Upper crustal dynamics of the 9°N OSC at the East Pacific rise : Linking surficial and melt sill structures

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I. Study area

The Overlapping Spreading Center (OSC) at 9° N on the East Pacific Rise has been migrating southward with an average rate of 42 km/Ma since 2 Ma.
The 1997 ARAD (Anatomy of a Ridge Axis Discontinuity) seismic experiment investigated the 3D seismic structure of the magma lenses beneath the OSC. Shots were fired every 37.5 m along 201 cross-axis seismic profiles. The profiles are 20 km long and spaced by 100m.
Here, we analyse the relationships between magma chamber geometry derived from this seismic experiment and the seafloor structures.

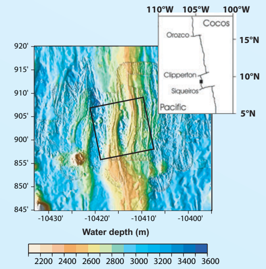


Figure 1 : Location of the study area. The ARAD 3D box is represented in black.

II. Seafloor structures

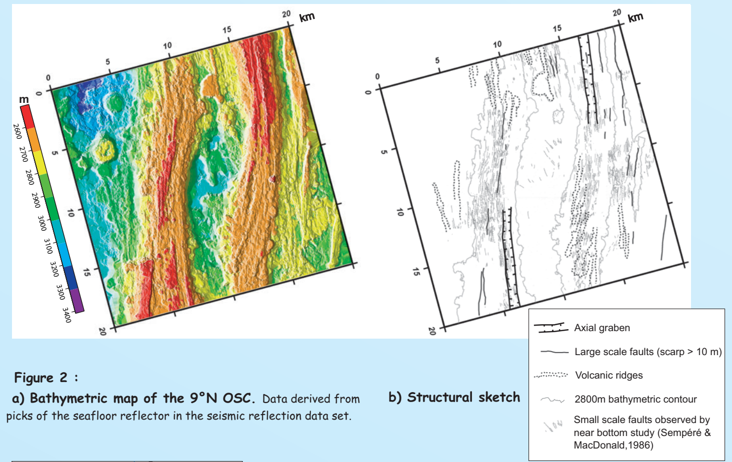
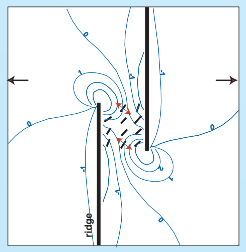


Figure 2 :
a) Bathymetric map of the 9°N OSC. Data derived from picks of the seafloor reflector in the seismic reflection data set.
b) Structural sketch



All volcanic and tectonic surface features follow the same curved path.
This curved shape is explained by the theory of propagating cracks in an elastic plate (Figure 3). As two cracks are propagating towards each other, the stress field is modified in such a way that their path will first diverge and then converge towards each other.

Figure 3 : Overlapping spreading centers in the propagating cracks theory (Pollard & Aydin 1984). The small black lines represent the principal stress planes near two echelon ridges subject to the plate pull boundary condition. In blue are the contours of the mean normal stress normalized by the ambient stress.

➡ Surface volcanic and tectonic features follow the curved shaped path predicted by elastic crack propagation theory.

III. Seismic constraints on the geometry of melt sills

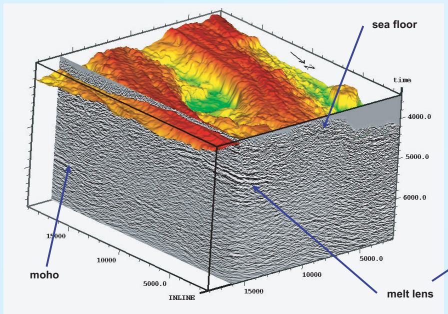


Figure 3 : ARAD 3D seismic reflection data set.

The seafloor and melt lens reflectors were picked in the 3D time migrated volume. The melt lens picks were converted to depth using the velocities derived from the ARAD seismic refraction study (Tong et al, 2003).

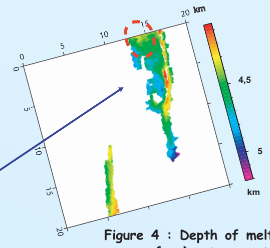


Figure 4 : Depth of melt lens reflectors (below sea surface). The main slow velocity anomaly at 3 km depth (<-0,6km/s) (Bazin et al, 2003) is contoured in red.

A tomographic study of the shallow Low Velocity Zone at 3 km below seafloor (Bazin et al., 2003) shows one main slow velocity anomaly, which is located below the western part of the eastern melt lens, in the north of our survey area (Figure 4).

IV. Relationships between seafloor and melt sills structures

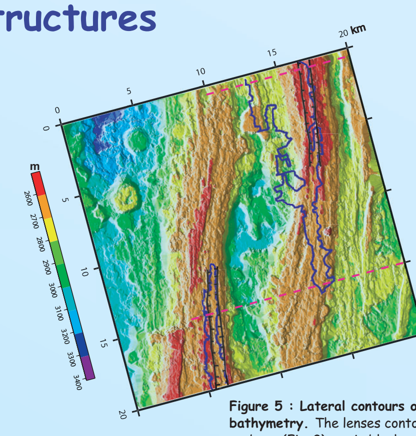


Figure 5 : Lateral contours of the melt lenses over bathymetry. The lenses contours are in blue, the axial grabens (Fig. 2) are in black.

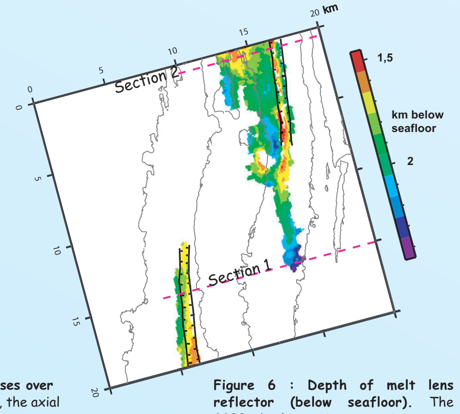


Figure 6 : Depth of melt lens reflector (below seafloor). The 2800m bathymetric contour is in grey.

The tip of the melt lens at the propagating northern limb does not follow the curved surface structures.

Also note that the northern melt lens is anomalously wide (4 km) in the northern part of our study area. It extends to the west of the Neo Volcanic Zone defined by the axial graben.

Shallowest regions of the northern melt lens coincide with the Neo Volcanic Zone and follow the curved shape of surface structures.

➡ What controls lenses location and shape ?

IV. Interpretation

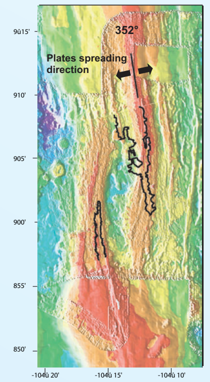


Figure 7: Contour of the melt lenses and plate spreading direction at the 9°N segment.

Orientation of the propagating melt lens :

The tip of the propagating melt lens is perpendicular to the plates spreading direction (figure 7).

This means that the ambient stress field at lens depth is the same as the regional stress field controlled by plate separation.

By contrast, surface tectonic and volcanic structures respond to the near field stresses associated to crack propagation in the brittle crust.

There thus exists a decoupling between the brittle upper crust and the ductile crust below the melt lens (Section 1).

This can certainly be explained by the ductile nature of the crust at lens depth. Indeed, shear stress is not well transmitted in ductile media. The interaction distance between the two "cracks" is reduced.

Shape of roof of melt lenses :

The lens is shallower below the neo-volcanic zone associated with the axial graben. If the top of the melt lens is a thermal crystallization boundary, frequent lava extrusion will bring the isotherms up, thus the melt lens up. Lava extrusion thus appears to influence the shape of the lens roof.

The melt path from the lens to the surface follows lithospheric weak zones which are controlled by the local stress field. The shape of the lens roof is thus influenced by the brittle upper crust stress field. In the OSC context, the lens roof follows the curved shape of the local normal stress directions.

The melt lens is anomalously wide and extends to the west of the axial graben in the north of our study area. The low velocity zone, interpreted as partly molten rocks deeper in the crust, is also offset to the west in this area (Bazin et al, 2003) (Figure 4). We propose that the location of lava extrusion can also influence the width of the melt lens. If there is no exit pathway for the magma directly above the supply melt-mush zone, the magma must travel sideways towards a zone of weakness in the lithosphere, where dyking is easier (Section 2).

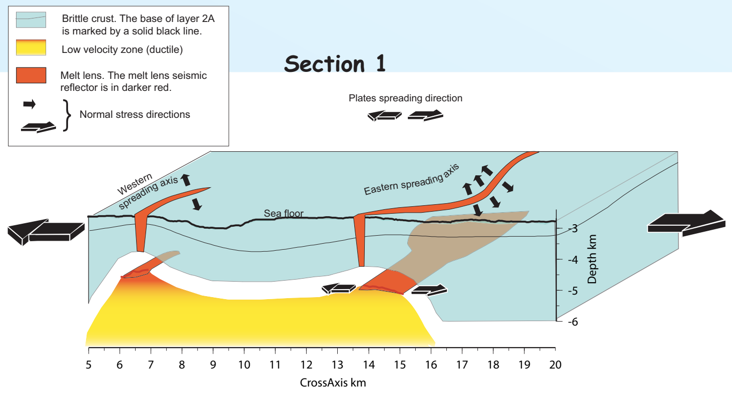


Figure 8 : Decoupling between the upper brittle crust and the ductile low velocity zone. The location of the cross-section is on figures 5 and 6. The seafloor, layer 2A and roof of melt lens dimensions are respected.

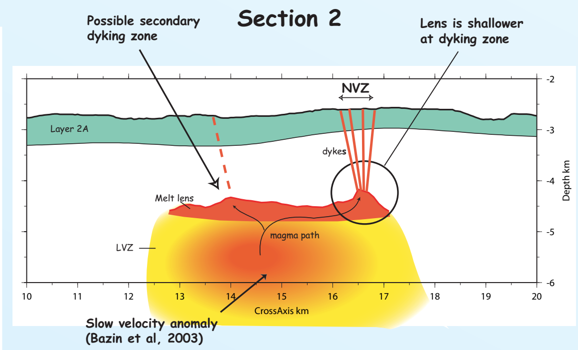


Figure 9 : Vertical section across the eastern melt sill. The seafloor, layer 2A and roof of melt lens dimensions are respected. The location of the cross-section is on figures 5 and 6.

Conclusion

Our study shows that the shape and location of the melt lens is influenced by :

-The ambient ductile stress field at lens depth (which keeps the same orientation as the regional stress field in our OSC area);

-The brittle upper crust stress field (curved in OSC areas) which controls the location of the extrusion zones.

-The location of the melt source below the melt lens.

Depending on the degree of activity of the spreading center, the melt lens will be more influenced by one or an other of these factors. It will be "surface shaped" if eruptions are frequent and "depth shaped" if not. In areas far from OSCs, near field and regional field stresses have similar orientations, producing a narrow (1km) and straight melt lens.

References

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Pollard and Aydin, JGR, 1984. Propagation and linkage of oceanic ridge segments.

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Tong et al., JGR, 2003. Influence of enhanced melt supply on upper crustal structure at a mid-ocean ridge discontinuity : A three-dimensional seismic tomographic study of 9°N East Pacific Rise.