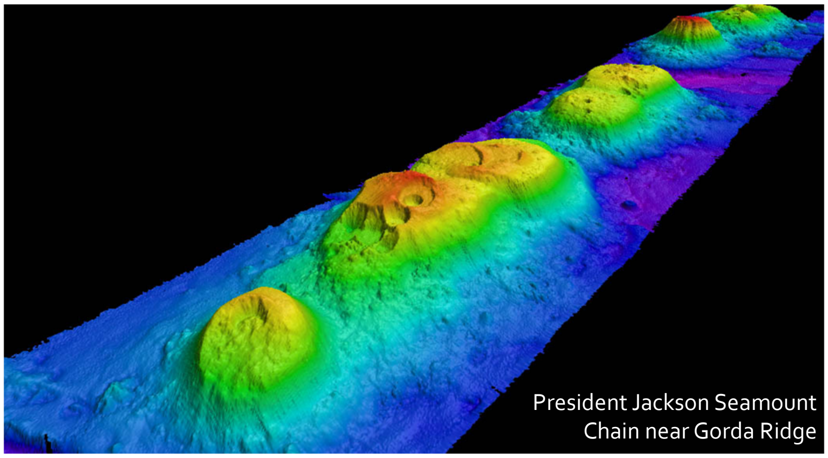
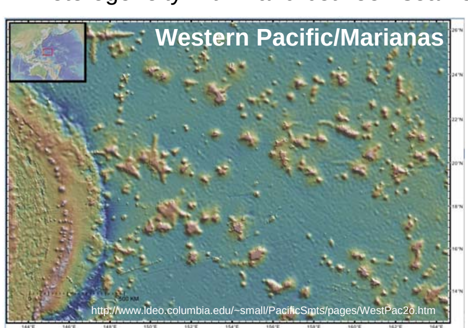
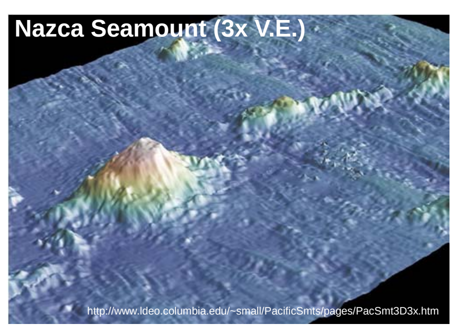
Near-Axis Seamount Volcanism



What are near-axis seamounts?

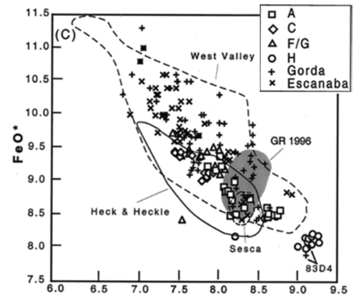
- Volcanic edifices, typically circular to elliptical, that form outside of the axial crustal accretion zone at mid-ocean ridges and backarc spreading centers
- Two main classes:
  - 1) Small ~40-300 m cones, steep outer flanks, can have flat summit or cone shape; short-lived, some form during single eruption; typically distributed widely over the seafloor
  - 2) Larger ~1000-2500+ m seamounts, more complex shapes, cratered summits; longer, more complex histories; often form in linear chains
- Typically start forming ~1-15 km from the axis and continue to grow off-axis, staying active in a zone several times wider, up to ~60-80 km, depending on spreading rate and volcano size
- Compositionally similar to axial lavas, but more primitive and diverse, geochemical heterogeneity within and between seamounts



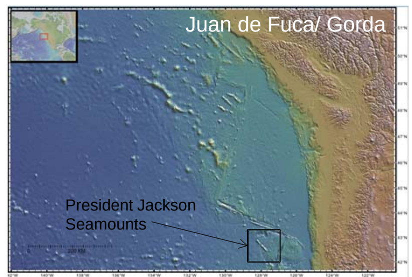


Characteristics of Near-axis Seamounts

- Range in height from ~40 to over 2500 m, typically in the ~100-1000 m range
- Small seamounts greatly outnumber large ones, but large seamounts account for more volume of crust
- Not much info on eruptive styles, but evidence for both effusive and explosive
- Lava composition vs. axial lavas:
  - More primitive (less time spent in crustal magma chamber)
  - Higher MgO (higher temperature)
  - More variable in composition overall
  - Both depleted normal (NMORB) and enriched (EMORB)
- Evolution:
  - Off-axis lava flows begin ~1 km off-axis
  - Seamounts initially form ~1-15 km off-axis
  - Continue growing episodically for ~50-100 kyr to ~3.5 Ma, depending on volcano size
  - Growth slows and volcanism stops within ~6 Ma, often much sooner for small cones

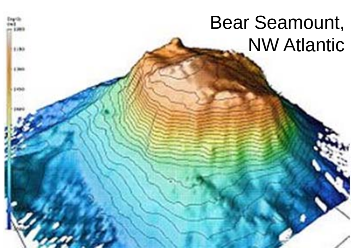


Davis et al., 2000



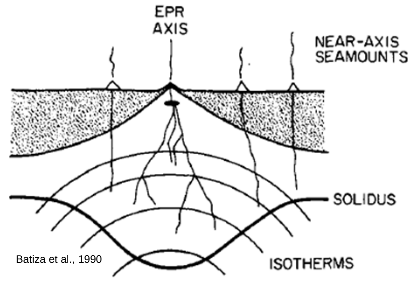
Controls on Seamount Formation

- Overall abundance controlled by variations in regional magmatic budget at both slow- [*Jaroslow, 2000*] and fast-spreading ridges [*Gomez, 2000*]
- Preferentially located near bends or discontinuities in ridge crest where crustal vulnerability is relatively high, and local topographic highs along ridge where local magma supply is high
- Do not appear to be controlled by lithospheric cracking or thermal contraction [*Forsyth, 2005*], but may be localized by fracture zones or other linear discontinuities [*Scheirer, 1995*]
- Seamount chains may be created by moving asthenospheric melt anomalies [*Forsyth, 2005*]; isolated volcanoes likely related to axial upwelling [*White, 1998*]
- Result from shallower melting than axial lavas, potentially from near the cooler edges of the upwelling zone [*Batiza, 1990*]
- Inferred width of zone where volcanoes initially form varies with spreading rate: <4 km for MAR, <20 km for NEPR, <30 km for SEPR, primarily on lithosphere <0.2 Ma age (<4-6 km brittle thickness), regardless of spreading rate [*White, 1998*]

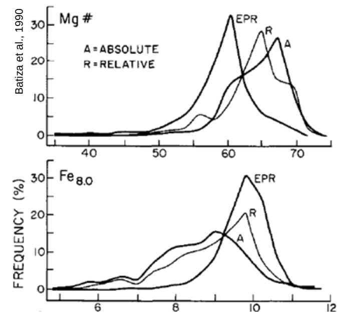


Importance of Near-Axis Seamounts

- Major element variability in MORB was initially assumed to result from mantle temperature and spreading rate variations, rather than actual heterogeneity within the mantle source
- Under ridges, source heterogeneity is largely erased through mixing in sub-axial crustal magma chambers
- Near-axis seamounts and cones bypass this zone of mixing and tap the mantle directly in small volumes, largely preserving the source heterogeneity and giving insight into the nature and scales of mantle heterogeneity
- These features cover a larger percentage of seafloor than any other submarine volcanic structures



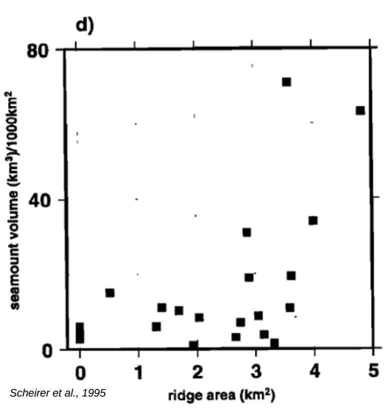
Batiza et al., 1990



Batiza et al., 1990

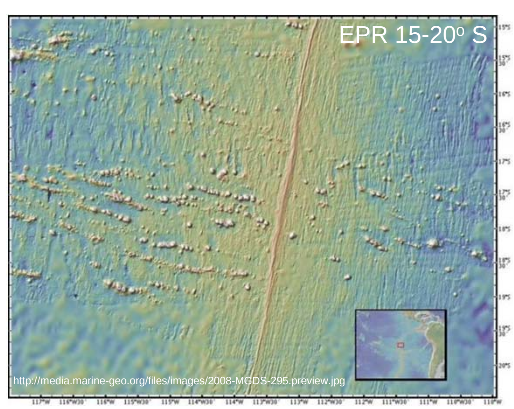
MOR Seamounts: Intermediate to Fast Spreading

- Overall abundance and volume correlates with spreading rate, intermediate (JdFR, ~60 mm/yr) has lower abundance than NEPR (~100-115 mm/yr), which has lower abundance than SEPR (up to ~150 mm/yr) [*Scheirer, 1995*]
- Largest seamounts and densest clustering associated with shallowest and broadest parts of ridge (highest local magma supply)
- Large seamounts tend to form linear chains, while smaller seamounts are more randomly distributed



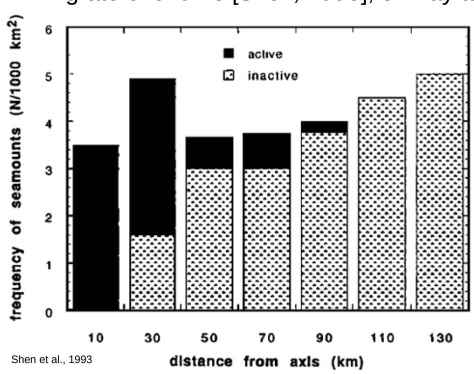
Scheirer et al., 1995

Seamount vol vs Ridge area EPR 8-17º N

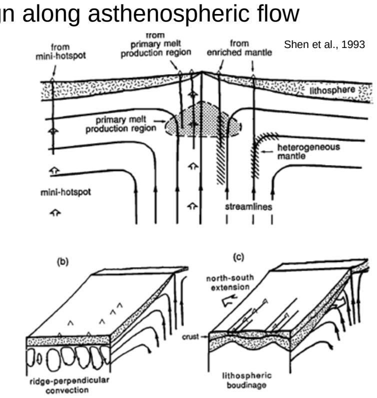


MOR Seamounts: Super Fast Spreading

- EPR 15-20^{o} S [*Shen et al., 1993, White et al., 1998*]:
  - Widest zone of active off-axis volcanism, recent (<100 kyr) lava flows identified as far as ~80 km from axis
  - Lava flows and volcanic debris around seamounts covers ~40-50% of seafloor, total volume of extruded off-axis material is ~1.5-2.2% of crustal volume
  - Decreasing volcanism away from axis, unknown whether due to increasing distance from axial upwelling or decreasing lithospheric vulnerability
  - Linear chains imply discrete sources in mantle that are active >1.8 my, which may migrate over time [*Shen, 1993*], or may align along asthenospheric flow



Shen et al., 1993



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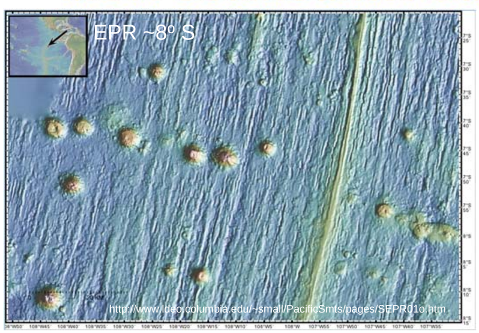
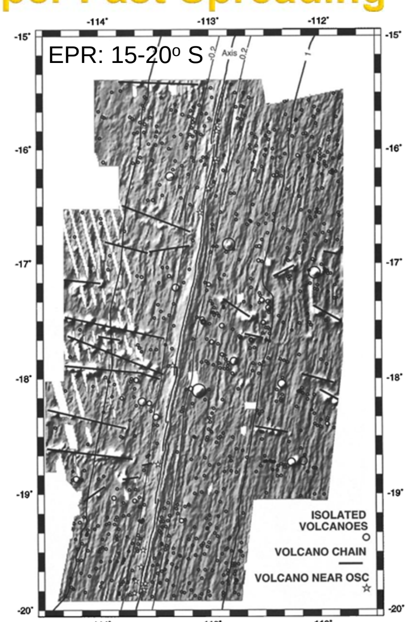
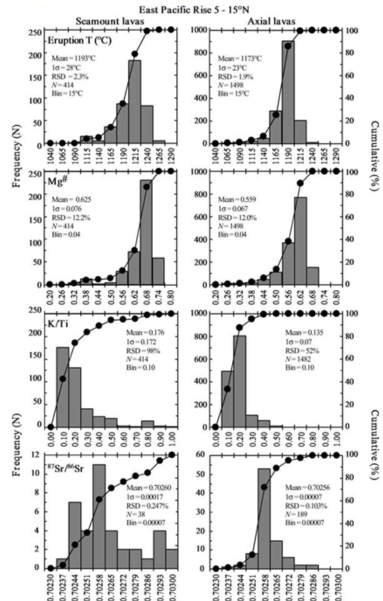




MOR Seamounts: Fast Spreading

- EPR 5-15º N [*Niu et al., 2002*]:
  - Lavas vary from extremely depleted tholeiites to highly enriched alkali basalts
  - Greater range of depletion and enrichment than known seafloor lavas in terms of incompatible elements
  - Results imply long term (>1 Ga) lithological heterogeneities on very small scales in EPR mantle source
  - Enriched component seems to be dispersed as physically distinct domains (diapirs?) within a more depleted matrix
- EPR 9º N [*Alexander et al., 1996*]:
  - Small cones cover 7-11% of seafloor, .02-.03% of crustal volume
  - Larger seamounts (>200 m) cover 6% of seafloor, .3-1% of crustal volume
  - Large and small features compete for magma supply, smaller features are "leakage" around larger edifices, small features stop growing beyond ~10 km when plumbing for large features matures and "leakage" stops

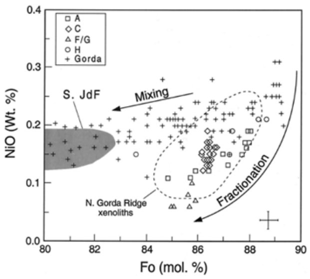


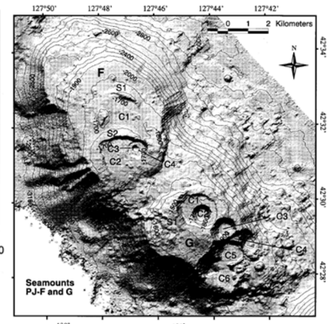
Comparison of axial vs. seamount lavas EPR 5-15º N [*Niu et al., 2002*]

MOR Seamounts: Intermediate Spreading

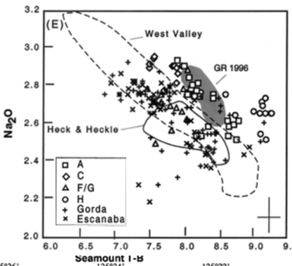
- Not nearly as much info as EPR seamounts, mostly focus on large chain-forming volcanoes along Juan de Fuca [*Clague et al., 2000*] and Gorda Ridges [*Davis et al., 2000*]
- Volumes range from 11 to 187 km^3, diameter from ~3-10 km, and height from ~500-2000 m for the surveyed chains
- President Jackson seamount chain (Gorda):
  - Lava compositions range from highly depleted to moderately enriched MORB
  - Higher MgO than axial lavas
  - Phenocrysts in equilibrium with melt and rare zoning indicate short residence time in crustal magma chambers
  - Often have multiple nested calderas and pit craters, implying episodic melt supply on time scale of 1000-10,000 yrs between eruptions
- Vance Seamounts (Juan de Fuca):
  - Some edifices are cut by ridge-parallel faults, implying formation within ~30-40 km of axis
  - Faults are interpreted as the pathway for seamount lavas to the seafloor
  - Seamounts must have magma chambers because calderas exist, but melts must pass through quickly to retain primitive character
  - Magma chamber volumes similar to HI volcanoes: ~3-5 km diameter, ~3 km^3 volume, 0.8 to 3 km below the seafloor
  - Chains are oblique to spreading direction and plate motion, align with asthenospheric flow
  - Lifespan of volcanoes is ~75 to 95 kyr (much shorter than EPR, based on asthenospheric flow rates, seems too short to construct a large edifice)

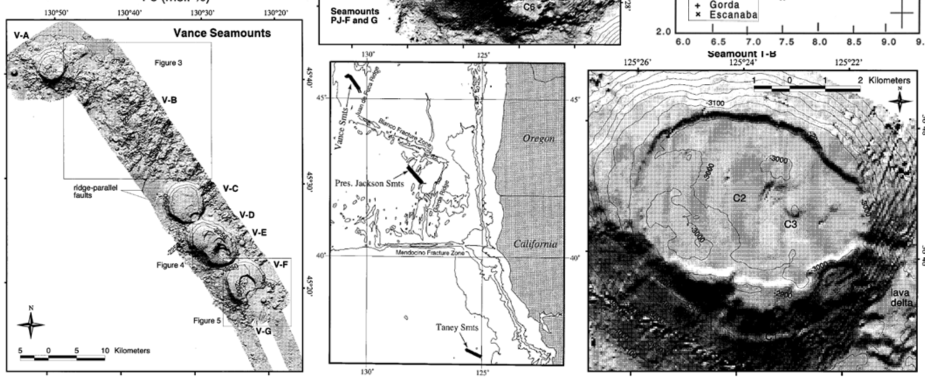
MOR Seamounts: Intermediate Spreading





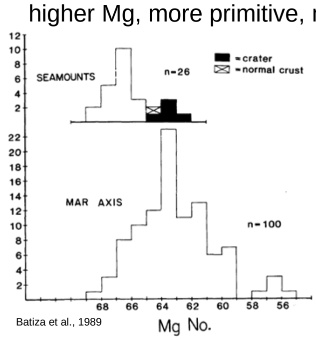
Figures from *Clague et al., 2000* and *Davis et al., 2000*



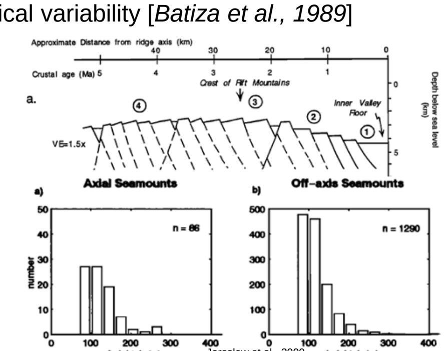


MOR Seamounts: Slow Spreading

- Form and grow within the inner rift valley floor (crust <0.6 Ma), don't appear to remain active more than a few km off-axis [*Jaroslow, 2000*]
- Commonly cut and modified by faulting within ~40 km (~4 m.y.) of axis, some major faults may even nucleate within the volcanoes
- Seamount population density generally correlates with crustal thickness, suggesting that local variations in magma supply control seamount abundance
- Seamount production shows temporal variations over m.y. timescales, similar to ridge which goes through tectono-magmatic cycles
- Although they all form in narrow zone around axis, there are still similar contrasts between those forming directly on-axis and those just off-axis as seen along EPR: higher Mg, more primitive, more geochemical variability [*Batiza et al., 1989*]

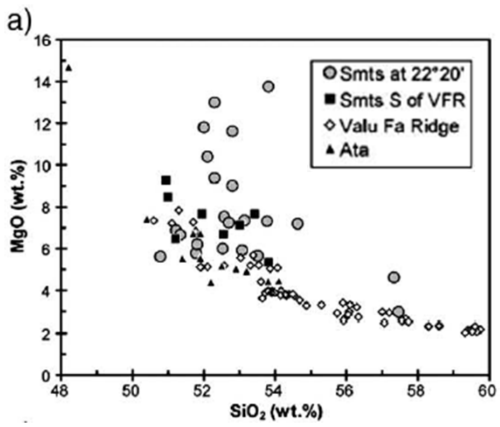


Consistently higher Mg# for seamount lavas indicates that they are more primitive

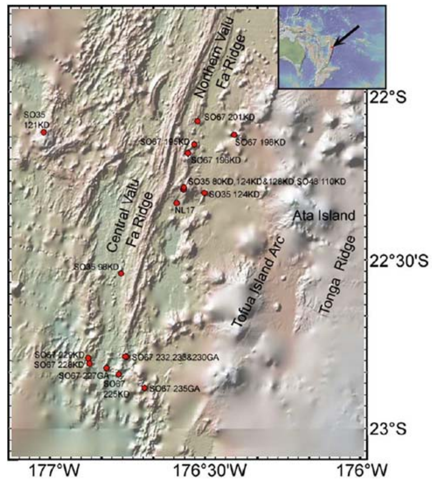


Backarc Seamounts

- Haase et al., 2009 studied seamounts E, W, and S of Valu Fa Ridge (VFR) in the Lau basin, SW Pacific
- South end of VFR is very close to the active arc (~40 km), heavily influenced by water-rich melt feeding nearby arc volcanoes, creating a high relief magmatically robust ridge despite intermediate spreading rates of ~39-60 mm/yr



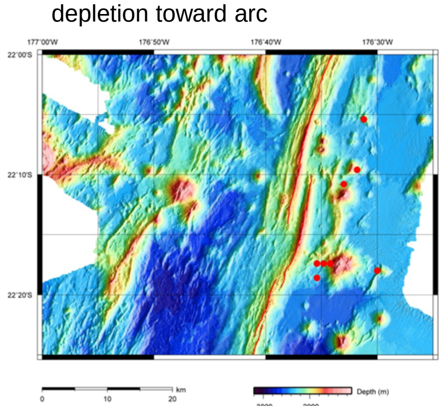
MgO vs SiO_2 showing higher MgO and lower SiO_2 of seamounts, plus greater MgO range of E & W seamounts



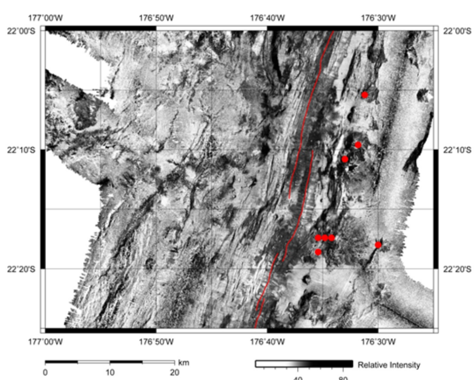
Bathymetry and sample locations, Haase et al., 2009

Seamounts east and west of axis

- Analogous to near-axis seamounts along MOR's:
  - More variable, primitive compositions than axial lavas
  - Separate, small volume plumbing systems under each edifice
- Implies mantle heterogeneity on scale of 5-10 km in the form of small diapirs
- Higher sediment contribution than arc lavas, may be derived from slab-top sediment melting deeper along slab [*Behn et al., 2011*]
- Seamounts W of axis less depleted than axial lavas, consistent with increasing depletion toward arc



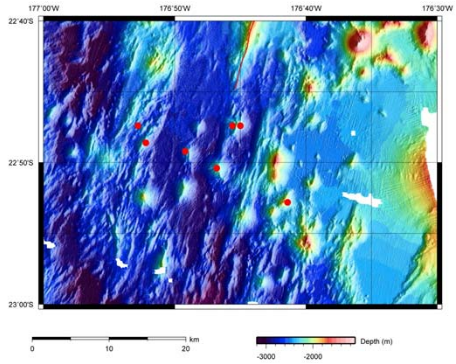
20 m compiled bathymetry plot



20 m sidescan plot

Seamounts south of axis

- Unique to backarc setting, overlie a zone of diffuse spreading before it matures into focused spreading along a single axis
- Similar composition to axial lavas overall, but more enriched
- Similar fabric, termed “ridges and knolls,” can be seen beyond the propagating tips of other backarc spreading centers, including elsewhere in the Lau basin [*Martinez et al., 2006b*]
- Lavas are more primitive and have different characteristics than lavas from normal MOR propagators



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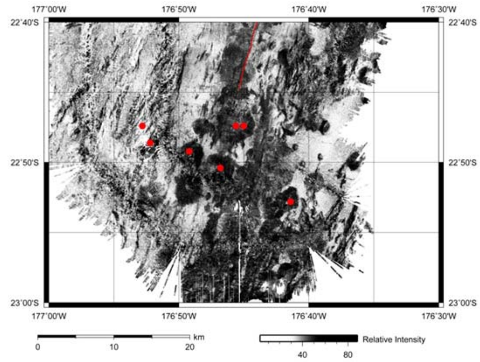

20 m compiled sidescan image

Summary

- Near-axis seamounts bypass the homogenizing processes within the axial magma chamber, allowing us to sample and understand small-scale heterogeneity within the mantle underneath oceanic spreading systems
- Form within a few km of the axis, continue growing to 10’s of km off-axis at intermediate and fast-spreading ridges, only grow within the inner rift valley at slow ridges
- Lavas are more primitive and higher MgO in general, vary between depleted NMORB and enriched EMORB, more variable within and between seamounts than axial lavas
- Seamount production correlates with changes in melt supply at different scales:
  - Spreading rate-related changes in melt supply at the regional to global scale for MOR’s, proximity to volcanic arc controls melt supply in backarc
  - Local changes in melt supply at the first and second-order segment scale: increased toward the center, decreased toward ends, local increases near discontinuities or fracture zones
- Near-axis seamounts in the backarc setting seem to be formed by a similar mechanism to MOR’s

The End…

Areas in need of further study

- Range of eruptive styles, explosive vs. effusive, both?
- Volume of individual eruptions
- Timing/frequency of eruptions
- More age data in general
- Hydrothermal systems/biota
- More seismic data to find extent of low-velocity zone under all types of ridges and its relationship to seamounts