Origin of sulfide mineralization of the Main Sulfide Zone, Shurugwi Subchamber of the Great Dyke: summary of recent studies

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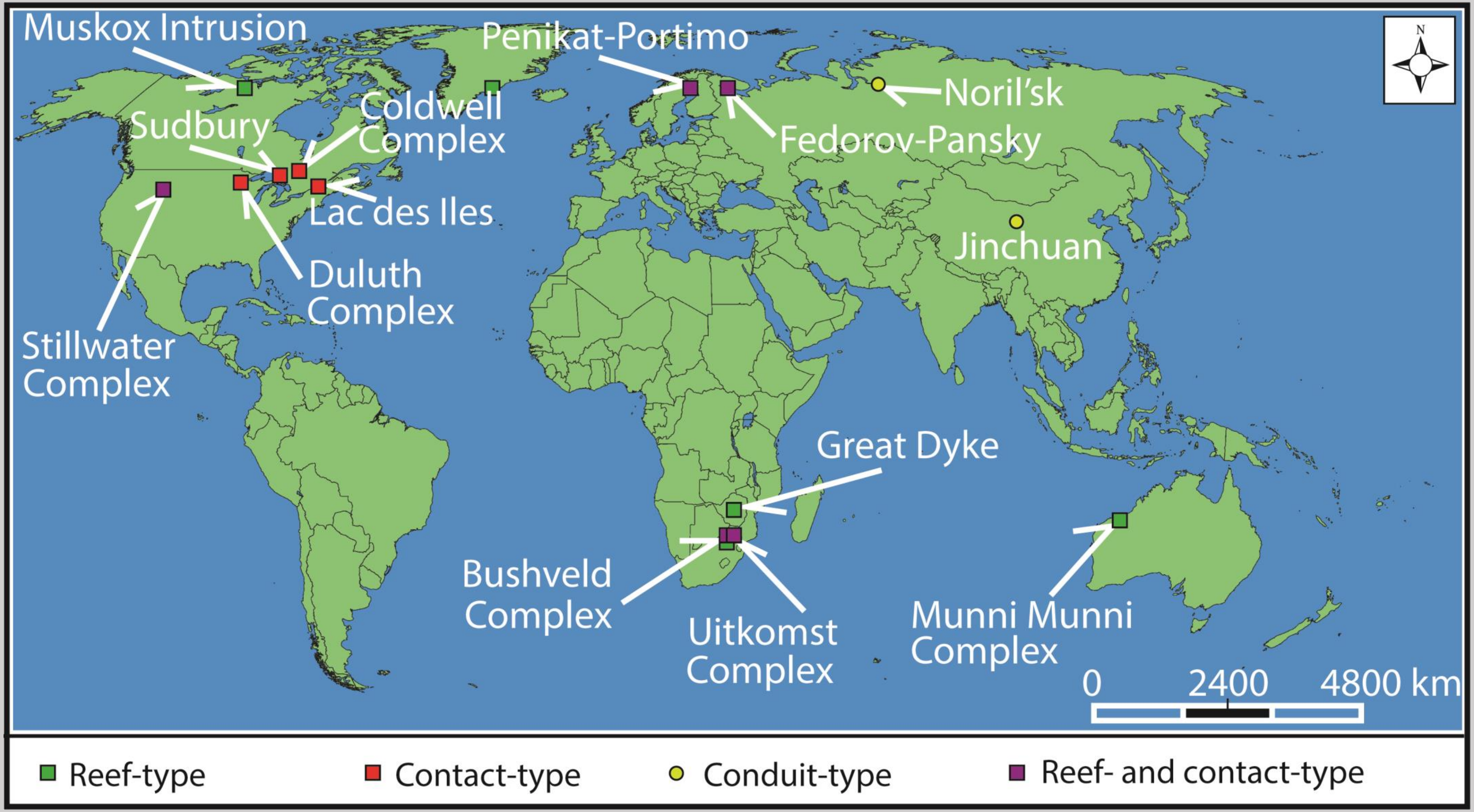
Purpose of study

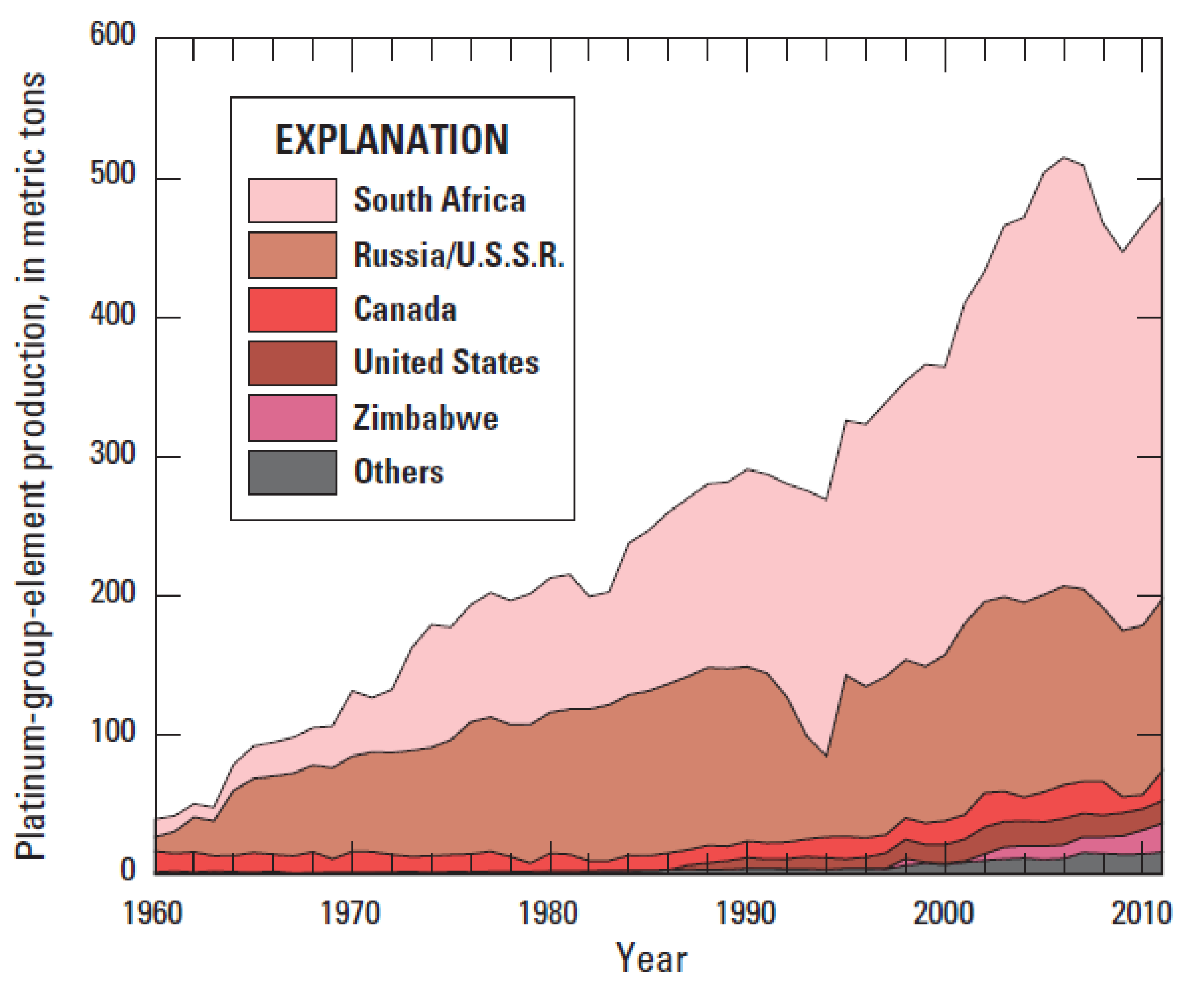
- Platinum-group elements continue to play a critical role in the world economy:
- Decrease harmful emissions from automobiles; catalysts for bulk-chemical production and petroleum refining; dental and medical devices; electronic applications e.g. in computer hard disks; jewelry
- Very few suitable rocks/countries from which PGEs can be obtained
- Great Dyke of Zimbabwe: a critical late entrant onto the PGE supply chain (hosts the world's 2^{nd} largest PGE reserves)
- Great Dyke PGE mines are lowest cash-cost platinum mines in the world
- Consequently, it is of significance that we understand the genesis of Great Dyke PGEs

Models for the origin of PGEs

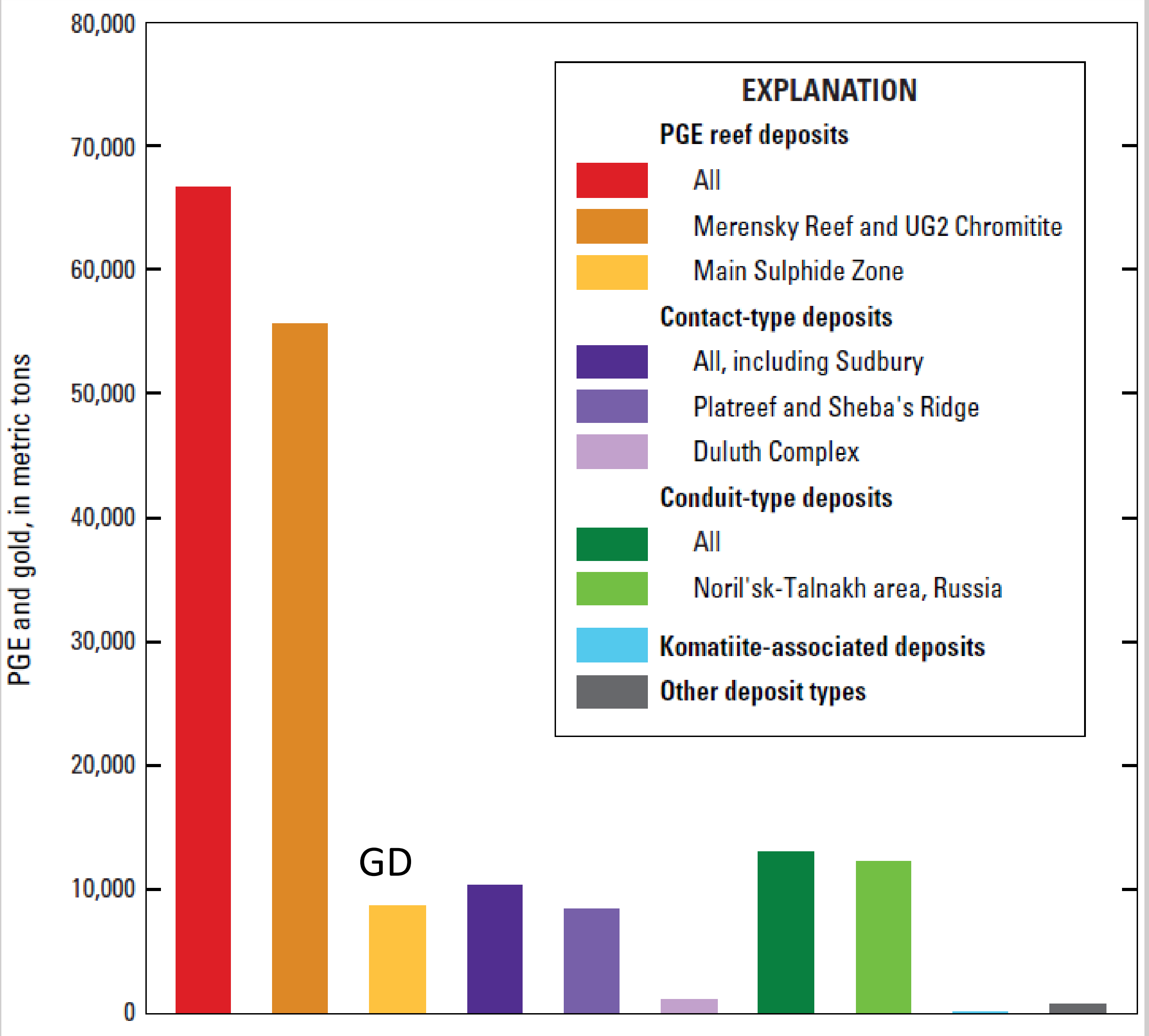
- 1. Immiscible sulfide liquid separating from silicate magma arising from injection of new magma (Campbell et al., 1983)
- 2. Scavenging of PGEs & S from the underlying cumulates by upward percolating Cl-rich fluids & subsequent deposition at chemical reaction front (Vermaak, 1976; Boudreau & Meurer, 1999)
- 3. Collection of PGE clusters suspended in the melt by immiscible sulfide liquid or chromite sinking to magma chamber floor (Tredoux et al., 1995)
- 4. Scavenging of PGEs by a fluid from primary sulfides precipitated in underlying rocks; the fluids reaches the crystal-magma interface and redissolves, causing a PGE-enriched immiscible sulfide to form (Boudreau, 1999)



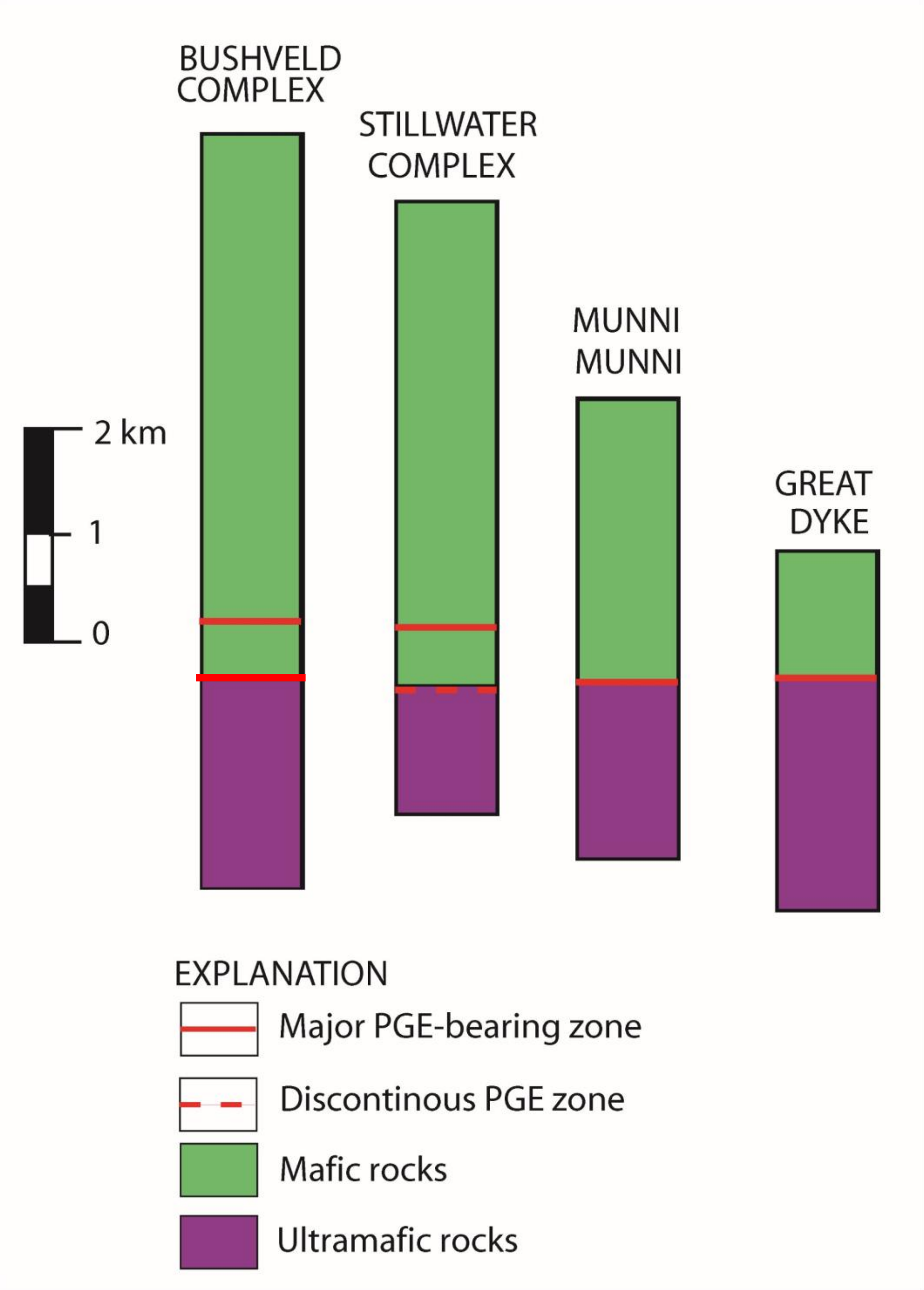
Global distribution of major magmatic platinum-group element sulfide deposits

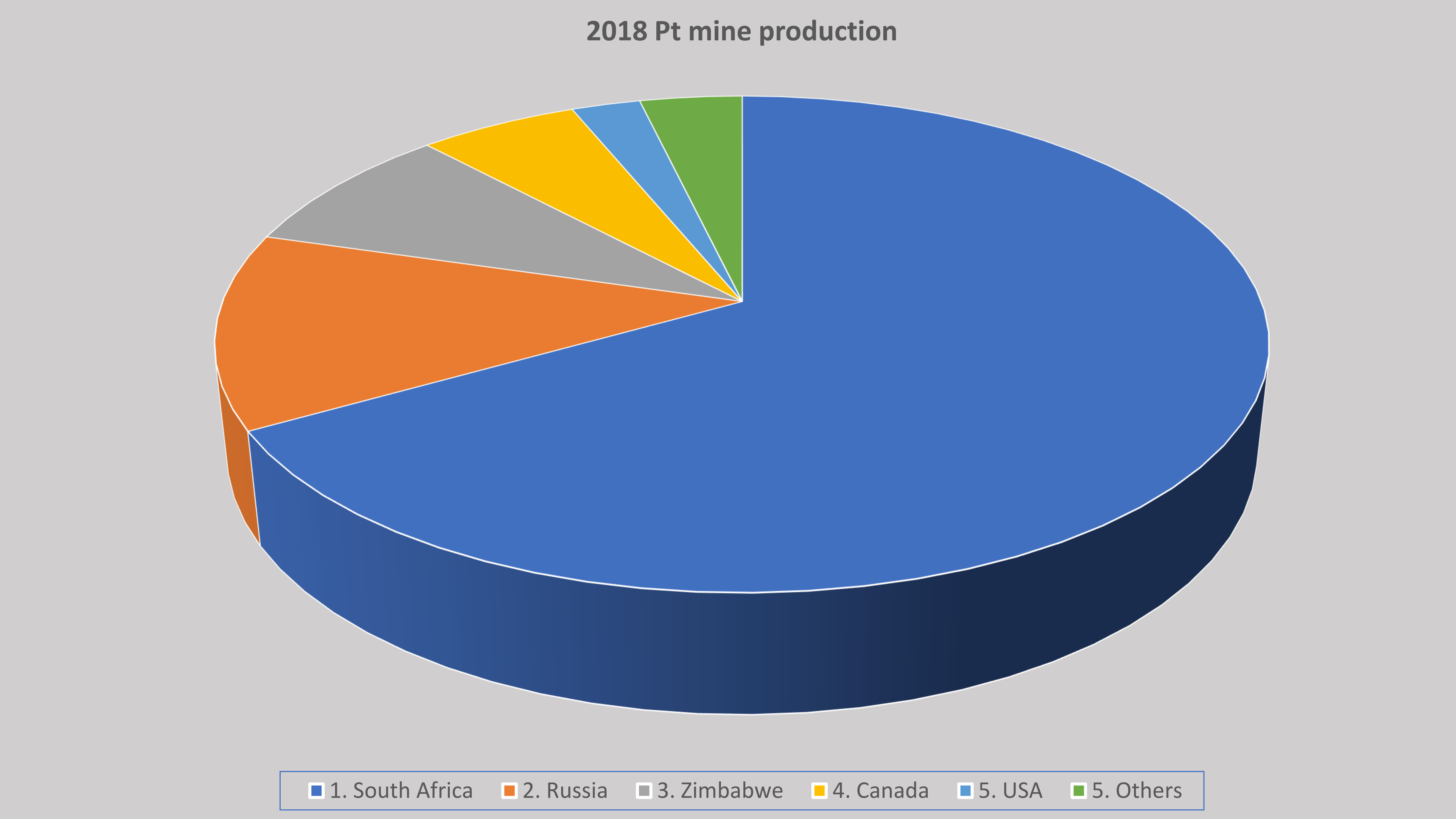


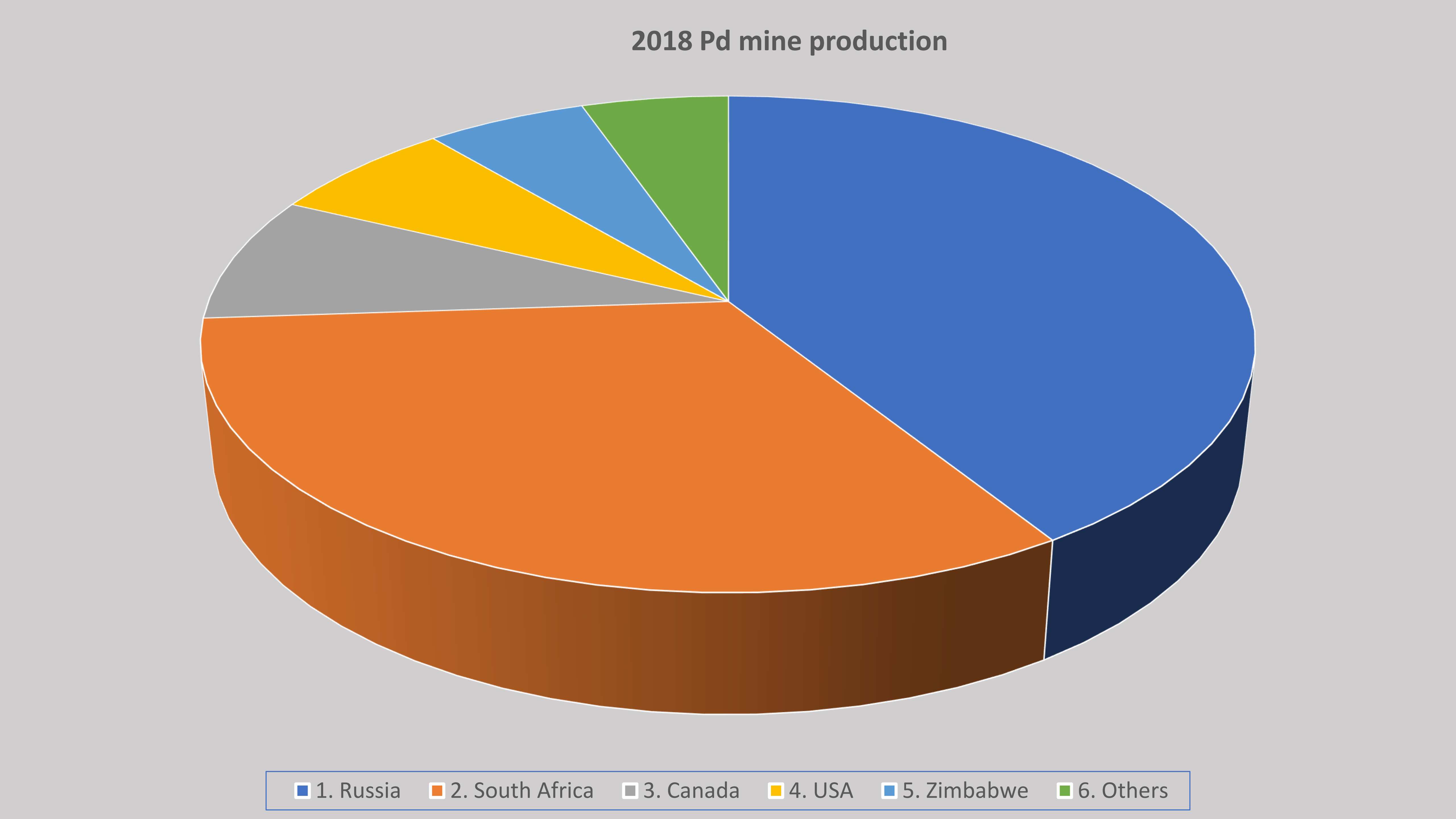
Graph showing PGE production by country, 1960-2011 (Zientek et al., 2017)



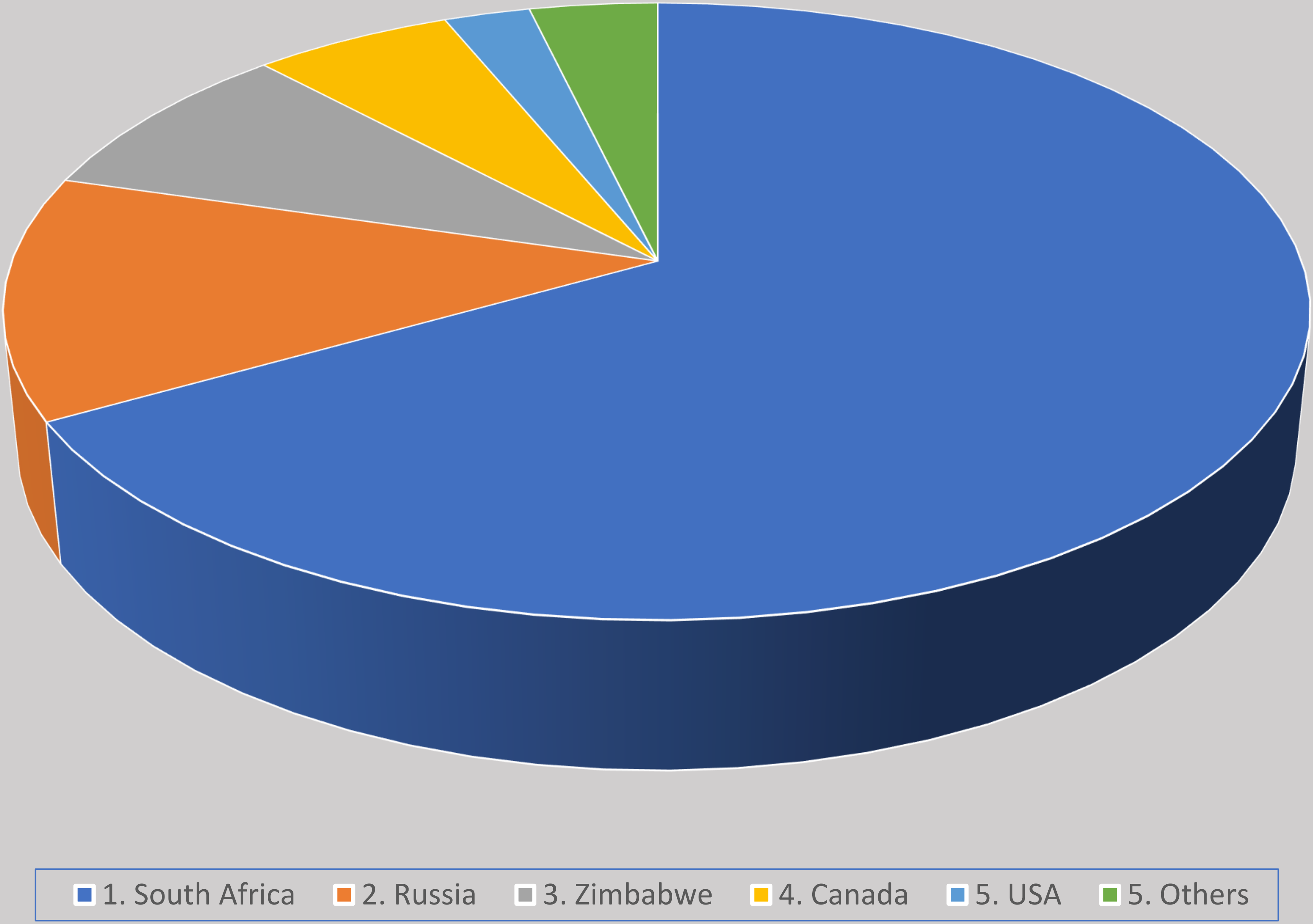
Graph showing PGE inventory from different types of deposits (Mudd, 2012)


BUSHVELD
COMPLEX
STILLWATER
COMPLEX
MUNNI
MUNNI
GREAT
DYKE
2 km
1
0
EXPLANATION
Major PGE-bearing zone
Discontinous PGE zone
Mafic rocks
Ultramafic rocks


2018 Pt mine production
1. South Africa
2. Russia
3. Zimbabwe
4. Canada
5. USA
5. Others


2018 Pd mine production
1. Russia
2. South Africa
3. Canada
4. USA
5. Zimbabwe
6. Others

PGM reserves



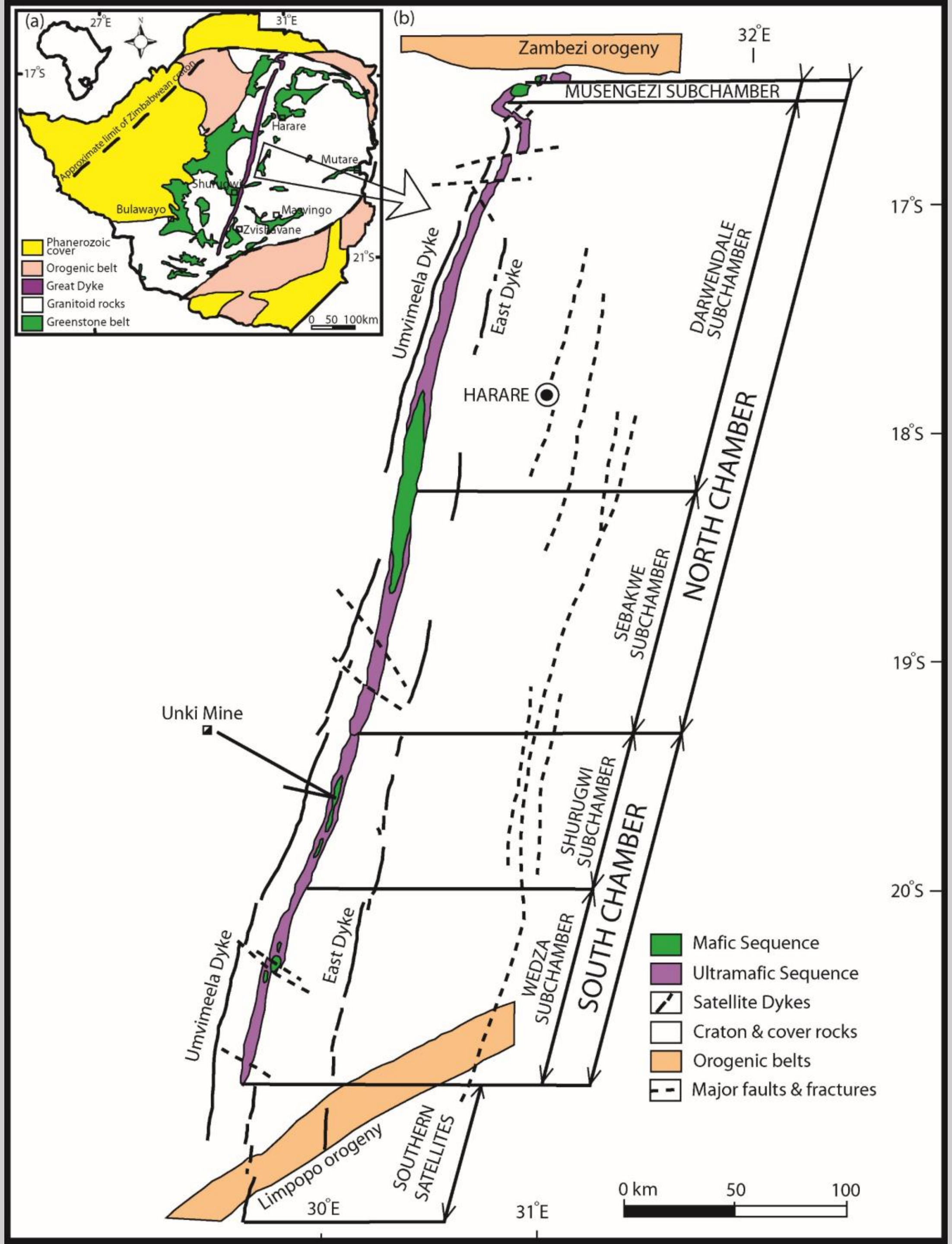
Selection of study area

- Focus and emphasis have largely been on the Darwendale Subchamber, & to a lesser extent, the Wedza Subchamber
- With mining operations in Shurugwi & Ngezi Subchambers, it is important that these Subchambers shouldn’t be neglected
- Worker/boss strong bond can lead to fruitful collaborations
- Chaumba/Musa strong bond kick-started it all
- Purpose was to document the origin of Shurugwi Subchamber sulfide mineralization using petrography & mineral compositions

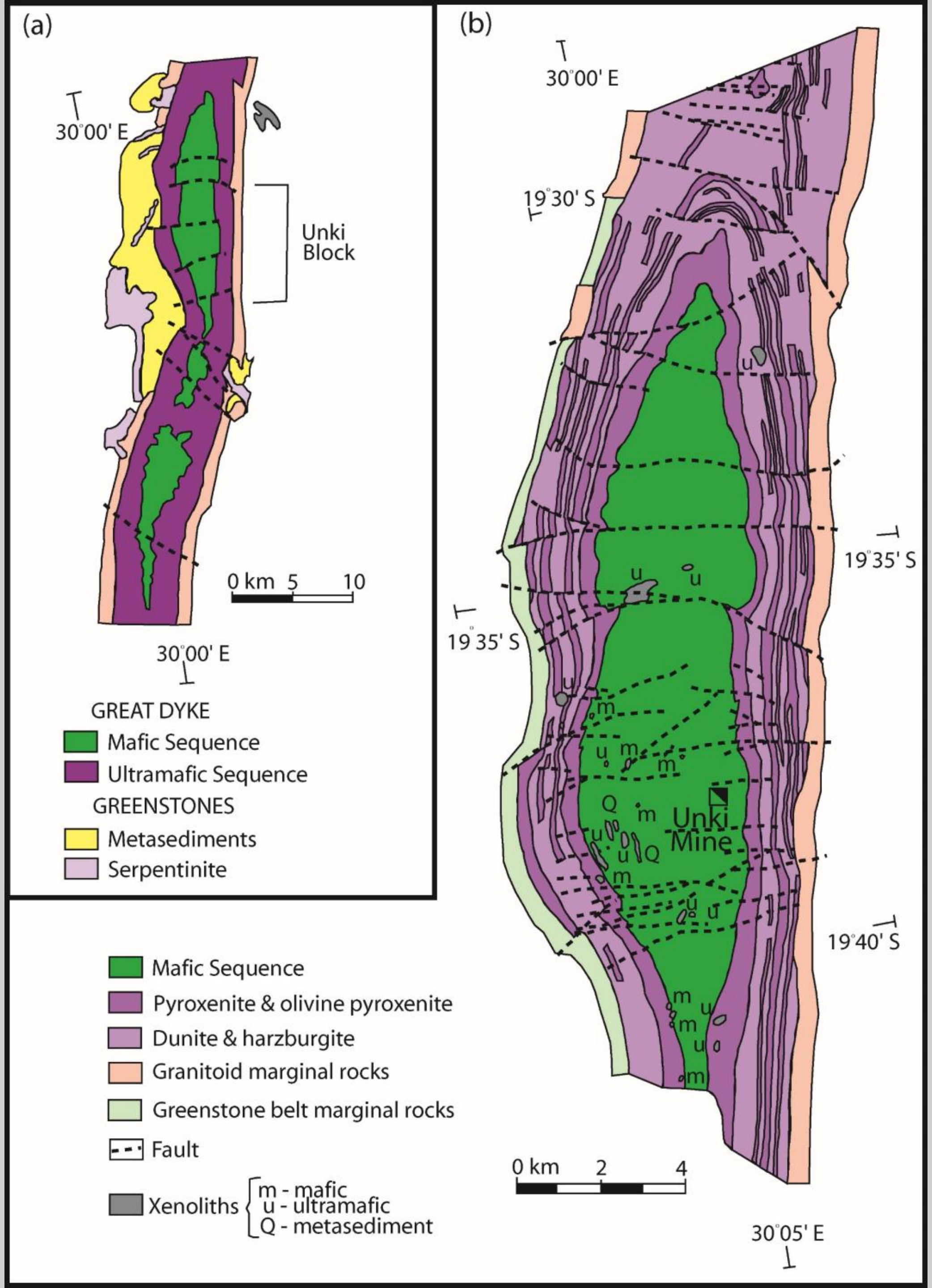
Very brief summary of Great Dyke Geology

- Unique among family of layered intrusions
- PGE-bearing horizons – Main Sulfide Zone (MSZ) is current sole target
- Origin of PGEs in MSZ?

Familiar map to every GSZ member



(a)
27°E
31°E
17°S
21°S
Approximate limit of Zimbabwean craton
Harare
Mutare
Shurugwi
Bulawayo
Masvingo
Zvishavane
Phanerozoic cover
Orogenic belt
Great Dyke
Granitoid rocks
Greenstone belt
0 50 100km
(b)
Zambezi orogeny
32°E
MUSENGEZI SUBCHAMBER
17°S
18°S
19°S
20°S
Umvimeela Dyke
East Dyke
DARWENDALE SUBCHAMBER
HARARE
NORTH CHAMBER
SEBAKWE SUBCHAMBER
Unki Mine
SHURUGWI SUBCHAMBER
SOUTH CHAMBER
WEDZA SUBCHAMBER
East Dyke
Umvimeela Dyke
Mafic Sequence
Ultramafic Sequence
Satellite Dykes
Craton & cover rocks
Orogenic belts
Major faults & fractures
Limpopo orogeny
SOUTHERN SATELLITES
30°E
31°E
0 km
50
100



(a)
30°00' E
Unki Block
0 km 5 10
30°00' E
GREAT DYKE
Mafic Sequence
Ultramafic Sequence
GREENSTONES
Metasediments
Serpentinite
(b)
30°00' E
19°30' S
19°35' S
19°35' S
19°40' S
Unki Mine
0 km 2 4
30°05' E
Mafic Sequence
Pyroxenite & olivine pyroxenite
Dunite & harzburgite
Granitoid marginal rocks
Greenstone belt marginal rocks
Fault
Xenoliths
m - mafic
u - ultramafic
Q - metasediment

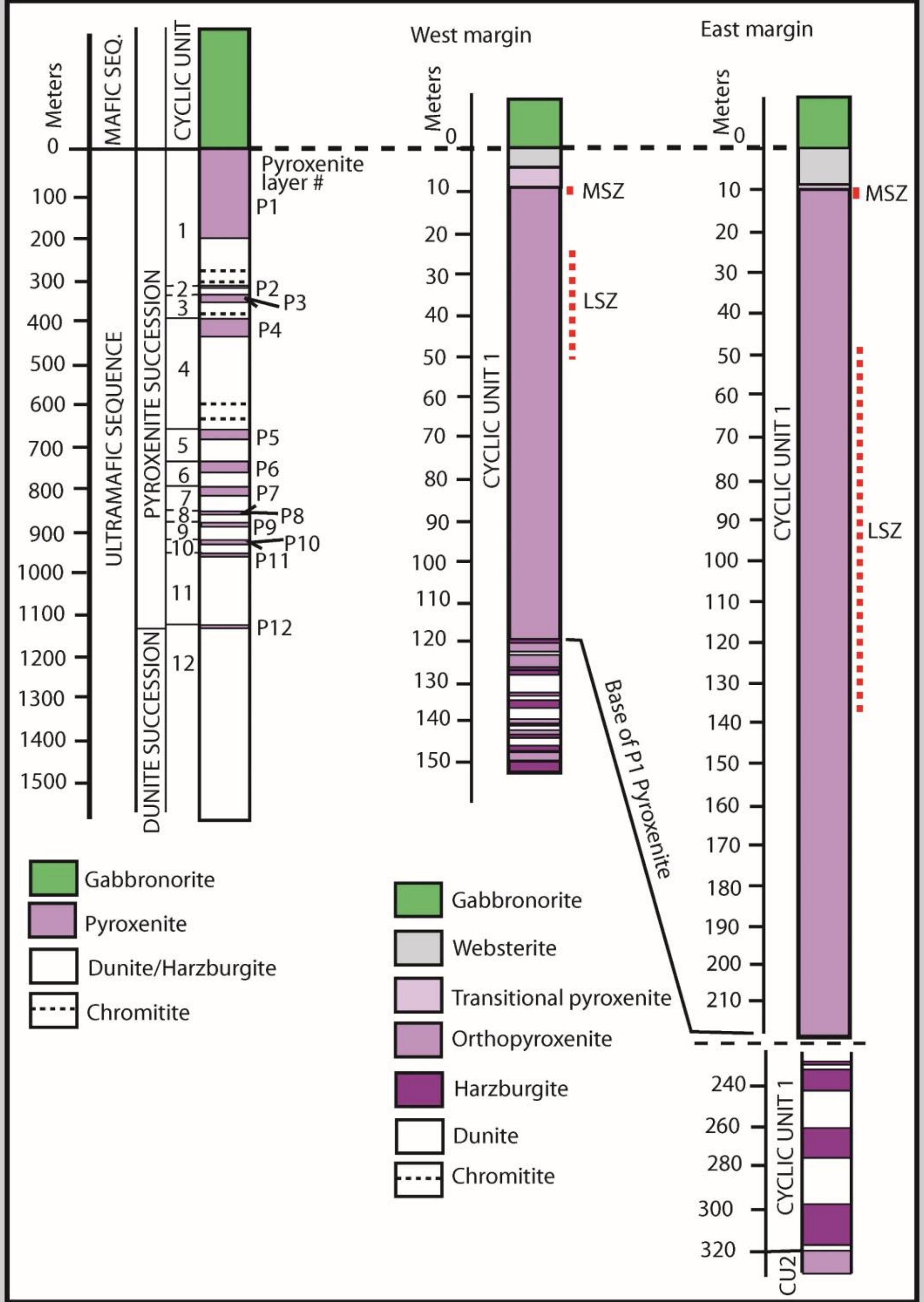
Mbada camp

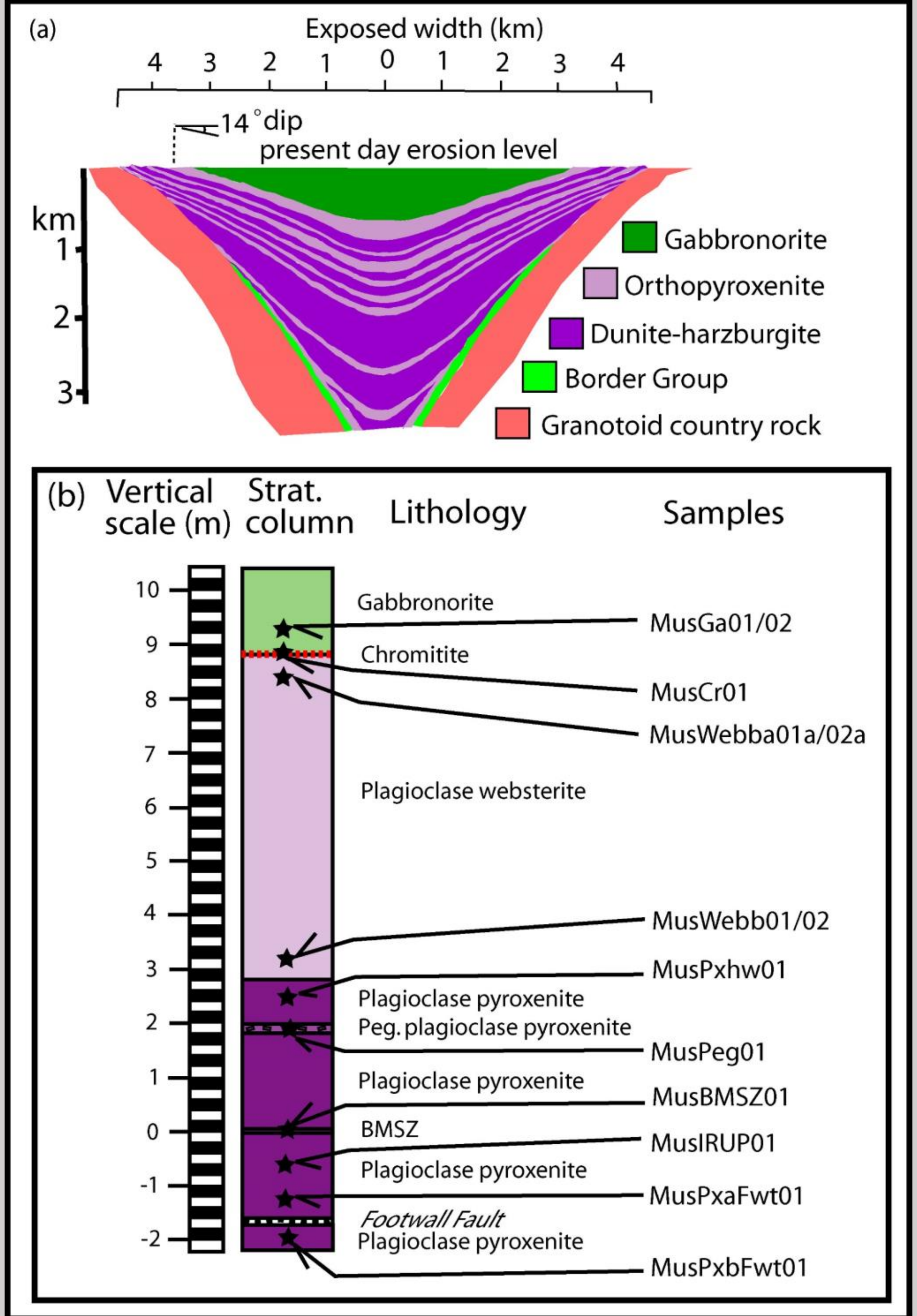
Administration building

Portal

Concentrator

Tailings dam

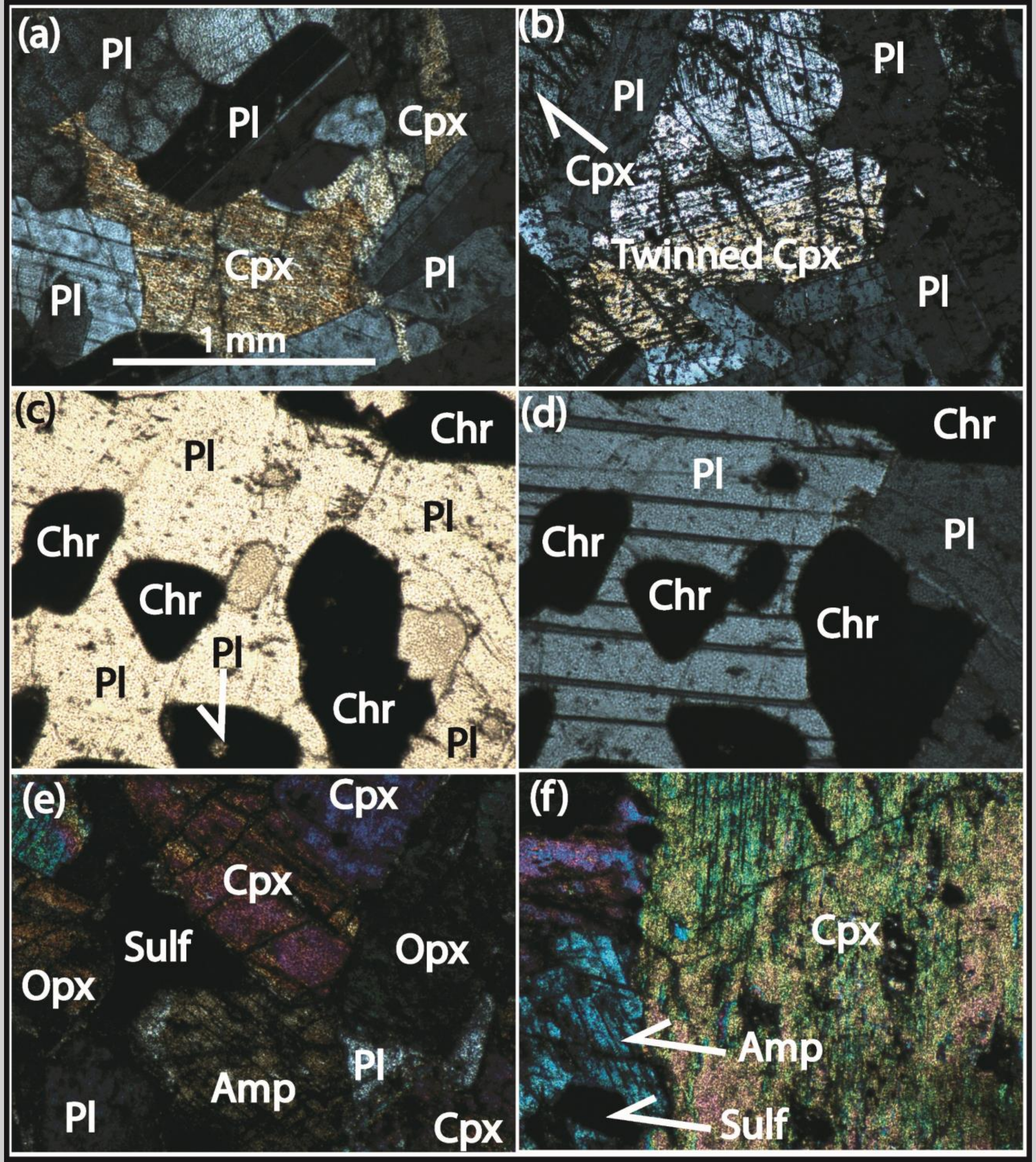

West margin
East margin
Meters
MAFIC SEQ.
CYCLIC UNIT
ULTRAMAFIC SEQUENCE
PYROXENITE SUCCESSION
DUNITE SUCCESSION
Pyroxenite layer #
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
MSZ
LSZ
CYCLIC UNIT 1
CU2
Base of P1 Pyroxenite
Gabbronorite
Pyroxenite
Dunite/Harzburgite
Chromitite
Gabbronorite
Websterite
Transitional pyroxenite
Orthopyroxenite
Harzburgite
Dunite
Chromitite


(a)
Exposed width (km)
4 3 2 1 0 1 2 3 4
14 °dip
present day erosion level
km
1
2
3
Gabbronorite
Orthopyroxenite
Dunite-harzburgite
Border Group
Granotoid country rock
(b)
Vertical scale (m)
Strat. column
Lithology
Samples
10
9
8
7
6
5
4
3
2
1
0
-1
-2
Gabbronorite
Chromitite
Plagioclase websterite
Plagioclase pyroxenite
Peg. plagioclase pyroxenite
Plagioclase pyroxenite
BMSZ
Plagioclase pyroxenite
Footwall Fault
Plagioclase pyroxenite
MusGa01/02
MusCr01
MusWebba01a/02a
MusWebb01/02
MusPxhw01
MusPeg01
MusBMSZ01
MusIRUP01
MusPxaFwt01
MusPxbFwt01

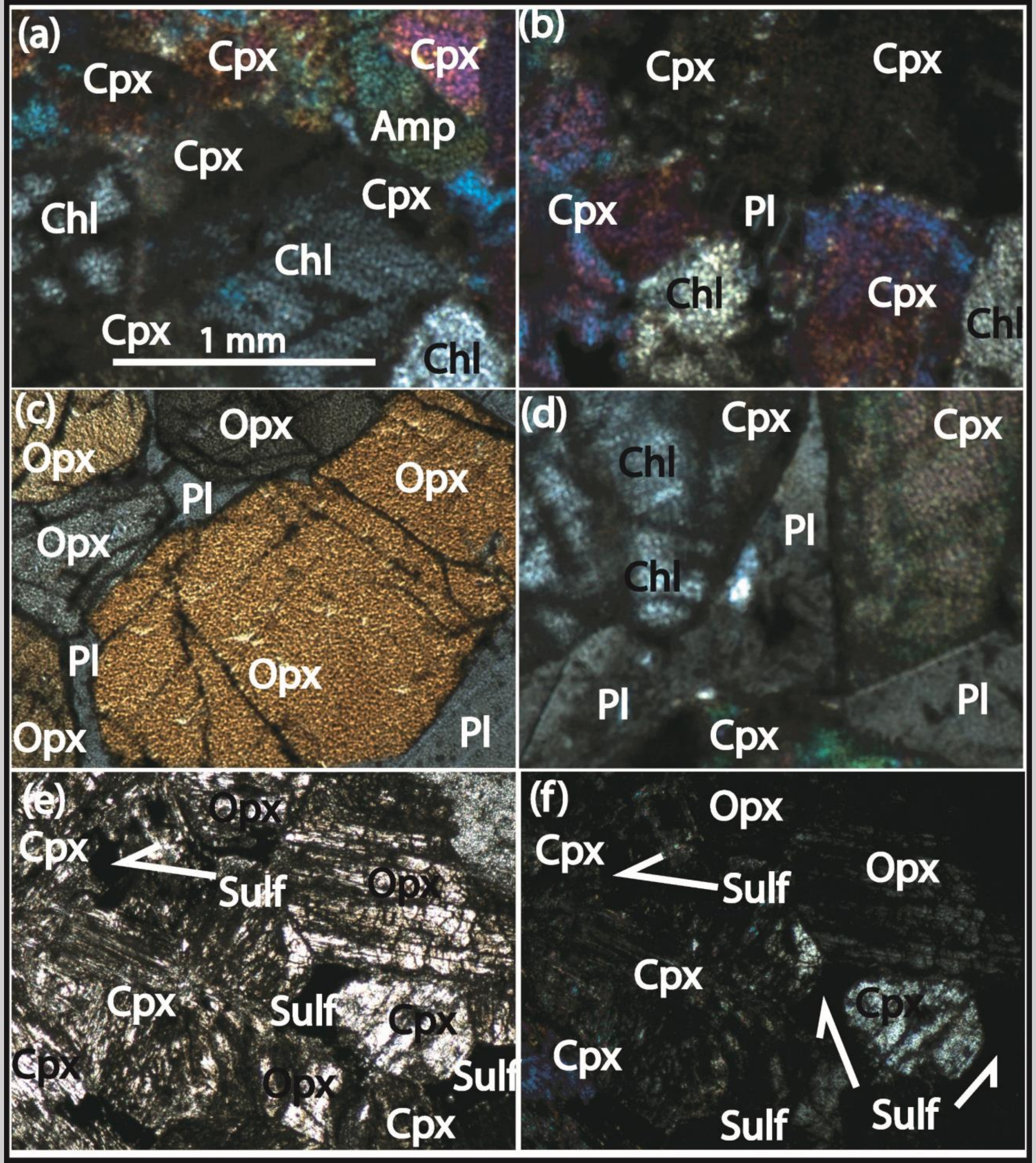
Gabbronorites

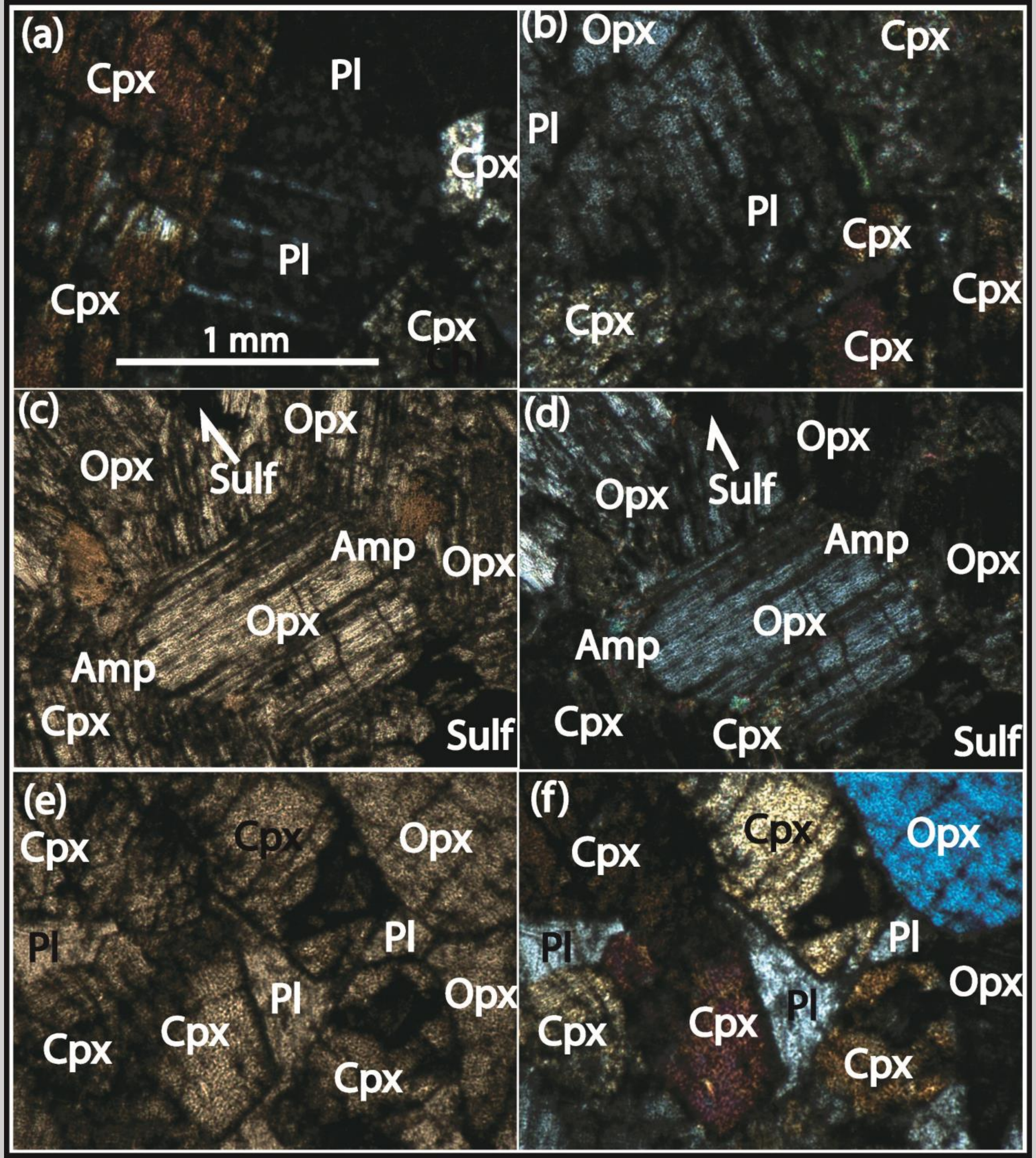
Sequences contact zone chromites

Websterites - altered



MSZ: note altered silicates, sulfides

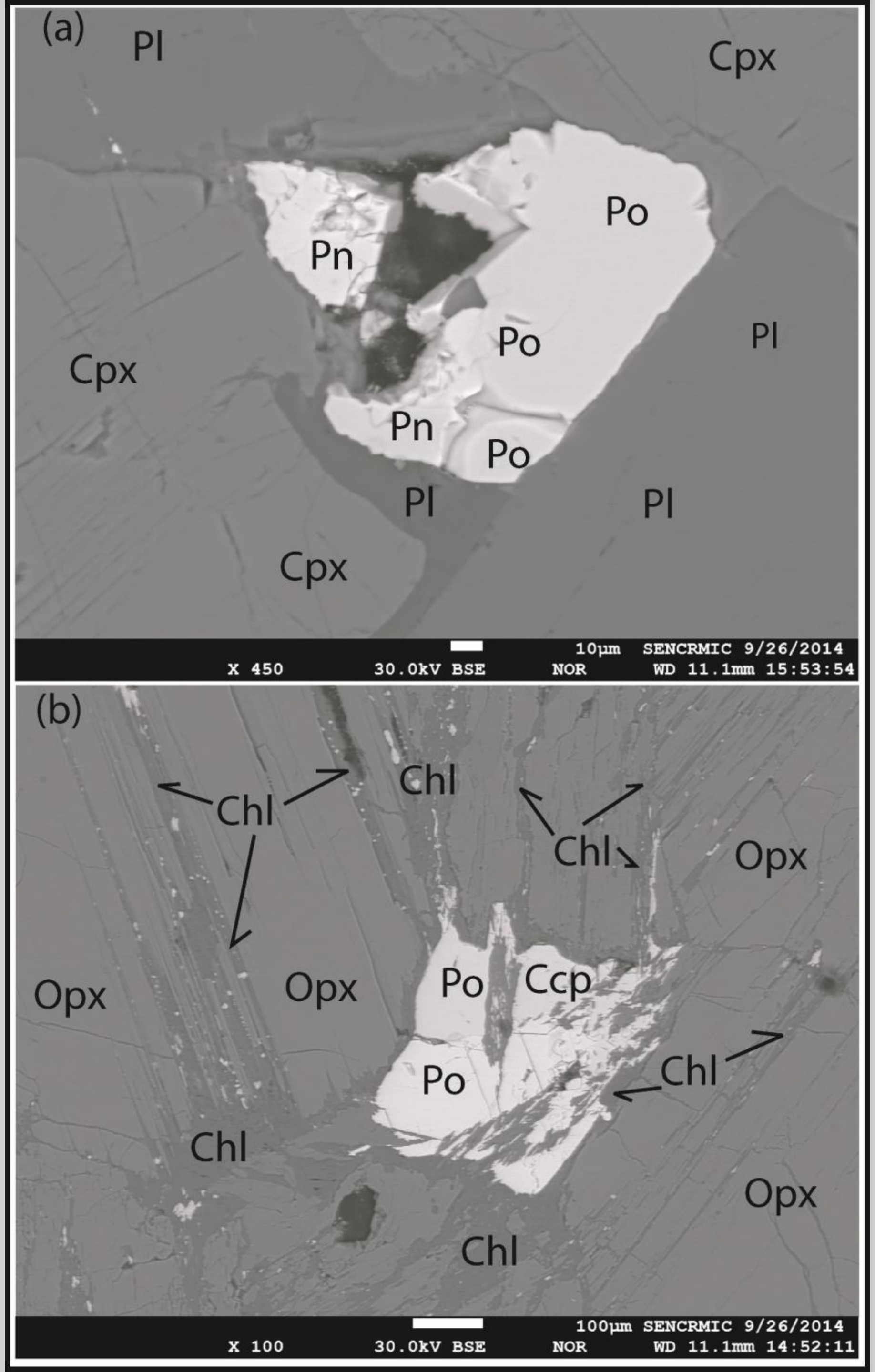




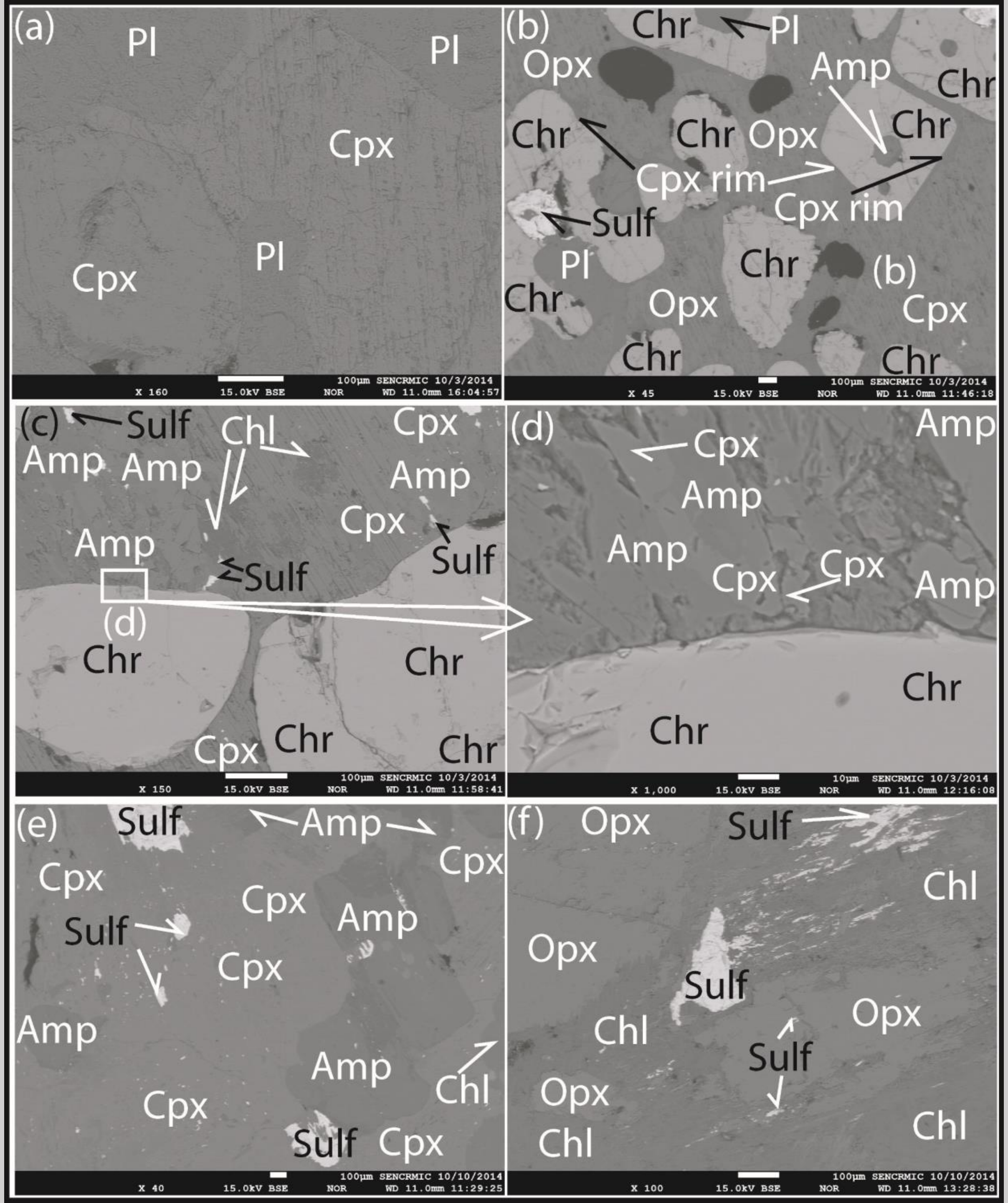
MSZ & underlying cumulates

Lower part of Mafic Sequence

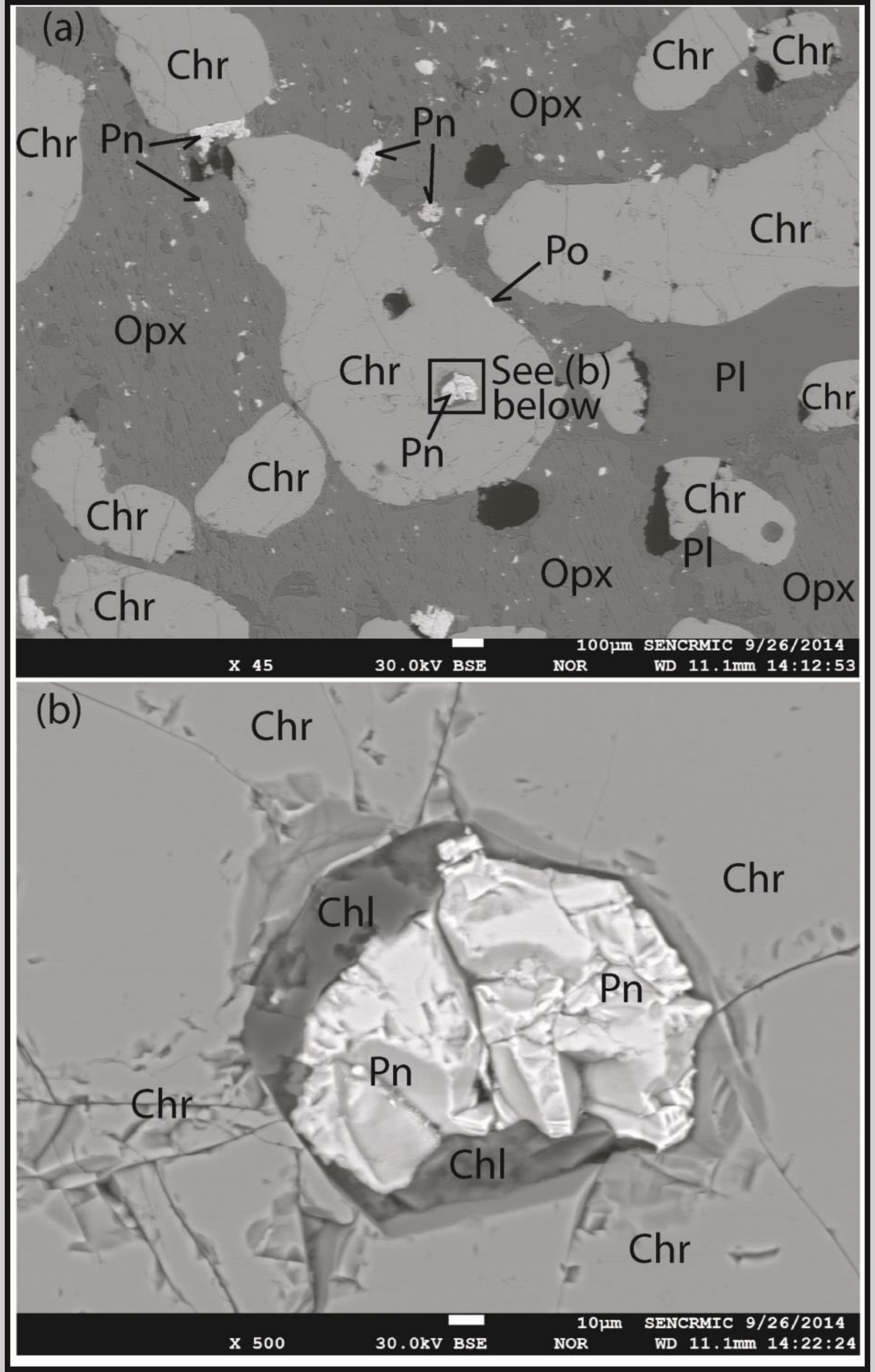
MSZ



Sequences contact zone chromitite

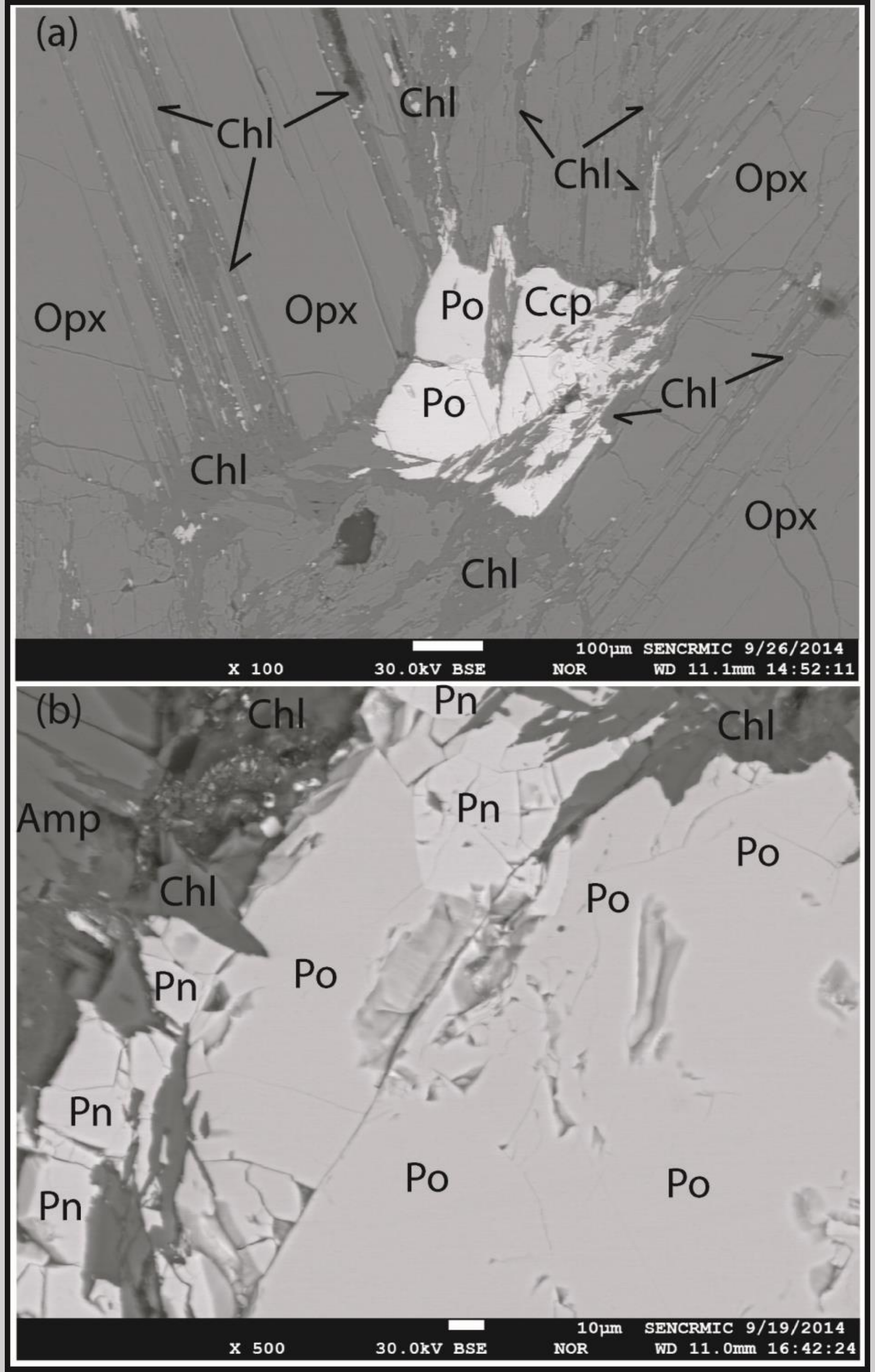


Sequences contact zone chromitite



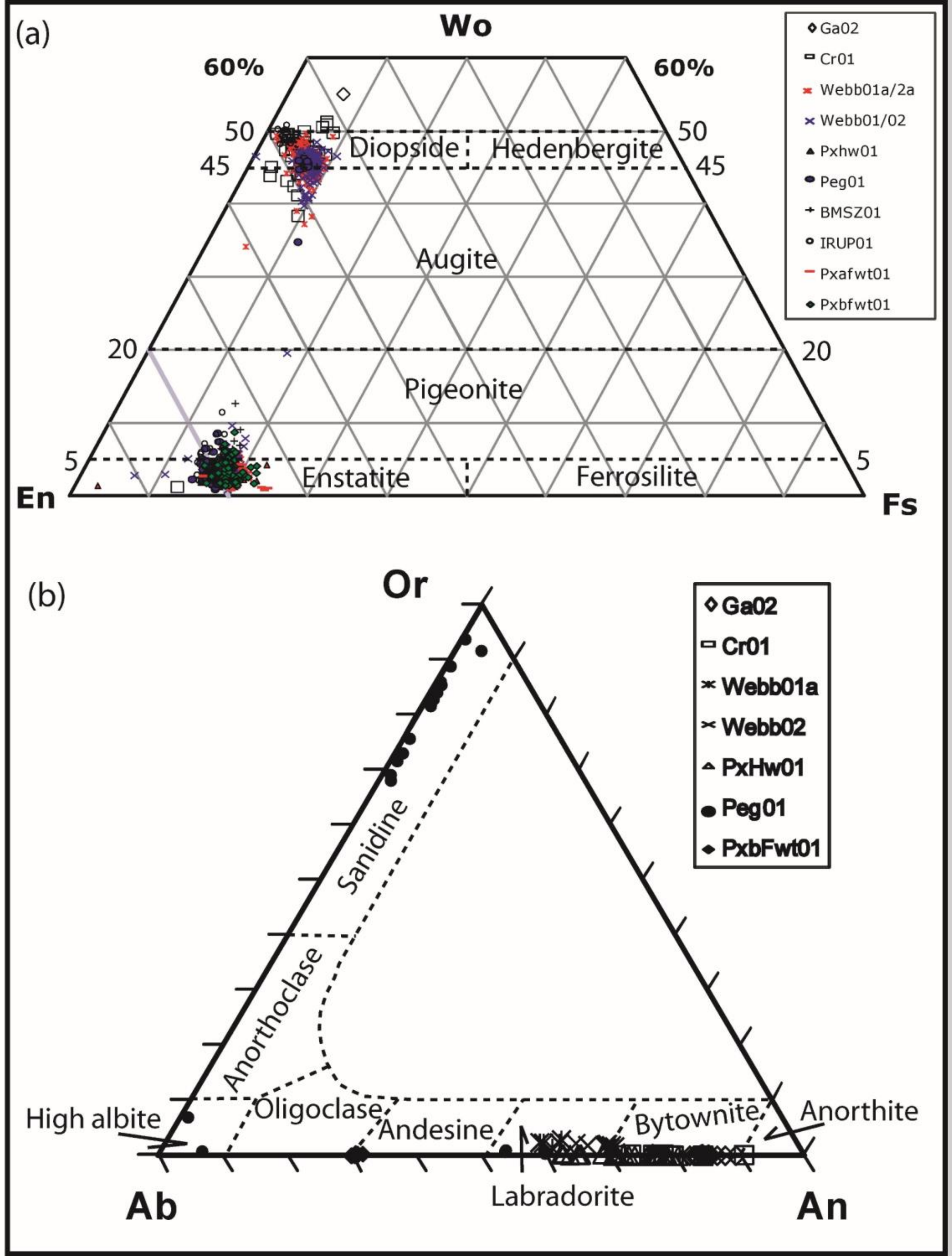
MSZ

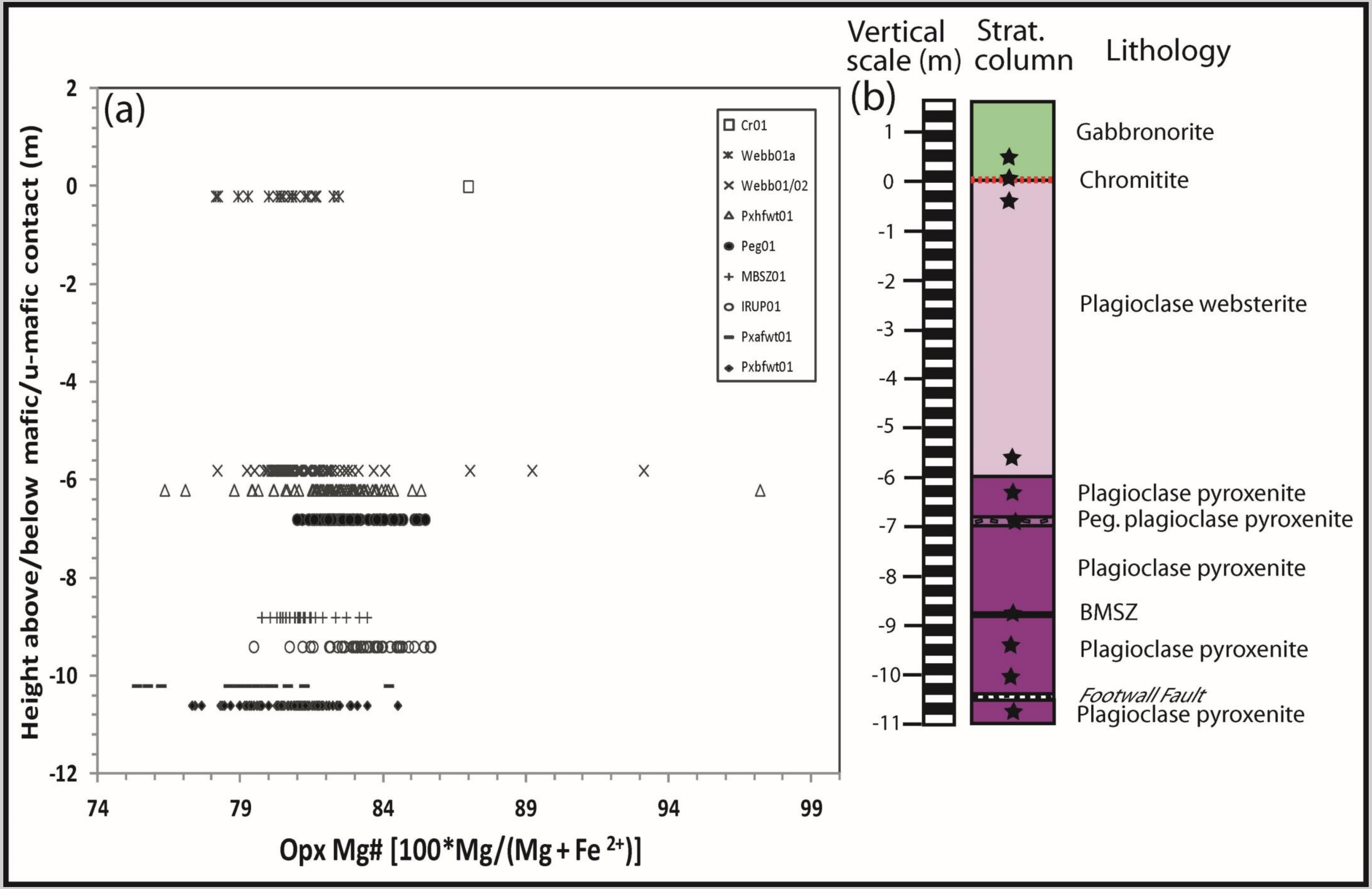
Base Metal
Sulfide Zone



Unki Mine Pxns

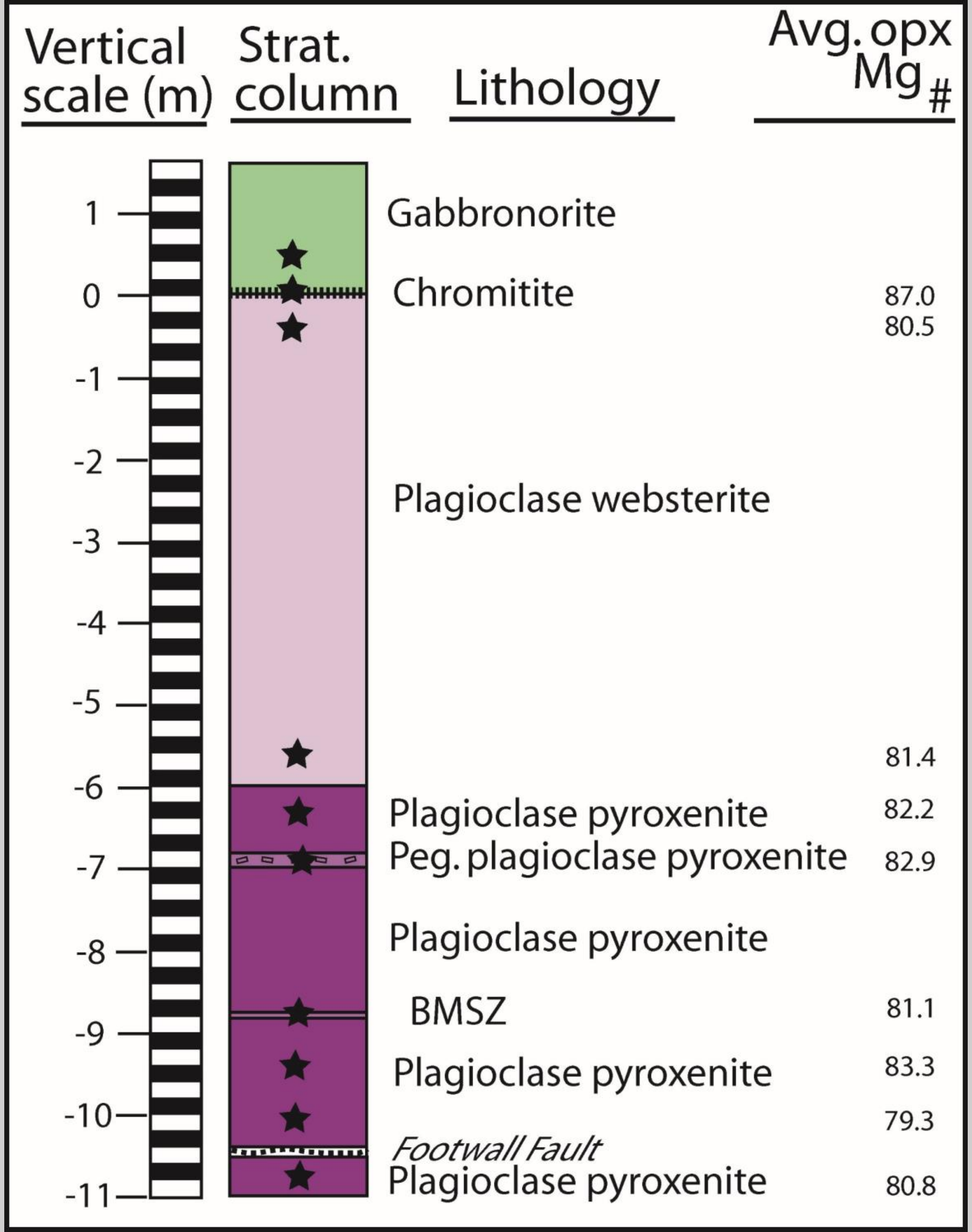
Unki Mine Pl

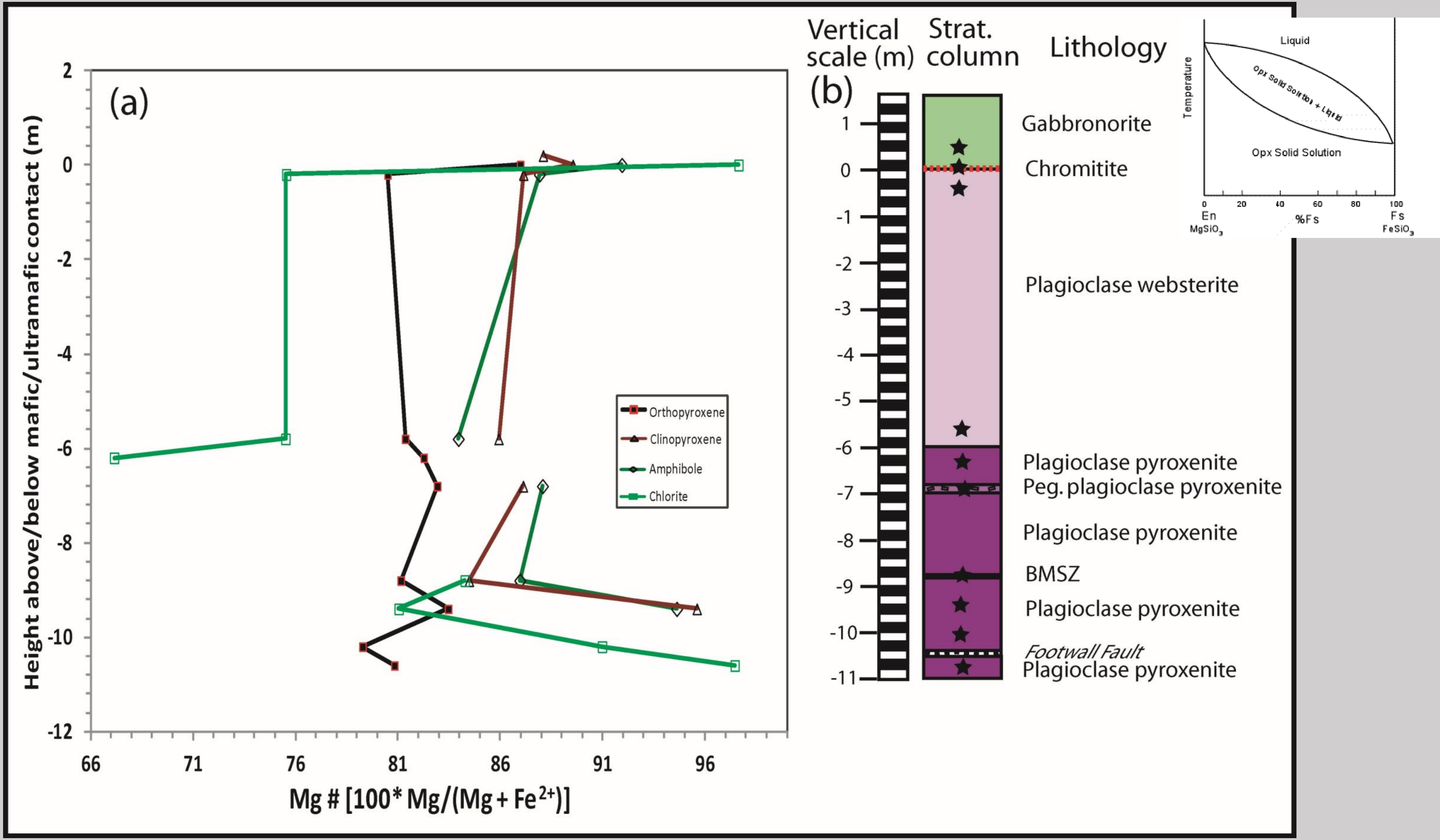




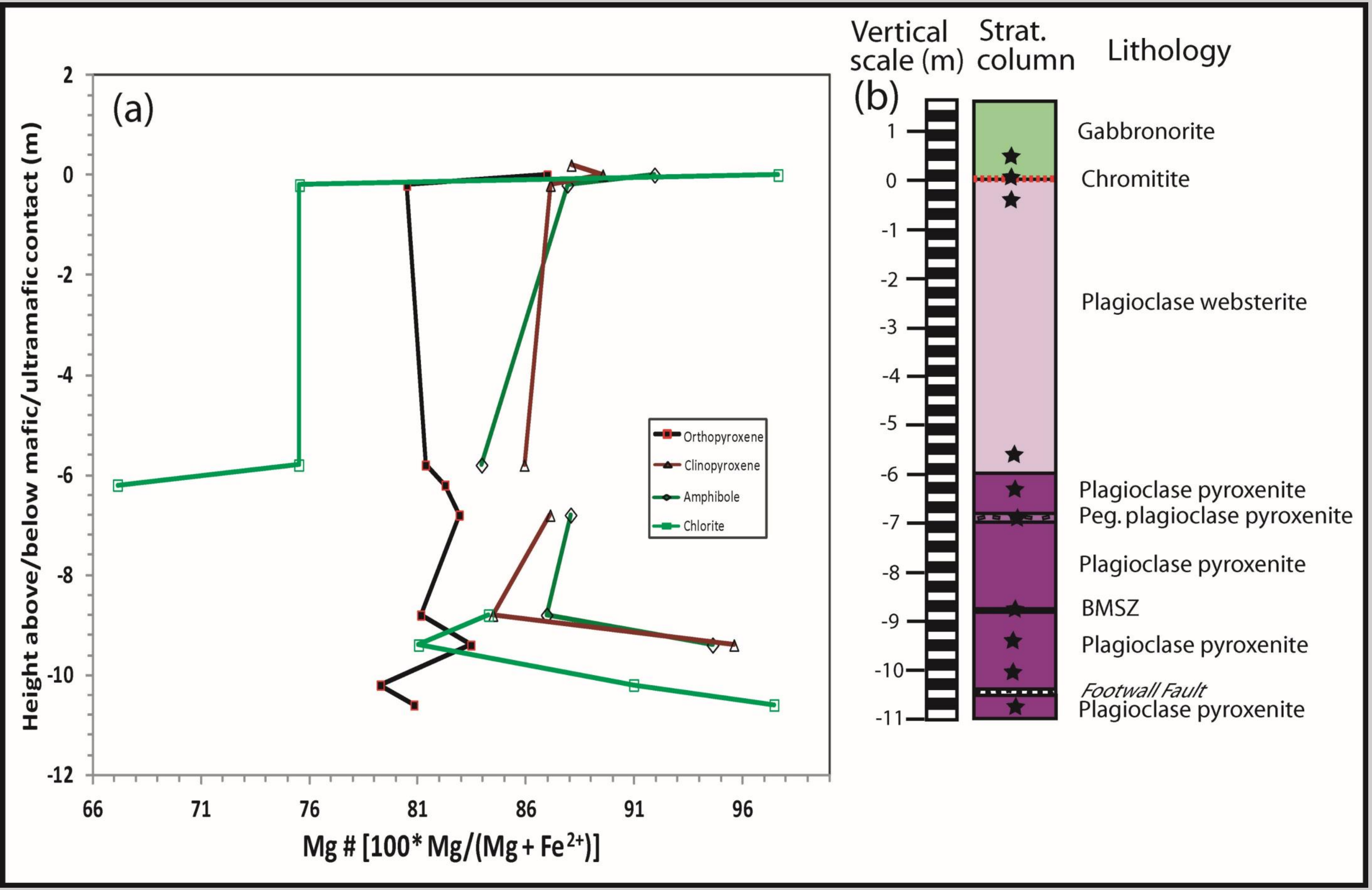
(a)
Height above/below mafic/u-mafic contact (m)
Opx Mg# [100*Mg/(Mg + Fe 2+)]
2
0
-2
-4
-6
-8
-10
-12
74
79
84
89
94
99
Cr01
Webb01a
Webb01/02
Pxhfwt01
Peg01
MBSZ01
IRUP01
Pxafwt01
Pxbfwt01
(b)
Vertical scale (m)
Strat. column
Lithology
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
Gabbronorite
Chromitite
Plagioclase websterite
Plagioclase pyroxenite
Peg. plagioclase pyroxenite
Plagioclase pyroxenite
BMSZ
Plagioclase pyroxenite
Footwall Fault
Plagioclase pyroxenite

Unki Mine opx Mg#

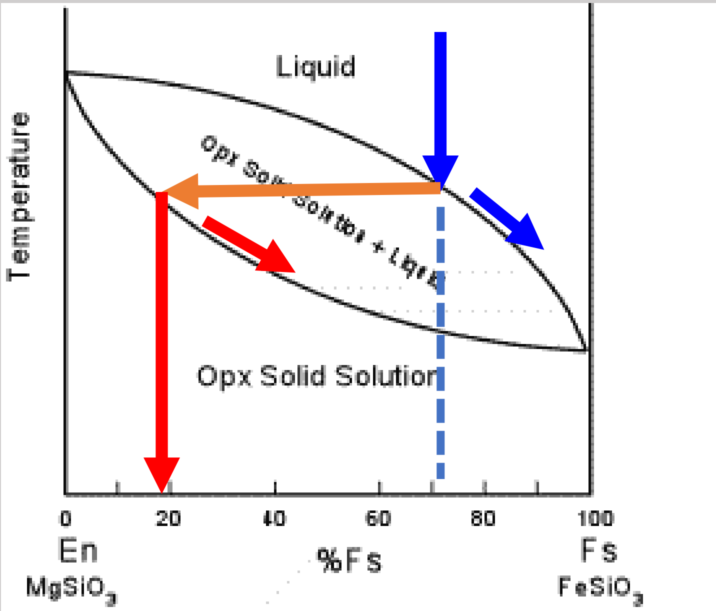




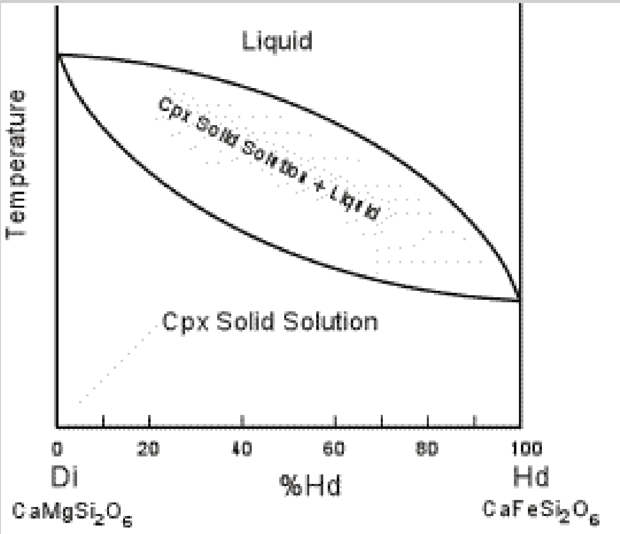
(a)
Height above/below mafic/ultramafic contact (m)
2
0
-2
-4
-6
-8
-10
-12
66
71
76
81
86
91
96
Mg # [100* Mg/(Mg + Fe2+)]
Orthopyroxene
Clinopyroxene
Amphibole
Chlorite
Vertical scale (m)
Strat. column
Lithology
(b)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
Gabbronorite
Chromitite
Plagioclase websterite
Plagioclase pyroxenite
Peg. plagioclase pyroxenite
Plagioclase pyroxenite
BMSZ
Plagioclase pyroxenite
Footwall Fault
Plagioclase pyroxenite
Liquid
Temperature
Opx Solid Solution + Liquid
Opx Solid Solution
0
20
40
60
80
100
En
MgSiO3
%Fs
Fs
FeSiO3



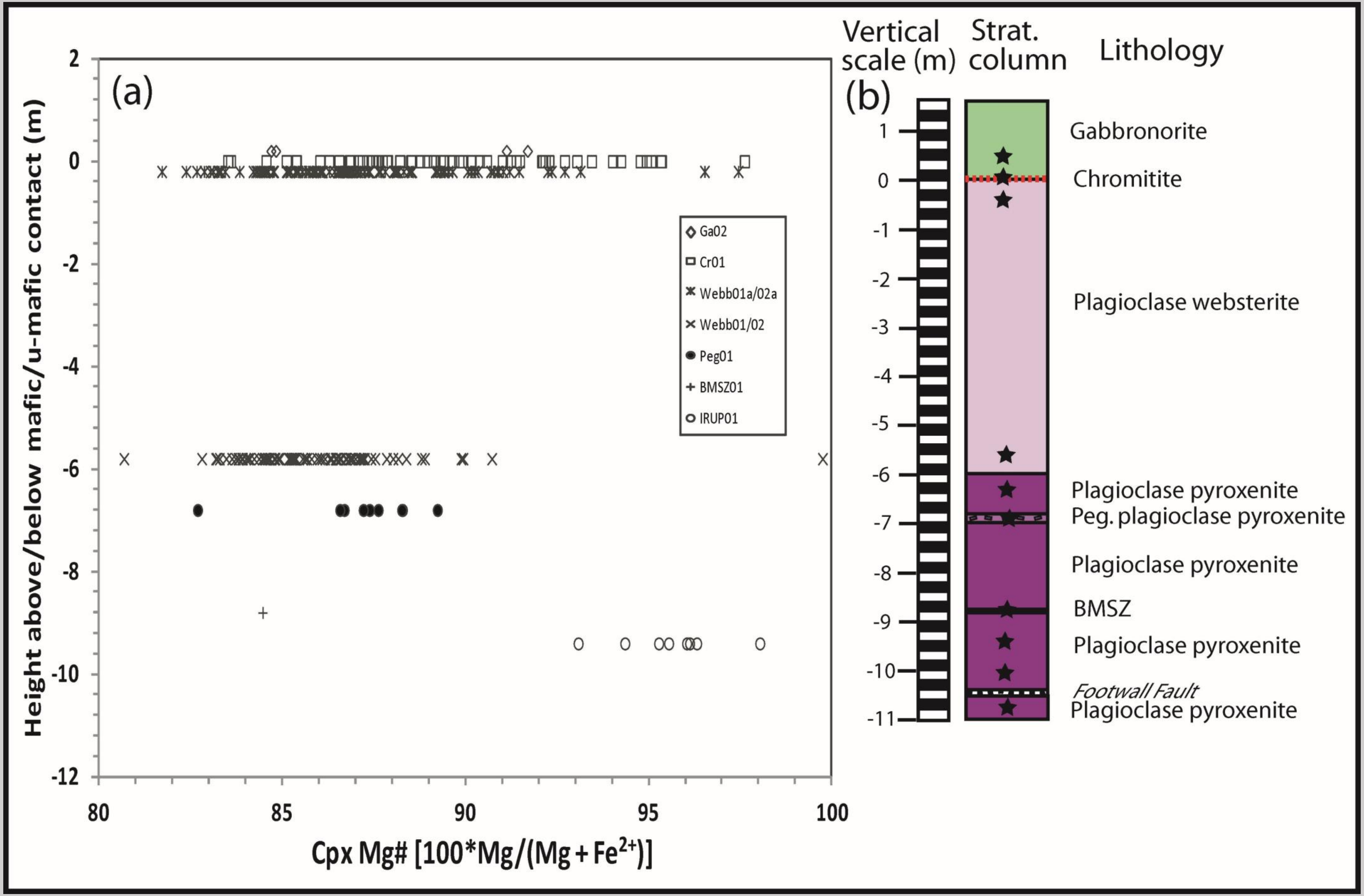
(a)
Height above/below mafic/ultramafic contact (m)
2
0
-2
-4
-6
-8
-10
-12
66
71
76
81
86
91
96
Mg # [100* Mg/(Mg + Fe2+)]
Orthopyroxene
Clinopyroxene
Amphibole
Chlorite
(b)
Vertical scale (m)
Strat. column
Lithology
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
Gabbronorite
Chromitite
Plagioclase websterite
Plagioclase pyroxenite
Peg. plagioclase pyroxenite
Plagioclase pyroxenite
BMSZ
Plagioclase pyroxenite
Footwall Fault
Plagioclase pyroxenite

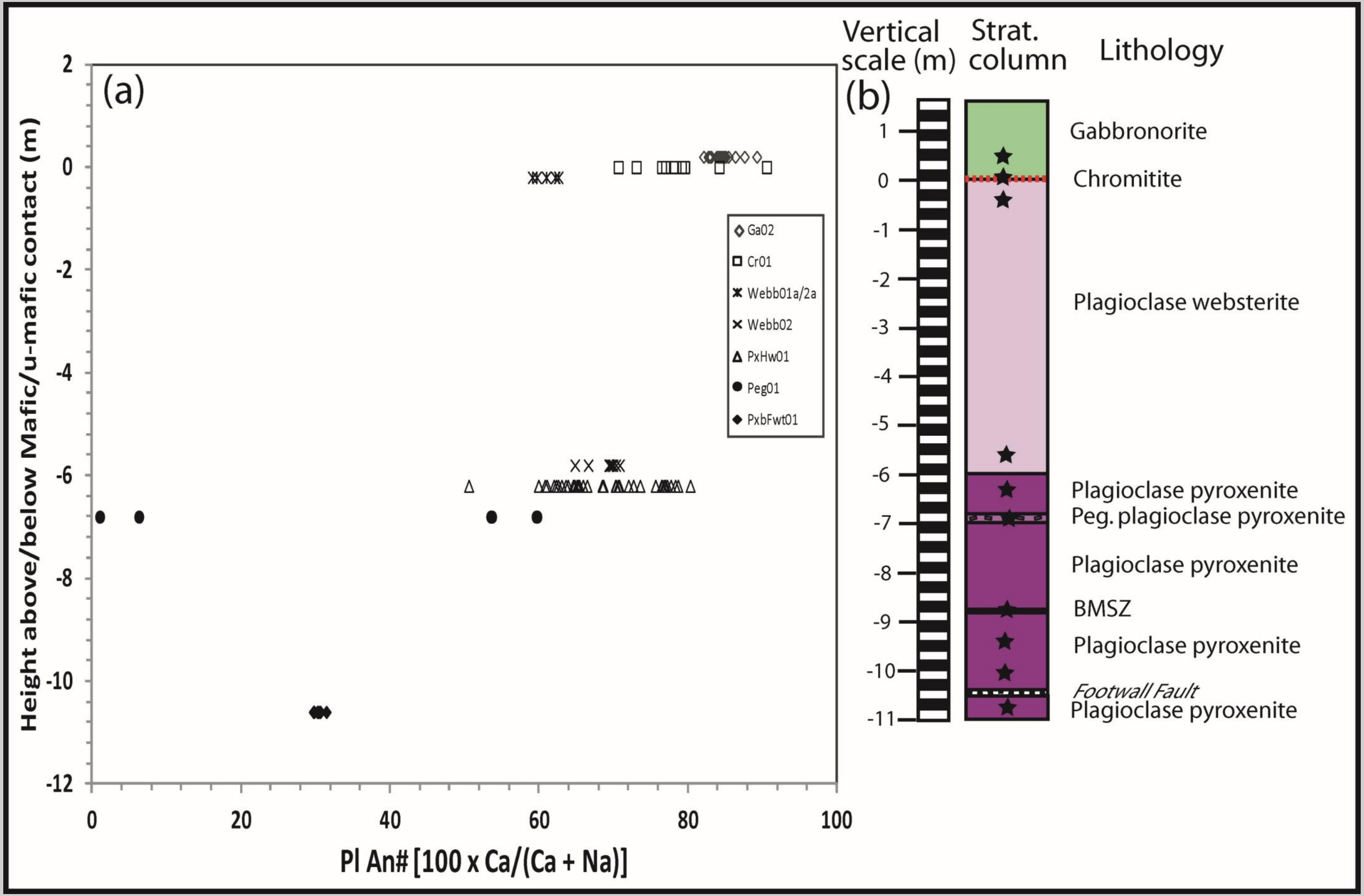


Liquid
Temperature
Opx Solid Solution
0
20
40
60
80
100
En
MgSiO3
%Fs
Fs
FeSiO3

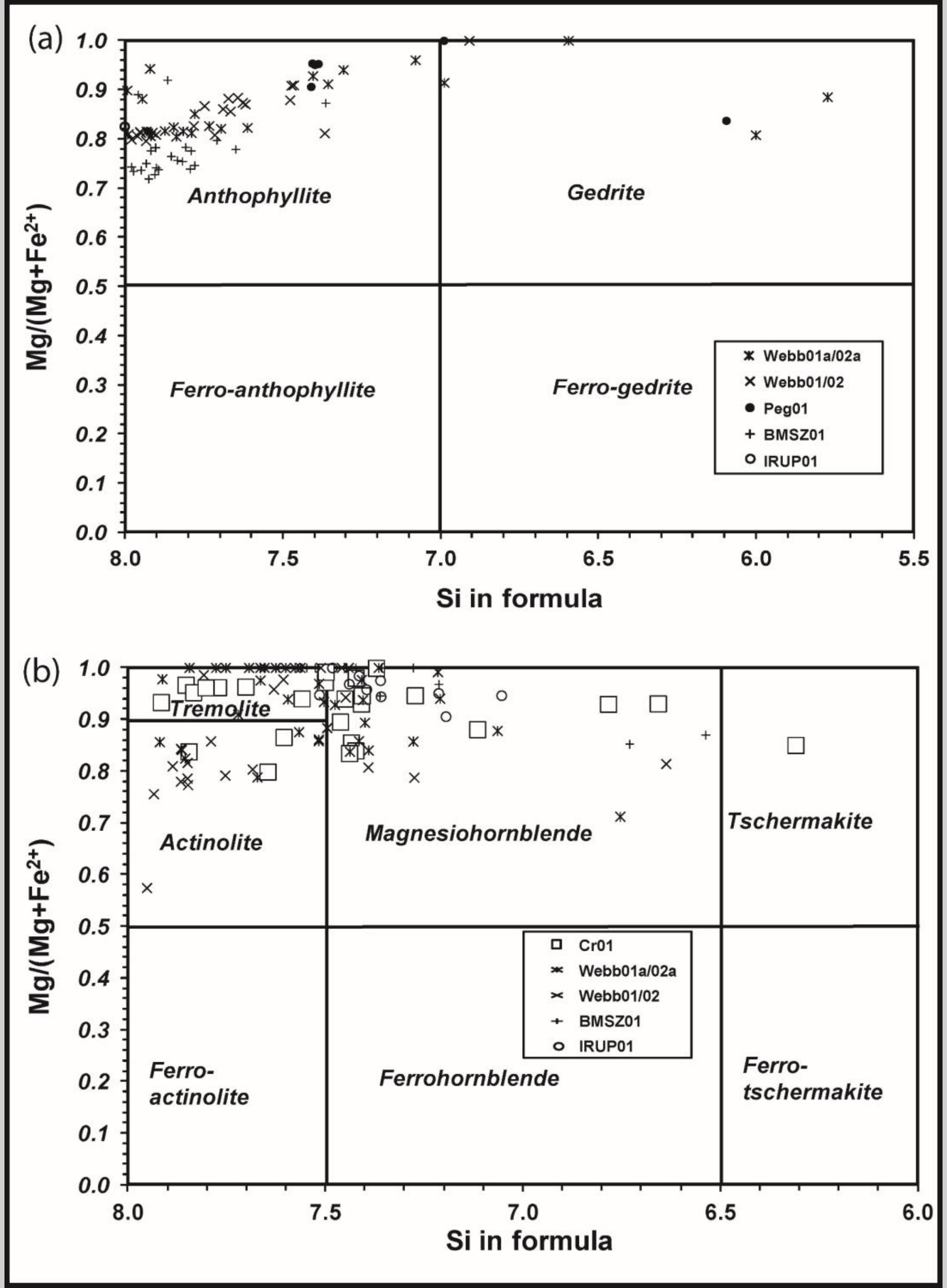


Liquid
Temperature
Cpx Solid Solution + Liquid
Cpx Solid Solution
0
20
40
60
80
100
Di
CaMgSi2O6
%Hd
Hd
CaFeSi2O6

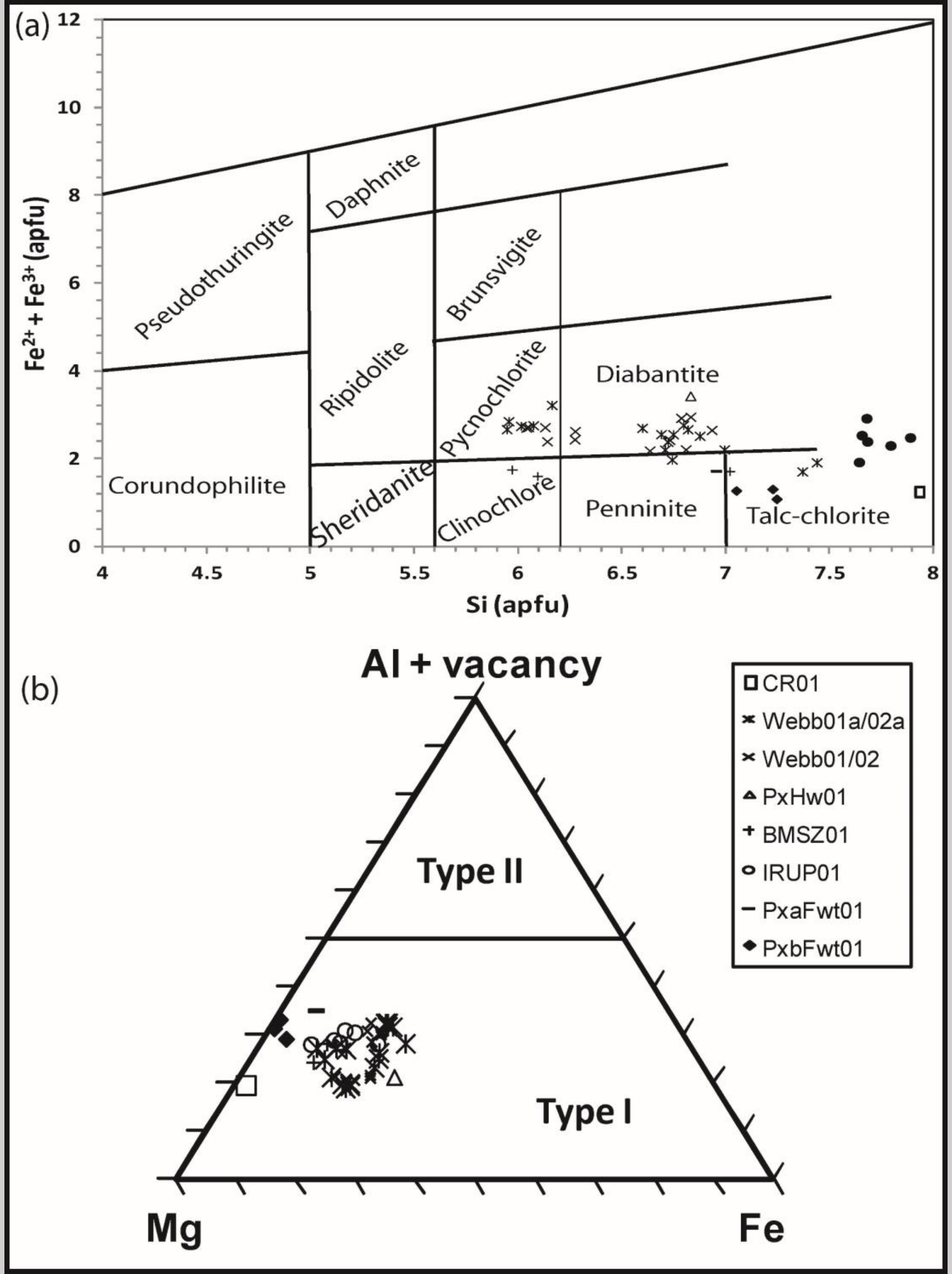

(a)
Height above/below mafic/u-mafic contact (m)
Cpx Mg# [100*Mg/(Mg + Fe2+)]
Ga02
Cr01
Webb01a/02a
Webb01/02
Peg01
BMSZ01
IRUP01
2
0
-2
-4
-6
-8
-10
-12
80
85
90
95
100
(b)
Vertical scale (m)
Strat. column
Lithology
Gabbronorite
Chromitite
Plagioclase websterite
Plagioclase pyroxenite
Peg. plagioclase pyroxenite
Plagioclase pyroxenite
BMSZ
Plagioclase pyroxenite
Footwall Fault
Plagioclase pyroxenite
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11


(a)
Height above/below Mafic/u-mafic contact (m)
2
0
-2
-4
-6
-8
-10
-12
0
20
40
60
80
100
Pl An# [100 x Ca/(Ca + Na)]
Ga02
Cr01
Webb01a/2a
Webb02
PxHw01
Peg01
PxbFwt01
(b)
Vertical scale (m)
Strat. column
Lithology
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
Gabbronorite
Chromitite
Plagioclase websterite
Plagioclase pyroxenite
Peg. plagioclase pyroxenite
Plagioclase pyroxenite
BMSZ
Plagioclase pyroxenite
Footwall Fault
Plagioclase pyroxenite

Unki Mine Amp

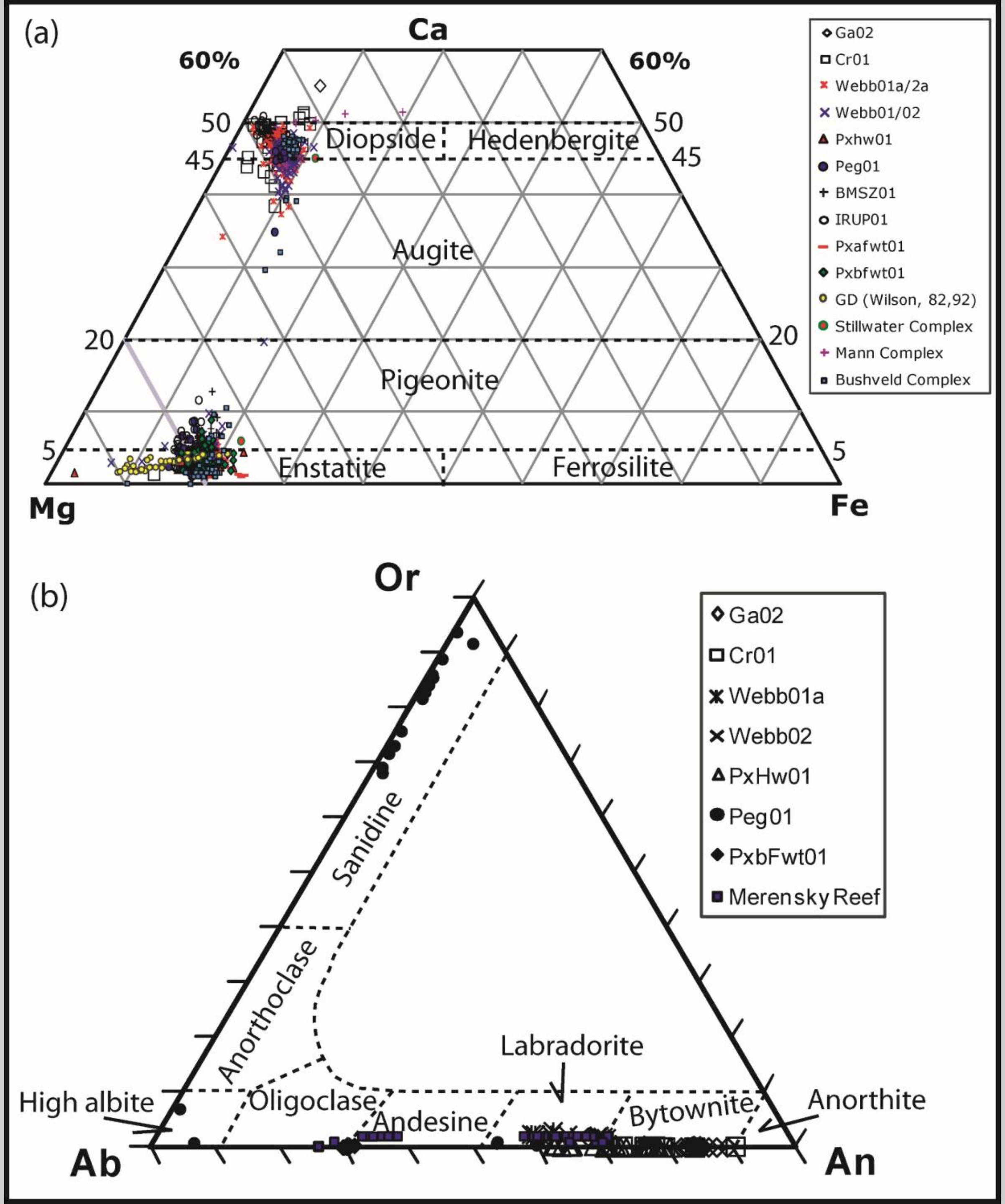


Unki Mine Chl



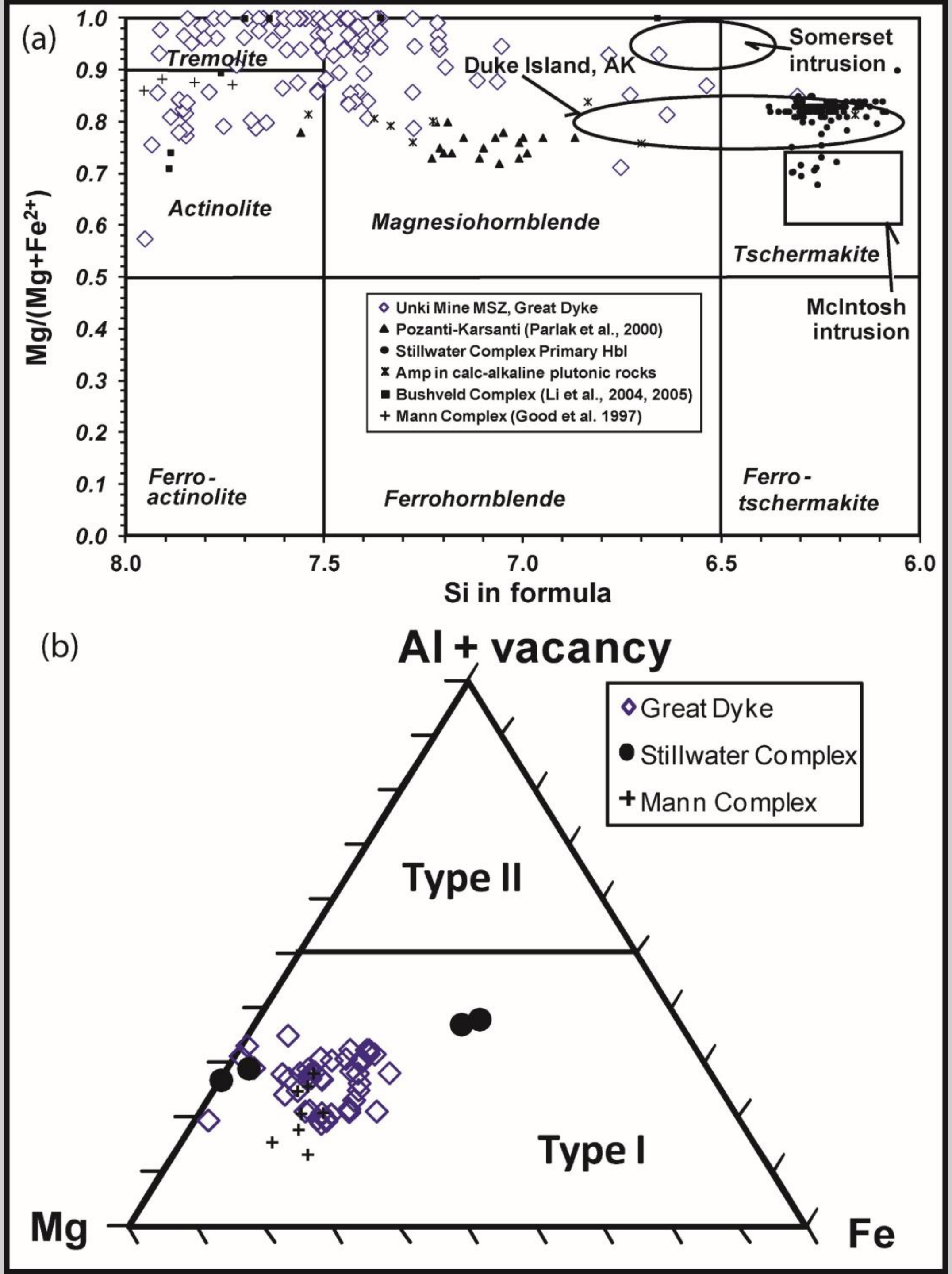
Unki Mine Pxn compared to those from other layered intrusions

Unki Mine Pl compared with MR Pl



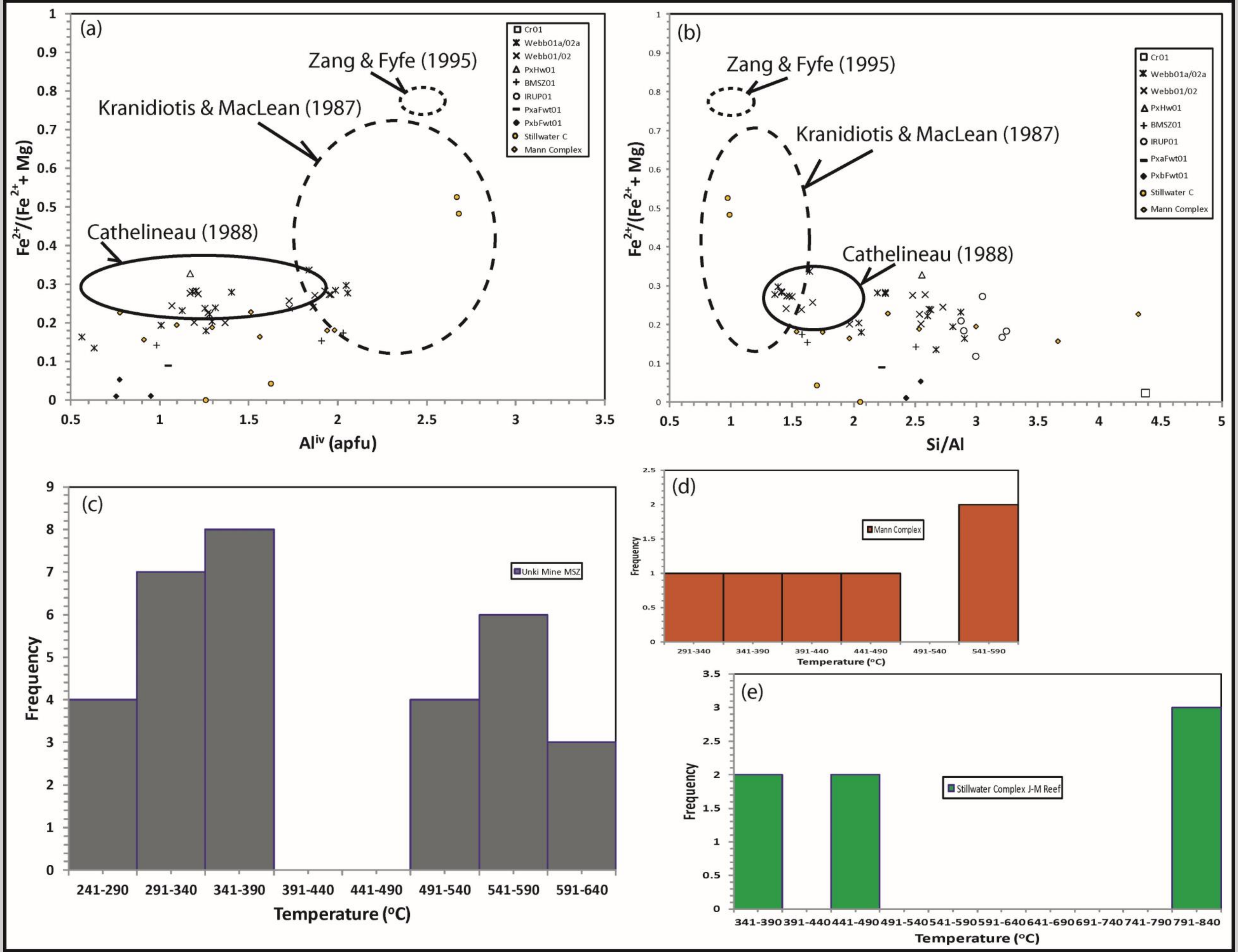
Unki Mine Amp compared with those from other layered intrusions

Unki Mine Chl compared with those from other layered intrusions



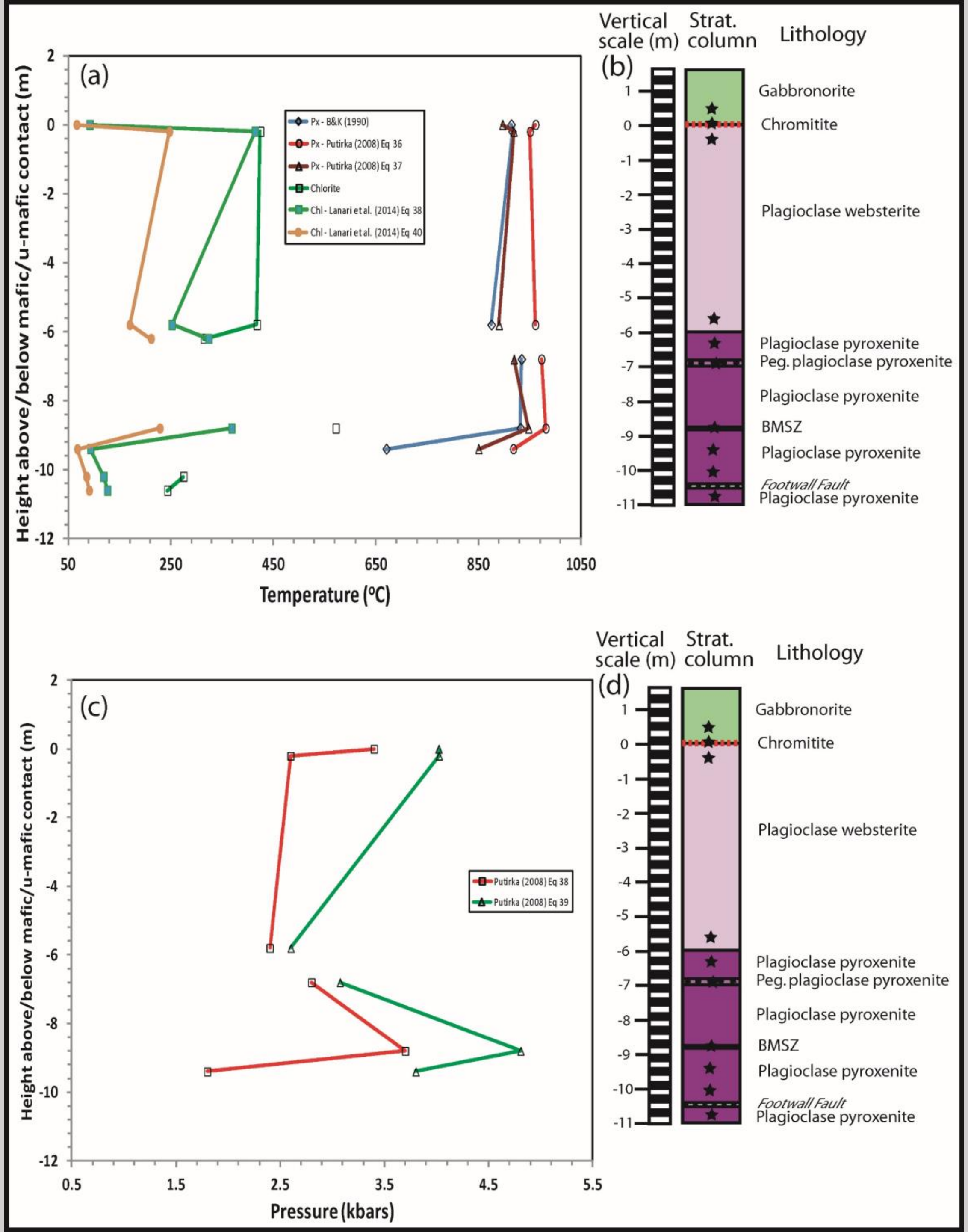
Chl thermometry equations selection

Unki Mine Chl temperatures of formation



Unki Mine pxn thermometry

Unki Mine pxn barometry



From “back of the envelop” calculations

- Assuming lithospheric conditions:
- Calculated pressures (1.8 - 4.8 kbar)
- Estimate the thickness of the overburden above the MSZ
- Assuming lithostatic conditions (3000 kg/m^3), the overburden during the hydrothermal alteration of the MSZ ranges from 6.1 -12.6 km and 8.8 - 16.3 km, respectively.
- Total thickness of the Mafic Sequence of 1150m in the Darwendale and Sebakwe Subchambers
- At the level of the MSZ at Unki Mine, thickness of the overburden above the 1150 m maximum thickness of the Great Dyke: **5-11 km and from 7.7-15 km**

Which model for the origin of Great Dyke MSZ PGEs

- 1. Immiscible sulfide liquid separating from silicate magma arising from injection of new magma (Campbell et al., 1983) **Likely?**
- 2. Scavenging of PGEs & S from the underlying cumulates by upward percolating Cl-rich fluids &subsequent deposition at chemical reaction front (Vermaak, 1976; Boudreau & Meurer, 1999) **Very likely**
- 3. Collection of PGE clusters suspended in the melt by immiscible sulfide liquid or chromite sinking to magma chamber floor (Tredoux et al., 1995) **Not for Cr**
- 4. Scavenging of PGEs by a fluid from primary sulfides precipitated in underlying rocks; the fluid reaches the crystal-magma interface and redissolves, causing a PGE-enriched immiscible sulfide to form (Boudreau, 1999) **Very likely**

Conclusions

- Primary magmatic PGE mineralization likely concentrated & remobilized by hydrothermal fluids
- Hydrosilicate minerals (amphibole, chlorite) were formed during the hydrothermal event
- Silicate minerals display record of this hydrothermal alteration
- Temperatures from chlorite thermometry are consistent with hydrothermal alteration

Acknowledgements

- Several former chief geologists, and exploration managers of many mines during my time in the Zimbabwean mining/exploration industry; in chronological order: 1. Peter Bourhill (Falconbridge), 2. Dr. Keith Viewing (Anglo American), 3. Dr. Tony Martin (Union Carbide), 4. Dr. Godfrey Dzinomwa (BHP), 5. Mike Moles (Independence Gold Mining) 6. Charley Murahwi (PV), & 7. Caston Musa (Zimbabwe Alloys)
- **Dr. Martin**'s Union Carbide's Lalapanzi chromite operation on the Great Dyke; **Dr. Viewing**'s Unki prospect project, **Charley Murahwi**'s Chirumhanzu chromitite pods, & **Caston Musa** offered me the joys of the Great Dyke Eluvials Project & the Inyala podiform project
- My former lecturers, and in particular my CLASSMATES, particularly at University of Zimbabwe where it all began. UZ is very special to me.

Further Acknowledgements and Outlook

- Collins Mwatahwa, my former classmate & friend, helped in various work to make this work possible
- Anglo American Platinum (my former employer)

A Critical Suggestion

- GSZ is a vibrant society; however it’s lacking one critical thing – peer-reviewed journal
- Every national society needs to have a good journal
- Countless practicing geologists & academics who can regularly contribute