Mantle wedge perturbation induced by slab detachment and the Mio-Pliocene bimodal volcanism in the Trans-Mexican Volcanic Belt

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Introduction: The TMVB anomaly

The Trans-Mexican Volcanic Belt (TMVB) is the Neogene volcanic arc built on the southern edge of the North American plate (Ferrari et al., 1999) (Figure 1). TMVB volcanism presents a wide range of chemical compositions. The geochemical signature of fluids from the subducting plate varies strongly and lavas with a slab melting fingerprint have been reported from several locations. Small amounts of lavas with an intraplate (or OIB) signature are found side by side with those with a subduction signature and with similar ages. In addition, seismicity associated with the subducting Cocos plate is abundant in the forearc region but ends rather abruptly just to the south of the TMVB at around 100 km depth (Figure 2) where the upper mantle has a relatively low density and high temperature. The arc itself is also oblique with respect to the present trench. The geochemical diversity, the trench-oblique orientation and absence of seismicity beneath the TMVB prompted several workers to develop genetic models at variance with a classic subduction scenario, including the presence of a mantle plume.

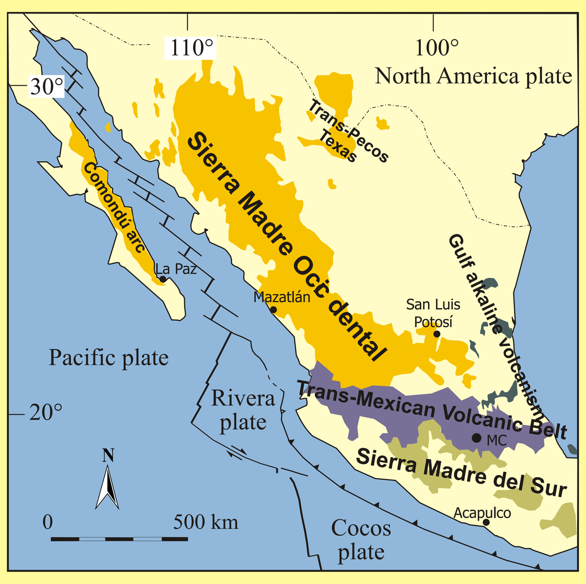


Figure 1

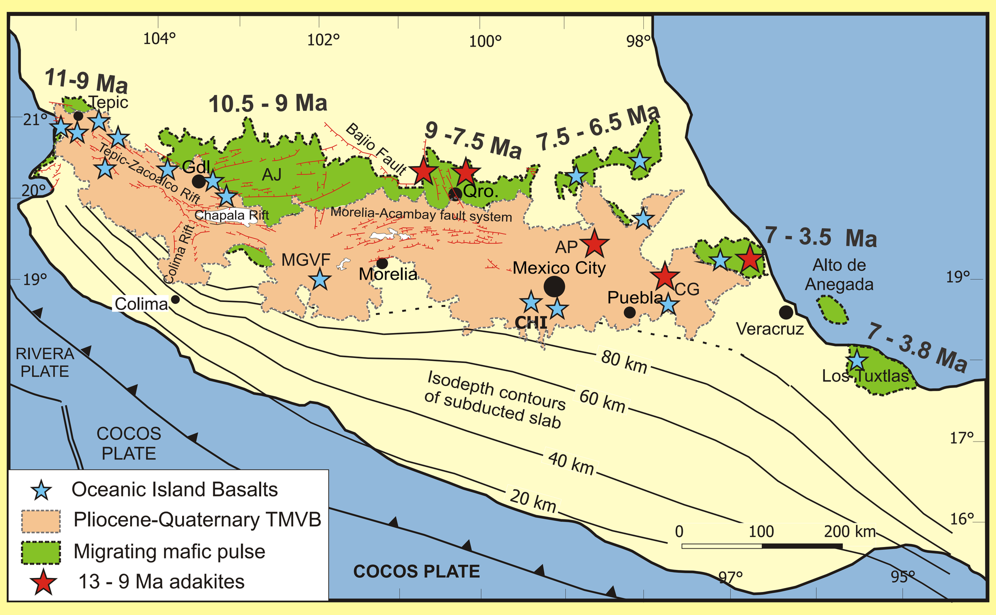


Figure 2.
Simplified geologic map (modified after Ferrari, 2004) with depth contours of subducting slabs in kilometers (from Pardo and Suarez, 1995).

GDL = Guadalajara; AJ = Altos de Jalisco; QRO = Queretaro; CHI = Sierra Chichinautzin; AP = Apan volcanic field; CG = Cerro Grande volcanic complex; MGVF = Michoacan-Guanajuato volcanic field.

The plume model

Moore et al. (1994) first suggested the presence of a mantle plume beneath Guadalajara. This model was later expanded by Marquez et al. (1999), who proposed that the entire TMVB is related to a mantle plume that impacted western Mexico in the late Miocene. In the model of Marquez et al. (1999) the plume first broke the subducting plate but the plate will eventually take revenge by cutting off the plume head (Figure 3).

Both models were based mostly on geochemistry and are inconsistent with the geology and tectonics of the TMVB. In their comment to the paper of Marquez et al. (1999) Ferrari & Rosas (1999) showed that:
- neither the rifting nor the OIBs present the age progression required by the plume model;
- in western Mexico, where the plume should have impacted, there is no evidence of regional uplift;
- the volume of OIB lava in the TMVB is only a fraction that of the subduction-related volcanism and much lower than typical continental flood basalts.

An additional problem is posed by the fact that nowhere else in world is a plume (supposing that they exist) claimed to have punched through a subducting plate and, even worse, in this model a plate is considered capable of cutting off the plume head. Proposed plumes have usually been sited away from subduction zones because these are regions of cold downwelling.
Shortly after these papers, the plume model for the TMVB was criticized by Sheth et al. (2000). Since that paper no-one has argued in favour of a TMVB plume, which thus died, decapitated, after a very brief life.

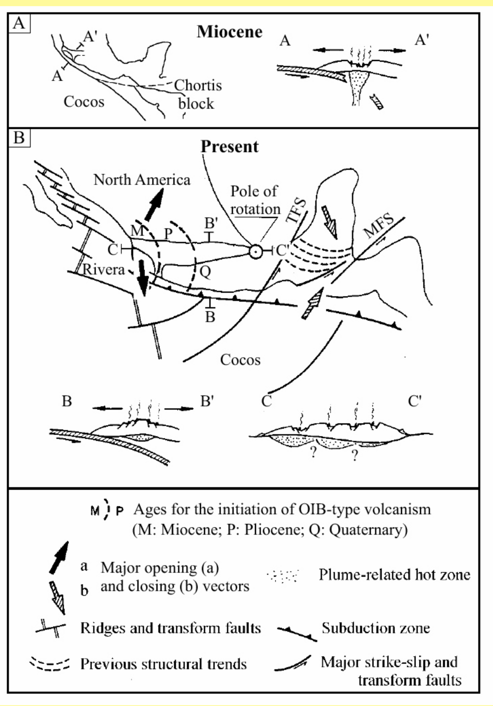
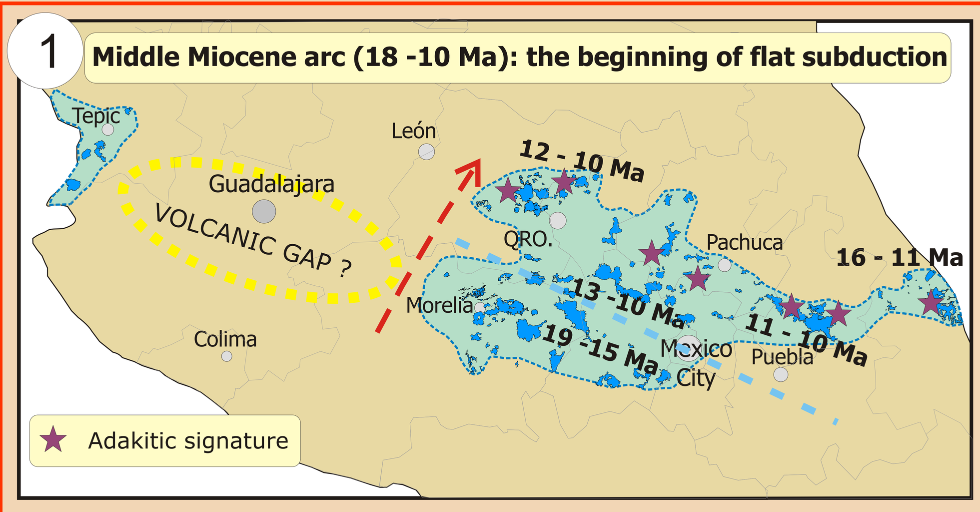


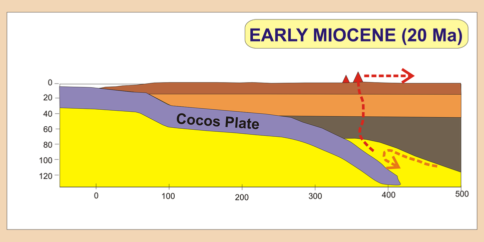
Figure 3. The plume model for the TMVB as originally proposed by Marquez et al. (1999). Original caption reads: Proposed tectonic model for evolution of Mexican volcanic belt. A: Disruption and foundering of subducted slab at subduction zone, rising of plume beneath western Mexico, and development of graben triple junction during Miocene. B: Propagating rift (see vectors), volcanism, and position of currently unrooted upper plume under Mexican volcanic belt. OIB – oceanic-island basalt, TFS – Tehuantepec fault system, MFS – Motagua fault system.

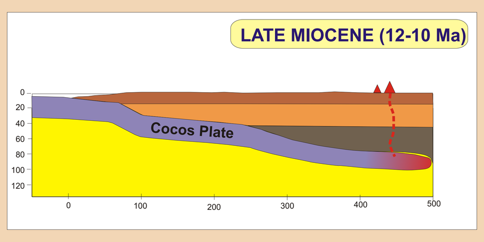
Geologic history of the TMVB and mantle evolution in central Mexico

The establishment of a consistent tectonic and petrogenetic model for the TMVB requires careful geologic study of the whole arc. In the past 6 years we developed the first digital geologic information system of the whole TMVB: http://satori.geociencias.unam.mx/Digital_Geosciences
The Geographic Information System (GIS) of the TMVB, which incorporates over 1,100 ages and 3,000 geochemical data, is now complete. The data show that the TMVB is a composite arc made by the superposition of **4 episodes** that correlate with slab loss and changes in slab geometry and subduction rate.

1 Middle Miocene arc (18 -10 Ma): the beginning of flat subduction

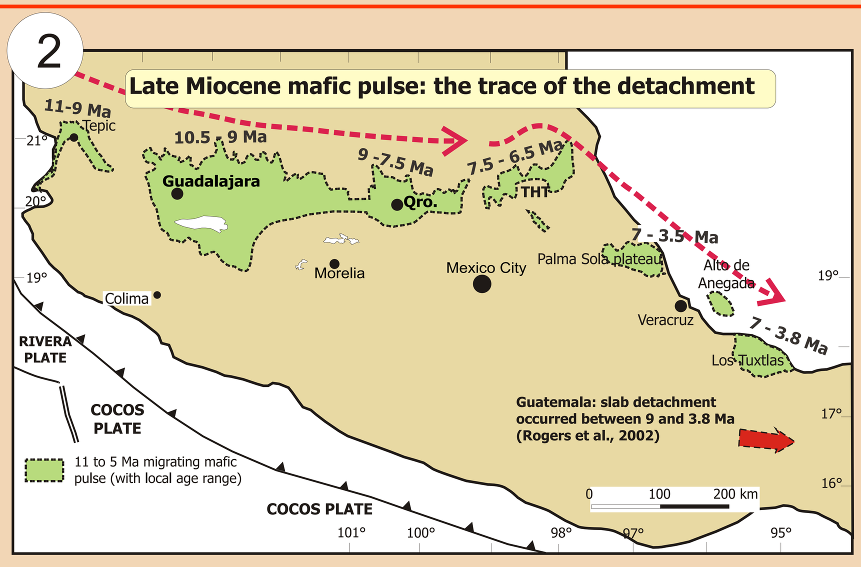






The initial TMVB consisted of a broad arc of andesitic to dacitic polygenetic volcanoes that extends from Long. 102° to the Gulf area (Long. 96°30') and between 18 and 10 Ma. During this period volcanism migrated far from the trench toward the NE. The youngest (12-10 Ma), and most inland centers, form a WNW-ESE belt with an adakitic signature (Gomez-Tuena et al., 2003). The progressively more inland position of the arc and the slab melt signature of the youngest products within this period suggest that the dip of the subducting slab changed from moderate to flat.

2 Late Miocene mafic pulse: the trace of the detachment



From 11 to 5 Ma an eastward-migrating pulse of mafic volcanism occurred across the whole of central Mexico (Ferrari et al., 2000; Orozco-Esquivel et al., 2003). This episode is thought to indicate the lateral propagation of a slab detachment episode, as hot sub-slab material flowing into the slab gap produced a transient thermal anomaly in the mantle wedge (Ferrari, 2004)(Figure 4). Slab detachment of the deeper and denser part of the plate was initiated in the southern Gulf of California area by the increasing coupling between the Magdalena microplate and the overriding North American plate. The tear in the slab propagated eastward from the Gulf of California to the Gulf of Mexico, parallel to the southern Mexico trench system, and it may have continued to the SSE up to Guatemala.

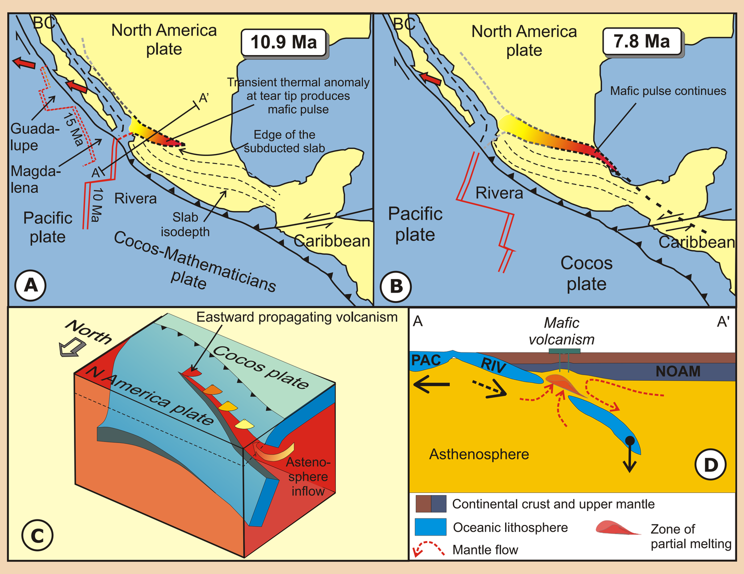
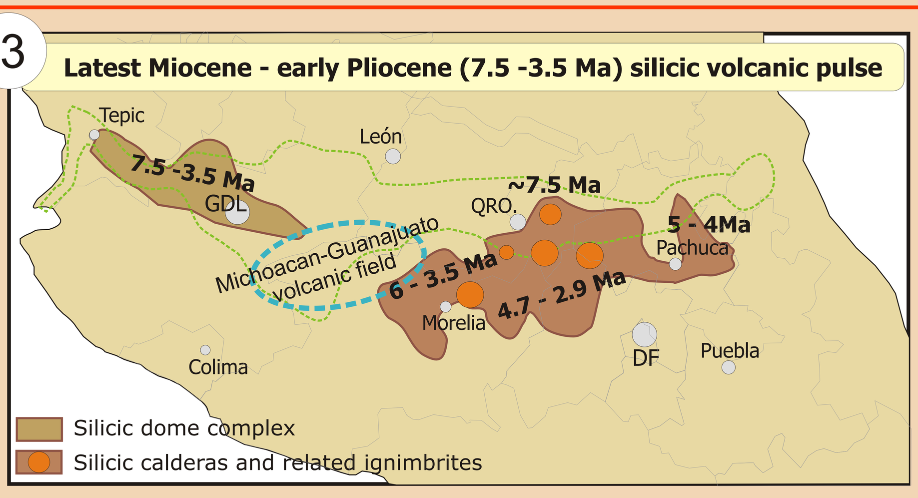
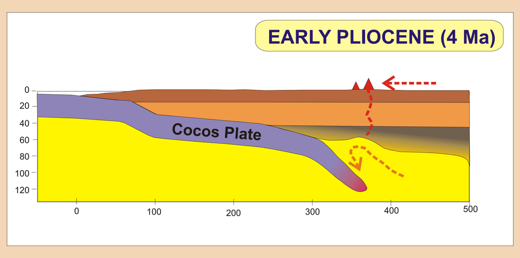
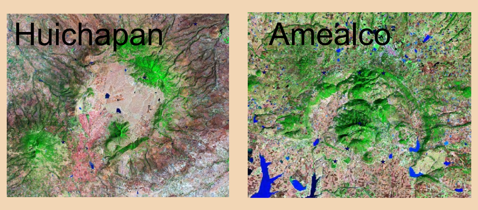


Figure 4: A and B: Late Miocene tectonic setting of Mexican subduction zone at 10.9 and 7.8 Ma with proposed location of slab detachment. Line AA' in A --> cross section in D. C: 3D block diagram showing proposed lateral propagation of detachment and resulting migrating volcanism induced by upwelling, hot, subslab asthenosphere (modified after Wortel and Spakman, 2000). D: Schematic cross section of detachment mechanism and consequences in western Mexico. Mafic volcanism on North America plate (NOAM) resulted from thermal melting of mantle wedge previously modified by subduction. RIV=Rivera plate; PAC=Pacific plate.

3 Latest Miocene - early Pliocene (7.5 -3.5 Ma) silicic volcanic pulse

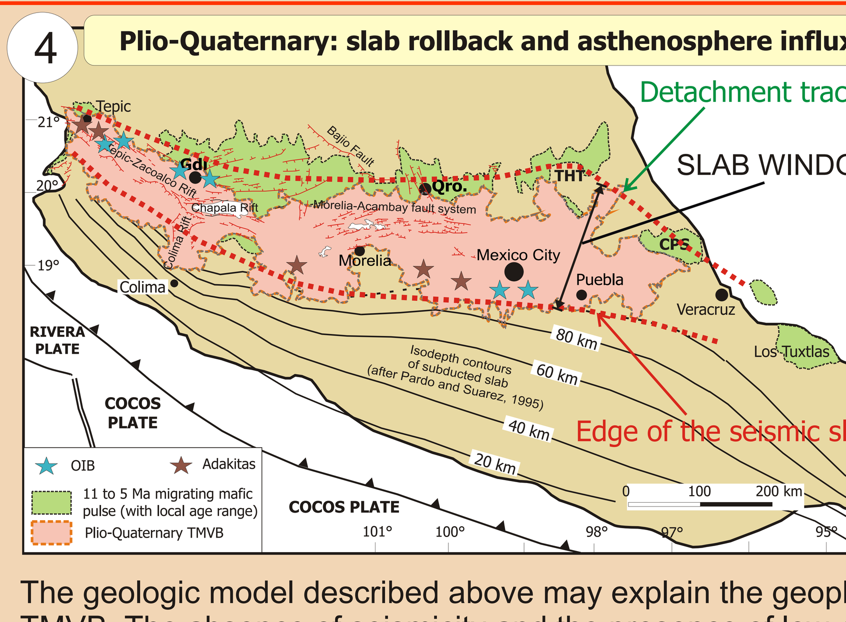


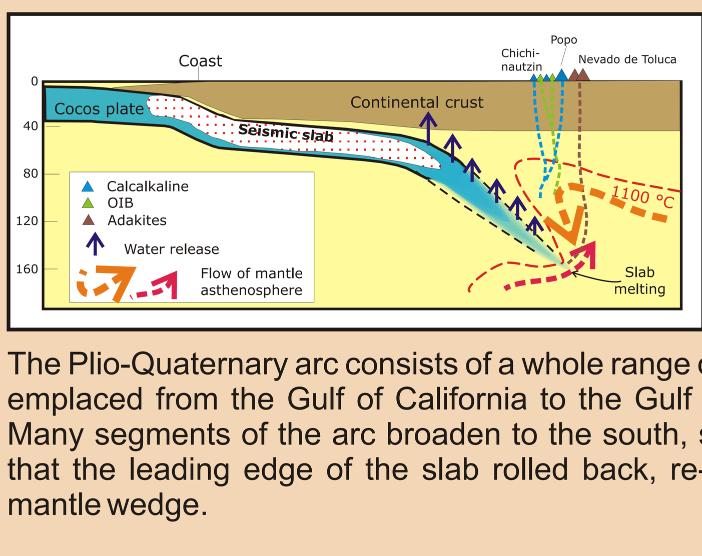




Following the mafic episode volcanism strongly decreased and become more evolved. Dacitic to rhyolitic dome and ignimbrites were emplaced in a belt located just to the south of the previous episode between 7.5 an 3.0 Ma. Dome complexes dominates in the western half of the TMVB, whereas caldera-forming ignimbrites are common to the east. For the western TMVB rhyolites, the available isotope data (87Sr/86Sr = 0.70396-0.70597; εNd = 4.07-5.01) point to a mantle origin with variable lower crust assimilation. This suggests that the latest Miocene switch of volcanism toward more silicic composition was the effect of the observed decrease of subduction rate of the Rivera plate, which is the expected consequence of the loss of slab pull after slab detachment. Decrease in convergence reduced flux of the mantle and amount of melting, so the magma started to pond in the crust and underwent fractional crystallization and variable assimilation.

4 Plio-Quaternary: slab rollback and asthenosphere influx



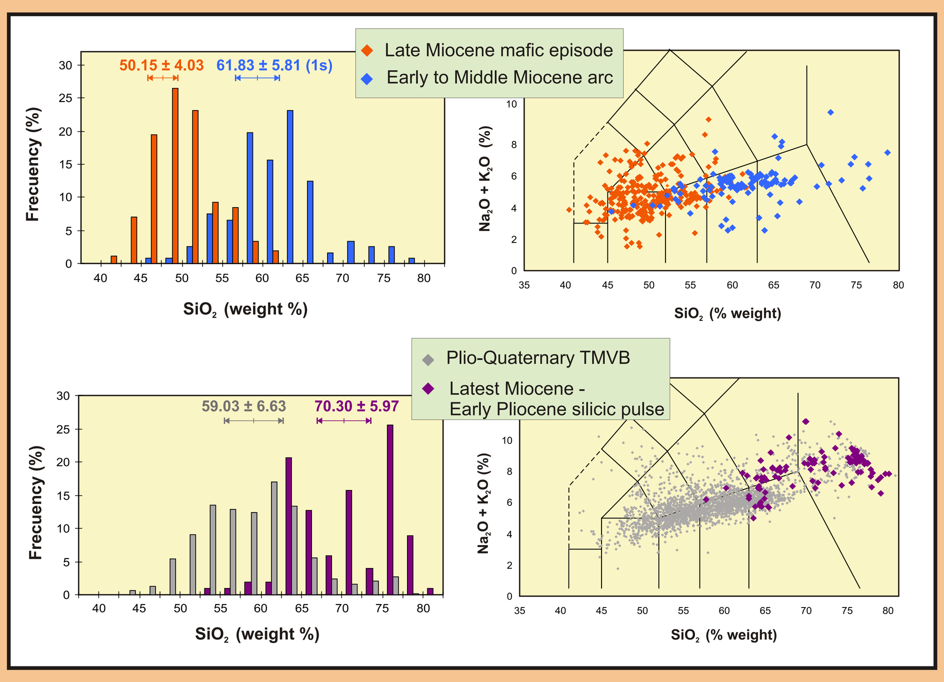


The Plio-Quaternary arc consists of a whole range of products emplaced from the Gulf of California to the Gulf of Mexico. Many segments of the arc broaden to the south, suggesting that the leading edge of the slab rolled back, re-creating a mantle wedge.

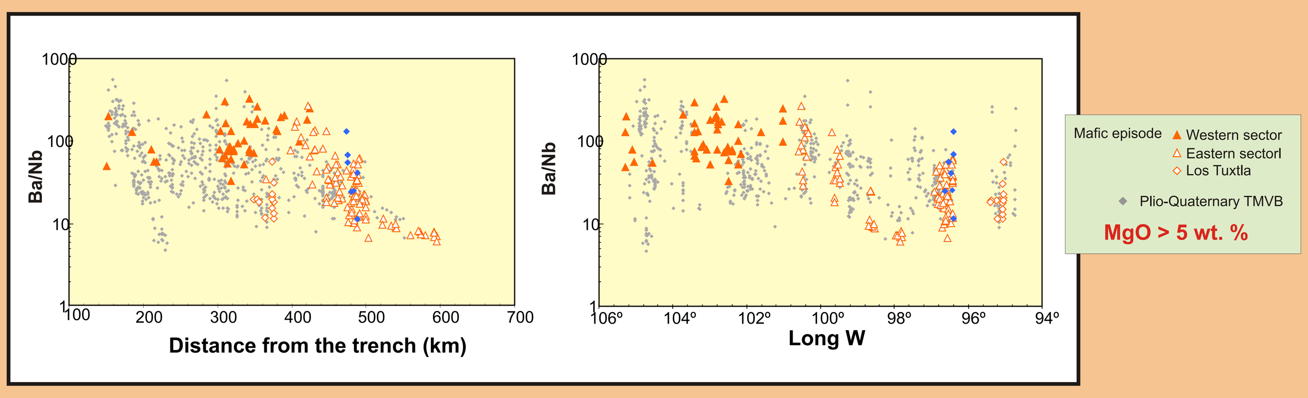
The geologic model described above may explain the geophysical and geochemical characteristics of central Mexico and the TMVB. The absence of seismicity and the presence of low-density mantle beneath the arc are consistent with the detachment model that predicts the upwelling of hot, sub-slab material into the slab gap. Similarly the OIB-type lavas emplaced since 5 Ma are located above a trench-parallel slab window that formed between the inferred detachment trace (the 11-5 Ma mafic pulse) and the leading edge of the present slab as defined by seismicity. In this context, the occurrence of these unusual intra-plate magmas is easily explained by the infiltration of enriched asthenosphere in the sub-arc mantle.

Analysis of geochemical characters of the volcanic episodes in the TMVB

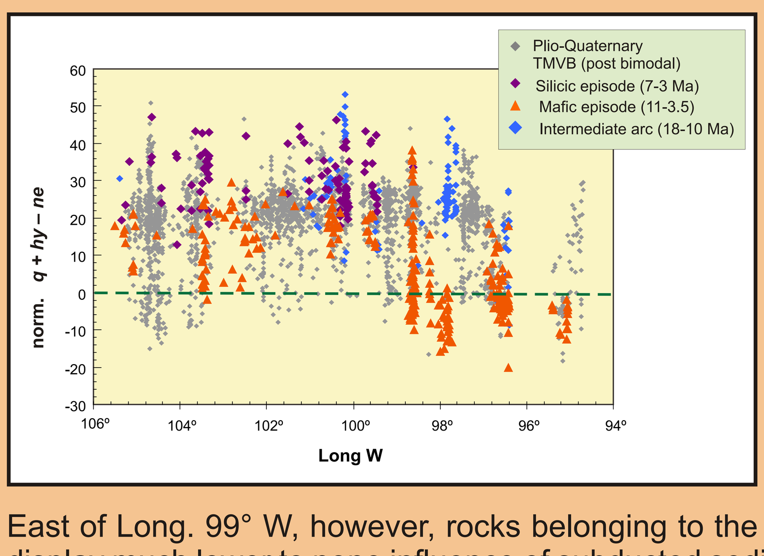
We have analyzed the geochemical character of the four episodes using a compilation of chemical data forabout 3,000 samples.



The mafic pulse is constituted by successions of massive lava flows with a basaltic composition [average SiO_2 = 50.7±4.0(1s)] clearly distinguishable from the successive episodes of silicic composition (average SiO_2 = 70.3±6) and the previous episode of intermediate composition (average SiO_2 = 61.8±5.8).

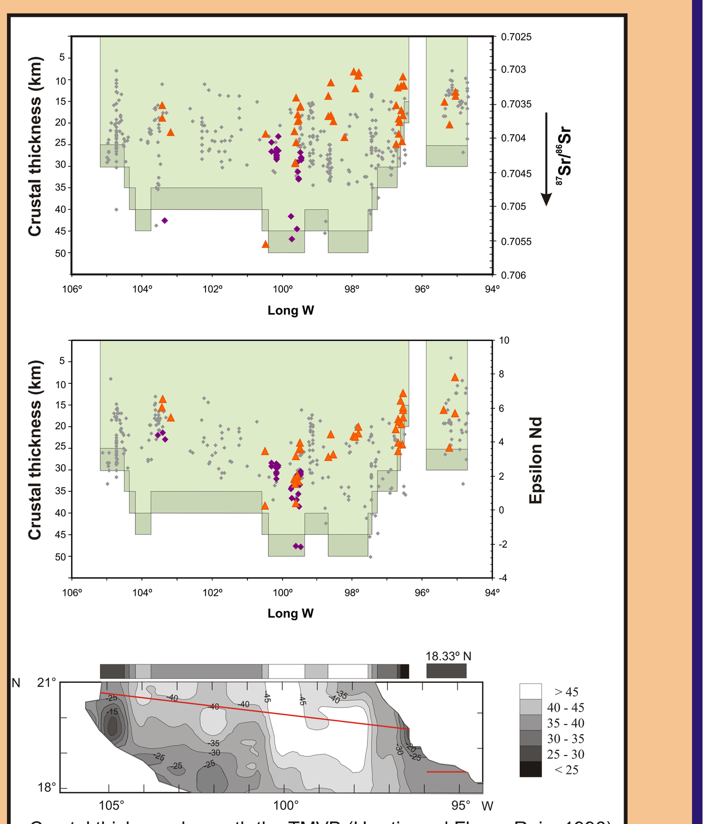


Most basalts have a subduction signature and their range of variation of geochemical parameters lies within that of the rest of TMVB, although they show no systematic correlation with distance from the trench.



East of Long. 99° W, however, rocks belonging to the mafic episode are Ne-normative and display much lower to none influence of subducted sediments and fluids (lower Ba/Nb, La/Nb and Th/Nb). This geochemical boundary separates the region of Oligo-Miocene subduction metasomatism related to the Sierra Madre Occidental (to the west) from the region where the mantle was unaffected by subduction since the Permian.

In the eastern half of the TMVB both basalts and rhyolites show the highest signature of crustal contamination in 87Sr/86Sr and Epsilon Nd values. This region corresponds to the area where crust is thicker and extension was much less intense than in the west or absent. Here partial melting of the crust may play an important role in generating the dacitic to rhyolitic magmas, likely as a consequence of the rollback of the slab that exposed the base of the upper plate to hotter asthenosphere.



Crustal thickness beneath the TMVB (Urrutia and Flores-Ruiz, 1996)

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