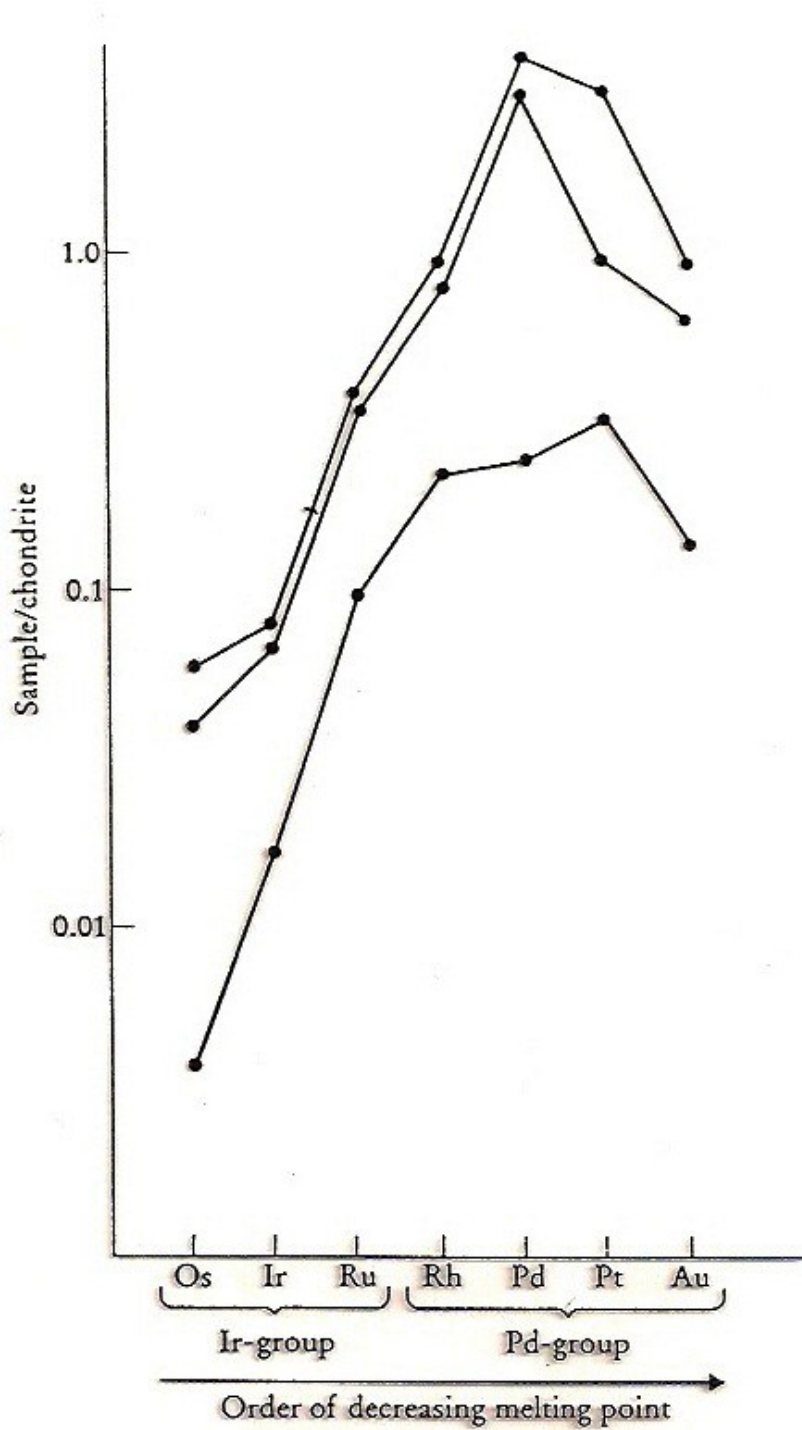
** Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr

Platinum group metals

- Dve podskupini:
 - Iridijeva (IPGE) - Os, Ir, Ru
 - Paladijeva (PPGE) - Rh, Pt, Pd, Au
- PGE so močno frakcionirane v sulfidni fazi in so merilo nasičenosti taline z žveplom.
- So tudi kazalec delnega taljenja v plašču, čeprav porazdelitveni koeficienti še niso natančno določeni.
- Vsebnosti so nizke – ppb.
- Običajno so koncentrirane v bazičnih in ultrabazičnih kamninah ter z njimi povezanimi kromiti in sulfidi.
 - IPGE – kromiti in sulfidi v dunitih
 - PPGE – sulfidi Fe, Ni in Cu v noritih, gabbrih in dunitih.
- Analiziramo jih z NAA.

Element	Symbol	Atomic no.	Charge	Ionic radius† (Å)	Melting point (°C)
Ruthenium	Ru	44	2+	0.74	2310
			3+	0.68	
			4+	0.62	
Rhodium	Rh	45	2+	0.72	1966
			3+	0.66	
			4+	0.60	
Palladium	Pd	46	2+	0.86	1552
			3+	0.76	
			4+	0.615	
Osmium	Os	76	2+	0.74	3045
			4+	0.63	
Iridium	Ir	77	2+	0.74	2410
			3+	0.68	
Platinum	Pt	78	2+	0.80	1722
			4+	0.625	

- PGE predstavimo z normaliziranimi multielementnimi diagrami.
 - Hondrit
 - Prvotni plašč
- Na x os jih razvrščamo glede na:
 - Tališče
 - Nezdržljivost v talini plašča
- Interpretacija PGE
 - Mera za zasičenje taline z žveplom



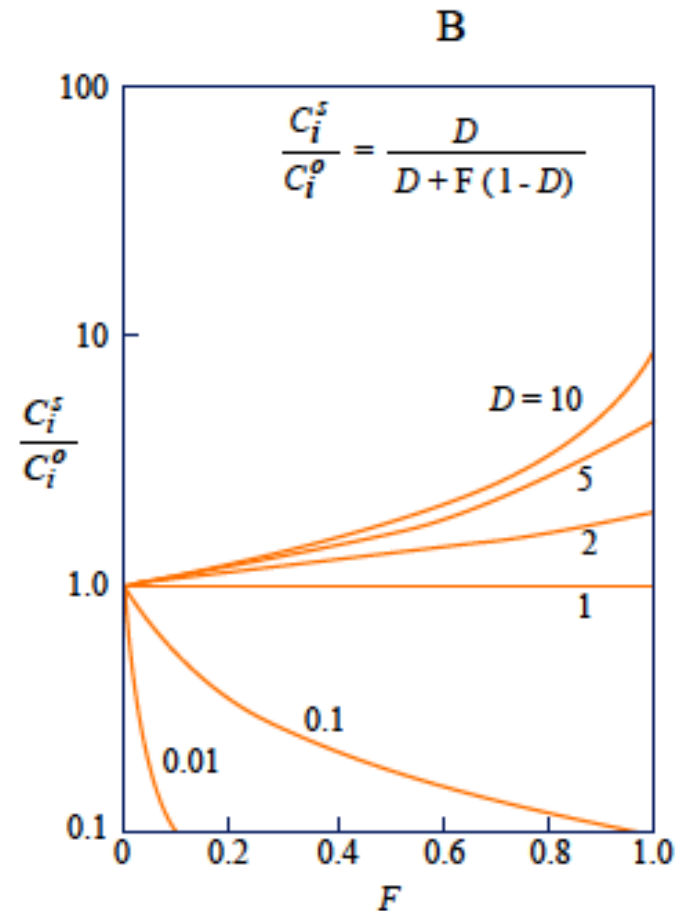
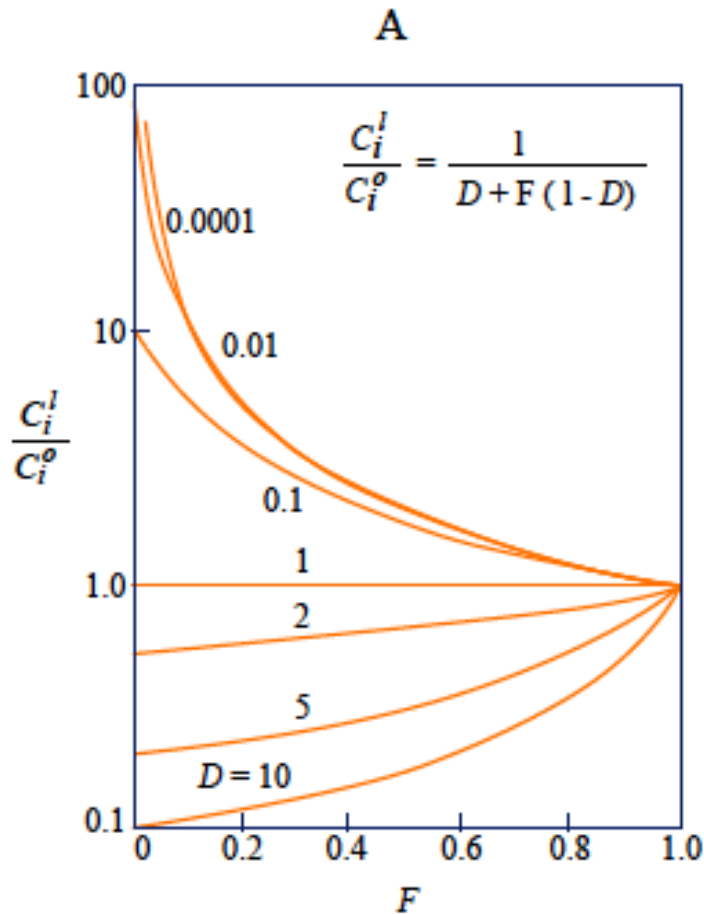
- Posebne skupine prvin.
- Bivariatni grafi.
- Grafi obogatitve/izgube
- Modeliranje magmatskih procesov
- Določanje tektonskega okolja.

Bivariatni grafi slednih prvin

- Prednost pred multielementnimi grafi je, da lahko predstavimo veliko število vzorcev.
- Učinkovitejši so tudi pri ugotavljanju geokemičnih trendov.
- Katere prvine so uporabne za odkrivanje posameznih procesov, je odvisno predvsem od njihovih porazdelitvenih koeficientov – združljivosti oz. nezdružljivosti v mineralu.
 - Najbolj uporabne so prvine z najbolj ekstremnim obnašanjem – visoko združljive ali visoke nezdružljive-

Grafi inkompatibilnih prvin

- Izredna občutljivost na delno taljenje, manj na frakcionirano kristalizacijo (najbolj za AFC).

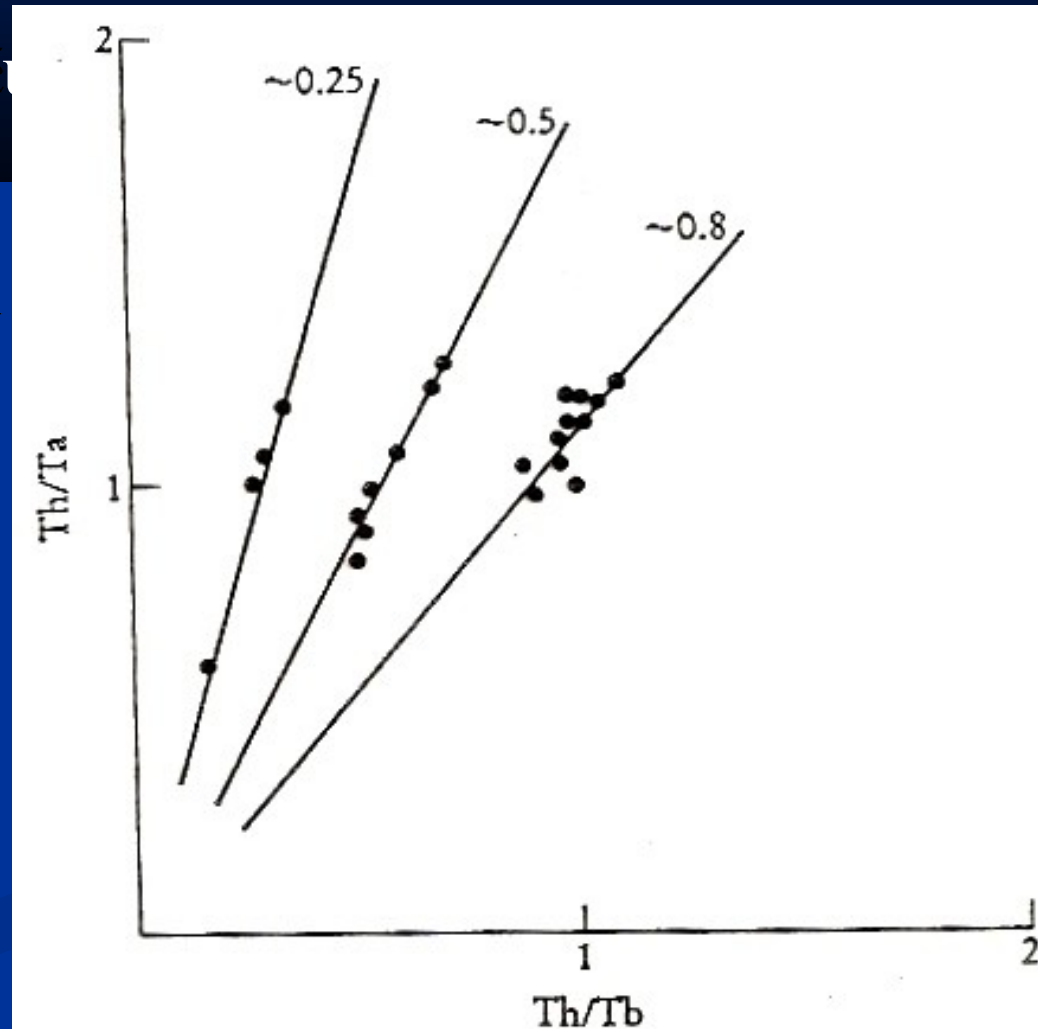


Grafi inkompatibilnih prvin

- Prepoznavanje značilnosti magmatskega izvora iz grafa dveh prvin.
- Prepoznavanje značilnosti magmatskega izvora iz grafa razmerij dveh prvin.
- Izračin porazdelitvenega koeficienta iz grafov recipročne (obratne) koncentracije prvin.

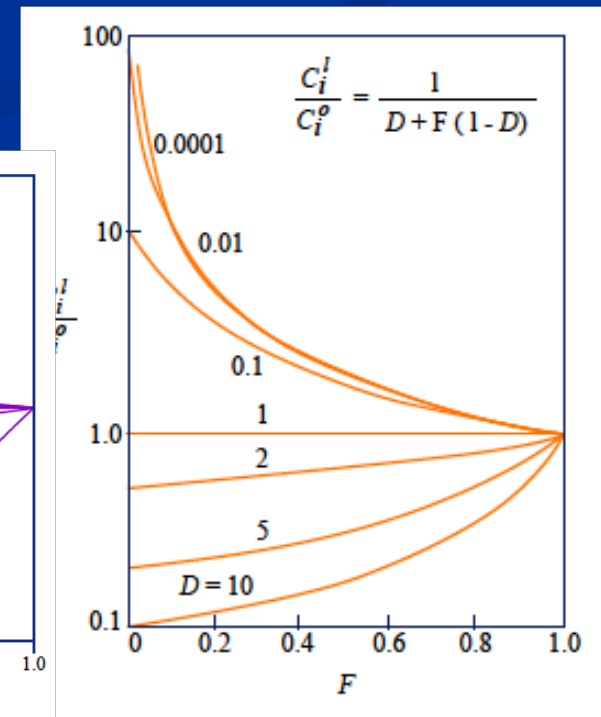
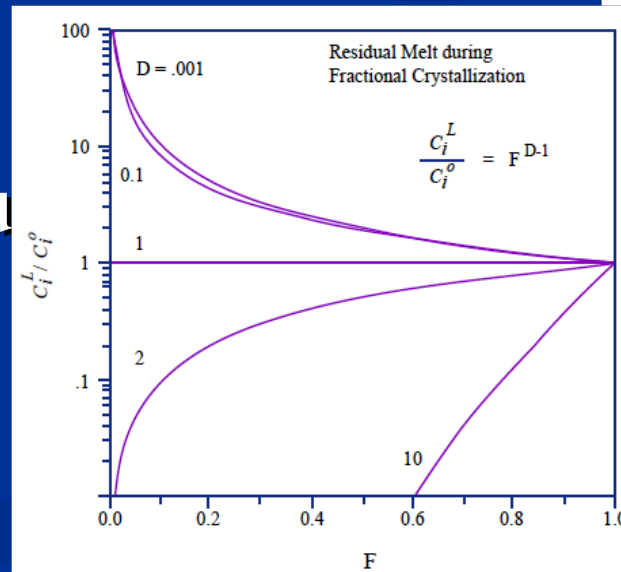
- Prepoznavanje značilnosti magmatskega izvora iz grafa dveh prvin.
 - Visoko nezdružljivi s podobnima D – ni spremembe med FC in majhna med BM.
 - Nagib premice določa razmerje koncentracij izvorne snovi.
 - Kakršnokoli sipanje vrednosti razmerja kaže na heterogenost izvora.
 - Cs-Rb-Ba, U-Nb-Ta-K, Ce-Pb, Pr-Sr, P-Nd, Zr-Hf-Sm, Eu-Ti, Ho-Y.
 - Y-Tb, La-Ta, La-Nb, Ta-Th, Ti-Zr, Ti-Y.
 - Razmerja ne veljajo za zelo majhne stopnje taljenja.
 - Težko jih uporabimo za granitne taline, saj je tam le malo prvin visoko nezdružljivih.
 - Izvor granitov lažje določimo z uporabo radioaktivnih

- Prepoznavanje značilnosti magmatskega izvora iz grafa razmerij dveh prvin.
 - Graf zelo zmanjša učinek FC, kar omogoča ugotavljanje značaj vira v plašču.
 - Različni izvori v plašču so razporejeni na različnih korelacijskih premicah.
 - Th, U, Pb, K, Ba, Ce, Nb
 - Th-Ce, K-Ce, U-Pb, Ba, Ce z Nb



Grafi kompatibilnih prvin

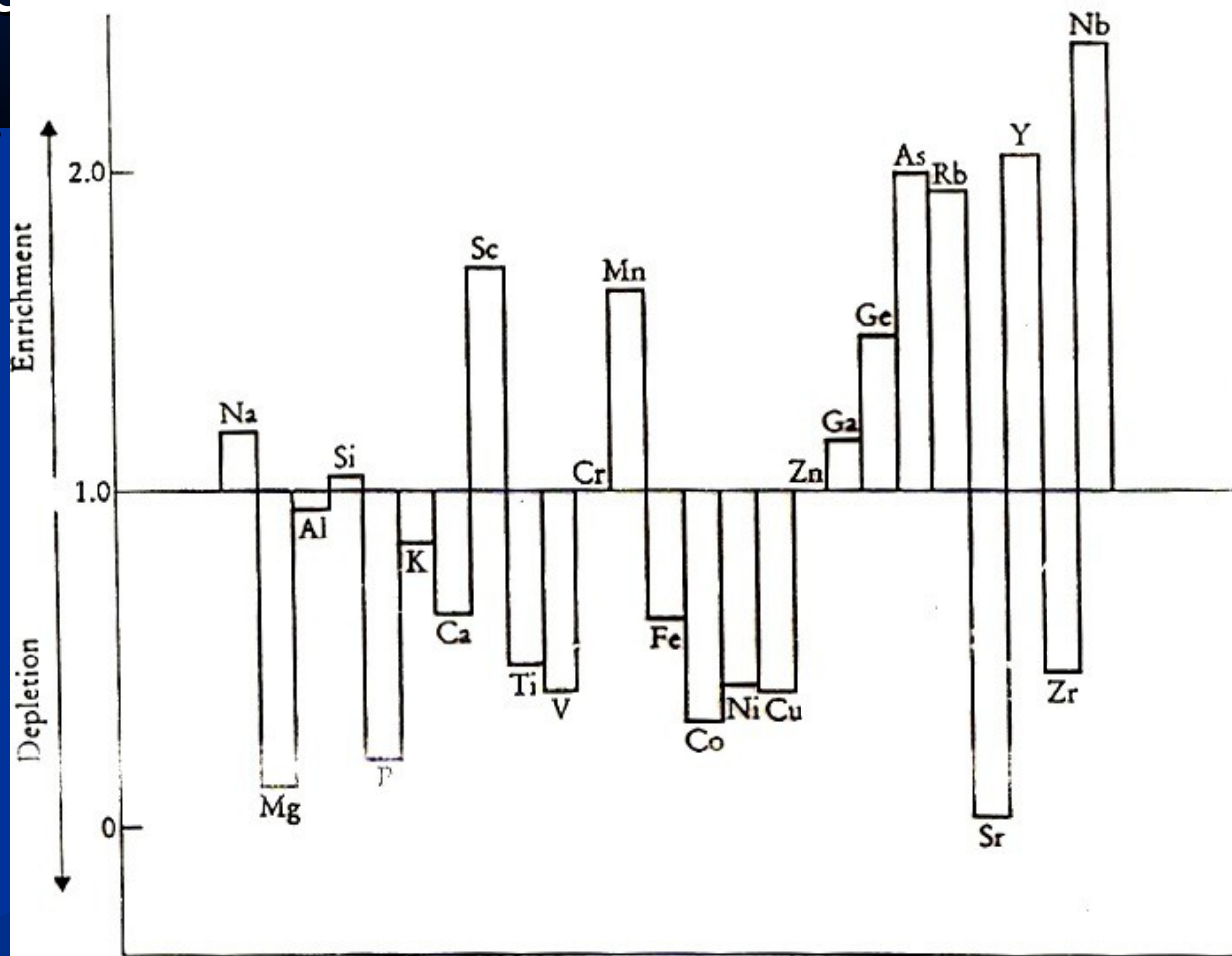
- Med frakcionirano kristalizacijo se močno spremenijo koncentracije združljivih prvin.
- Grafi združljivih prvin z diferenciacijskim indeksom ali magnezijevim številom so uporabni za testiranje frakcionirane kristalizacije.
- Testiranje AFC.
- Značilnosti izvora pri delnem taljenju



- Posebne skupine prvin.
- Bivariatni grafi.
- **Grafi obogatitve/izgube**
- Modeliranje magmatskih procesov
- Določanje tektonskega okolja.

Grafi obogatitve/izgube

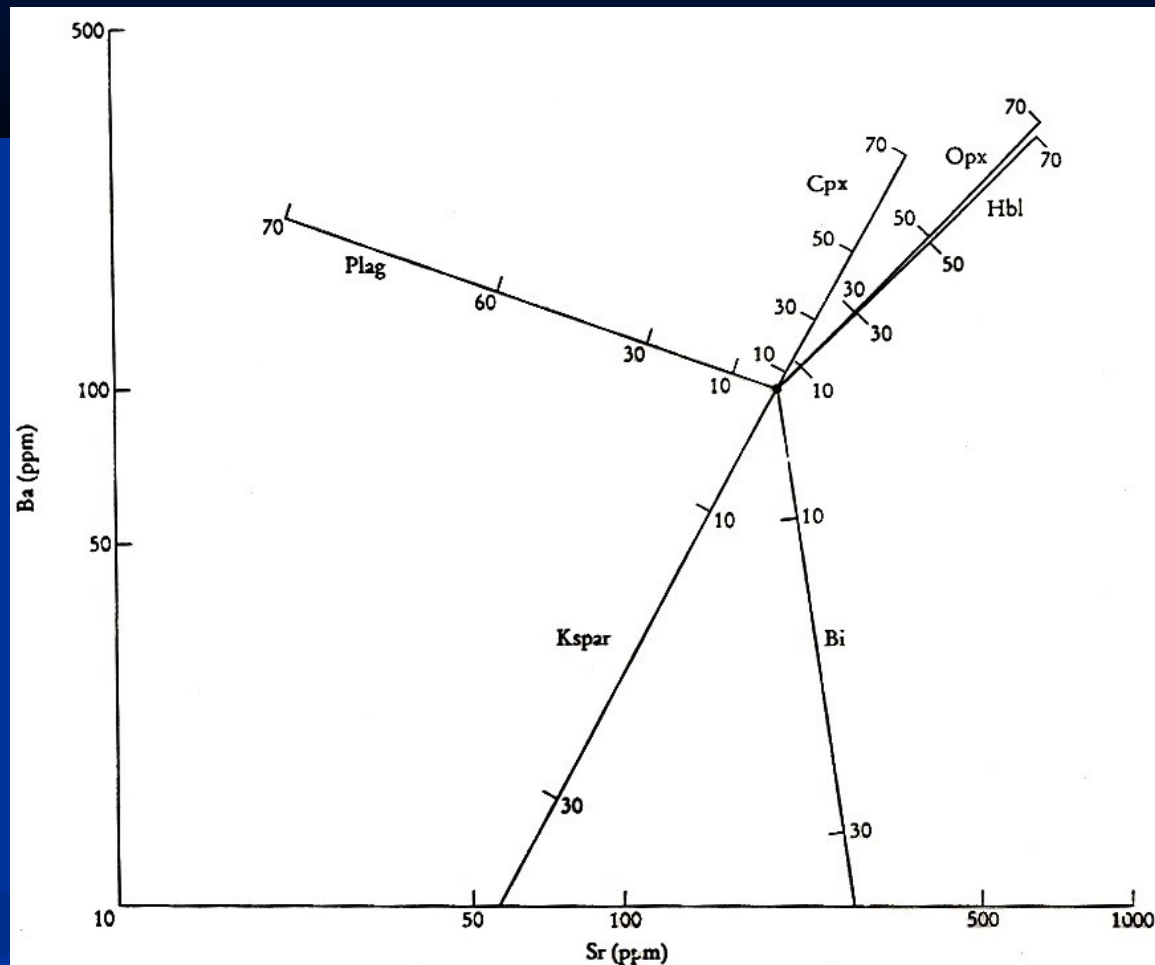
- Primerjava relativne obogatitve oz. osiromašenja med zgodnjimi in kasnejšimi kamninami magmatske serije
- Mobilnost prvin.



- Posebne skupine prvin.
- Bivariatni grafi.
- Grafi obogatitve/izgube
- Modeliranje magmatskih procesov
- Določanje tektonskega okolja.

Modeliranje magmatskih procesov

- Vektorski diagrami.
 - Vektorji mineralov.
 - Trend minerala ali združbe, ki se frakcionira.
 - Vektorji delnega taljenja.
 - Trend spremembe sestave taline in izvorne kamnine.



Ba ppm

5000

4000

3000

2000

1000

0

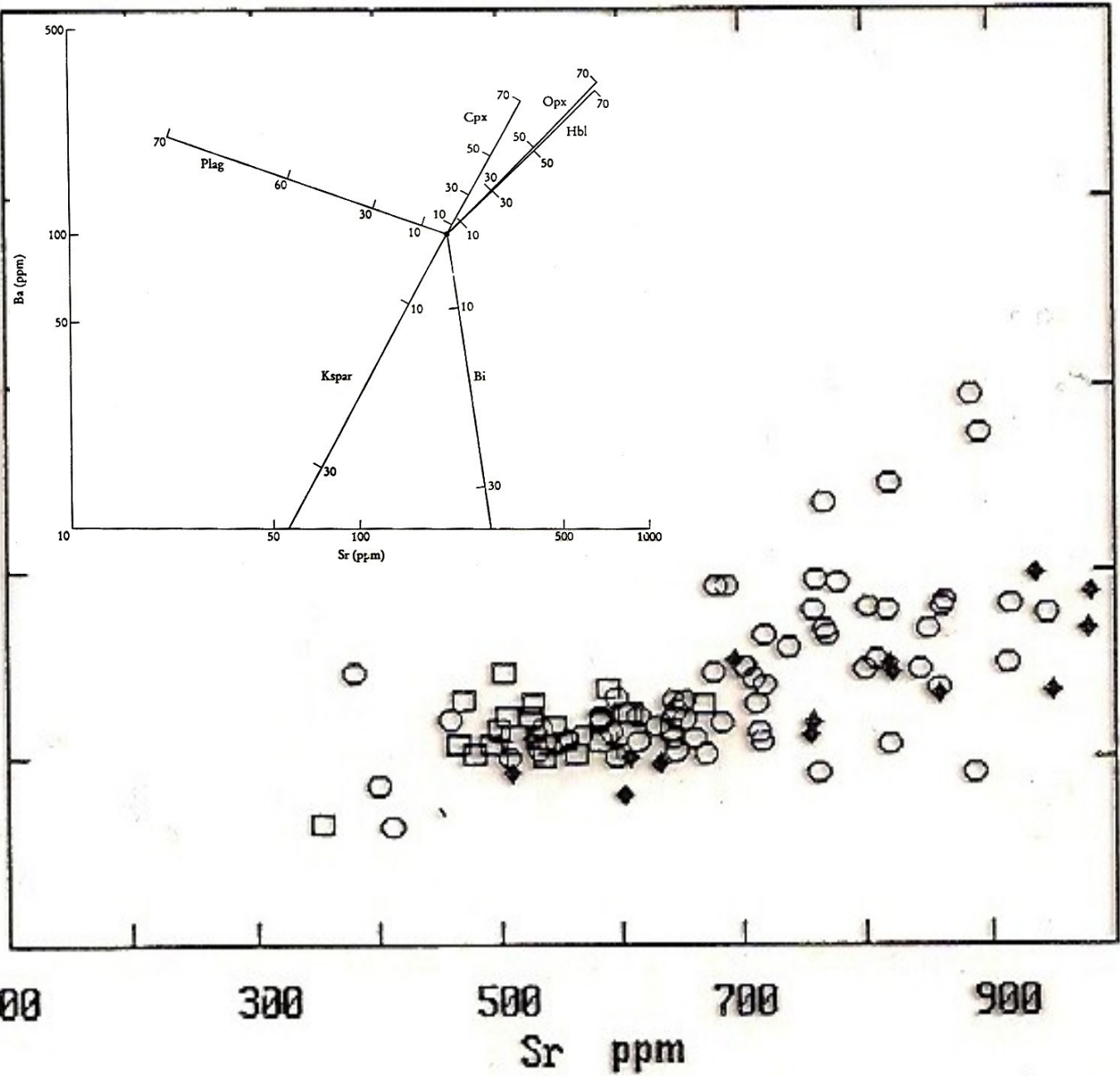
100

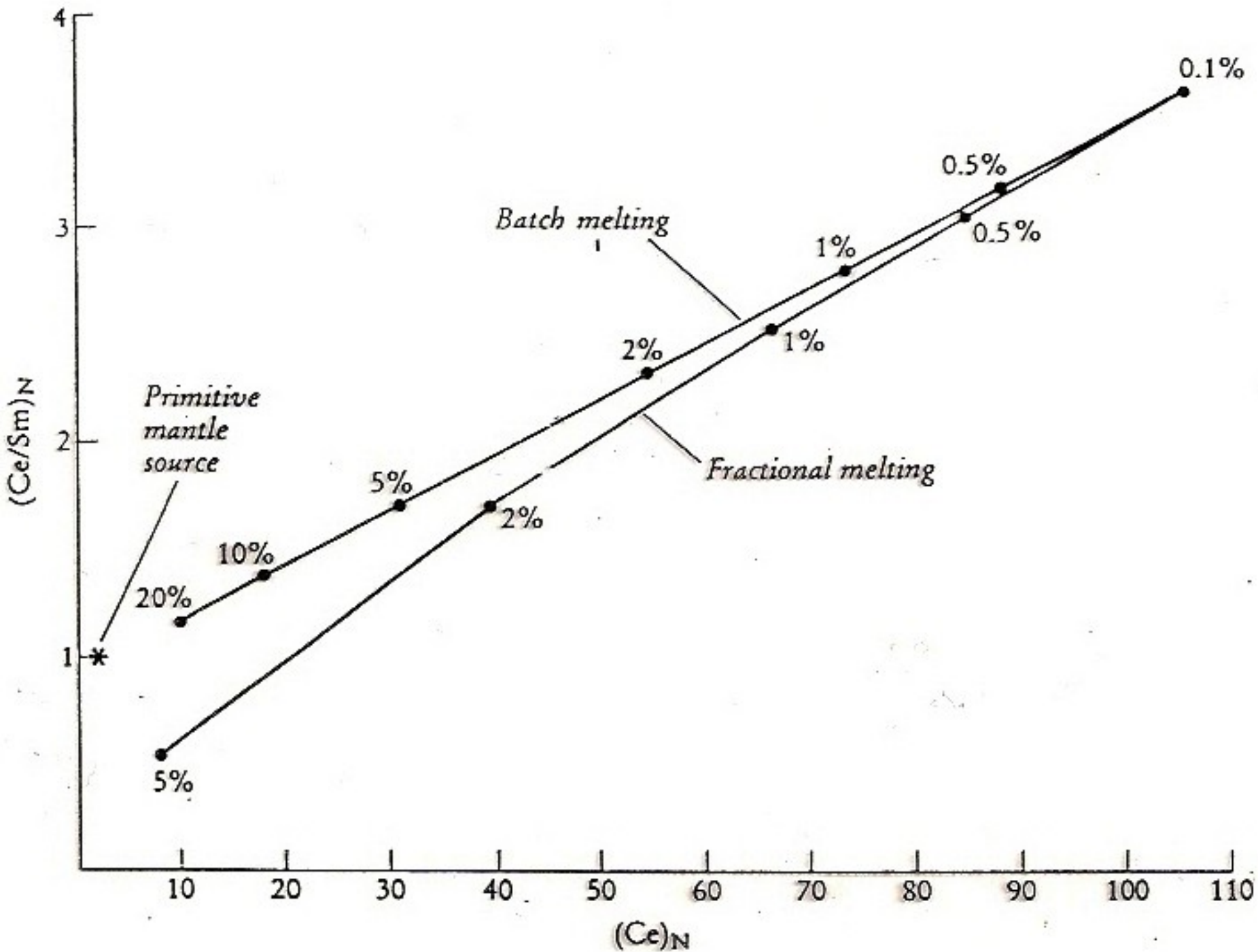
300

500

700

900



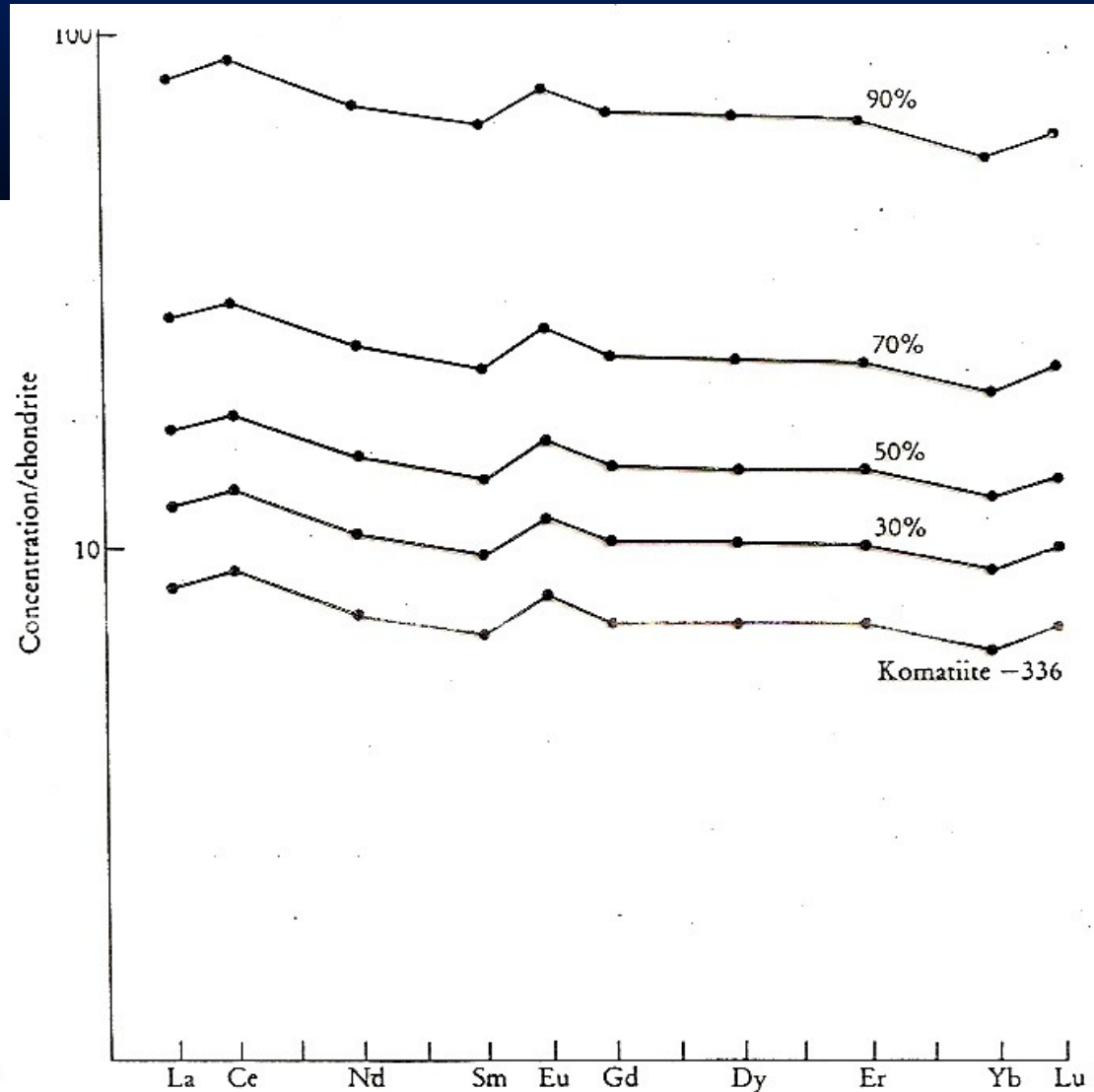
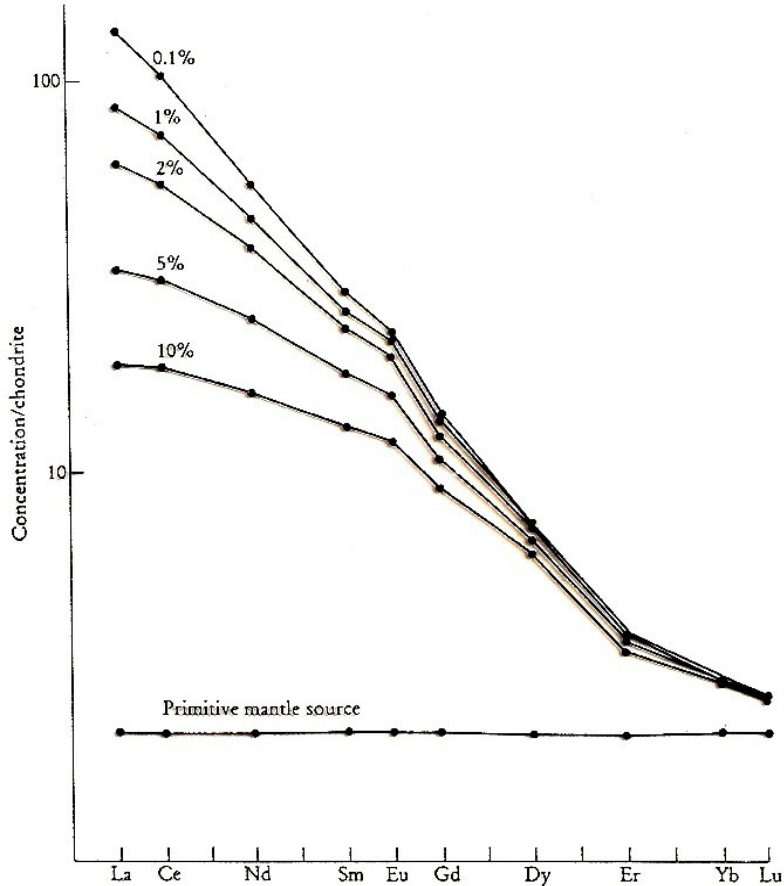


Modeliranje magmatskih procesov

Multivariatni diagrami.

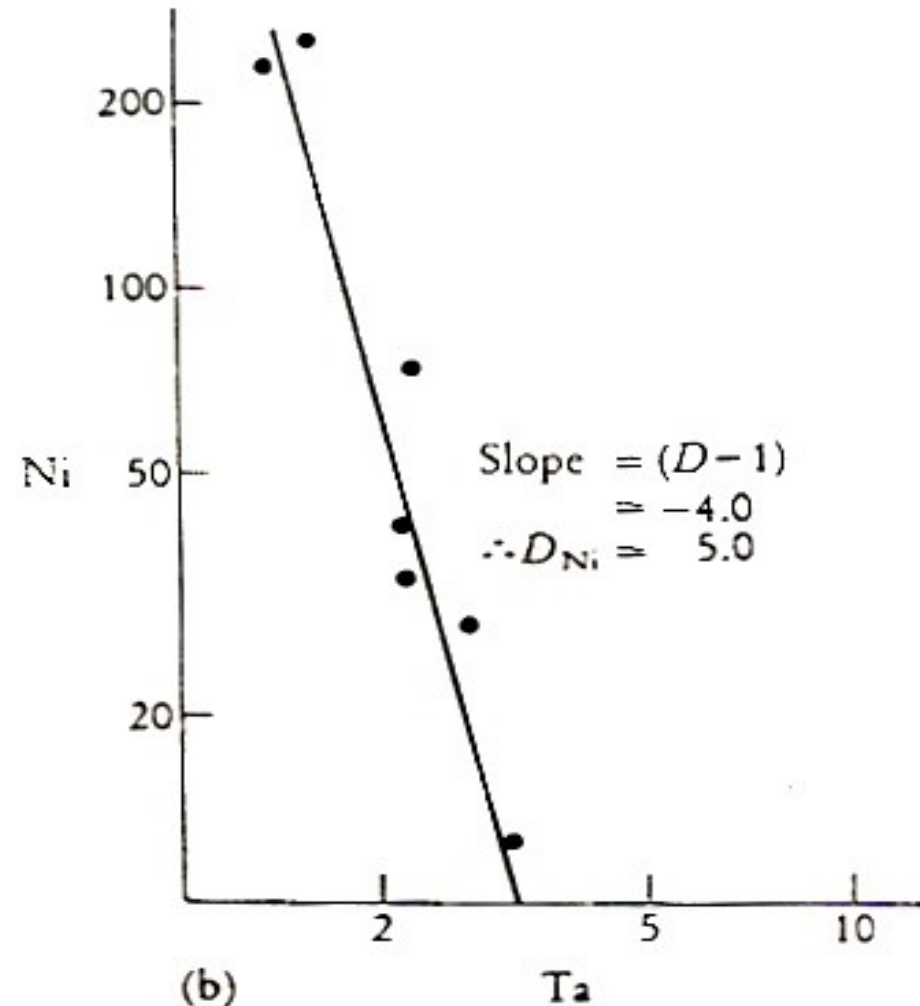
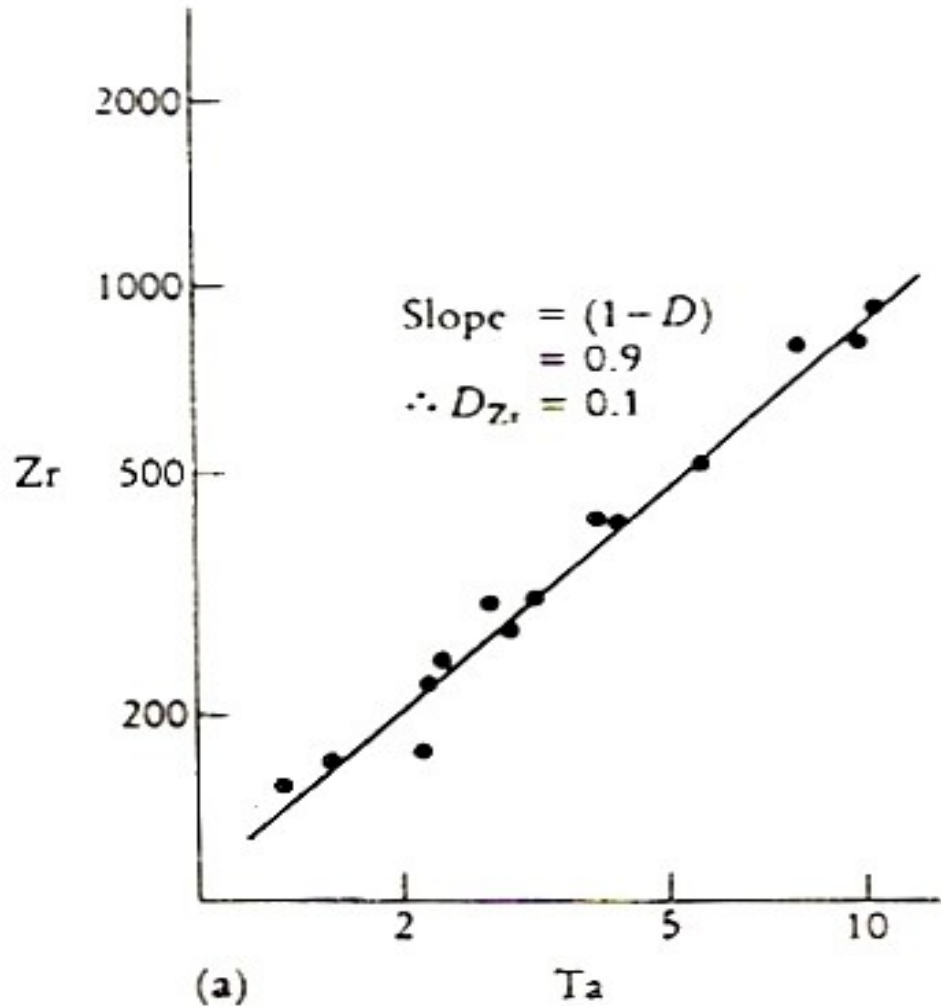
REE

Spider diagrami



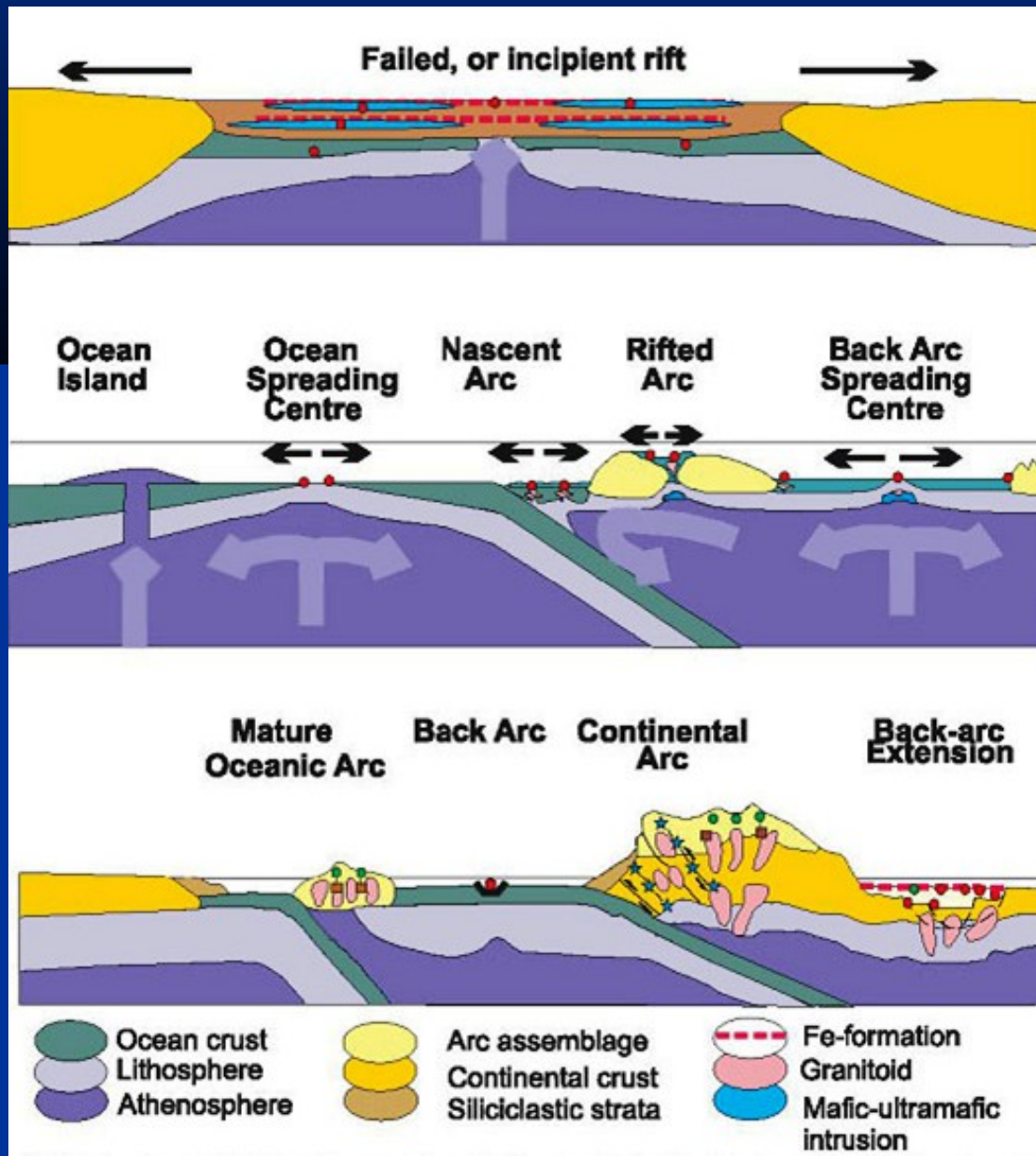
Modeliranje magmatskih procesov

■ Inverzne tehnike.



- Posebne skupine prvin.
- Bivariatni grafi.
- Grafi obogatitve/izgube
- Modeliranje magmatskih procesov
- Določanje tektonskega okolja.

Določanje tektonskega okolja



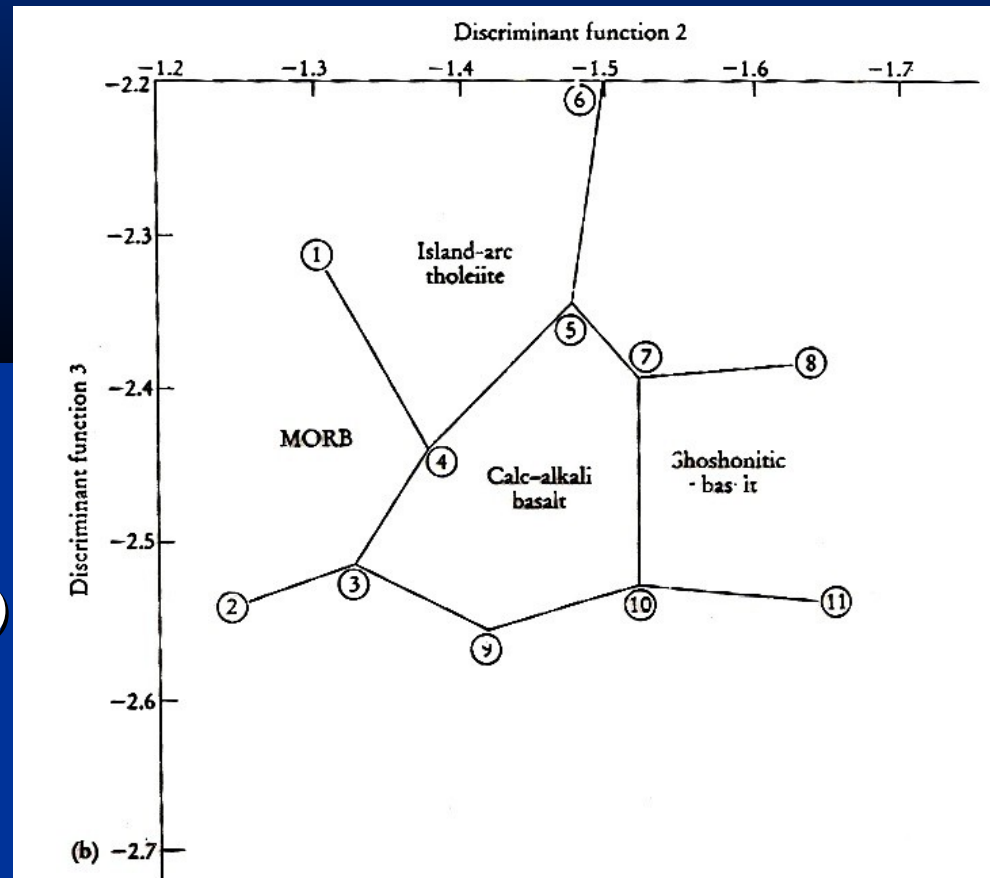
Geokemično prepoznavna tektonska okolja

- Oceanski greben (Mid-Ocean Ridge) MORB
 - Normalni
 - Anomalni
 - Začetek razpiranja
- Greben za-otočnega bazena (Back-arc basin ridge)
- Greben pred-otočnega bazena (Fore-arc basin ridge)
- Vulkanski lok (Volcanic Arc)
 - Oceanski – tholeiitni bazalt
 - Oceanski – kalcijsko-alkalni bazalt
 - Aktivni kontinentalni rob
- Okolje trka (Collisional Setting)
 - Celina – celina
 - Celina - otočni lok
- Okolje znotraj plošče (Interplate Setting)
 - Znotraj celine – normalna skorja
 - Znotraj celine – stanjšana skorja
 - Oceanski otok
- Pasivni celinski rob (Passive continental margin)

■ Načrtovanje diagramov.

■ Diskriminantna analiza.

- Poznana sedanja tektonska okolja – bazalti.
- Uporaba več prvin sočasno.
- Uporaba nemobilnih prvin (Ti, Zr, Y, Nb, Sr)
- Uporaba prvin z ustrezno analitiko.



(b) Discrimination diagram based upon functions F2 and F3; the plotting coordinates (extracted from Pearce, 1976 — Figure 2) are:

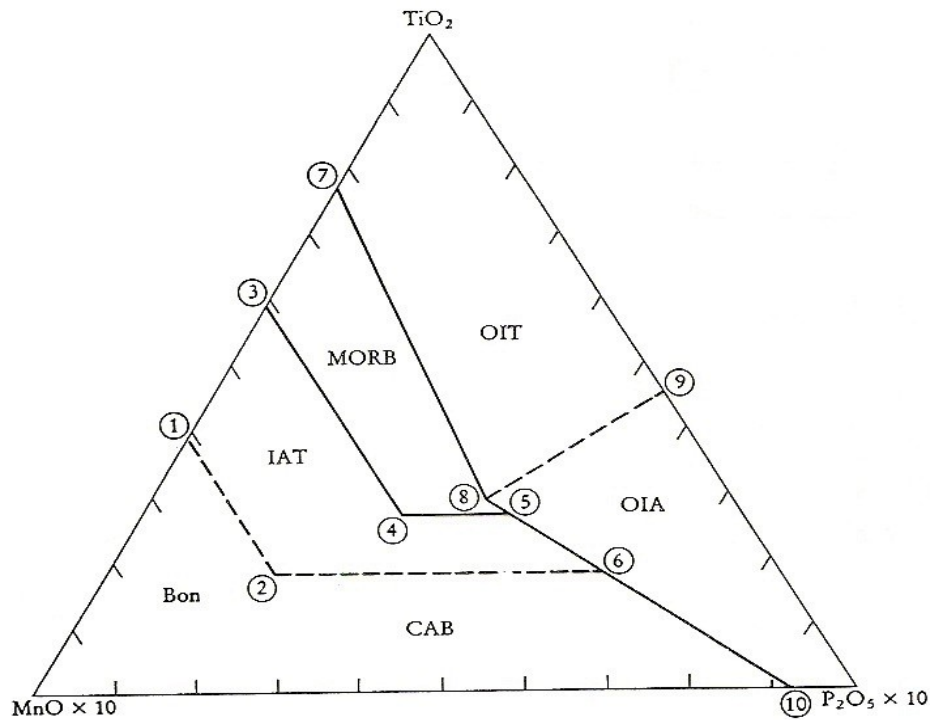
$$\begin{aligned} F1 &= + 0.0088\text{SiO}_2 - 0.0774\text{TiO}_2 + 0.0102 \text{Al}_2\text{O}_3 + 0.0066\text{FeO} - 0.0017\text{MgO} \\ &\quad - 0.0143\text{CaO} - 0.0155\text{Na}_2\text{O} - 0.0007\text{K}_2\text{O} \\ F2 &= - 0.0130\text{SiO}_2 - 0.0185\text{TiO}_2 - 0.0129 \text{Al}_2\text{O}_3 - 0.0134\text{FeO} - 0.0300\text{MgO} \\ &\quad - 0.0204\text{CaO} - 0.0481\text{Na}_2\text{O} - 0.0715\text{K}_2\text{O} \\ F3 &= - 0.2210\text{SiO}_2 - 0.0532\text{TiO}_2 - 0.0361 \text{Al}_2\text{O}_3 - 0.0016\text{FeO} - 0.0310\text{MgO} \\ &\quad - 0.0237\text{CaO} - 0.0614\text{Na}_2\text{O} - 0.0289\text{K}_2\text{O} \end{aligned}$$

■ Izbira diagrama.

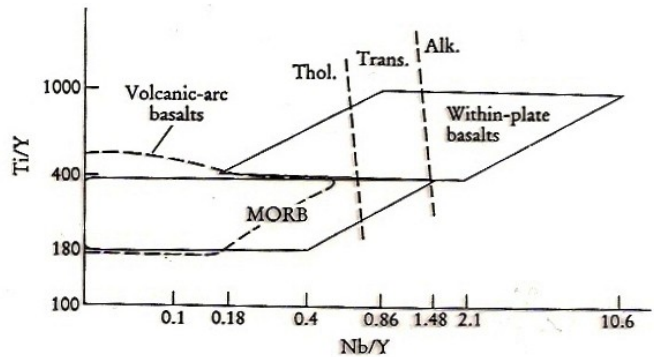
- Vrsta kamnine (bazalt – granit).
- Število vzorcev, uporabljenih za načrtovanje diagrama.
- Število tektonskih okolij, ki jih diagram loči.
- Prekrivanje tektonskih okolij na diagramu.
- Mobilnost uporabljenih prvin.
- Dostopnost analitike.
- Kombinacija več diagramov.

Table 5.1 Discrimination diagrams which may be used to determine the tectonic setting of basalts

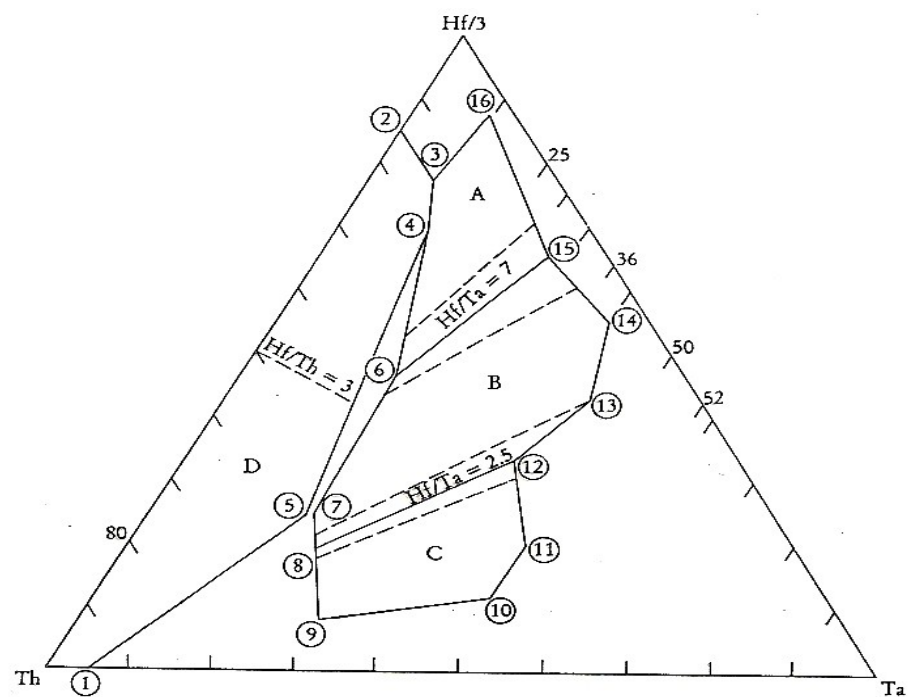
MORB	Figure	Within-plate basalts	Figure
Ti-Zr	5.2(a,b)	<i>Ocean-island tholeiites</i>	
Ti-Zr-Sr	5.3	Ti-V	5.10
Zr/Y-Zr	5.5	FeO-MgO-Al ₂ O ₃	5.20
Ti-V	5.10	MnO-TiO ₂ -P ₂ O ₅	5.22
Cr-Y	5.12	K ₂ O-H ₂ O	5.23
Cr-Ce/Sr	5.12	<i>Ocean-island alkali basalts</i>	
TiO ₂ -Y/Nb	5.15	MnO-TiO ₂ -P ₂ O ₅	5.22
FeO-MgO-Al ₂ O ₃	5.20	<i>Continental tholeiites</i>	
MnO-TiO ₂ -P ₂ O ₅	5.23	Ti-V	5.10
Discr. function (Ti-Zr-Y-Sr)	5.4	La-Y-Nb	5.11
Discr. function (majors)	5.19	TiO ₂ -Y/Nb	5.15
<i>N-type MORB</i>		FeO-MgO-Al ₂ O ₃	5.20
Zr-Nb-Y	5.8	K ₂ O-TiO ₂ -P ₂ O ₅	5.21
Th-Hf-Ta	5.9	<i>Continental alkali basalts</i>	
La-Y-Nb	5.11	La-Y-Nb	5.11
<i>E-type MORB</i>		<i>Volcanic-arc basalts</i>	Figure
Zr-Nb-Y	5.8	Ti-Zr	5.2(b)
Th-Hf-Ta	5.9	Zr/Y-Zr	5.5(a)
La-Y-Nb	5.11	Cr-Y	5.12(a)
FeO-MgO-Al ₂ O ₃	5.20	Cr-Ce/Sr	5.12(b)
<i>Transitional MORB</i>		FeO-MgO-Al ₂ O ₃	5.20
K ₂ O/Yb-Ta/Yb	5.13	K ₂ O-H ₂ O	5.23
<i>Back-arc basin tholeiites</i>	Figure	<i>Island-arc tholeiites</i>	
Ti-V	5.10	Ti-Zr-Y	5.1
La-Y-Nb	5.11	Ti-Zr	5.2
K ₂ O-H ₂ O	5.23	Ti-Zr-Sr	5.3
<i>Within-plate basalts</i>	Figure	Discr. function (Ti-Zr-Y-Sr)	5.4
Ti-Zr-Y	5.1	Th-Hf-Ta	5.9
Ti-Zr	5.2(b)	Ti-V	5.10
Discr. function	5.4	La-Y-Nb	5.11
Zr/Y-Zr	5.5(a)	K ₂ O/Yb-Ta/Yb	5.13
Zr/Y-Ti/Y	5.6	Discr. function (majors)	5.19
Cr-Y	5.12(a)	MnO-TiO ₂ -P ₂ O ₅	5.22
Cr-Ce/Sr	5.12	<i>Continental-arc</i>	
Discr. function (majors)	5.19	Zr/Y-Zr	5.5(b)
<i>Alkali</i>		<i>Oceanic-arc</i>	
Zr/Y-Nb/Y	5.7	Zr/Y-Zr	5.5(b)
Zr-Nb-Y	5.8	<i>Calc-alkaline basalts</i>	
Th-Hf-Ta	5.9	Ti-Zr-Y	5.1
Ti-V	5.10	Ti-Zr	5.2(a)
K ₂ O/Yb-Ta/Yb	5.13	Ti-Zr-Sr	5.3
TiO ₂ -Y/Nb	5.15	Discr. function	5.4
<i>Tholeiitic</i>		Th-Hf-Ta	5.9
Ti/Y-Nb/Y	5.7	La-Y-Nb	5.11
Zr-Nb-Y	5.8	K ₂ O/Yb-Ta/Yb	5.13
K ₂ O/Yb-Ta/Yb	5.13	Discr. function (majors)	5.19
<i>Transitional</i>		MnO-TiO ₂ -P ₂ O ₅	5.22
Ti/Y-Nb/Y	5.7	<i>Shoshonitic basalts</i>	
K ₂ O/Yb-Ta/Yb	5.13	K ₂ O/Yb-Ta/Yb	5.13
		Discr. function (majors)	5.19



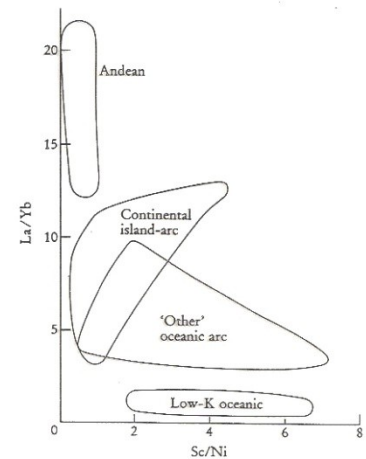
The MnO-TiO₂-P₂O₅ discrimination diagram for basalts and basaltic andesites (45-54 wt % SiO₂) (after Mullen, 1983). The fields are MORB; OIT — ocean-island tholeiite or seamount tholeiite; OIA — ocean-island alkali basalt or seamount alkali basalt; CAB — island-arc calc-alkaline basalt; IAT — island-arc tholeiite; Bon — boninite. The boninite field occupies the MnO-rich sector of the CAB field. The plotting coordinates (extracted from Figure 1 of Mullen, 1983) for constructing the boundary lines on the triangular diagram are as follows:



The Ti/Y-Nb/Y discrimination diagram for basalts showing the fields of within-plate basalts, MORB and volcanic-arc basalts (dashed line). The within-plate basalts may be divided into tholeiitic (Thol.), transitional (Trans.) and alkali (Alk.) basalt types (after Pearce, 1982). The values given along the ordinate and abscissa are to allow the construction of the field boundaries and are extracted from Pearce (1982 — Figure 9a).



The Th-Hf-Ta discrimination diagram for basalts (after Wood, 1980). The fields are: A, N-type MORB; B, E-type MORB and within-plate tholeiites; C, alkaline within-plate basalts; D, volcanic-arc basalts. Island-arc tholeiites plot in field D where Hf/Th > 3.0 and calc-alkaline basalts where Hf/Th < 3.0. The broken lines indicate transitional zones between basalt types. The plotting coordinates for the boundary lines (extracted from Wood, 1980 — Figure 1) are:



The La/Yb-Sc/Ni discrimination diagram for andesites (after Bailey, 1981) showing the fields of Andean-type (active continental margin), continental island-arc, low-K oceanic...

Granite types classified according to tectonic setting (after Pearce *et al.*, 1984)

Ocean-ridge granites (ORG)

Granites associated with normal ocean ridges

Granites associated with anomalous oceanic ridges

Granites associated with back-arc basin ridges

Granites associated with fore-arc basin ridges

Volcanic-arc granites (VAG)

Granites in oceanic arcs dominated by tholeiitic basalt

Granites in oceanic arcs dominated by calc-alkali basalt

Granites in active continental margins

Within-plate granites (WPG)

Granites in intracontinent ring complexes

Granites in attenuated continental crust

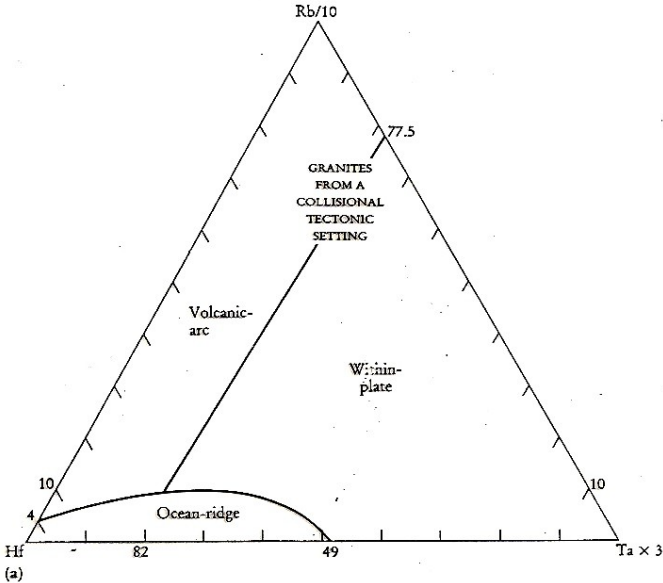
Granites in oceanic islands

Collisional granites (COLG)

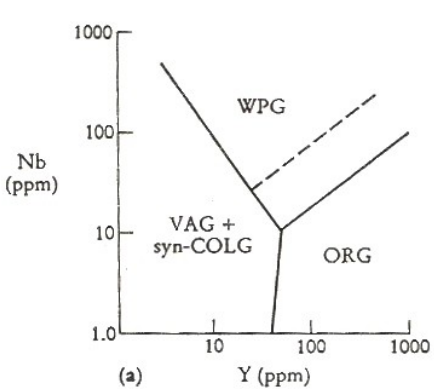
Syn-tectonic granites associated with continent-continent collision

Post-tectonic granites associated with continent-continent collision

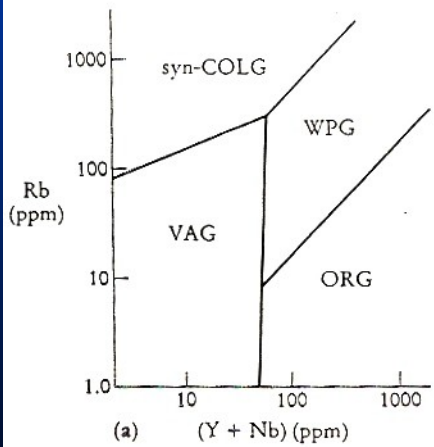
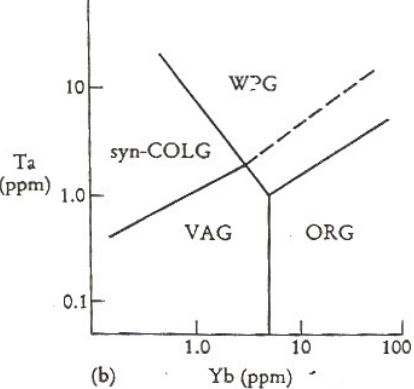
Syn-tectonic granites associated with continent-arc collision



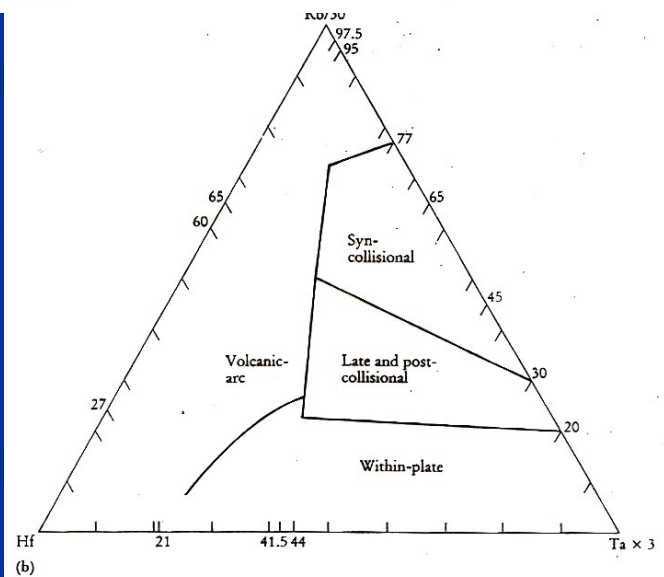
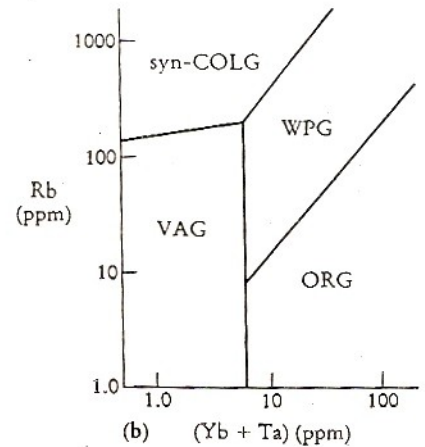
(a) The Hf-Rb/10-Ta x 3 discrimination diagram for granites (after Harris *et al.*, 1986), showing the fields for volcanic-arc granites, within-plate granites and ocean-ridge granites. Granites from a collisional tectonic setting plot across the field boundary between volcanic-arc and within-plate granites. The plotting coordinates are extracted from Harris *et al.* (1986 - Figure 1).



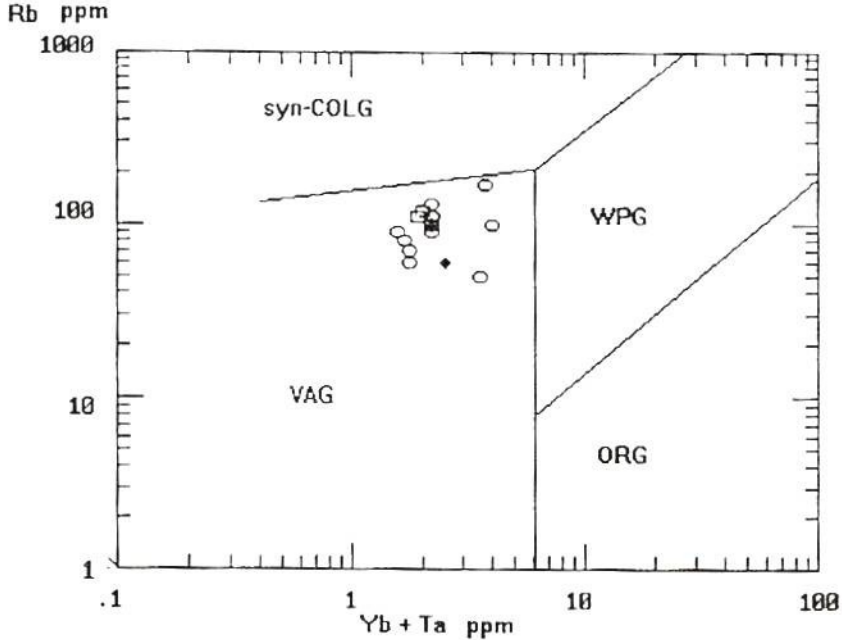
(a) The Nb-Y discrimination diagram for granites (after Pearce *et al.*, 1984), showing the fields of volcanic-arc granites (VAG), syn-collisional granites (syn-COLG), within-plate granites (WPG) and ocean-ridge granites (ORG). The broken line is the field boundary for ORG from anomalous ridges. The plotting coordinates (Y,Nb) are as follows (after Pearce *et al.*, 1984) 1,200 to 50,10; 40,1 to 50,10; 50,10 to 1000,100; 25,25 to 1000,400; (b) The Ta-Yb discrimination diagram for granites (after Pearce *et al.*, 1984), showing the fields of volcanic-arc granites (VAG), syn-collisional granites (syn-COLG), within-plate granites (WPG) and ocean-ridge granites (ORG). The broken line is the field boundary for ORG from anomalous ridges. The plotting coordinates (Yb, Ta) are as follows (after Pearce *et al.*, 1984): 0.55,20 to 3,2; 0.1,0.35 to 3,2; 3,2 to 5,1; 5,0.5 to 5,1; 5,0.05 to 100,7; 3,2 to 100,20.



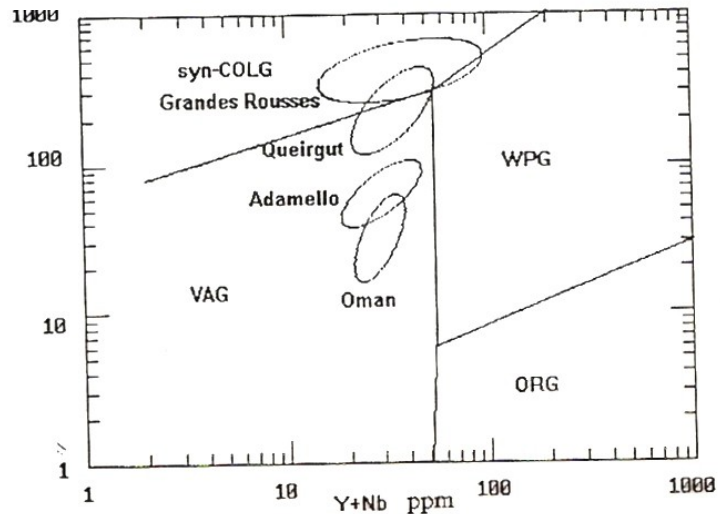
(a) The Rb-(Y + Nb) discrimination diagram for granites (after Pearce *et al.*, 1984) showing the fields of syn-collisional granites (syn-COLG), within-plate granites (WPG), volcanic arc granites (VAG) and ocean-ridge granites (ORG). The plotting coordinates [(Y + Nb), Rb] for the field boundaries (taken from Pearce *et al.*, 1984) are: 2,80 to 55,300; 55,300 to 400,2000; 55,300 to 51.5,8; 51.5,8 to 50,1; 51.5,8 to 2000, 400. (b) The Rb-(Yb + Ta) discrimination diagram for granites (after Pearce *et al.*, 1984), showing the fields of syn-collisional granites (syn-COLG), within-plate granites (WPG), volcanic-arc granites (VAG) and ocean-ridge granites (ORG). The plotting coordinates [(Yb + Ta), Rb] for the field boundaries (taken from Pearce *et al.*, 1984) are: 0.5,140 to 6,200; 6,200 to 50,200; 6,200 to 6,8; 6,8 to 6,1; 6,8 to 200,400.



(b) The Hf-Rb/30-Ta x 3 discrimination diagram for granites (after Harris *et al.*, 1986), showing the fields for volcanic-arc granites, within-plate granites, syn-collisional granites and late to post-collisional granites. The plotting coordinates are extracted from Harris *et al.* (1986 - Figure 6).



Slika 17. Rb/Yb + Ta diagram določanja tektonskega okolja nastanka granitoidov (Pearce et al., 1984). syn-COLG - sin-kolizijski granitoidi, VAG - granitoidi vulkanskih lokov, WPG - granitoidi znotraj plošč, ORG - granitoidi oceanskega grebena. Legenda je enaka kot pri sliki 4.



Slika 19. Rb/Y + Nb diagram določanja tektonskega okolja nastanka granitoidov z vrisanimi položaji nekaterih post-kolizijskih granitoidov (Pearce, 1984). Oznake so enake kot pri sliki 17.