ERSC 3P21

Igneous Rocks
Nomenclature and Classification

Introduction

- Numerous means exist for classifying and naming igneous rocks
- As humans we feel the need to recognize and categorize common or contrasting features in related things
  - Eg. animals or plants
    - Kingdom, phylum, order, genera, class, species
- Systems of rock nomenclature and classification may reflect
    - Genetic, textural, chemical or mineralogical features

Genetic

- Basic systems which classifies igneous rocks ______________________________

  ___________ ______________

  ___________ ______________

  ___________ ______________

-
-

Textural

- Relies on the ____________________ ______________________________
  - ________ __________ - < 1 mm
  - ________ __________ - 1-5 mm
  - ________ __________ - > 5 mm
-
- Specific textures may aid in classification
  - eg.

Chemical

- Requires a ______________________ of the rock in order to classify it
- This is not practical under field conditions, where only a ________ and ________ are available
- Chemical classification has been proposed for ___________, a comparable scheme for ___________ is not available
- This leaves a system based on mineralogy

Mineralogical

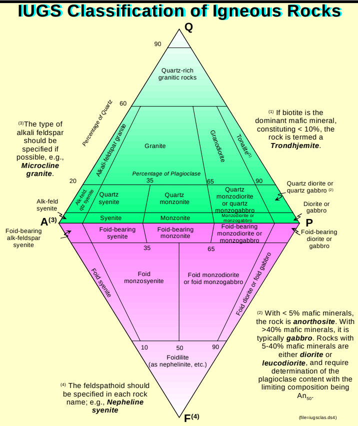
- Requires only a ________ and ________ and the ability to ___________________ present in a rock
- System gaining acceptance and the one you will use is the result of several years work by the IUGS Subcommission on the Classification of Igneous Rocks, chaired by Alfred Streckeisen
- AKA – The Streckeisen Classification

Mineralogical

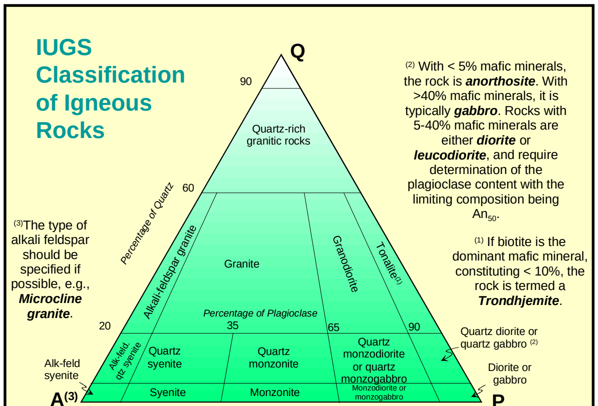
- Based on Modal Mineralogy
  - (**MODE** –

)
- A simple, field based system
- Based on the percentages of:
  - ___________ (____)
  - _______________ (____)
  - ________________ (____), and
  - ______________, eg. nepheline, leucite etc. (____)
  - Subdivisions are dependant on the percentage of mafic minerals

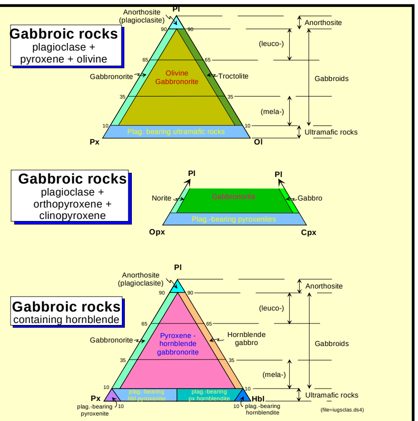
IUGS Classification of Igneous Rocks



IUGS Classification of Igneous Rocks



IUGS Classification of Mafic Igneous Rocks



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Chemistry of Igneous Rocks

- The chemical composition of any sample (igneous, metamorphic or sedimentary) is determined by analyzing a powder of the rocks
- The actual process is covered ERSC 3P31

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Chemistry of Igneous Rocks

The composition of an igneous rock is dependant on:

1.
2.
3.
4.
   -
5.

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Chemistry of Igneous Rocks

- Generally three groups of elements are analyzed when studying Igneous Rocks
  - –
  - –
  - –

Chemistry of Igneous Rocks

Major Elements

- 13 oxide components, reported in wt.%

• SiO_2	35-80 wt%
• Al_2O_3	8-22 wt%
• TiO_2, Fe_2O_3, FeO, MnO, MgO, CaO	4-30 wt %
• Na2O	1.5-8 wt%
• K_2O	0.5-8 wt%
• $H_2O^{+,-}$	Varies
• P_2O_5	< 0.15 wt%
• CO_2	Varies

- Reported as percentages, the total should = 100%

Periodic Table of the Elements

Major Elements

H
C
Na Mg Al Si P
K Ca Ti Mn Fe

Oxide	Granite	Granodiorite	Diorite	Syenite	Anorthosite	Gabbro	Basalt
SiO_2	72.04	66.80	58.58	57.49	51.05	51.06	50.06
TiO_2	0.30	0.54	0.96	0.82	0.63	1.17	1.87
Al_2O_3	14.42	15.99	16.98	17.23	26.57	15.91	15.94
Fe_2O_3	1.22	1.52	2.55	3.05	0.99	3.10	3.90
FeO	1.68	2.87	5.13	3.22	2.07	7.76	7.50
MnO	0.05	0.08	0.12	0.13	0.05	0.12	0.20
MgO	0.71	1.80	3.73	1.84	2.14	7.68	6.98
CaO	1.82	3.92	6.66	3.54	12.76	9.88	9.70
Na_2O	3.69	3.77	3.60	5.48	3.18	2.48	2.94
K_2O	4.12	2.79	1.81	5.03	0.62	0.96	1.08
P_2O_5	0.12	0.18	0.29	0.29	0.69	0.24	0.34
No.	2485	885	872	517	104	1451	3796

Average chemical compositions (wt%) of common igneous rocks

Data from LeMaitre (1976)

Chemistry of Igneous Rocks

Minor or Trace Elements

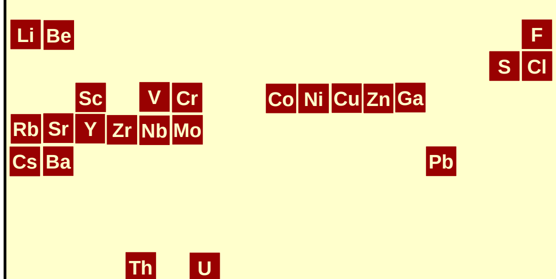
–

–

- Basalt – analyze for ___, ___, ___ but not ___, ___, ___, as these latter are not present in detectable amounts
- Granite pegmatite with lepidolite – analyze for ___, ___ and ___, but not ___, ___ and ___

Periodic Table of the Elements

Trace Elements



Chemistry of Igneous Rocks

Rare Earth Elements

- REE or _______________, with atomic number between ____ to ____
-
- Rare Earth Elements are important for

Periodic Table of the Elements

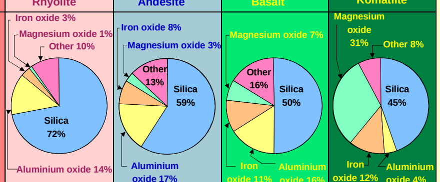
Rare Earth Elements

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

- Several aspects which historically have played and continue to play a role in the classification of Igneous rocks will also be considered
  -
  -
  -
  -

Gradation in Silica Content

- Referred to as _____ or ______, implying a range of silica content
- ______ > ____ wt% SiO_2
  - Granites ~ 72 wt% SiO_2, granodiorites ~ 68 wt % SiO_2
- _________ _____ - _____ wt% SiO_2
  - Andesite ~ 57 wt% SiO_2
- ________ ___ - _____ wt% SiO_2
  - Basalts range from 48-50 wt% SiO_2
- _________ < ______ wt% SiO_2
  - Peridotites 41 to 42 wt% SiO_2

Descriptive Terms	Acidic > 66 wt% SiO_2	Intermediate 52-66 wt% SiO_2	Basic 45-52 wt% SiO_2	Ultrabasic < 45 wt% SiO_2
Intrusive	Granite	Diorite	Gabbro	Peridotite
Extrusive	Rhyolite	Andesite	Basalt	Komatiite
Composition				
Major Minerals	Quartz Potassium Feldspar Sodium Feldspar (plagioclase)	Amphibole Intermediate plagioclase feldspar	Calcium Feldspar (plagioclase) Pyroxene	Olivine Pyroxene
Minor Minerals	Muscovite Biotite Amphibole	Pyroxene	Olivine Amphibole	Calcium Feldspar (plagioclase)
Most Common Colour	Light coloured	Medium gray or medium green	Dark grey to black	Very dark green to black

Gradation in Silica Content

Colour Gradation

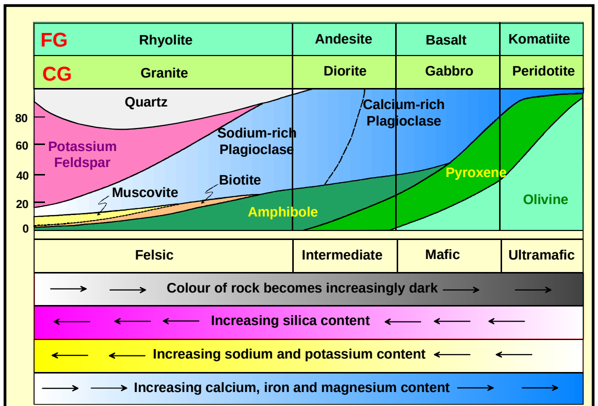
Felsic Rocks

- –
- –

Mafic Rocks

- –
- –
- –

Ultrabasic vs ultramafic



Colour Gradation

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Silica Saturation

Minerals present in igneous rocks can be divided into two groups:

1. Those which are ___________ with ______ or a primary SiO_2 mineral (tridymite, cristobalite etc.).
   - minerals are __________ with respect to Si,
     - e.g., _________________.
2. Those which ______ _______ with a primary silica mineral.
   - These are ______________ minerals
     - e.g.

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Silica Saturation

- The occurrence of quartz with an _______________ mineral causes a reaction between the two minerals to form a ___________ mineral.

$2SiO_2 + NaAlSiO_4$ ===> $NaAlSi_3O_8$

Q + ne ===> ab

$SiO_2 + Mg_2SiO_4$ ===> $2MgSiO_3$

Q + ol ===> en

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Silica Saturation

Incompatible Phases

- Under magmatic conditions some minerals react with free silica to form other, more silica-rich, minerals: These reactant minerals are said to be **undersaturated** (with respect to SiO_2).
- Other minerals are stable (can coexist) with free silica (generally in the form of quartz) and are said to be **saturated** (with respect to SiO_2).

Silica Saturation

Typical reactions are:

$2SiO_2$ + $NaAlSiO_4$	=======>	$NaAlSi_3O_8$
Q + ne	=======>	ab
$2SiO_2$ + KAlSiO4	=======>	KAlSi3O8
Q + ks	=======>	or
SiO_2 + $KAlSiO_4$	=======>	$KAlSi_2O_6$
Q + ks	=======>	lc
SiO_2 + Mg_2SiO_4	=======>	$2MgSiO_3$
Q + ol	=======>	en

Silica Saturation

Shand (1927) proposed the following list of minerals, subdivided on the basis of silica **saturation** and/or **undersaturation**.

Saturated (+Q)	Undersaturated (-Q)
all feldspars	leucite
all pyroxenes	nepheline
all amphiboles	sodalite
micas	cancrinite
fayalite (Fe-rich olivine)	analcite
spessartine $Mn_3Al_2(SiO_4)_3$	forsterite (Mg-rich olivine)
almandine $Fe_3Al_2(SiO_4)_3$	melanite (Ti garnet)
sphene	andradite $Ca_3(Fe,Ti)_2(SiO_4)_3$
zircon	pyrope $Mg_3Al_2(SiO_4)_3$
topaz	perovskite
magnetite	melilite
ilmenite	corundum
apatite	calcite

Undersaturated and **saturated** minerals can coexist stably under magmatic conditions, but quartz, tridymite and cristobalite can only coexist stably with **saturated** minerals. For example Q + ne is an impossible igneous assemblage, so is Q + ol (Mg - rich), but Q + ol (Fe- rich) is stable.

Silica Saturation

The saturation concept can also be applied to rocks

- ________________ - contains primary silica mineral
- ______________ - contains neither quartz nor an unsaturated mineral
- ____________ - contains unsaturated minerals

Alumina Saturation

- Independent of the silica saturation
- Alumina saturation is based on the 1:1 alkali:alumina ratio of feldspars and feldspathoids (ne, lc, ks).
- Any excess or deficiency in alumina in a rock is reflected in the mineralogy.
- Four classes of alumina saturation are employed:

Alumina Saturation

1. **Peraluminous** - $Al_2O_3 > (CaO + Na_2O + K_2O)$
   –
   –
2. **Metaluminous** - $Al_2O_3 < (CaO + Na_2O + K^2O)$ but $Al_2O_3 > (Na_2O + K_2O)$.
   –
   –

Alumina Saturation

3. **Subaluminous** - $Al_2O_3 = (Na_2O + K_2O)$
   -
   -
4. **Peralkaline** - $Al_2O_3 < (Na_2O + K_2O)$ and rarely $Al_2O_3 < K_2O$
   -
   -
   -

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- Two additional types of analysis are useful in examining igneous rocks
- ________________
  – requires ________________
- ________________
  – requires ________________

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Modal Analysis

- Produces an ____________________

____

____

- Methods of analysis are:
  1.
  2.

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Modal Analysis

3. POINT COUNT
   –

   –

Modal Analysis

3. POINT COUNT (Continued)

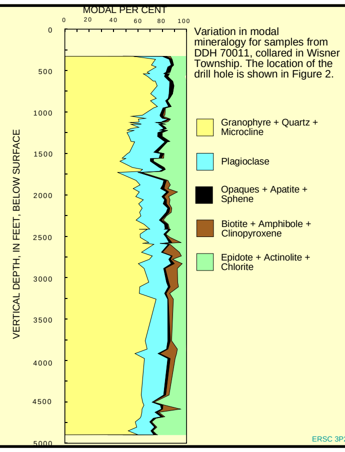
Advantages
   –

   –
   –

Disadvantages
   –
   –
   –

Modal Analysis Results for DDH 70011

DEPTH (M)	SAMPLE #	GR	QTZ	MICRO	PLAG	EPI	ACT	AMP	CHL	BIO	SPH	AP	OP
329.00	70011-1	50.90	6.10	0.00	23.30	2.50	1.30	0.90	9.20	2.50	0.00	0.30	2.80
364.00	70011-2	66.00	8.40	0.00	11.40	4.00	1.10	0.00	6.80	0.00	1.00	0.10	1.20
435.00	70011-4	68.40	2.80	0.00	16.10	5.90	1.20	0.20	3.40	0.00	0.00	0.00	1.90
457.00	70011-6	70.50	4.40	0.00	9.70	9.00	1.90	0.10	0.80	0.00	0.00	0.00	3.20
521.00	70011-7	63.90	3.70	0.00	15.50	7.40	0.10	0.00	6.10	0.00	0.00	0.20	3.10
537.00	70011-8	62.20	7.30	0.00	11.80	12.60	1.10	0.00	2.90	0.00	0.00	0.00	0.90
540.30	70011-9	63.60	3.70	0.00	14.50	7.50	1.00	0.00	5.80	0.00	0.00	0.00	4.00
541.00	**70011-10**	**59.70**	**5.00**	**0.00**	**17.90**	**7.40**	**1.10**	**0.00**	**5.60**	**0.00**	**0.20**	**0.20**	**2.90**
572.00	70011-11	64.70	3.30	0.00	13.80	8.80	0.20	0.00	4.80	0.10	0.40	0.00	2.30
627.00	70011-12	69.80	2.80	0.00	13.10	7.40	0.70	0.00	3.60	0.00	0.00	0.10	2.50
628.00	70011-13	67.50	6.80	0.00	11.80	6.80	0.50	0.10	3.40	0.00	0.00	0.00	2.50
685.00	70011-14	72.30	3.50	0.00	10.20	4.50	0.70	0.00	5.00	0.30	0.10	0.00	3.30
779.00	70011-16	67.40	3.10	0.00	15.10	7.20	0.80	0.00	3.50	0.00	0.10	0.00	2.80
837.00	70011-17	71.90	3.30	0.00	9.80	12.00	0.70	0.00	1.10	0.10	0.80	0.10	0.10
865.00	70011-18	64.20	6.20	0.00	12.30	7.90	3.30	0.00	4.50	0.00	0.40	0.30	0.90
935.00	**70011-19**	**74.90**	**1.10**	**0.00**	**9.20**	**4.10**	**1.00**	**0.00**	**7.50**	**0.00**	**0.60**	**0.00**	**1.50**
952.00	70011-20	69.00	3.90	0.00	7.70	6.60	3.60	0.30	7.00	0.00	0.40	0.30	1.10
1039.00	70011-22	59.20	4.60	0.00	14.40	4.40	1.90	1.60	11.50	0.10	0.70	0.40	1.30
1052.00	**70011-23**	**50.00**	**4.80**	**0.00**	**23.60**	**5.30**	**2.30**	**0.20**	**11.60**	**0.30**	**0.70**	**0.20**	**0.90**
1078.00	70011-24	61.10	4.90	0.00	14.00	3.70	2.00	0.10	9.20	2.70	1.20	0.30	0.90
1086.60	**70011-25**	**55.90**	**4.40**	**0.00**	**24.70**	**3.50**	**1.20**	**0.40**	**8.30**	**0.20**	**0.50**	**0.20**	**0.50**
1117.50	70011-26	54.60	6.40	0.00	18.90	3.70	3.80	0.50	7.80	2.20	1.50	0.10	0.60
1021.25	70011-27	56.50	4.30	0.00	18.80	5.90	2.50	0.50	8.20	1.20	1.40	0.10	0.60
1128.00	70011-28	49.80	4.10	0.00	20.90	5.20	4.00	0.50	12.70	0.00	0.70	0.10	1.90
1147.25	70011-29	59.20	3.60	0.00	18.10	2.30	4.00	0.10	11.30	0.00	1.00	0.20	0.20



Normative Analysis or NORM

- **NORM** –
- The original purpose for the norm was essentially ___________. An elaborate classification scheme based on the normative mineral percentages was proposed.
- The classification groups together rocks of ______ _____ ______________ irrespective of their actual mineralogy.
- Various types of NORMs have been proposed - CIPW, Niggli, Barth with each having specific advantages and/or disadvantages.

Normative Analysis or NORM

- The CIPW norm, originally proposed in 1919, was very elegant and based on a number of simplifications:
  1.
  2.
  3.
  4.
- Since CIPW introduced in _______ several other normative calculations have been suggested
  – e.g. Niggli norm, Barth mesonorm. The latter is used for granitic rocks.

CIPW Normative calculation

Oxides		SiO2	TiO2	Al2O3	Fe2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	Total				
wt%	70011-11	70.40	0.79	12.31	5.23		0.06	1.02	2.08	3.85	2.55	0.16	1.01	98.45				
					2.29	2.94												
Anhydrous		71.51	0.80	12.50	2.33	2.99	0.06	1.04	2.11	3.91	2.59	0.16		100				
Mol. Wt. (/)		60	80	102	160	72	71	40	56	62	94	142			Mol. wt.			
Mol. Prop.		1192	10	123	15	42	1	26	38	63	28	1			(*)	NORM		
Q	(S)	538													60	32.31	Q	
or	(K:A:6S)	165		28							28				556	15.32	or	
ab	(N:A:6S)	378		63						63					524	33.05	ab	Plag
an	(C:A:2S)	64		32					32						278	8.88	an	
lc	(K:A:4S)														436	0.00	lc	
ne	(N:A:2S)														284	0.00	ne	
C	(A)			0											102	0.00	C	
ac	(4:F+++:4S)	0			0					0					462	0.00	ac	
wo	(C:S)								0						116	0.00	wo	
en	(M:S)	1						1							100	0.12	en	Diopside
fs	(F++:S)	1				1									132	0.11	fs	
wo	(C:S)	2							2						116	0.23	wo	
en	(M:S)	25						25							100	2.47	en	Hyp
fs	(F++:S)	17				17									132	2.24	fs	
fo	(2M:S)														140	0.00	fo	Ol
fa	(2F++:S)														204	0.00	fa	
mt	(F++:F+++)				15	15									232	3.37	mt	
he	(F+++)				0										160	0.00	he	
il	(F++:T)		10			10									152	1.52	il	
ap	(3.33C:P)								4			1			310	1.18	ap	
TOTALS		1192	10	123	15	42		26	38	63	28	1						

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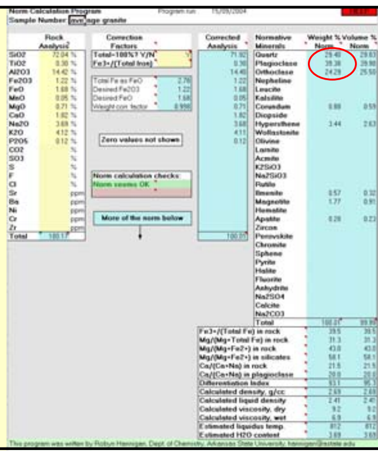

NORM for average granite composition used earlier

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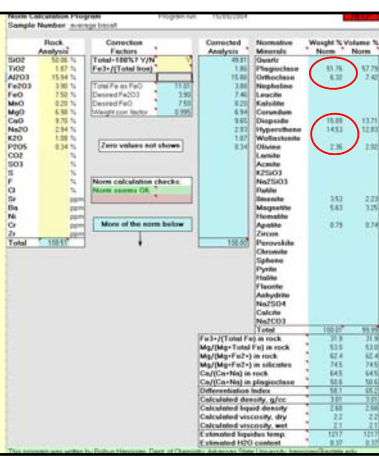

NORM for average basalt composition used earlier

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Presenting Chemical Data

- Now that we have analyzed the samples of interest how can we present the results in a succinct and coherent manner

Variation Diagrams

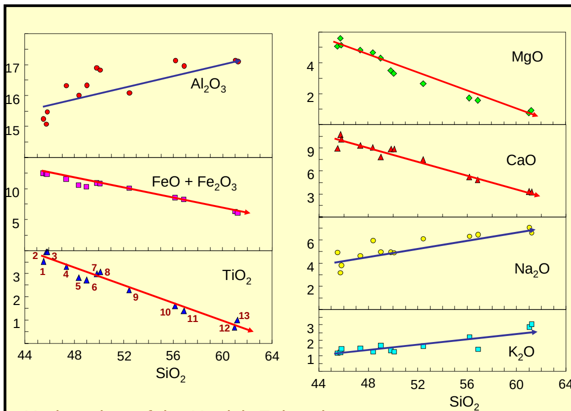
- An objective of any research program involving chemical analysis of rocks is to describe and display chemical variations within the rocks for simplicity and to facilitate condensing information
- The best way of accomplishing this is through graphical means
- Any element or oxide may be chosen as the X-axis value, resulting in a similar set of diagrams

Variation Diagrams

- Oldest method is the ________ or ______ diagram (first proposed in _____), which plots the data as _______ or _________ against other _______ or _________
- A Harker diagram uses SiO_2 as abscissa (X-axis), as it is generally the _______ _________ oxide and exhibits the greatest range in value within a suite of rocks being considered

Within province chemical variation, oxide results given in weight percent, for volcanic rocks from the Hanish-Zukur Islands, Red Sea (data from Gass et al. 1973)

The samples 1 thru 13 are arranged by increasing SiO_2 content



Harker plots of the Hanish-Zukur data

Within province chemical variation, oxide results given in weight percent, for volcanic rocks from the Hanish-Zukur Islands, Red Sea (data from Gass et al. 1973)

The samples 1 thru 13 are arranged by increasing SiO_2 content

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO2	45.51	45.74	45.83	47.36	48.37	49.00	49.82	50.09	52.45	56.17	56.87	61.01	61.22
TiO2	3.52	3.93	3.92	3.30	2.82	2.73	2.98	3.08	2.29	1.61	1.40	0.68	1.00
Al2O3	15.24	15.08	15.47	16.32	16.01	16.33	16.90	16.83	16.09	17.13	16.96	17.14	17.1
Fe2O3	3.64	4.06	9.26	4.64	5.51	2.20	1.79	1.71	5.51	3.23	4.13	5.09	2.03
FeO	8.84	8.36	3.02	6.89	5.04	8.12	9.14	9.14	4.60	5.32	4.18	1.21	4.06
MnO	0.22	0.20	0.20	0.20	0.22	0.22	0.23	0.24	0.26	0.22	0.24	0.22	0.20
MgO	5.07	5.58	5.14	4.82	4.67	4.31	3.50	3.31	2.67	1.73	1.57	0.76	0.92
CaO	8.91	10.72	10.11	9.30	9.04	7.77	8.84	8.84	7.49	5.20	4.83	3.33	3.28
Na2O	4.95	3.17	3.81	4.63	5.97	4.98	4.96	4.89	6.11	6.33	6.47	7.07	6.61
K2O	1.19	1.23	1.46	1.49	1.28	1.66	1.35	1.28	1.64	2.22	1.43	2.87	3.05
H2O+	0.97	1.15	0.98	0.89	0.39	1.98	0.23	0.26	0.38	0.52	0.46	0.24	0.21
H2O-	0	0	0	0	0.68	0	0.26	0.33	0.51	0.32	0.46	0.38	0.32
P2O5	0.85	0.68	0.74	0.83		0.89							
Total	98.91	99.9	99.94	100.67	100.00	100.19	100.00	100.00	100.00	100.00	99.00	100.00	100.00

Within province chemical variation, oxide results given in weight percent, for volcanic rocks from the Hanish-Zukur Islands, Red Sea (data from Gass et al. 1973)

The samples 1 thru 13 are arranged by increasing SiO_2 content

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO2	45.51	45.74	45.83	47.36	48.37	49.00	49.82	50.09	52.45	56.17	56.87	61.01	61.22
TiO2	3.52	3.93	3.92	3.30	2.82	2.73	2.98	3.08	2.29	1.61	1.40	0.68	1.00
Al2O3	15.24	15.08	15.47	16.32	16.01	16.33	16.90	16.83	16.09	17.13	16.96	17.14	17.1
Fe2O3	3.64	4.06	9.26	4.64	5.51	2.20	1.79	1.71	5.51	3.23	4.13	5.09	2.03
FeO	8.84	8.36	3.02	6.89	5.04	8.12	9.14	9.14	4.60	5.32	4.18	1.21	4.06
MnO	0.22	0.20	0.20	0.20	0.22	0.22	0.23	0.24	0.26	0.22	0.24	0.22	0.20
MgO	5.07	5.58	5.14	4.82	4.67	4.31	3.50	3.31	2.67	1.73	1.57	0.76	0.92
CaO	8.91	10.72	10.11	9.30	9.04	7.77	8.84	8.84	7.49	5.20	4.83	3.33	3.28
Na2O	4.95	3.17	3.81	4.63	5.97	4.98	4.96	4.89	6.11	6.33	6.47	7.07	6.61
K2O	1.19	1.23	1.46	1.49	1.28	1.66	1.35	1.28	1.64	2.22	1.43	2.87	3.05
H2O+	0.97	1.15	0.98	0.89	0.39	1.98	0.23	0.26	0.38	0.52	0.46	0.24	0.21
H2O-	0	0	0	0	0.68	0	0.26	0.33	0.51	0.32	0.46	0.38	0.32
P2O5	0.85	0.68	0.74	0.83		0.89							
Total	98.91	99.9	99.94	100.67	100.00	100.19	100.00	100.00	100.00	100.00	99.00	100.00	100.00
CaO	**5**	**1**	**2**	**3**	**4**	**8**	**6**	**7**	**9**	**10**	**11**	**12**	**13**

Order of analyses if sorted by decreasing CaO content

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Within province chemical variation, oxide results given in weight percent, for volcanic rocks from the Hanish-Zukur Islands, Red Sea (data from Gass et al. 1973)

The samples 1 thru 13 are arranged by increasing SiO_2 content

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO2	45.51	45.74	45.83	47.36	48.37	49.00	49.82	50.09	52.45	56.17	56.87	61.01	61.22
TiO2	3.52	3.93	3.92	3.30	2.82	2.73	2.98	3.08	2.29	1.61	1.40	0.68	1.00
Al2O3	15.24	15.08	15.47	16.32	16.01	16.33	16.90	16.83	16.09	17.13	16.96	17.14	17.1
Fe2O3	3.64	4.06	9.26	4.64	5.51	2.20	1.79	1.71	5.51	3.23	4.13	5.09	2.03
FeO	8.84	8.36	3.02	6.89	5.04	8.12	9.14	9.14	4.60	5.32	4.18	1.21	4.06
MnO	0.22	0.20	0.20	0.20	0.22	0.22	0.23	0.24	0.26	0.22	0.24	0.22	0.20
MgO	5.07	5.58	5.14	4.82	4.67	4.31	3.50	3.31	2.67	1.73	1.57	0.76	0.92
CaO	8.91	10.72	10.11	9.30	9.04	7.77	8.84	8.84	7.49	5.20	4.83	3.33	3.28
Na2O	4.95	3.17	3.81	4.63	5.97	4.98	4.96	4.89	6.11	6.33	6.47	7.07	6.61
K2O	1.19	1.23	1.46	1.49	1.28	1.66	1.35	1.28	1.64	2.22	1.43	2.87	3.05
H2O+	0.97	1.15	0.98	0.89	0.39	1.98	0.23	0.26	0.38	0.52	0.46	0.24	0.21
H2O-	0	0	0	0	0.68	0	0.26	0.33	0.51	0.32	0.46	0.38	0.32
P2O5	0.85	0.68	0.74	0.83		0.89							
Total	98.91	99.9	99.94	100.67	100.00	100.19	100.00	100.00	100.00	100.00	99.00	100.00	100.00
CaO	**5**	**1**	**2**	**3**	**4**	**8**	**6**	**7**	**9**	**10**	**11**	**12**	**13**
Na2O	**5**	**1**	**2**	**3**	**8**	**7**	**6**	**4**	**9**	**10**	**11**	**13**	**12**

Order of analyses if sorted by increasing Na_2O content

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For large datasets, graphical methods are preferred.

Harker diagram for Crater Lake

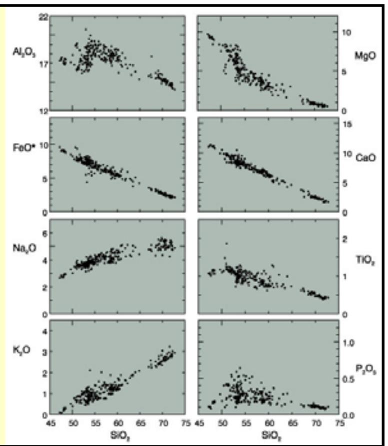


Figure 8-2. Harker variation diagram for 310 analyzed volcanic rocks from Crater Lake (Mt. Mazama), Oregon Cascades. Data compiled by Rick Conrey (personal communication).

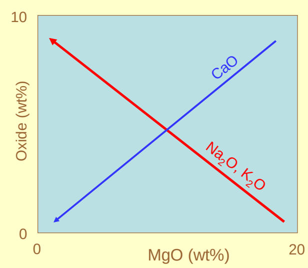
Fractionation Indices

- No genetic link can be inferred from Harker diagrams, i.e. that the lowest SiO_2 sample represents the original or first liquid
- To attempt to discern a genetic link between analyses in a given suite of rocks various fractionation indices have been developed
- These indices are not realistic, but provide a first approximation to discerning a genetic link between samples

Fractionation Indices

MgO Index

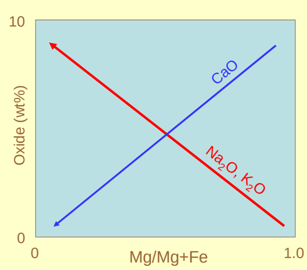
-
-



Fractionation Indices

Mg-Fe Ratios

-
- Involve a ratio of Mg to Fe:
  -
  -
  -



Fractionation Indices

Normative Ab/Ab+An

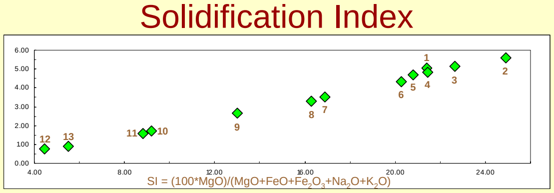
-
-
-
-

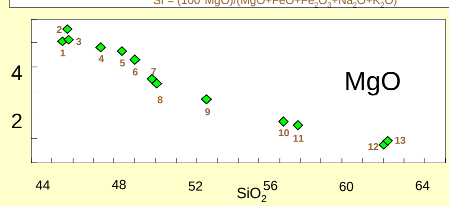
Fractionation Indices

Solidification Index

- SI= $100MgO/(MgO+FeO+Fe_2O_3+Na_2O+K_2O)$
- When applied to ________, the SI is similar to the Mg/Fe ratio, due to the ______________
- As fractionation progresses, the residual liquids become ________ in _______, thus Na_2O and K_2O contents offset the Mg-Fe index
- For _______ rocks, SI is high
- For _______ rocks, SI is low

Solidification Index





Data from Hanish-Zukur Islands

Fractionation Indices

Differentiation Index

- DI = normative Q+Or+Ab+Ne+Ks+Lc
- Based on _____________ analysis
- For mafic rocks
  - DI is ______, as the minerals used are ______ in the NORM
- For felsic rocks
  - DI is ______, as the minerals in these rocks are _________ in the NORM

Triangular Variation Diagrams

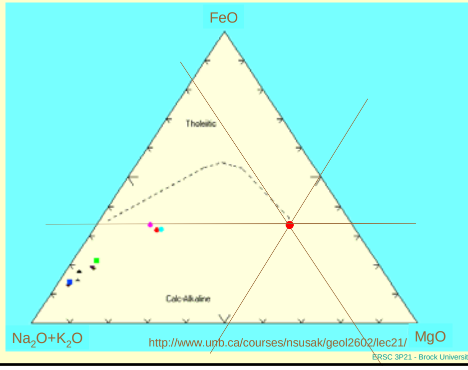
- The previous diagrams each essentially employ two variables
- It is possible to graphically present data such that 3 chemical parameters are represented
- Two diagrams used
  - AFM
  - Na_2O-K_2O-CaO
- Big disadvantage is that the absolute values of the analysis are not readily evident, as they must be ratioed to plot on the diagram

AFM

- Used mainly for ________ rocks, as MgO and FeO are abundant in these lithologies

• A = $Na_2O + K_2O$	5	17%
• F = FeO (+ Fe_2O_3)	10	33%
• M = MgO	<u>15</u>	<u>50%</u>
	30	100%

AFM



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$CaO-Na_2O-K_2O$

- Used mainly for _______ rocks, as these three oxides are abundant in these lithologies
- Simple ratio of either weight percent of atomic proportions are used to calculate the data points

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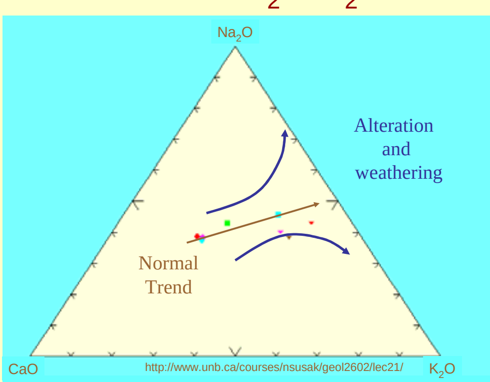
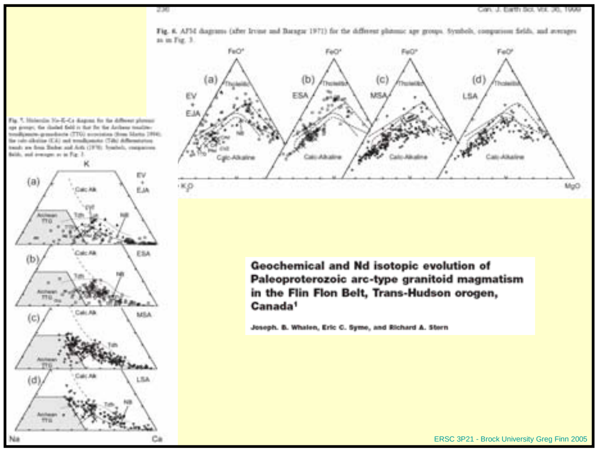
$CaO-Na_2O-K_2O$




Geochemical and Nd isotopic evolution of Paleoproterozoic arc-type granitoid magmatism in the Flin Flon Belt, Trans-Hudson orogen, Canada[1]
Joseph. B. Whalen, Eric C. Syme, and Richard A. Stern
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