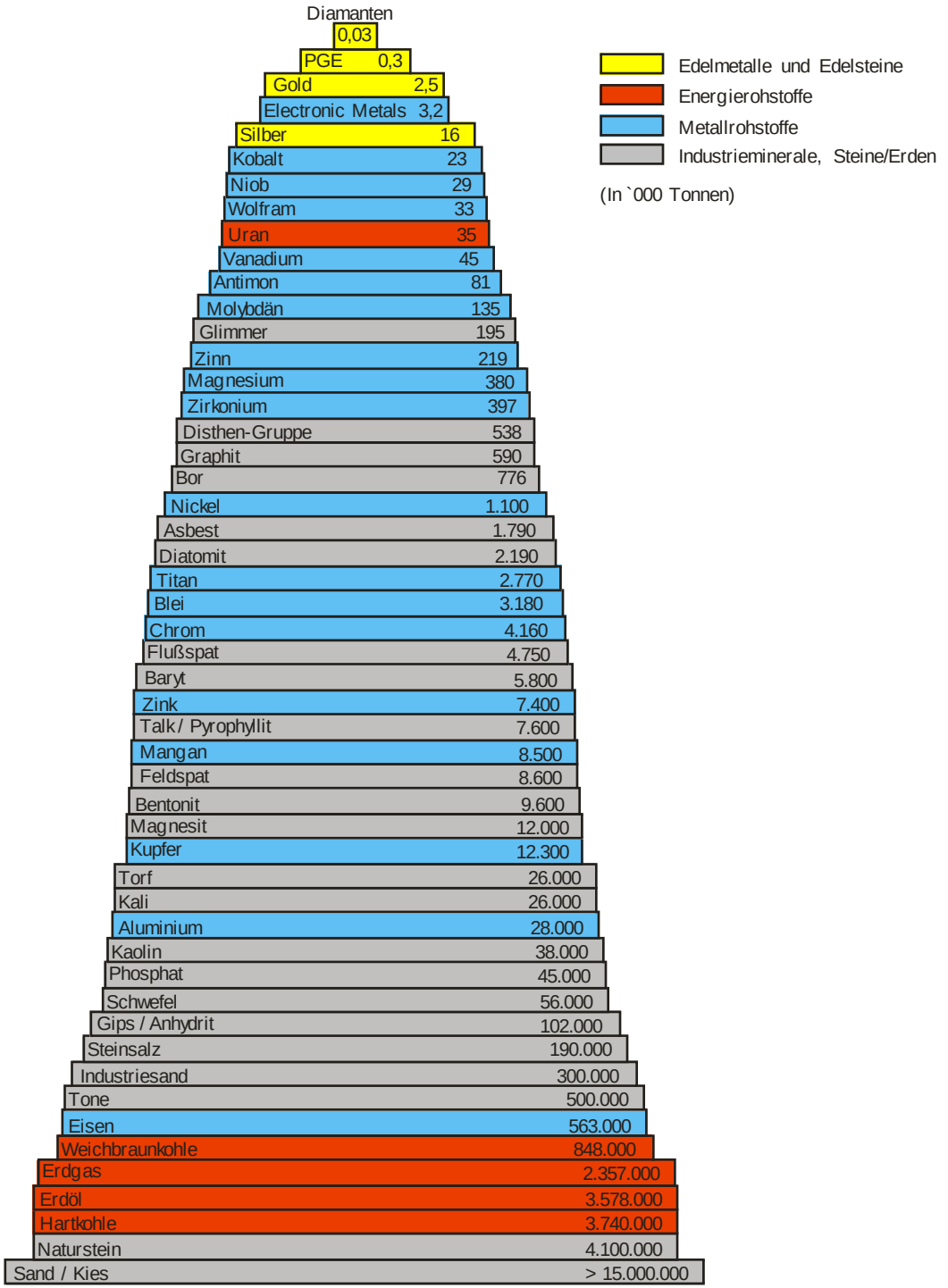
Lesotho Promise (603 ct)

- Recovered in Aug 2006 from Letseng le Terai, Lesotho (Aug 2006)

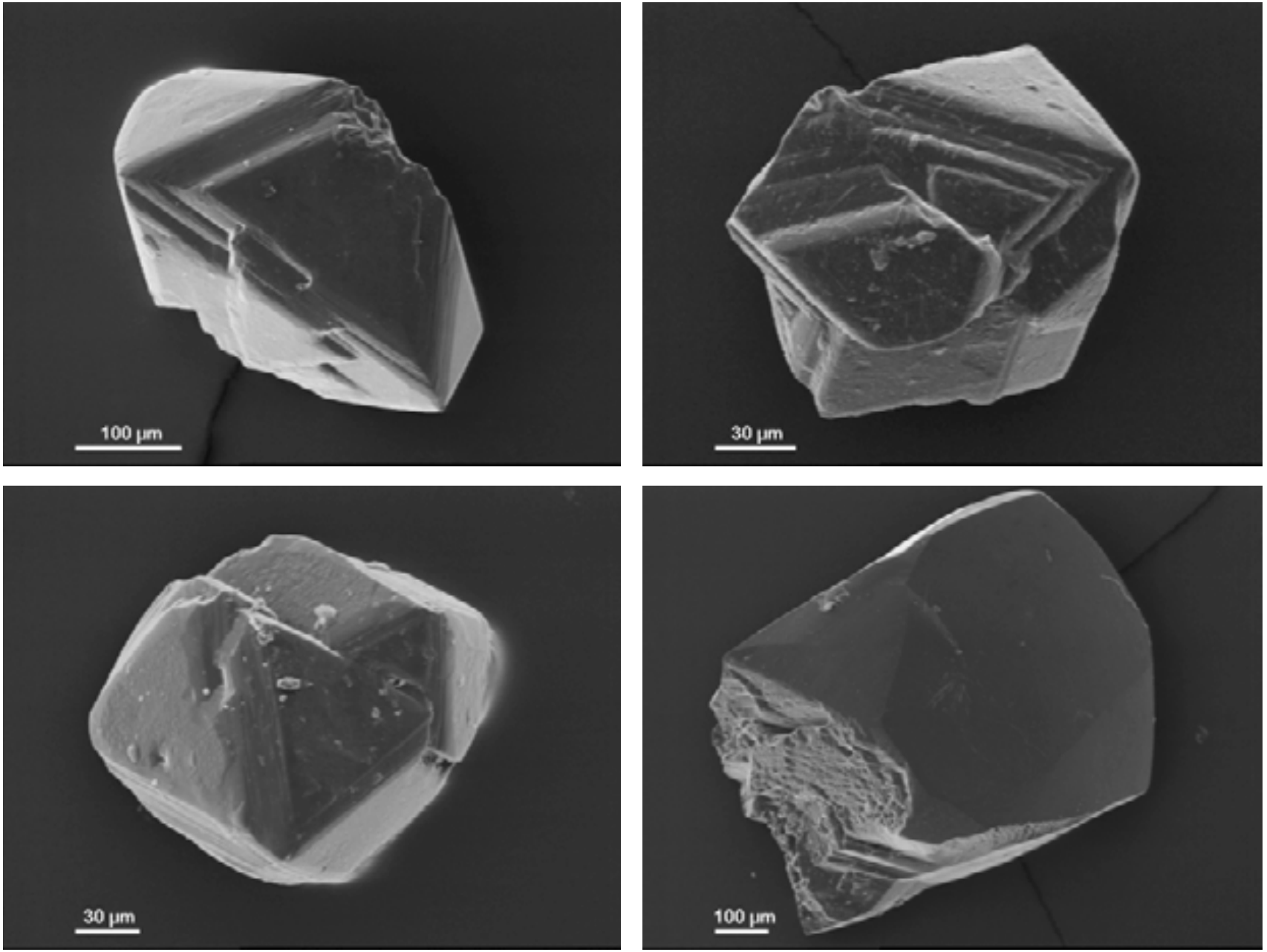
- Sold for 12.4 M USD (20,564 USD/ct)

- Manufactured to 26 D flawless polished gems of 0.55 to 75 ct (total weight 224 ct)

- Will sell for ~25 M USD


Diamanten
0,03
PGE 0,3
Gold 2,5
Electronic Metals 3,2
Silber 16
Kobalt 23
Niob 29
Wolfram 33
Uran 35
Vanadium 45
Antimon 81
Molybdän 135
Glimmer 195
Zinn 219
Magnesium 380
Zirkonium 397
Disthen-Gruppe 538
Graphit 590
Bor 776
Nickel 1.100
Asbest 1.790
Diatomit 2.190
Titan 2.770
Blei 3.180
Chrom 4.160
Flußspat 4.750
Baryt 5.800
Zink 7.400
Talk/ Pyrophyllit 7.600
Mangan 8.500
Feldspat 8.600
Bentonit 9.600
Magnesit 12.000
Kupfer 12.300
Torf 26.000
Kali 26.000
Aluminium 28.000
Kaolin 38.000
Phosphat 45.000
Schwefel 56.000
Gips / Anhydrit 102.000
Steinsalz 190.000
Industriesand 300.000
Tone 500.000
Eisen 563.000
Weichbraunkohle 848.000
Erdgas 2.357.000
Erdöl 3.578.000
Hartkohle 3.740.000
Naturstein 4.100.000
Sand / Kies > 15.000.000
Edelmetalle und Edelsteine
Energierohstoffe
Metallrohstoffe
Industrieminerale, Steine/Erden
(In `000 Tonnen)

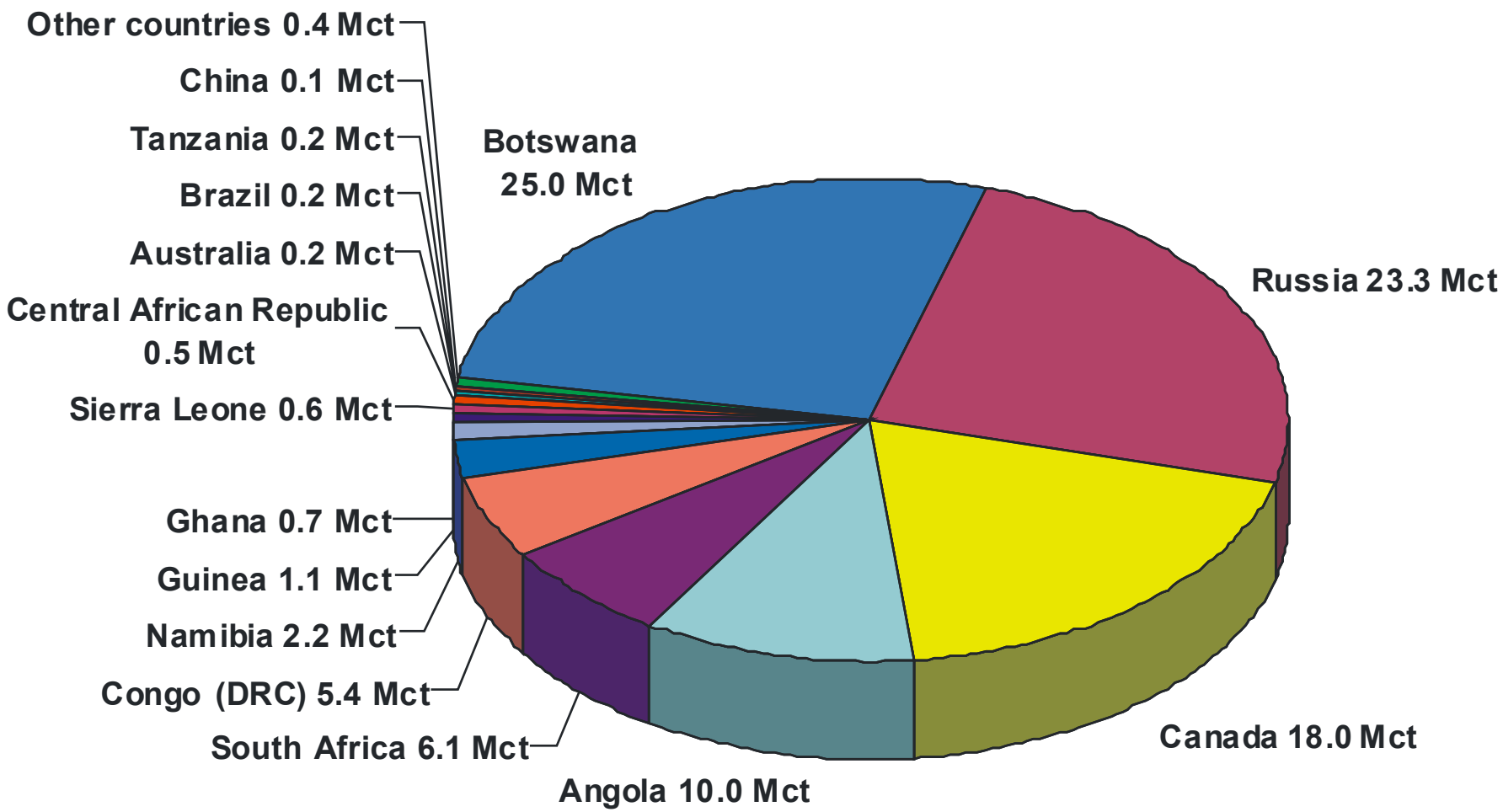
0.2 ct



Microdiamonds: REM images

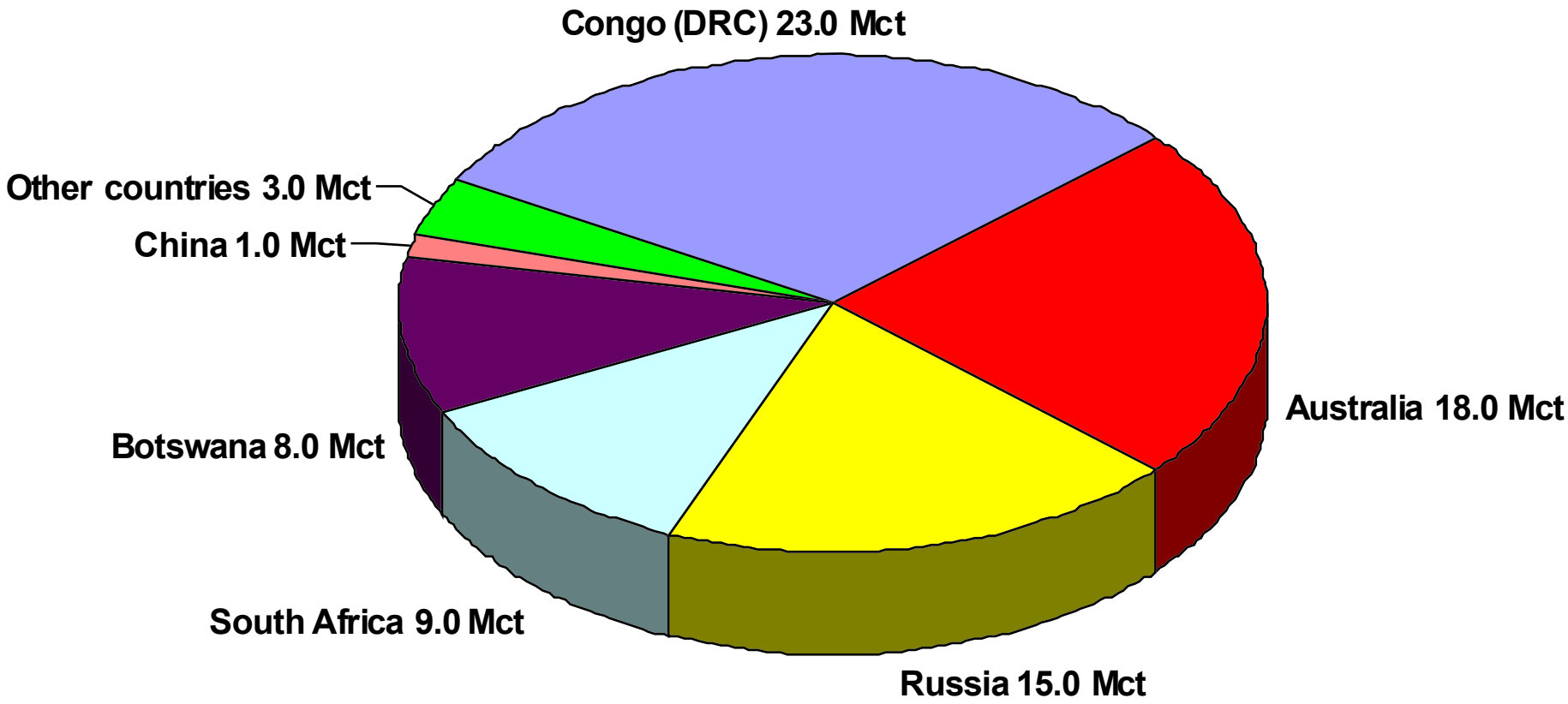

1 mm
Carbonado

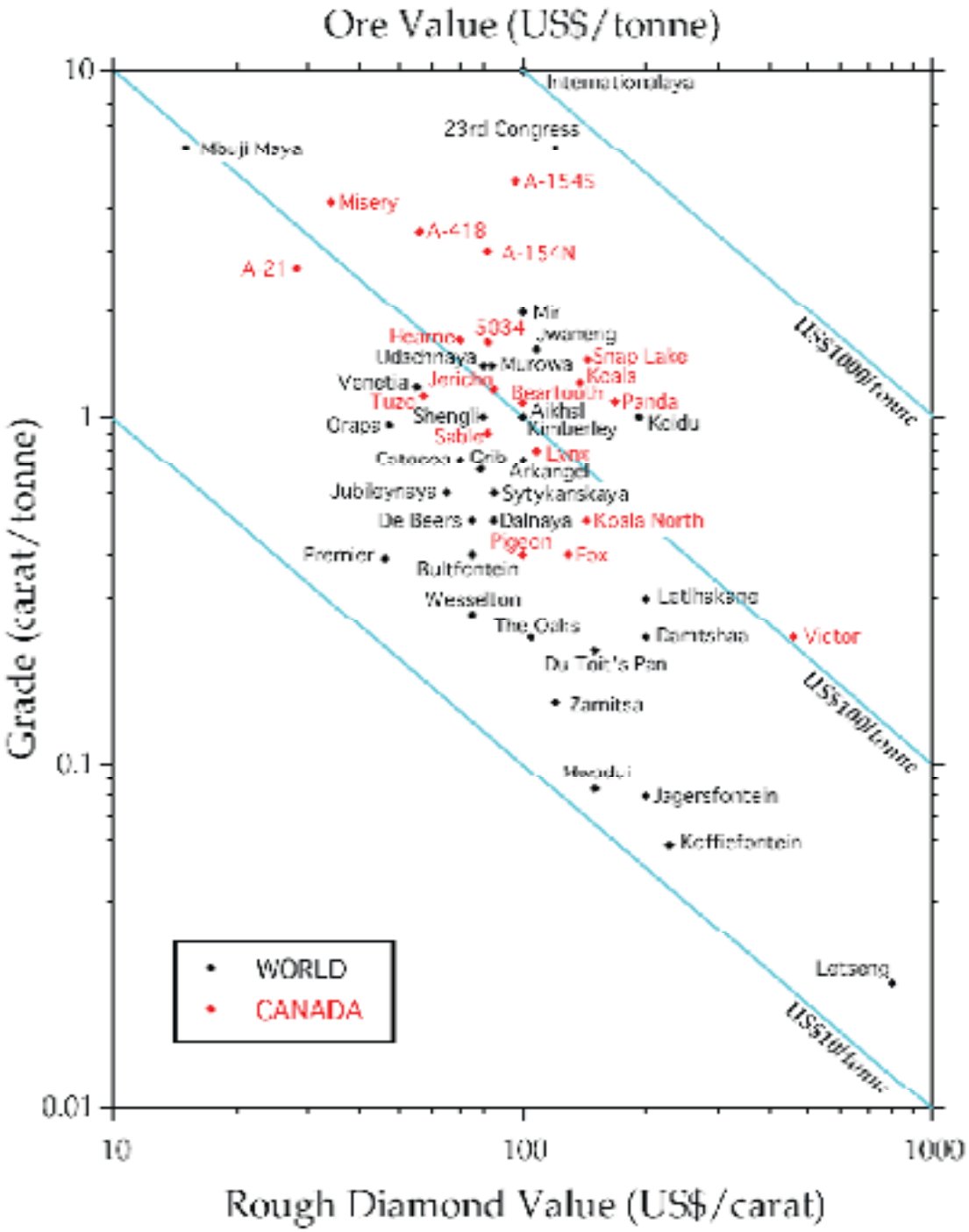
DIAMOND (GEM QUALITY) WORLD MINE PRODUCTION 2008 (94 Mct)



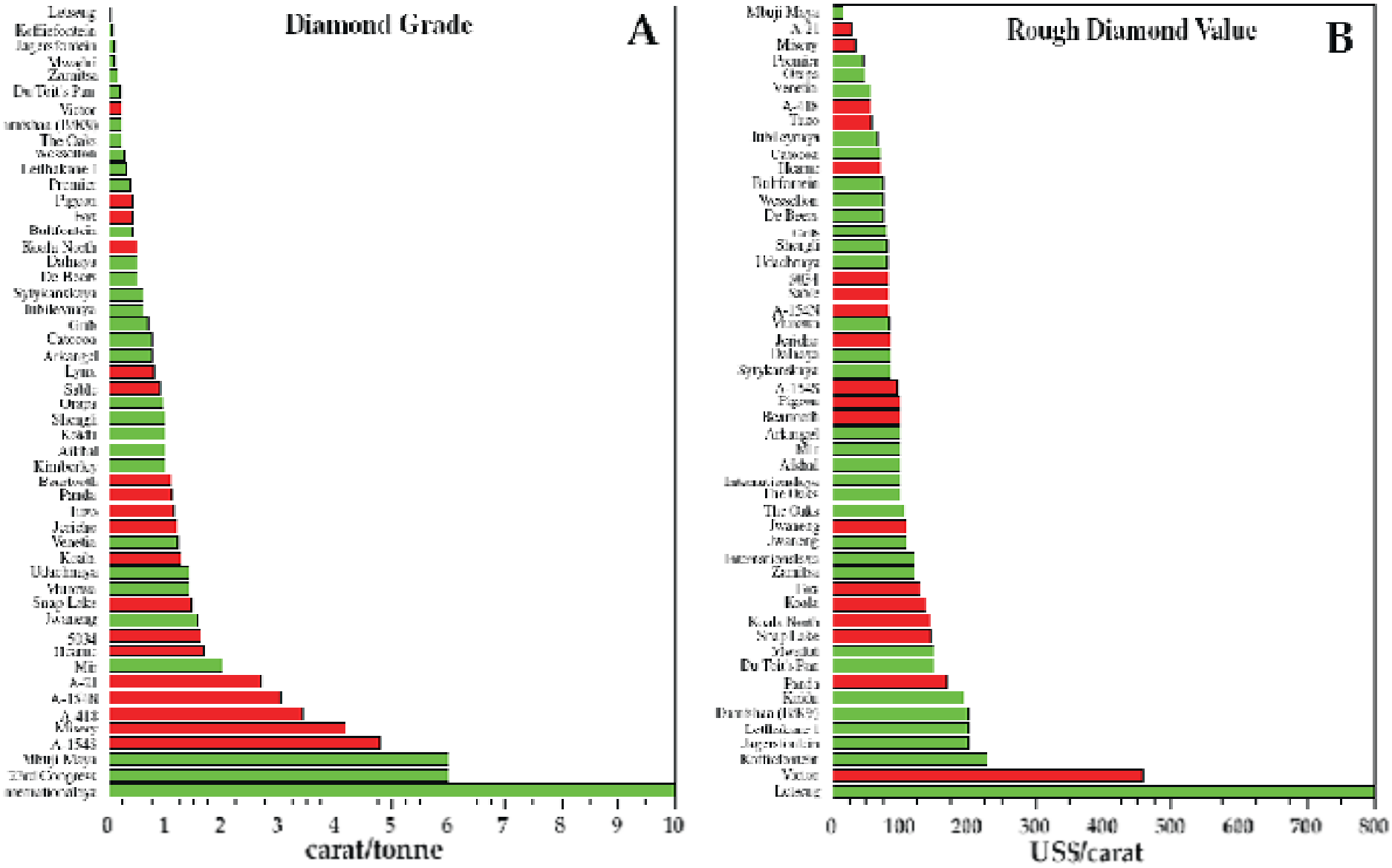
Total value: ~14 billion USD

Diamond (industrial) world mine production 2008 (75 Mct)



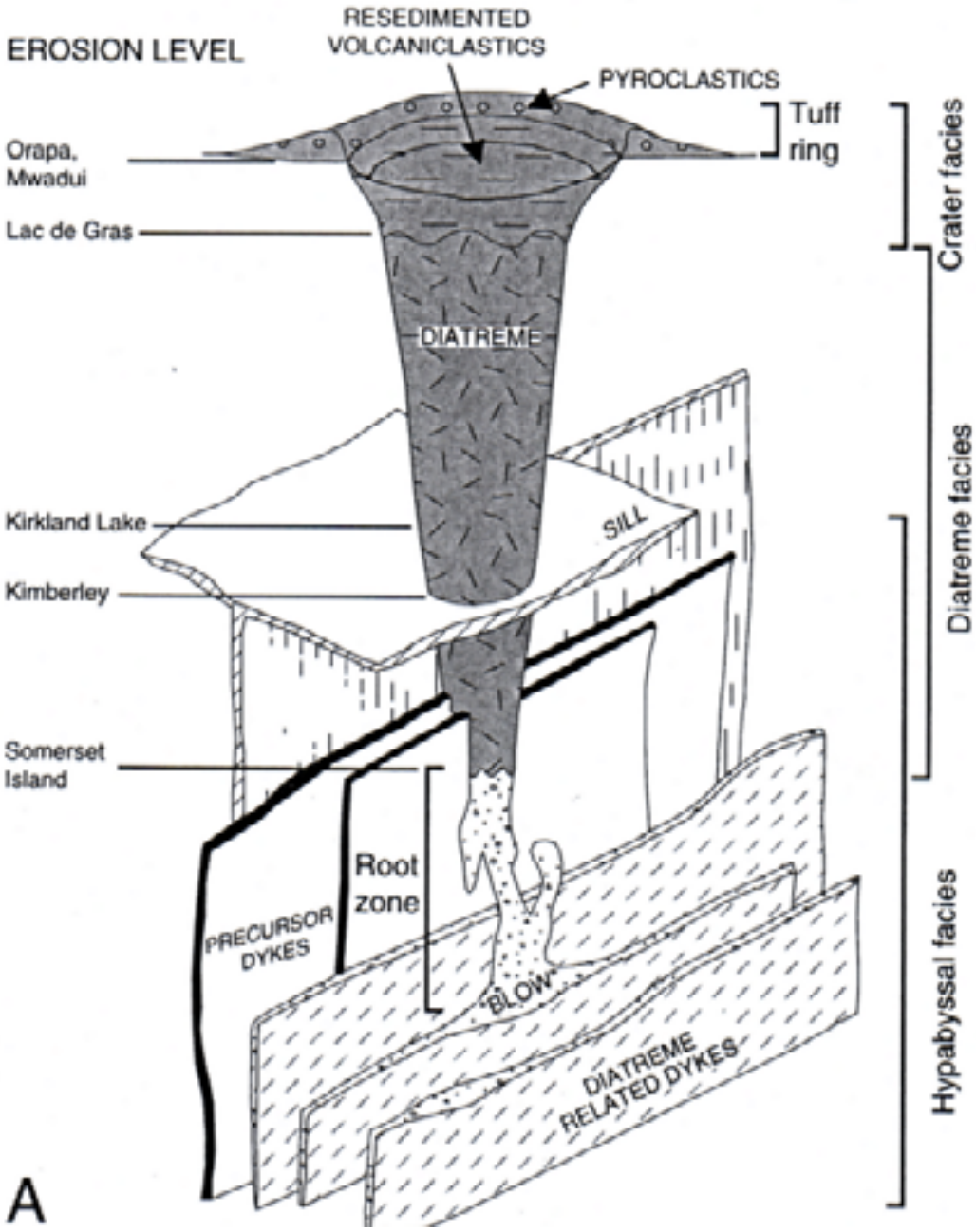


Kjarsgaard (2007)

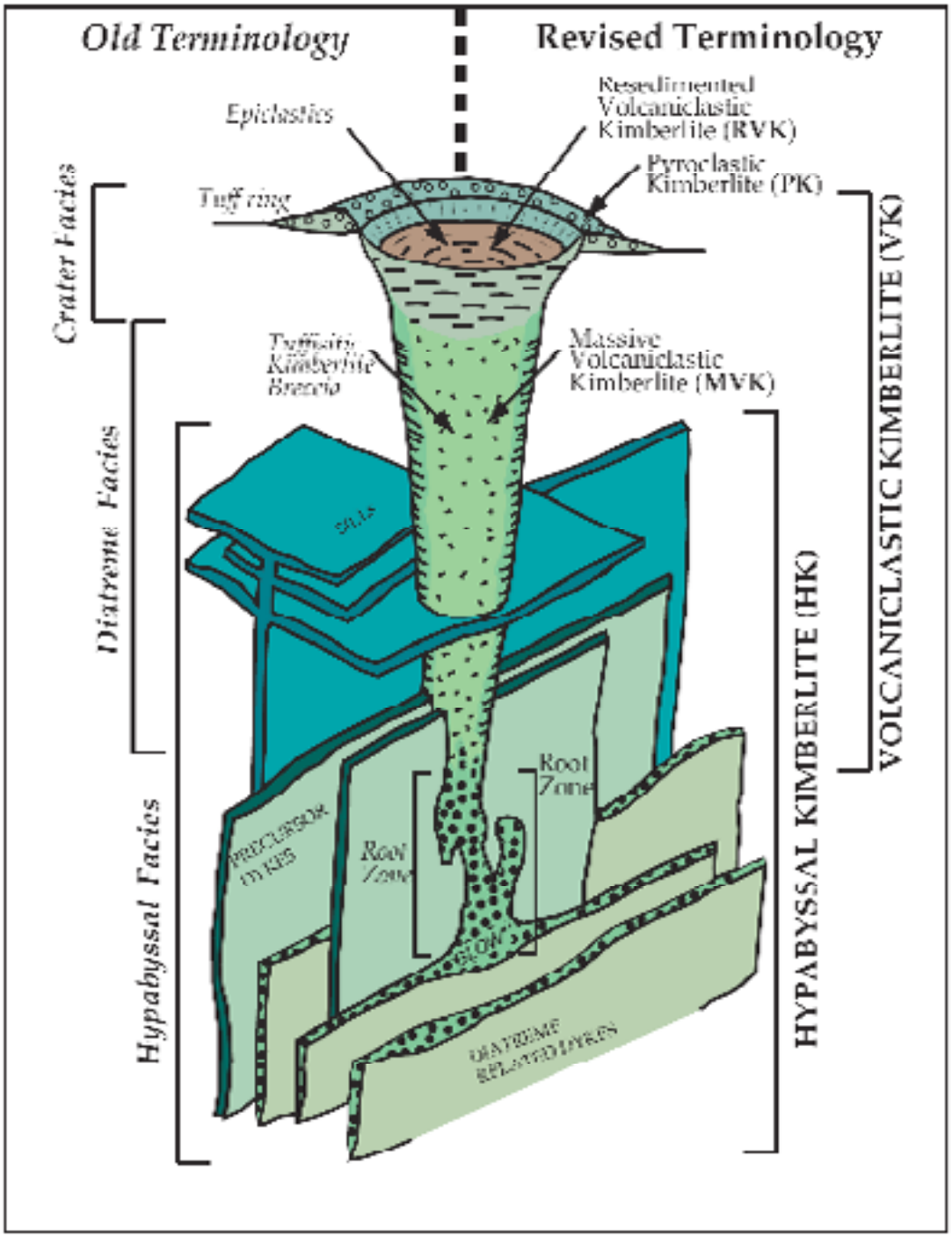


Kjarsgaard (2007)


88.7 ct (18 g)
3 cm long
The Shah: 88.7 ct (Moscow)
1591 India, 1739 Persia, 1829 Russia

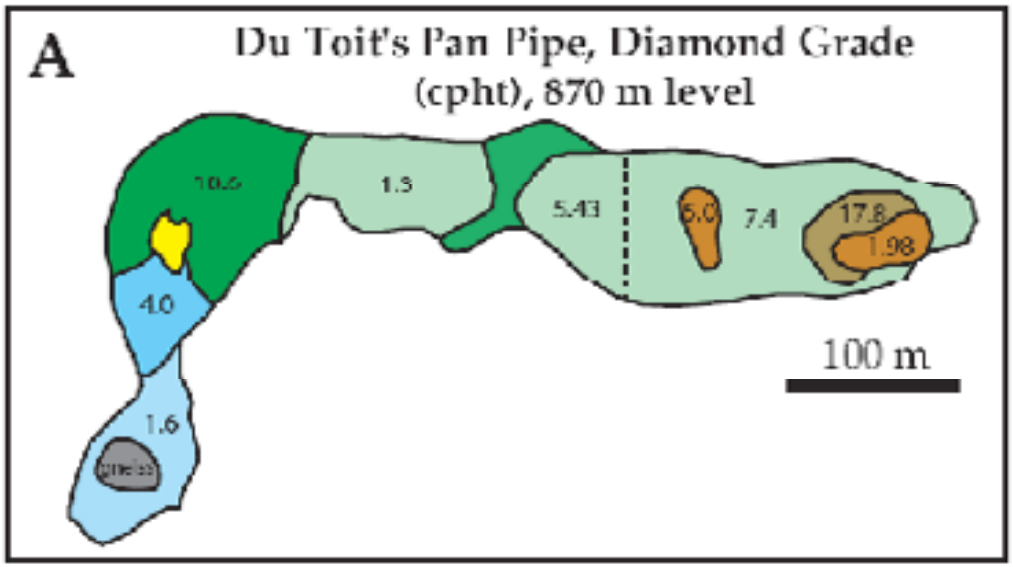


Model of an idealized kimberlite system with crater, diatreme and hypabyssal facies, plus present-day erosional level for some systems
Fipke et al. (1995)
Geol Surv Can Bull 423: 11



The classic South African model of a kimberlite pipe with old nomenclature (left side of figure) and a simpler, revised two-fold nomenclature system (right side of figure) to describe rocks from kimberlite magmatic systems (Mitchell, 1995; Kjarsgaard, 2003; Sparks et al., 2006).
PK = pyroclastic kimberlite
RVK = resedimented volcaniclastic kimberlite
MVK = massive volcaniclastic kimberlite
HK = hypabyssal kimberlite
Figure modified after Kjarsgaard, 2003).

Kjarsgaard (2007)



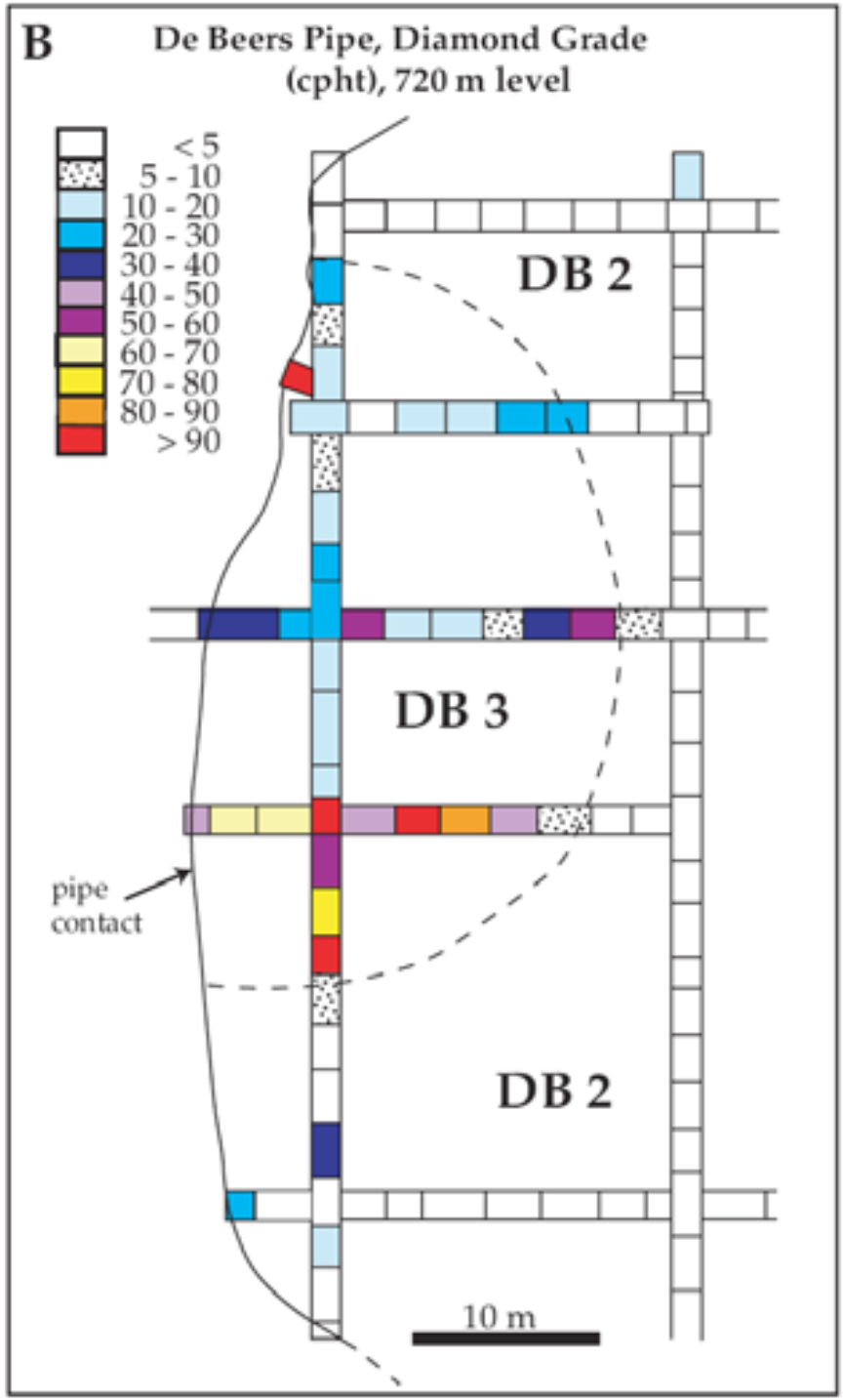
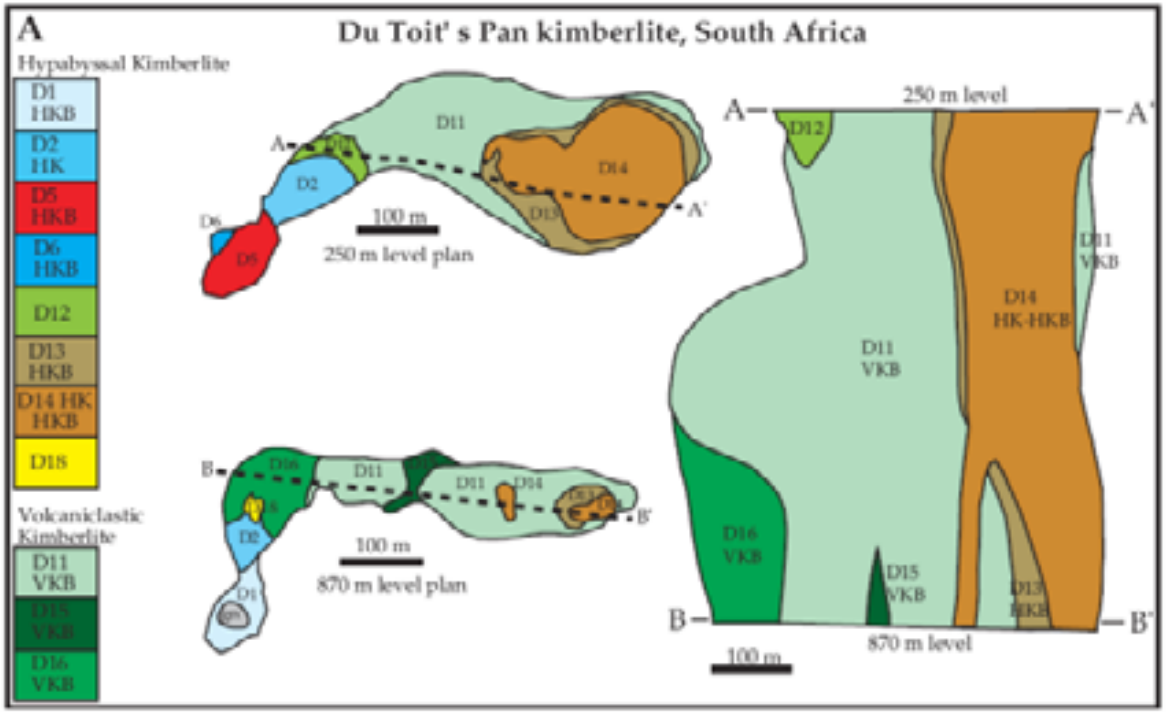
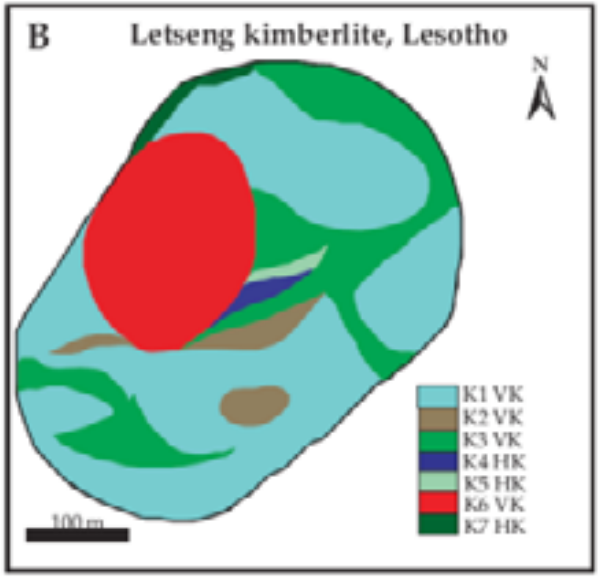


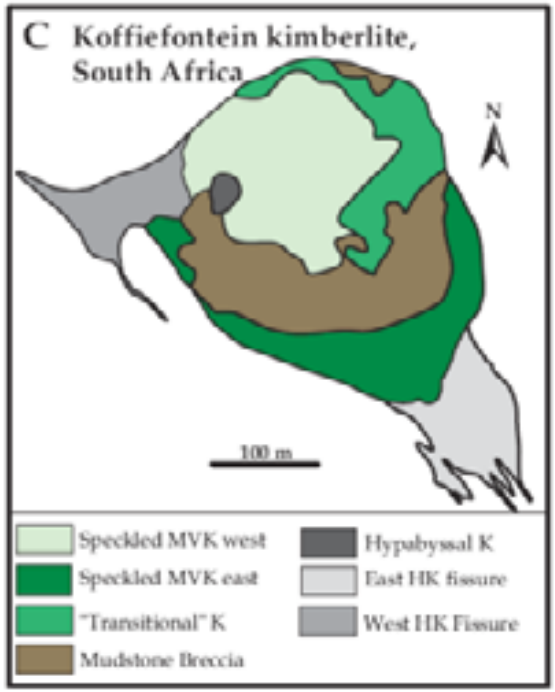
FIGURE 5. (A) Du Toit's Pan kimberlite, South Africa, 870 m level, illustrating the variation of diamond grade in cpht in relation to the different geological phases of kimberlite (after Clement, 1982). (B) De Beers kimberlite, South Africa, 720 m level, illustrating the variation of diamond grade in cpht within the DB2 and DB3 kimberlite intrusions (adapted from Clement, 1982). Note: cpht = carats per hundred tonnes.

Kjarsgaard (2007)

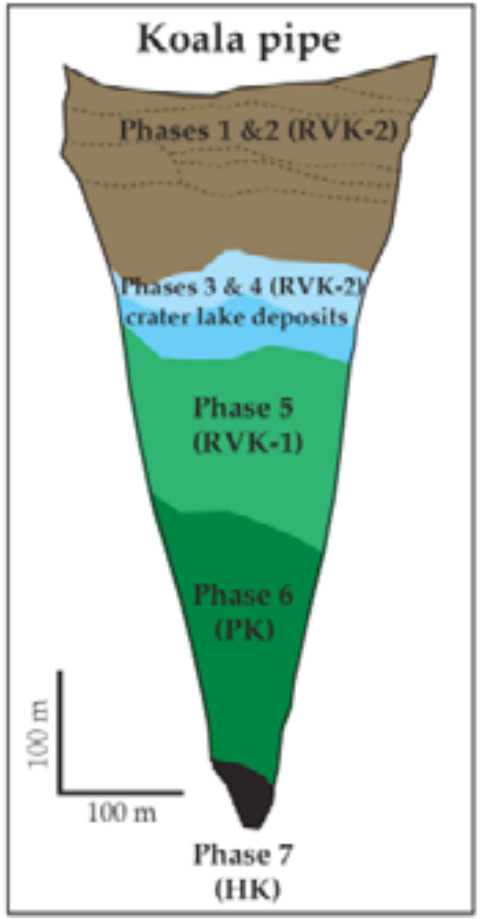




Plan view



Cross section



Multiple intrusive phases in kimberlite pipes

Kjarsgaard 2007: 263-264)

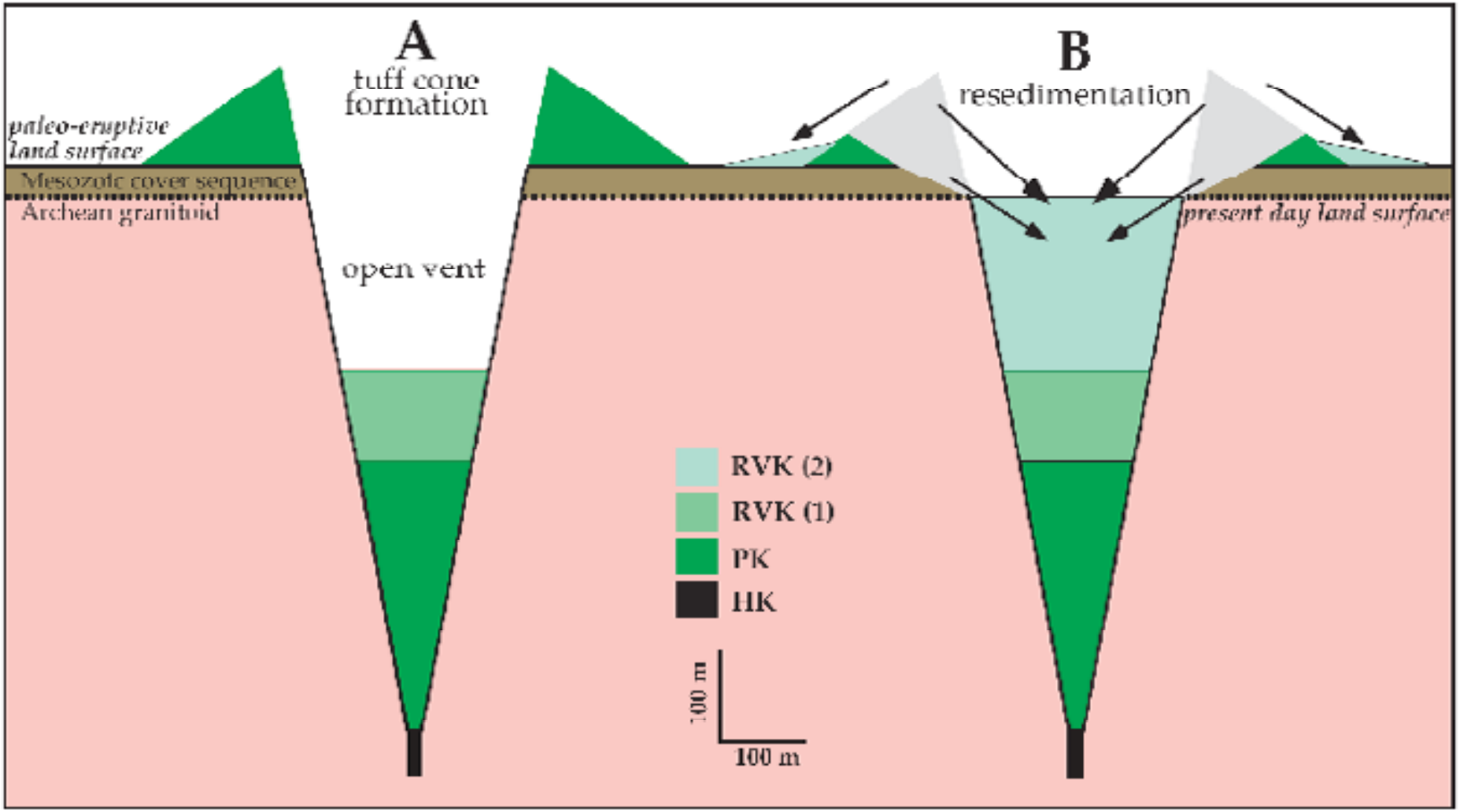
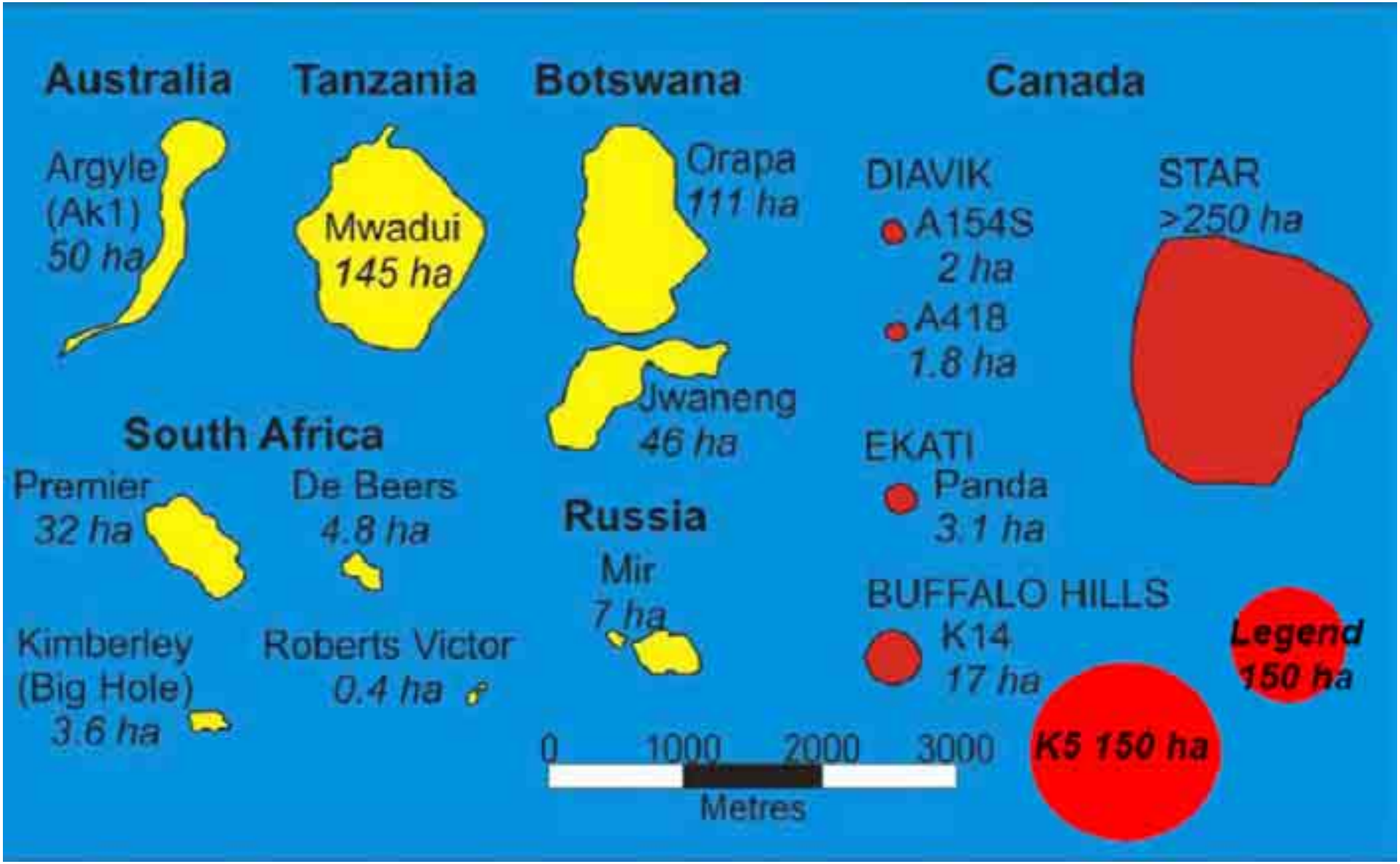


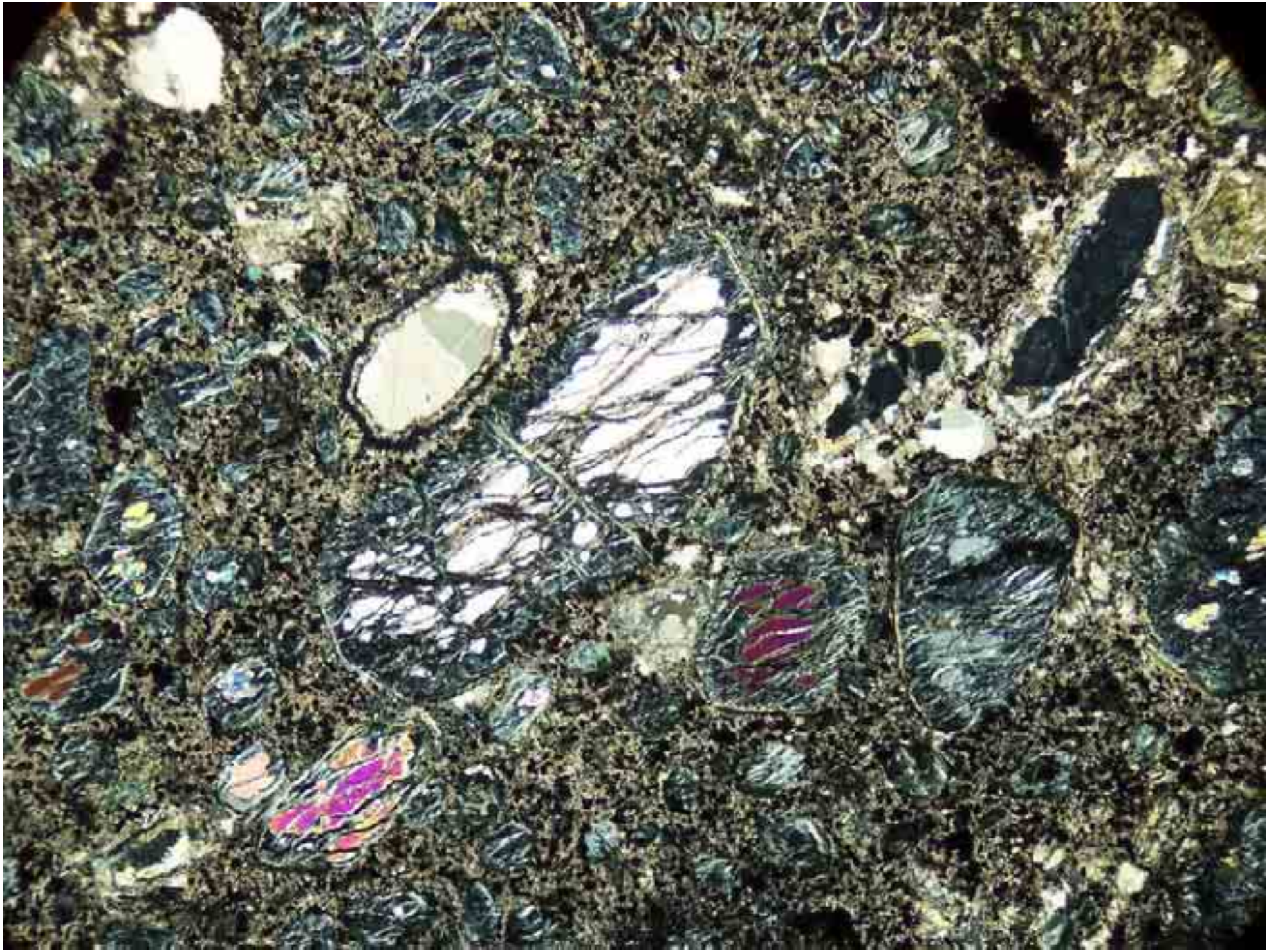
FIGURE 19. (A) Scaled model for the reconstruction of a kimberlite tephra cone at the Koala pipe, NWT. The tephra cone is 600 m in diameter and 108 m high with a crater rim diameter of 300 m an angle of repose of ~36°, and an internal crater wall angle of ~78°. The tephra cone sits on a 32 m thick Mesozoic cover sequence, on top of Archean granitoids. (B) Resedimentation of kimberlite (from the tephra cone) and cover sequence sediments by grain flow and slumping processes, into the open excavated pipe. The model assumes it is not feasible for the entire tephra cone to be resedimented into the open pipe, i.e., tephra will also be displaced away from the open pipe. 1:1 scale, no vertical exaggeration. Adapted and modified after Kjarsgaard (2003, 2007)

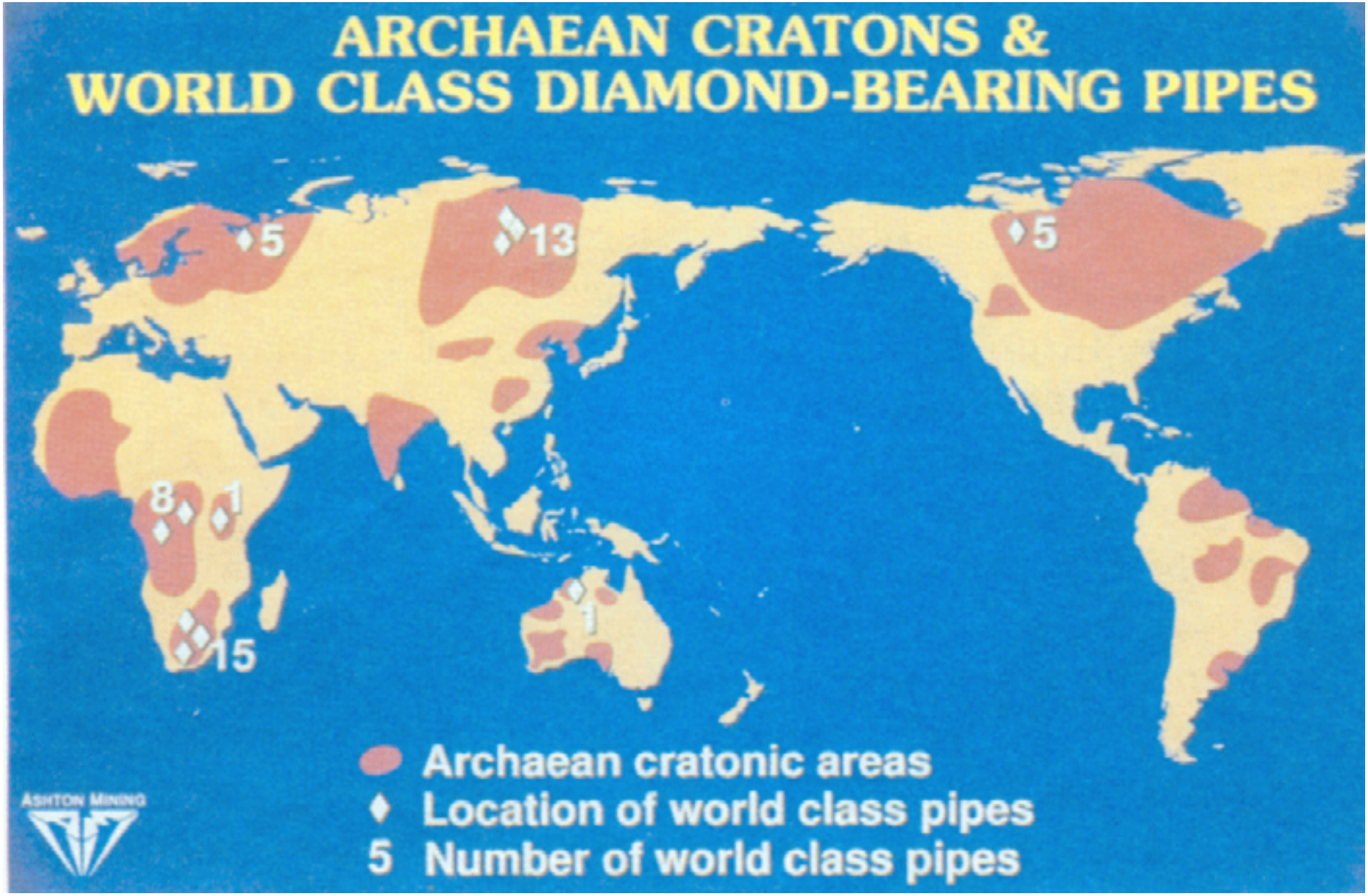
Kjarsgaard (2007)

World kimberlite sizes

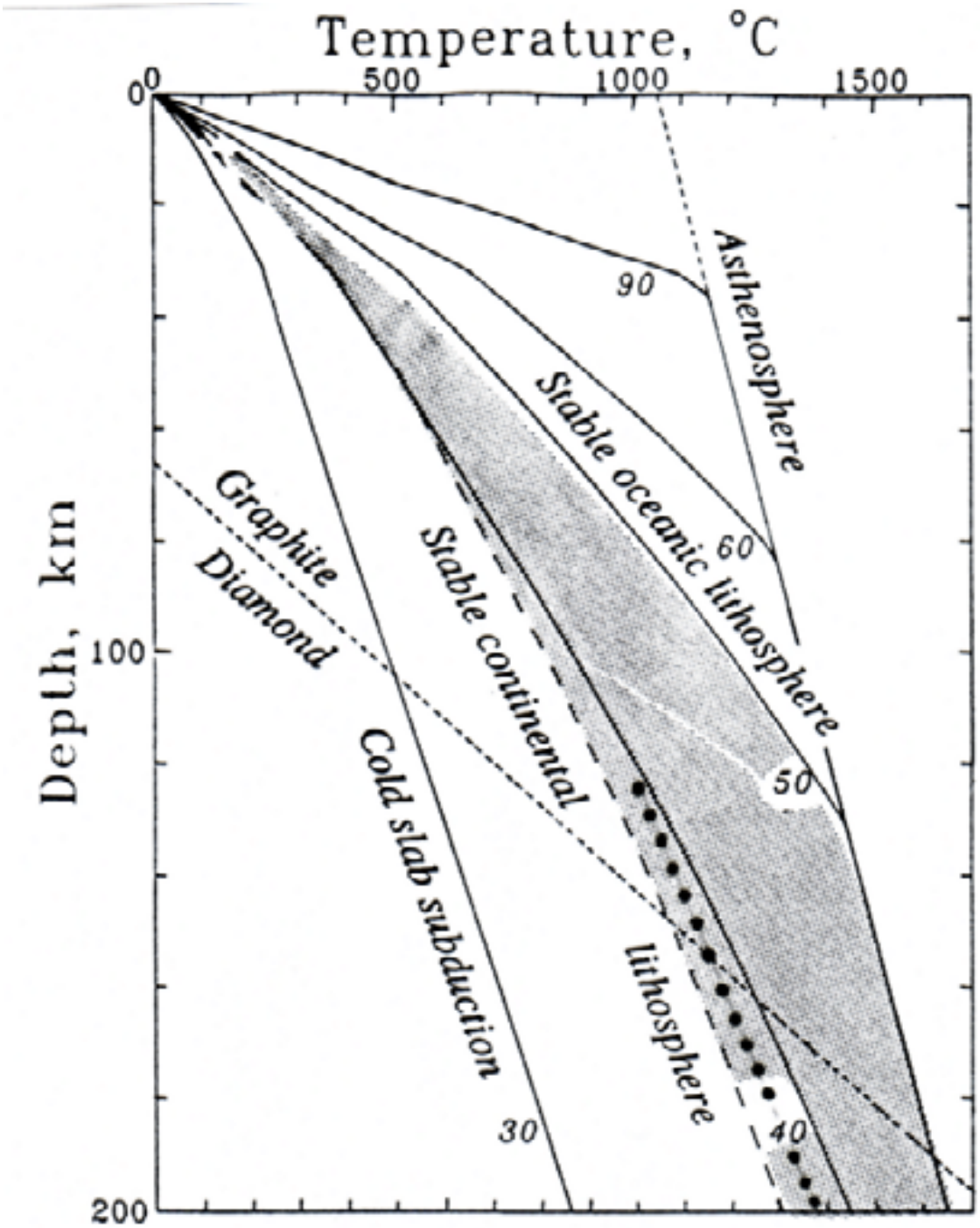


Tokapal, central India: Tuff-facies kimberlite with olv phenocrysts (black)

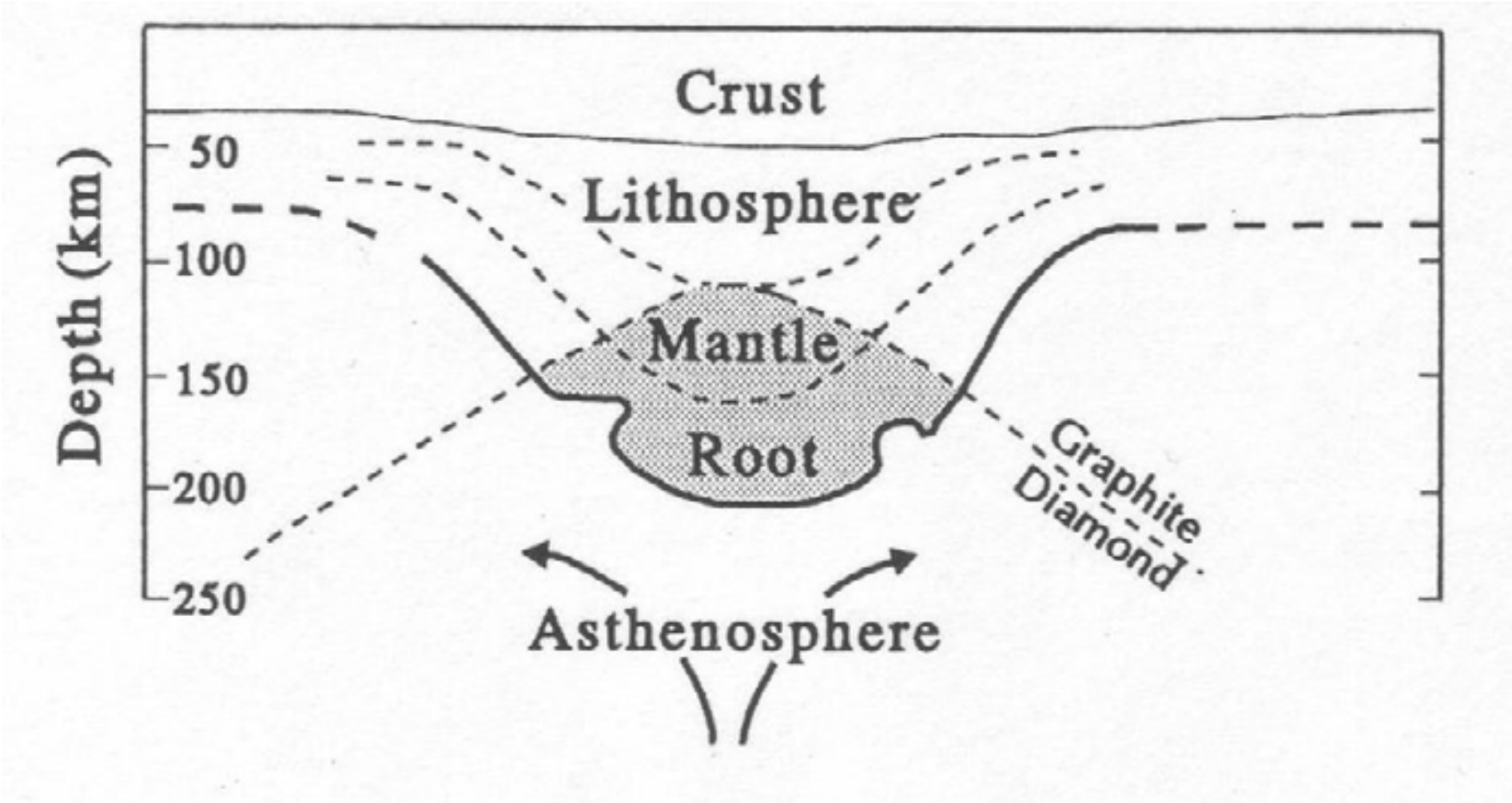




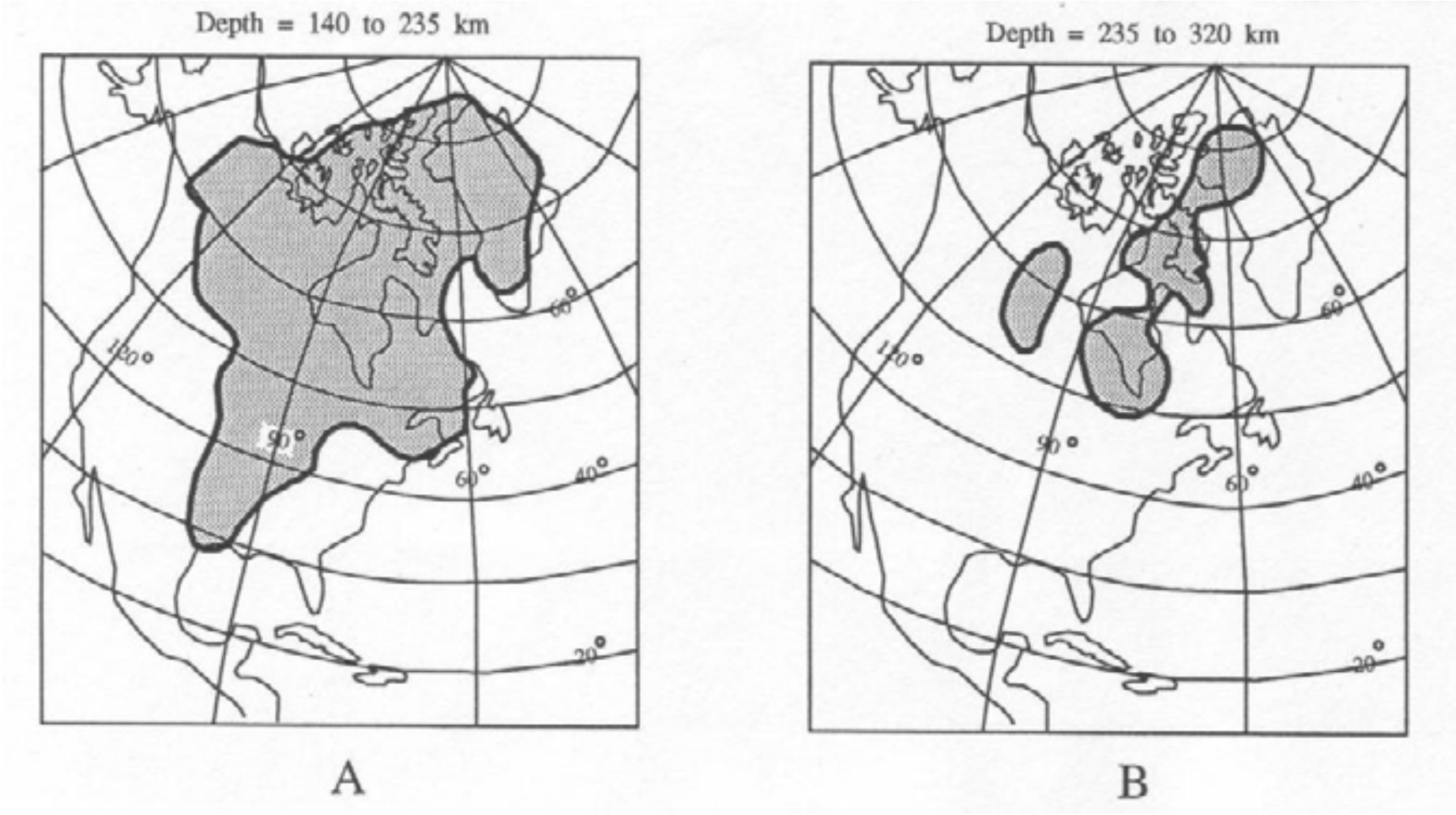
Clifford's Rule: Diamondiferous kimberlites are on Archean cratons



Graphite-diamond phase transition, asthenosphere-lithosphere boundary (basalt dry solidus), and conductive geotherms for surface heat flow values from 30 (cold subduction) to 90 mW/m^2 (young oceanic lithosphere). Stippled line is typical of Archean cratons
(Morgan 1995, J Geochem Expl 53: 148)

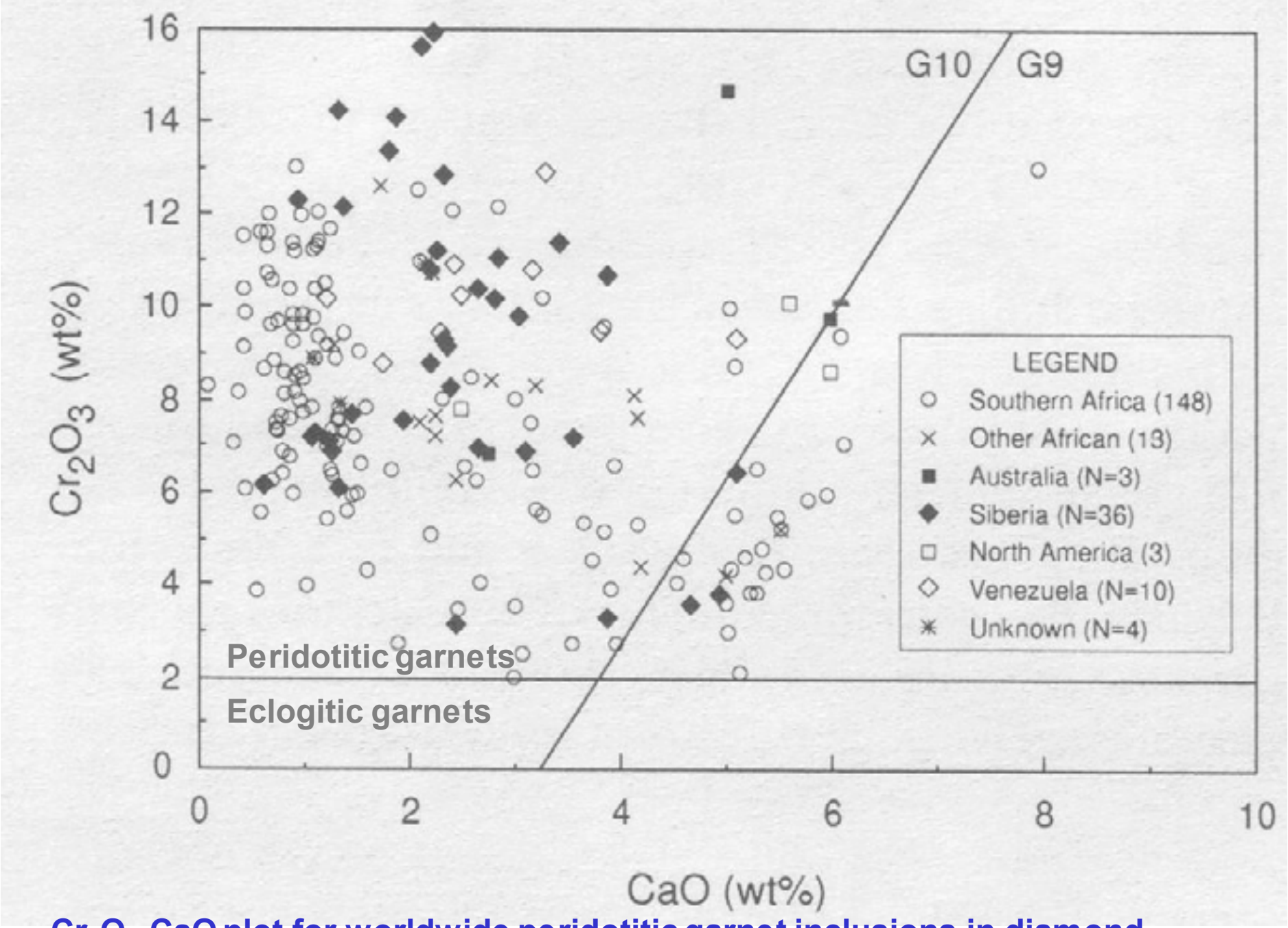


Simplified model of a diamondiferous lithospheric mantle root.
The downward deflected dashed lines are the 900 and 1200°C isotherms within the root; asthenosphere is at around 1500°C.
Helmstaedt and Gurney (1995) J Geochem Expl 53: 128

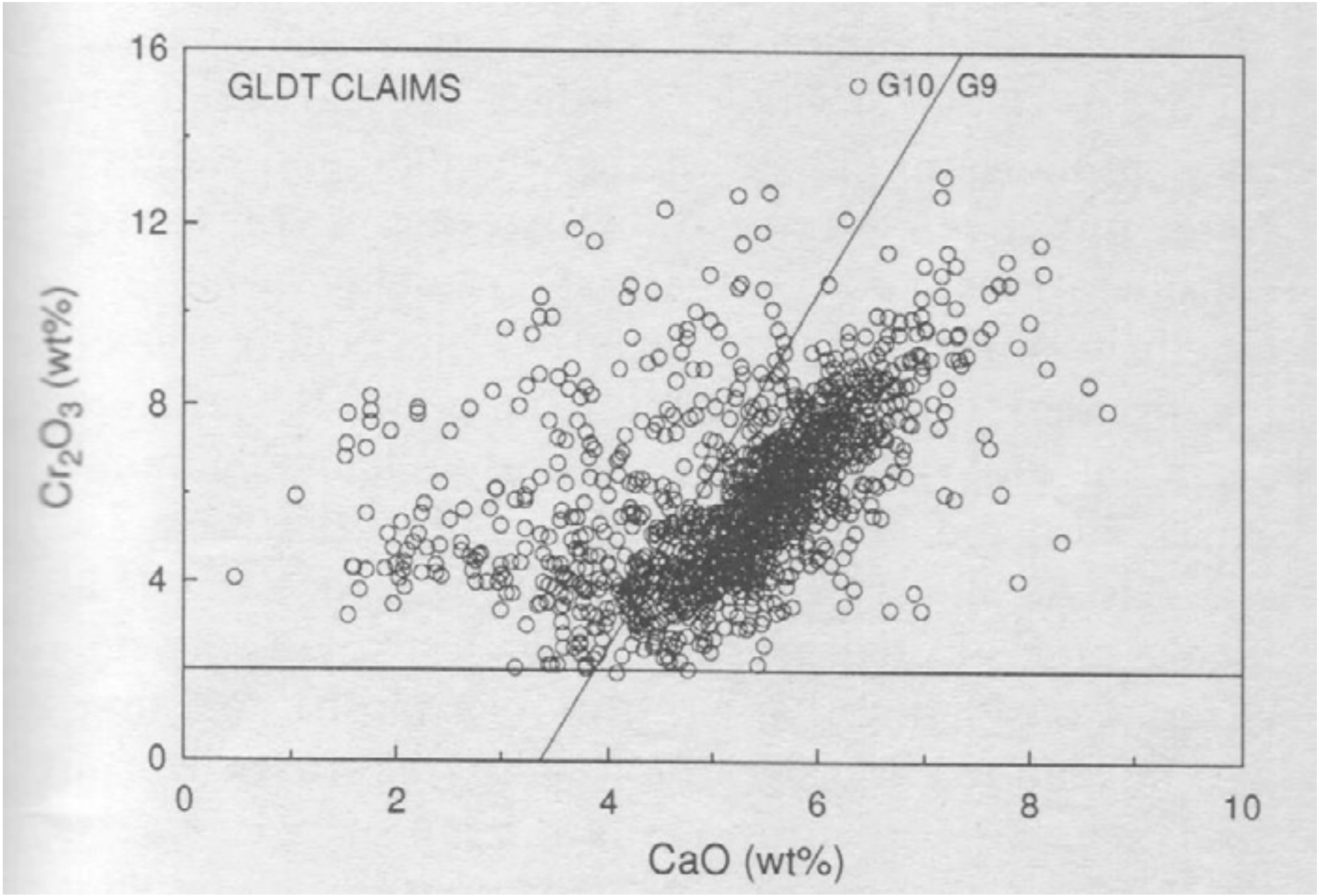


Positive shear-wave perturbations (+3 % contour) under North America from seismic tomography

Helmstaedt and Gurney (1995) J Geochem Expl 53: 131



Cr_2O_3-CaO plot for worldwide peridotitic garnet inclusions in diamond
Gurney (1984)

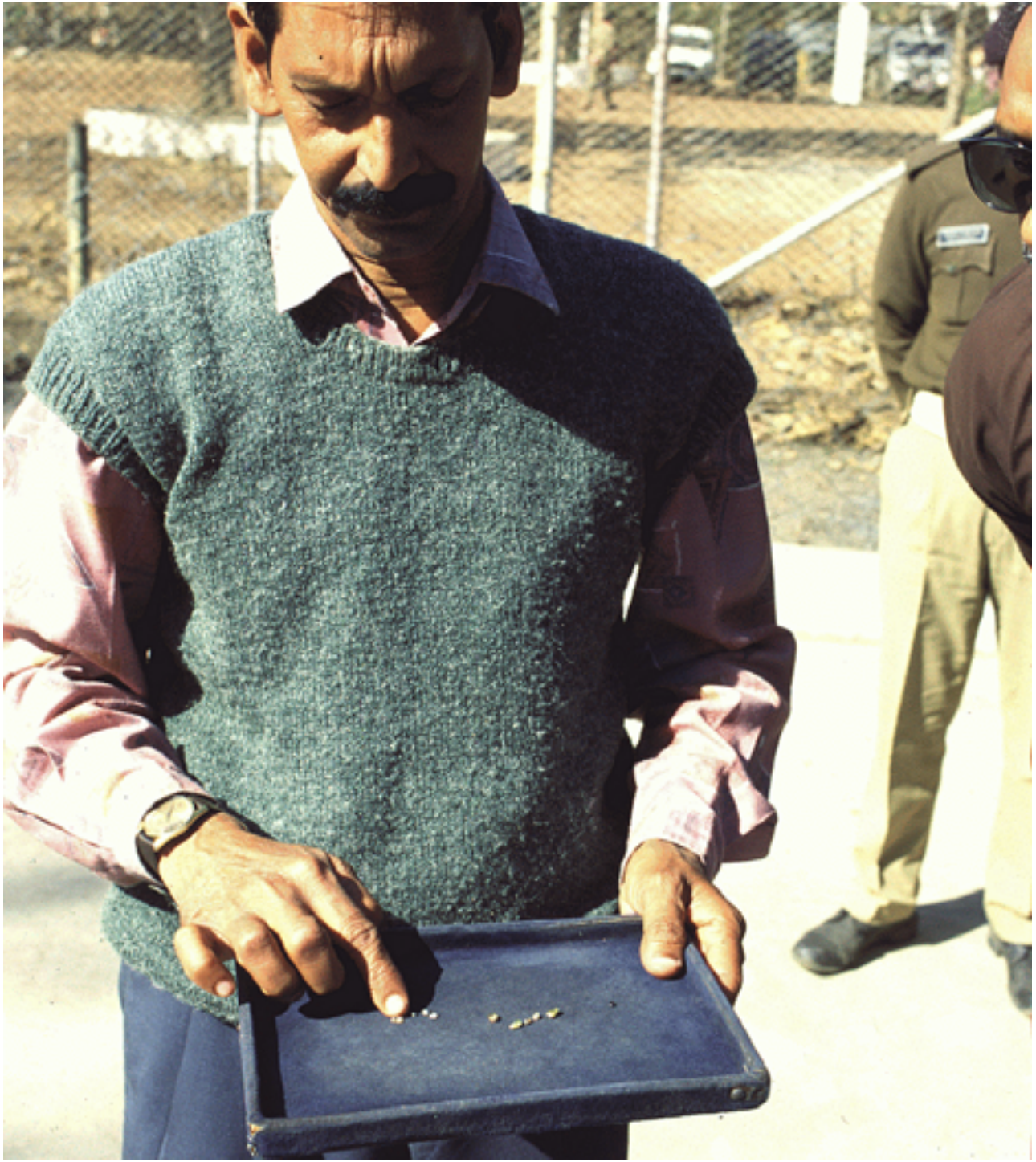


Peridotitic garnet composition plot for Diamet's property, NWT, Canada, which later became known as Lac de Gras diamond district (Internal report 1990)

Majhgawan Mine, 18 Mt (150 m depth) @ 0.1 ct/t, 220 USD/ct

Majhgawan mine, India: Sorting of heavy-mineral concentrate

Break each ten stones recovered



Gem (4) Near-gem (5) Industrial (1)

Artisanal paleoplacer mining near Majhgawan, India

Diamantina, Brazil,
18th century

Espinhaco Range, Serro, Brazil


Espinhaco Supergroup (1.75 Ga)

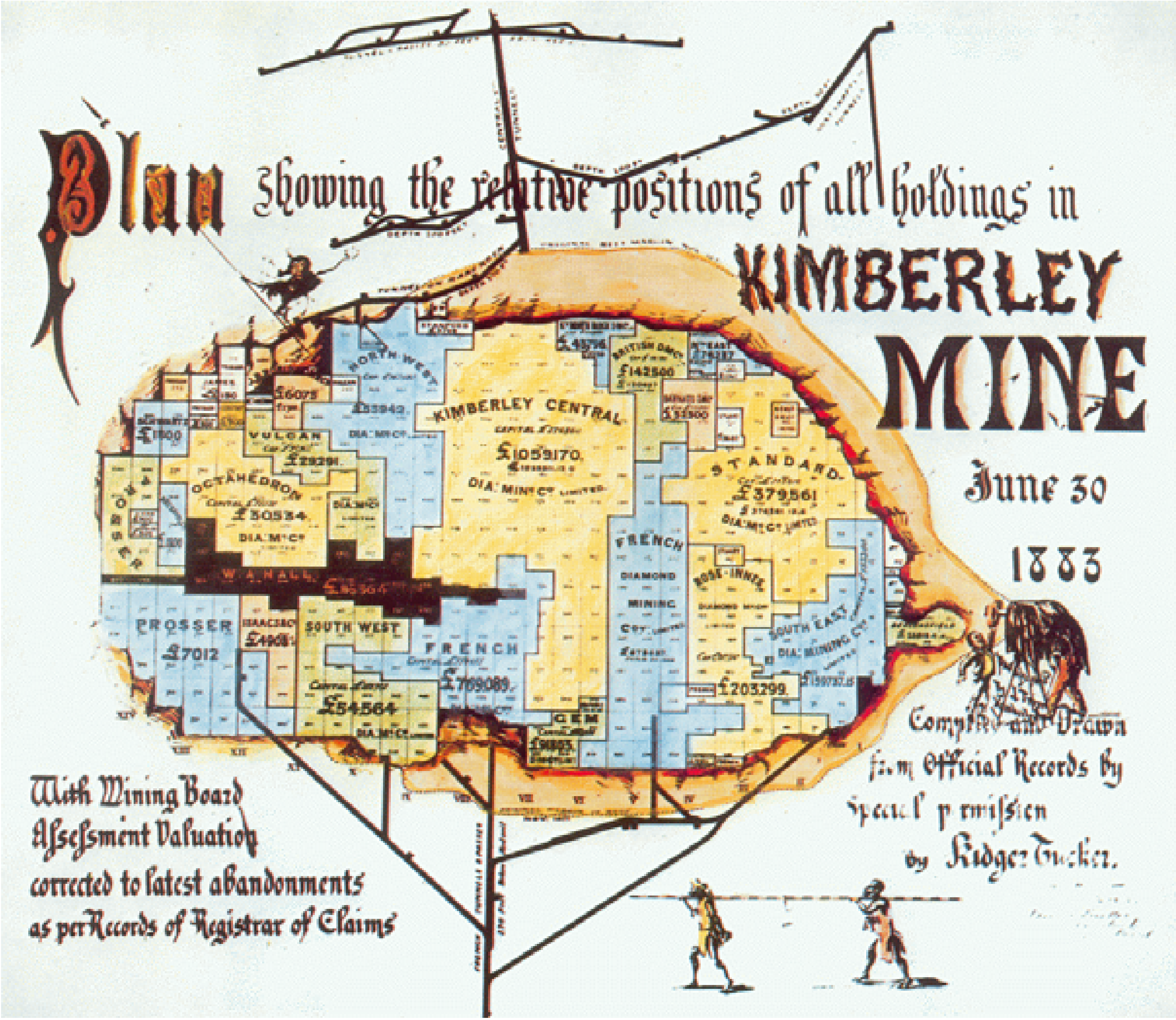
Campo Sampaio, Diamantina district, Brazil

„Sopa“ at Campo Sampaio, Diamantina district, Brazil

Campo Sampaio, Diamantina district, Brazil

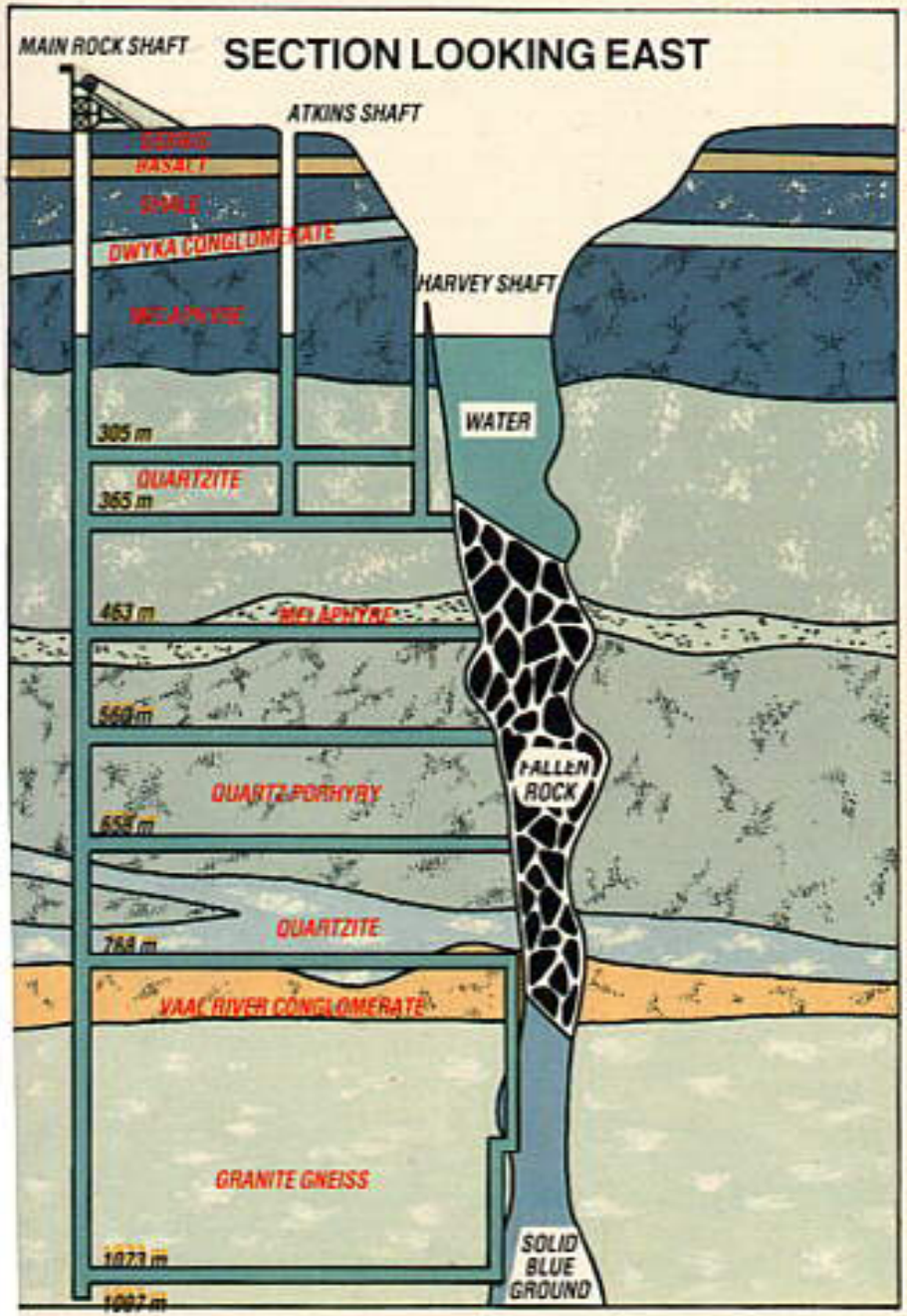
Brumadinho, Diamantina district, Brazil: ~0.3 ct/m^3, ~180 USD/ct

Diamond-PGE-Au placer at Serro, Diamantina district, Brazil


Plan showing the relative positions of all holdings in
KIMBERLEY
MINE
June 30
1883
KIMBERLEY CENTRAL
£1059170
DIA. MIN. Co. LIMITED
STANDARD
£379561
FRENCH
DIAMOND
MINING
NORTH WEST
VULCAN
£29291
OCTAHEDRON
£50534
DIA. M. Co.
PROSSER
£7012
SOUTH WEST
£54564
FRENCH
ROSE-INNES
SOUTH EAST
DIA. MINING Co.
£203299
GEM
BRITISH DIAM.
£142500
from Official Records by
special permission
by Ridger Tucker.
With Mining Board
Assessment Valuation
corrected to latest abandonments
as per Records of Registrar of Claims

The „Big Hole“ 1879

Kimberley: Big Hole, 463x1097 m, stopped in 1914



The Kimberley Mine

DISCOVERED 16TH JULY 1871 BY FLEETWOOD RAWSTORNE

AREA AT SURFACE	17 ha
PERIMETER	1,6 km
AXIS NORTH & SOUTH	500 m
AXIS EAST & WEST	457 m
SURFACE TO TOP OF HARD ROCK	90 m
SURFACE TO WATER	165 m
DEPTH OF WATER	230 m
GROUND EXCAVATED	22 500 000 t
DIAMONDS PRODUCED	14 504 566 carats
EQUIVALENT TO	2722 kg
WORKING CEASED	AUGUST 1914


Kimberley pipe (Big Hole)
De Beers pipe
Dutoitsspan pipe
Boshoff Road dump
Kimberley
Wesselton p
Bultfontein pipe
De Beers treatment p
Image © 2008 DigitalGlobe
4.00 km
Zeiger 35 J 283892.90 m O 6816260.68 m S
Übertragung 100%
Sichthöhe

Kimberley: Kimberlite (Blue Ground: Diatreme-facies heterolithic breccia). Width of photograph is 10 cm.

Premier (Cullinan) Mine, South Africa: 35 ct/100 t recovered grade, 50 USD/ct

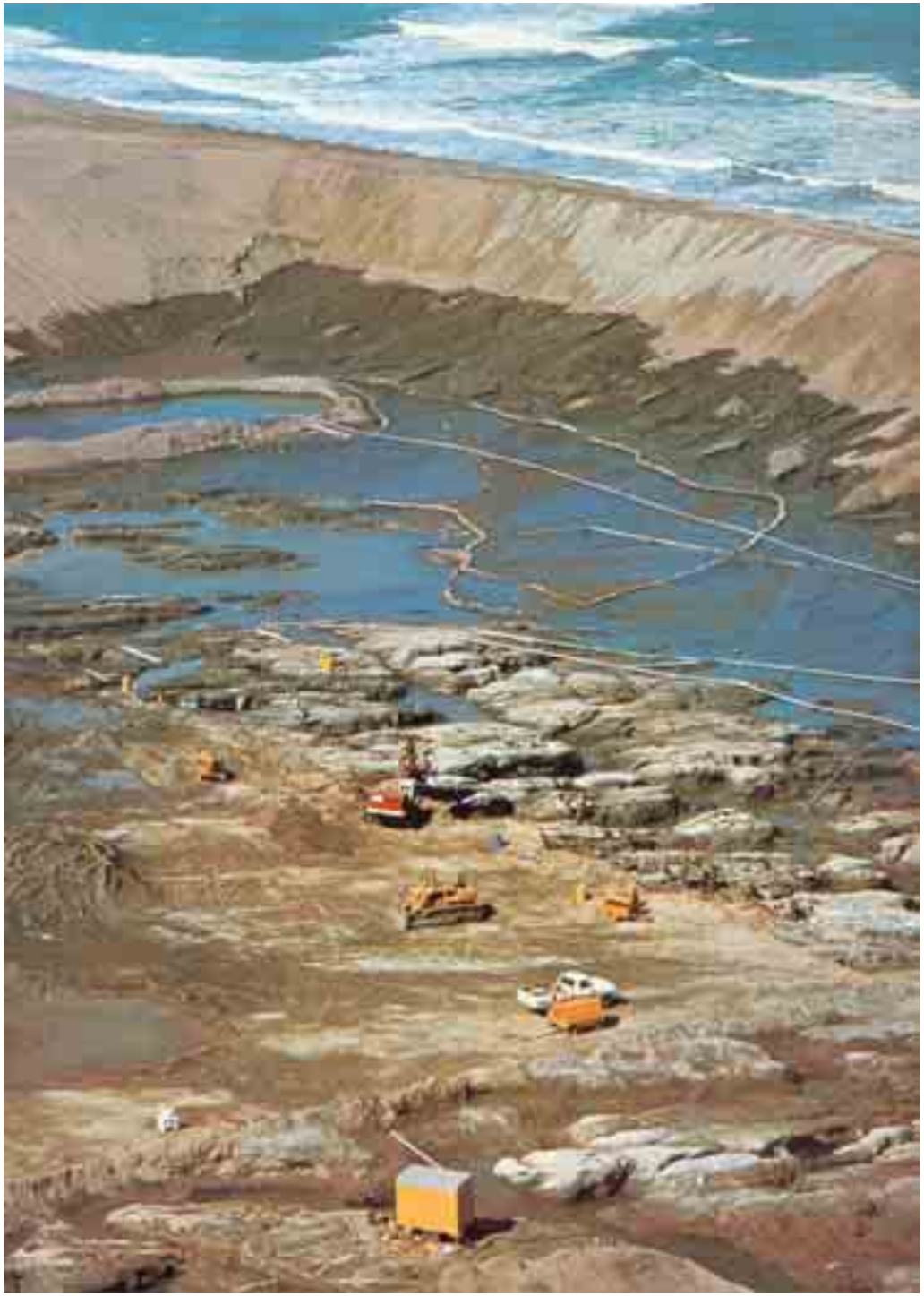

Kimberley
Atlantic
Ocean
300 km
Image © 2008 DigitalGlobe
© 2008 Cnes/Spot Image
Image NASA
Google


Sperrgebiet
30 km
Google


Oranjemund
Image © 2008 DigitalGlobe
Google
2802 m

Riffle structures in basement

Oranjemund area, Namibia



La mine à ciel ouvert d'Oranjemund, en Namibie

Congo/Zaire:
Mbuji-Mayi

Pipe

Sierra Leone: Diamond placers in the Sewa River

La mine géante de Mirny, en Sibérie

Zarnitza kimberlite, Yakutia, Russia

Aug 1954 discovered, Dec 1998 in production

Heterolithic breccia with platform lime-stone

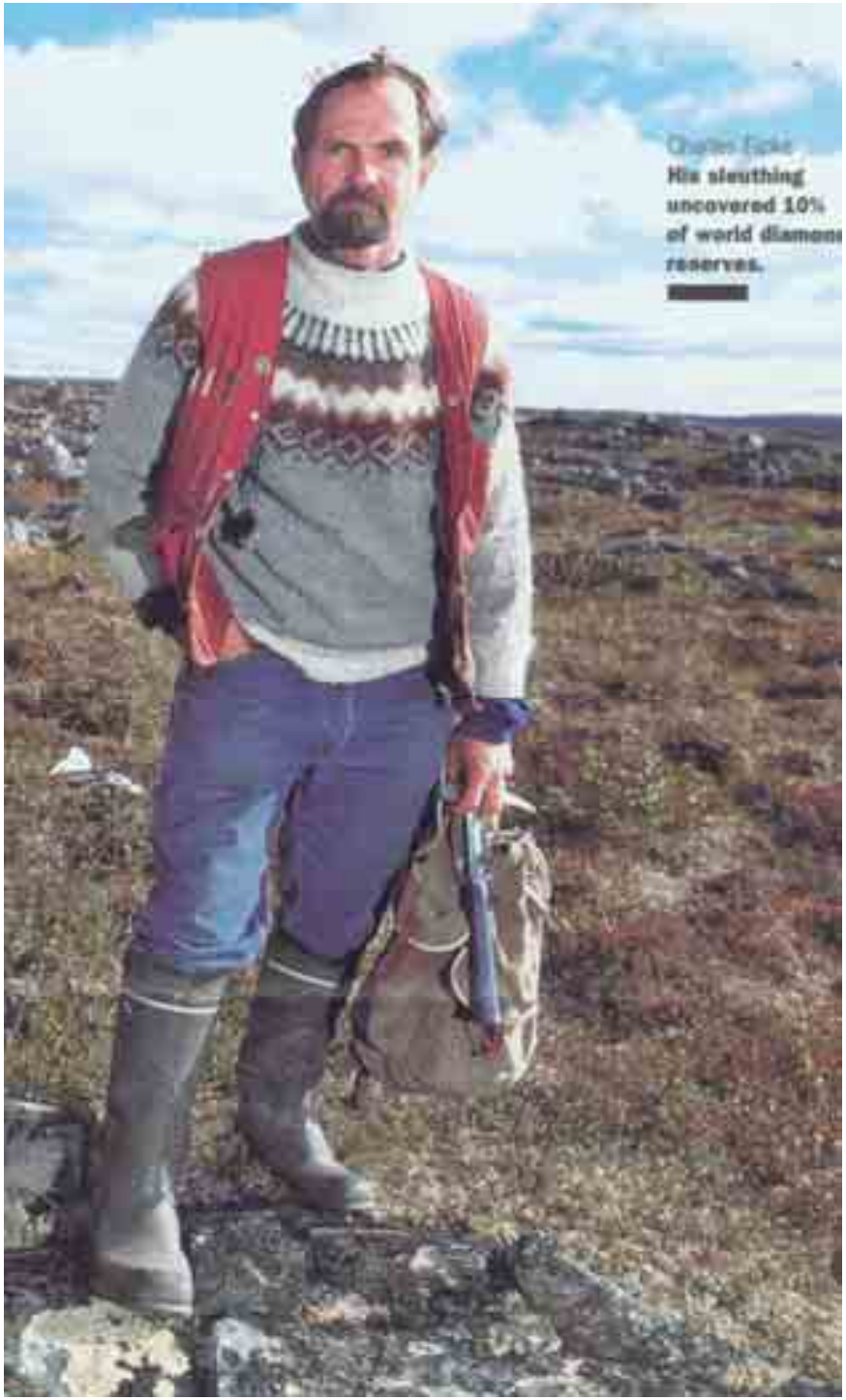
2 cm

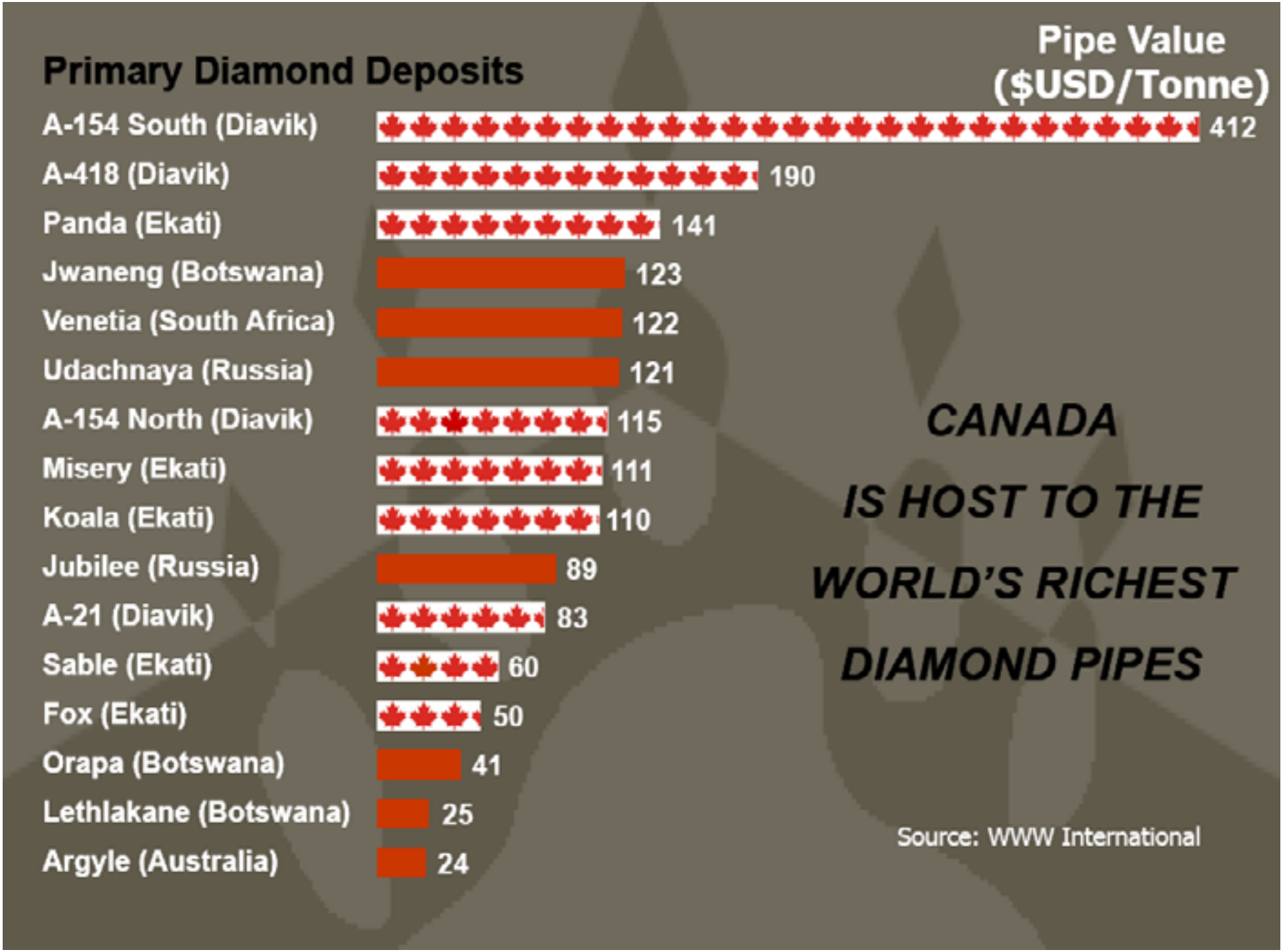
Grib pipe: 98 Mt (500 m depth) @ 66 ct/100t, ~90 USD/ct

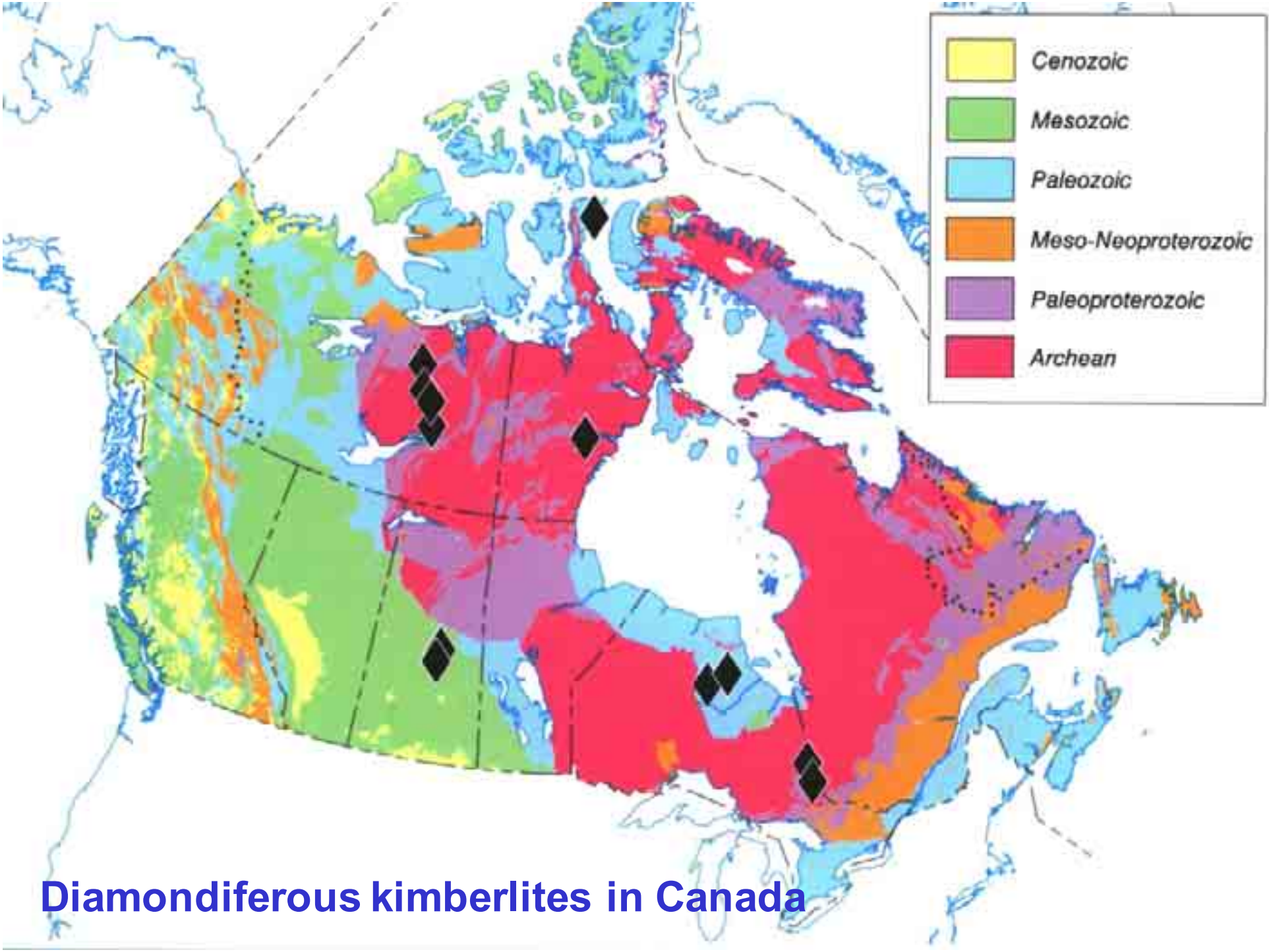
Lomonosov deposit (6 pipes along 9.5 km trend, 10-37 h in surface area): Arkhangelskaya, Karpinsky-1, Karpinsky-2, Pioneerskaya, Pomorskaya, Lomonosov

Arhangelskaya pipe

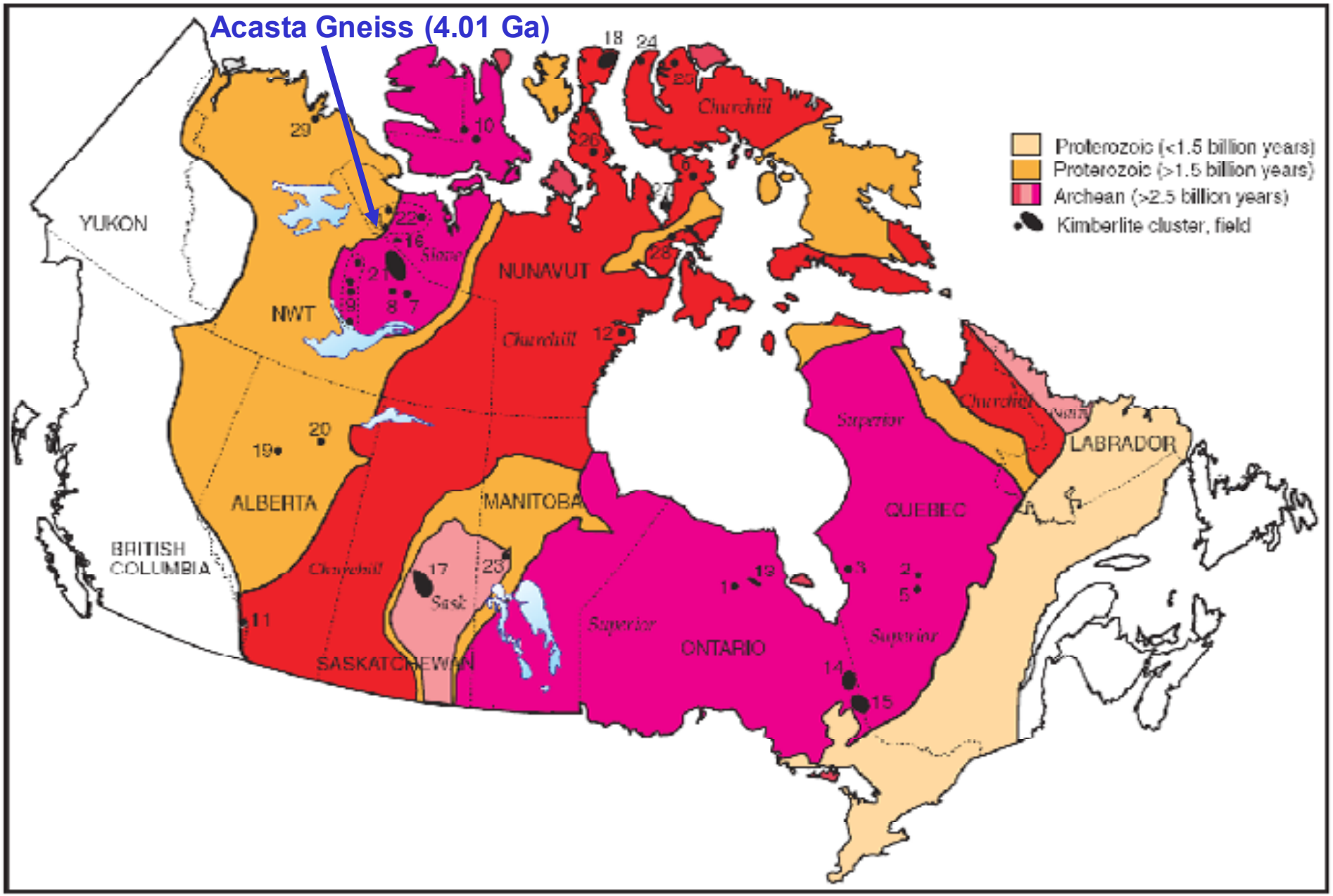
Charlie Fipke (Forbes, 14 Dec 1998)



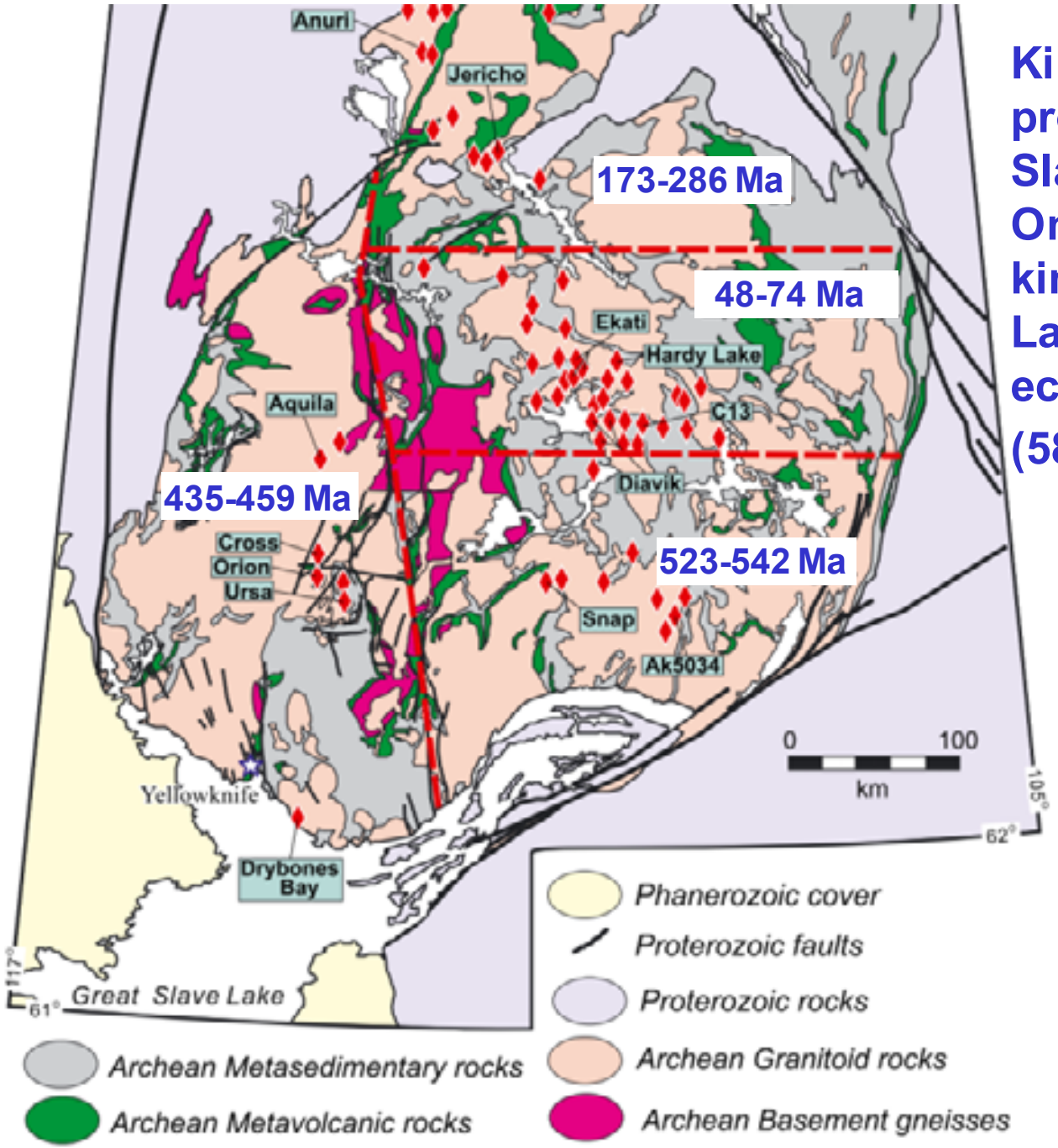

Primary Diamond Deposits
Pipe Value ($USD/Tonne)
A-154 South (Diavik) 412
A-418 (Diavik) 190
Panda (Ekati) 141
Jwaneng (Botswana) 123
Venetia (South Africa) 122
Udachnaya (Russia) 121
A-154 North (Diavik) 115
Misery (Ekati) 111
Koala (Ekati) 110
Jubilee (Russia) 89
A-21 (Diavik) 83
Sable (Ekati) 60
Fox (Ekati) 50
Orapa (Botswana) 41
Lethlakane (Botswana) 25
Argyle (Australia) 24
CANADA IS HOST TO THE WORLD'S RICHEST DIAMOND PIPES
Source: WWW International



Diamondiferous kimberlites in Canada



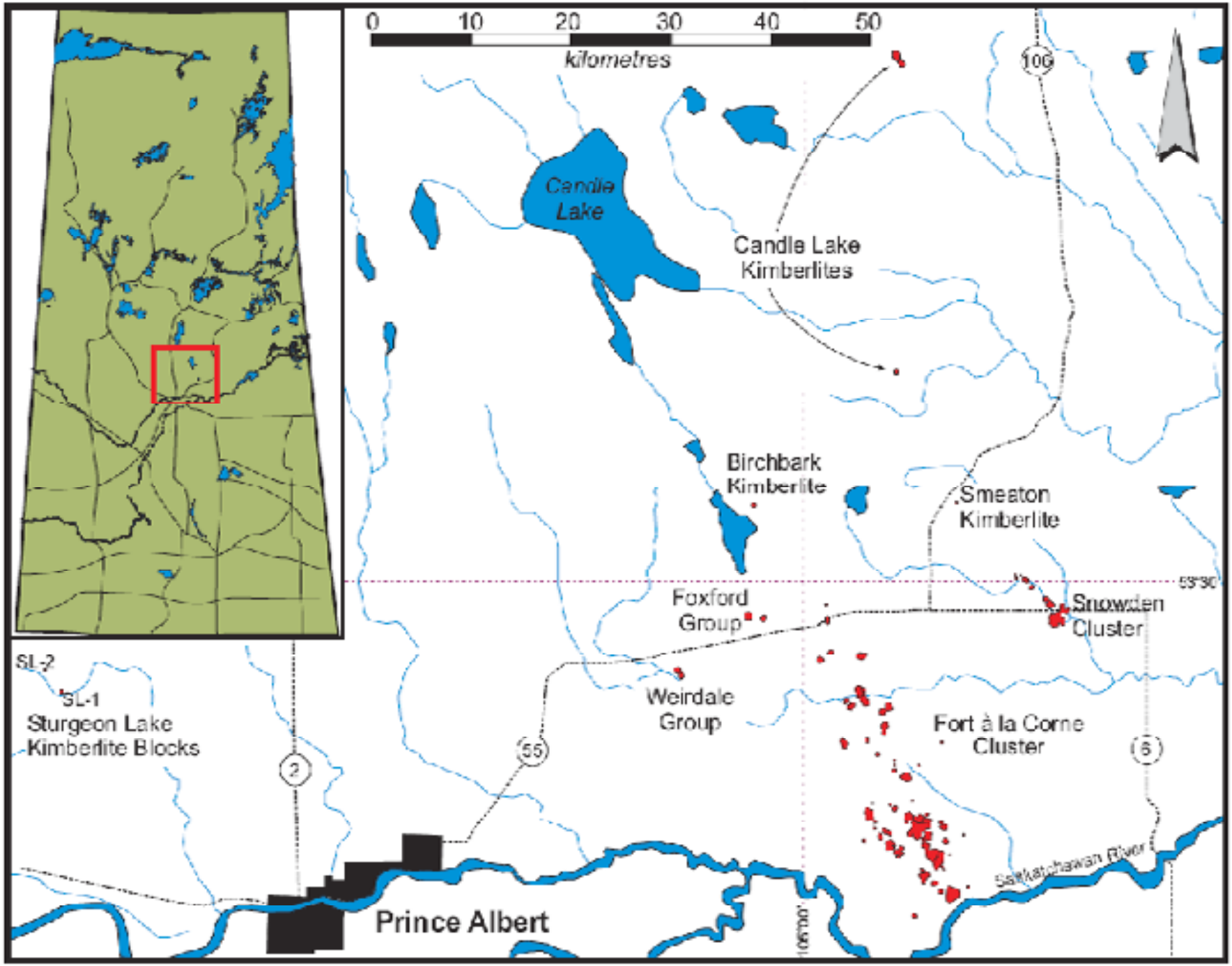
Canadian kimberlite clusters and the Archean Slave, Superior, Sask, Nain and Churchill cratonic blocks. The six diamond mines active and in development (21 Ekati and Diavik – 53-56 Ma, 16 Jericho – 172 Ma, 8 Snap Lake – 523-535 Ma, 7 Gahcho Kué – 542 Ma, 10 Victor – 175-180 Ma) are in the Slave craton (Kjarsgaard 2007: 253)



Kimberlite age provinces in the Slave Craton: Only the Eocene kimberlites at the Lac de Gras are economic so far

(58 kimberlites dated)

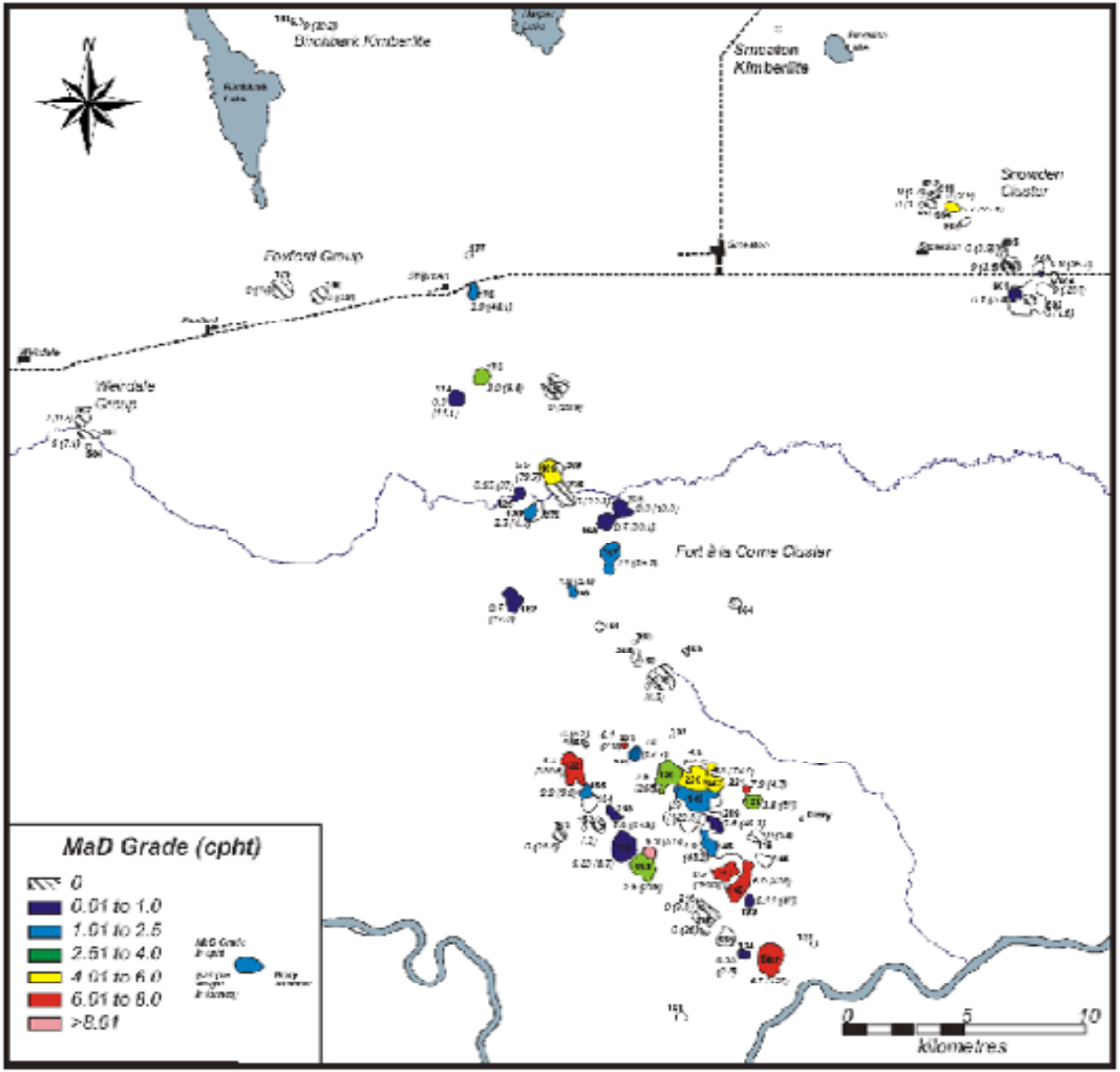
Heaman et al. (2004: 392)


0 10 20 30 40 50
kilometres
Candle Lake
Candle Lake Kimberlites
Birchbark Kimberlite
Smeaton Kimberlite
Foxford Group
Snowden Cluster
Weirdale Group
Fort à la Corne Cluster
SL-2
SL-1
Sturgeon Lake Kimberlite Blocks
Prince Albert
Saskatchewan River
106
55
2
5
55°30'

Fort-à-la-Corne kimberlite field, Saskatchewan, Canada (98 Ma):

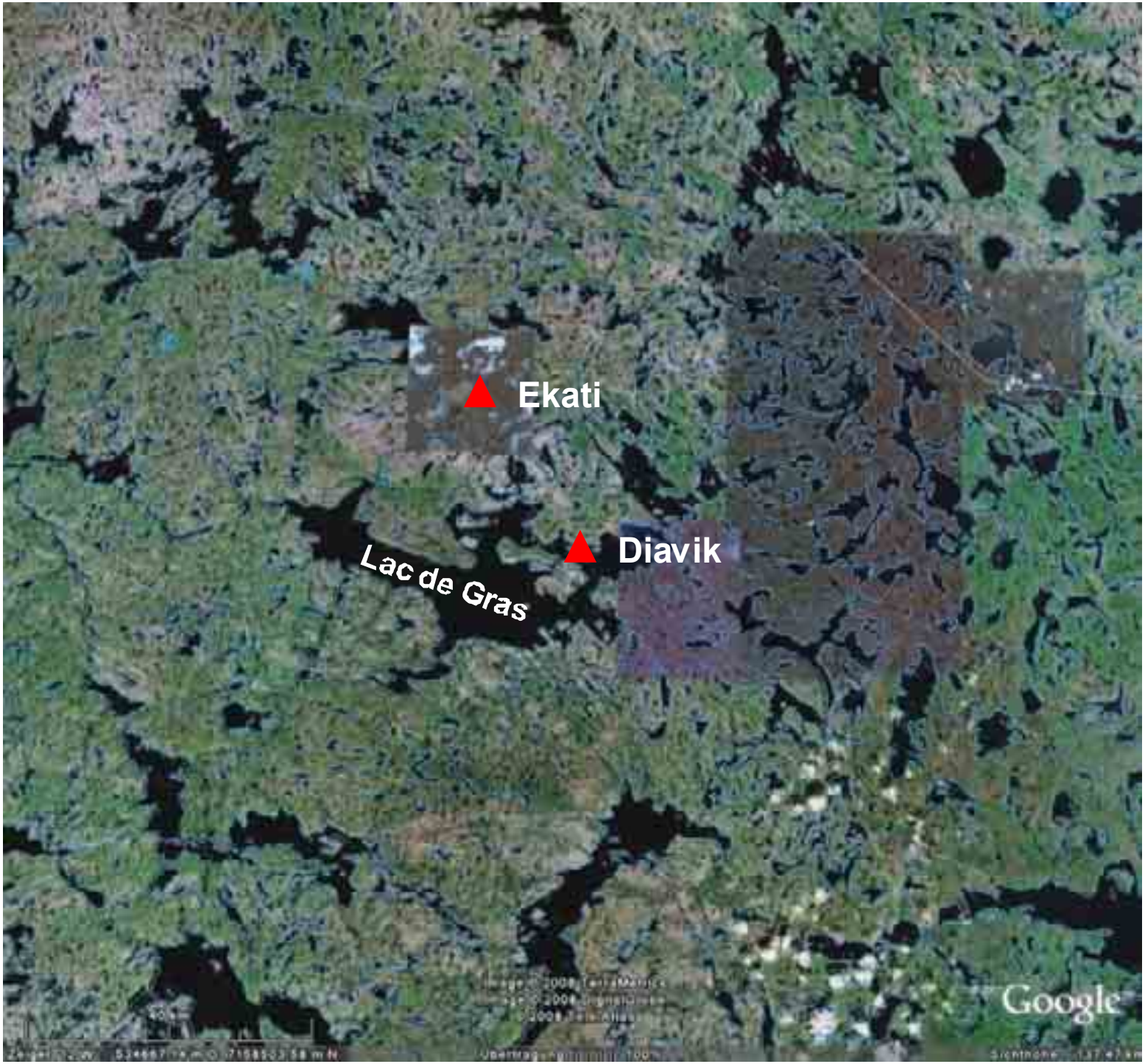
Pyrope xenocrysts in serpentinized olivine-lapilli tuff

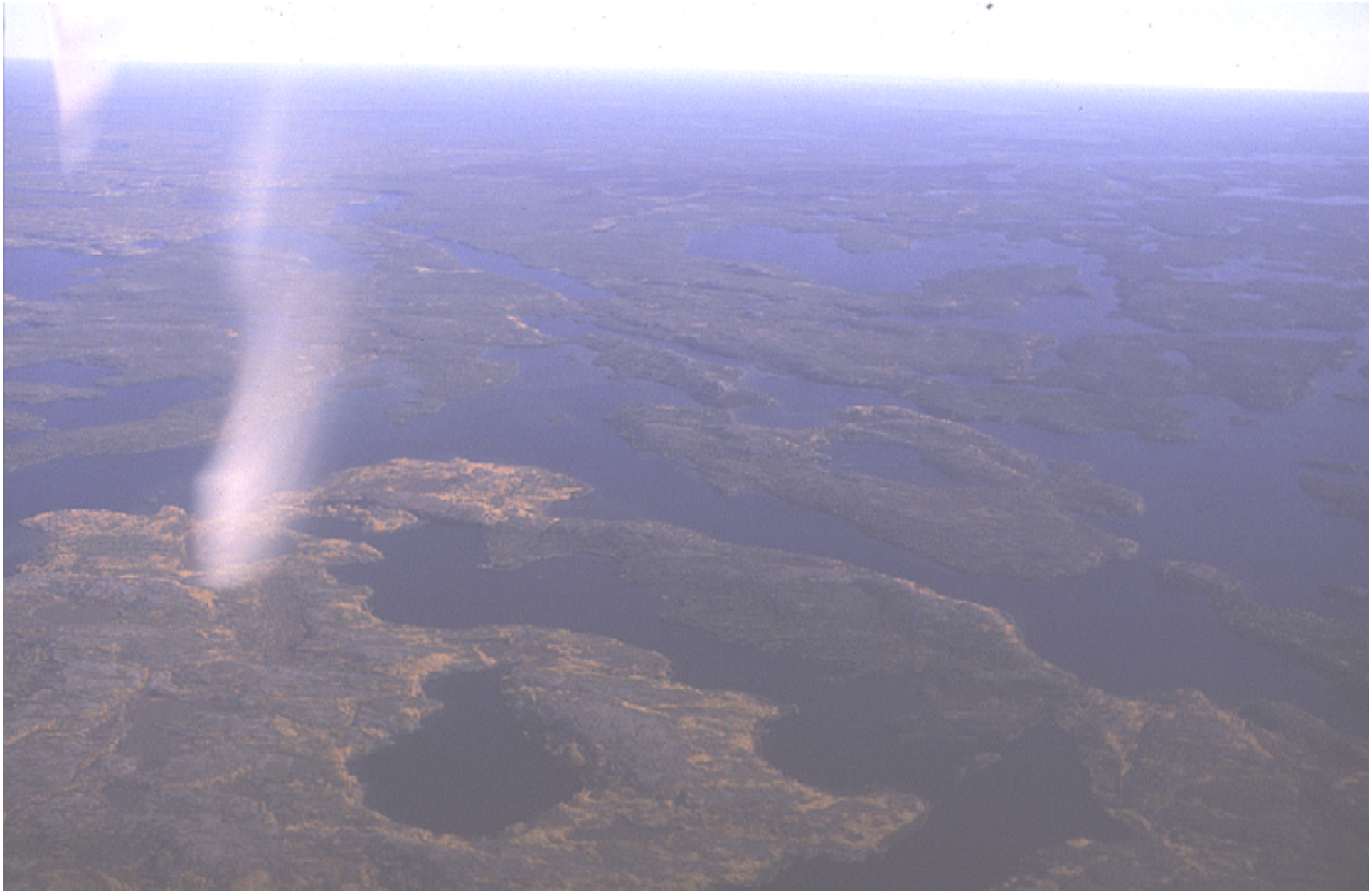
2 cm



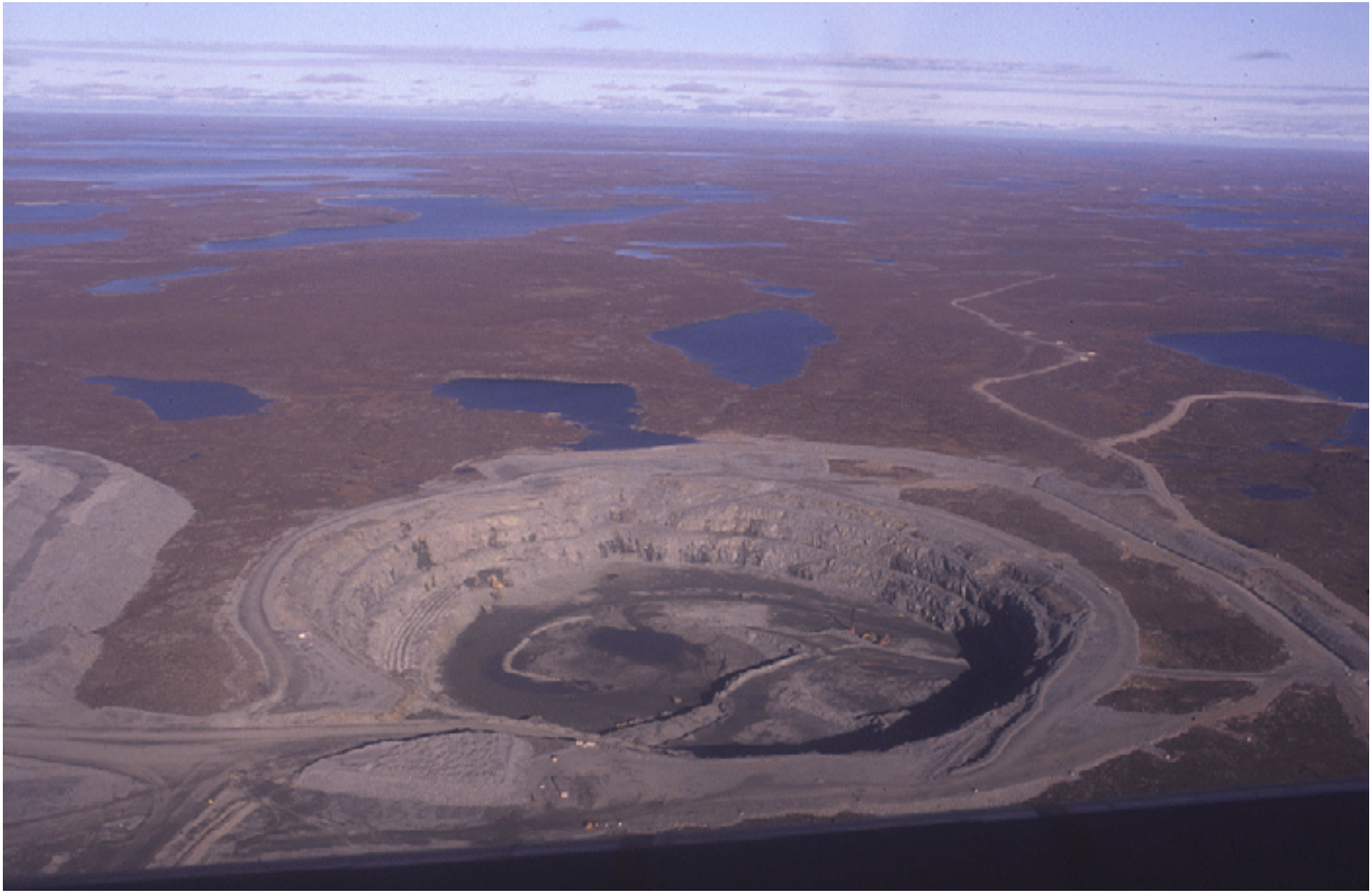
FALC kimberlite field

Macrodiamond grade (>1.5 mm) up to 10 cpht, ~80 USD/ct


Ekati
Diavik
Lac de Gras
Google



Lac de Gras area, Northwest Territories, Canada



Ekati Mine (Sep 1999), 700 M USD, 3.6 ct/t @ 130 USD/ct
Open pit mining from 1997 until 2003, now underground

Panda pit

Koala North pit

Koala pit

Ekati Mine, Aug 2000

Diavik (Sep 1999), 1.4 b USD mine development,
4 pipes @ 3.5 ct/t, 135 Mct @56 USD/ct

Diavik project

In 1994-95 Diavik discovered four diamondiferous kimberlite pipes offshore East Island

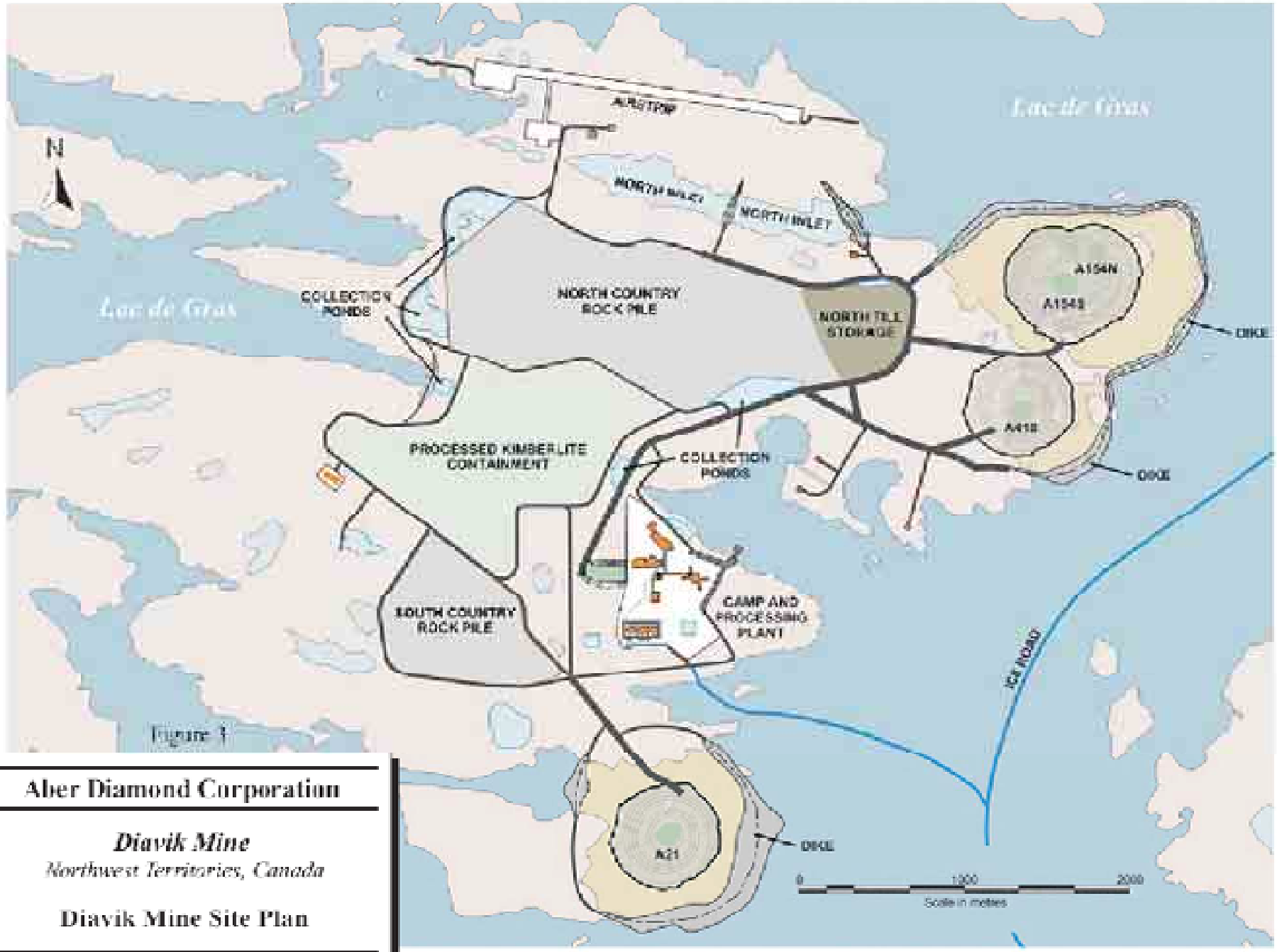


Figure 1

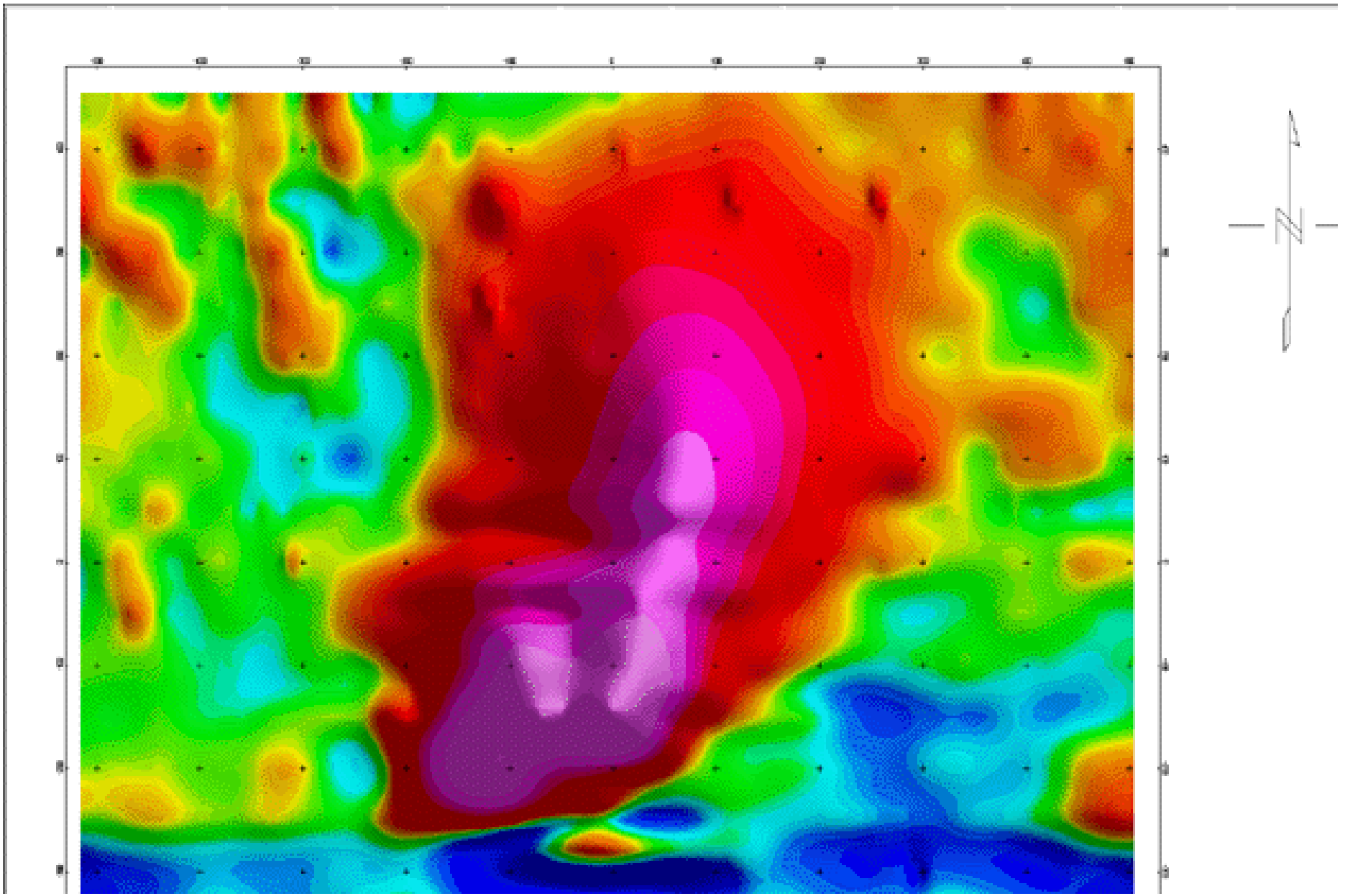
Aber Diamond Corporation

Diavik Mine

Northwest Territories, Canada

Diavik Mine Site Plan

April 2015



Electromagnetic anomaly (helicoper-born geophysics)

Drill core logging

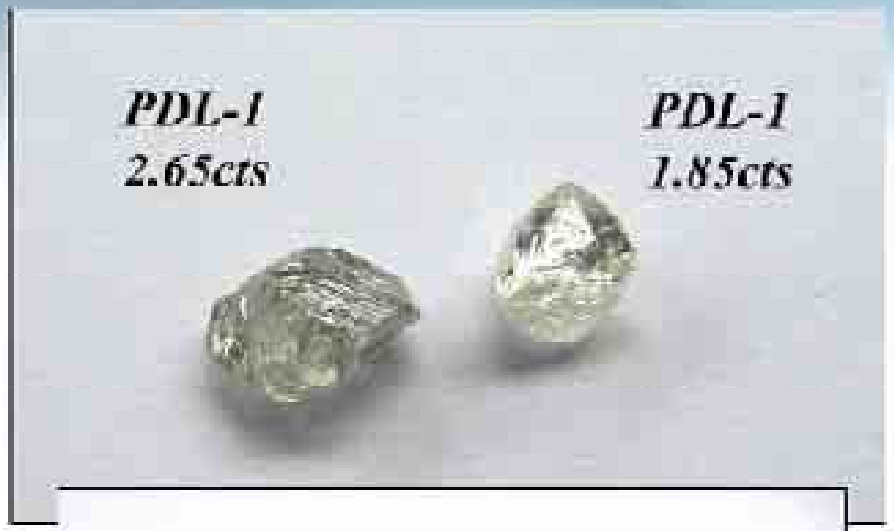
In 1995, Diavik began constructing underground access to mine a 6000 tonne bulk sample from two pipes, A-418 and A-154 South.

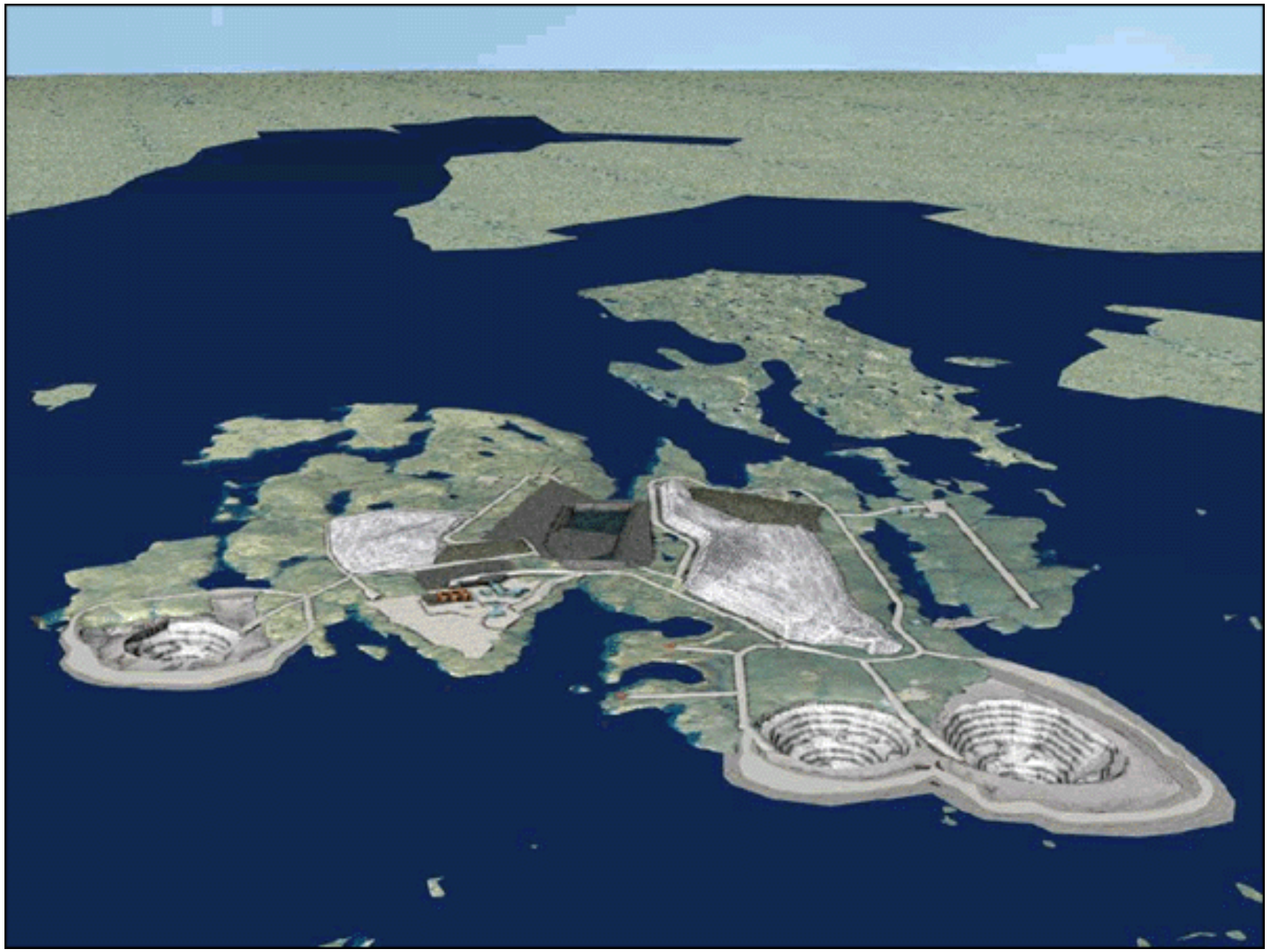
Diavik, NWT, Canada: Kimberlite (53 Ma) with Eocene wood incln

Sorting and cleaning of rough diamonds from the processing plant

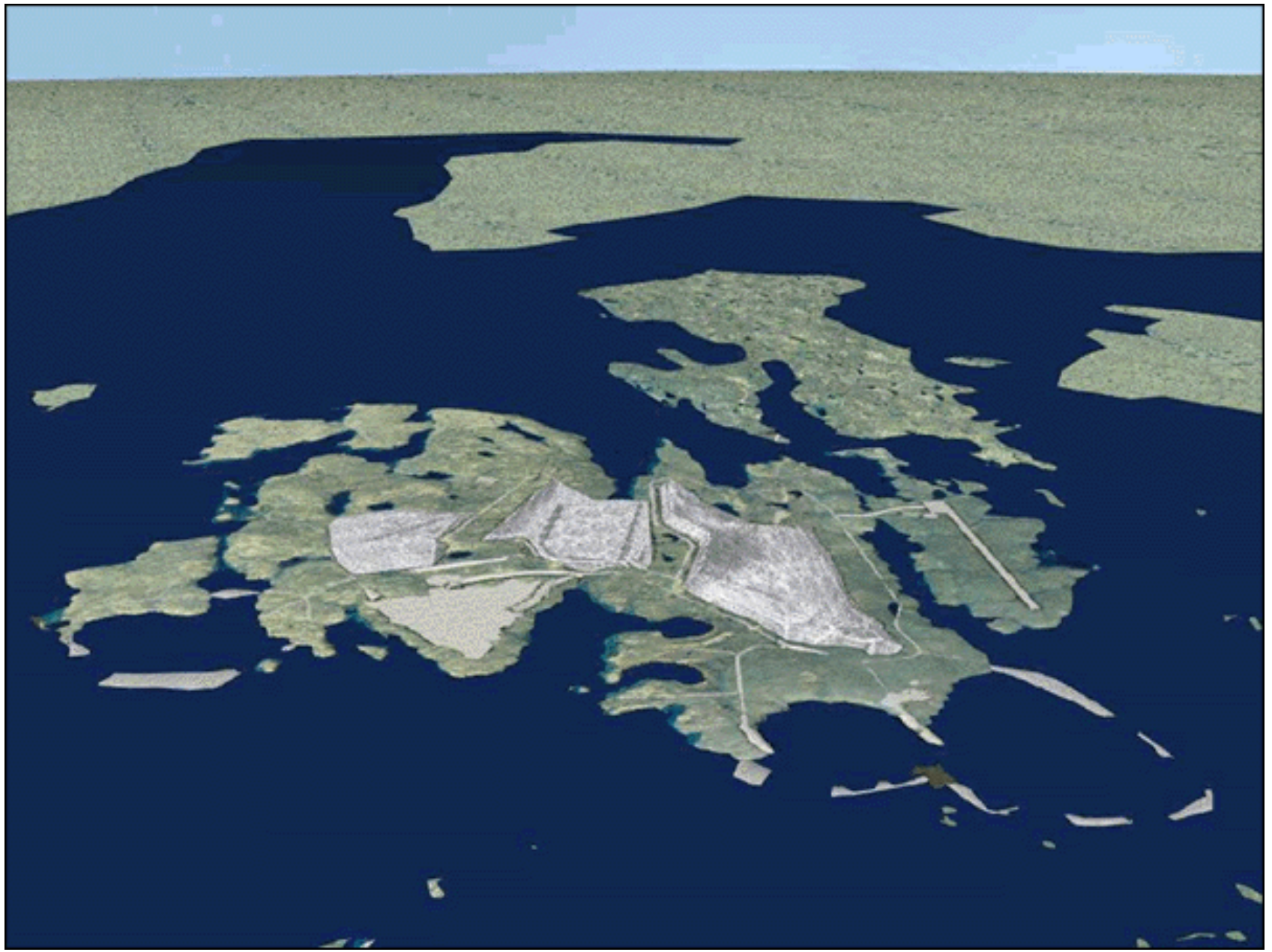
PEREGRINE DIAMONDS LTD

Valuation: average USD/ct





Diavik at maximum impact in 2018



Diavik after mine closure in 2020

Diavik, summer 2001

Temporary ice road (2 months) from Yellowknife

Diavik in winter 2001/2002

Diavik in summer 2002

Dike completed in summer 2002

Diavik end of Sep 2002: dewatering finished

Diavik in 2005: average strip ratio 11.8 to 1 (waste to ore)

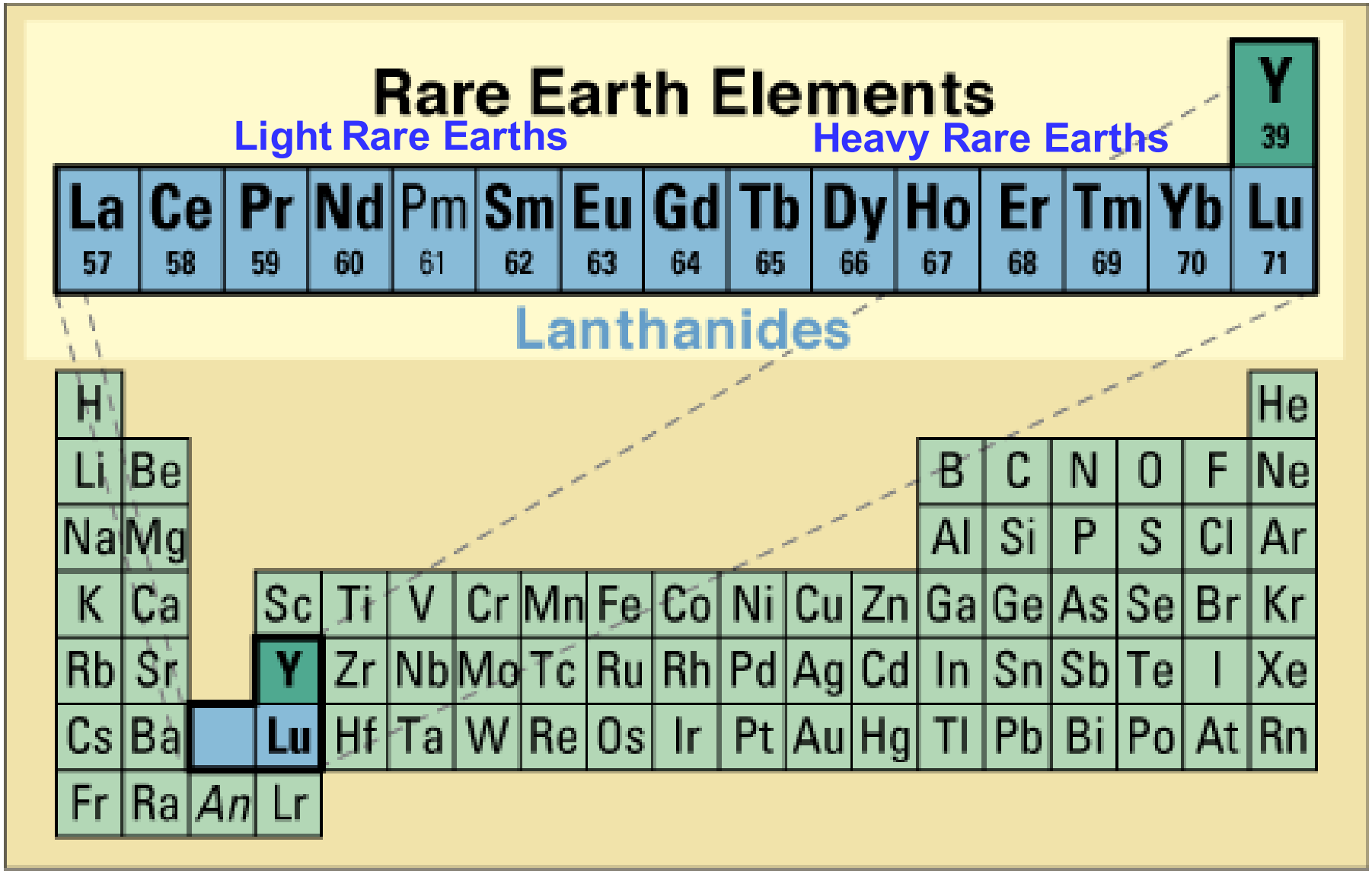
Diavik

Diavik in 2007

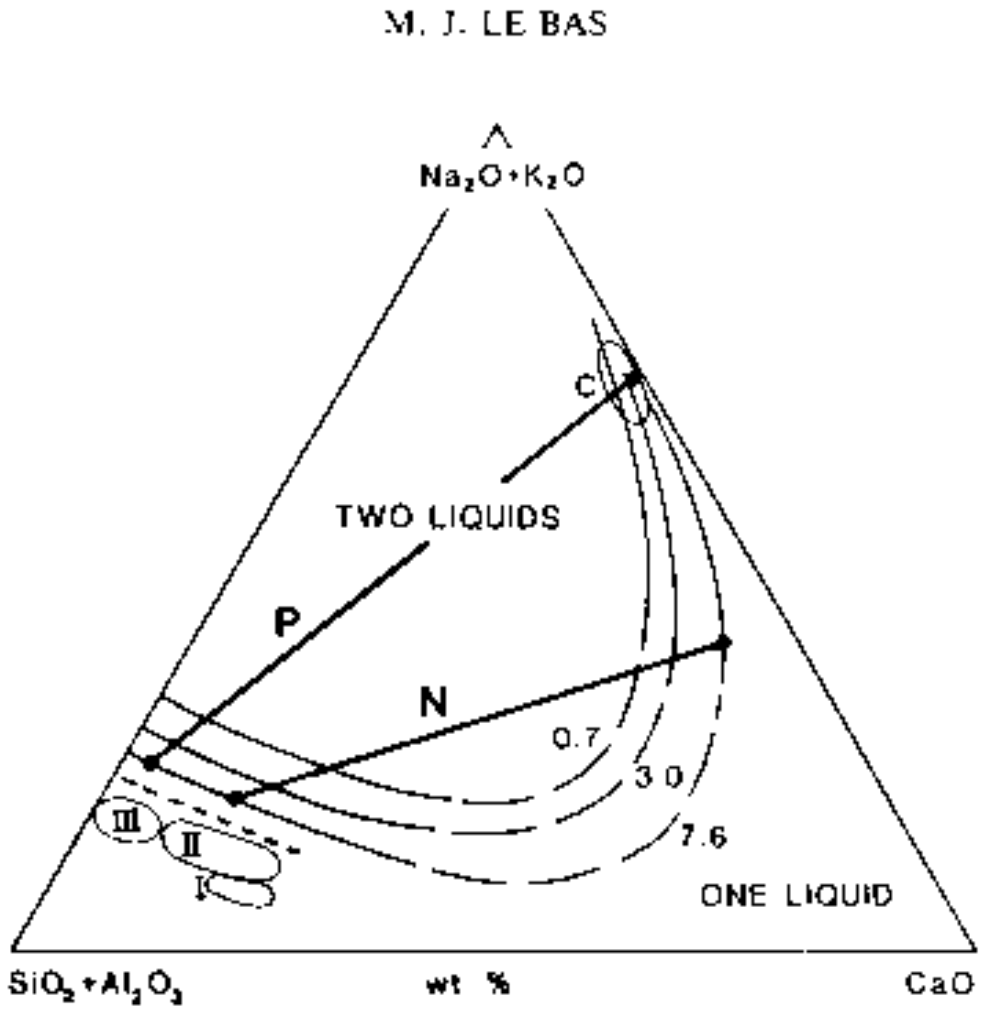
Carbonatite:
magmatic rock with >50 vol% carbonate (calcite, dolomite, ankerite)

Criteria for magmatic origin:
- **enrichment in Sr, Ba, Nb, LREEs**
- **initial $^{87}Sr/^{86}Sr$ <0.706**
- **association with nepheline-bearing rocks**
- **presence of perovskite, pyrochlore, apatite**

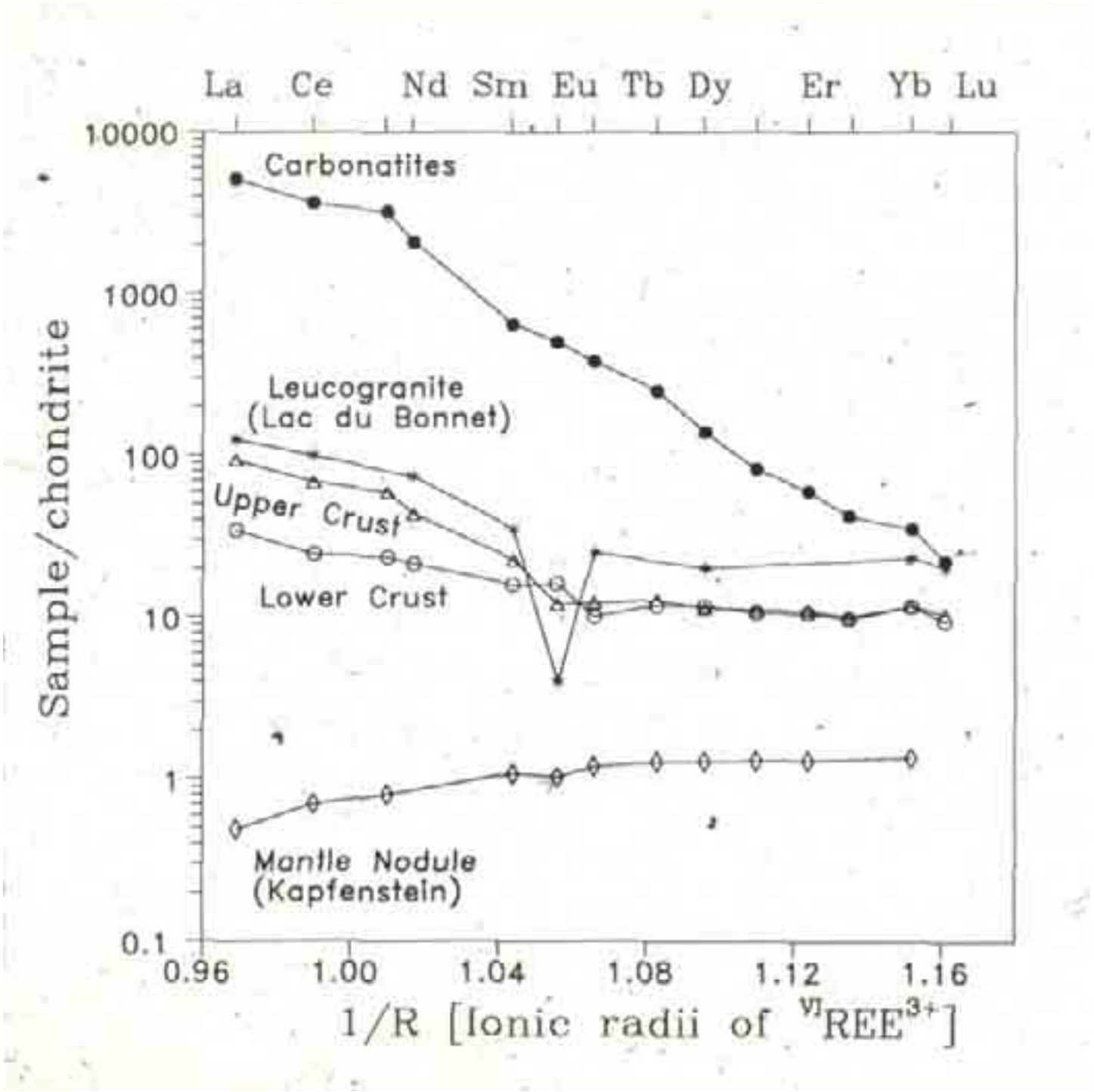
Ore deposits associated with carbonatite:
REE (Bayan Obo, China; Mountain Pass, USA)
Nb (Araxa, Brazil)
Phosphate for fertilizer industry


Rare Earth Elements
Light Rare Earths
Heavy Rare Earths
Y
39
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

Oldoinyo Lengai is a stratovolcano (2890 m NN) in the Western Rift Valley of Tanzania and is the only recent example of carbonatite volcanism, producing highly fluid natro-carbonatitic lava that emerges at 500 to 590°C only.



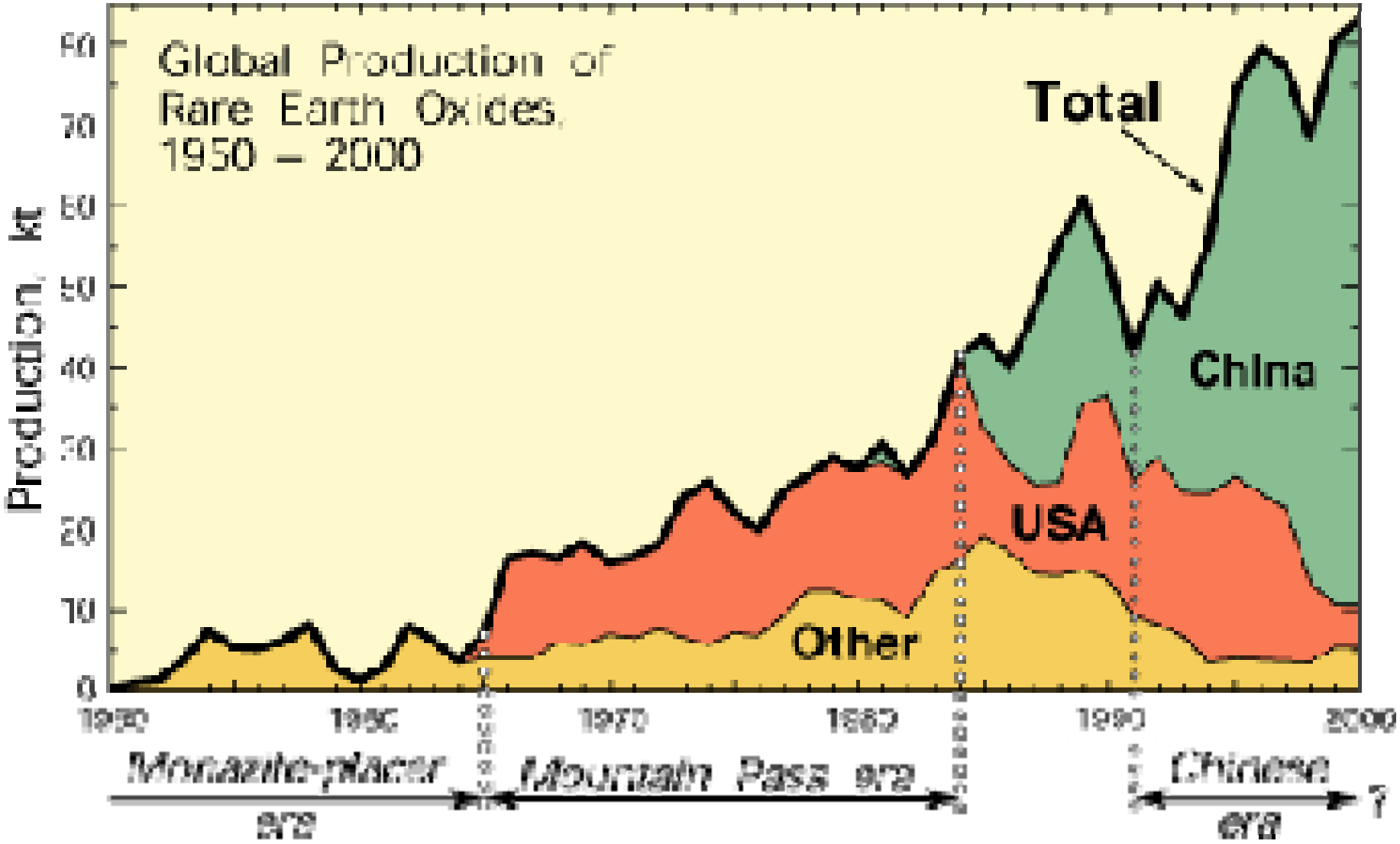
Liquid immiscibility in the major oxide-CO_2 system at 1150°C and 0.7, 3.0 and 7.6 kbar with tie lines P (phonolite-natrocarbonatite) and N (nephelinite-calcic natrocarbonatite). LREEs, Nb, Th, P partition preferentially in carbonate liquid.


La Ce Nd Sm Eu Tb Dy Er Yb Lu
10000
1000
100
10
1
0.1
Sample/chondrite
Carbonatites
Leucogranite
(Lac du Bonnet)
Upper Crust
Lower Crust
Mantle Nodule
(Kapfenstein)
0.96
1.00
1.04
1.08
1.12
1.16
1/R [Ionic radii of VIREE3+]

Global production

World mine production 2008: 124,000 t REO

China: 120,000 t REO; India: 2,700 t REO; Brazil: 650 t REO; Malaysia: 380 t REO



"Other" mainly from Australia, Russia, Malaysia, Brazil, and India

From USGS Fact Sheet 087-02, by Haxel and others, 2002

Inner Mongolian Province, northern China

Bayan Obo, northern China: iron-REE ore open pit mining
>60 Mt @ 35 % Fe, 4-5 % Re_2O_3

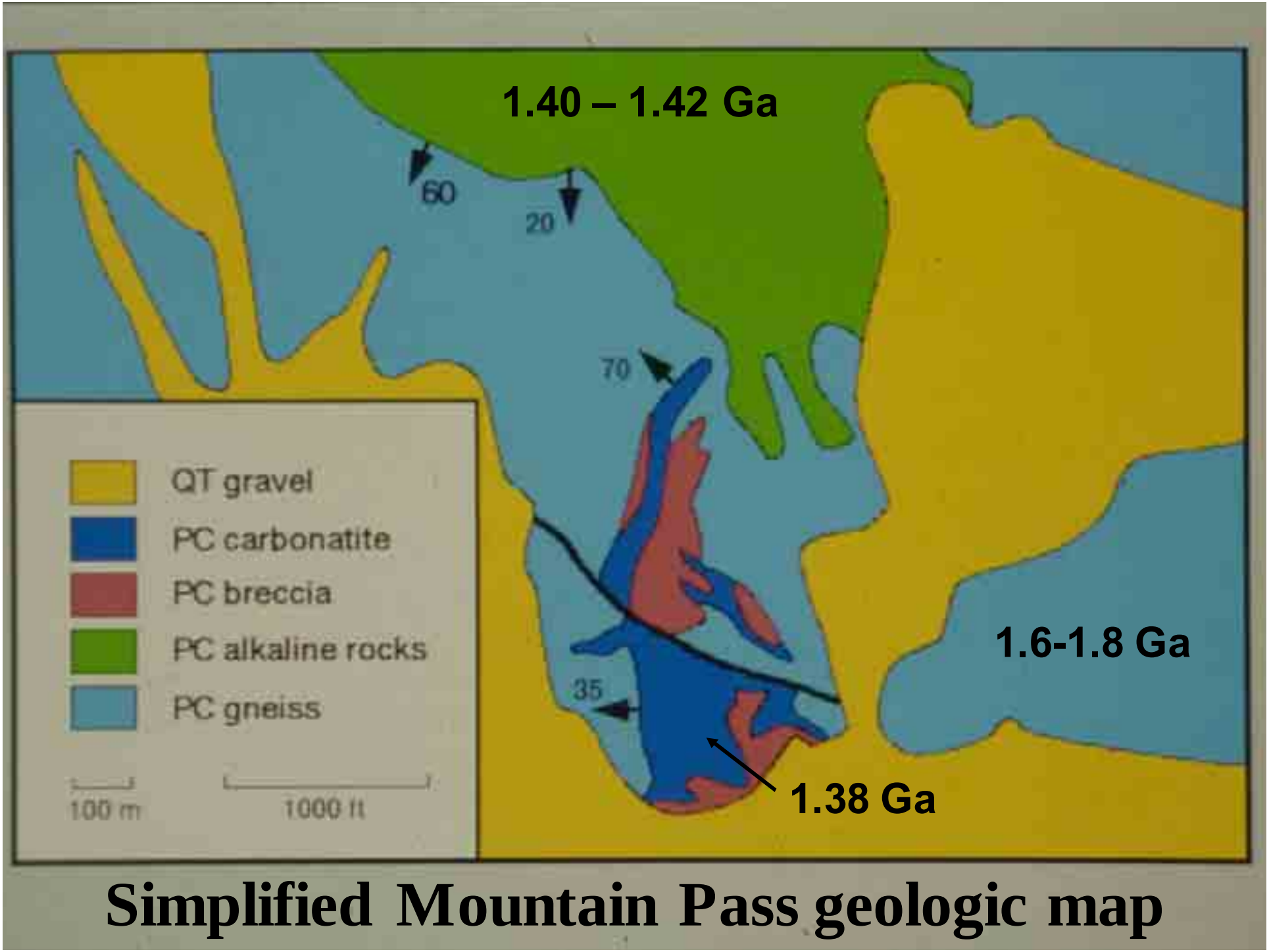
Bayan Obo: magnetite-fluorite-bastnaesite-monazite ore (1.4 Ga)

Bayan Obo, northern China: carbonatite dyke


Las Vegas
Mountain Pass
Los Angeles

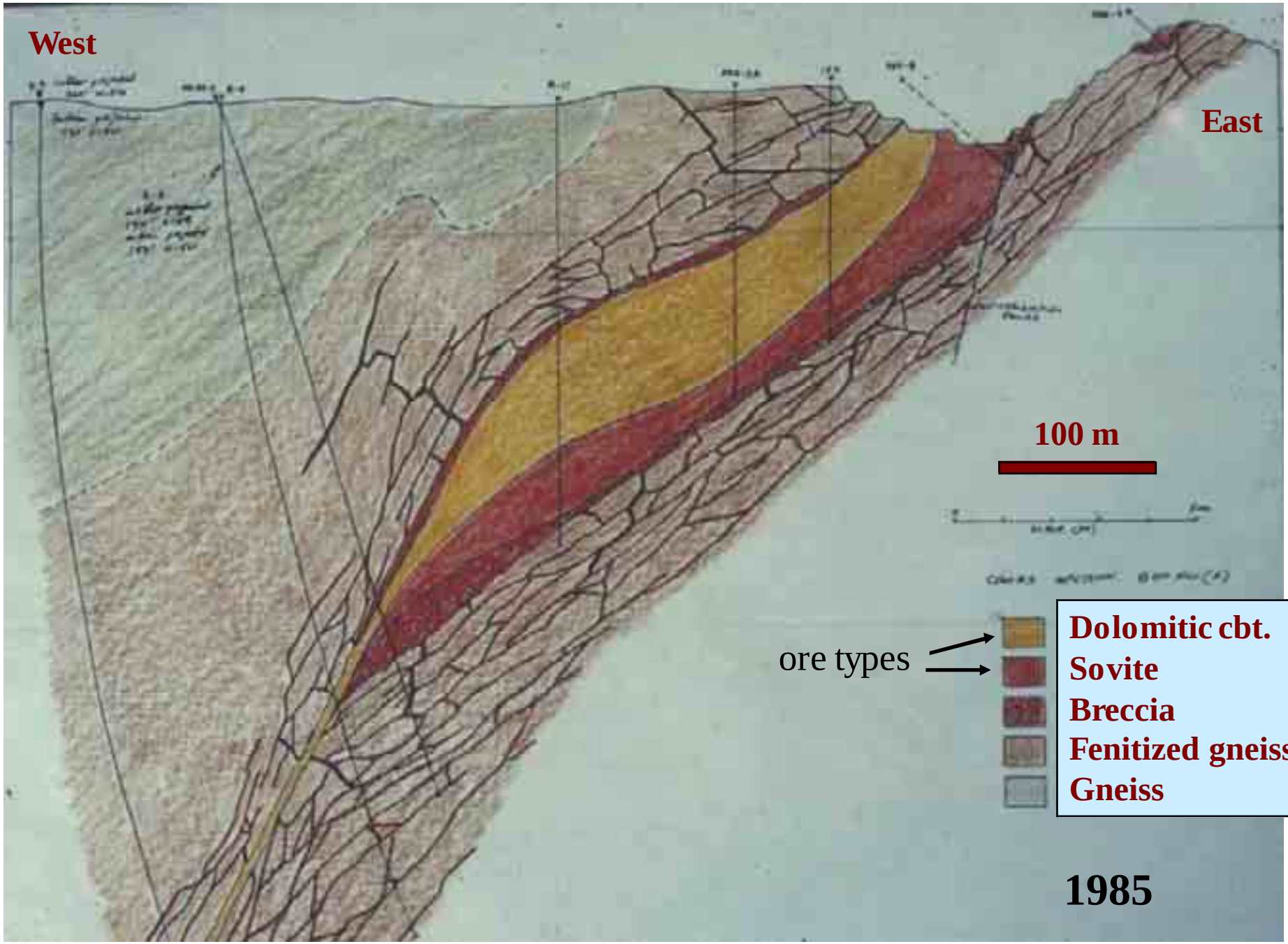
Mountain Pass, California

Mountain Pass: world leader in rare earth production 1965-1985, mine now inactive, present reserves 25 Mt @ 5-10 % RE_2O_3



Simplified Mountain Pass geologic map

800 NW X-sect


West
East
100 m
ore types
Dolomitic cbt.
Sovite
Breccia
Fenitized gneiss
Gneiss
1985


CM 1 2 3 4 5 6
Bastnasite barite sovite
Calcite
Barite
Bastnasite
Bastnasite
1 mm


Bastnasite barite beforsite
Dolomite
Barite
Bastnasite

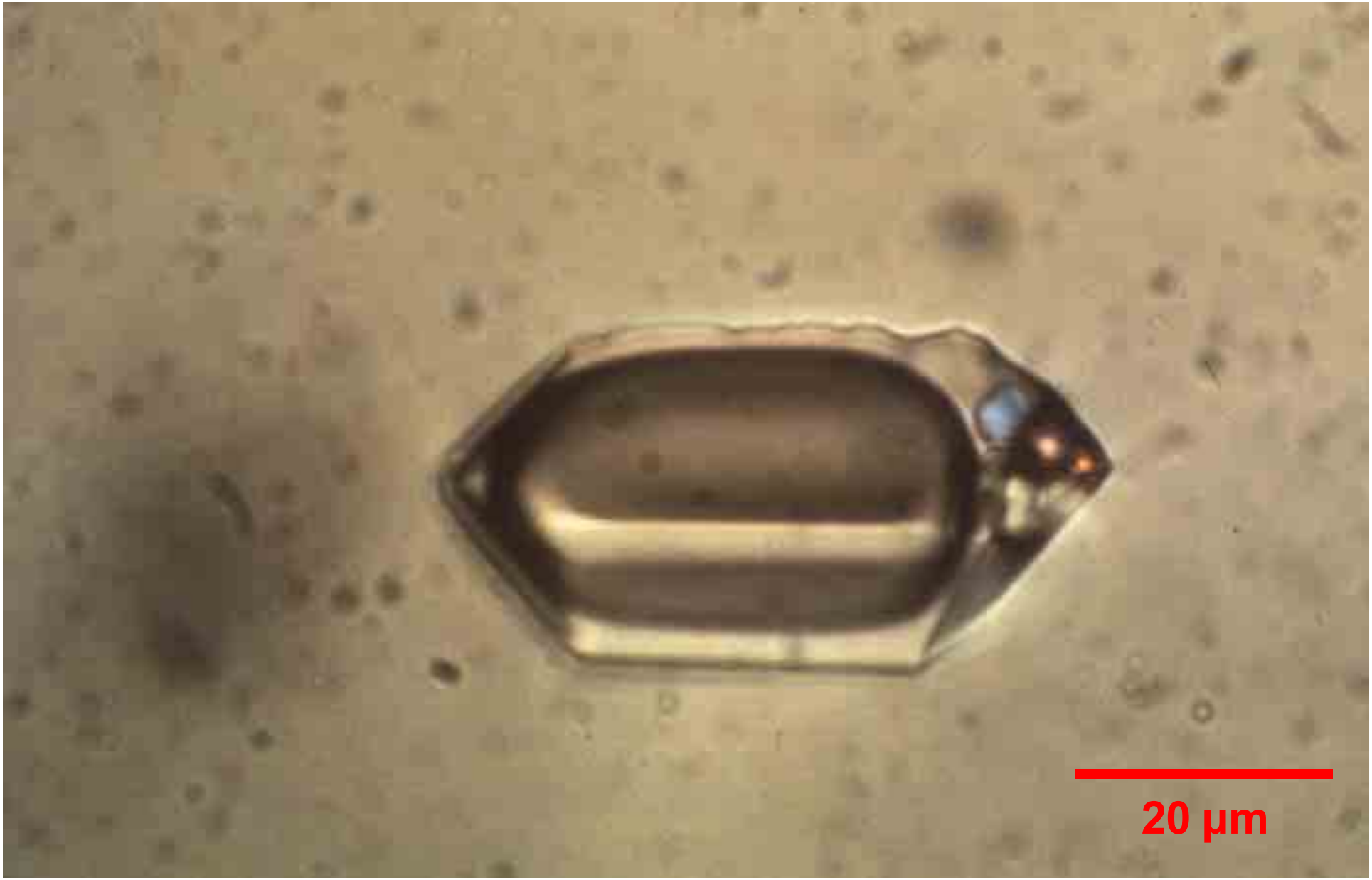
Syenite

Tanganjika Rift

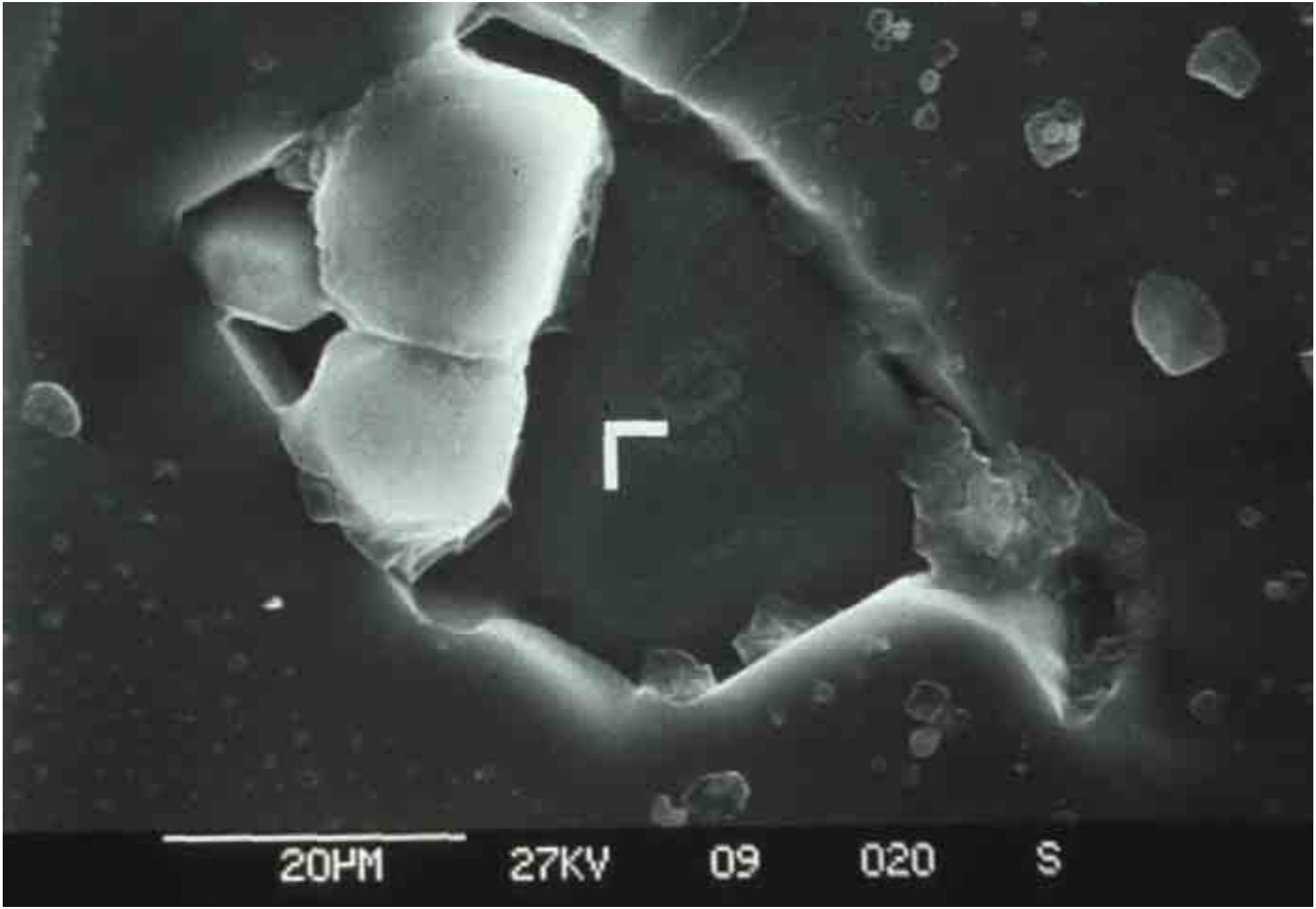
Gakara, Burundi: bastnaesite-monazite vein system (587 Ma)

Gakara, Burundi: bastnaesite-monazite vein in weathered schist

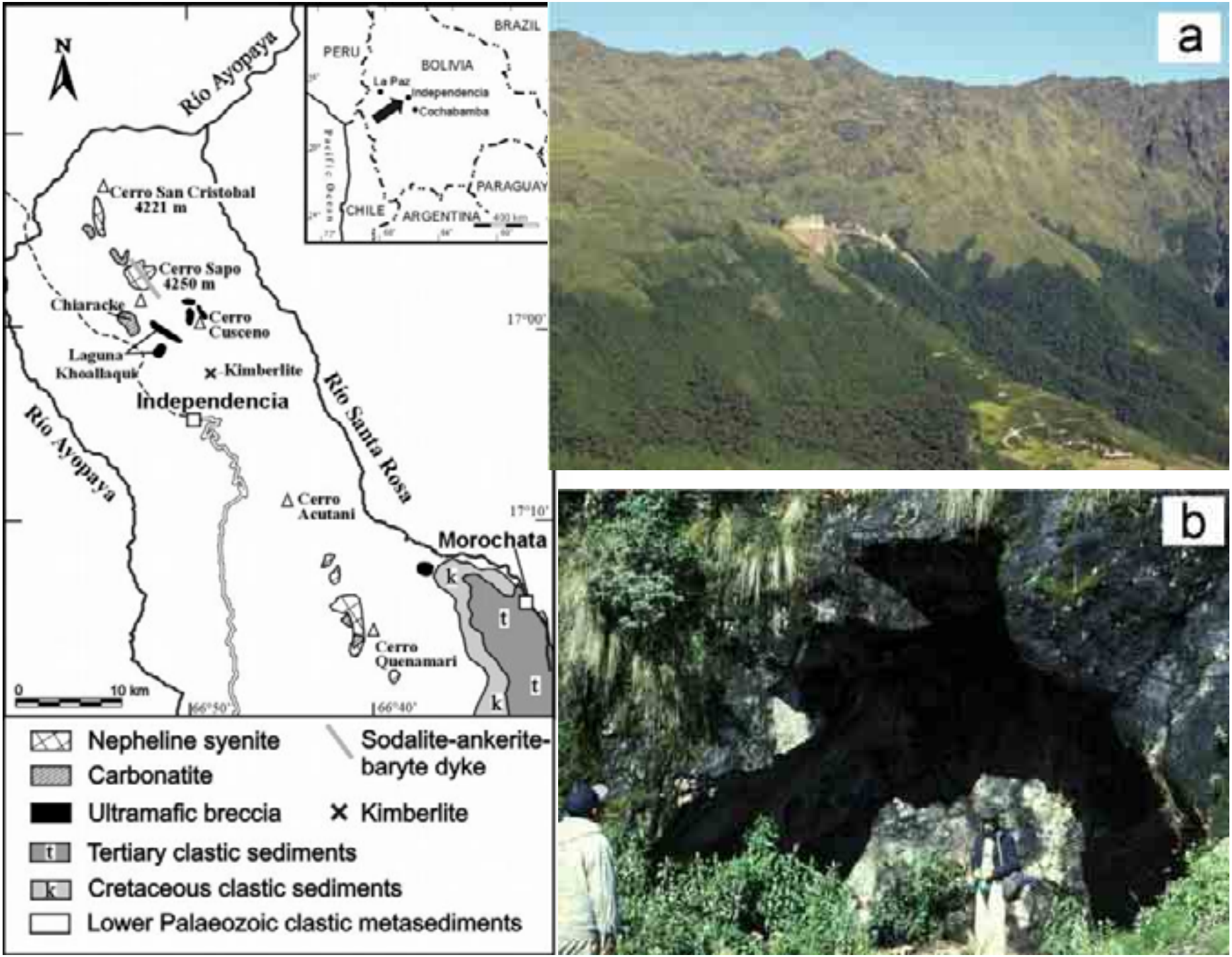
Gakara REE deposit, Burundi: Multiphase fluid inclusions in quartz

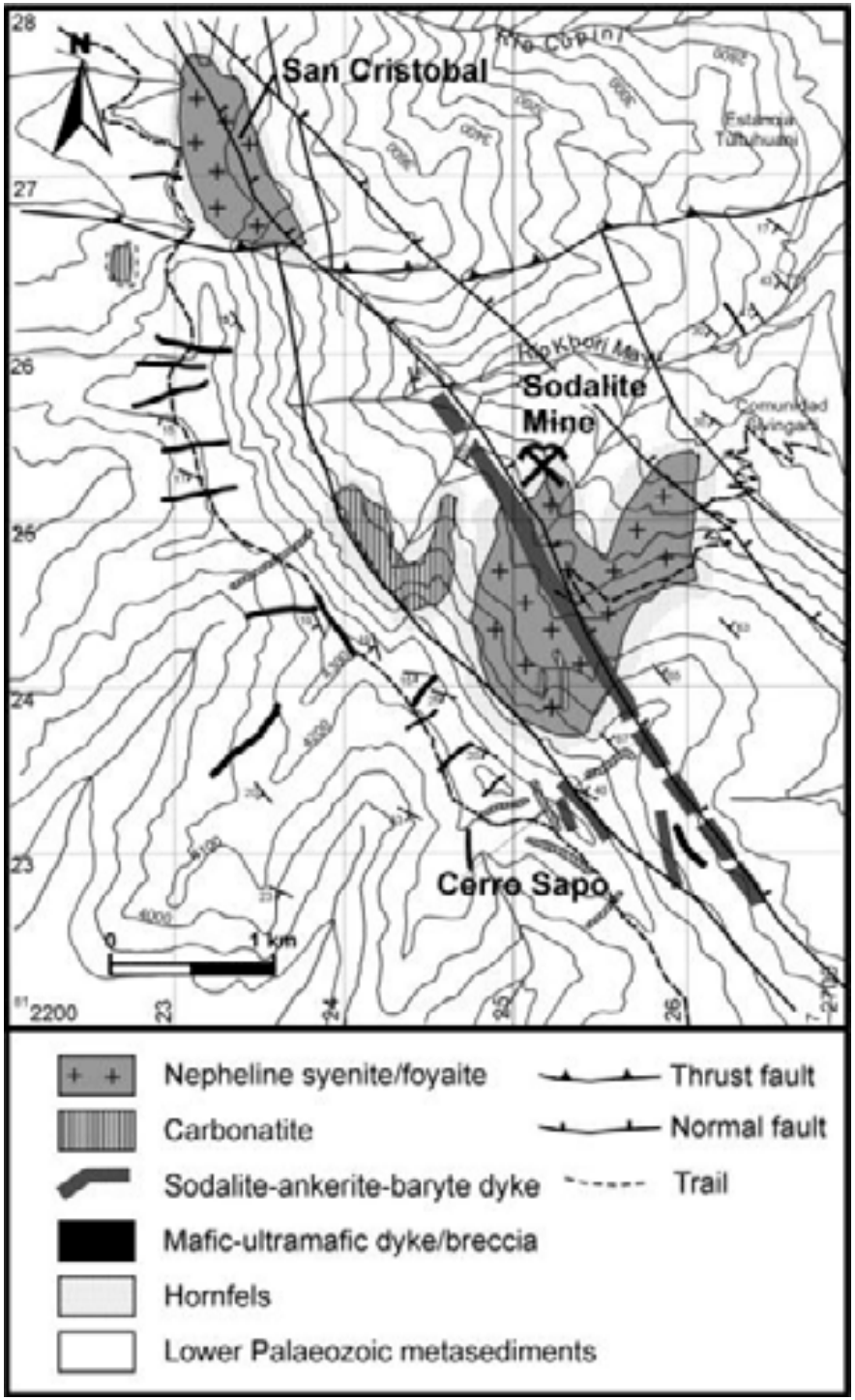


Gakara REE deposit, Burundi: liquid CO_2 fluid inclusion in quartz

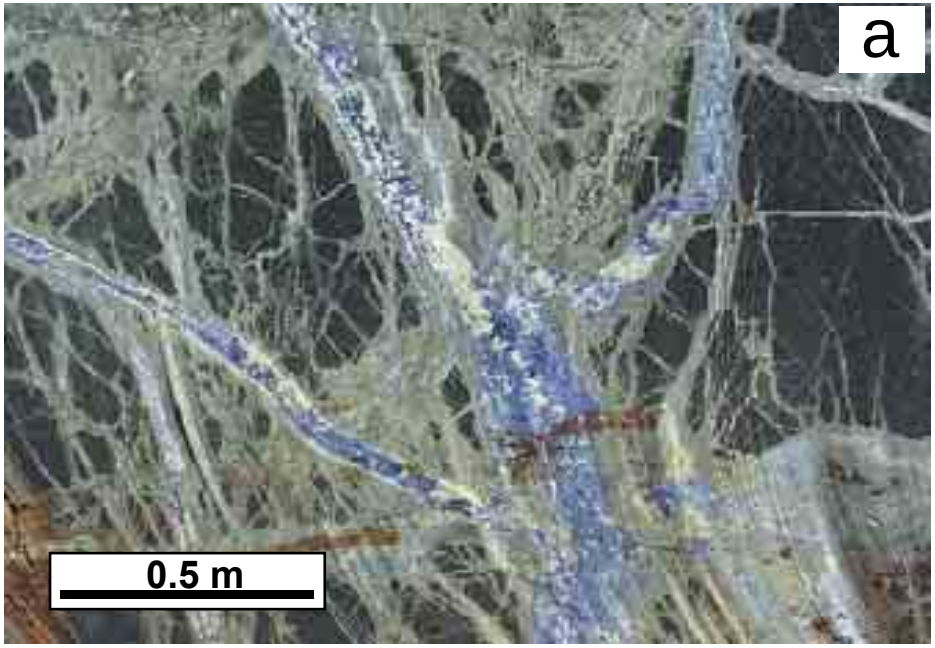


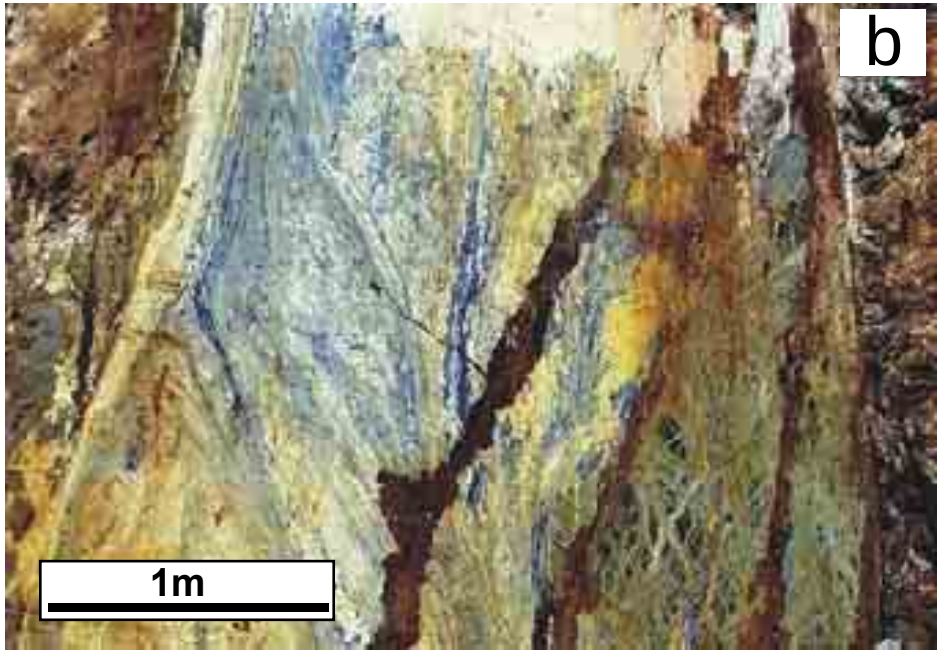
Gakara REE deposit, Burundi: opened fluid inclusion in quartz with NaCl (halite), KCl (sylvite), K_2SO_4 (arcanite)

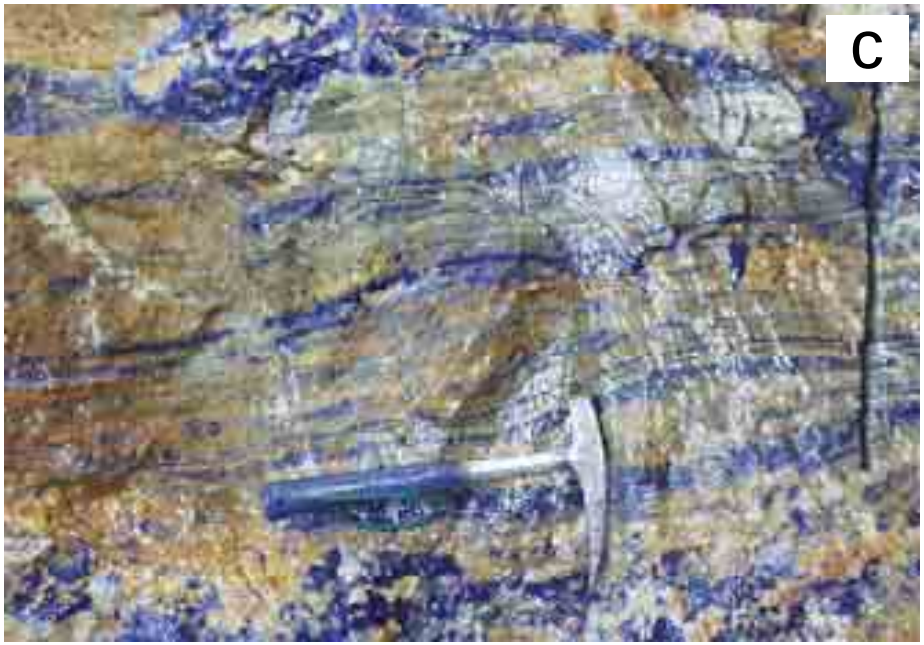

N
Río Ayopaya
Cerro San Cristobal
4221 m
Cerro Sapo
4250 m
Chiaracke
Cerro
Cusceno
Laguna
Khoallaqui
Kimberlite
Independencia
Río Ayopaya
Río Santa Rosa
Cerro
Acutani
Morochata
Cerro
Quenamari
17°00'
17°10'
66°50'
66°40'
0
10 km
BRAZIL
PERU
BOLIVIA
La Paz
Independencia
Cochabamba
PARAGUAY
CHILE
ARGENTINA
Pacific Ocean
400 km
a
b
Nepheline syenite
Carbonatite
Ultramafic breccia
Tertiary clastic sediments
Cretaceous clastic sediments
Lower Palaeozoic clastic metasediments
Sodalite-ankerite-baryte dyke
Kimberlite
t
k

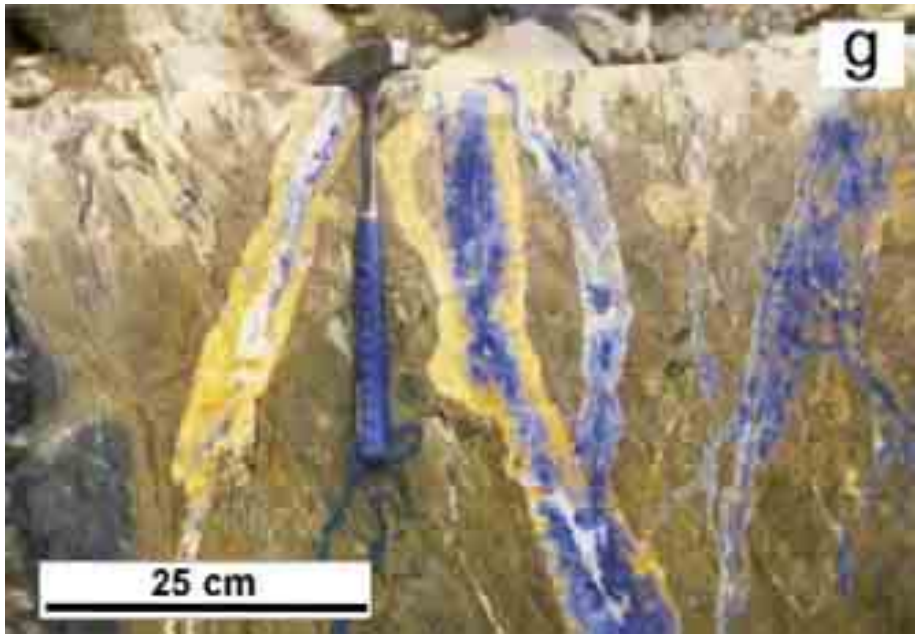

N
San Cristobal
Sodalite
Mine
Cerro Sapo
0
1 km
Nepheline syenite/foyaite
Carbonatite
Sodalite-ankerite-baryte dyke
Mafic-ultramafic dyke/breccia
Hornfels
Lower Palaeozoic metasediments
Thrust fault
Normal fault
Trail


a









Sodalite (blue): $Na_4Al_3Si_3O_{12}Cl$; Ankerite (brown); Baryte (white)


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 cm
http://www.e-sga.org


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 cm

Catalão, Brazil: Pyrochlore $(Na,Ca)_2(Nb,Ta)_2O_6(OH,F)$

Pyrochlore $(Na,Ca)_2(Nb,Ta)_2O_6(OH,F)$