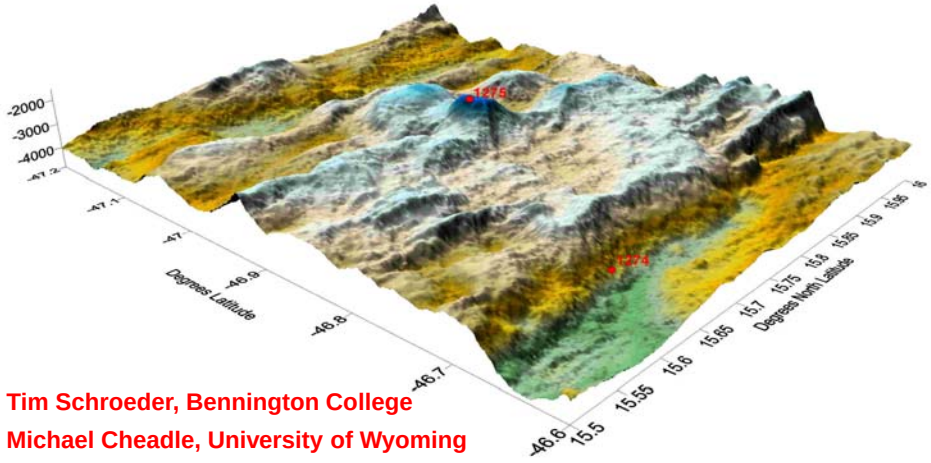
Oceanic core complexes and detachment faults: Can you have one without the other?



Tim Schroeder, Bennington College
Michael Cheadle, University of Wyoming
Wolfgang Bach, University of Bremen
Niels Jöns, University of Bremen

Acknowledgements:

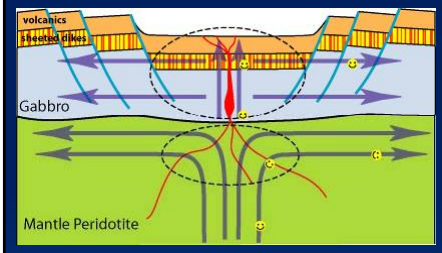
- ODP Leg 209 Scientific Party

  Especially the structural geology group: Dr. Mike Cheadle (University of Wyoming), Dr. Henry Dick (Woods Hole), Dr. Ulrich Faul (Boston University), and Dr. Jack Casey (University of Houston)

- Ocean Drilling Program Shipboard Technical Staff
- *JOIDES Resolution* Crew
- Dr. Toshiya Fujiwara (JAMSTEC)

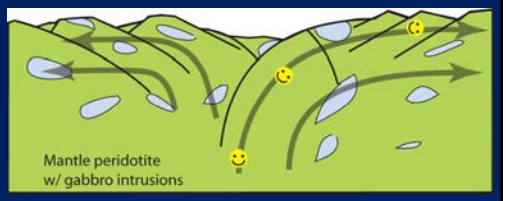
Background: Non-volcanic ridges:

Volcanic Ridge



- Magmatism builds crust
- Mantle corner flow by distributed deformation beneath magmatic crust

Non-Volcanic Ridge



- Little shallow magmatism – plate accreted by tectonic denudation of mantle
- Extensional faults accommodate spreading
- Wherever peridotite/gabbro exposed, the seafloor must be a fault surface
- Corner flow in shallow lithosphere; localized deformation
- Associated w/ Oceanic Core Complexes

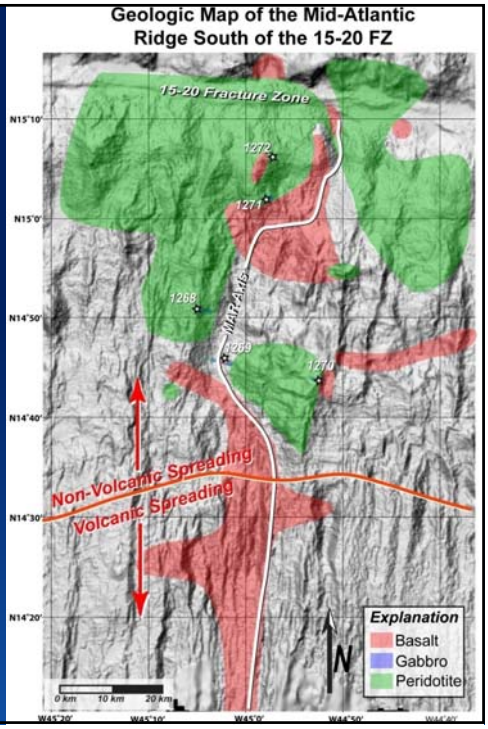
Mid-Atlantic Ridge near the 15-20 Fracture Zone:

- Extensive region of non-volcanic spreading
- Clear boundary between volcanic and non-volcanic spreading regions
- Widespread mantle exposure

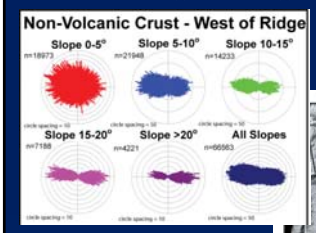
Why does this happen? One idea…

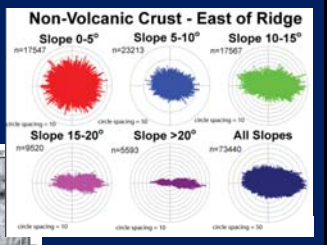
Ridge cooled by old plate across transform

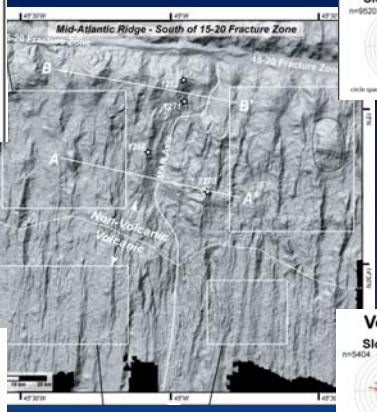
thickens mantle lithosphere and inhibits magma ascent to ridge axis

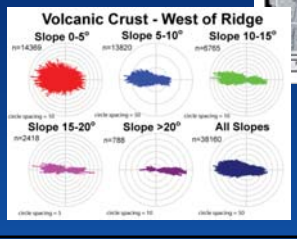


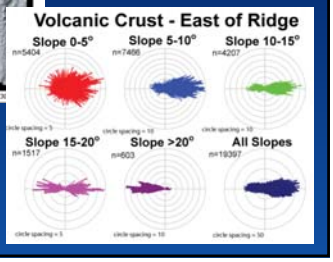
Slope aspect analysis



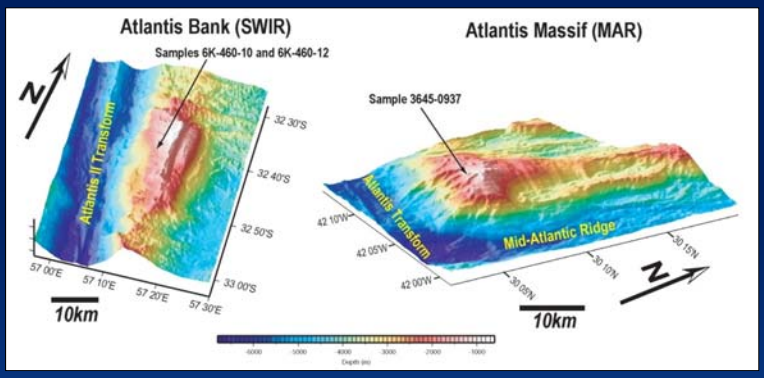




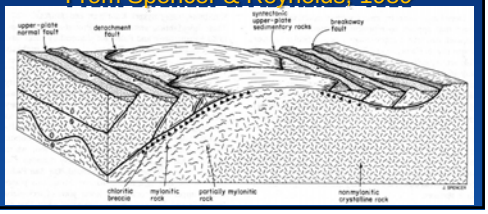




Oceanic Core Complexes are found along non-volcanic ridge segments

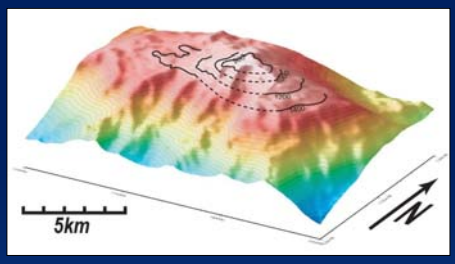


From Spencer & Reynolds, 1989



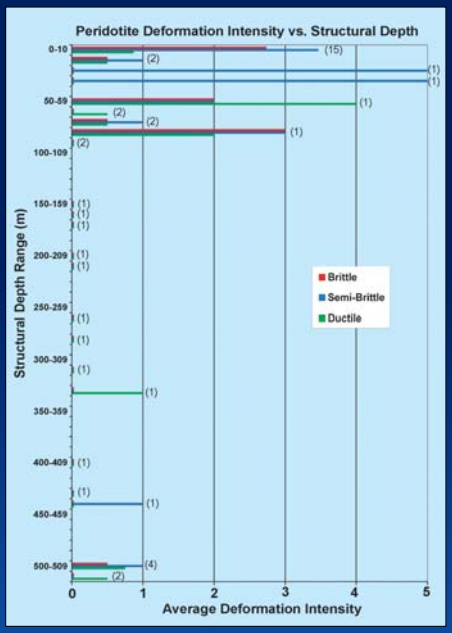
Domal massifs of gabbro & peridotite with surface corrugations; thought to be analogous to continental MCC's

Are OCC's capped by detachment faults?

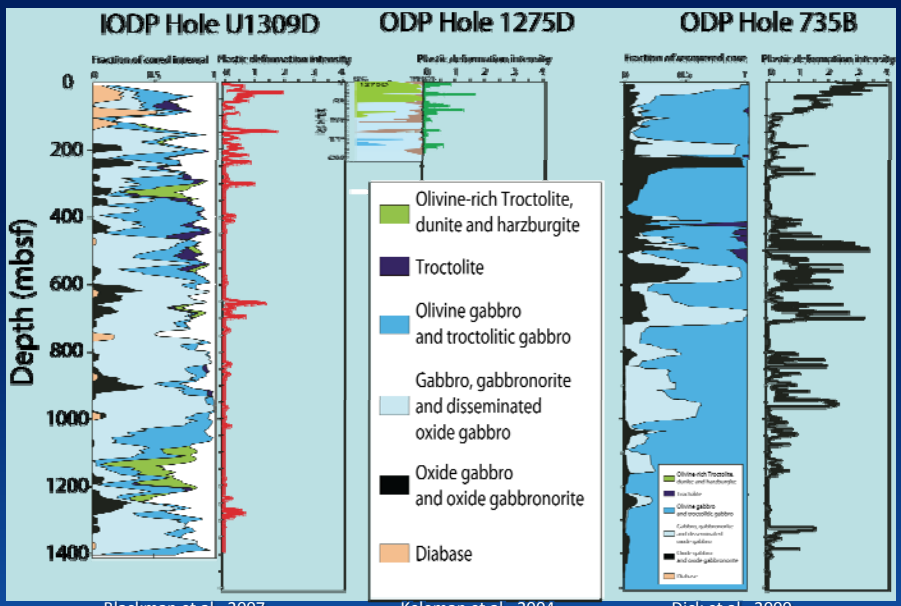


It would seem so…

Reconstructed "paleo-depths" of samples collected from the Atlantis Massif landslide headwall show strong localization of deformation near the domal surface



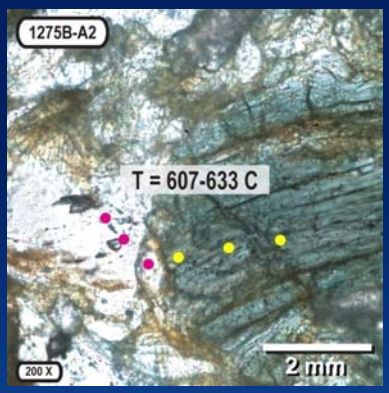
The three drilled oceanic core complexes show similar patterns



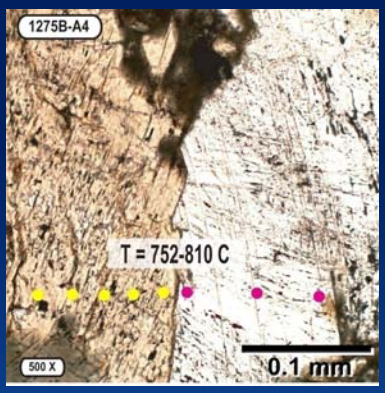
Blackman et al., 2007 Keleman et al., 2004 Dick et al., 2000

Characteristics of detachment faults capping OCC's:

Strain localization at amphibolite to granulite facies progressively overprinted & cut by lower-temperature deformation fabrics



Amphibole-Plagioclase thermometry indicates strain localization at 600-700°C

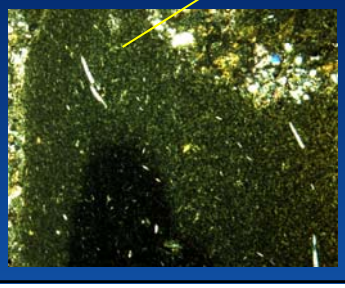


Undeformed amphibole-plagioclase pairs equilibrated 750-850°C

Characteristics of detachment faults capping OCC's:

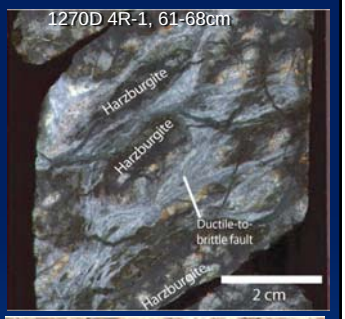
Oceanic detachment faults contain numerous intrusions of evolved melt and/or melt-derived hydrothermal fluids

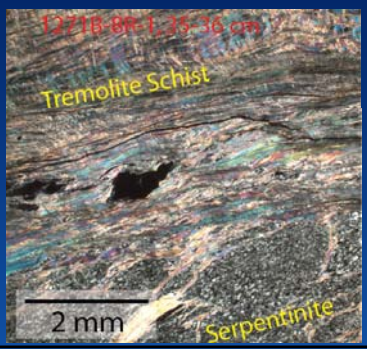
Diabase intruded the active detachment fault at ODP Site 1275 on the M.A.R.

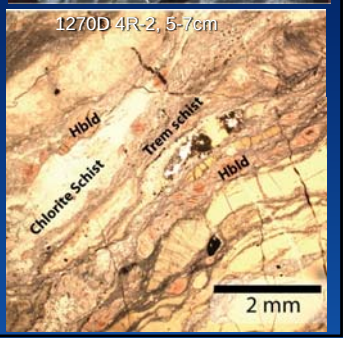


Characteristics of detachment faults capping OCC's:

- Mixing of evolved melt and peridotite in detachment faults produce rocks of hybrid mantle-crust composition
- Tremolite-chorite +/- talc schists with accessory Fe-Ti oxides, apatite, and zircon
- Similar to "blackwall" assemblages in ophiolites
- REE in amphiboles are ~300 x chrondrite (flat REE slopes)

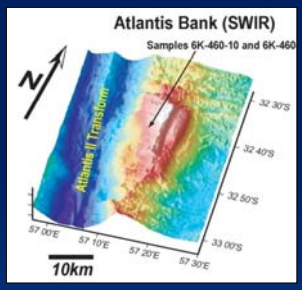


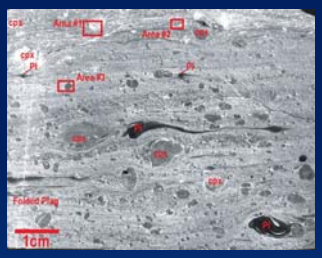




An interesting parallel with continental core complexes:

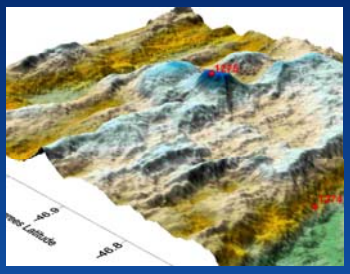
- Wide variability in footwall rheology between individual OCC's, but same overall fault geometry (& surface morphology)

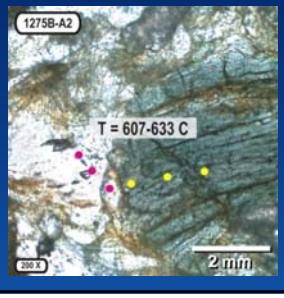




Granulite Ultramylonite

Strain localization at >900°C

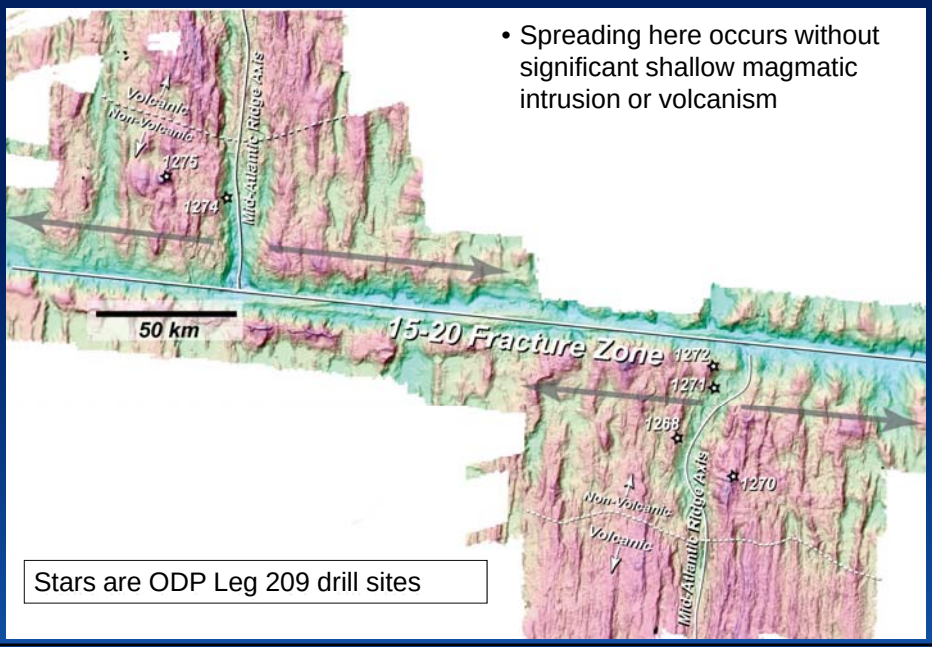




Amphibolite Cataclasis

Strain localization at ~650 to 700°C

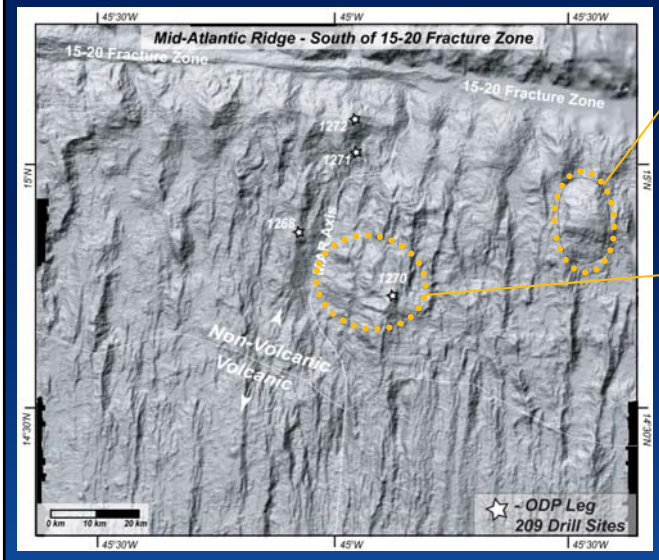
ODP Leg 209: A close look at a region of non-volcanic spreading



- Spreading here occurs without significant shallow magmatic intrusion or volcanism

Stars are ODP Leg 209 drill sites

South of the 15-20 Fracture Zone:



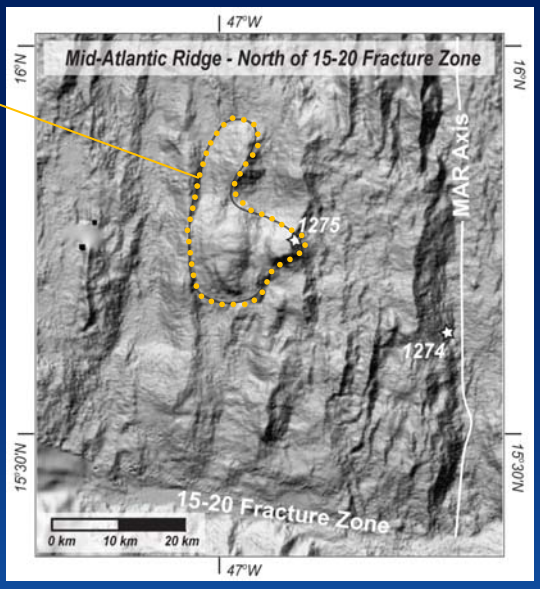
Clear oceanic core complex

Corrugated detachment fault cut by later generations of faulting

North of the 15-20 Fracture Zone:

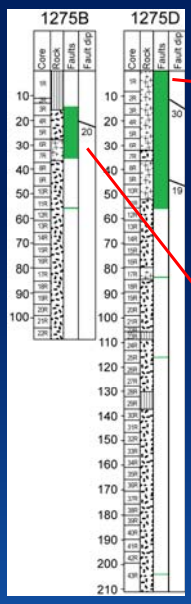
Clear oceanic core complex
Drilled at Site 1275

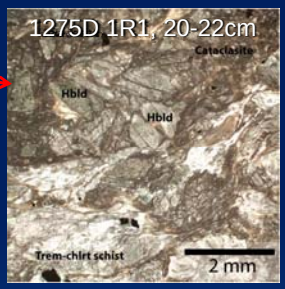
Only 3% of the "non-volcanic" seafloor near the 15-20 FZ are corrugated, domal core complexes



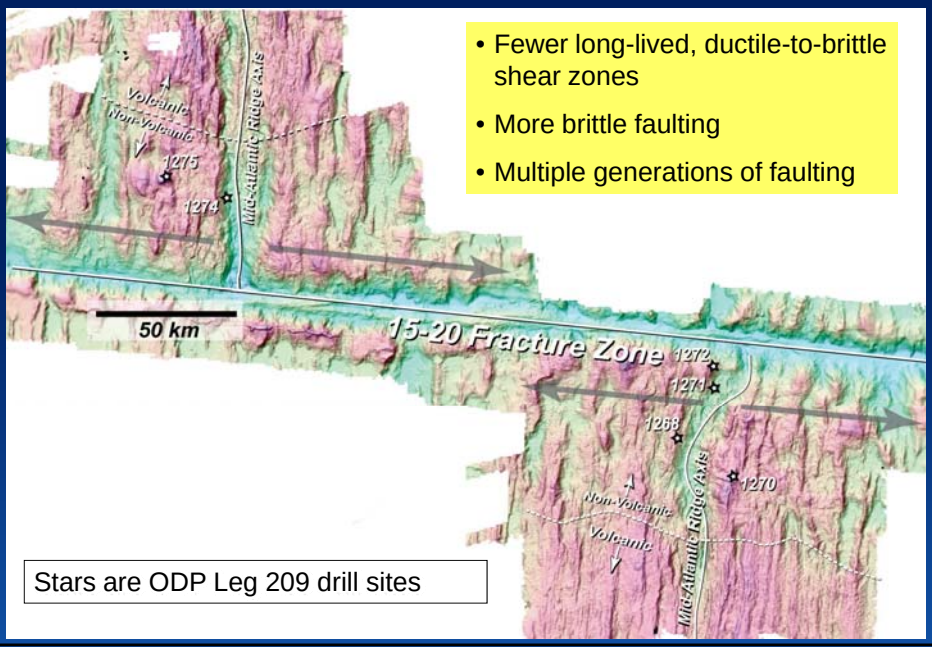
ODP Leg 209: Results From Site 1275 Core Complex:

- Dominantly gabbro and troctolite
- Faults rocks contain fragmented diabase; injected during deformation
- Protomylonite, cataclasite, and tremolite/talc schist
- Detachment fault active from ~700°C to < 300°C





ODP Leg 209: Drilling at “non-core complex” sites



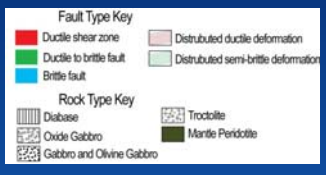
- Fewer long-lived, ductile-to-brittle shear zones
- More brittle faulting
- Multiple generations of faulting

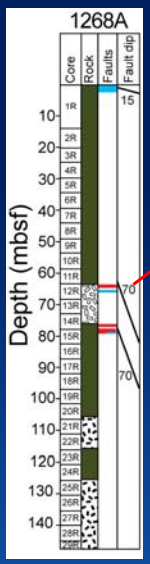
Stars are ODP Leg 209 drill sites

ODP Leg 209: Results From Non-Core Complex Sites:

Ductile Shear Zones:

- Active from ~900-700°C
- Syntectonic granulite mineral assemblages (many overprinted by static greenschist alteration)
- Most localized on gabbro intrusions



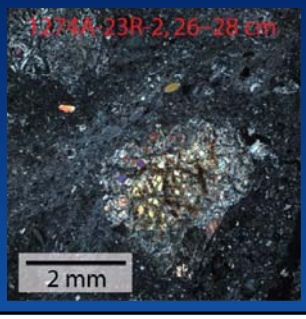


1268 14R3, 19-30cm

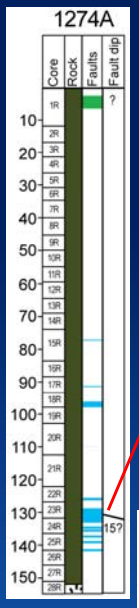
ODP Leg 209: Results From Non-Core Complex Sites:

Brittle Faults; sites 1272 and 1274:

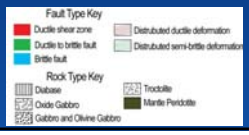
- Non-cohesive gouge or cataclasite
- Serpentine gouge with olivine porphyroclasts
- Lack the “hybrid” crust-mantle mineral assemblages of detachment faults
- Rocks from sites with extensive brittle faults contain O and S isotopes indicating dominantly low-T (<150°C) alteration (Alt et al., 2007)



Olivine porphyroclasts in serpentine gouge from Site 1274



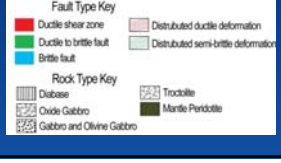
1274A 23R-2, 18-40 cm

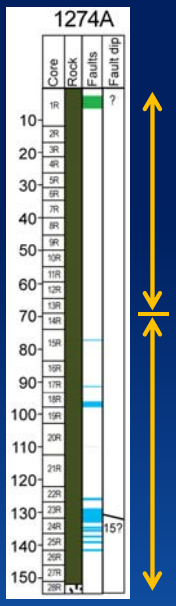


ODP Leg 209: Results From Non-Core Complex Sites:

Brittle Faults & Alteration at 1274

- Upper half of hole contains the most fresh peridotite recovered during leg 209 (60-70% altered)
- Interval with abundant fault gouge intervals have much higher degree of alteration (80% to 100%)





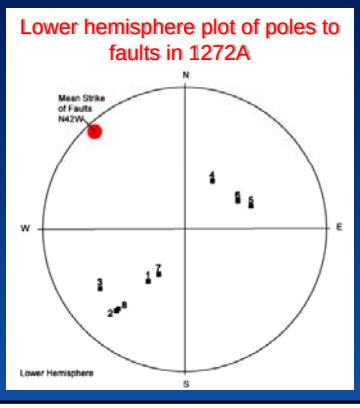
- 60% to 70% alteration
- Alteration dominantly by oxidation in presence of seawater at <150°C

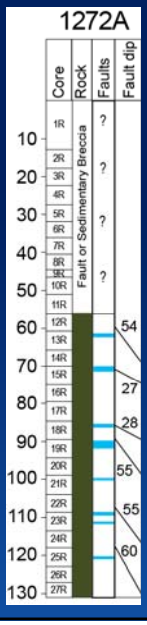
- 80% to 100% alteration
- Alteration at higher temperatures than upper portion of hole (~200°C) and under somewhat more reducing conditions

ODP Leg 209: Results From Non-Core Complex Sites:

Brittle Faults at Hole 1272A: Too many faults in all the wrong orientations

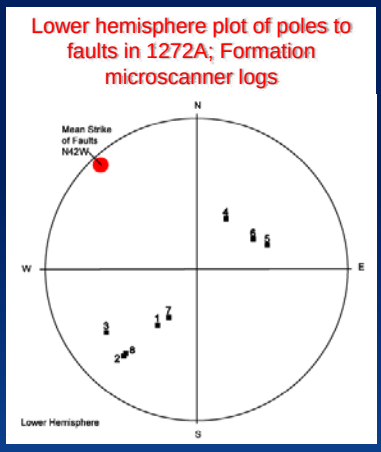
- Upper 55 m of hole is a carbonate-matrix breccia – landslide or tectonic???
- Lower half of hole contains abundant brittle fault zones; non-cohesive and semi-cohesive serpentinite gouge
- Faults have "anomalous" orientations

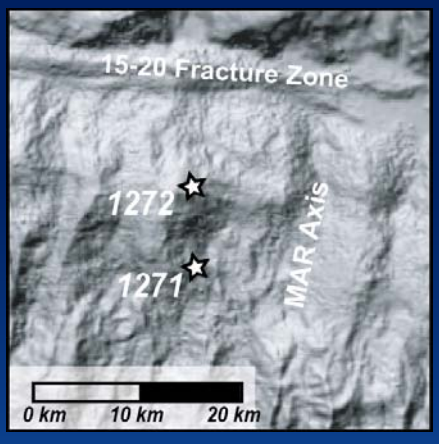




ODP Leg 209: Results From Non-Core Complex Sites:

Faults logged in Hole 1272A have no surface bathymetric expression



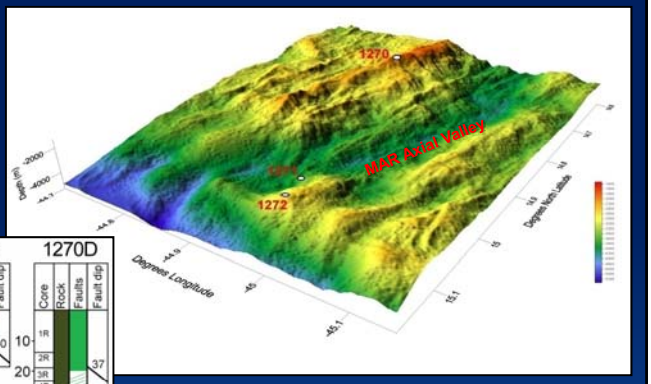


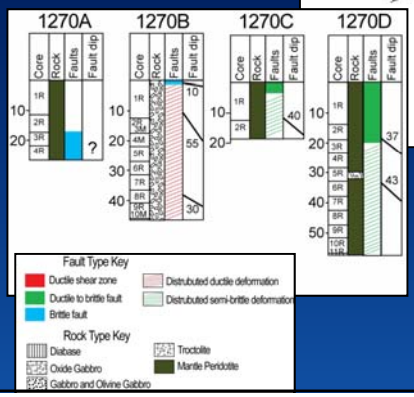
- Logged faults represent early activity – cut and/or rotated by later faults
- Site bathymetry was formed by later a fault generation(s)

ODP Leg 209 Site 1270: Is this a core complex???

Site 1270:

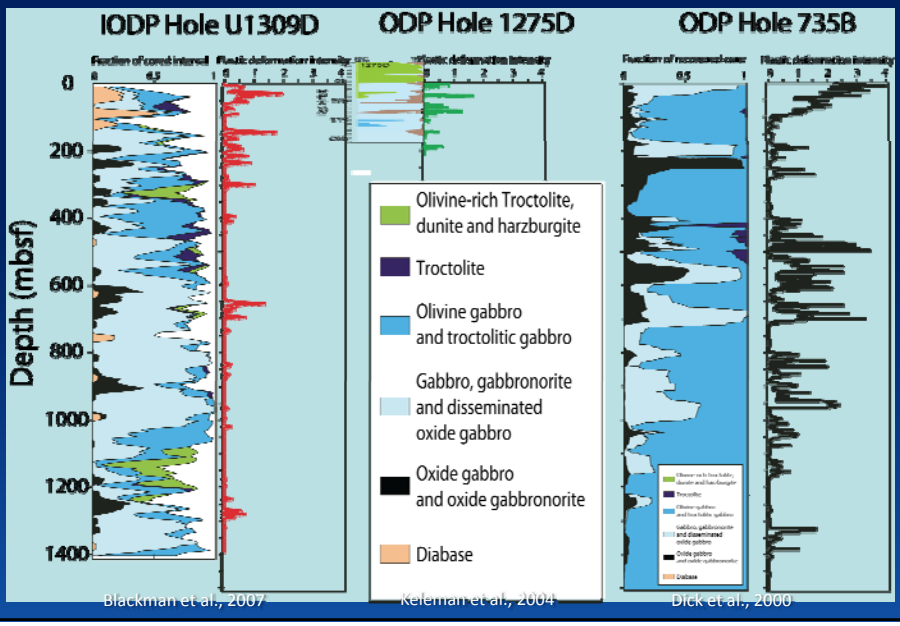
The slope from the axial valley to site 1270 most likely is a long-lived “detachment” fault





- The massif is “sort of” corrugated
- The four shallow holes contain many faults – some of which have significant melt infiltration with strain localization at high temperatures
- Detachment is cut by secondary faults

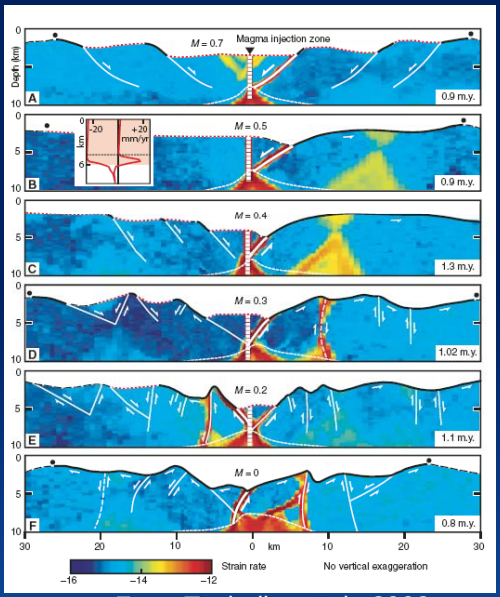
Super-generalization: The three drilled oceanic core complexes are mostly gabbro and have “simple” faulting patterns



Wrap-Up:

Is there a correlation between large gabbro intrusions and oceanic core complexes during dominantly non- magmatic spreading?

Modeling by Tucholke et al., (2008; *Geology*) suggests that oceanic core complexes form when approx. ½ of spreading is accommodated by magma intrusion vs. faulting

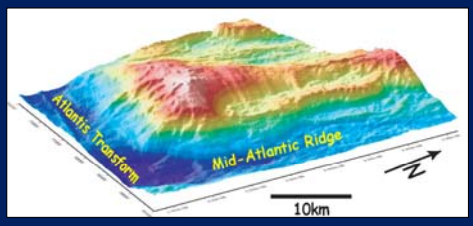


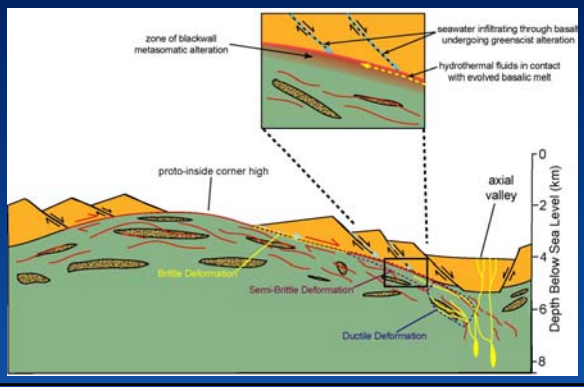
From Tucholke et al., 2008, *Geology* (Figure 2)

Wrap-Up:

Oceanic core complexes represent a special case of non-volcanic spreading;

OCC's may form when detachment faults are localized into a magma chamber beneath the ridge axis – fault may be the "dike-gabbro transition"

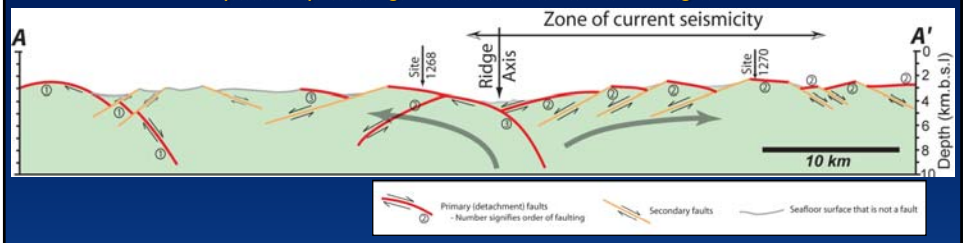




Wrap-Up: The more general case

Non magmatic spreading is accommodated by a complex sequence of faulting, including both long-lived, detachment-style faults (10-20 km displacement) and other faults that may pre- and post-date detachments

Proposed spreading model for the 15-20 FZ region



- Detachment faults dip steeply into the upwelling mantle column and rotate to gentle dip near surface
- Spreading on the opposite side of the ridge from the detachment fault is accommodated by multiple secondary normal faults
- Changing fault "polarity" causes complex patterns and unexpected orientations