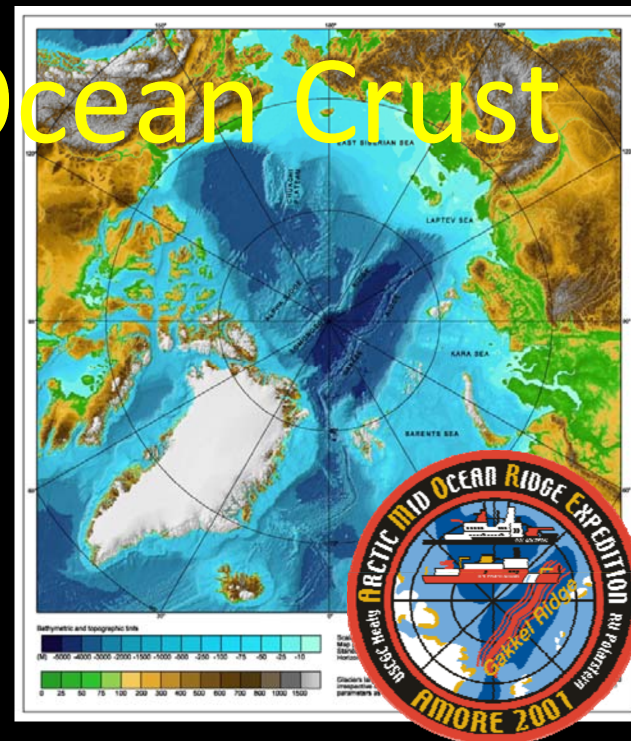
It Ain't Your Daddy's Ocean Crust

Henry Dick

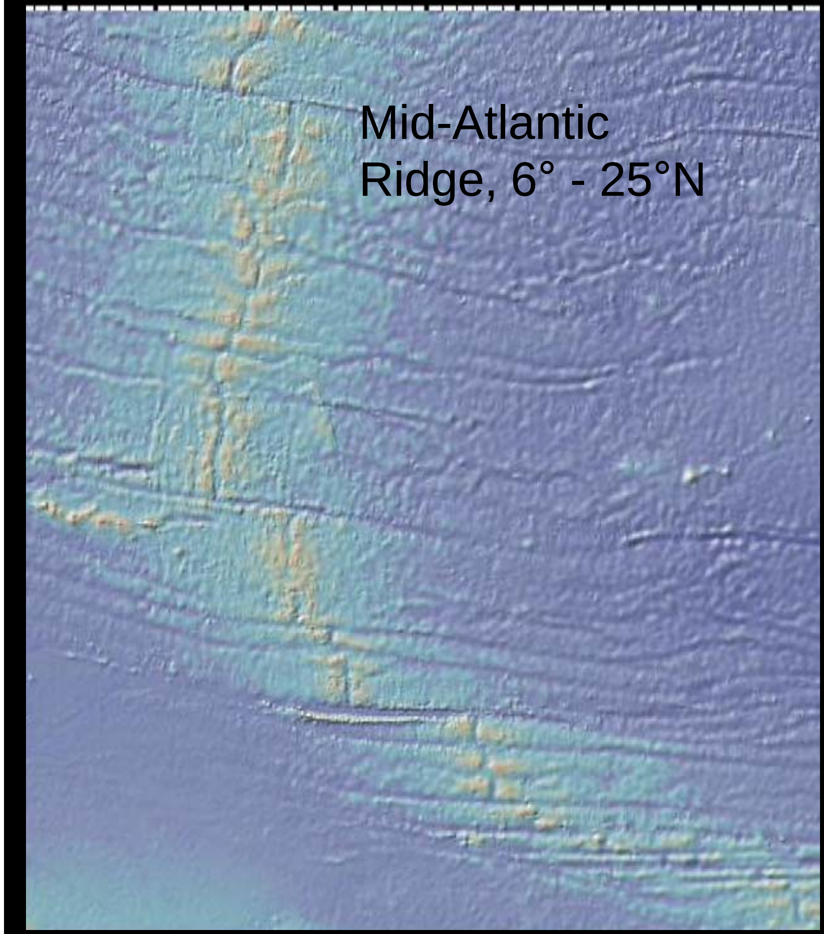
Yale PhD 1976

Advisors
RL Armstrong, H Winchell,
P Orville



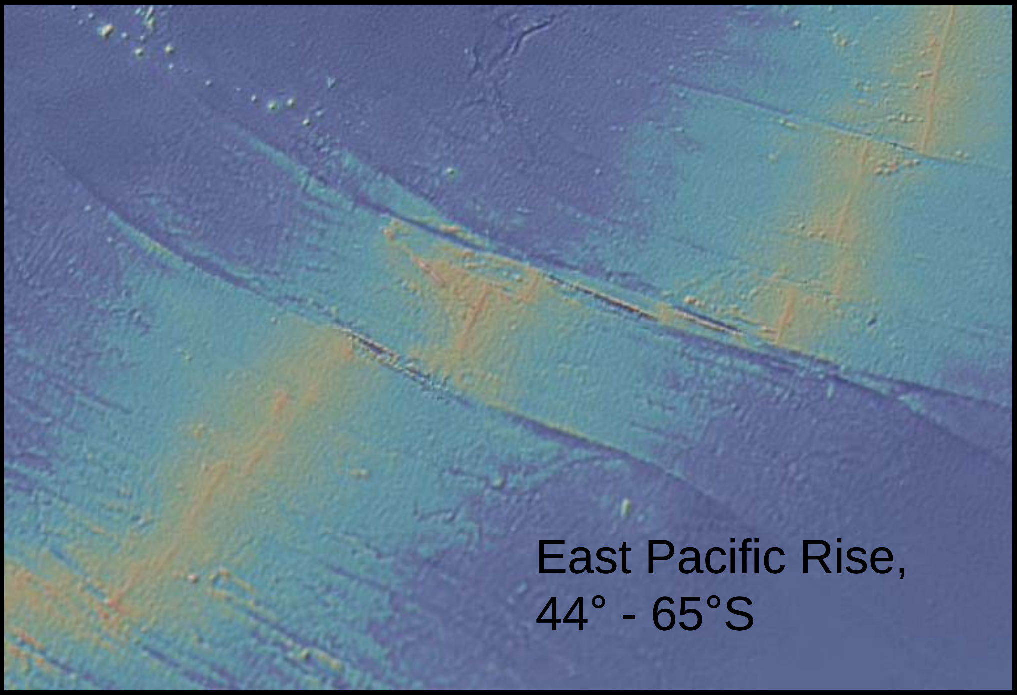
87°N September 2001

55°S December 2000



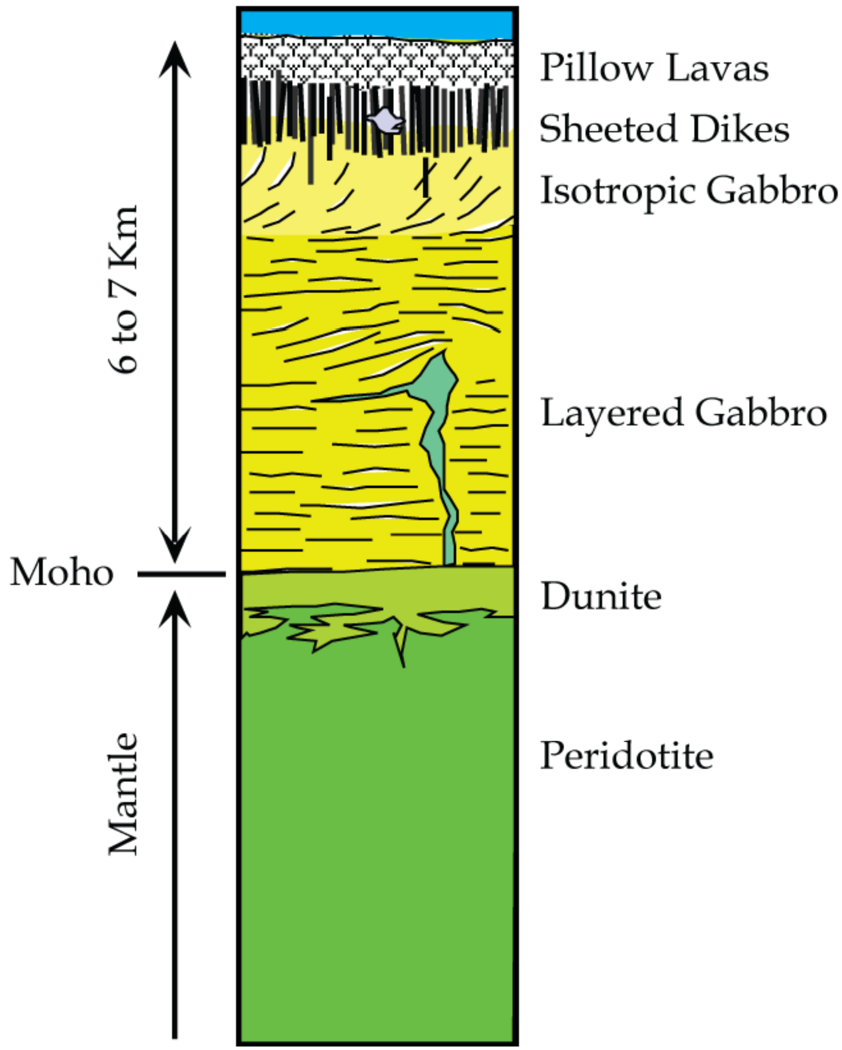
Until recently accretionary plate boundaries have been adequately described by two orthogonal plate boundary structures:

Transform Faults
&
Accretionary Magmatic Segments

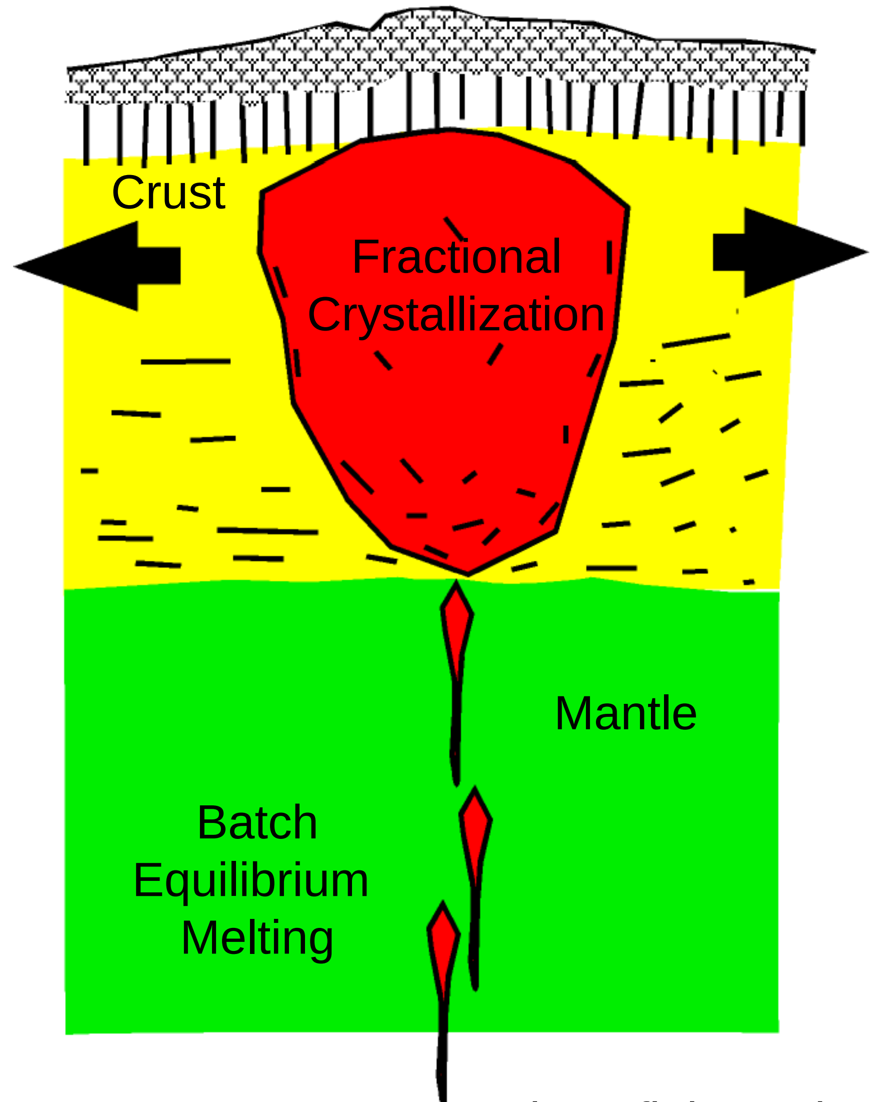


Non-transform offsets, leaky transforms, and over-lappers are important but secondary features, but the first-order elements of a ridge were described by the two main plate boundary structures.

Penrose Ophiolite Ocean Crust
Model based on ocean seismology,
dredge samples and ophiolites

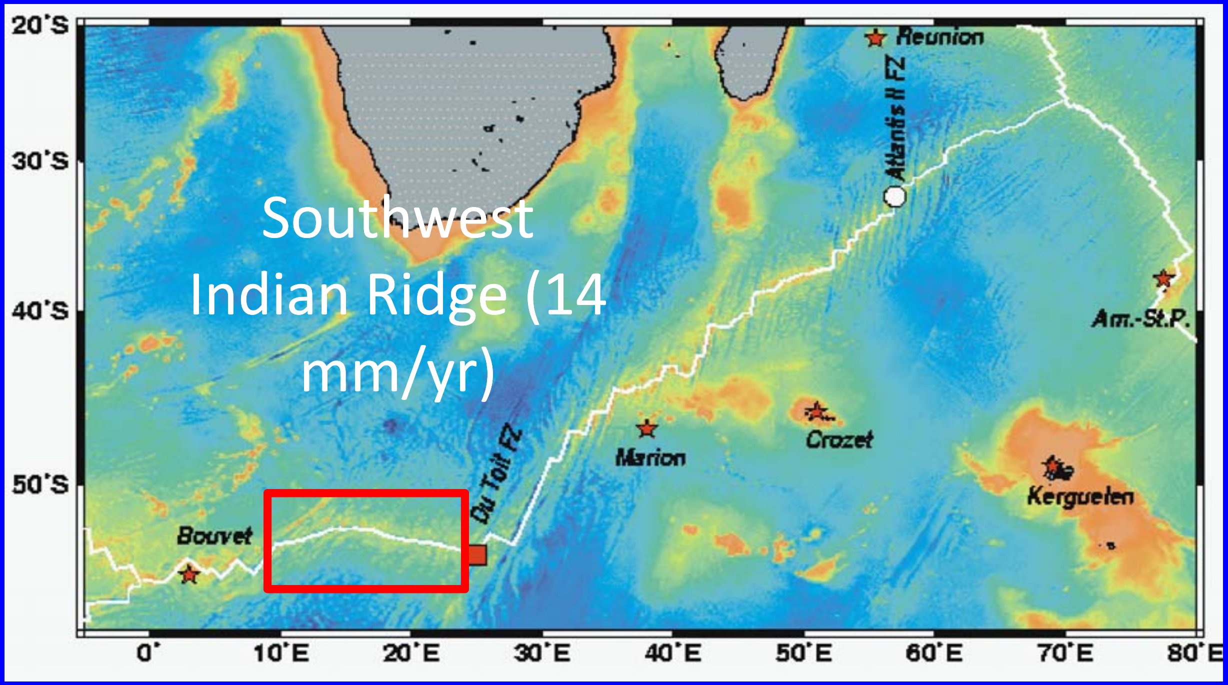


And by analogy to the great
layered intrusions like
Bushveldt and Stillwater



The Infinite Onion

Dick. Lin & Schouten, Nature, 2003

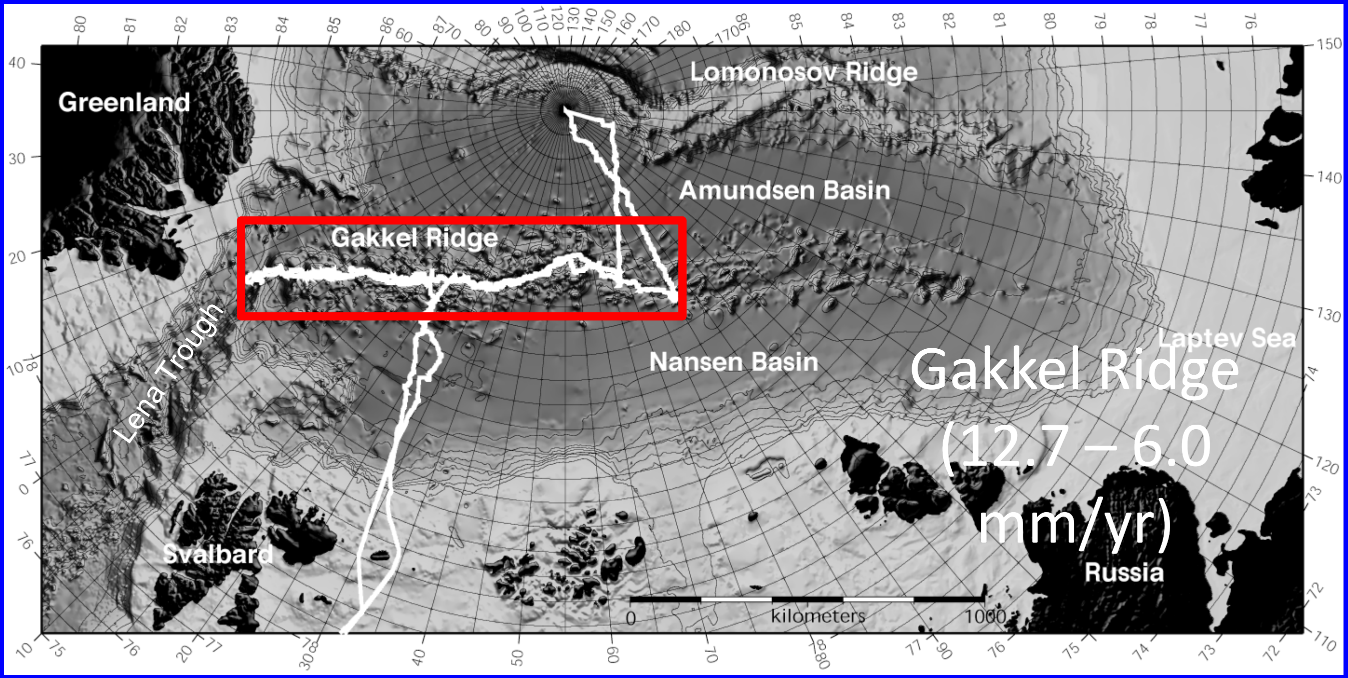


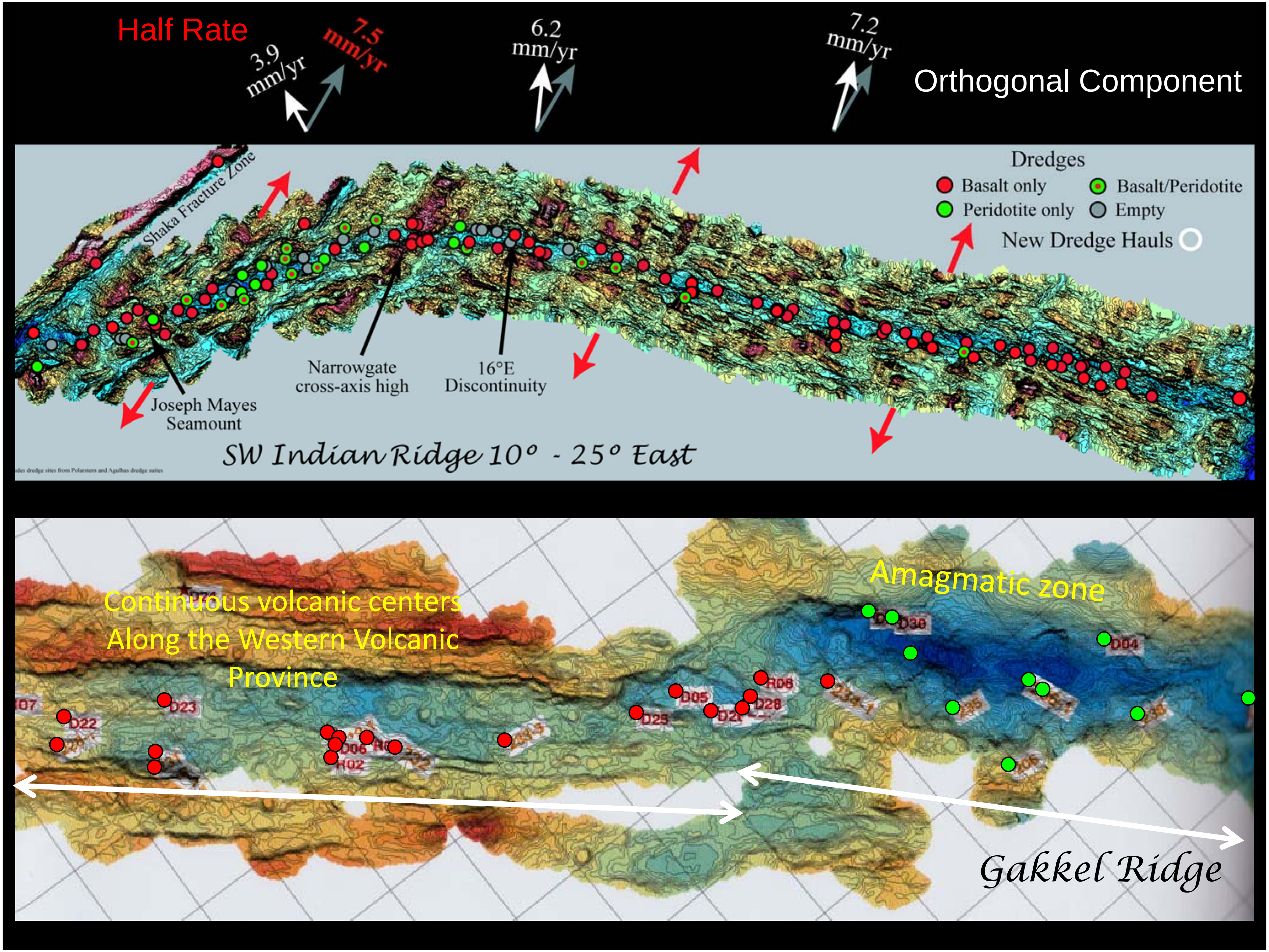
Many plate boundaries (SWIR, Arctic) are not well described by transform faults and magmatic ridge segments. In particular, there are large regions of oblique spreading ridge with no transforms.

Ultra Slow Spreading Ridges

ESR < ~12 mm/yr

Recently recognized as a new class as distinct from slow-spreading as slow-spreading are from fast

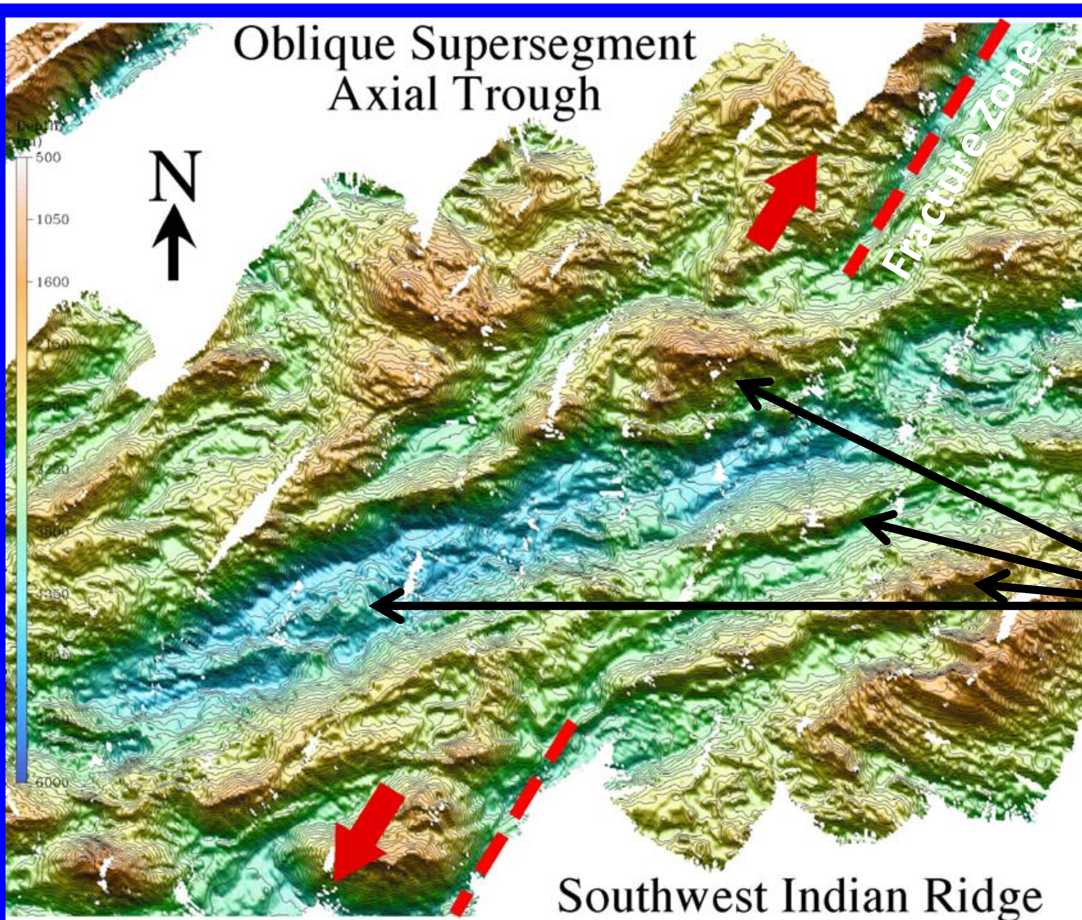




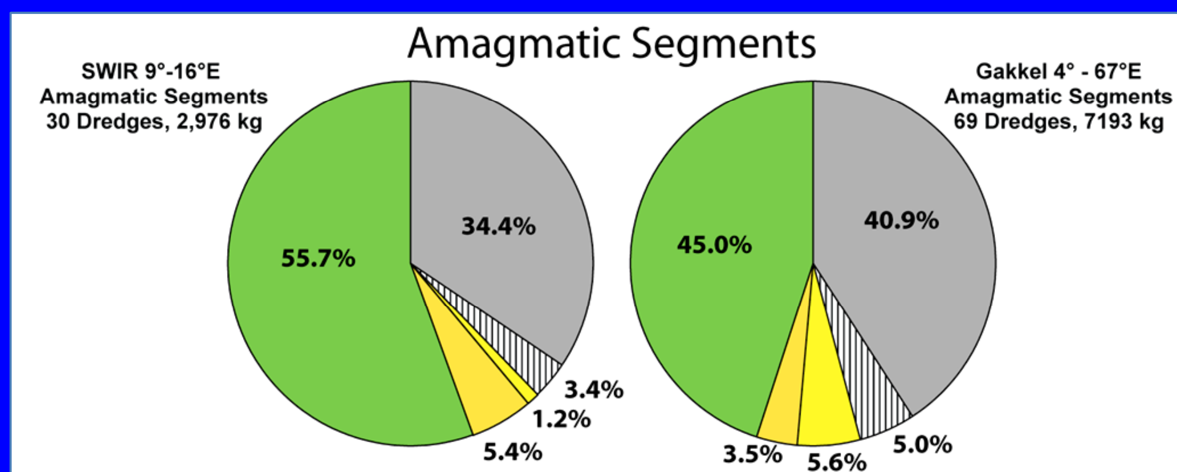
Half Rate
3.9 mm/yr
7.5 mm/yr
6.2 mm/yr
7.2 mm/yr
Orthogonal Component
Dredges
Basalt only
Basalt/Peridotite
Peridotite only
Empty
New Dredge Hauls
Shaka Fracture Zone
Narrowgate cross-axis high
16°E Discontinuity
Joseph Mayes Seamount
SW Indian Ridge 10° - 25° East
Continuous volcanic centers Along the Western Volcanic Province
Amagmatic zone
D22
D23
D05
D25
D28
R08
D30
D04
D06
R02
Gakkel Ridge

Amagmatic Accretionary Segments

The Fourth Class of Plate Boundary Structure

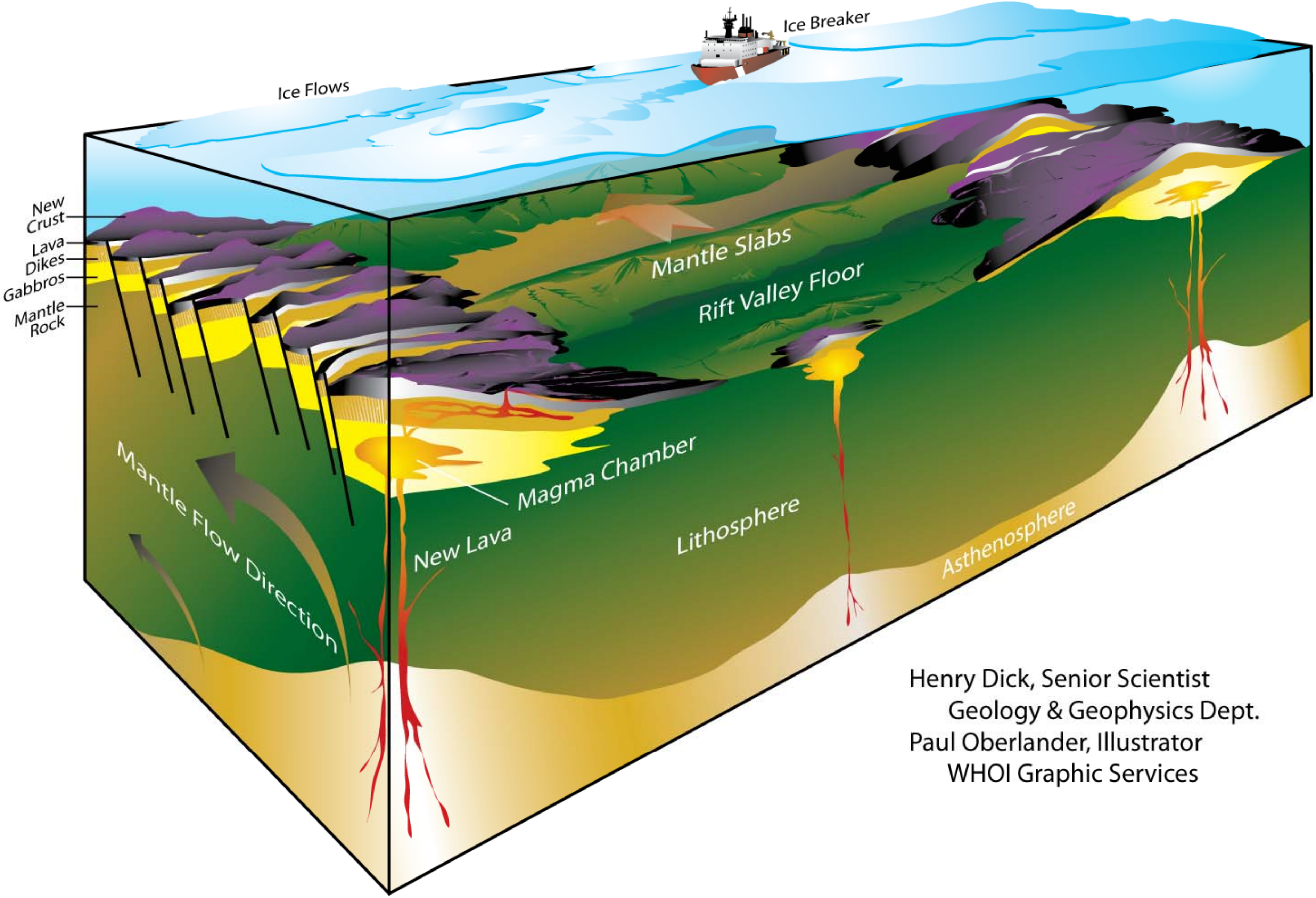


Mantle
Blocks

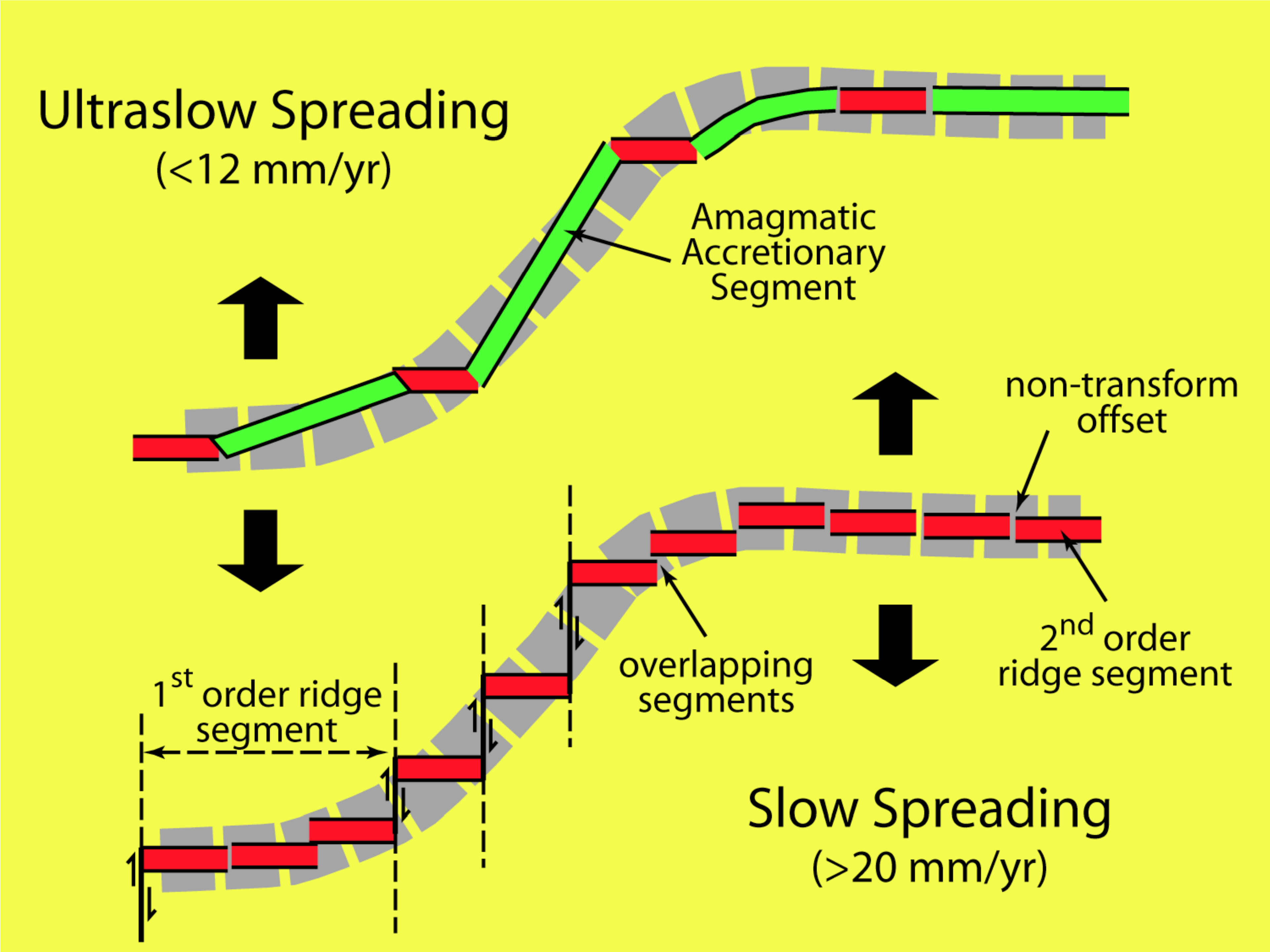


Basalt
Diabase
Gabbro
Dunite
Peridotites

Magmatic and Amagmatic Spreading Along the the Ultraslow Spreading Gakkel Ridge
A New Kind of Seafloor Spreading

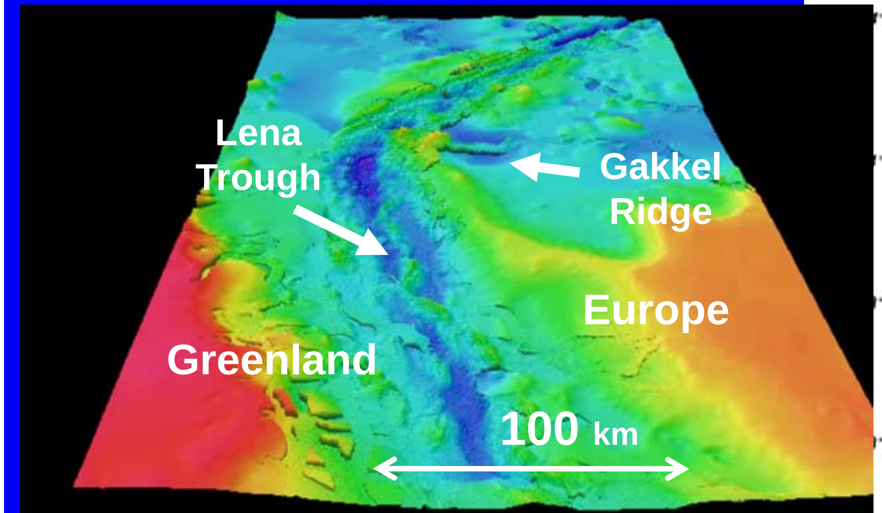


Henry Dick, Senior Scientist
Geology & Geophysics Dept.
Paul Oberlander, Illustrator
WHOI Graphic Services

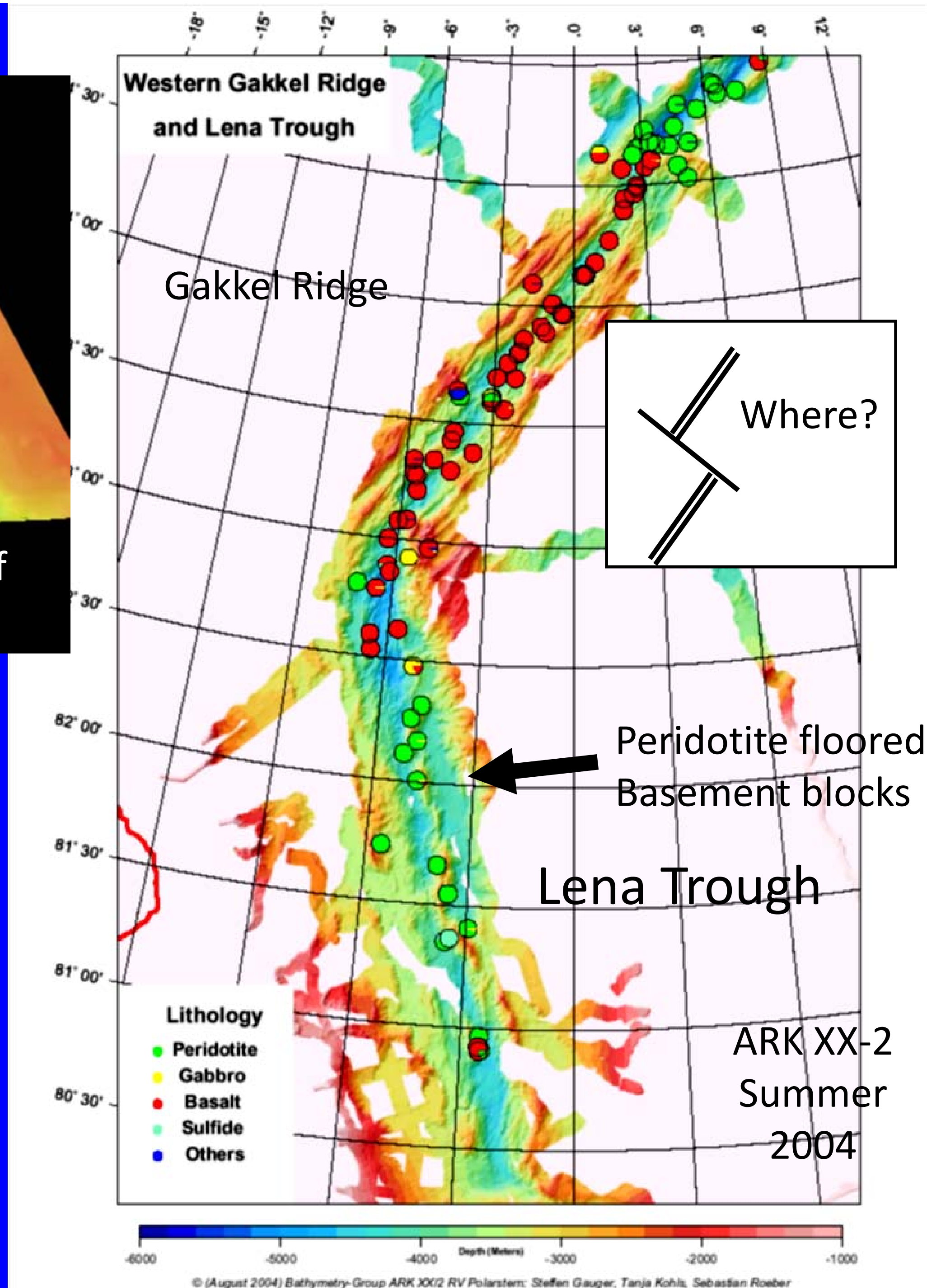


Ultraslow Spreading
(<12 mm/yr)
Amagmatic
Accretionary
Segment
non-transform
offset
1st order ridge
segment
overlapping
segments
2nd order
ridge segment
Slow Spreading
(>20 mm/yr)

J. Snow, pers. Comm. 2007

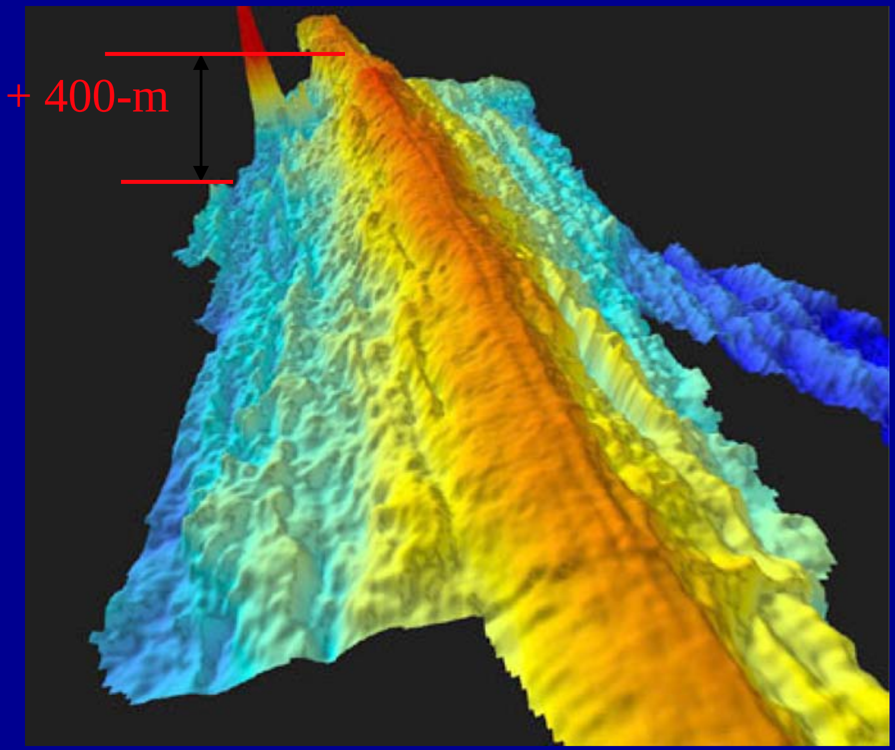


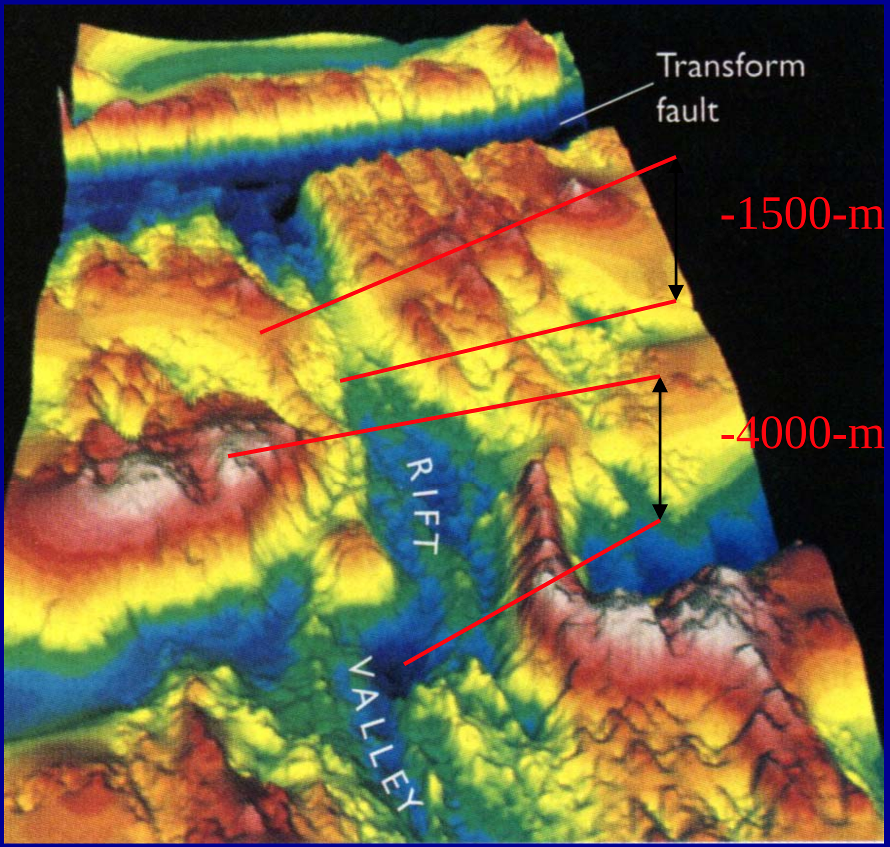
Lena Trough – a modern example of the ocean – continent transition



Amagmatic accretionary segments seen at ultra slow ridges spreading at an ESR <12 mm/yr are likely the characteristic plate boundary structure of non-volcanic rifted margins.

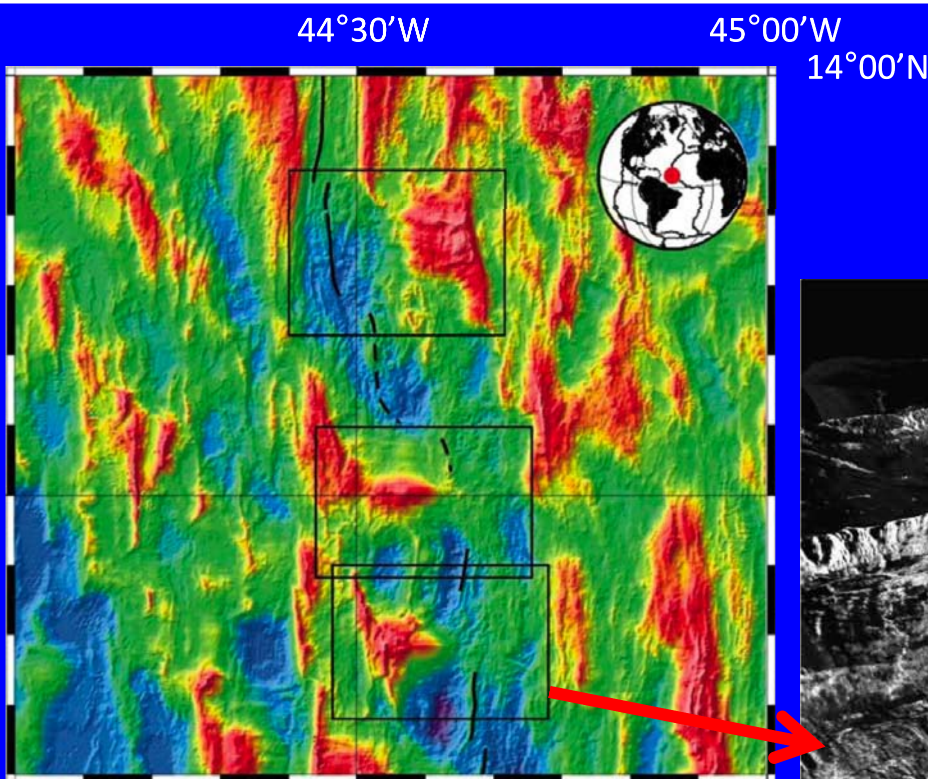
Fast Spreading Ridges
(~ 85 to 160 mm/yr)
East Pacific Rise



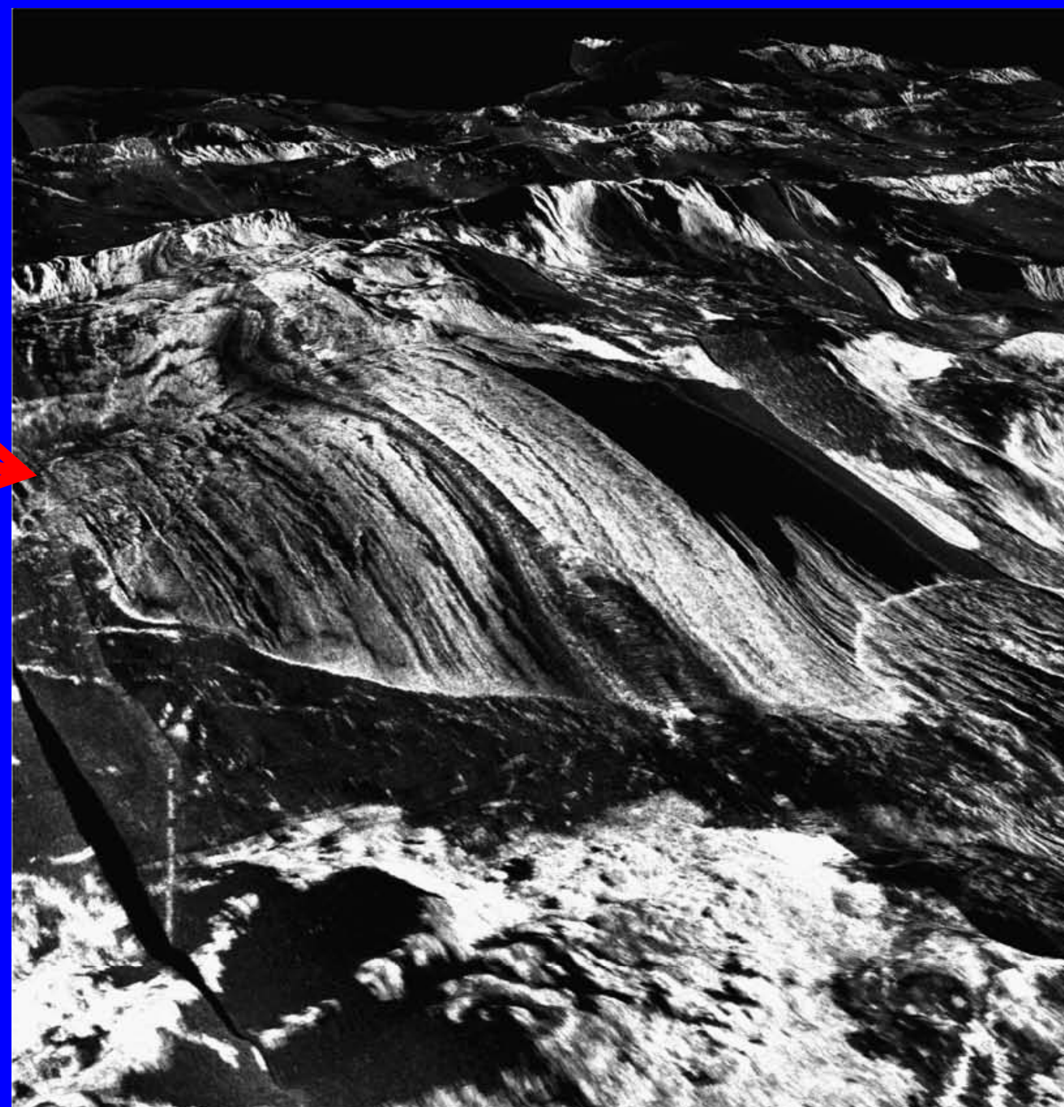


Slow Spreading Ridges
(~ 10 to 55 mm/yr)
Mid-Atlantic Ridge

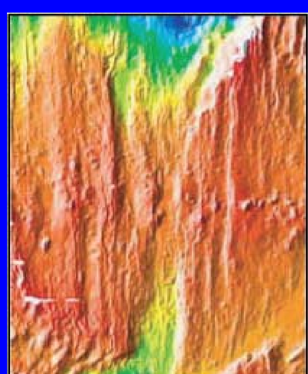
13°20’N Core Complex
Mid-Atlantic Ridge
(MacLeod et al. EPSL, 2009)



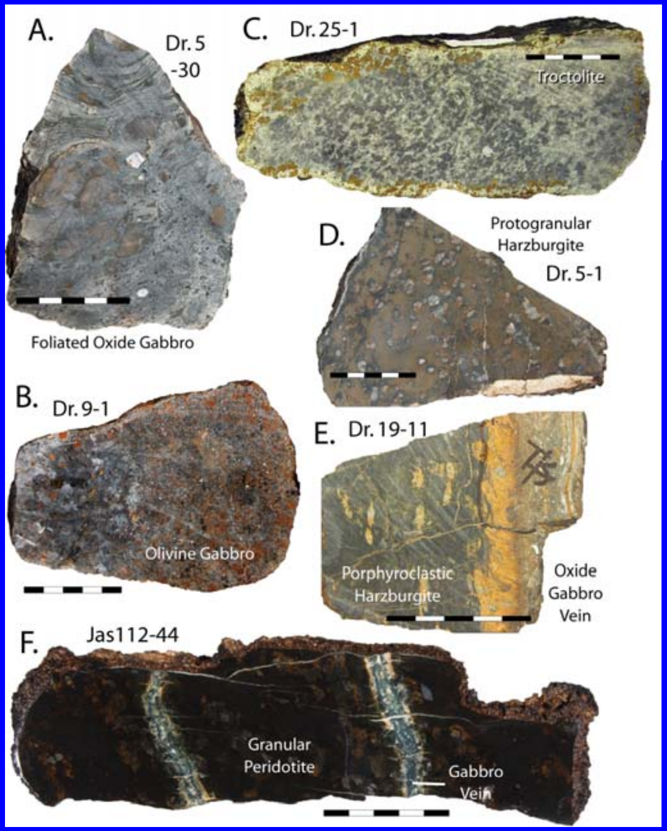
Asymmetric Spreading

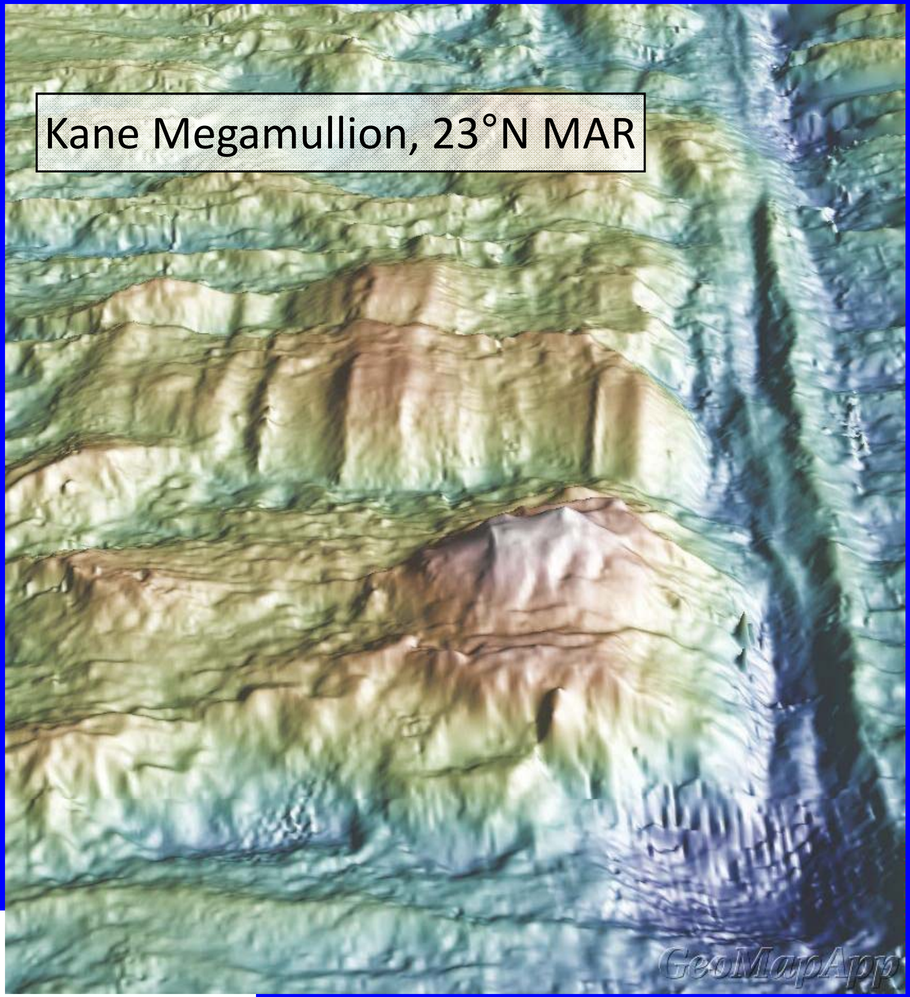


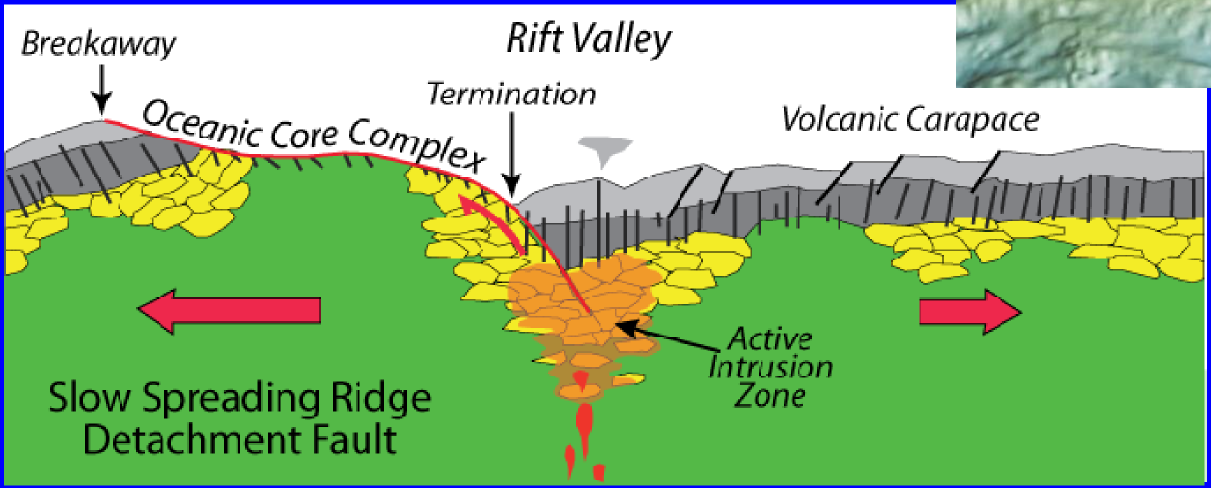
Symmetric Spreading



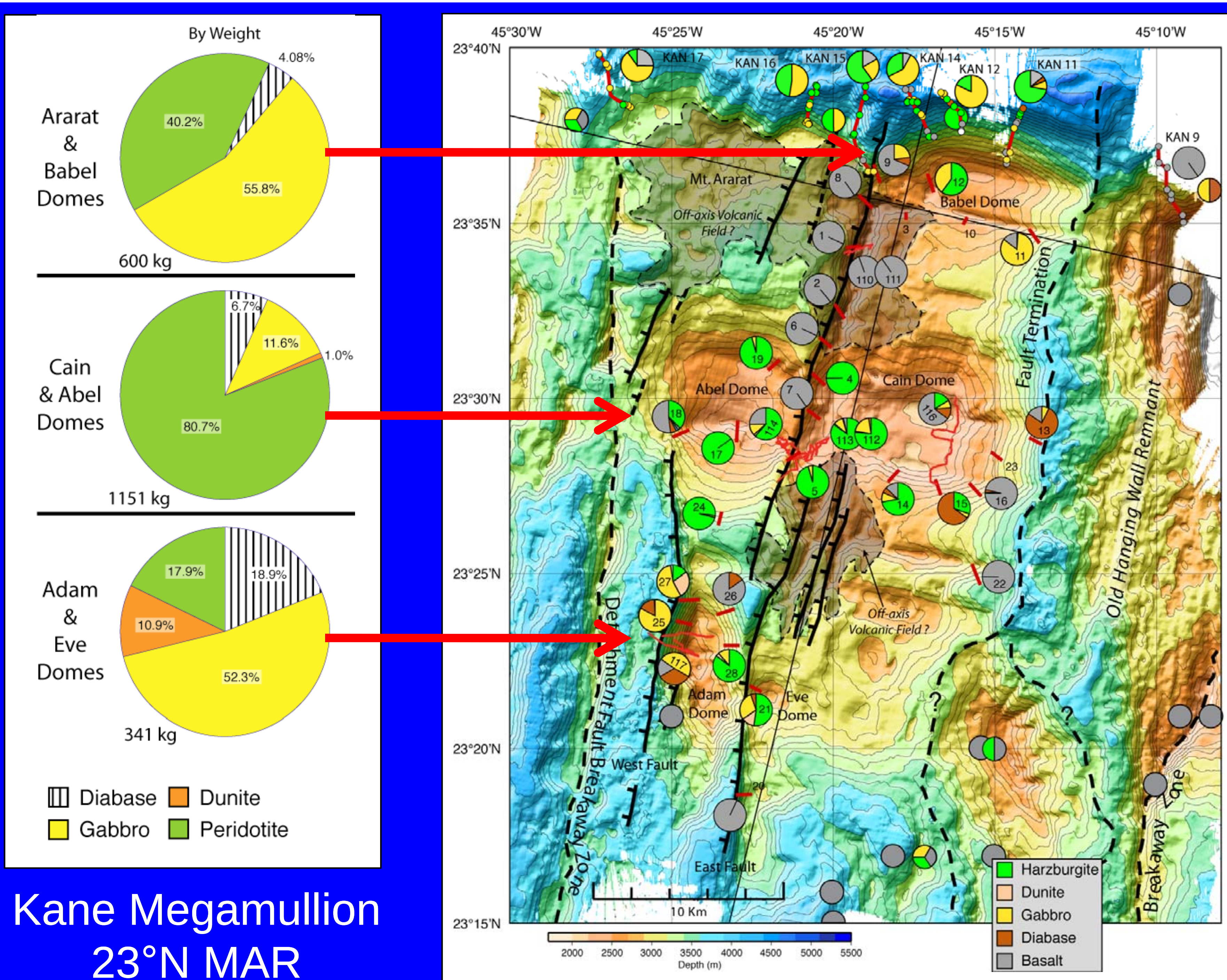
Escartin et al., Nature (2008) found close to 50% of the MAR seafloor mapped from 12.5° to 35°N has spread asymmetrically.







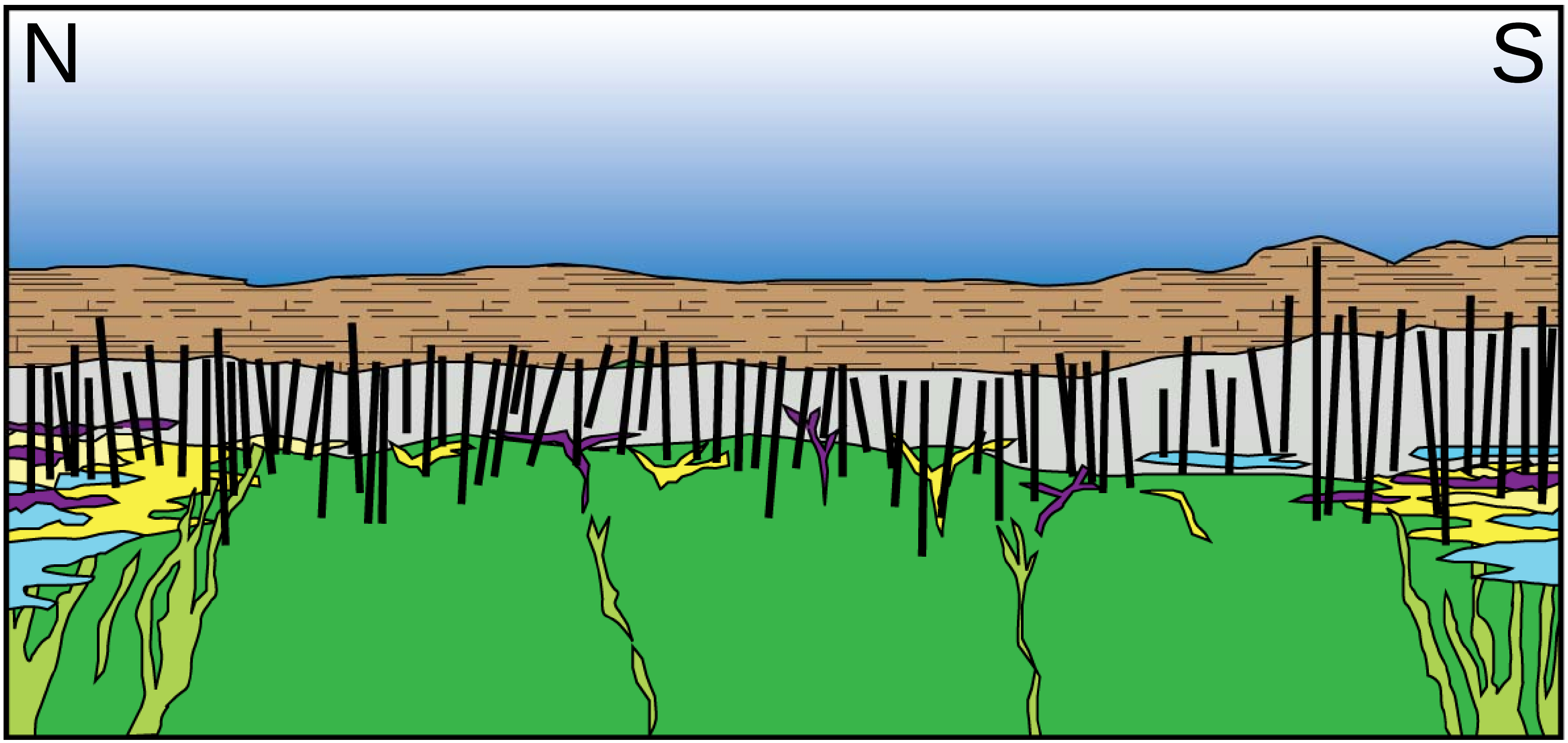
Based on: Dick, Tivey & Tucholke, G3, 2008



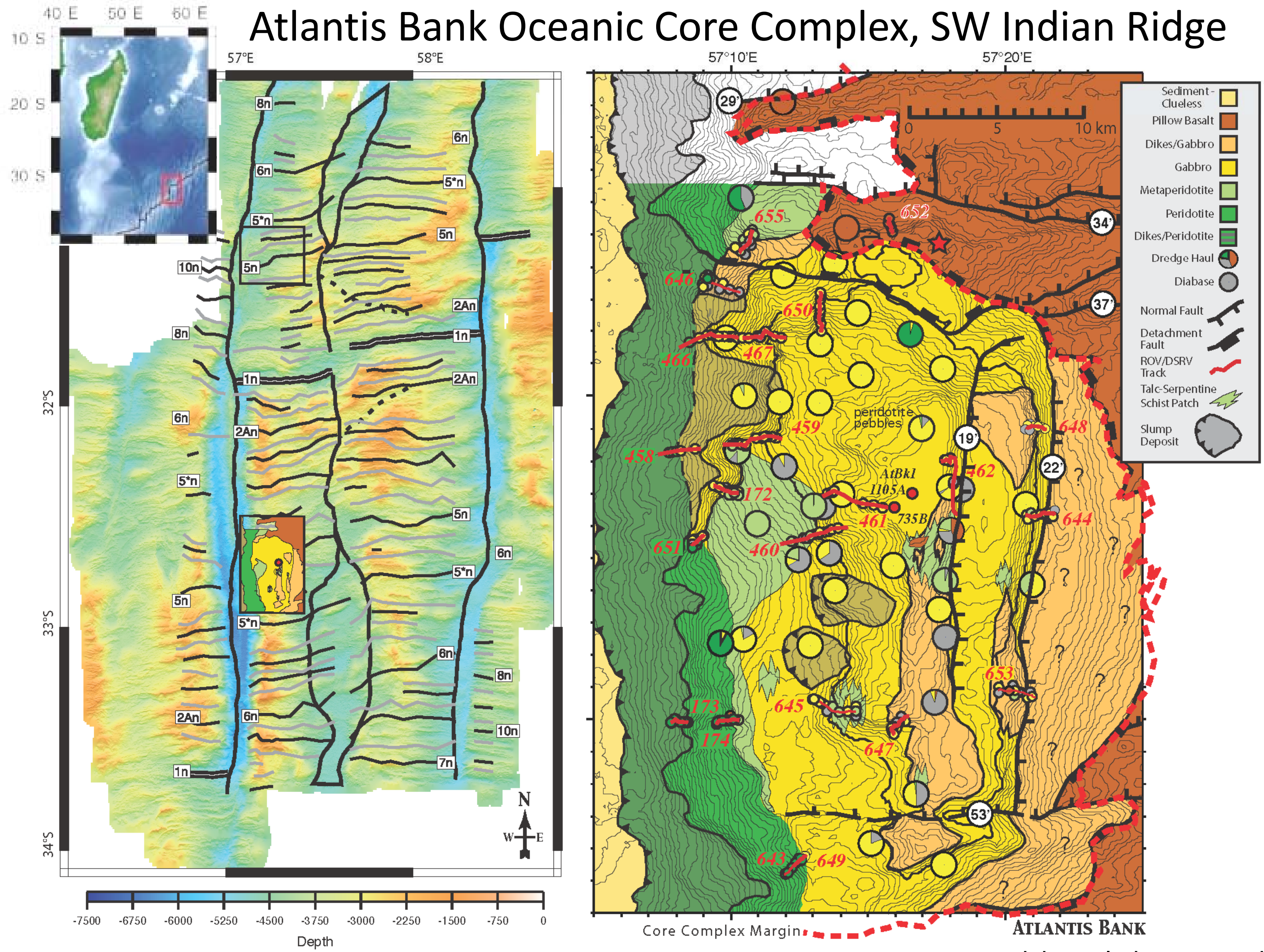
Kane Megamullion
23°N MAR

Major Surprise

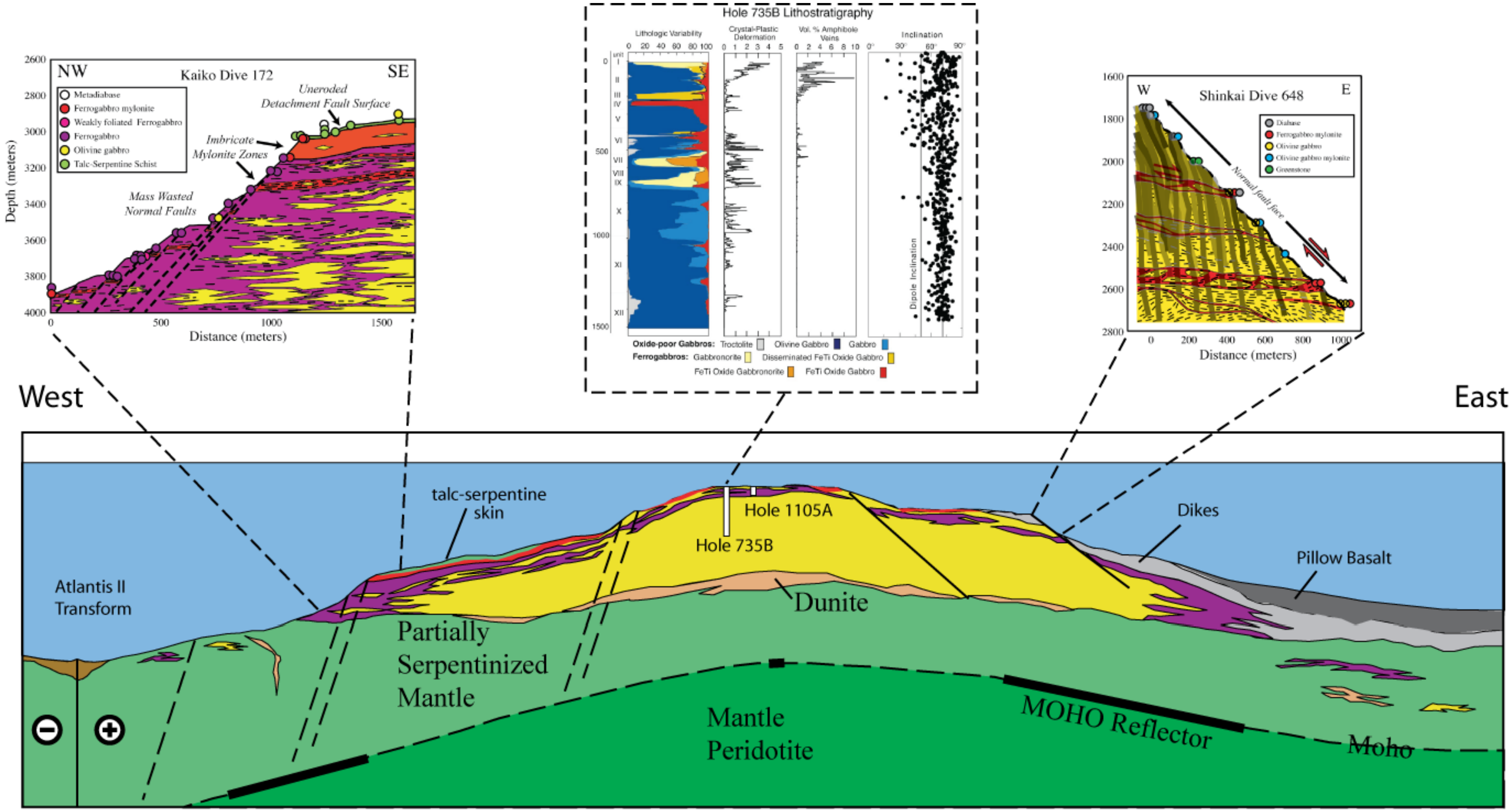
A large area of the crust beneath the mid-point of a "normal" second-order magmatic ridge segment consists of pillow basalts and dikes directly overlying the mantle.



Atlantis Bank Oceanic Core Complex, SW Indian Ridge

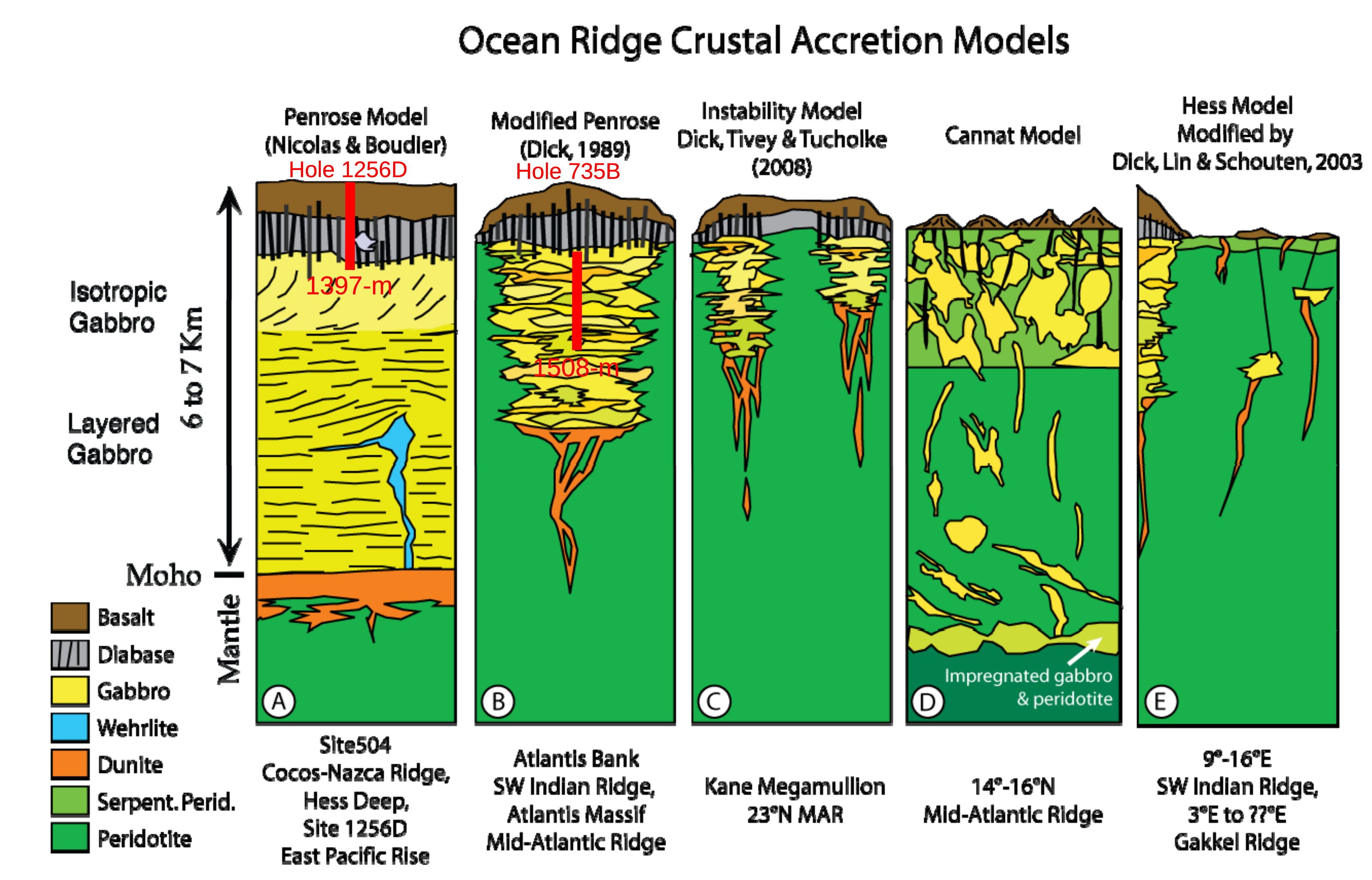


Dick et al., in preparation



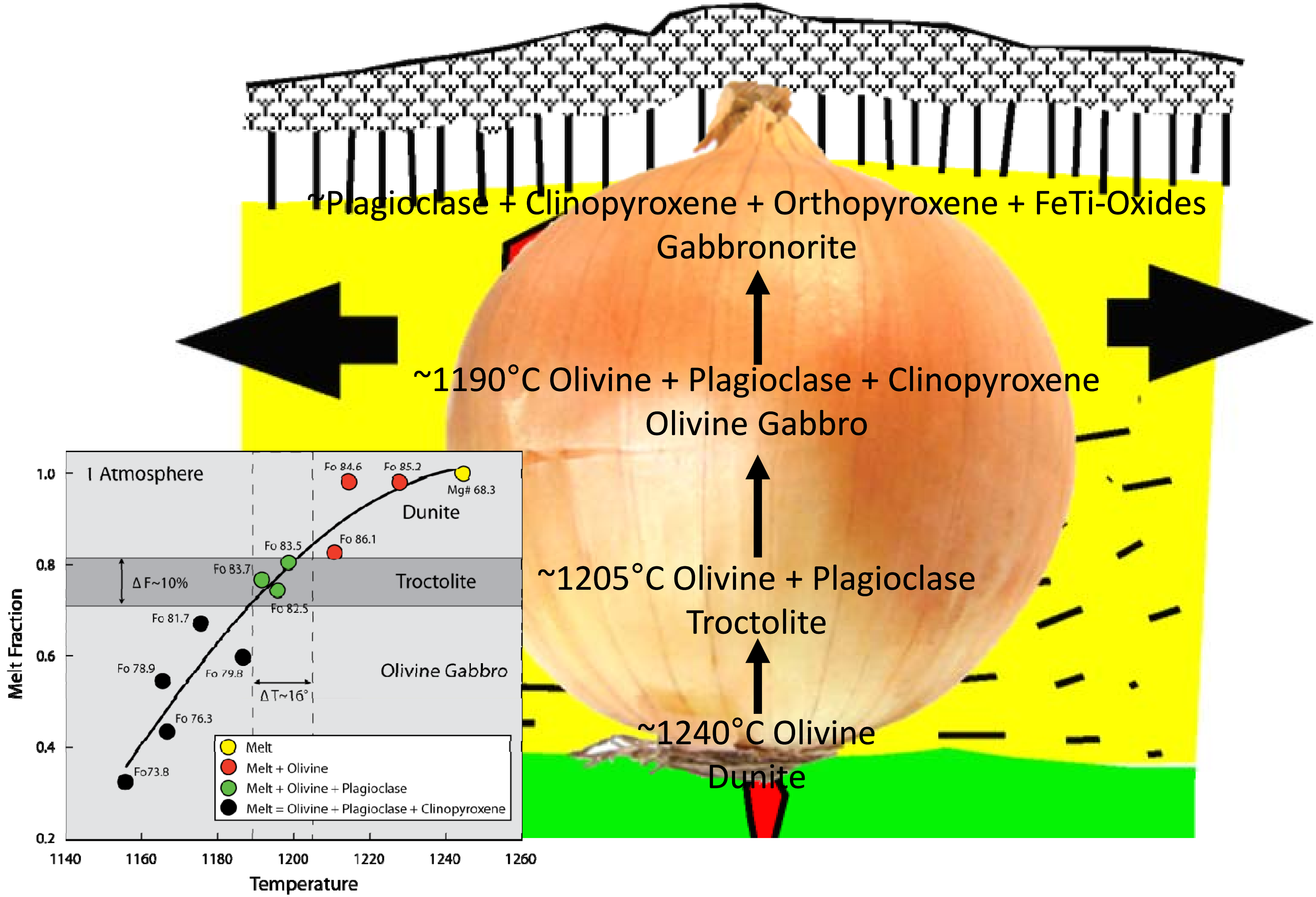
Longitudinal section through the Atlantis Bank Oceanic Core Complex representing a 1.4 km thick gabbro massif extending over ~700 km^2

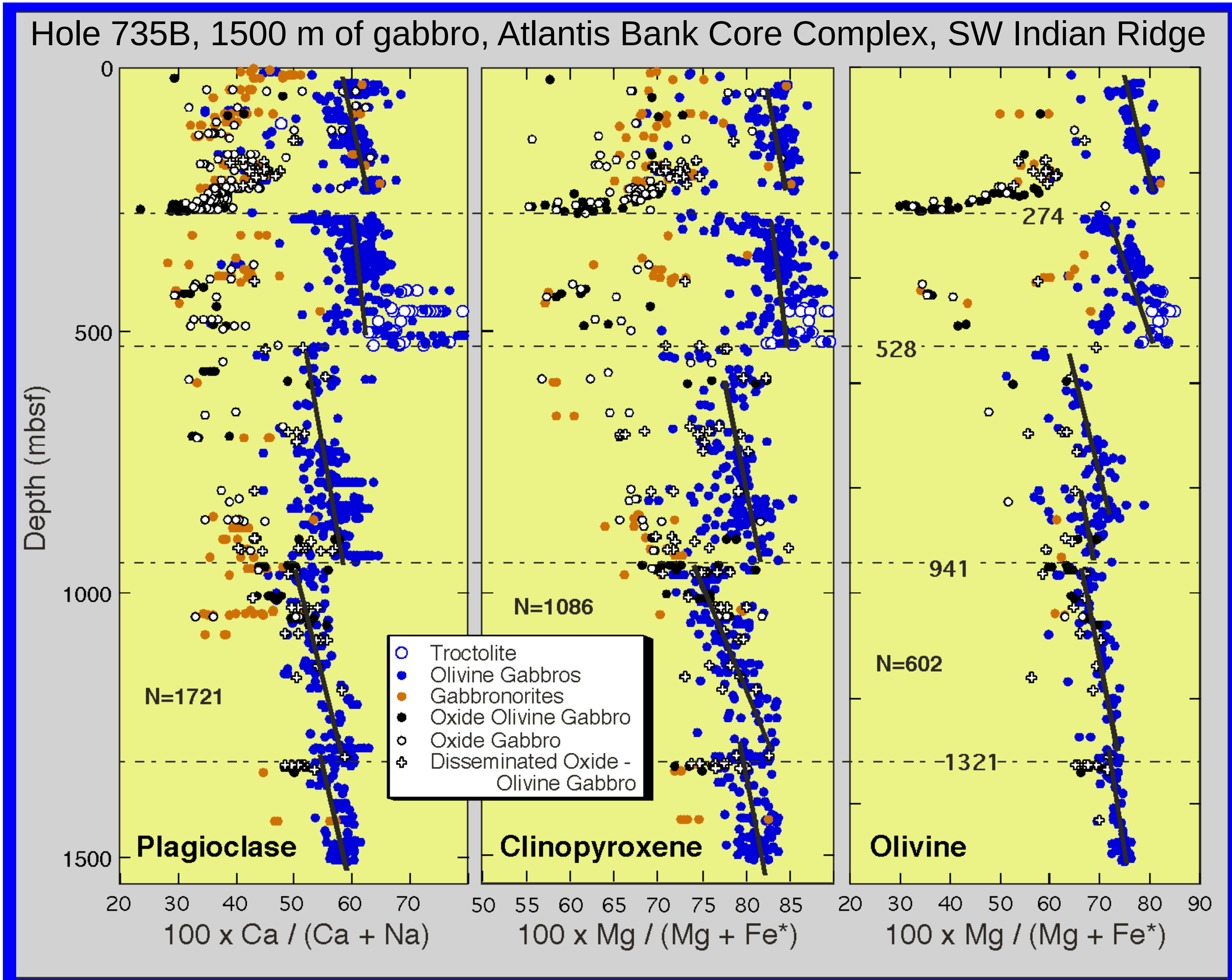
Dick et al., in preparation



We now know the ocean crust varies dramatically with spreading rate, ridge geometry, mantle thermal structure & fertility. -- Accordingly exploration has just begun.

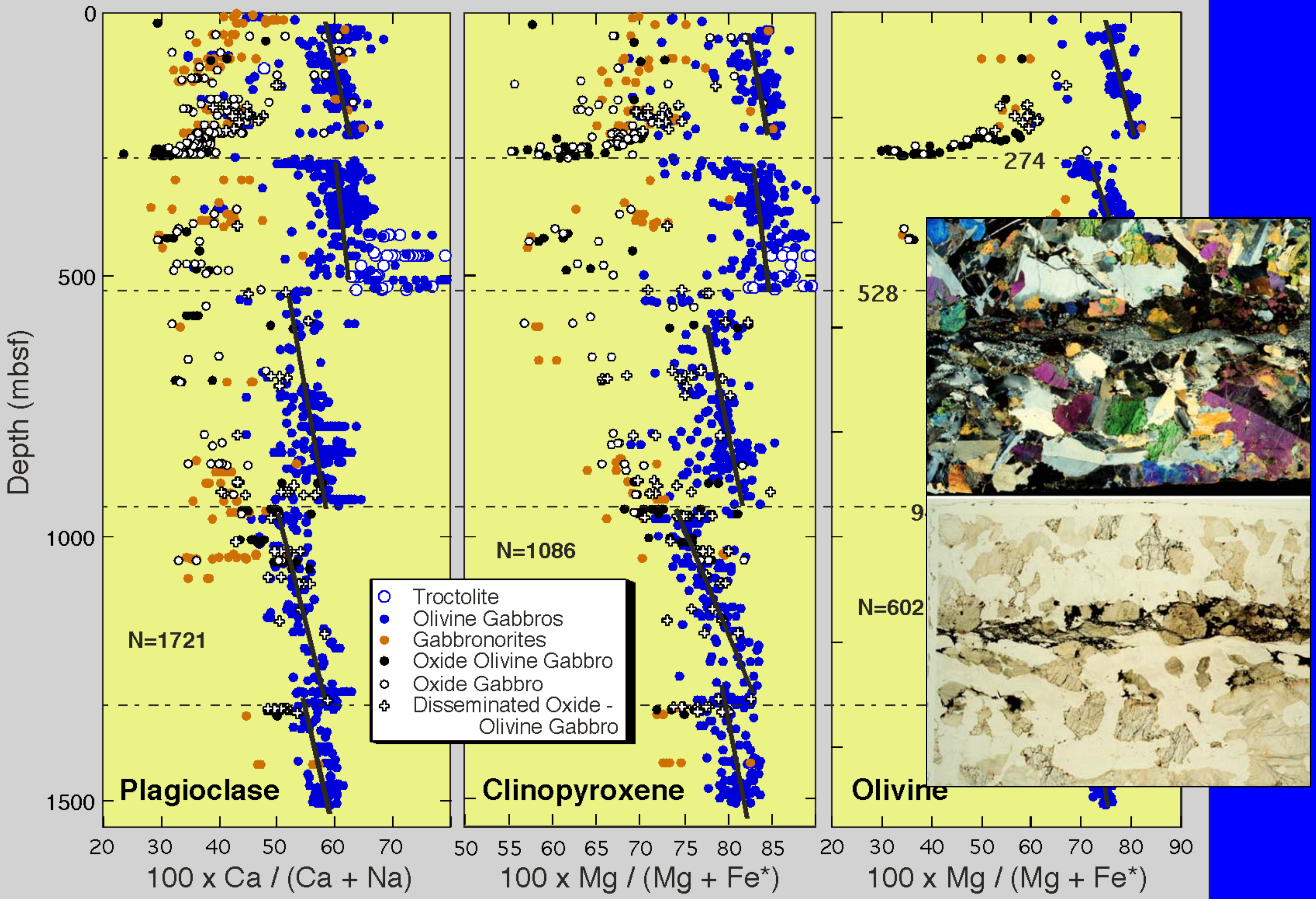
Is this really how the lower crust forms?





Dick et al., Ocean Drilling Prg Sci. Res. V. 176. 2002

Hole 735B, 1500 m of gabbro, Atlantis Bank Core Complex, SW Indian Ridge



Dick et al., Ocean Drilling Prg Sci. Res. V. 176. 2002

Reactive melt infiltration through Troctolite:

Melt + Olivine and Calcic Plagioclase → Melt + Cpx + Sodic Plagioclase

Adam Dome Magmatic Complex Troctolites, Kane Megamullion MAR

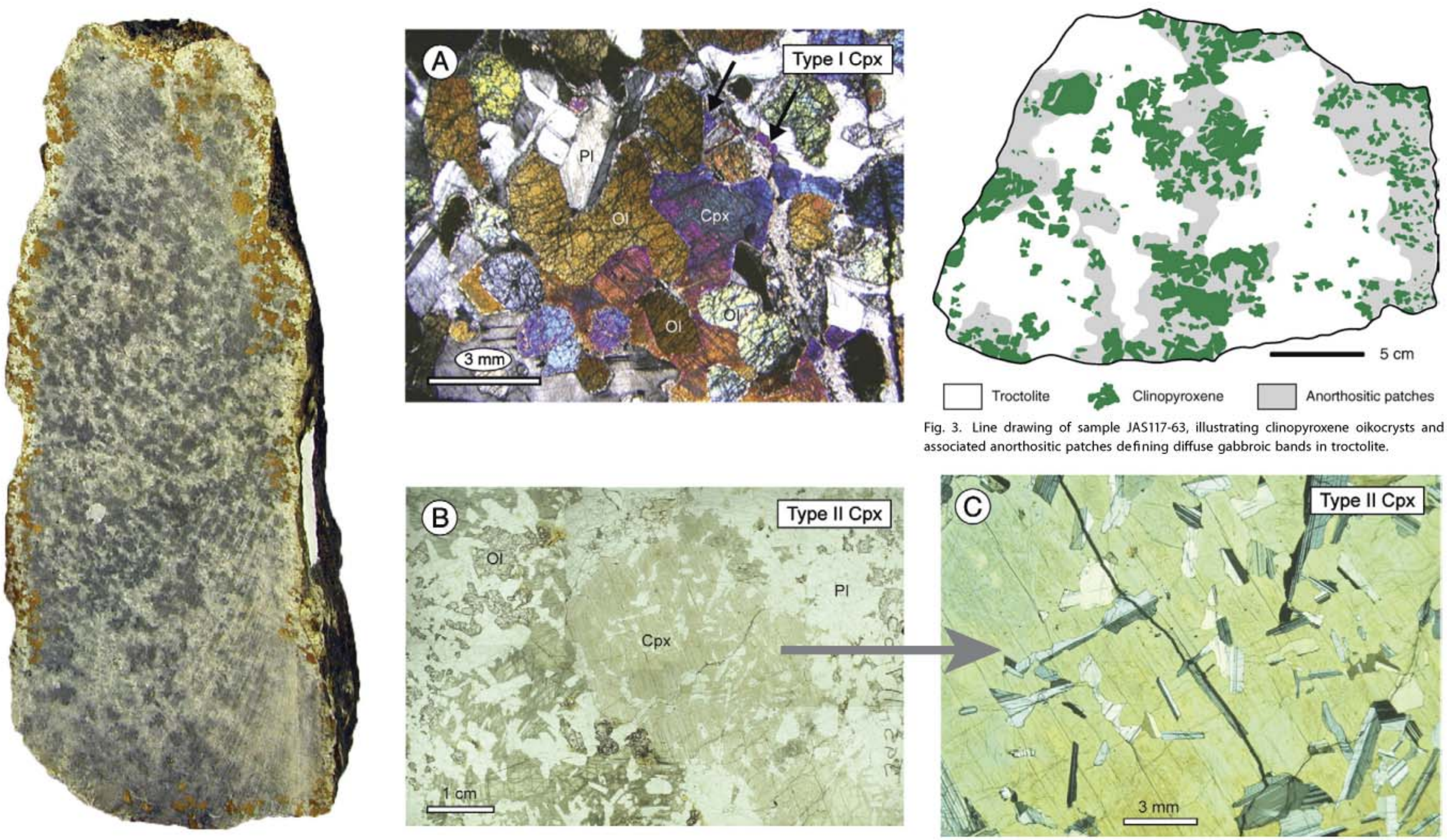
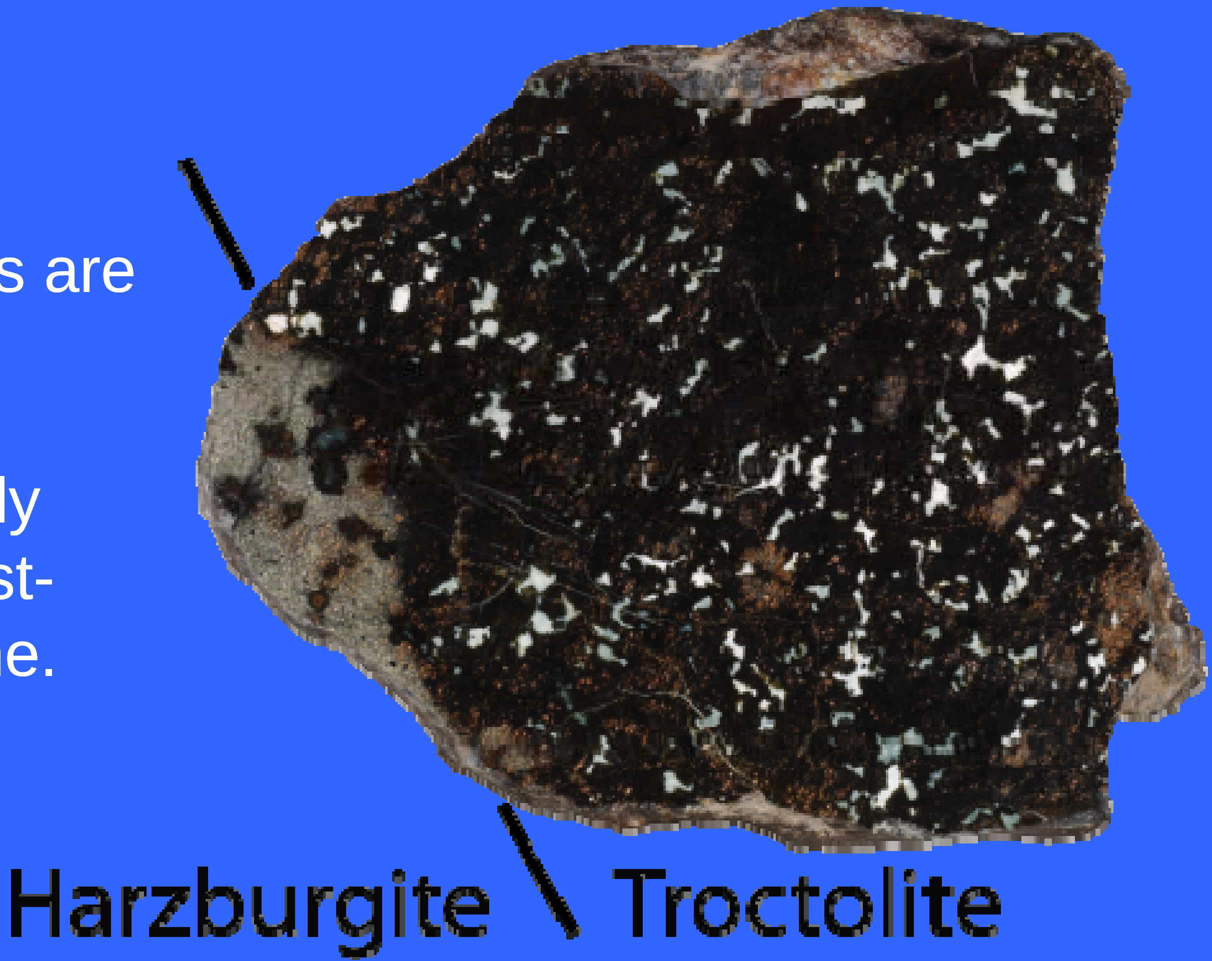


Fig. 3. Line drawing of sample JAS117-63, illustrating clinopyroxene oikocrysts and associated anorthositic patches defining diffuse gabbroic bands in troctolite.

Lissenberg & Dick, G3, 2008

Evidence for melt – rock reaction in the mantle at the base of the crust:

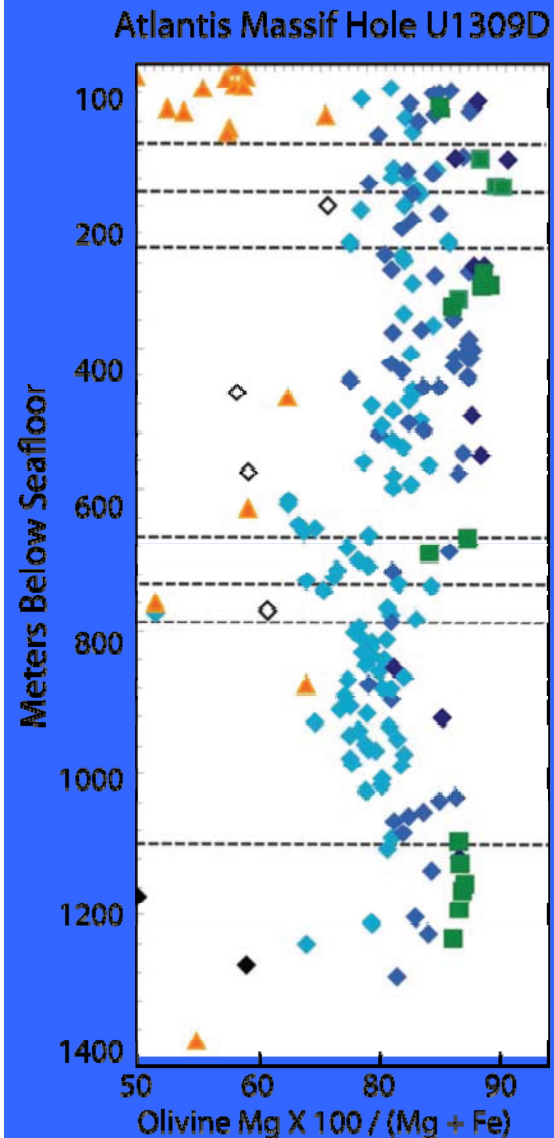
Olivine-rich troctolites are found in contact with mantle peridotites in abyssal dredges likely representing the crust-mantle transition zone.

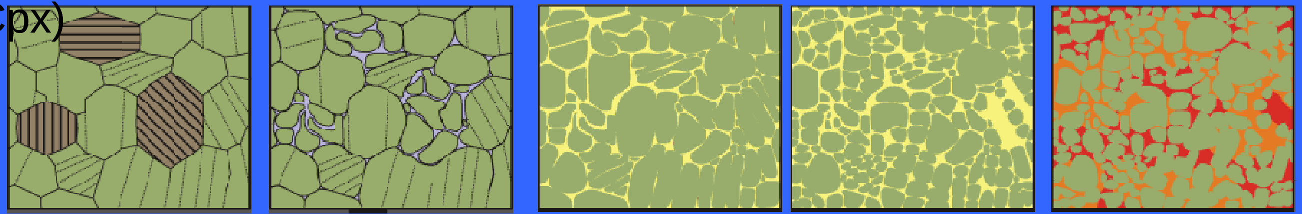


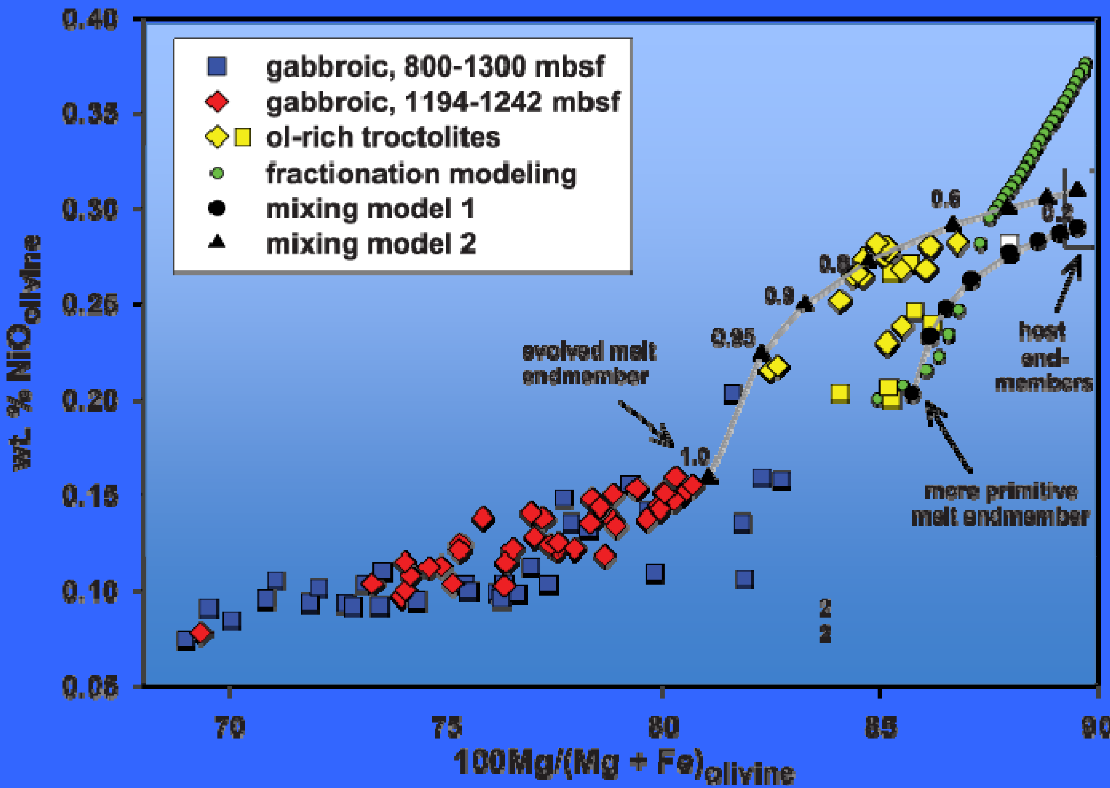
American-Antarctic Ridge Troctolite in contact with altered harzburgite

Olivine-rich troctolites apparently derived from mantle harzburgite rafted up to high levels in the lower crust

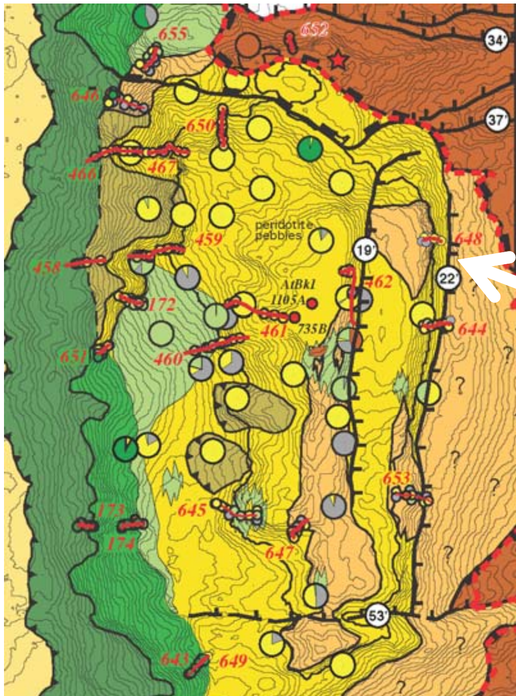
Harzburgite + Melt → Dunite + Melt → Troctolite (Ol + Pl + Cpx)



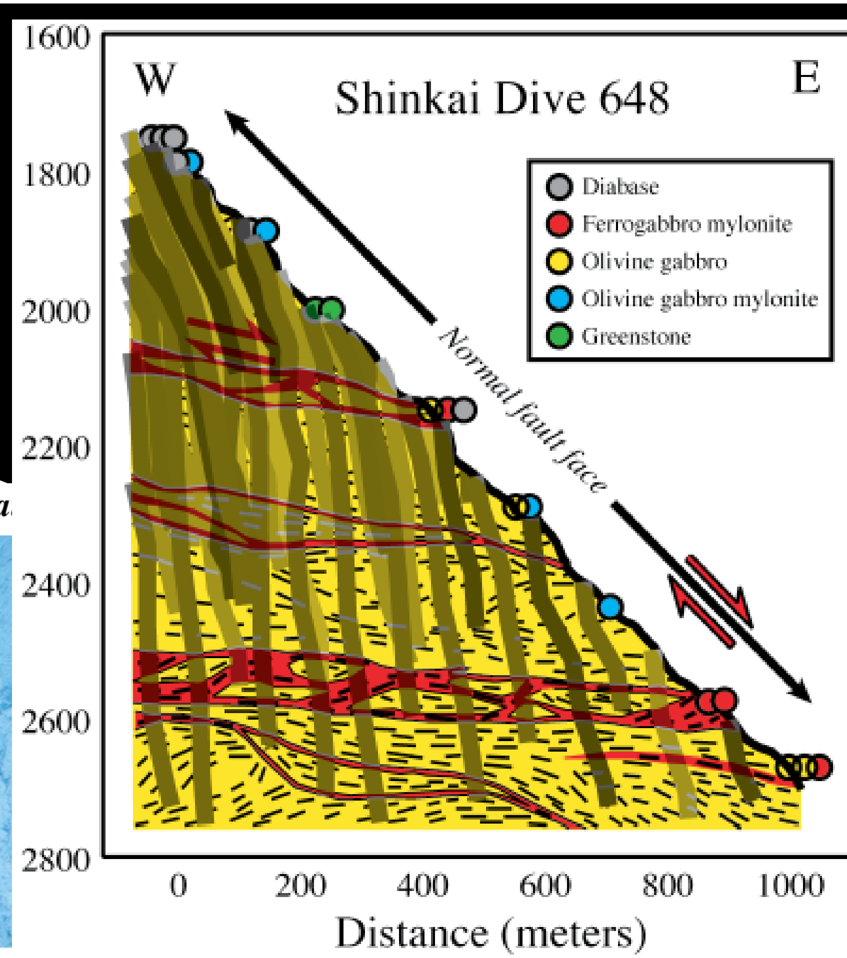




Suhr et al. G3 2008, and Drouin et al., EOS 2007, EOS 2008



Dive 648, a normal fault face exposing a 1-km section of dike-gabbro transition.



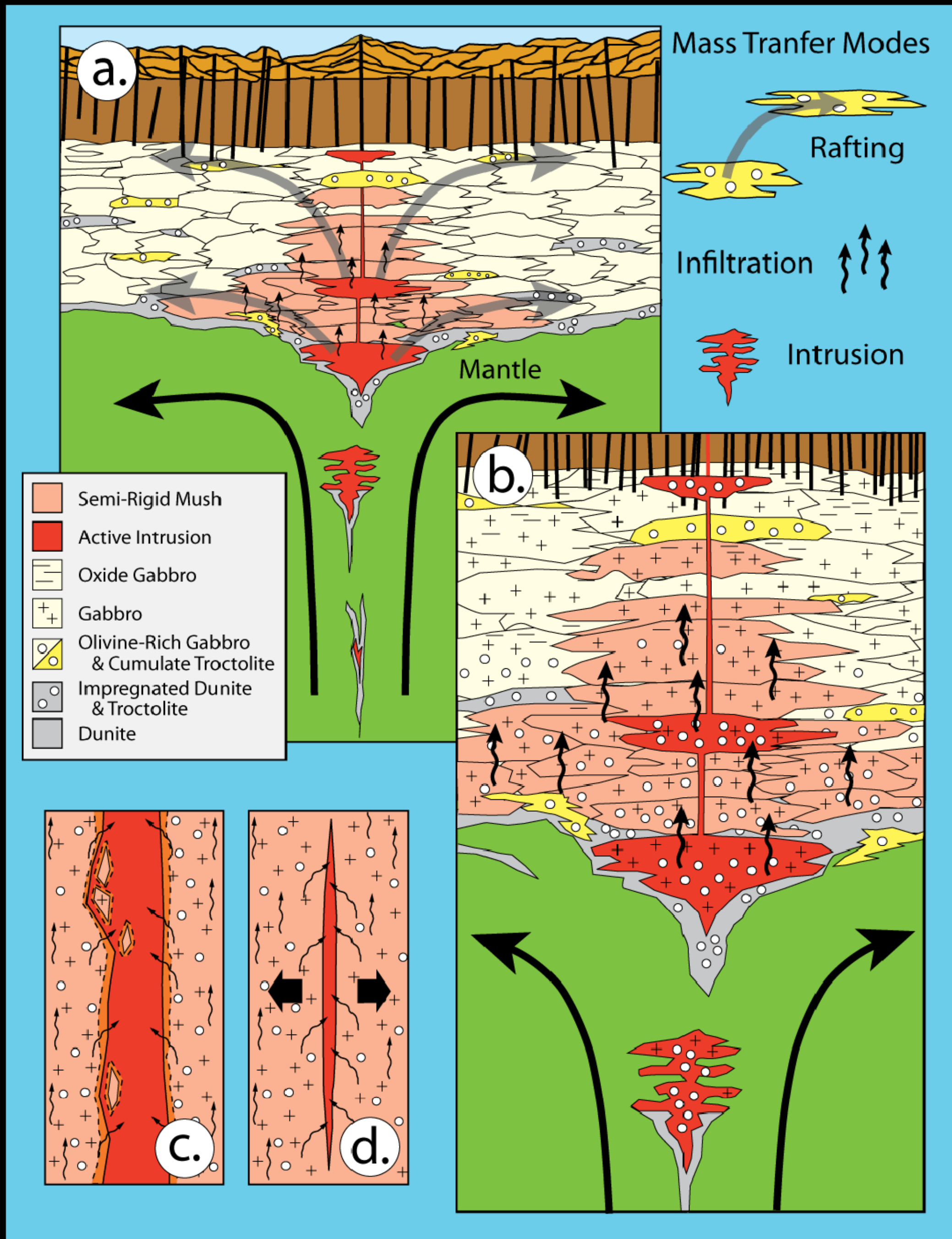
Slickensides & Shingle Structure on Fa

Sheeted Dikes

Sheeted Dikes

Rafting

Building the lower crust from the base Up


a.
Mass Tranfer Modes
Rafting
Infiltration
Intrusion
Mantle
Semi-Rigid Mush
Active Intrusion
Oxide Gabbro
Gabbro
Olivine-Rich Gabbro
& Cumulate Troctolite
Impregnated Dunite
& Troctolite
Dunite
b.
c.
d.