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Geothermal potential of a passive margin in the Baja California Peninsula, México

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ABSTRACT

Currently regional exploration models utilize Play fairway analysis, and an important parameter to guide the feasibility of an area is the geologic environment; in this context, passive margins have been classified as low heat flow regions unsuitable for geothermal exploration. Nevertheless, they should not be ruled out because heat flow studies have revealed drifting margin locations where high heat discharge generates a promising geothermal resource. The geothermal gradient variation in the passive margins depends on the thermal regime present during the initial rifting processes, the rifting style, the heat generation in the margin crust, and the thermal interaction with the spreading centers.

Recently, intense heat discharge has been determined in three passive margins: the Gulf of California, the Gulf of Aden and the South China Sea. These areas present oblique rifting. In the Gulf of Aden there is presence of recent volcanism and in the Gulf of California southeastern passive margin seismological studies have discovered crustal thinning and intense seismic activity related with active extension. Heat flow measured in the Gulf of California and the Gulf of Aden reaches values above 600 mW·m-2, which makes them suitable areas for geothermal exploration.

The observed heat discharge in some passive margins supports their inclusion as prospective areas for geothermal resources. Here, the anomalous passive margin on the eastern side of the Gulf of California is analyzed as a prospective region for geothermal resources.

1. INTRODUCTION

The documented thermal history of some passive margins points out the occurrence of high geothermal gradients that provide conditions for hydrocarbon maturation, which has been profited by the oil companies to increase the exploration targets to this geological setting. Oil exploration projects have investigated the thermal regime of passive margins of different ages and numerical models of conductive heat transport have shown that high heat flow values are frequent in passive margins during diverse stages of the rifting process (Nemčok et al., 2016). One example of this type of margin is the Ghana Ridge, where modelled thermal history indicates heat flow may have reached values above 200 mW m-2 during some rifting stages even 30 My after the break-up. The variations in the geothermal gradient and heat flow in margins have been investigated also in the Southwest African and the Norwegian margins (Gholamrezaie et al., 2018).

The comparison of the world heat flow map and the location of the identified passive margins shows that there are various locations where passive margins coincide with high heat flow (Fig. 1). Some high heat flow reported examples are the western passive margin of the Gulf of California (Prol-Ledesma et al., 2022), the north-eastern margin of the Gulf of Aden (Lucazeau et al., 2009) and the South China Sea (Zhang et al., 2014), in all of them, Cenozoic oblique rifting processes are related with the formation of the high heat flow passive margins.

The geothermal gradient variation in passive margins depends on the thermal regime present during the initial rifting processes, the rifting style, the heat generation in the margin crust, and the thermal interaction with the spreading centers. The factors that affect heat flow at a passive margin are mainly expressed in features as crustal thickness, Curie Point Depth, relative plate motion record, seismic activity and seismic velocity, and frequently involve the formation of pull-apart basins. In some margins, the presence of hydrothermal manifestations at diverse rifting stages provides information on heat transport mechanisms and thermal history. Oil exploration in passive margins has produced data that disclosed the presence of high geothermal gradients that could be used for exploitation of geothermal energy or for direct uses. Therefore, these tectonic settings should not be directly discarded as unsuitable for geothermal exploration.

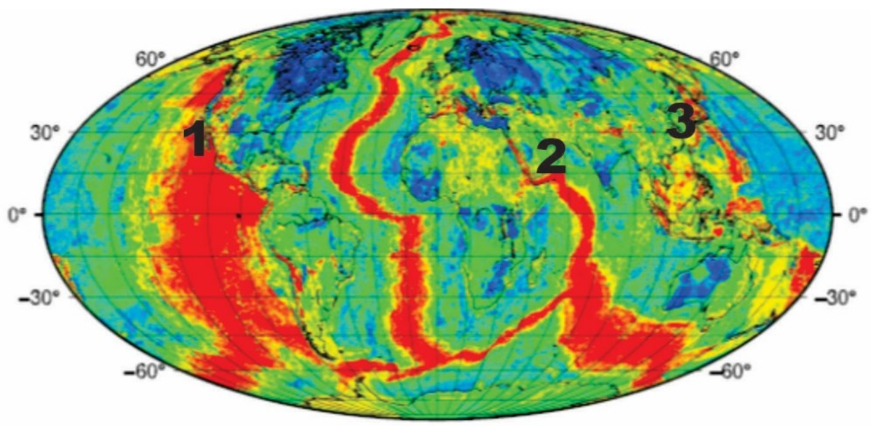

Figure 1: World map of heat flow (Lucazeau, 2019) with the reported areas where passive margins coincide with high heat flow values: 1 – passive margin in the south-western Gulf of California (Prol-Ledesma et al., 2022); 2 – passive margin at the north-eastern margin of the Gulf of Aden (Lucazeau et al., 2009); 3 – passive margin at the South China Sea (Zhang et al., 2014).

The main objective of this work is to provide evidence of the geothermal potential of the south-western passive margin of the Gulf of California that justifies the consideration of this geological setting as prospective geothermal areas.

2. TECTONIC SETTING

The Gulf of California is an oblique rift, which resulted from a complex evolution since the first contact between the paleo-trench and a segment of the east Pacific Rise at 29 Ma. According to the stratigraphic record, strike-slip and transtensional faulting caused continental rupture and the formation of the Gulf of California at ca. 6.3 Ma. Strike-slip motion along the west margin of the BCP has been continuous since at least 5 Ma and has generated transtensional stresses in its southern section that produced an extensional regime that has remained active even after the start of sea floor spreading within the Gulf of California (Michaud et al., 2004). In the period following the opening of the Gulf of California, in the south-western part of the Gulf of California, the Alarcon spreading centre began forming proto-oceanic crust ca. 3–3.5 My, and true sea-floor spreading at present rates started at 2.4 My (Umhoefer et al., 2008), reaching the stage of mature sea floor spreading with a well-developed oceanic crust; therefore, the southern part of the Baja California Peninsula (BCP) is considered a passive margin.

The separation of the East Pacific Rise (EPR) from the southern BCP has been tracked using structural, age and seismic data (Paramo et al., 2008). After the end of subduction of the Farallon Plate, the transcurrent motion between the Pacific and the North America Plates started along the western Baja California margin (Michaud et al., 2004). The Tosco-Abreojos and the San Lázaro-Santa Margarita faults, on the western coast of the BCP, accommodated a large part of the displacement between the Pacific Plate and the Baja California Microplate, and have exhibited continuous strike-slip faulting activity since at least 5 My (Fletcher et al., 2007), this motion in the western margin of the BCP has generated transtensional shearing in its southern section that produced an extensional regime. Fault slip data, and the focal mechanisms of earthquakes along the passive margin confirm that active extension presently occurs (Bonini et al., 2019; Umhoefer et al., 2020).

Regional seismic tomography studies, performed throughout the Gulf of California (Wang et al., 2009, 2013) reveal low seismic velocity anomalies caused by mantle upwelling related with sea floor spreading in the Gulf of California: Wagner-Consag, Delfín and Guaymas basins. Further surface wave tomography studies demonstrated that an important low velocity zone, similar in magnitude to the low seismic velocity observed in the Alarcon spreading centre and in the upper Gulf of California, is located in the southern part of the BCP, nonetheless this area is not on a spreading centre but in the western passive margin; furthermore, in addition to this low seismic velocity in the upper mantle, this area is characterized by intense seismic activity and extensive hydrothermal manifestations, which reveal the presence of important geothermal resources.

3. HYDROTHERMAL MANIFESTATIONS

The thermal regime of passive margins does not follow a homogeneous low heat flow pattern in all cases, the south-eastern coast of the BCP presents active hydrothermal activity along the passive margin and current exploration has pointed out numerous prospective geothermal areas. Figure 2 shows the location of geothermal manifestations where reconnaissance work has been carried out. Many hydrothermal manifestations were discovered during the reconnaissance work, as San Cosme and El Manglar.

The documented surface manifestations are clustered in three areas (Fig. 2): The Las Tres Vírgenes volcanic complex to the north, San Juan Londo Valley to the centre and La Paz-Los Cabos area to the south. A geothermal field is currently under exploitation in Las Tres Vírgenes but there are no advanced exploration or exploitation plans in the rest of the geothermal areas. There are preliminary geoscientific studies in few areas: Bahía Concepción (Prol-Ledesma et al., 2004); San Siquisismunde, El Centavito and Agua Caliente

(Arango-Galván et al., 2015); and La Paz-Los Cabos (Prol-Ledesma et al., 2022), most reports conclude that the exploitation of these resources would make an important contribution to the energy production in the BCP.

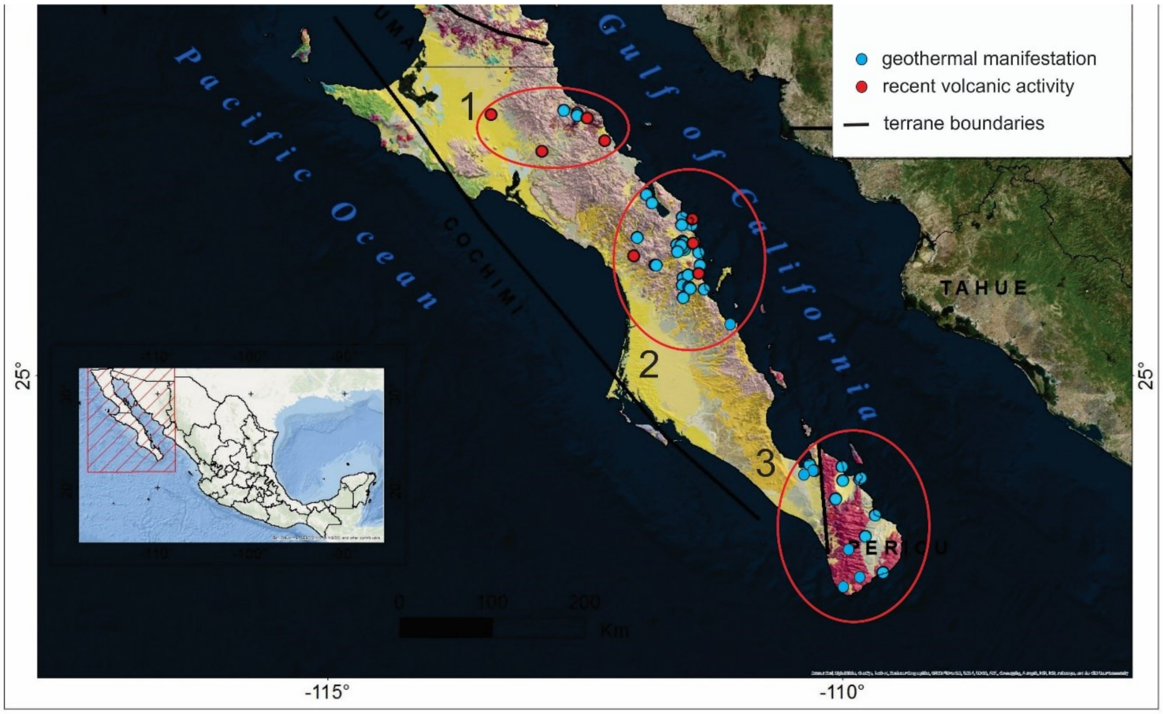

Figure 2: Location of the reported recent volcanic activity and the hydrothermal manifestations on the western Gulf of California passive margin. 1 – Las Tres Vírgenes cluster; 2 – San Juan Londo Valley cluster; 3 – La Paz-Los Cabos cluster.

3.1 San Juan Londo Valley

This cluster includes the geothermal areas: Bahía Concepción, Punta Pulpito, Los Volcanes, San Siquisismunde, El Centavito, Agua Caliente, Punta Mangle and Piedras Rodadas (Fig. 3). Preliminary evaluation of the energy potential of San Siquisismunde, El Centavito, Agua Caliente yields a combined minimum capacity of approximately 400 MWe (Arango-Galván et al., 2015). The capacity of Bahía Concepción geothermal system has not been evaluated, but the deep temperature estimation indicates the reservoir temperature is higher than 200°C (Prol-Ledesma et al., 2004).

Further studies are necessary in Los Volcanes and Piedras Rodadas, where hydrothermal discharge is dominated by vapor and gas with precipitation of silica and carbonates.

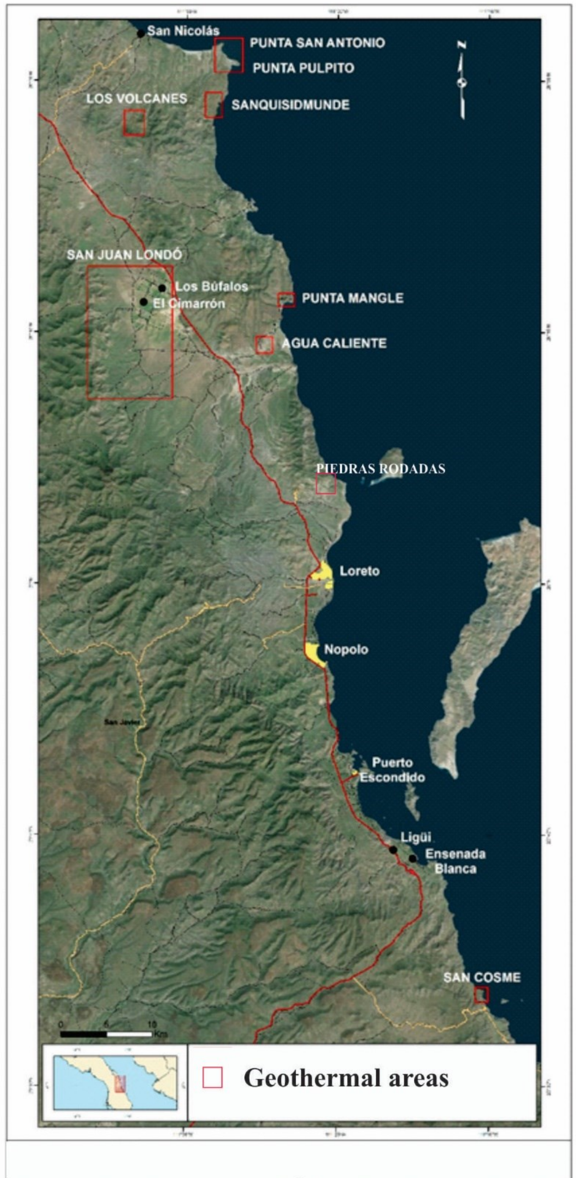

Figure 3: Geothermal areas in the San Juan Londo cluster.

3.2 La Paz-Los Cabos

This cluster includes numerous thermal springs (Fig. 4) that have been chemically and isotopically analysed and the results indicate strong mixing with shallow aquifers (Hernández-Morales and Wurl, 2016; Prol-Ledesma et al., 2022). Their chemical composition has been used for geothermometric estimation of temperature at depth and notwithstanding the mixing processes, calculated temperatures are still above 100°C and in the Los Cabos hot wells, the temperature at depth is above 200°C. This area has rising energy needs, as a highly rated touristic center and presently there is only one plant producing electricity from fossil fuels in spite of its abundant geothermal resources.

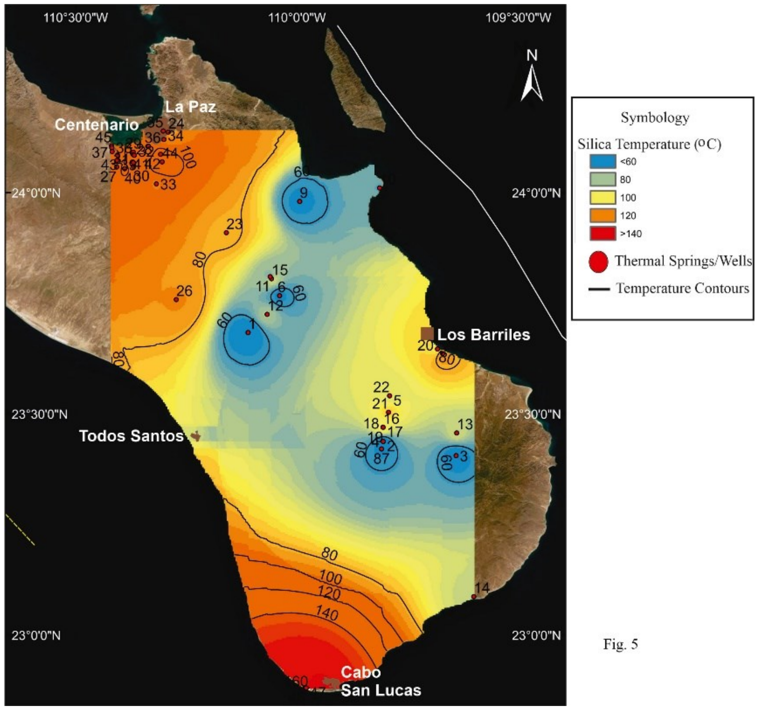

Figure 4: Silica temperature calculated for geothermal manifestations (thermal springs and hot groundwater wells) in the area of La Paz-Los Cabos cluster. (after Prol-Ledesma et al., 2022). Isolines indicate calculated silica temperature.

4. CONCLUSIONS

Studies of passive margins have been focused on tectonic or hydrocarbons exploration, as it has been the case in the Gulf of Aden and the South China Sea. In the southern region of the Baja California Peninsula, most studies have been driven by the complex tectonic setting, but we expect that in the near future advanced geothermal exploration will uncover the vast geothermal potential of this area, as it was revealed by the preliminary reports on the hydrothermal manifestations in this passive margin.

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