GEOL 102

PETROLOGY

Magma Series

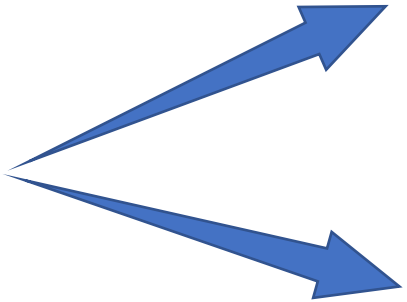
Petrotectonic Associations

Suites of rocks that formed in response to similar geological conditions. These commonly develop at divergent & convergent boundaries, and in hotspots.

1. Divergent Boundaries

Regions where partial melting of ultramafic rock results to basaltic magma

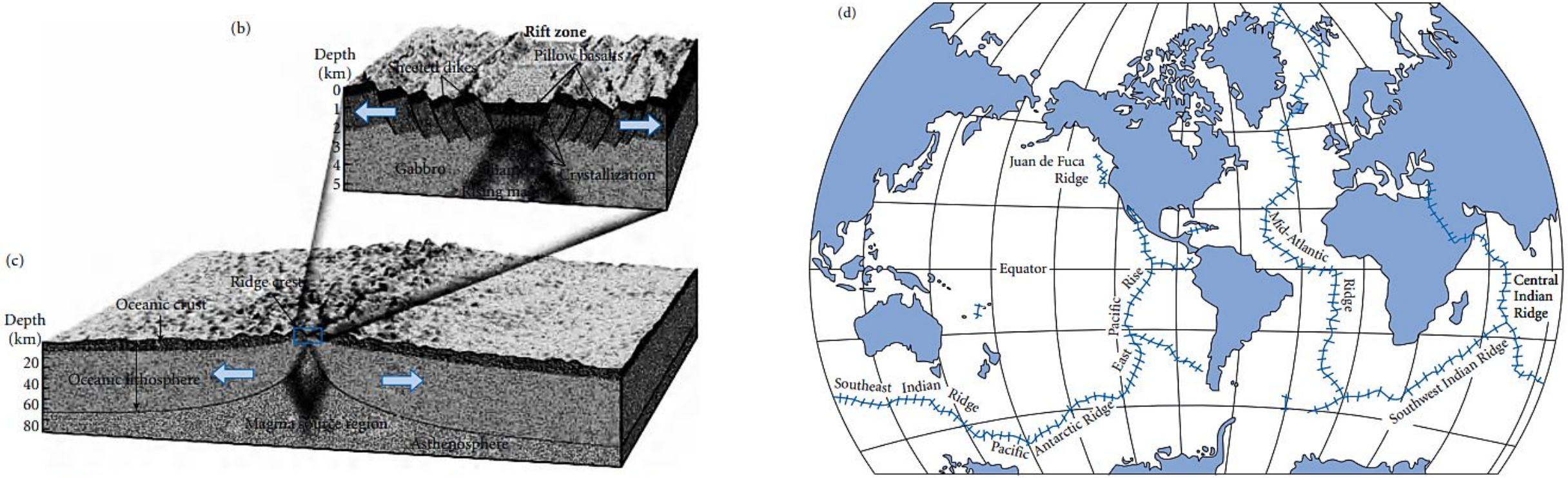
Ultramafic Rock
(Peridotite)



Oceanic Crust
(Basalt)

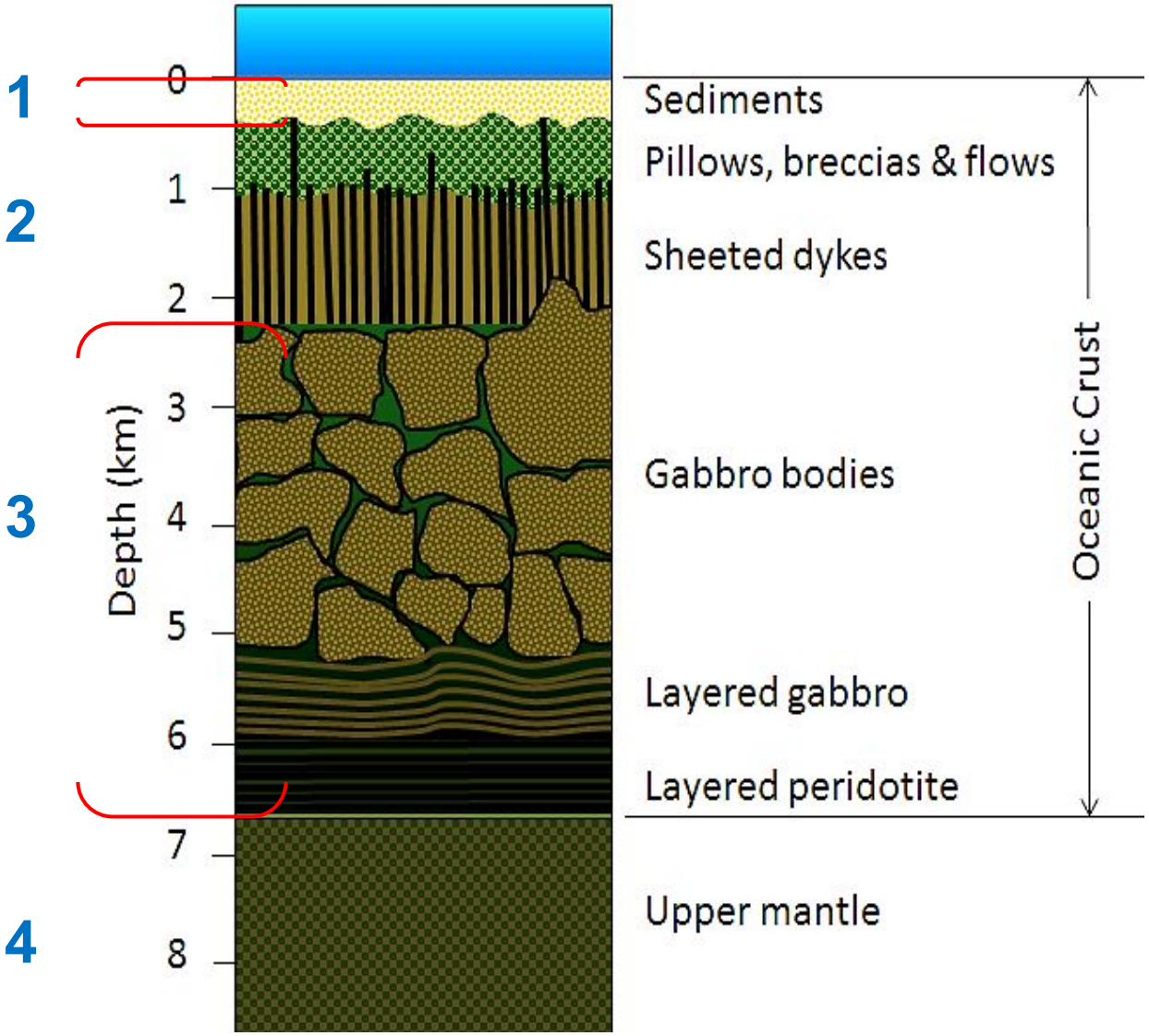
Oceanic Lithosphere
(Residual ultramafic rock)

1. Divergent Boundaries



(b) Cross-section of Divergent boundary, (c) oceanic crust and lithosphere, (d) mid-oceanic ridge systems on Earth

Ocean Crust Cross-Section



Layer 1 = well-stratified marine pelagic sediments

Layer 2 = upper pillow basalt, and lower sheeted diabase dike complex

Layer 3 = upper massive isotropic gabbro, middle cumulate (layered) gabbro, and lower layered peridotite

Layer 4 = non-cumulate metamorphosed depleted mantle peridotite refractory residue

A. Mid-oceanic Ridge Basalts (MORB)

- most abundant volcanic rock
- Tholeiites with low SiO_2 & K_2O but high in MgO, Al_2O_3, and compatible elements (Ni, Cr)
- From partial melting of depleted mantle source (Mantle Lherzolite) from low $^{87}Sr/^{86}Sr$ ratio, low volatile and incompatible element concentration.
- Divided into Normal MORB and Enriched MORB based on minor and trace element abundance

A. Mid-oceanic Ridge Basalts (MORB)

Normal MORB (N-MORB)	Enriched MORB (E-MORB)
Strongly depleted in highly incompatible elements;	Highly abundant in incompatible elements (LREE).
Chondritic La/Sm < 1.8	Chondritic La/Sm > 0.7
MgO > 65%, K_2O < 0.10, TiO_2 < 1.0	MgO > 65%, K_2O > 0.10, TiO_2 > 1.0
partial melting of well-mixed depleted mantle source	partial melting of more fertile mantle source

A. Mid-oceanic Ridge Basalts (MORB)

Where is the “fertile” source of E-MORB?

1. Deeper, more fertile mantle
2. Depleted upper mantle locally fertilized by prior intrusions of magma from deeper mantle
3. Lateral mixing along mid-oceanic ridges with materials from nearby plumes

A. Mid-oceanic Ridge Basalts (MORB)

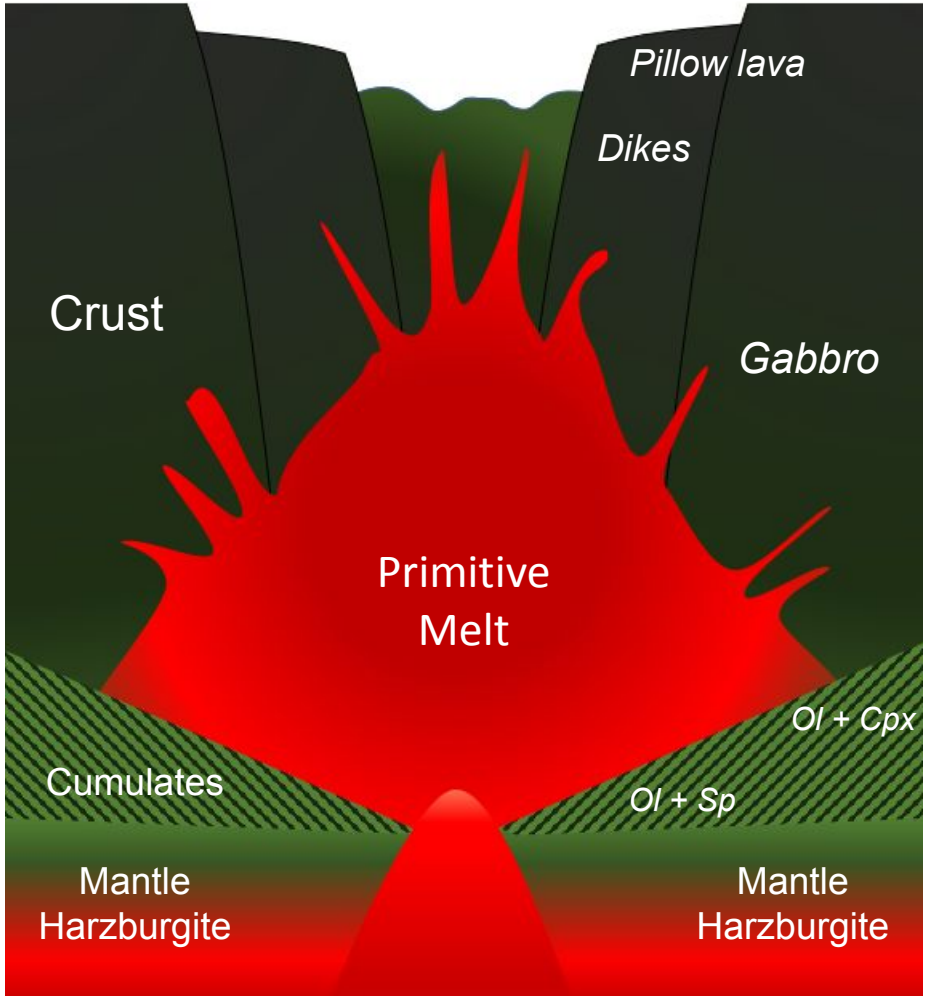
How does MORB form?

- Separation of plates in divergent regions
- Upward motion of mantle into the extended region
- Decompression partial melting associated with near-adiabatic rise
- N-MORB melting initiated at 60-80km depth in upper depleted mantle where it inherits depleted trace element and isotopic character.
- Melt blobs separate at 25-35km depth

A. Mid-oceanic Ridge Basalts (MORB)

How does MORB form?

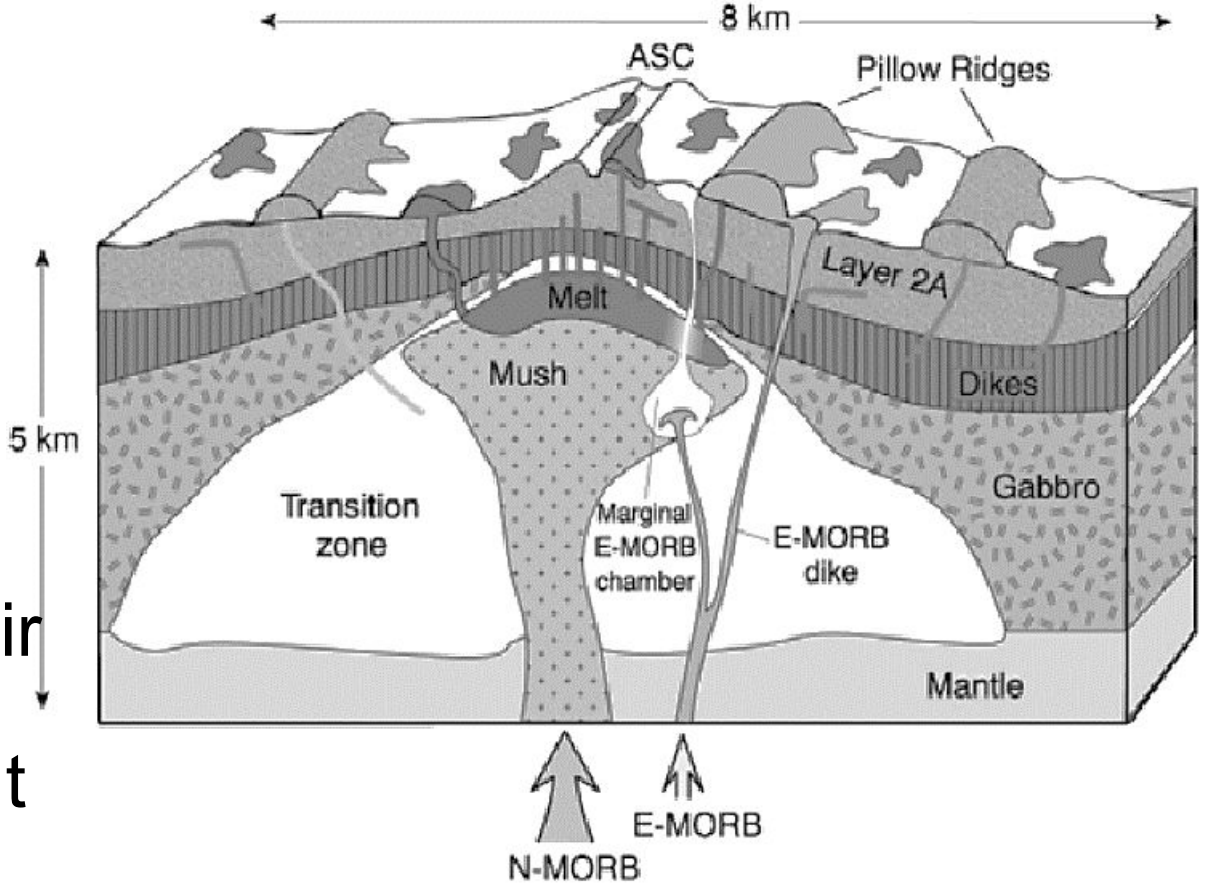
Axial Magma Chamber
(Original model)



A. Mid-oceanic Ridge Basalts (MORB)

How does MORB form?

- Small sill-like magma bodies surrounded by Mush and Transition Zones
- Mush Zones (<30% melt) is continuous with magma reservoir
- Transition Zone have lesser melt



A. Mid-oceanic Ridge Basalts (MORB)

How does MORB form?

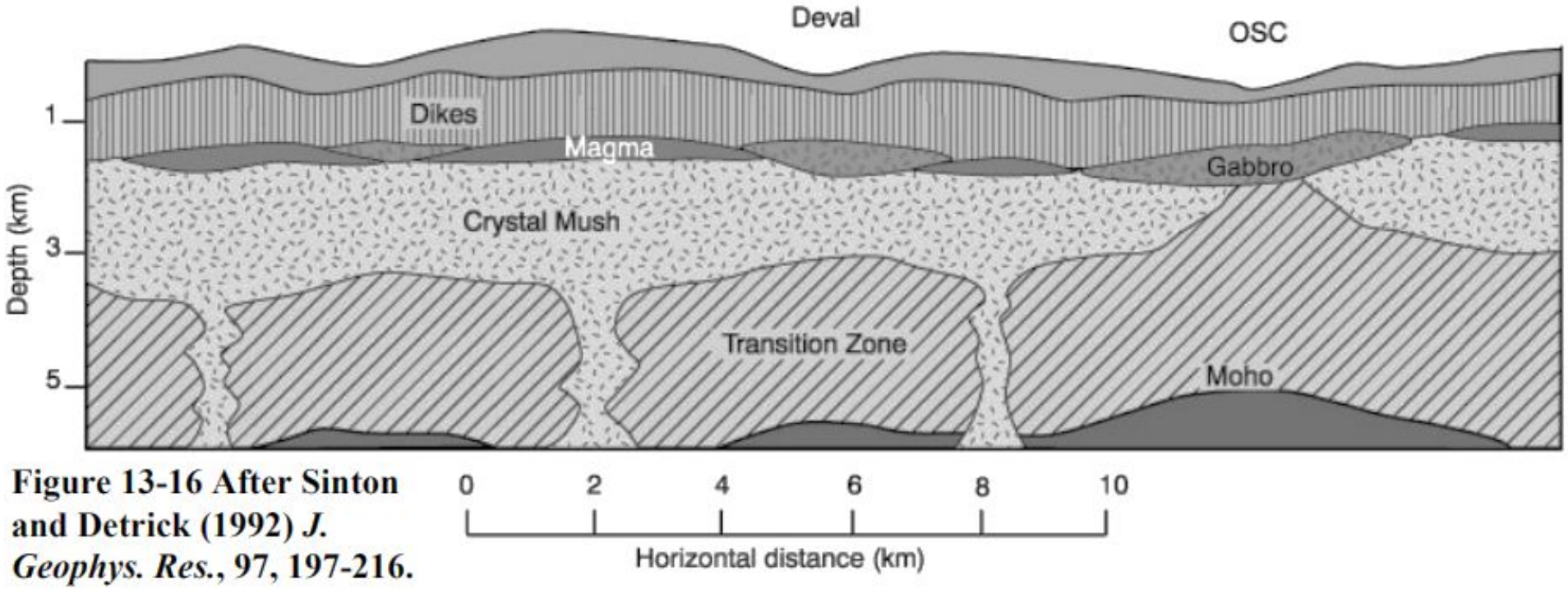
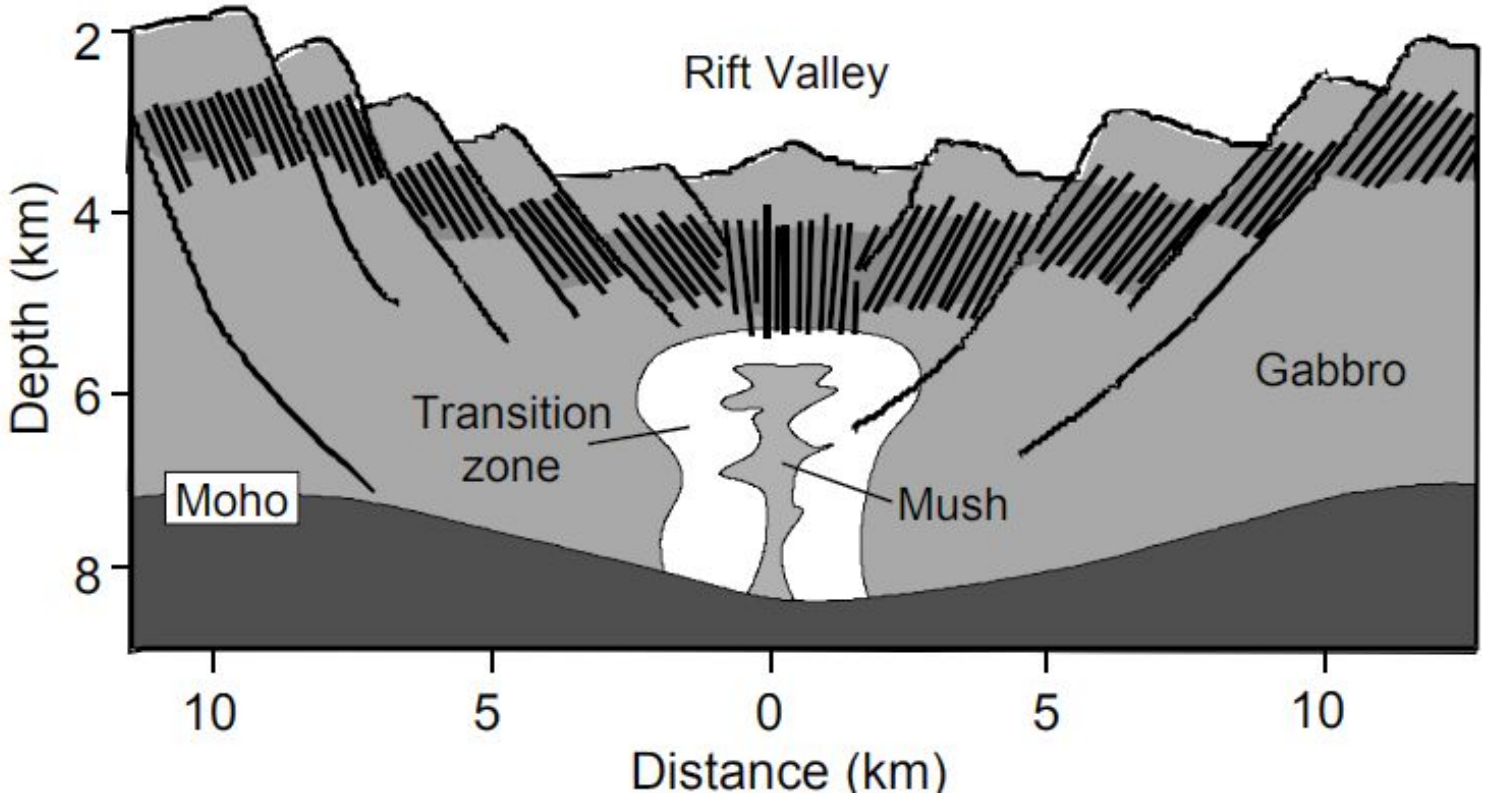


Figure 13-16 After Sinton and Detrick (1992) *J. Geophys. Res.*, 97, 197-216.

A. Mid-oceanic Ridge Basalts (MORB)

How does MORB form?



A. Mid-oceanic Ridge Basalts (MORB)

Other rocks in divergent margins:

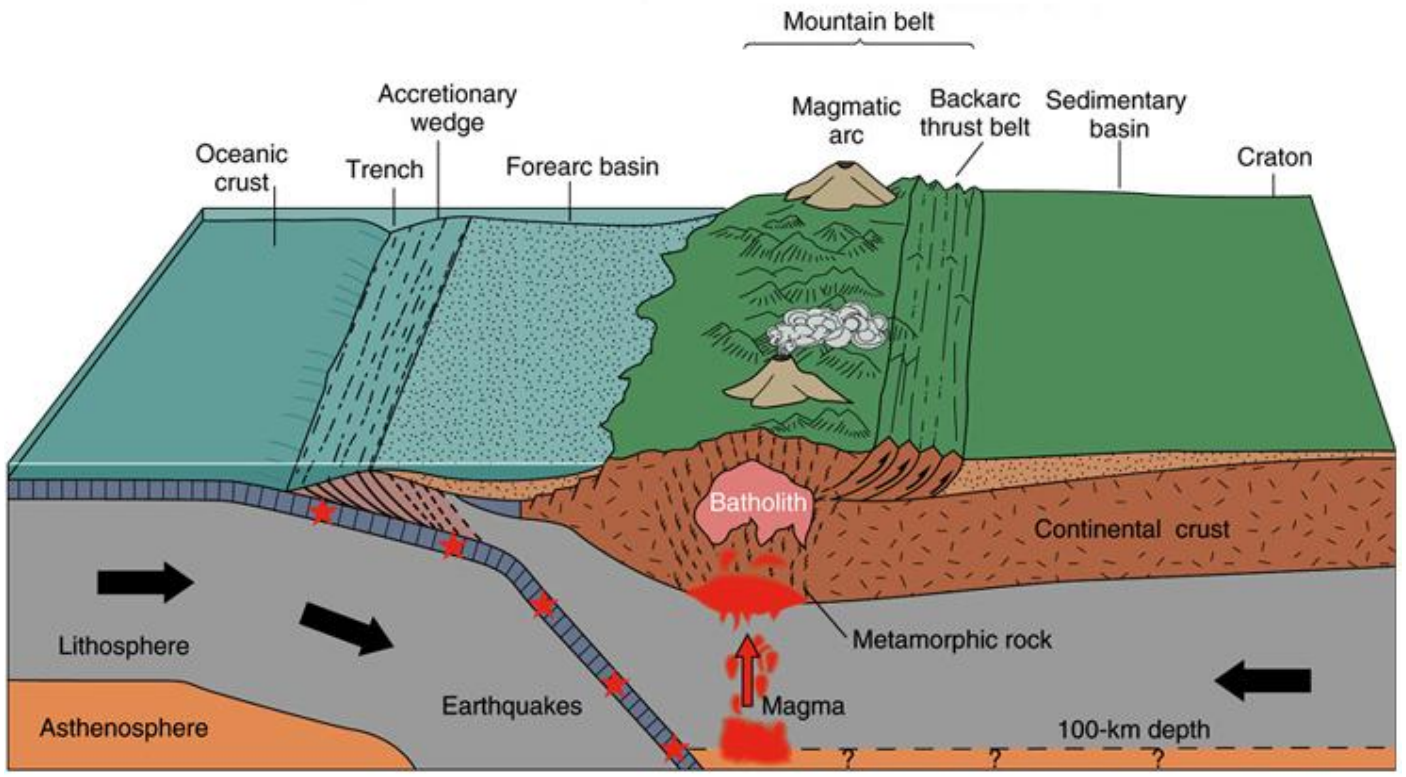
- High aluminum basalts (Al_2O_3 > 16%)
- High TiO_2 (>1.3%) andesitic to rhyolitic volcanic rocks

TRIVIA:

Divergent margins generate the bulk of ocean floor rocks (70% of Earth's area) which are all < 200 MYO.

2. Convergent Boundaries

Magmatism along the trench resulting to both plutonic rocks and volcanic arc rocks



2. Convergent Boundaries

Factors:

Composition and Thickness of overlying plate	• Thin overlying oceanic crust produces metaluminous mafic to intermediate rocks. • Thick overlying continental crust produces peraluminous, potassic intermediate to silicic rocks.
Composition of rock undergoing anatexis	• Composition of resulting plutonic and volcanic rocks are affected if the partially melted rocks are the overlying ultrabasic mantle wedge, basic to silicic forearc basement, subducted basic-ultrabasic ocean lithosphere or marine pelagic sediments.
Flux Melting	• Volatile-rich minerals (mica, amphibole, serpentine, talc, carbonates, clays, brucite) release volatile vapor that lowers melting temperature of mantle peridotite

2. Convergent Boundaries

Factors:

Diversification Process and Metamorphic Reactions	• Fractionation, Assimilation, Magma Mixing, and Metamorphism strongly alters the magma composition generated in overlying wedge of arc system
Dip Angle of Subduction Zone	• Old, cold, dense lithosphere = steep subduction • Young, warm, buoyant lithosphere = shallow subduction • Steeply-inclined subduction = melting of thick wedge mantle slab • Shallow-dipping subduction = melting of thin wedge mantle slab

2. Convergent Boundaries

- Phanerozoic convergent margins dominated by Calc-alkaline suites; enriched in SiO_2, Alkali (Na_2O, K_2O), LIL, LREE, and volatiles
- Presence of hydrous minerals hornblende and biotite indicate that arc magma has > 3% H_2O
- Arc rocks display variations in K_2O (low in tholeiite, medium in calc-alkaline, and high in calc-alkaline to shoshonite; reflects increasing K_2O and K_2O/Na_2O and decreasing Fe enrichment.

2. Convergent Boundaries

- Low-K_2O tholeiites in with thin slab 0km – 20km
- Medium- to High-K_2O calc-alkaline andesite in thick slab 20km – 40km
- High-K_2O shoshonite in very thick slab > 40km

- Ocean-ocean = young island arc volcanic complex
- Ocean-continent = mature continental arc complex
- Continent-continent = ceased subduction & collision

B. BADR

- Calc-alkaline group of **Basalt, Andesite, Dacite, Rhyolite** is signature of volcanic rock suite of convergent margin.
- One of most voluminous rock assemblages next to MORB
- Linear trend in Harker plots indicate descent from common source (parent basaltic magma)
- Andesite is most common calc-alkaline volcanic rock

B. BADR

BASALT

- Basalt in convergent margin are aphanitic to aphanitic-porphyritic Arc Tholeiites (low K_2O) and Calc-alkaline Basalts (mod K_2O).
- Arc Tholeiites have higher Al_2O_3 (>16%) than tholeiitic basalts (MORB, OIB); **High Alumina Basalt**
- Calc-alkaline basalts have higher alkali (K_2O) than tholeiites and has no Fe enrichment.
- Plagioclase phenocrysts is common

B. BADR

ANDESITE

- Volcanic rock with 52% - 63% SiO_2. Divided based on SiO_2:
  - Basaltic Andesite = 52% - 57% SiO_2 in young island arc
  - Silicic Andesite = 57% - 63% SiO_2 in mature continental arc
- Gray, porphyritic-aphanitic with phenocryst of plagioclase (zone euhedral), hornblende (reaction rims), and pyroxene, and biotite.
- 25^o subduction angle, anatexis of thick continental hanging wall plates and partial melting of subducted slab at 70-200km depth

B. BADR

DACITE

- 63% - 68% SiO_2; TAS extends to 77%
- Quartz-phyric volcanic rock between andesite & rhyolite
- Enriched in plagioclase. Phenocrysts are subhedral to euhedral zoned oligoclase and labradorite or sanidine. Minor minerals are biotite, hornblende, augite, hypersthene, and enstatite

B. BADR

TRACHYANDESITE (Latite and Shoshonite)

- 66% - 69% SiO_2; TAS extends starting limit at 57% SiO_2
- Phenocryst of andesine to oligoclase in a groundmass of orthoclase and augite.

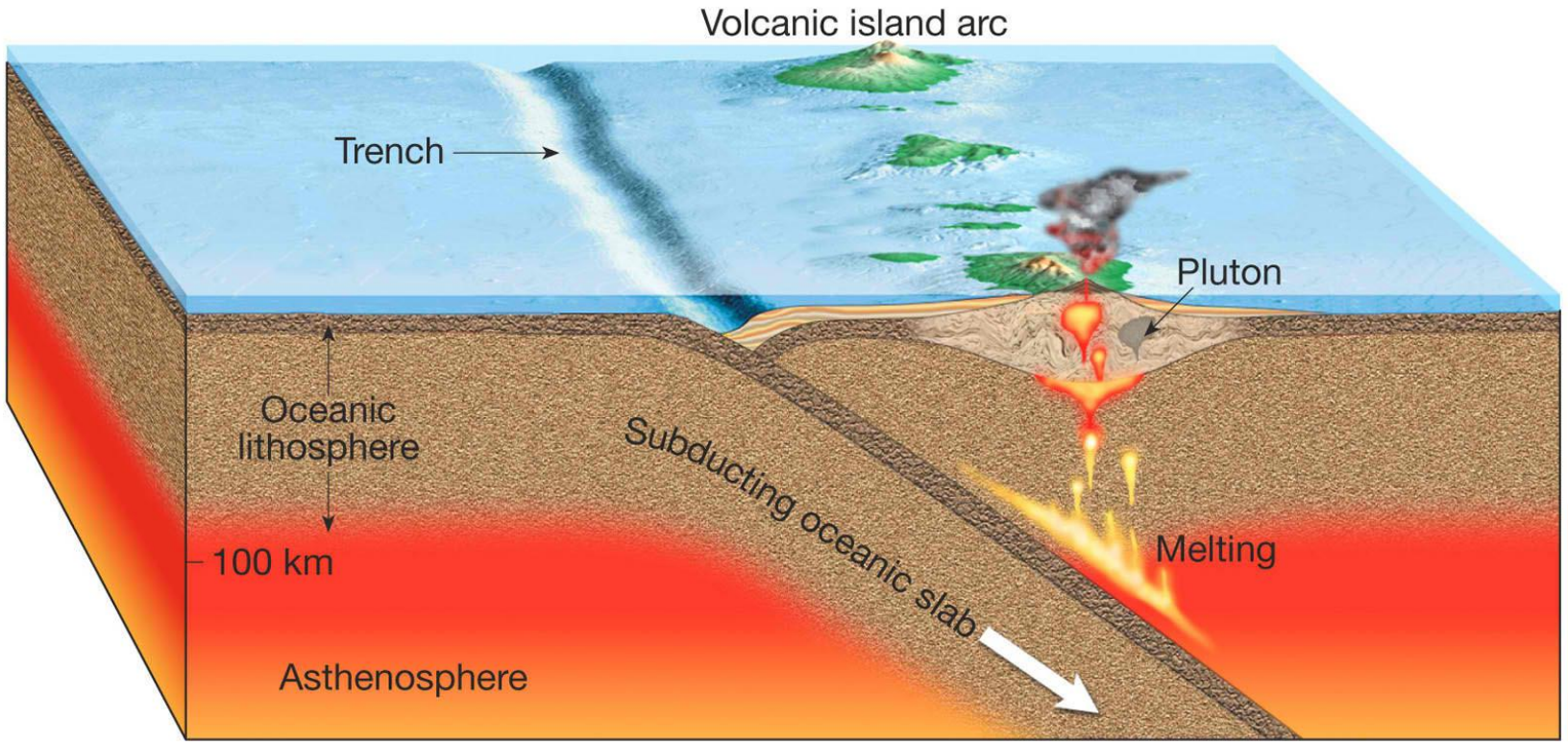
B. BADR

Rhyolite and Rhyodacite

- > 69% $SiO_2$and 68% - 73% SiO_2 respectively
- Explosive silicic eruption producing fragmental, glassy, and aphanitic to aphanitic-porphyritic texture.
- Occur as glass (obsidian or pumice), pyroclastic tuffs & breccia, or as aphanitic to aphanitic-porphyritic crystalline rocks
- Phenocryst of alkali feldspar or quartz, with minor hornblende and biotite

3. Island Arcs

Magmatism along the trench resulting to both plutonic rocks and volcanic arc rocks



3. Island Arcs

- Underlain by intermediate to mafic plutonic suits dominated by diorite, quartz diorite, granodiorite, tonalite, and gabbro.
- Island arc granodiorites are metaluminous, with hornblende, biotite, and minor muscovite.
- Young island arcs produce andesite and basaltic andesite, low-potassium arc tholeiite basalts, Boninites, and Adakites

3. Island Arcs

- Low-potassium arc tholeiites occur in oceanward side nearest the trench
- Tholeiite island arc basalt form at subduction zones with thin overlying plates
- Major element concentration in tholeiite is similar to MORB (low K_2O & Fe enrichment) indicating similar depleted mantle source by flux melting; but has higher potassium & LIL and lower HFS
- Tholeiitic island arcs are basalt, basaltic andesite, and andesite in the volcanic arc

C. Island Arc Basalts

BONINITES

- High-Mg intermediate volcanic rock w/ SiO_2-saturated groundmass
- Phenocryst of orthopyroxene and no plagioclase phenocrysts.
- Enriched in Cr, Ni, volatiles, LEE, Zr, Ba, Sr; depleted in HREE & HFS
- Occur proximal to trench with geochemical signature of primitive mantle-derived magma produced early in the subduction cycle
- Product of subduction-related melting in the forearc of young island arc system

C. Island Arc Basalts

ADAKITES

- SiO_2-saturated w/ high Sr/Y and L/Yb ratio (LREE enriched) and low HFS (Nb, Ta)
- Form at continent-continent collision site due to shallow slab subduction of continental lithosphere

Questions?