Zircon Dating of Oceanic Crustal Accretion

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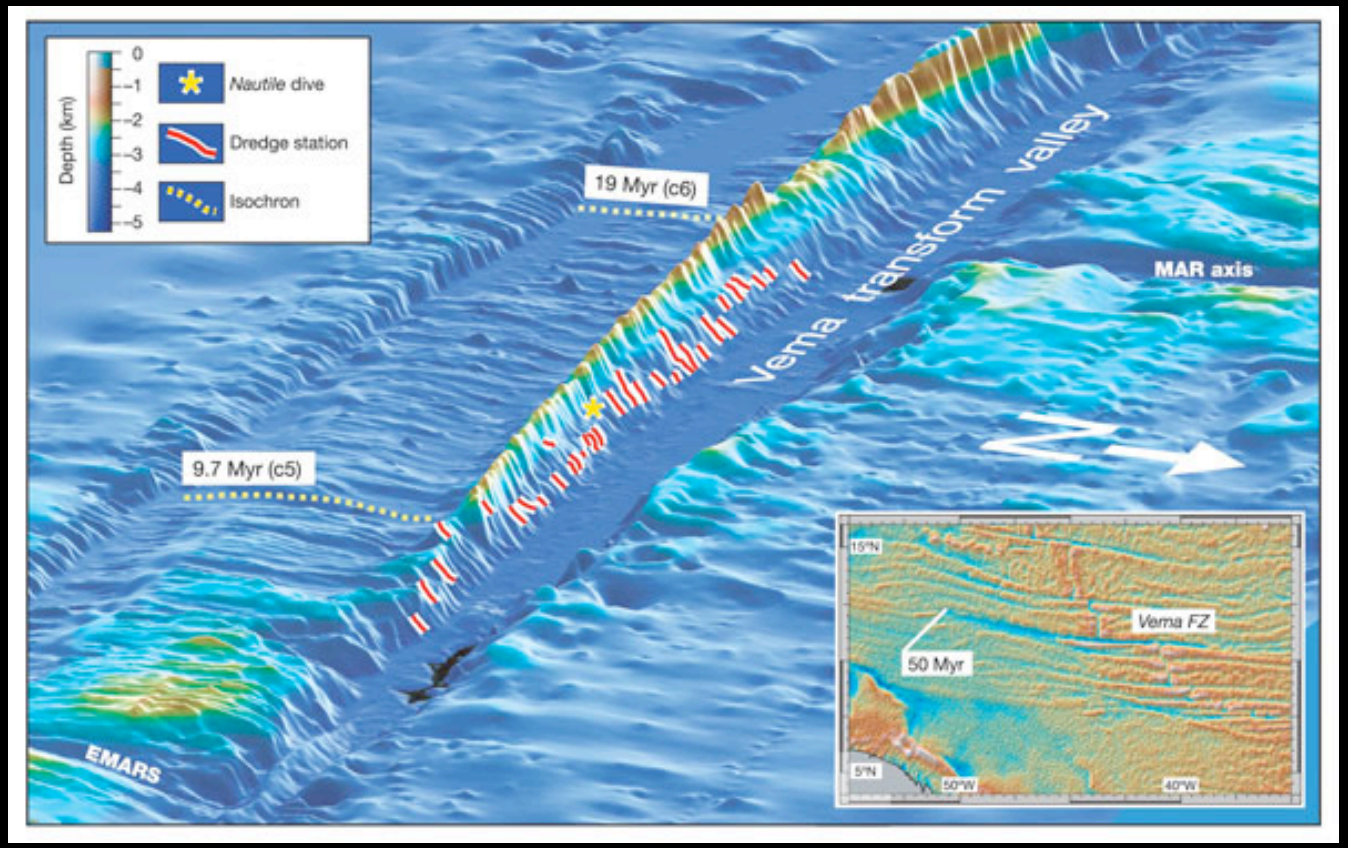
Introduction

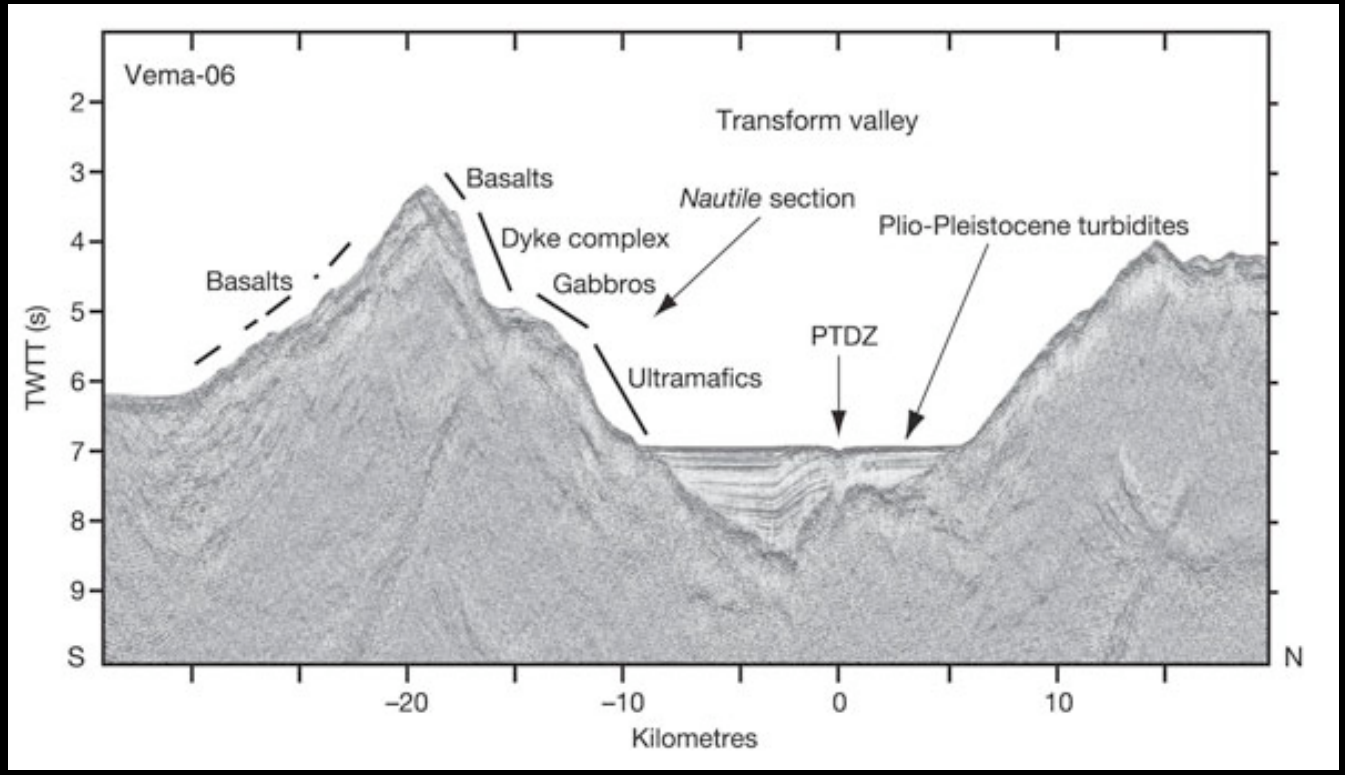
- The discovery of seafloor spreading in the 1960s enabled the formulation of the theory of plate tectonics.
- New oceanic crust is produced at a very narrow mid-ocean ridge axis, and subsequently moves outward.
- Crustal growth is controlled by the transfer of melt from the mantle to the crust.
- The time scales of melt delivery from the mantle and the resulting patterns of intrusive magmatism in these settings are not well known.
- This is largely because of the inaccessiblily of lower crustal sections.
- In this study, the authors perform high-precison uranium-lead dating of zirons in gabbros from exposed lower crustal sections to constrain the time scales of intrusive magmatisim beneath mid-ocean ridge spereading center.

Vema transform zone



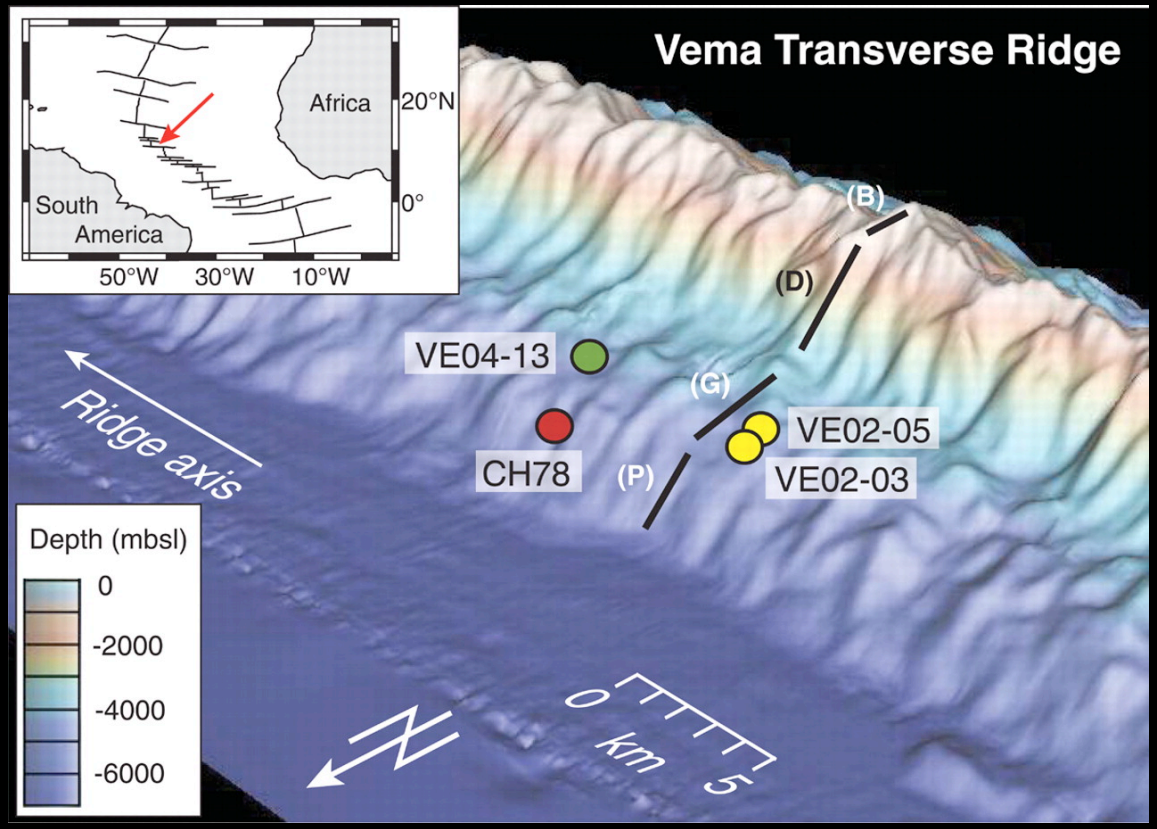
- The Vema transform offsets the Mid-Atlantic Ridge (MAR) by 310 km.
- The Vema transverse ridge runs on the southern side of the Vema transform.
- The northern side of the Vema transverse ridge exposes upper lothospheric section (Vema lithospheric section, VLS).

Vema lithospheric section (VLS)



- The VLS consists of a $\sim$ 1km mantle peridotite basal unit, overlain by a gabbroic unit, then by a dyke complex and topped by pillow basalt.

Location of samples dated in this study



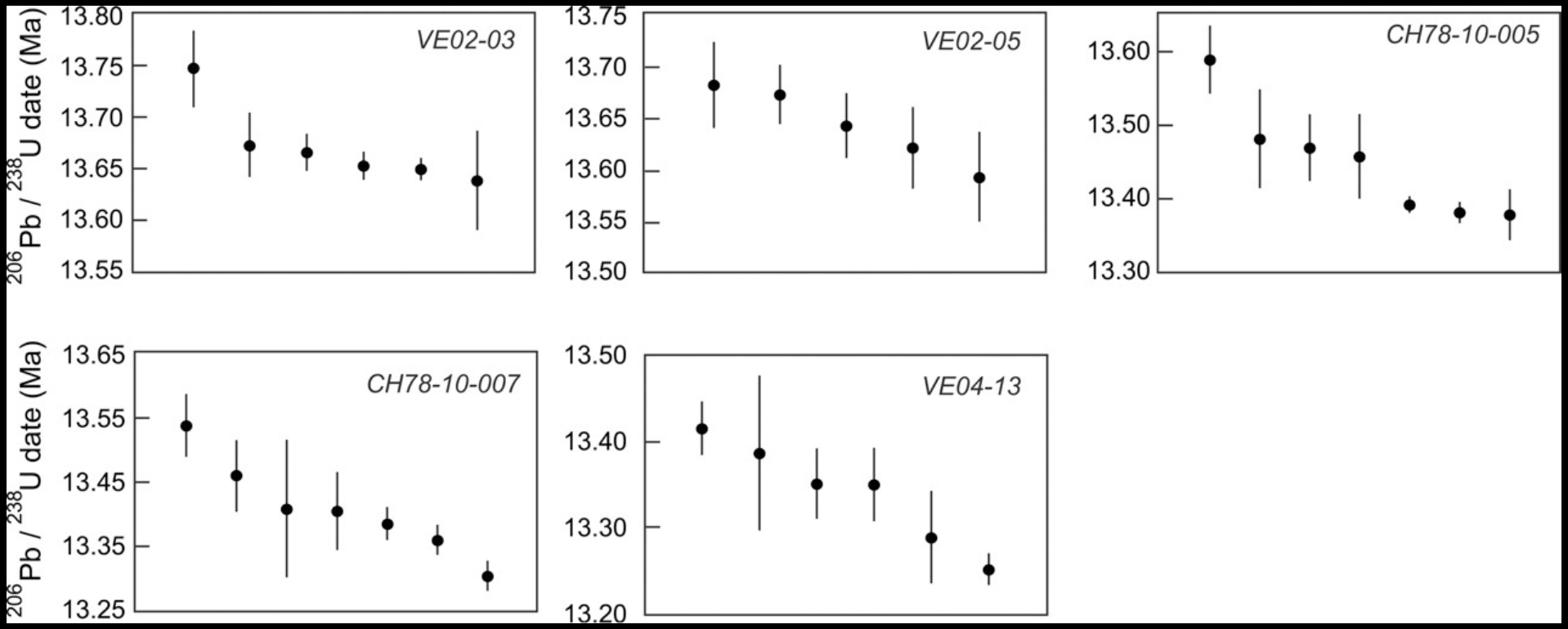
- The studied samples come from a narrow (6 km) section of the VLS centered around 42^{o}42'W.
- Authors obtained 31 zircon grains and grain fragments separated from five gabbroic samples.
- Samples with prefix VE were collected by submersible craft.
- Samples with prefix CH were collected by dredging along the VLS.

Analitycal technique

CA(Chemical Abrasion)-TIMS

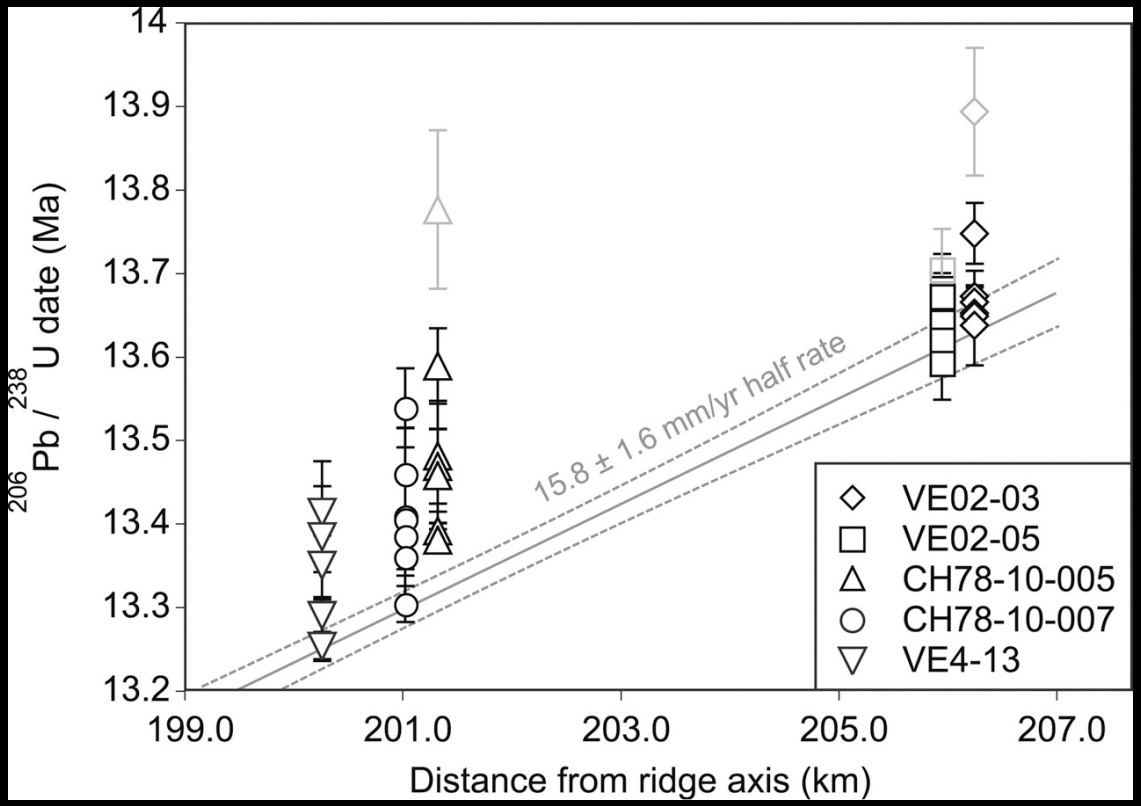
- partially open system behavior (Pb loss) has been recognized as a major factor limiting the accuracy of zircon age determination.
- CA (Chemical Abrasion)-TIMS completely remove zircon domains that have lost Pb, and then analyze residual, perfectly closed-system ziron.
  - annealed at 900 degree C for 60 hours
  - dissolved in two steps at progressively higher temperatures
- These steps sample zircon domains that are completely free from Pb loss.
- U-Pb zircon dates were datermined by isotope dilution-thermal ionization mass spectrometry (ID-TIMS) at the Massachusetts Institute of Technology.

CA-TIMS results for gabbros from the VLS



- Individual zircon dates range from 13.75 to 13.25 Ma.
- The single zircon grains (along the x axis) show a range in ^{206}Pb/^{238}U dates for each sample (90,000 to 235,000 years) that exceeds the analytical uncertainties.

$^{206}Pb/^{238}U$ dates of individual zircon crystals versus distance from the ridge axis



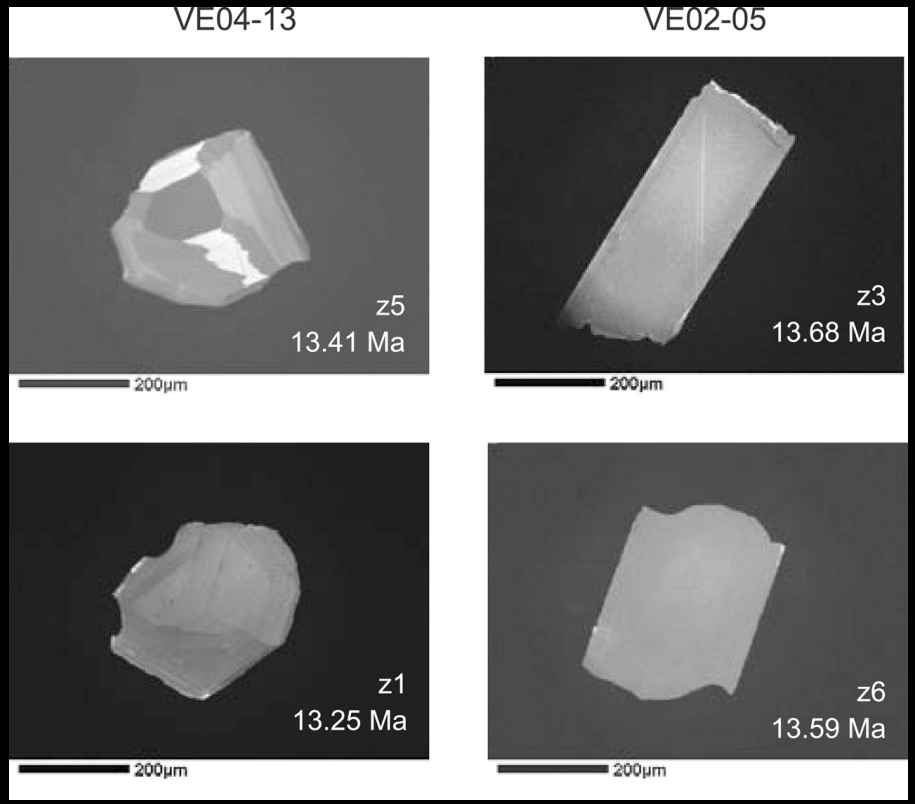
- Individual zircon dates show a good correlation with sample location.
- The youngest zircon grains of each of the samples define a half-spreading rate of 15.8 mm/year.
- The rate agree with the rate of 16.1 mm/year predicted by plate motion models.
- Each sample has zircon dates that span 90,000 to 235,000 years.
- These ranges reflect the time scale of zircon crystallization in mid-ocean ridge plutonic systems.

Discussion

The ranges of zircon dates (9,000 to 23,5000 years) may reflect the assimilation of slightly older adjacent plutonic rocks during intrusion and cooling.

- The date of each grain would represent a mixture of a slightly older core and a younger magamatic rim.
- The range of each sample reflect varying amounts and/or age of inherited components.
- This is not consistent with
  - texture of zircon grains from each sample.

Cathodoluminescence images of zircon grains from Vema gabbros



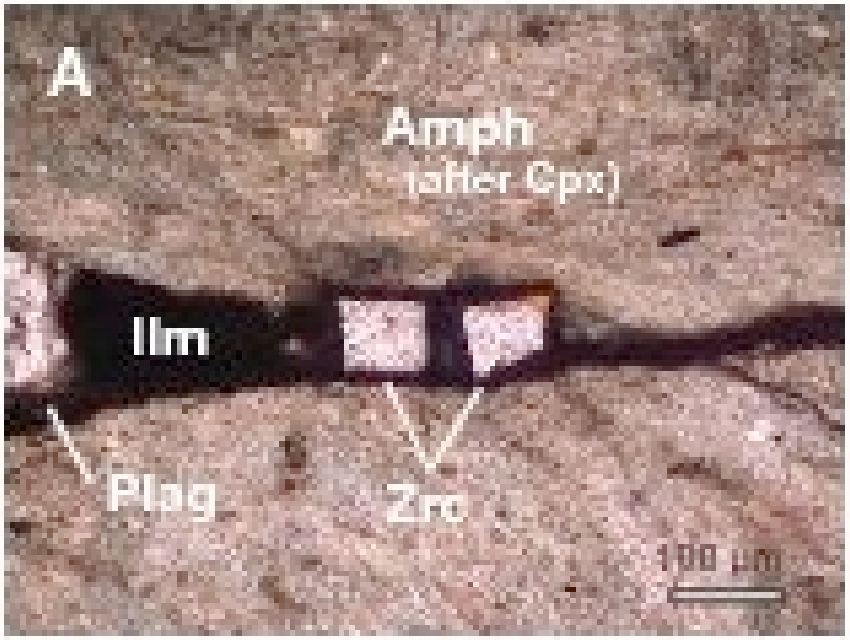
- There is no evidence for inherited cores overgrown by younger rims.
- Internal structures are consistent with growth during a single magmatic episode.

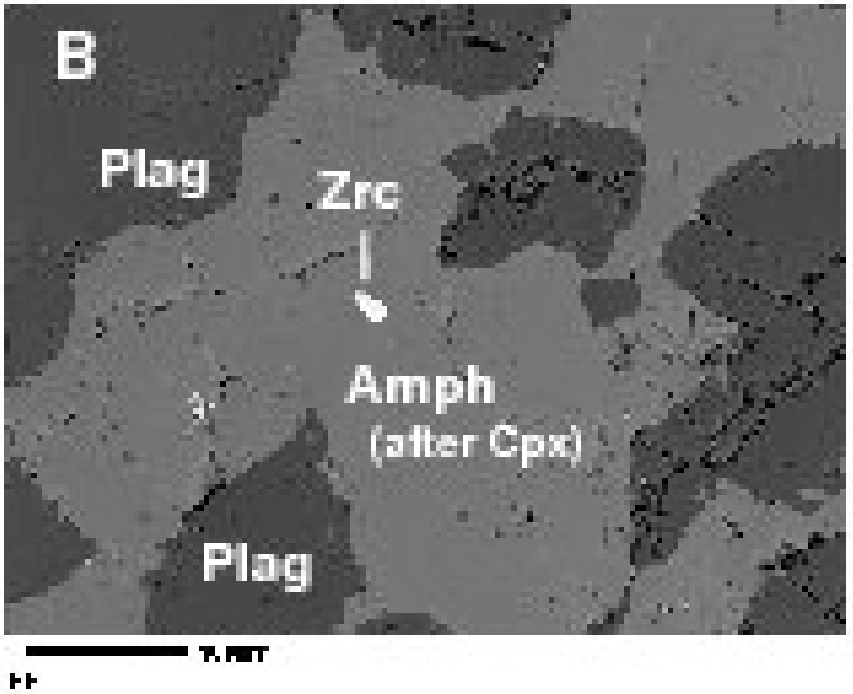
Discussion

The ranges of zircon dates (9,000 to 23,5000 years) reflect the time scale of zircon crystallization in mid-ocean ridge plutonic systems.

- This is consistent with
  - petrographic observations.
  - thermochronology-derived cooling rates.
  - seismic velocity anomalies at slow-spreading ridges.

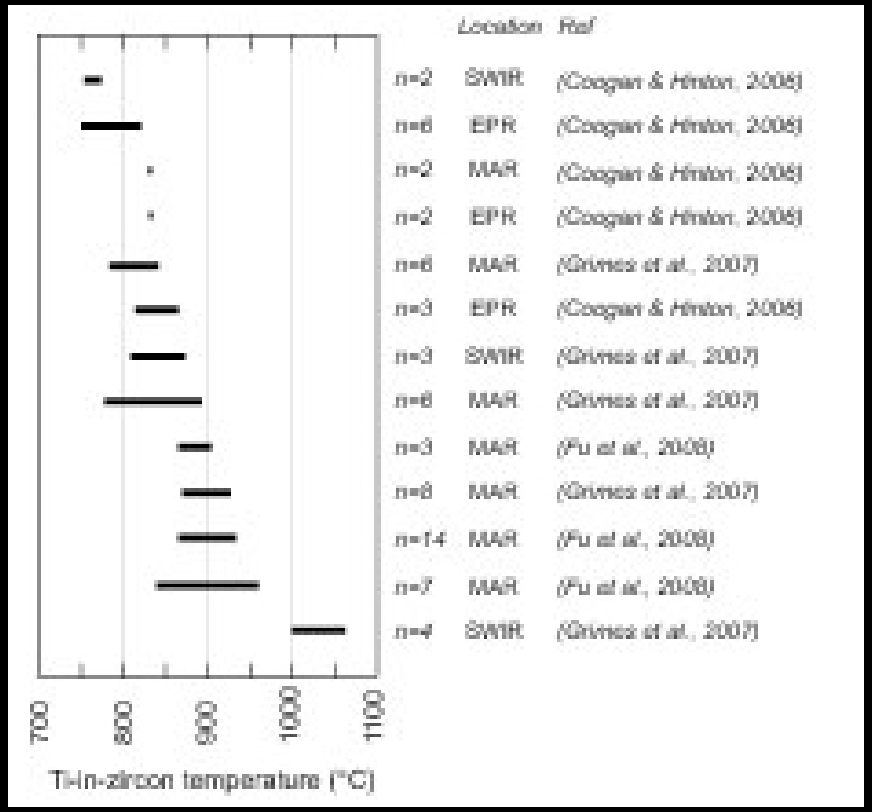
Petrographic relationships of zircon in sample VE02-05.





- Some zircons are included in amphibole (secondary after pyroxene) and plagioclase, whereas others occur along grain boundaries.
- This consistent with an extended history of zircon grains.

Cooling rates of the Vema gabbros



Compalison of crystallization temperatures from mid-ocean ridge zircons.

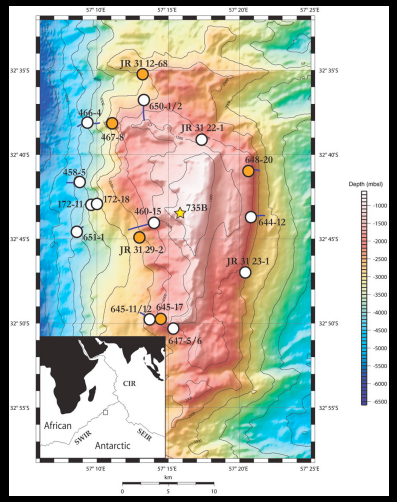
- Temperatures are calculated with the Ti-in-zircon thermometer (Ferry and Watson, 2007)
- T = $-4,800/[log(ppmTi - in - zircon) + loga_{SiO2} + loga_{TiO2} - 5.711]$
- The range in temperatures for each samples is shown by black bars.
- Zircon in individual oceanic gabbros may crystallize over a temperature range of $\sim 60^o$ to 120^oC.

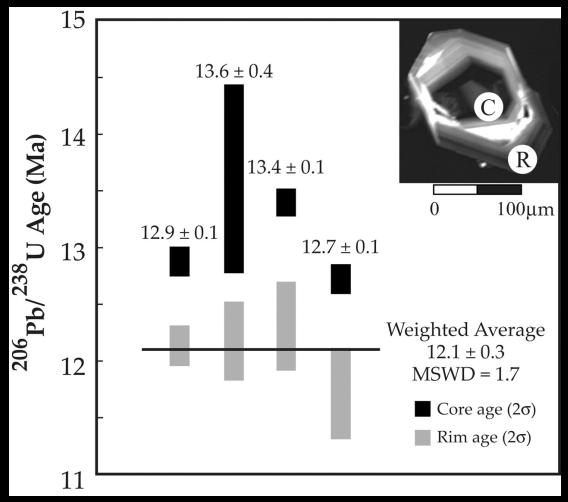
- The ranges of zircon dates indicates that the Vema gabbros cooled at rates of $\sim 300^o$ to 1300^oC/myrs.
- This is consistent with thermochronology-derived cooling rates of 800^oC/myrs determined for slow-spreading lower crust.

Seismic velocity anomalies at slow-spreading ridges

- Assuming the half spreading rate of 15.8 mm/year, new oceanic crust moves outward about 1.4 to 3.7 km during the age span(90,000 to 235,000 years).
- Crustal growth is controlled by the transfer of melt from the mantle to the crust.
- This requires the presence of partial melt extend about 1.4 to 3.7 km.
- At slow-spreading ridge segments, lower crustal negative velocity anomalies, signaling the presence of partial melt, extend up to $\pm$10 km across axis.

Comparison with previous studies





Schwartz et al. 2005 provided U-Pb age determinations of lower oceanic crust exposed at teh Atlantic Bank.

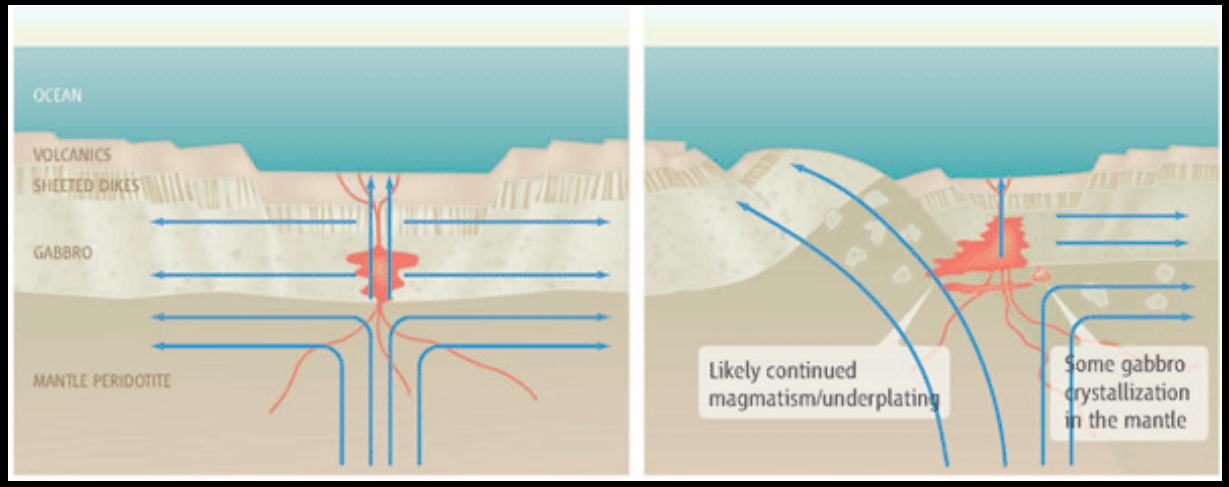
- Core ages are statistically older than their corresponding rims, indicating a second period of growth at 12.1 Ma. The age of the cores is interpreted to be 13.6 My.

- The data from Atlantic Bank document the presence of inherited cores of up to 1.5 My older than corresponding rims, with zircon dates as much as 2.5 My older than the predicted magnetic ages.
- This extended time span of crustal growth was attributed to crystallization of gabbros in the mantle at depths of up to 18 km, followed by uplift to lower crustal depths and renewed magmatism.

Discussion

- Results from the VLS are distinct from dating study at Atlantic Bank.
- At the VLS, the linear progression of ages away from the ridge axis suggest that the crust fromed by highly regular, ridge-centered, shallow delively of melt.
- In contrast, the extended time span of crustal growth suggest that crystallization of gabbros in the mantle at depths of up to 18 km, followed by uplift to lower crustal depths and renewed magmatism.

Discussion



- The difference growth histories may relate to contrasting spreading histories.
- Atlantis Bank exposes sections of lower crust unroofed by low-angle detachment falults.
- The detachment faults are inferred to root in the lower crust or mantle beneath the ridge axis.
- This would lead to a pluton emplacement pattern, that deviates considerably from that of a requlär, symmetrically spreading ridge segment.
- The Vema samples come from an intact crustal section devoid of detachment faults.
- The regular pattern of crustal accretion and absence of anomalously old ages may be typical of symetrical accretion at slow-spreading ridge.

Figure S3

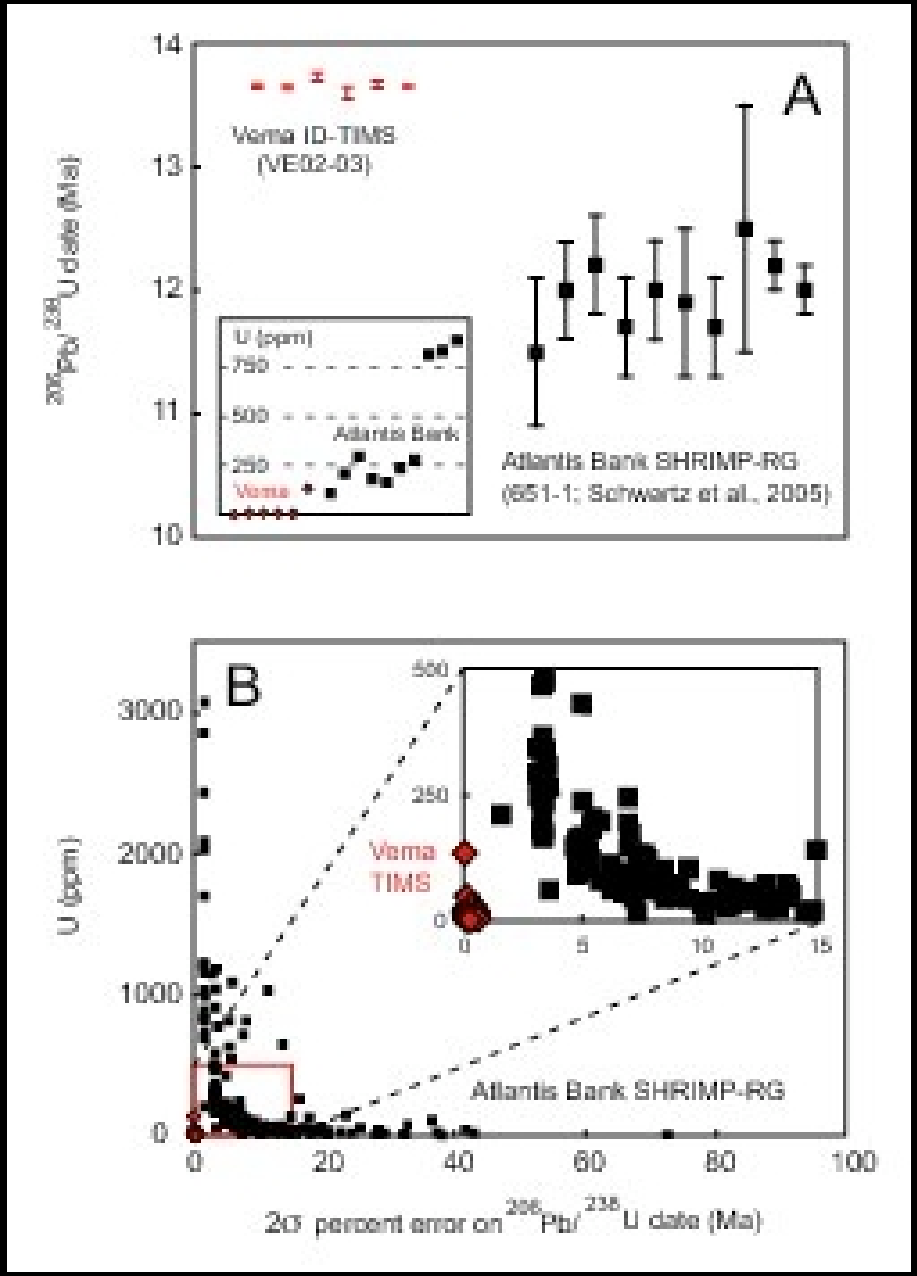

A
Vema ID-TIMS
(VE02-03)
Atlantis Bank SHRIMP-RG
(651-1; Schwartz et al., 2005)
U (ppm)
750
500
250
Atlantis Bank
Vema
^{206}Pb/^{238}U date (Ma)
14
13
12
11
10
B
Vema
TIMS
Atlantis Bank SHRIMP-RG
U (ppm)
3000
2000
1000
0
0
20
40
60
80
100
2σ percent error on ^{206}Pb/^{238}U date (Ma)

Figure S4