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THE EARLY CRETACEOUS SUBAQUEOUS VOLCANISM IN THE PUCUSANA FORMATION, CENTRAL COASTAL RANGES OF PERU: A LATE NEOCOMIAN SLAB WINDOW

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The Lower Cretaceous volcaniclastic facies and restricted distribution of the Pucusana Formation in the Central Coastal Ranges of Peru has always been an interpretation challenge and a puzzle. This unit consist of more than 800 meters of disorganized and stratified volcaniclastic breccias, thick, medium, and thin bedded volcaniclastic sandstone, and thick bedded basalts to andesitic basalt lava flows, with subordinate thin to medium bedded lime mudstone and fossiliferous packstone toward the top. Six distinctive lithofacies in this formation document the evolution of a subaqueous fan-like volcanic apron developed during ensimatic extension contemporaneous with mid-ocean ridge (MOR) oblique subduction during the lattermost Neocomian. It is envisioned that this MOR had an orientation oblique to subparallel to the trench and impinged near the latitude of Mala, The strain partitioning set off by the oblique Farallon Plate convergence gave rise to trench parallel strike slip faults that bounded the Western Peruvian Trough (WPT). At the same time the Trench Ridge Trench (TRT) triple junction migrated northwestward and caused asthenospheric upwelling along the subducted MOR accompanied by pervasive subcontinental lithosphere thinning under the WPT. These coeval tectonic events, complemented by subduction of oceanic fracture zones (transform faults?) provided the driving mechanism to diachronously open the WPT like a zipper. Indeed, the enriched mid ocean ridge basalts (EMORB) and volcaniclastic sequence of the Pucusana Formation was deposited contemporaneous with the emplacement of the lower Cretaceous intrusives (Linga Super Unit). This thinned trough, floored by oceanic crust, was the site of unceasing transtension and large subsidence that latter, during Albian times, was the site of the Casma Group thick volcaniclastic deposition, In fact, the emplacement of the Peruvian Costal Batholith (PCB) used this thinned trough that spawned intrusive and volcanic rocks characterized by the absence of crustal contamination.

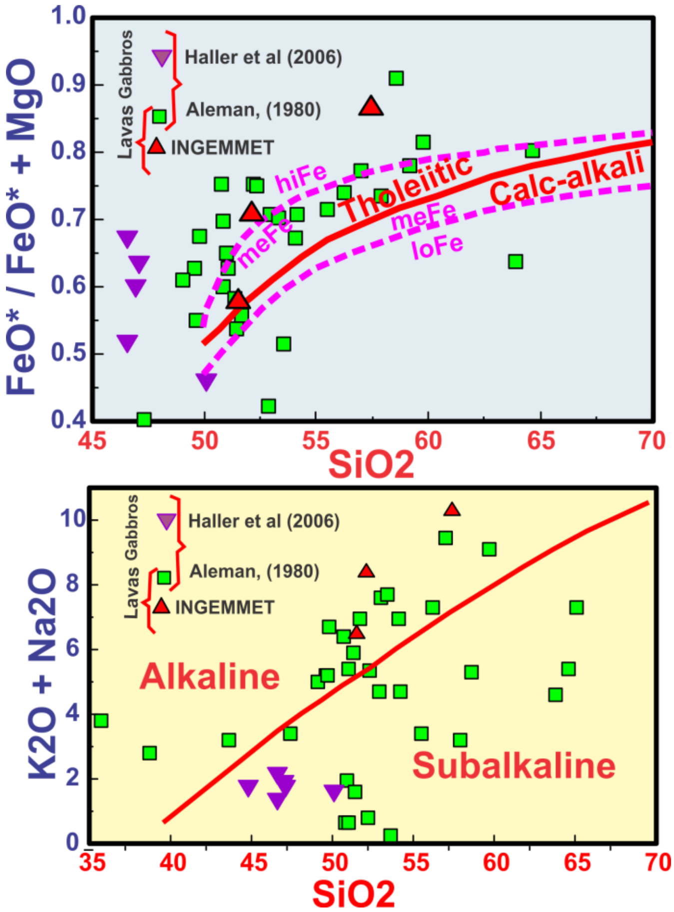

Fig. 1 Binary diagrams to discriminate the tholeiitic and alkaline nature of the Pucusana lavas

This alternative and novel interpretation is not only supported by the well-defined EMORB/Ocean Island Basalt (OIB) on the Rock/Chondrite spider diagram showing a gentle slope that implies the tapping of an undepleted, perhaps deeper mantle but also by 1) a robust Lead isotope database that supports the absence of regional crustal contamination north of the Calicanto Fault including the analysis of lavas and gabbros from the Condestable Mine (De Haller, 206), 2) the absence of old inherited zircon cores (Polliand et al, 2005; De Haller et al, 2006),, 3) the patterns uniqueness for new REE and trace element analysis of the Pucusana Formation (Figs, 1, 2 and 3) the abrupt facies change, and isotope signature of the Casma Group northward of the ridge impinging, and so on. Nevertheless, we must keep in mind the distinctiveness presence of a Neocomian shallow subduction prior to ridge impinging that hindered any contribution from the supra-slab asthenosphere. Therefore, the geochemistry patterns of REE and trace elements is somehow atypical from those described in the literature in an already capricious isotope ratios distribution in areas with steeper subduction angle and more orthogonal relation between the MOR and the trench (Gorring and kay, 2001).

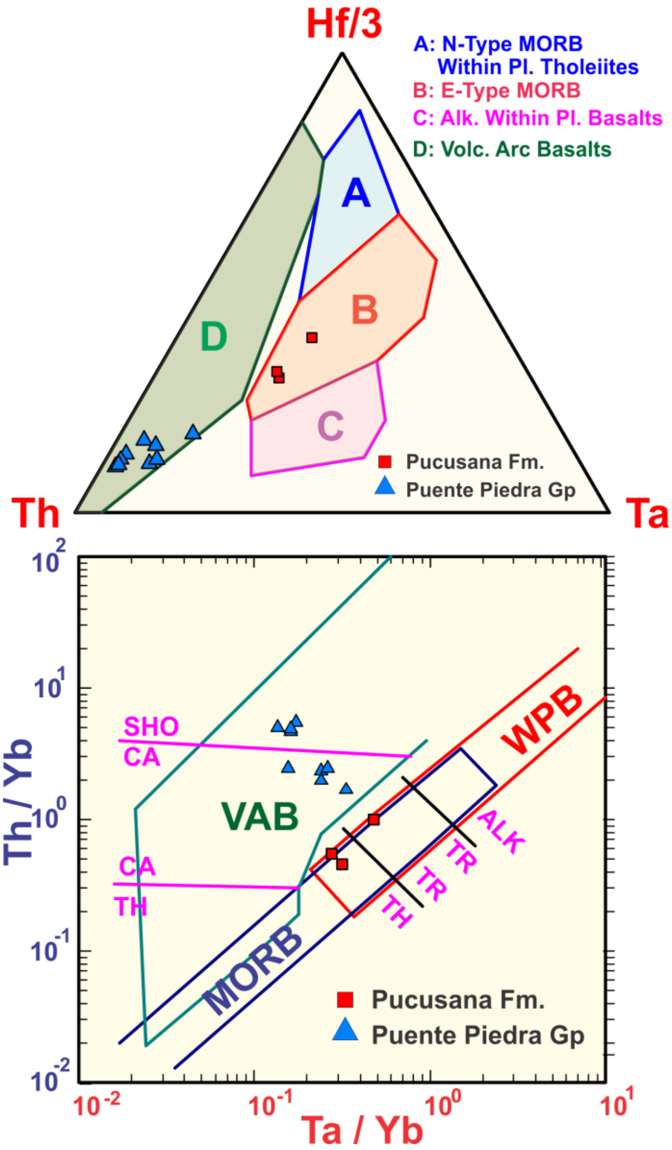

Fig. 2 Hf-Th-Ta ternary diagram (after Wood, 1980) and Th/Yb versus Ta/Yb binary diagram (after Pearce, 1982) that helps in discriminating the geochemical signature of the Pucusana Formation's lavas from the Puente Piedra Group's lavas.

INTRODUCTION

The stratigraphy, facies and geodynamic interpretation of the Pucusana Formation has been a brainteaser because of multiple interpretations ccorrelating this unit with the Jurassic Puente Piedra Group (Bosc, 1963; Rivera et al, 1975; Atherton et al, 1985) or with the Copara Formation (Cardozo, 1990; Romero et al, 2005; De Haller et al 2006). New lines of evidence have documented that this unit is underlain the Morro Solar Group and overlying by the Lurin or Pamplona formations of the Lima Group (Aleman et al, 2004). Furthermore, the age of this unit has been dated (127.1 ± 1.6 Ma) and published from a lava flow we collected in the middle part of the measured section at the type locality (Romero et al, 2006), unfortunately they correlated this unit with the Pamplona and Atocongo formations and ignored the existence of a continuous section along the coast where the Pucusana Formation is overlain by the Lurin Formation, which in turn is overlain by the Pamplona and Atocongo formations, both units having interbedded lavas and volcaniclastics (Aleman et al, 2004). At the Condestable Mine volcanic activity has been dated between 116.7 ± 0.4 and 114.6 ± 1 Ma (De Haller et al, 2006) and the Pucusana Formation is overlain the Morro Solar Group, while less than one kilometer south, the Pucusana Formation is absent at the Perico Hill. Indeed, at this hill there is a continuous sequence that goes from the Morro Solar Group in slight unconformity contact with the Pamplona which in turn is followed by the Atocongo Formation with beautiful coral biostromes capped by volcaniclastics of the Casma Group (Scott and Aleman, 1984, Aleman et al 2004). Further north, around Huacho, there have been some incorrect extrapolation regarding the presence of the Pucusana Formation based on the documentation of lower Cretaceous gabbros and diorites from the Linga Super Unit and poorly constrained seismic interpretation (Llerena et al, 2013).

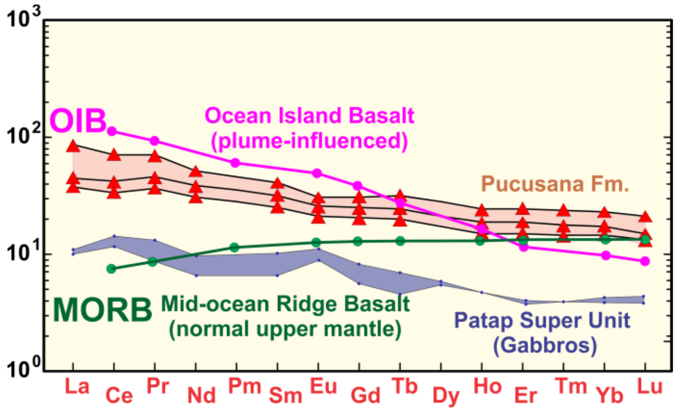

Fig.3. Rock/Chondrite spider plot of the Pucusana Formation compared with the average OIB and N-MORB as well as the gabbros of the Patap Super Unit (Atherton et al, 1979).

Detail facies analysis suggests the occurrence of explosive eruptions from active calderas, which were very close to the shoreline. Although there are several large scale clinoforms and shallow incised channels, the main volcaniclastic deposition took place by subaqueous sediment gravity flow processes and their downslope flow transformations, with many of these flows passing upwards and distally from debris flow and high density flows into beds deposited by more diluted sediment gravity flows and/or fallout from suspension. Multiple lava flows are interbedded with these volcanic breccias and lapilli tuffs (Aleman et al, 2004). They are mainly tholeiitic lavas and vary in composition from subalkaline (subalkaline basalts to dacites) to alkaline (alkali basalt to trachydacite) (Fig. 1). When they are plotted in a binary diagram of Th/Yb versus Ta/Yb (after Pearce, 1982), or in the triangle diagram Hf-Th-Ta (Wood, 1980), the Pucusana Formation are "MORB within plate basalts" and E-type MORB lavas compared to the Jurassic Puente Piedra are mainly "volcanic arc basalts" (fig. 2). Whereas the La/Ta ratio is less than 20, typical of OIB signature

(Gorring and Kay, 2001), the Ba/La and K/Ba ratios is highly variable, perhaps due to the barite mineralization corroborated in the ore deposits of the Condestable Mine (De Haller, 2006). At the Pucusana Beach, while the upper contact of the Pucusana formation is transitional with the thick limestones and evaporites of the Lurin Formation, the base is not exposed. Fortunately, drilling exploration at the Raul/Condesable Mine has corroborated previously inferred contact with the Morro Solar Group (Aleman, 1980, Aleman et al, 2004).

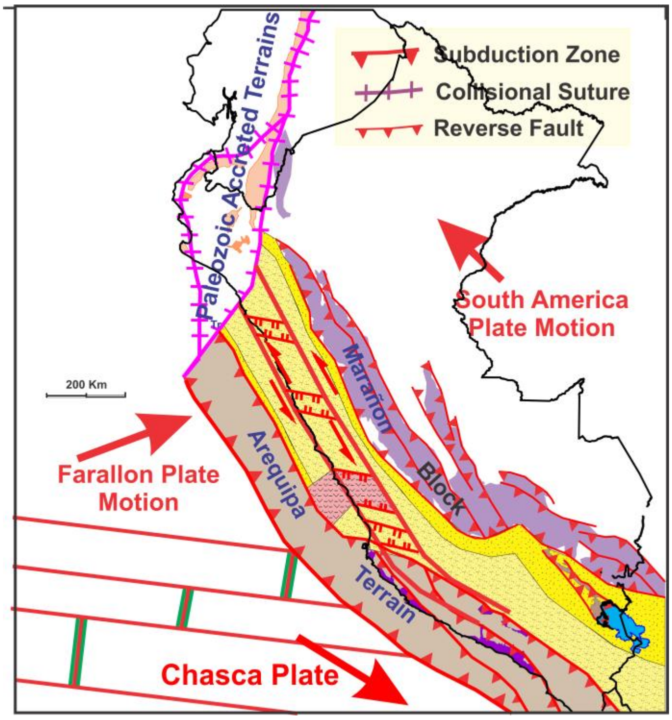

Fig.4. Possible paleogeographic reconstruction during the late Neocomian, showing the subduction of and the oblique approach of MOR. Relative plate motion and the name of the Chasca Plate is after Müller et al, (2016)

Initially, because of the lack of REE and trace elements, and isotope analysis in the lavas of the Pucusana Formation, its geodynamic interpretations varied from an early arc volcanism (Aleman, 1980) to subduction of a fracture zone (Aleman et al 2004). Also, its miscorrelation with the Copara Formation contributed to be interpreted as part of the marginal basin described by Atherton, (1985) (Cardozo, 1990, Romero et al, 2006, De Haller et al 2006). It is important to remark that, although Atherton (1985) suggested thinning of the continental crust, their model did not include opening but instead, an "aborted" marginal basin.

CONCLUSIONS

In our opinion, an oblique MOR subduction during the "Neocomian Flat Slab" provides a viable interpretation that fits the new REE and Trace Element data of the Pucusana Formation volcanism (Fig.3 and 4). Any other interpretation of this Early Cretaceous Volcanism should explain: 1) The restricted distribution of the Pucusana Formation between north of the Calicanto Fault (near Mina Raul/Condestable) and the Pucusana Beach, 2) the gentle slope in the Rock/Chondrite and Rock/MORB spider diagram characteristic of EMORB or OIB (Fig. 3), 3) The absence of subduction slab melting indicators in the Pucusana Formation (Fig. 2 and 3), 4) The mixing trend of Pb isotopes signatures between Nazca Plate MORB and the Pacific Ocean Sediments (Mukasa, 1990; De Haller et al, 2006, Mamani et al, 2010) (Fig. 5), 5) the absence of old inherited zircon cores that precludes any involvement of continental crust which exist at both sides of the WPT (Polliand et al, 2005; De Haller et al, 2006), 6) the presence of significant crustal assimilation in the Arequipa-Toquepala segments south of the Calicanto Fault, (Atherton 1985, Mukasa,1990; De Haller, 2006, Gunnesch et al 1990, Mamani et al, 2010), 7) the presence of lower Cretaceous Igneous activity and intrusives older than the Patap Super Unit, 8) the need to have a mantle-derived material that floored and filled the WPT, 9) the abrupt facies change of the overlain Casma Group at the latitude of Mala (Aleman et al, 2004), 10) continuous basic volcanism as far north as in the Lancones Basin (Morris and Aleman, 1975).

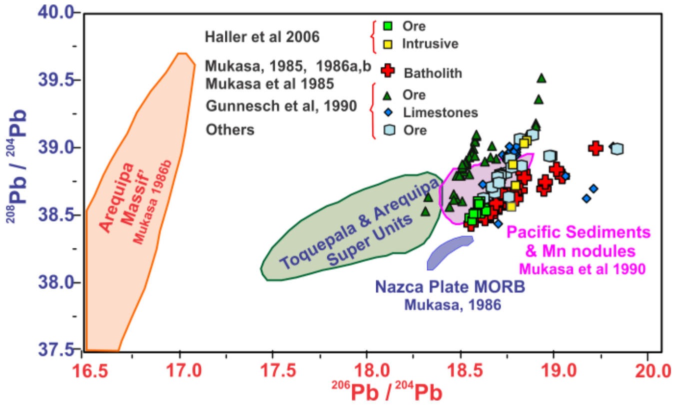

Fig. 5. .Lead isotopes of the Pucusana Formation showing the lack of crustal contamination of the lavas and intrusives away from the Toquepala and Arequipa Super Units of the Coastal Batholith.

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