Magmatic evolution of the Late Devonian Mount Douglas leucogranites, southwestern New Brunswick, Canada; An example of extreme fractional crystallization

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Abstract: The Late Devonian Mount Douglas intrusive suite (MD, ~600 km^2) of southwestern New Brunswick, Canada, eastern part of the Saint George Batholith, is a suite of peraluminous leucogranites extended from Red Rock Lake to Mount Douglas. Extreme fractional crystallization associated with formation of this suite is the most important factor affecting the magmatic evolution, producing three compositionally and chronologically different intrusive units, Dmd1, Dmd2, and Dmd3. Petrochemical data show that the subunits of the Mount Douglas Granite have within-plate geochemical character with evidence of hybrid I- and S-type affinity.

Very low K/Rb (average 102.7), Nb/Ta (≤ 6.8), and Zr/Hf (≤ 37.45) ratios in Dmd3 compared to Dmd1 possibly reflect significant involvement of extreme low T crystal fractionation in the last- stages of magmatic differentiation; The continuous variation trends for many major and trace elements (e.g., Zr vs. TiO_2, Zr/Hf vs. K/Rb, F vs. K/Rb, and Pb vs. Ba) suggest that probably Dmd2 and Dmd3 were generated by extensive fractionation of the parental Dmd1 magma. Also, normalized to the least-evolved sample of the MG granites (Dmd1), the Dmd3 unit is the most enriched in Rb, Th, U, Ce, Ta, Pb, Nd, Sm, Dy, Y, Yb, and Lu, and depletion of Cs, Ba, Sr, P, Zr, Eu, and Ti content, reflects their production of the same parental magma by crystal fractionation from Dmd1 to Dmd3. A flat "birdwing shape" REE patterns with the most pronounced negative Eu anomalies and the lowest $(La/Yb)_N$ (ranging from 1.7-7.4) ratios of Dmd3 show the highly evolved attributes of Dmd3. Calculation of zircon saturation temperatures supports an interpretation of crystal fractionation from Dmd1 to Dmd3. Estimated average temperatures using the bulk rock Zr composition for Dmd1, Dmd2, and Dmd3 range 747-826˚C, 733-817˚C, and 729-816˚C, respectively. All above data suggest that they might have a single genetic group with different fractionation originated from a homogenous parental magma, in which this fractionation increases from the early unit (Dmd1) to the latest unit (Dmd3); significant mineral occurrences, such as Sn, W, and Mo, seem to be mostly associated with the latest and most highly differentiated Dmd3 intrusive phases.

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Magmatic Evolution of the Late Devonian Mount Douglas Leucogranites, Southwestern New Brunswick, Canada; an Example of Extreme Fractional Crystallization

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David Lentz

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UNIVERSITY OF NEW BRUNSWICK

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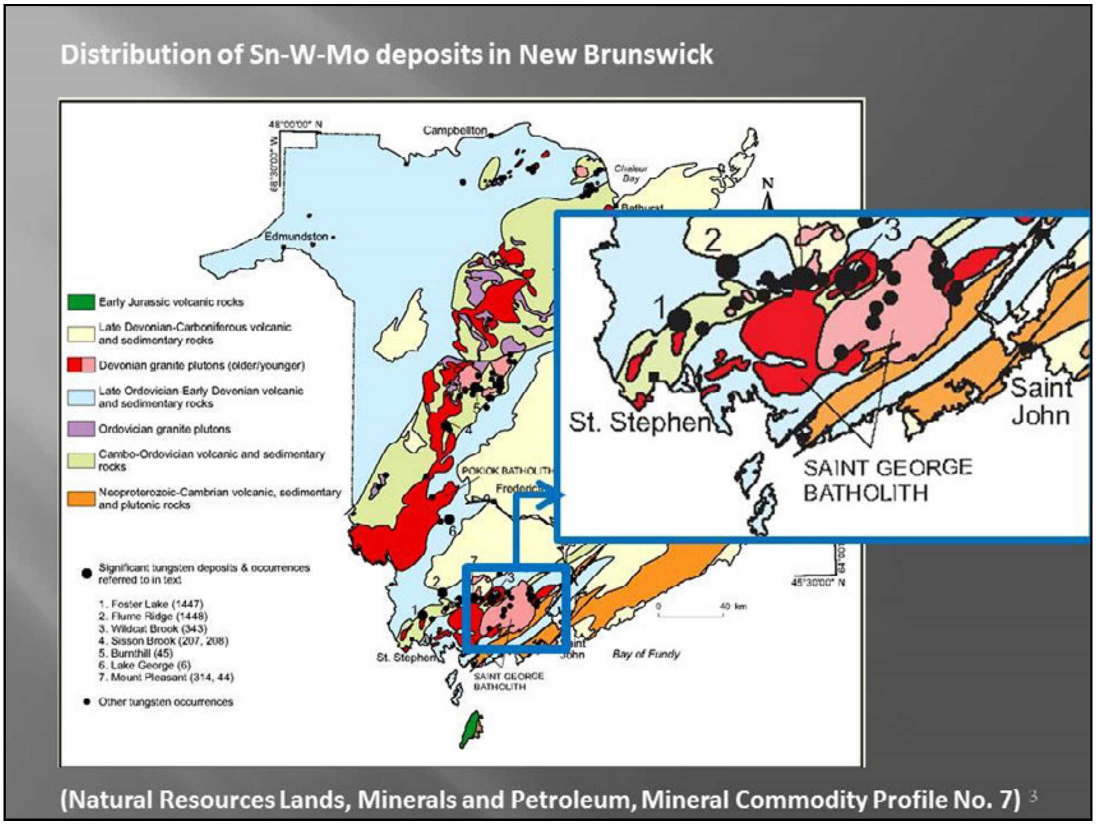
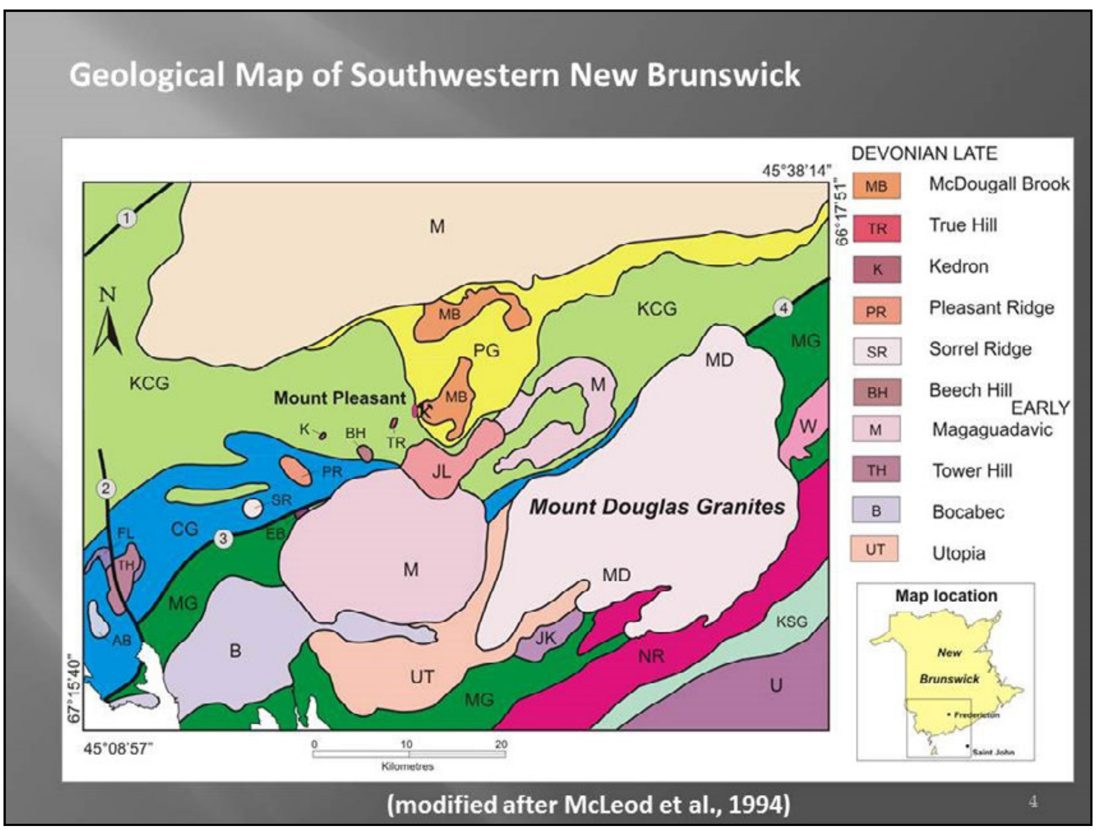
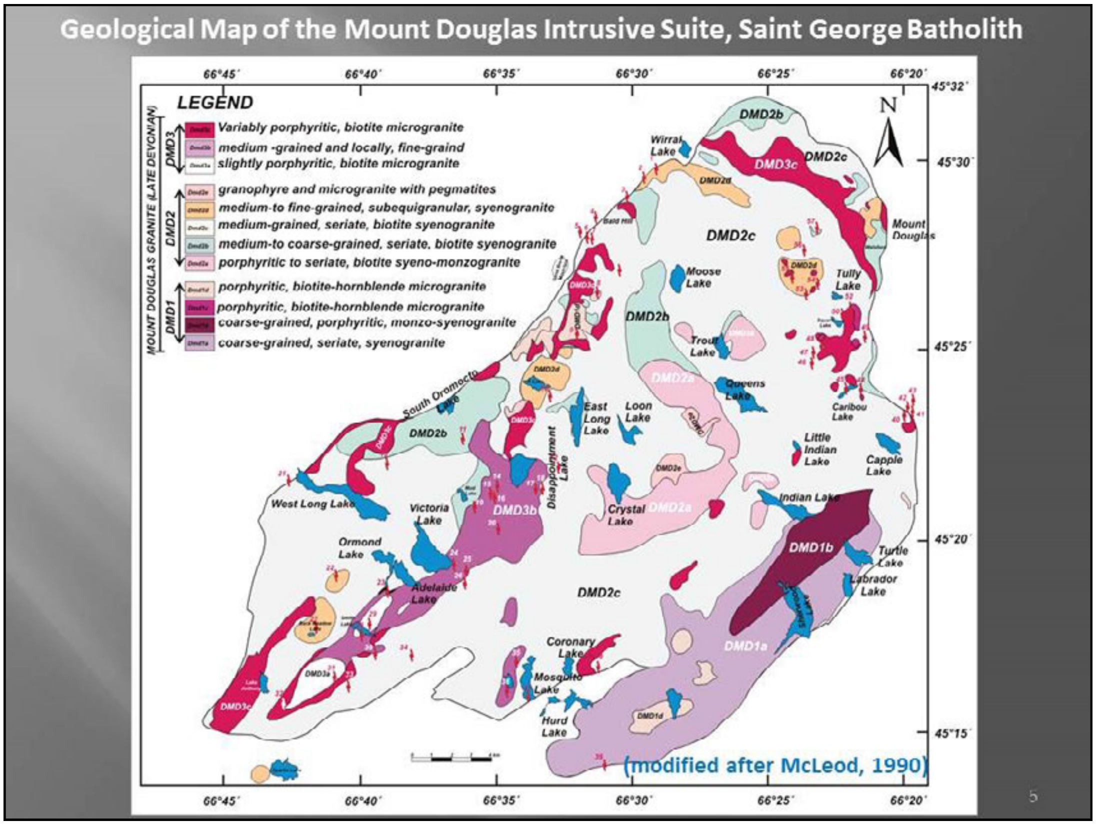
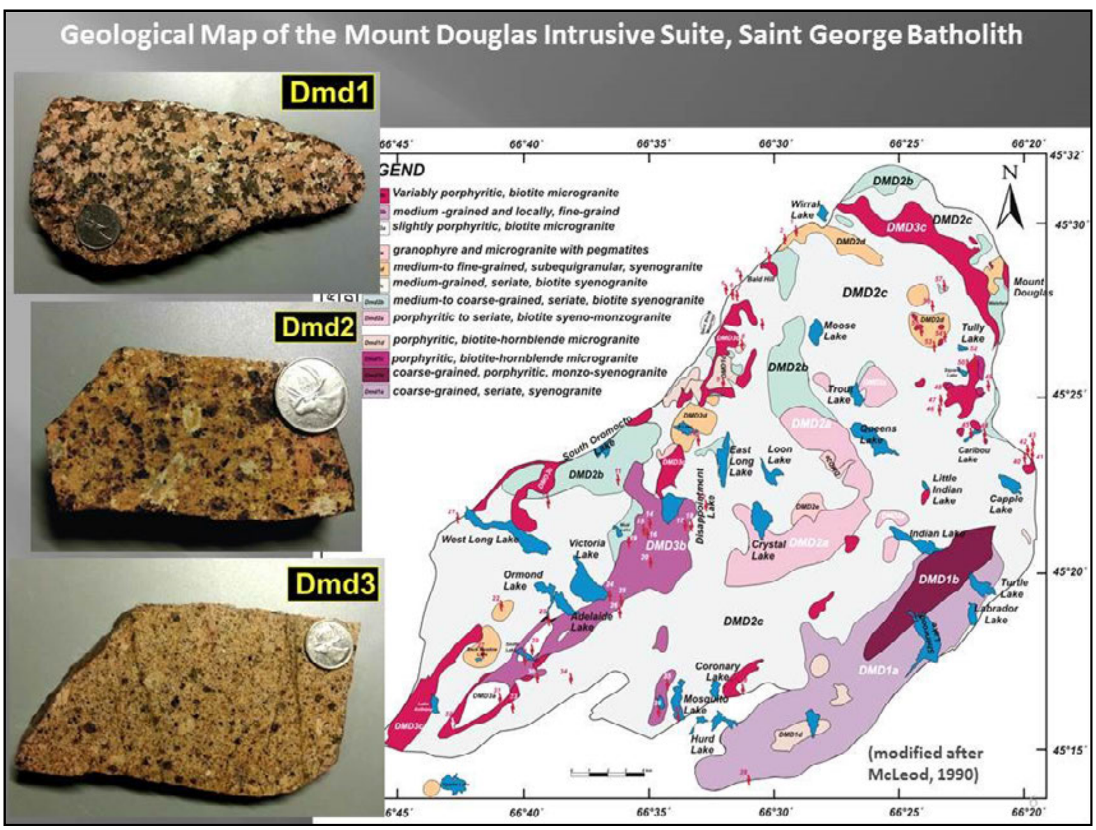
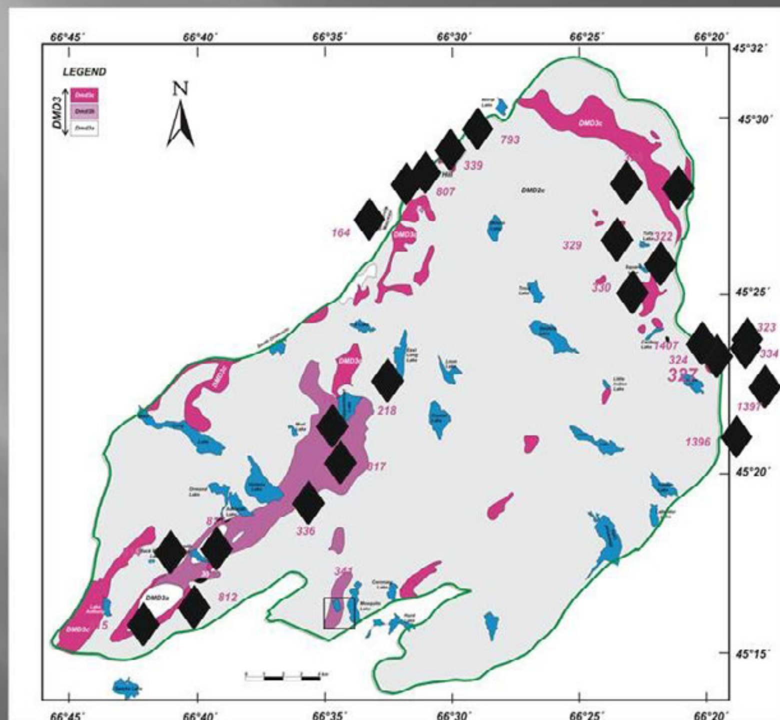

Distribution of Sn-W-Mo deposits in New Brunswick
Campbellton
Chaleur Bay
Bathurst
Edmundston
Early Jurassic volcanic rocks
Late Devonian-Carboniferous volcanic and sedimentary rocks
Devonian granite plutons (older/younger)
Late Ordovician Early Devonian volcanic and sedimentary rocks
Ordovician granite plutons
Cambo-Ordovician volcanic and sedimentary rocks
Neoproterozoic-Cambrian volcanic, sedimentary and plutonic rocks
Significant tungsten deposits & occurrences referred to in text
1. Foster Lake (1447)
2. Flume Ridge (1448)
3. Wildcat Brook (343)
4. Sisson Brook (207, 208)
5. Burnthill (45)
6. Lake George (6)
7. Mount Pleasant (314, 44)
Other tungsten occurrences
POKIOK BATHOLITH
Bay of Fundy
St. Stephen
Saint John
SAINT GEORGE BATHOLITH
45°30'00" N
40 km
(Natural Resources Lands, Minerals and Petroleum, Mineral Commodity Profile No. 7)
3


Geological Map of Southwestern New Brunswick
45°38'14"
66°17'51"
67°15'40"
45°08'57"
M
KCG
MB
PG
Mount Pleasant
K
BH
TR
PR
SR
JL
CG
EB
FL
TH
MG
AB
B
UT
JK
NR
KSG
U
W
MD
Mount Douglas Granites
0 10 20
Kilometres
DEVONIAN LATE
MB McDougall Brook
TR True Hill
K Kedron
PR Pleasant Ridge
SR Sorrel Ridge
BH Beech Hill
EARLY
M Magaguadavic
TH Tower Hill
B Bocabec
UT Utopia
Map location
New Brunswick
Fredericton
Saint John
(modified after McLeod et al., 1994)
4


Geological Map of the Mount Douglas Intrusive Suite, Saint George Batholith
LEGEND
MOUNT DOUGLAS GRANITE (LATE DEVONIAN)
DMD3
Variably porphyritic, biotite microgranite
medium -grained and locally, fine-graind
slightly porphyritic, biotite microgranite
DMD2
granophyre and micrograinite with pegmatites
medium-to fine-grained, subequigranular, syenogranite
medium-grained, seriate, biotite syenogranite
medium-to coarse-grained, seriate, biotite syenogranite
porphyritic to seriate, biotite syeno-monzogranite
DMD1
porphyritic, biotite-hornblende microgranite
porphyritic, biotite-hornblende microgranite
coarse-grained, porphyritic, monzo-syenogranite
coarse-grained, seriate, syenogranite
66°45′
66°40′
66°35′
66°30′
66°25′
66°20′
45°32′
45°30′
45°25′
45°20′
45°15′
N
DMD2b
DMD3c
DMD2c
DMD2a
DMD3b
DMD1b
DMD1a
Wirral Lake
Mount Douglas
Moose Lake
Tully Lake
Trout Lake
Queens Lake
South Oromocto Lake
East Long Lake
Loon Lake
Disappointment Lake
Caribou Lake
Little Indian Lake
Capple Lake
West Long Lake
Victoria Lake
Crystal Lake
Indian Lake
Ormond Lake
Adelaide Lake
Turtle Lake
Labrador Lake
Coronary Lake
Mosquito Lake
Hurd Lake
(modified after McLeod, 1990)
5


Geological Map of the Mount Douglas Intrusive Suite, Saint George Batholith
Dmd1
Dmd2
Dmd3
Variably porphyritic, biotite microgranite
medium -grained and locally, fine-graind
slightly porphyritic, biotite microgranite
granophyre and micrograinite with pegmatites
medium-to fine-grained, subequigranular, syenogranite
medium-grained, seriate, biotite syenogranite
medium-to coarse-grained, seriate, biotite syenogranite
porphyritic to seriate, biotite syeno-monzogranite
porphyritic, biotite-hornblende microgranite
porphyritic, biotite-hornblende microgranite
coarse-grained, porphyritic, monzo-syenogranite
coarse-grained, seriate, syenogranite
DMD2b
DMD3c
DMD2c
DMD2a
DMD3b
DMD1b
DMD1a
Mount Douglas
Moose Lake
Tully Lake
Trout Lake
Queens Lake
East Long Lake
Loon Lake
Caribou Lake
Little Indian Lake
Capple Lake
West Long Lake
Victoria Lake
Crystal Lake
Indian Lake
Ormond Lake
Adelaide Lake
Turtle Lake
Labrador Lake
Coronary Lake
Mosquito Lake
Hurd Lake
(modified after McLeod, 1990)

Mineral occurrences associated with the Mount Douglas Suite



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Geochemical Studies

McLeod's whole rock analytical data (1990)

high content:

SiO_2 (68-78 wt.%)

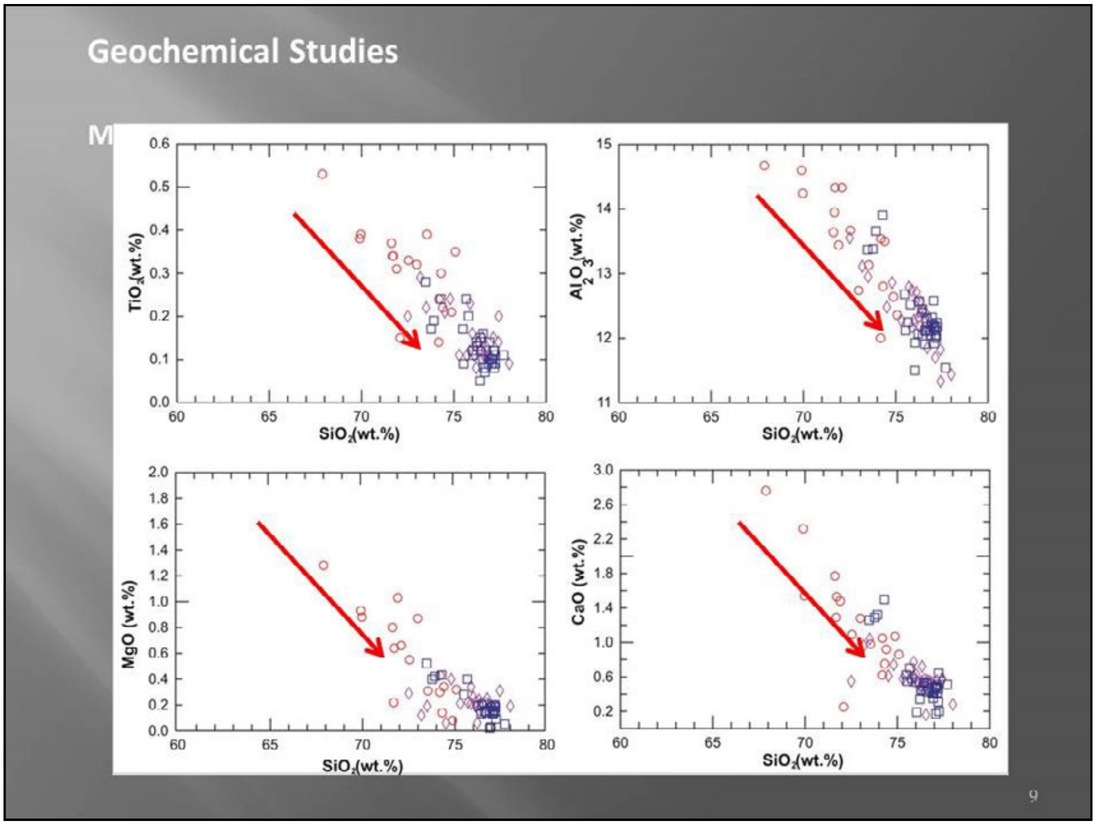
K_2O (3.5-7.8)

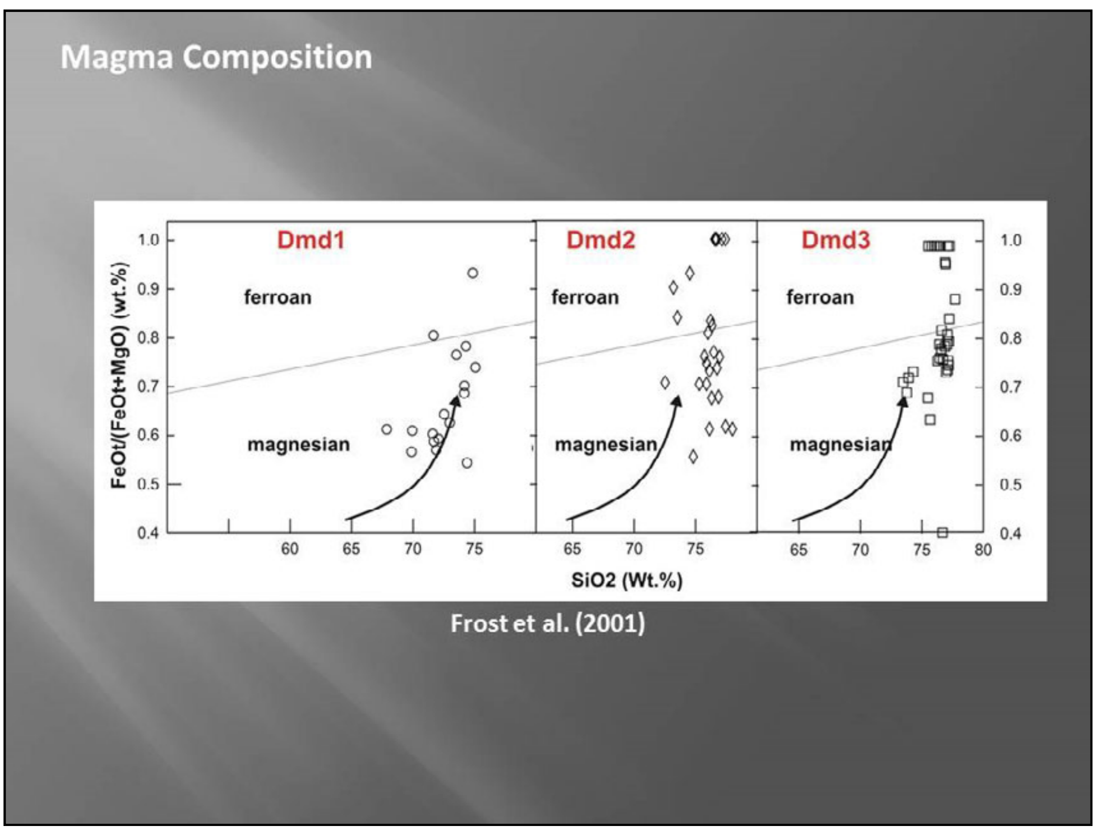
(Fe_2O_3+FeO)/MgO (average 8.7)

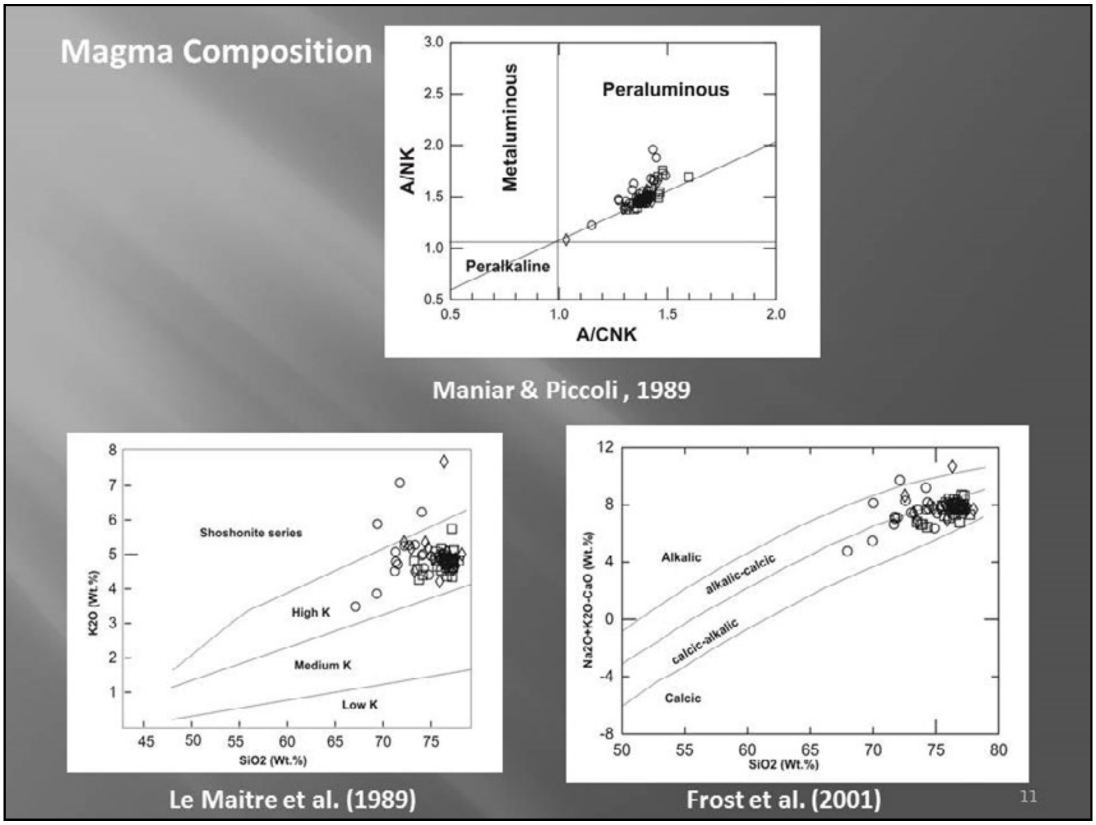
Alkalis

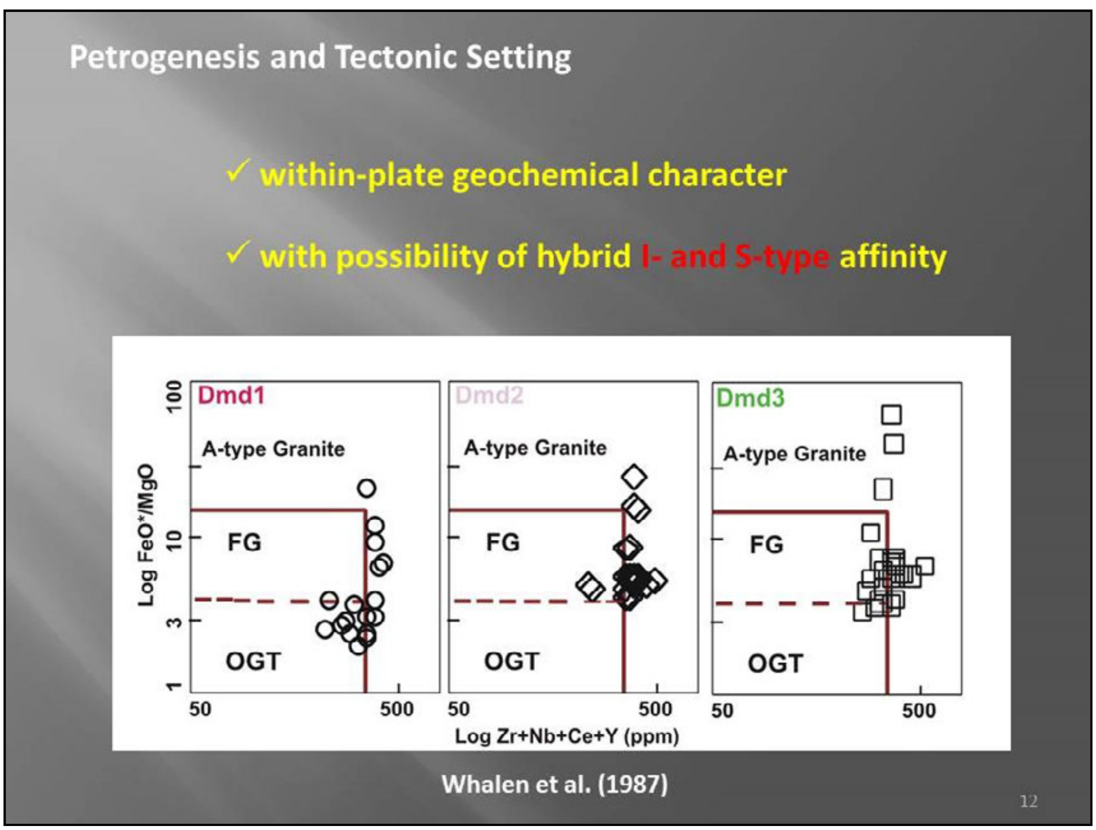
Dmd3
SiO2: 76.4 wt.%

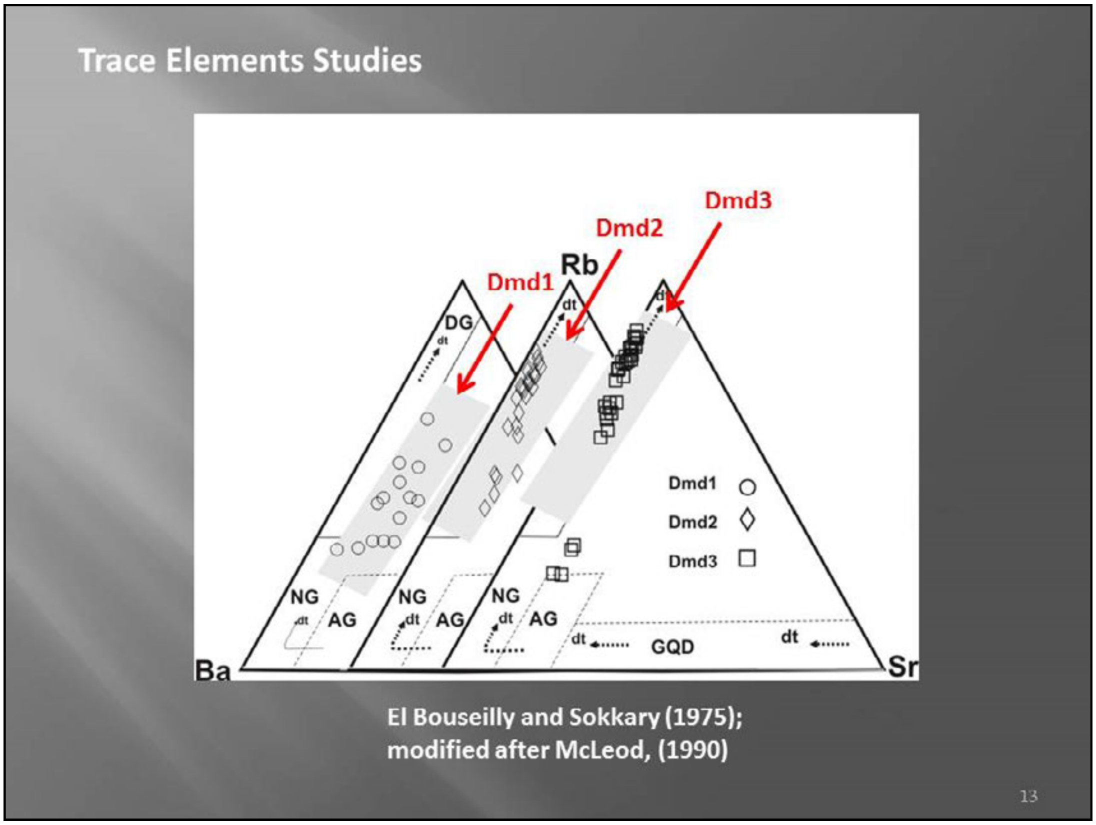
8

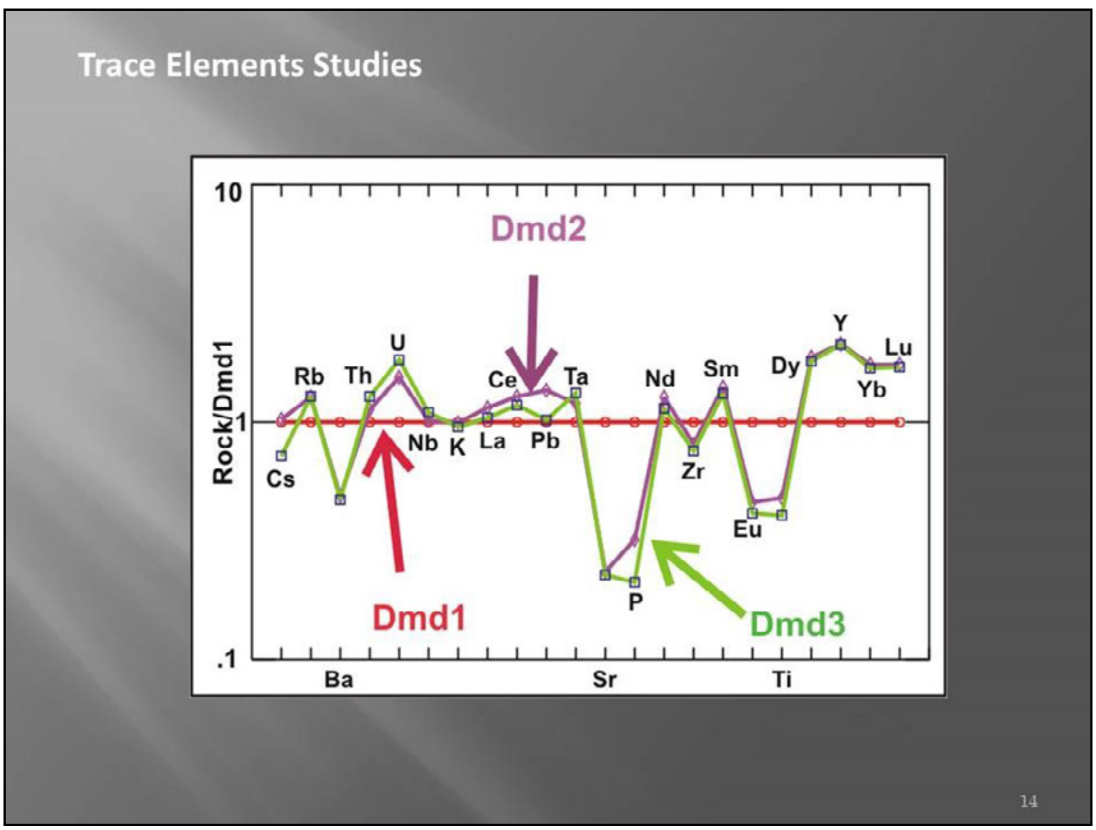

Geochemical Studies
M
TiO_2(wt.%)
Al_2O_3(wt.%)
MgO (wt.%)
CaO (wt.%)
SiO_2(wt.%)
9

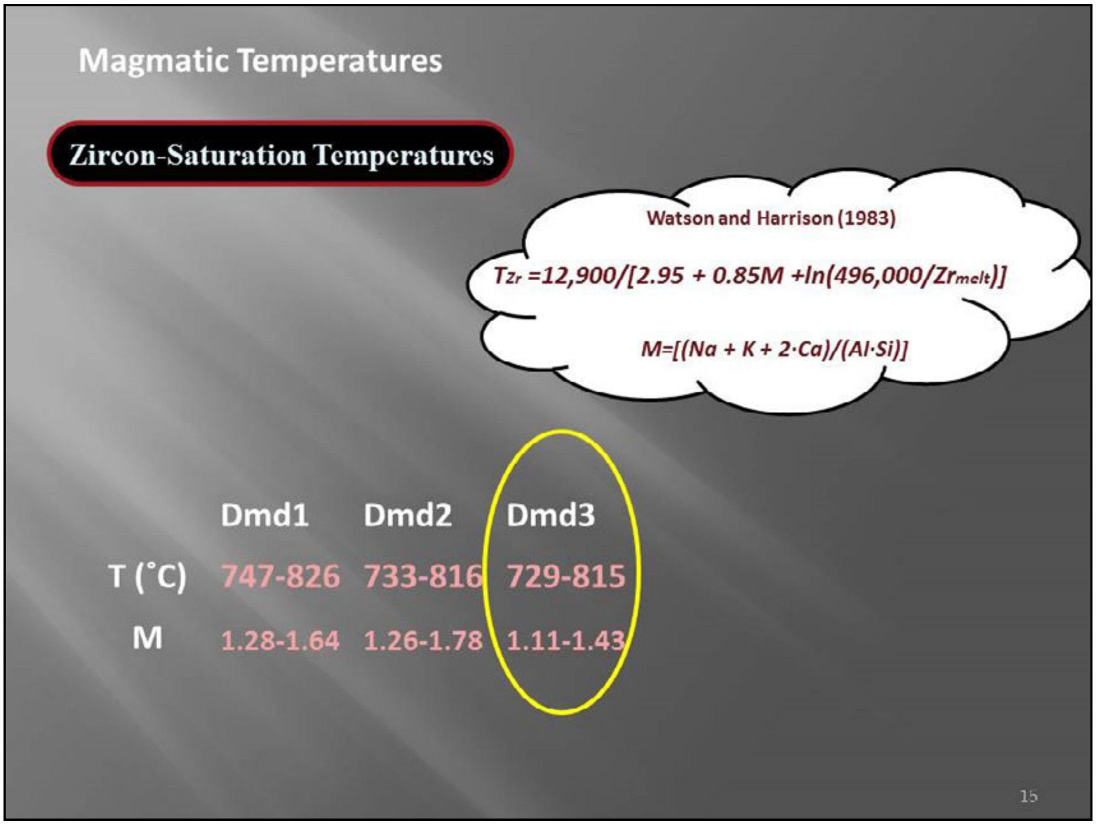

Magma Composition
Dmd1
Dmd2
Dmd3
ferroan
magnesian
FeOt/(FeOt+MgO) (wt.%)
SiO2 (Wt.%)
Frost et al. (2001)

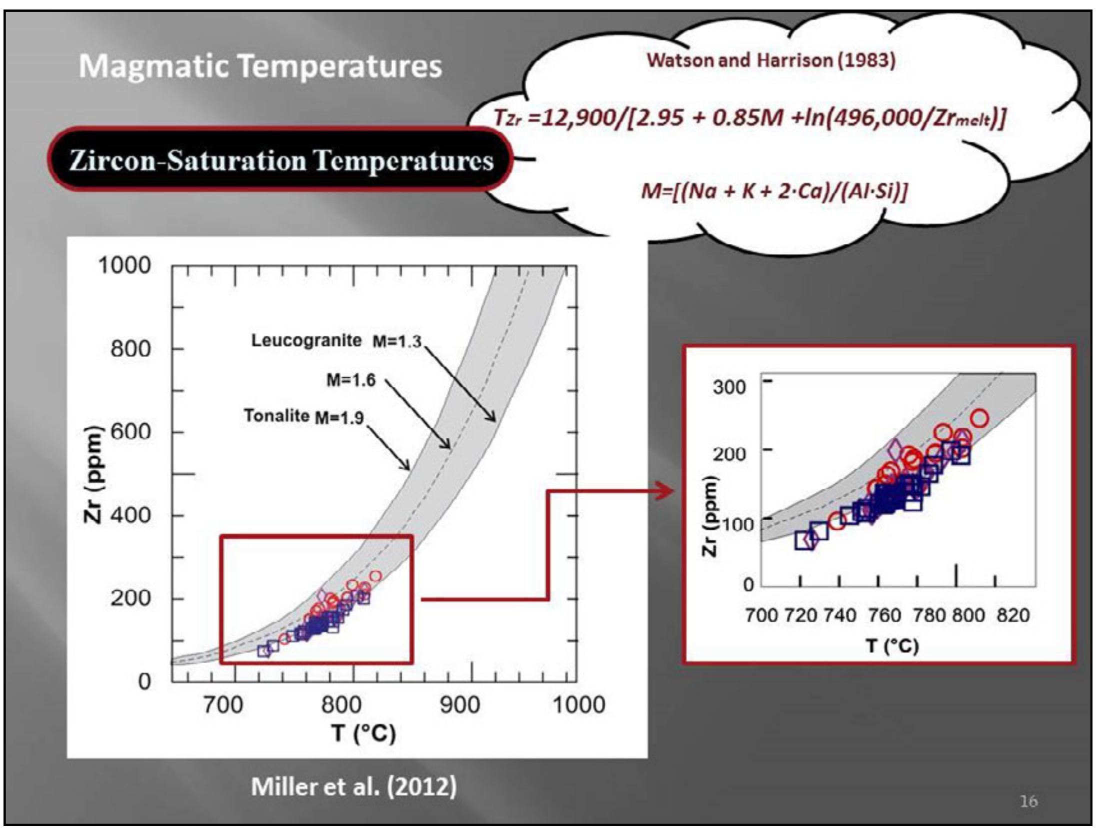

Magma Composition
Metaluminous
Peraluminous
Peralkaline
A/NK
A/CNK
Maniar & Piccoli , 1989
Shoshonite series
High K
Medium K
Low K
K2O (Wt.%)
SiO2 (Wt.%)
Alkalic
alkalic-calcic
calcic-alkalic
Calcic
Na2O+K2O-CaO (Wt.%)
SiO2 (Wt.%)
Le Maitre et al. (1989)
Frost et al. (2001)
11

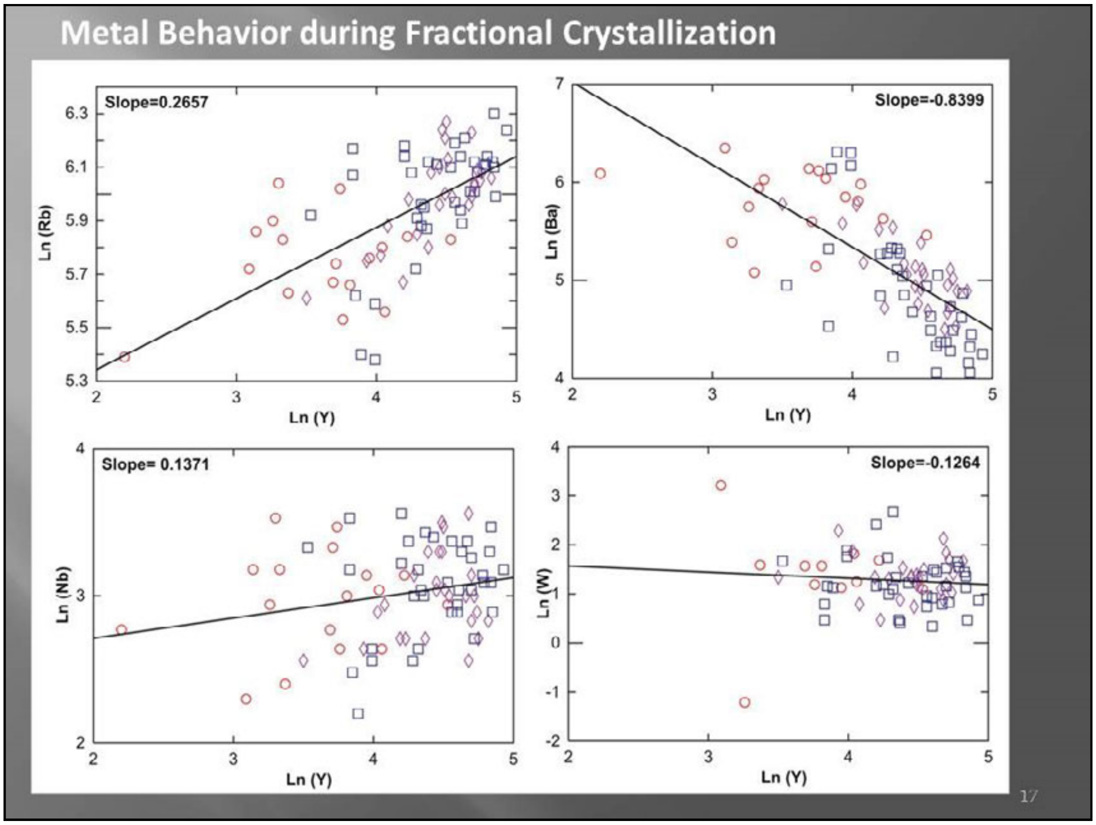

Petrogenesis and Tectonic Setting
✓ within-plate geochemical character
✓ with possibility of hybrid I- and S-type affinity
Dmd1
Dmd2
Dmd3
A-type Granite
FG
OGT
Log FeO*/MgO
Log Zr+Nb+Ce+Y (ppm)
Whalen et al. (1987)
12

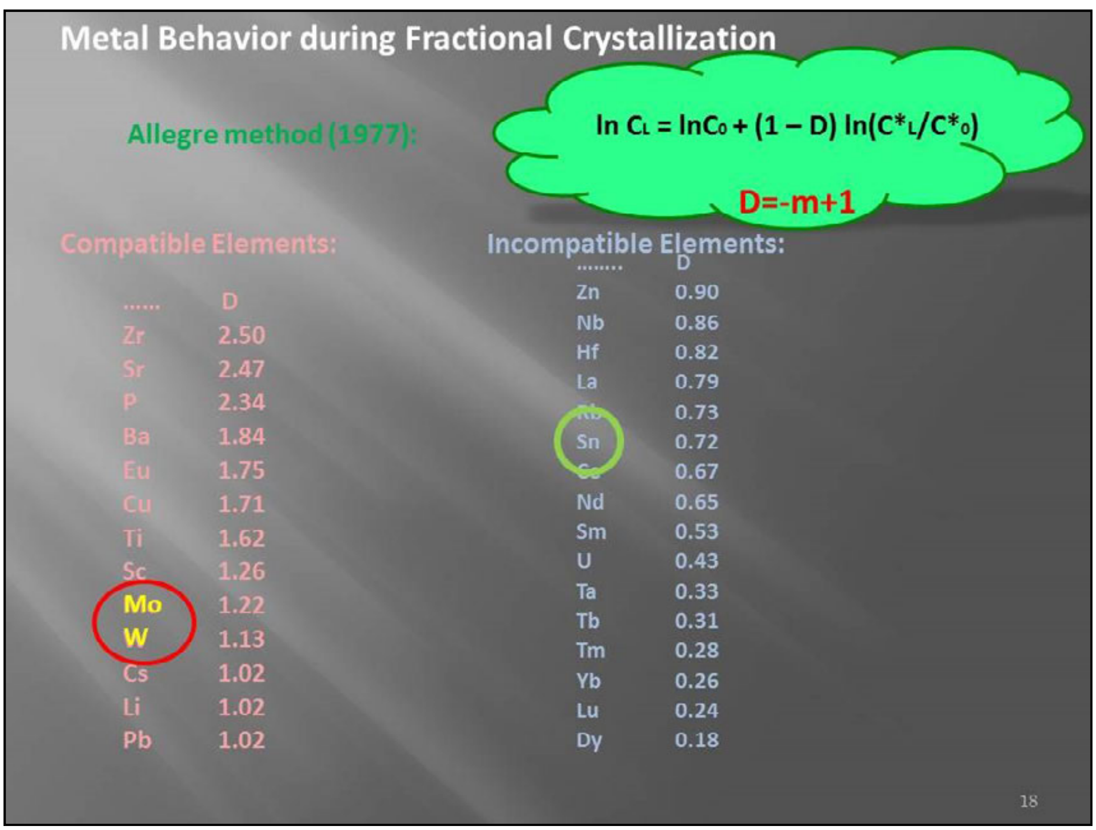

Trace Elements Studies
Dmd3
Dmd2
Rb
Dmd1
DG
dt
NG
AG
GQD
Ba
Sr
Dmd1
Dmd2
Dmd3
El Bouseilly and Sokkary (1975);
modified after McLeod, (1990)
13

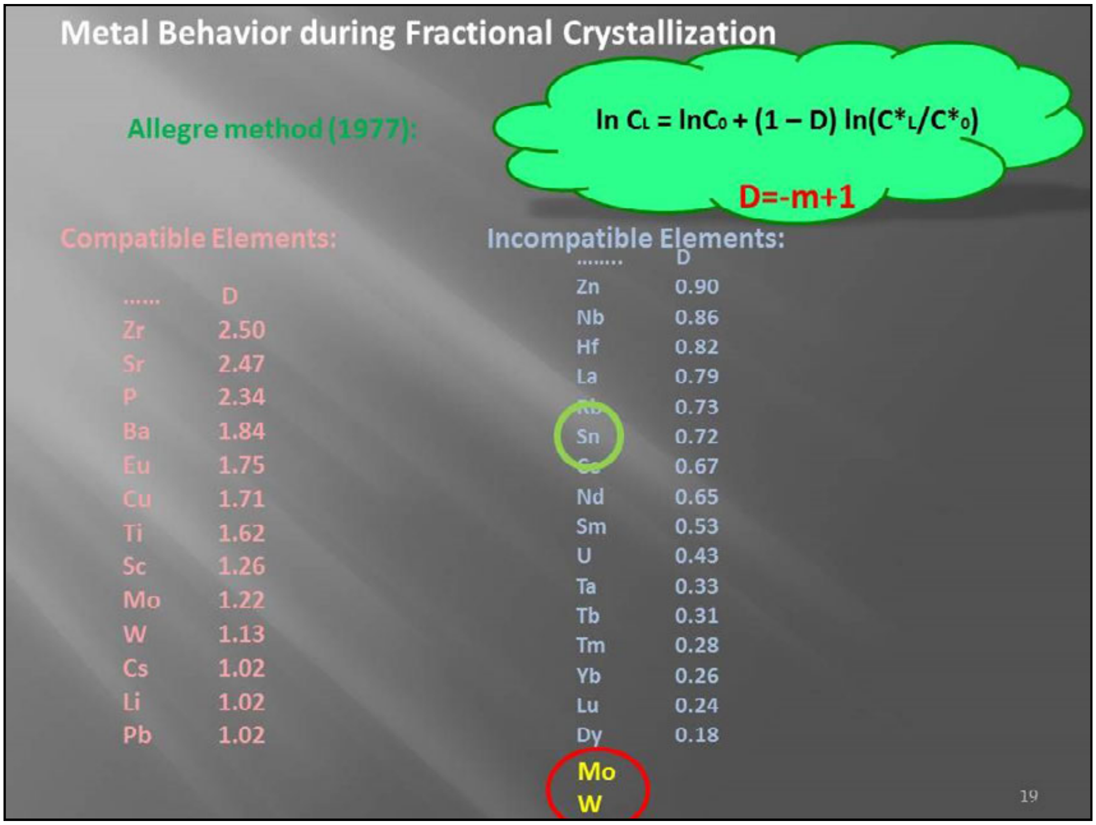

Trace Elements Studies
10
1
.1
Rock/Dmd1
Dmd2
Dmd1
Dmd3
Cs
Rb
Th
U
Nb
K
La
Ce
Pb
Ta
P
Nd
Zr
Sm
Eu
Dy
Y
Yb
Lu
Ba
Sr
Ti
14


Magmatic Temperatures
Zircon-Saturation Temperatures
Watson and Harrison (1983)
Tzr =12,900/[2.95 + 0.85M +ln(496,000/Zrmelt)]
M=[(Na + K + 2·Ca)/(Al·Si)]
Dmd1 Dmd2 Dmd3
T (˚C) 747-826 733-816 729-815
M 1.28-1.64 1.26-1.78 1.11-1.43
15


Magmatic Temperatures
Zircon-Saturation Temperatures
Watson and Harrison (1983)
Tzr =12,900/[2.95 + 0.85M +ln(496,000/Zrmelt)]
M=[(Na + K + 2·Ca)/(Al·Si)]
Leucogranite M=1.3
M=1.6
Tonalite M=1.9
Zr (ppm)
T (°C)
Miller et al. (2012)
16


Metal Behavior during Fractional Crystallization
Slope=0.2657
Ln (Rb)
Ln (Y)
Slope=-0.8399
Ln (Ba)
Ln (Y)
Slope= 0.1371
Ln (Nb)
Ln (Y)
Slope=-0.1264
Ln (W)
Ln (Y)
17


Metal Behavior during Fractional Crystallization
Allegre method (1977):
ln CL = lnC0 + (1 – D) ln(C*L/C*0)
D=-m+1
Compatible Elements:
...... D
Zr 2.50
Sr 2.47
P 2.34
Ba 1.84
Eu 1.75
Cu 1.71
Ti 1.62
Sc 1.26
Mo 1.22
W 1.13
Cs 1.02
Li 1.02
Pb 1.02
Incompatible Elements:
.... D
Zn 0.90
Nb 0.86
Hf 0.82
La 0.79
0.73
Sn 0.72
0.67
Nd 0.65
Sm 0.53
U 0.43
Ta 0.33
Tb 0.31
Tm 0.28
Yb 0.26
Lu 0.24
Dy 0.18
18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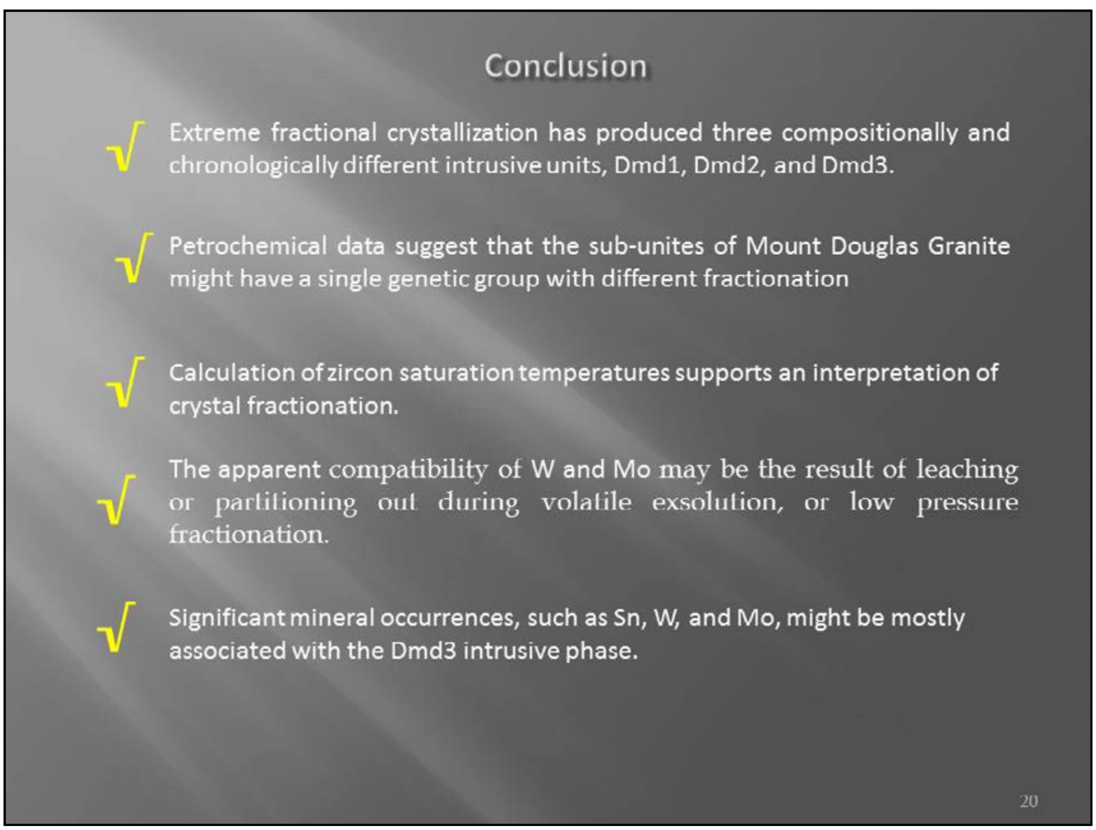
W 1.13
Cs 1.02
Li 1.02
Pb 1.02
Incompatible Elements:
.... D
Zn 0.90
Nb 0.86
Hf 0.82
La 0.79
0.73
Sn 0.72
0.67
Nd 0.65
Sm 0.53
U 0.43
Ta 0.33
Tb 0.31
Tm 0.28
Yb 0.26
Lu 0.24
Dy 0.18
Mo
W
19


Conclusion
√ Extreme fractional crystallization has produced three compositionally and chronologically different intrusive units, Dmd1, Dmd2, and Dmd3.
√ Petrochemical data suggest that the sub-unites of Mount Douglas Granite might have a single genetic group with different fractionation
√ Calculation of zircon saturation temperatures supports an interpretation of crystal fractionation.
√ The apparent compatibility of W and Mo may be the result of leaching or partitioning out during volatile exsolution, or low pressure fractionation.
√ Significant mineral occurrences, such as Sn, W, and Mo, might be mostly associated with the Dmd3 intrusive phase.
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