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Magmatic–tectonic effects of high thermal regime at the site of active ridge subduction: the Chile Triple Junction model

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Abstract

High thermal gradients are expected to be found at sites of subduction of very young oceanic lithosphere and more particularly at ridge–trench–trench (RTT) triple junctions, where active oceanic spreading ridges enter a subduction zone. Active tectonics, associated with the emplacement of two main types of volcanic products, (1) MORB-type magmas, and (2) calc-alkaline acidic magmas in the forearc, also characterize these plate junction domains. In this context, MORB-type magmas are generally thought to derive from the buried active spreading center subducted at shallow depths, whereas the origin of calc-alkaline acidic magmas is more problematic. One of the best constrained examples of ridge–trench interaction is the Chile Triple Junction (CTJ) located southwest of the South American plate at 46°12′S, where the active Chile spreading center enters the subduction zone. In this area, there is a clear correlation between the emplacement of magmatic products and the migration of the triple junction along the active margin. The CTJ lava population is bimodal, with mafic to intermediate lavas (48–56% SiO_2) and acidic lavas ranging from dacites to rhyolites (66–73% SiO_2). Previous models have shown that partial melting of oceanic crust plus 10–20% of sediments, leaving an amphibole- and plagioclase-rich residue, is the only process that may account for the genesis of acidic magmas. Due to special plate geometry in the CTJ area, a given section of the margin may be successively affected by the passage of several ridge segments. We emphasize that repeated passages will lead to the development of very high thermal gradients allowing melting of rocks of oceanic origin at temperatures of 800–900°C and low pressures, corresponding to depths of 10–20 km depth only. In addition, the structure of the CTJ forearc domain is dominated by horizontal displacements and tilting of crustal blocks along a network of strike-slip faults. The occurrence of such a deformed domain implies that an important tectonic coupling may exist between the upper and the lower plates leading to the partitioning of the continental lithosphere and to the tectonic underplating of very young oceanic lithosphere below the continental wedge. We assume that in the case of the CTJ, the uncommon

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situation of three successive ridge segments entering the trench at 2–3 Ma intervals only resulted in a strong and finally long-lived thermal anomaly. This anomaly caused remelting of underplated portions of very young, still hot oceanic lithosphere. Only particular geometrical RTT configurations are able to produce such features. These include linear continental margin, short ridge segments slightly oblique to the trench and short transform faults. Finally, the CTJ example shows that a possible scenario for the origin of calc-alkaline acidic rocks in the near-trench region involves coeval tectonic coupling and repeated passage of thermal anomalies due to successive subduction of short ridge segments. Therefore, the local abundance of calc-alkaline acidic rocks, associated with MORB-type lavas in ancient series, could be the tracer of plate tectonic configurations involving the subduction of short ridge segments in a relatively short duration.

Keywords: calc-alkaline magmas; spreading ridge; subduction; thermal anomaly

1. Introduction

In the situation of normal oceanic subduction, the downgoing oceanic lithosphere is generally mature and thick and tends to sink passively into the upper mantle. The thermal structure of most subduction zones is characterized by cold temperature regimes and almost all regions of active subduction exhibit thermal gradients among the lowest found at the Earth's surface. However, exceptions to such situations do exist. They can be found at the site of the subduction of very young oceanic lithosphere and more particularily at ridge–trench–trench (RTT) triple junctions, where active oceanic spreading ridges enter a subduction zone. Recent investigations have confirmed that such particular plate configurations lead to complex structural patterns due to specific tectonic–magmatic interactions (Bourgois et al., 2000). Diffuse deformation affecting both the continental and the subducting lithospheres characterizes these plate junction domains. Active tectonics is associated with the emplacement of volcanic products in forearc regions supposed to lack magmatic activity, far away from the volcanic axes of normal arcs. Ridge subduction processes occurred along a large portion of the Pacific margins during the Cenozoic and may have considerably affected the geochemical signatures of the continental lithosphere in the corresponding forearc domains. Therefore, in order to better estimate the consequences of ridge–trench interactions, it is important to study in detail the situations of very young crust or active ridge subduction. In this paper, we attempt to show how recent data collected at a modern RTT junction, the Chile Triple Junction, may help to better constrain the tectonic and magmatic interactions that are expected to occur at such particular plate boundaries in general.

2. Ridge–trench interactions in the past and present

For kinematic reasons, most of the RTT triple junctions are not fixed and tend to migrate at various rates along continental margins. The circum-Pacific region has been affected by the passage of multiple triple junctions due to the drift of the Kula–Pacific–Farallon–Antarctica diverging plate boundaries since at least 60 Ma. Therefore, most of the present-day active margins of Japan, Alaska, California, Central America, Chile and Antarctica have been the sites of ancient interactions between oceanic ridges and trenches. Numerous models of magmatic–tectonic interactions at RTT junctions have been proposed from the analysis of ancient series, such as those exposed in Japan (Hibbard and Karig, 1990; Maeda and Kagami, 1996), Alaska (Moore et al., 1983; Sisson and Pavlis, 1993; Lytwyn et al., 1997), California (Johnson and O'Neil, 1984; Sharma et al., 1991; Cole and Basu, 1992, 1995), Central America (Johnston and Thorkelson, 1997), Antarctica (Hole and Larter, 1993), and South Chile (Herron et al., 1981; Cande and Leslie, 1986; Nelson et al., 1993; Lagabrielle et al., 1994). In these different cases, two main types of magmas can be emplaced within the sediments of the forearc domain, often an accretionary wedge: (1) MORB-type magmas, and (2) calc-alkaline acidic magmas (Hibbard and Karig, 1990; Sisson and Pavlis, 1993; Cole and Basu, 1992, 1995; Lytwyn et al., 1997). MORB-type magmas are generally thought to derive from the buried active spreading center subducted at shallow depths. Calc-alkaline acidic magmas cannot originate as 'normal' arc products because the mantle wedge that produces such arc melts is not present below these regions located close to the trench axis.

Different associations of acidic magmas can be obtained by mixing of these sources. Based on isotopic analyses, various combinations of petrogenetic processes have been proposed to have occurred at the sites of ancient ridge subduction. In most cases, the contribution of oceanic-mantle-derived material to the forearc magmatism has been clearly evidenced. This implies that important transfers of material from the downgoing oceanic plate to the overriding continental lithosphere may occur at RTT junctions.

Three possible mechanisms that may account for the production of the calc-alkaline acidic magmas have been proposed:

1. anatexis of continental material triggered by heating of the crustal wedge above the spreading center buried at depth (Johnson and O'Neil, 1984; Maeda and Kagami, 1996);
2. partial melting of altered oceanic crust and sediments (Forsythe et al., 1995; Harris et al., 1996);
3. assimilation of continental crust coupled with fractional crystallization (AFC) of MORB magmas of oceanic-ridge origin (Sharma et al., 1991; Lagabrielle et al., 1994; Cole and Basu, 1995; Lytwyn et al., 1997).

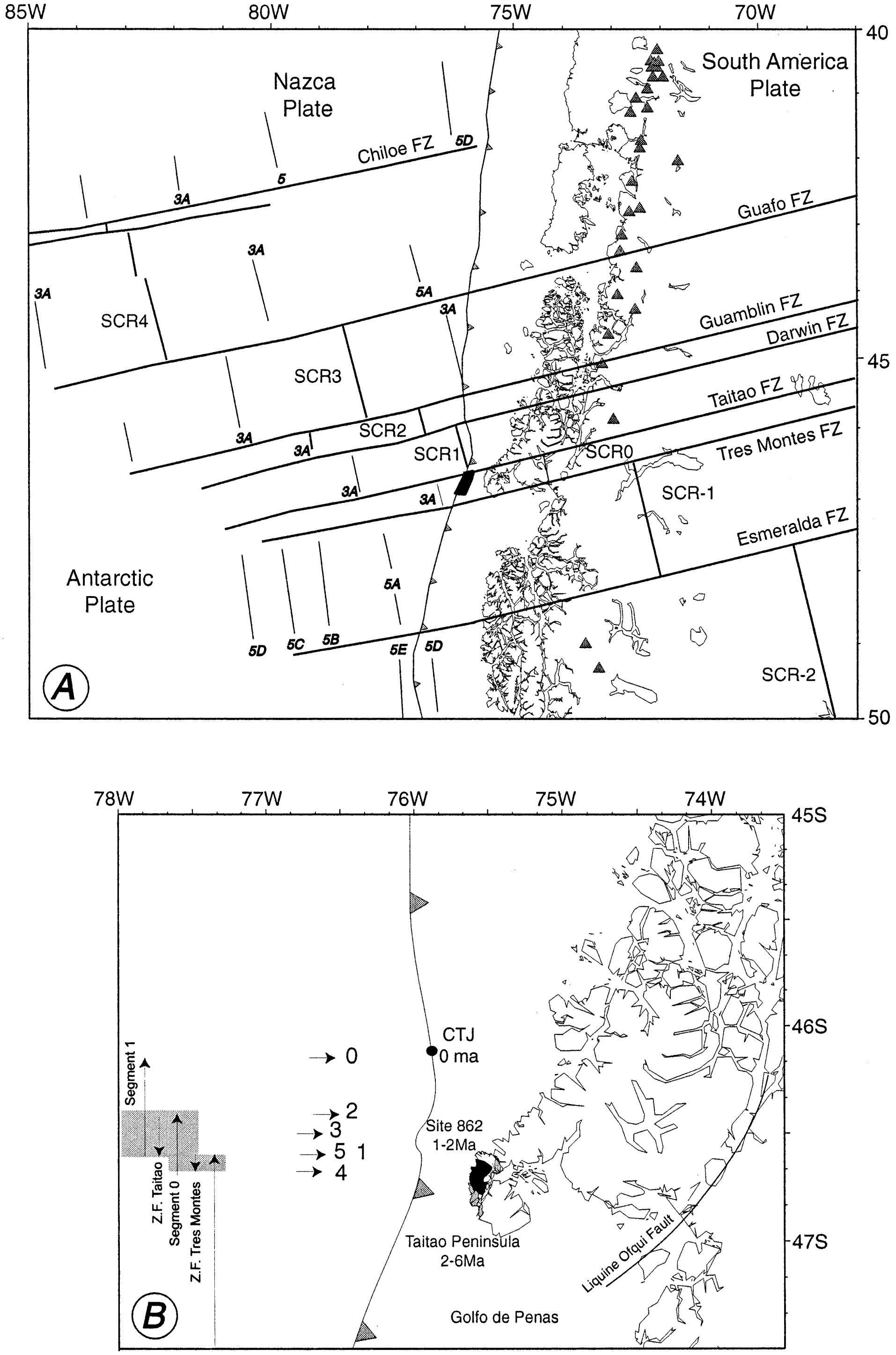
Only four regions in the Pacific hemisphere are the site of present-day interactions between subduction and active seafloor spreading:

1. the region west of Vancouver Island where the Explorer ridge is subducting beneath the North America plate (Kreemer et al., 1998);
2. the portion of the Mid-America Trench where the Cocos–Nazca ridge is subducting beneath the Caribbean Plate (Johnston and Thorkelson, 1997);
3. the eastern part of the Woodlark Basin where a spreading axis is subducting beneath the Solomon arc system (Taylor, 1987);
4. and finally, the South Chile region where the Chile spreading ridge enters the Peru–Chile trench at 46°S (Cande et al., 1987; Nelson et al., 1993; Klein and Karsten, 1995; Bourgois et al., 2000).

3. Chile Triple Junction: repeated subduction of ridge segments and tectonic coupling

One of the best constrained examples of ridge–trench interaction is the Chile Triple Junction located at 46°12′S, which represents the site where the Antarctic, Nazca and South America plates meet (Fig. 1). The segment of the South Chile Ridge (SCR1), which is presently subducting, is oriented N160 and entered the trench ca 0.3 Ma ago. Two short ridge segments were previously subducted at ca 6 and 3 Ma (Cande and Leslie, 1986). Several investigations in the CTJ region during the last 10 years have shown that the subduction of the Chile ridge since 6 Ma has been coeval with the emplacement of magmatic suites and possible ophiolite obduction close to the trench axis (Mpodozis et al., 1985; Forsythe and Nelson, 1985; Kaeding et al., 1990; Bourgois et al., 1993, 1996; Nelson et al., 1993; Lagabrielle et al., 1994; Le Moigne et al., 1996) (Fig. 2). Extremely fresh acidic magmatic products have been dredged recently in the trench at different localities (Fig. 3) located only several kilometers away from the triple junction (Bourgois et al., in press; Guivel, 1999). Similar products, ranging in age from ca 1.5 to 6 Ma, are present 10–50 km south of the triple junction in areas of the margin that have been interacting with the subducting ridge since 6 Ma (Berhmann et al., 1992; Guivel et al., 1999).

There is a clear correlation between the emplacement of magmatic products and the migration of the triple junction along the margin, as already emphasized by previous authors (Mpodozis et al., 1985; Nelson et al., 1993). To better discuss this correlation, attention must be paid to the particular geometry of the spreading ridge relative to the trench. Since 6 Ma, the Chile ridge entering the trench has consisted of short segments separated by fracture zones trending N80–N70. This implies that in the transform–trench–trench configuration, the junction migrates southward (Cande and Leslie, 1986; Forsythe et al.,

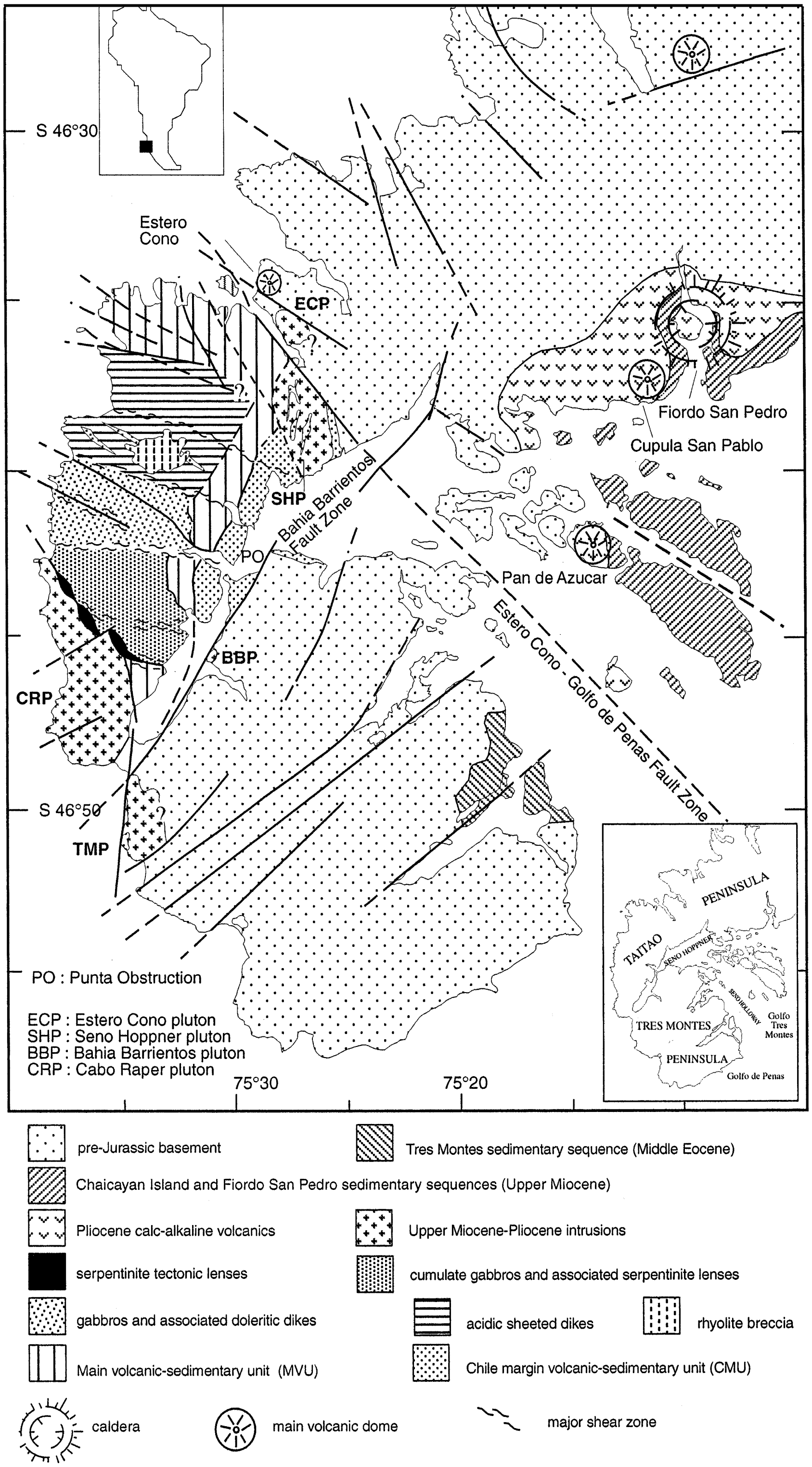

85W
80W
75W
70W
40
45
50
Nazca Plate
South America Plate
Antarctic Plate
Chiloe FZ
Guafo FZ
Guamblin FZ
Darwin FZ
Taitao FZ
Tres Montes FZ
Esmeralda FZ
SCR4
SCR3
SCR2
SCR1
SCR0
SCR-1
SCR-2
3A
5
5D
5A
5B
5C
5E
A
78W
77W
76W
75W
74W
45S
46S
47S
CTJ 0 ma
Site 862 1-2Ma
Taitao Peninsula 2-6Ma
Golfo de Penas
Liquine Ofqui Fault
0
2
3
5 1
4
Segment 1
Z.F. Taitao
Segment 0
Z.F. Tres Montes
B

1986; Nelson et al., 1993). This has a major consequence as a given section of the margin may be successively affected by the passage of several ridge segments. Indeed, kinematic reconstructions show that south of the present-day Chile Triple Junction, a section of the margin, only 100 km long, has been the site of the subduction of three successive ridge segments (Cande and Leslie, 1986). Fig. 1B shows that forearc acidic rocks are located where the triple junction migrated alternatively to the north and to the south between 6 Ma and the Present. According to thermal models by De Long et al. (1979), the temperature increase due to ridge subduction in the near forearc region at 10–40 km from the trench is at a maximum 1–2 Ma after the ridge crest entered the trench and may reach 600°C at 20 km depth. Therefore, repeated passages may lead to the development of very high thermal gradients. This may allow melting of rocks of oceanic or continental origin due to temperature conditions of 800–900°C and low pressures, corresponding to depths of 10–20 km depth only.

Of particular importance is the fact that parts of the forearc region south of the present-day triple junction are highly deformed. Field investigations in the Taitao and Tres Montes Peninsulas have revealed a set of recent conjugate ductile shear zones, suggesting strong tectonic coupling between the downgoing oceanic crust and the upper continental crust. The limit between the Tres Montes and Taitao Penisulas corresponds to a shear corridor up to 3 km wide, called the Bahia Barrientos fault zone (Fig. 2) (Bourgois et al., 1993; Nelson et al., 1993). Folded and verticalized siltsones and interbedded lavas of Pliocene and lower Pleistocene age are exposed along the northern shore of Bahia Barrientos (Bourgois et al., 1993). These rocks are part of the Chile Margin volcanic-sedimentary unit, as defined by Bourgois et al. (1993) and Lagabrielle et al. (1994). Kinematic features, such as sedimentary strata offset along repeated vertical faults, are well-exposed in some places, such as at Punta Obstruction (Fig. 2). They indicate dextral motion within the fault zone. This fault zone parallels the southern termination of the Liquine-Ofqui fault (Fig. 1B), the 1000 km long strike-slip fault of the southern Andes that connects to the trench south of the Golfo de Penas (Cembrano et al., 1996). Additional fault zones, with rather similar orientations, are observed within the Tres Montes Peninsula and in the Golfo de Penas where they are associated with a subsiding sedimentary basin. At the site of the present-day triple junction, a major vertical fault, the Taitao Canyon fault, connects to the trench axis immediately south of the point where the subducting ridge segment SCR1 disappears below the inner wall (Fig. 4). This fault can be considered as a present-day active equivalent of the Bahia Barrientos fault zone or of the southern termination of the Liquine-Ofqui fault, both related to previous positions of the triple junction to the south (Fig. 4). Another major fault zone is the Estero Cono-Golfo de Penas Fault zone, trending N140, which corresponds to the northeastern boundary of the ophiolite body against the continental basement (Fig. 2).

Numerous conjugate vertical faults are also present within the Bahia Barrientos ophiolite itself. They consist of 50–100 m wide dextral ductile shear zones, trending N110–130 and showing typical imbricated tectonic phacoids of gabbros and serpentinites. They are well exposed along the shore of Bahia Barrientos. Ductile shear zones are also observed within the Pliocene plutons, where shear sense criteria such as S/C plane relationships can be analyzed in some localities. Although no detailed study has been achieved at a regional scale for reasons of difficult access, shear sense criteria

Fig. 1. (A) Simplified map showing the main oceanic features of the Nazca and Antarctica Plates along Southern Chile with the continuation of structures under the continental lithosphere. SCR-2 to SCR4 designate the segments of the Southern Chile active spreading ridge (SCR). Labels SCR-2 to SCR0 refer to the segments that are already subducted. (B) Detailed map showing the successive locations of the Chile Triple Junction (CTJ) at different ages in My (labels on horizontal arrows). The age ranges of calc-alkaline volcanic rocks sampled in the Taitao Peninsula, drilled at ODP Site 862 or dredged during the CTJ cruise of R/V l'Atalante are indicated. LOF: Liquine-Ofqui fault.


S 46°30
S 46°50
75°30
75°20
Estero Cono
ECP
SHP
BBP
CRP
TMP
PO
Bahia Barrientos Fault Zone
Estero Cono - Golfo de Penas Fault Zone
Fiordo San Pedro
Cupula San Pablo
Pan de Azucar
PO : Punta Obstruction
ECP : Estero Cono pluton
SHP : Seno Hoppner pluton
BBP : Bahia Barrientos pluton
CRP : Cabo Raper pluton
TAITAO
PENINSULA
SENO HOPPNER
SENO HOLLOWAY
TRES MONTES
PENINSULA
Golfo Tres Montes
Golfo de Penas
pre-Jurassic basement
Tres Montes sedimentary sequence (Middle Eocene)
Chaicayan Island and Fiordo San Pedro sedimentary sequences (Upper Miocene)
Pliocene calc-alkaline volcanics
Upper Miocene-Pliocene intrusions
serpentinite tectonic lenses
cumulate gabbros and associated serpentinite lenses
gabbros and associated doleritic dikes
acidic sheeted dikes
rhyolite breccia
Main volcanic-sedimentary unit (MVU)
Chile margin volcanic-sedimentary unit (CMU)
caldera
main volcanic dome
major shear zone

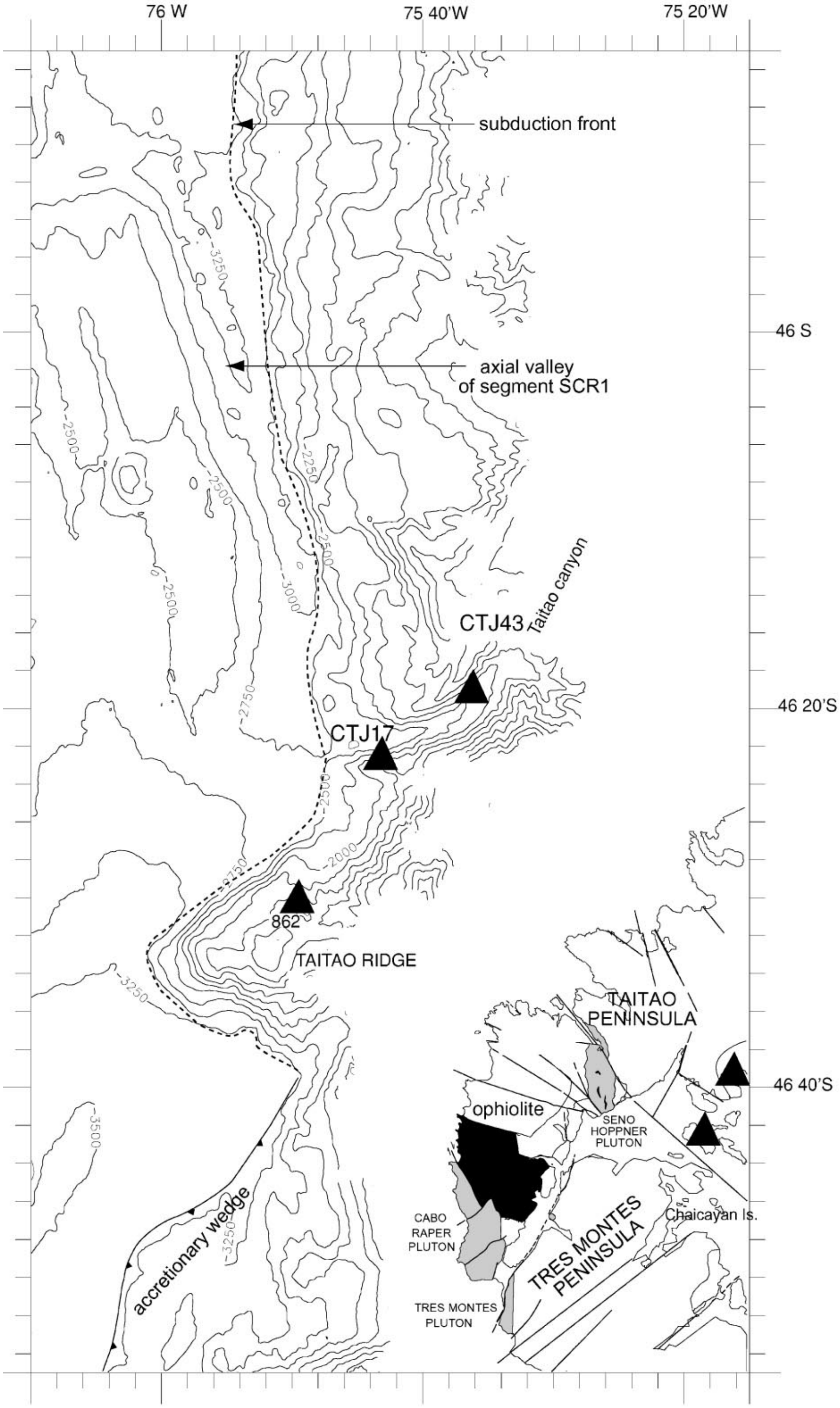
obtained along ductile faults in the Seno Hoppner pluton and in the northernmost exposures of the Cabo Raper pluton are consistent with fossil extension in a N80 direction, in response to possible motions along a buried spreading segment at depth.

In addition to horizontal movements, a large amount of evidence for uplift of continental basement, probably as consequences of block tilting, has been observed. In the case of the Bahia Barrientos fault zone, continental rocks forming most of the Tres Montes Penisula basement are juxtaposed against obducted ophiolites of the Taitao Peninsula (Fig. 4). This implies that relatively rapid motions occurred in response to ridge subduction, leading to the uplift of the continental basement of the northern edge of the Golfo de Penas. More recent vertical offsets occurred along the Taitao Canyon fault, as revealed by results of dredging during the CTJ cruise. Continental basement is exposed along the southern flank of the Taitao canyon, whereas greenschist-facies basalts of MORB affinity are exposed along its northern flank (Bourgois et al., in press).

The structure of the fore-arc domain is therefore dominated by horizontal displacements and tilting of crustal blocks along a network of strike slips faults. The occurrence of such a deformed domain implies that an important tectonic coupling may exist between the upper and the lower plates, leading to the partitioning of the continental lithosphere. Such coupling has been confirmed by seismological investigations in the fore-arc region immediately overlying the buried segment of the Chile ridge at the latitude of the triple junction (Murdie et al., 1993). Microseismic data have confirmed that present-day displacements along conjugate faults within the continental wedge are consistent with E–W extension at the subducted ridge segment SCR0. Strong coupling has also been demonstrated to occur immediately south of the triple junction itself, where tectonic slices of oceanic crust and sediments are presently accreted to the margin, forming the prominent Taitao Ridge. Site 862 of ODP Leg 141 drilled the upper section of the Taitao Ridge and recovered sediments and overlying oceanic basaltic lavas interlayered with lavas of more acidic compositions. The origin of the Taitao Ridge has been debated before its internal structure was known (Bangs et al., 1992). Forsythe et al. (1995) pointed out that geophysical data suggest that the Taitao Ridge consists of dense igneous rocks and could represent an equivalent of the Bahia Barrientos ophiolite exposed on the Taitao Peninsula. Drilling results obtained at Site 862 confirmed the geochemical similarities between the Taitao Ridge lavas and lavas exposed sub-aerially, on the Taitao Peninsula (Forsythe et al., 1995; Guivel, 1999). These results suggest that the Taitao Ridge is a nascent ophiolite in the process of being uplifted and tectonically emplaced within the fore-arc domain. Six channel seismic lines shot during the CTJ cruise of R/V l'Atalante in 1997 (Bourgois et al., 1997, in press) have confirmed that the Taitao Ridge consists of at least three superposed tectonic units separated by gently dipping thrust faults that delineate two N145-trending ridges. The lowest units have a seismic signature of acoustic basement, and the upper unit shows a typical section of oceanic basement and its sedimentary cover. Dredges performed along the flanks of the Taitao Ridge recovered lavas of various compositions (basalts and andesites) and volcaniclastic sediments, demonstrating the oceanic origin of this structure (Guivel, 1999).

According to the results obtained on the structure of the Taitao Ridge, we assume that the emplacement of the Bahia Barrientos ophiolite exposed on the Taitao Peninsula is the consequence of tectonic coupling during ridge–forearc interactions that occurred several Ma ago when the Chile Triple Junction was located farther south. From age data obtained on plutonic rocks that cross-cut the ophiolite (Mpodozis et al., 1985; Guivel et al., 1999), this obduction may have occurred around 6–7 Ma.

Fig. 2. Geological map of the Taitao Peninsula based on a compilation of results from field studies by different authors (Mpodozis et al., 1985; Bourgois et al., 1993; Nelson et al., 1993; Guivel et al., 1996; Le Moigne et al., 1996).


76 W
75 40'W
75 20'W
46 S
46 20'S
46 40'S
subduction front
axial valley
of segment SCR1
3250
2500
2500
2250
2250
2500
2500
3000
2500
2750
Taitao canyon
CTJ43
CTJ17
2500
2000
2750
862
TAITAO RIDGE
3250
3500
3250
accretionary wedge
TAITAO
PENINSULA
ophiolite
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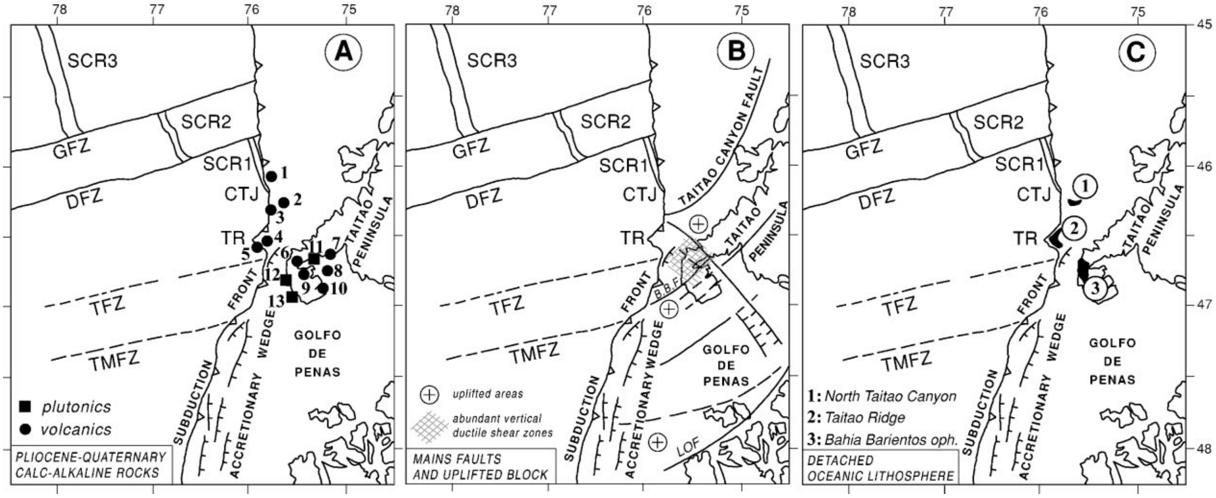


Fig. 4. Synthetic maps around the Taitao Peninsula showing the main magmatic–tectonic features related to spreading ridge subduction processes that affected the Chile margin during the Upper Miocene to the Present. (A) Location of the Pliocene to Quaternary calc-alkaline magmatic rocks. (1) basaltic andesites, volcano (DR-CTJ28); (2) dacites, North Taitao Canyon (DR-CTJ43); (3) dacites, North Taitao canyon (DR-CTJ17); (4) basalts and dacites/rhyolites from Leg ODP141, Site 862; (5) andesites from Taitao Ridge (DR-CTJ11); (6) Bimodal dike complex, Taitao Peninsula; (7) Fiordo San Pedro, Cupula San Pablo; (8) Pan de Azucar; (9) Main volcanic-sedimentary Unit; Chile Margin Unit; (10) Peninsula Launquen; (11), (12), (13) Seno Hoppner, Cabo Raper, Tres Montes plutons. (B) Main faults and uplifted blocks as discussed in text (B.B.F.: Bahia Barientos Fault; LOF: Liquine-Ofqui Fault). (C) Location of sections of oceanic lithosphere supposed to have been tectonically detached and incorporated to the forearc region during ridge-trench interaction.

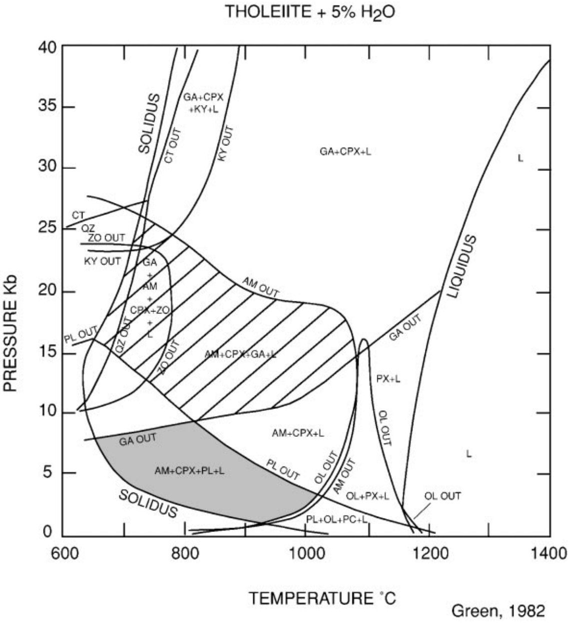
4. Discussion: conditions for forearc magmatism linked to ridge subduction

4.1. Source and pressure conditions

Isotopic data for Chile Triple Junction volcanic rocks of different ages plot within a rather restricted range ($^{87}Sr/^{86}Sr$: 0.702658–0.704995; $^{143}Nd/^{144}Nd$: 0.513151–0.512686, $\delta^{18}O$: +5.7 to +6.93% (Guivel, 1999). These data suggest that the Chilean continental basement is not involved as a major component of the magma sources. The CTJ lava population is bimodal with mafic to intermediate lavas (48–56% SiO_2) and acidic lavas ranging from dacites to rhyolites (66–73% SiO_2). The acidic lavas display $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ ratios higher than those of mafic to intermediate lavas, together with consistently lower $^{143}Nd/^{144}Nd$ ratios. These features suggest that acidic lavas cannot exclusively result from closed system fractional crystallization of basaltic magmas, and the variation observed for $^{143}Nd/^{144}Nd$ ratios seems inconsistent with their derivation from a mixture of depleted mantle plus altered oceanic crust. However, Forsythe et al. (1995) considered that the acidic lavas recovered from the Taitao Ridge during Leg ODP 141 (Site 862) derive from the remelting of altered basalts containing crustal components found in association with the acidic lavas. Our calculations based on trace elements and isotopic data (Guivel et al., 1999; Guivel, 1999) show that partial melting of oceanic crust plus 10–

Fig. 3. Compilation of geologic and bathymetric data in the CTJ region with location of acidic lavas emplaced in both trench and forearc domains close to the triple junction. Detailed bathymetric data were obtained during the cruise CTJ of R/V l'Atalante in 1997 (Bourgois et al., 2000). Labels CTJ refer to samples dredged during the CTJ cruise, and 862 refers to drilling site ODP862 on the Taitao Ridge.

20% of sediments is the only process that may account for the observed compositions. Such a blend has already been suggested as representative of the most likely source of the Austral Volcanic Zone (AVZ) adakites (Stern and Kilian, 1996). However, the unique feature of the partial melting processes beneath the CTJ is that they occurred at shallow depths. Indeed, the compositions of the CTJ acidic lava are only reproduced, in our calculations, by using the experimental results of Beard and Lofgren (1991) under pressures of 3 kb and with excess H_2O (Guivel, 1999). Under these conditions, 30–40% melting produces acidic liquids, and leaves an amphibole- and plagioclase-rich residue (Fig. 5). These conditions can be considered as appropriate for the genesis of CTJ acidic lavas. High amounts of water are likely to be available in this tectonically complex situations where slices of oceanic lithosphere (including serpentinized ultramafic rocks, as observed in the Taitao Peninsula) are incorporated in the forearc region.



Green, 1982

Fig. 5. Pressure–temperature diagram showing experimental phase relations for dry and wet basalts melting by Green (1982). The shaded area corresponds to P–T conditions to induce partial melting of basalts at shallow depth, and the hatched area corresponds to P–T conditions for adakitic-magma genesis.

4.2. Temperature conditions

Remelting of oceanic rocks at shallow depth should be possible only when portions of oceanic lithosphere are submitted to abnormal conditions of a very high thermal gradient with temperatures ranging between 850 and 950°C. These conditions may occur if slices of very young, and still hot, oceanic lithosphere are first underplated below the continental wedge and subsequently submitted to thermal anomalies due to ridge subduction. Thermal results obtained from ODP Leg 141 indicate high temperature gradients of 80–100°C/km at sites 859 and 863 at the toe of the continental wedge, immediately above the subducted oceanic crust. The thermal signatures show rapid variations associated with strong convective fluid circulation. This confirms that anomalously high temperatures can be expected close to the décollement, a few kilometers within the continental wedge. Evidence for high temperatures is also found on the Taitao Peninsula, where hot springs are present. Water collected from springs in the Seno Hoppner pluton reaches temperatures up to 94°C, and the chemical composition indicates that this water circulated at depth within oceanic crust (J. Boulègue, unpublished results).

Tectonic underplating might occur preferentially where high mechanical coupling allows tectonic forces to detach slices of very young oceanic lithosphere below the continental wedge. Such scenarios have already been considered in theoretical models of interactions between continental lithosphere and very young oceanic plates (van den Beukel, 1990; van den Beukel and Wortel, 1992). We have stressed the strong tectonic imprint in the region of the CTJ as revealed by previous investigations both onland (Taitao Peninsula) and at sea on the Taitao Ridge. Such a tectonic imprint confirms that high coupling between the continental and the oceanic lithosphere occurred there during the successive subduction of spreading ridge segments (Fig. 6). The thermal anomaly due to the subduction of one ridge segment may not be sufficient to allow important re-melting of oceanic rocks by itself, and we suspect that a second passage is needed for acidic magma genesis. We suppose that the uncommon situation of three successive ridge segments entering

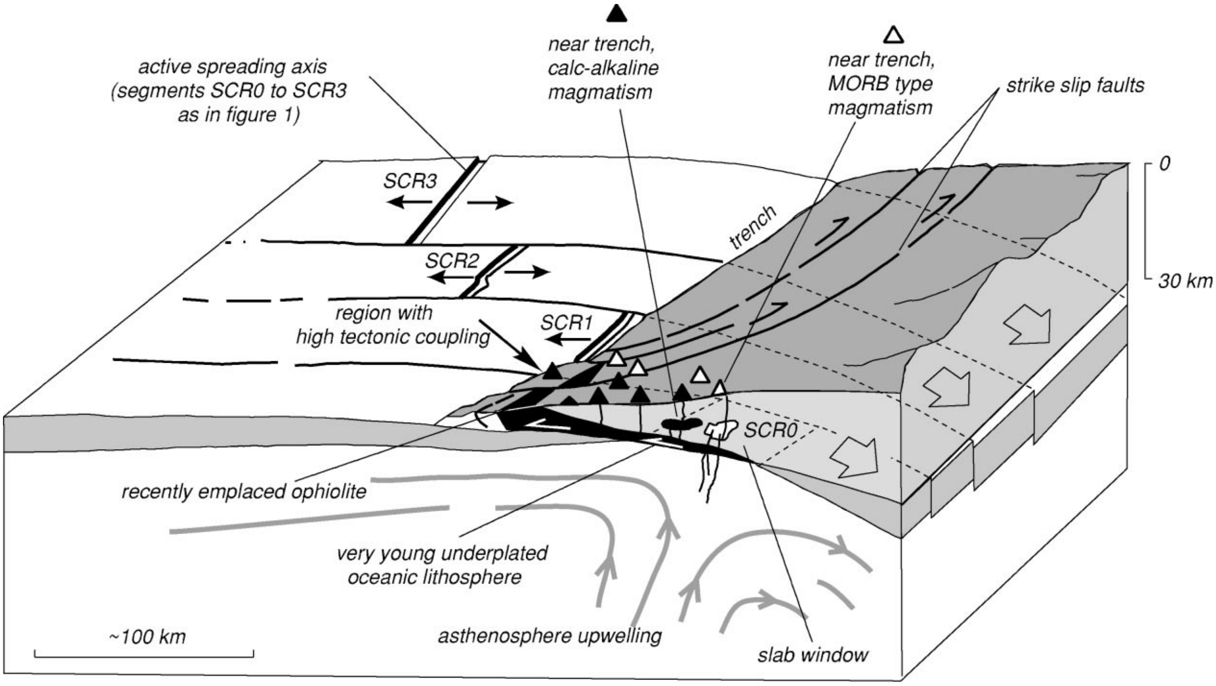


Fig. 6. Idealized block diagram based on the Chile Triple Junction region showing the main important magmatic–tectonic processes that may occur during subduction of an active spreading ridge below a continental margin. Calc-alkaline acidic rocks originate from the partial melting of very young, still hot, oceanic lithosphere (and sediments) trapped as tectonic slices at the base of the continental crust. Associated MORB-type lavas are emplaced directly from the buried spreading segment at depth. Only plate tectonic configurations involving oblique subduction of short ridge segments in a relatively short duration may account for such processes.

the trench at 2–3 Ma interval only, in a given region of the fore-arc, may lead to a strong and long-lived thermal anomaly. A similar non-steady-state thermal evolution of the melting zones occurs beneath slow-spreading ridges. This evolution has been studied by numerical models that simulate successive cycles of reheating followed by cooling. It is shown that the computed melt fraction will not decrease below 5–10% in cases where thermal input is separated by periods of 700 kyr (Tisseau and Tonnerre, 1995). Of course, only very particular geometric RTT configurations are able to produce such scenarios. The required set of conditions includes a linear continental margin, short ridge segments slightly oblique to the trench and short transform faults.

Finally, a possible scenario for the origin of calc-alkaline acidic rocks in the near-trench region — where this type of magmas is not expected normally to occur — involves coeval tectonic coupling and repeated passage of thermal anomalies due to successive subduction of short ridges segments (Figs. 6 and 7). Tectonic coupling leads to the underplating of very young, hot lithosphere at the toe of the continental margin, while repeated ridge subductions favors the re-melting of the underplated oceanic material. Such situations are extremely rare at present. In particular, the present-day Explorer Ridge and Cocos–Nazca boundary subduction zones do not seem to fit with the scenario described here, because in both cases the geometry of the ridge axis and transform faults is not similar to the CTJ configuration. Nevertheless, our results suggest that the local abundance of calc-alkaline acidic rocks, associated with MORB-type lavas in ancient series, could be a tracer of plate tectonic configurations involving the temporally close subduction of several short ridge segments. Such a situation favors remelting of oceanic crustal fragments trapped during subduction due to strong mechanical coupling.

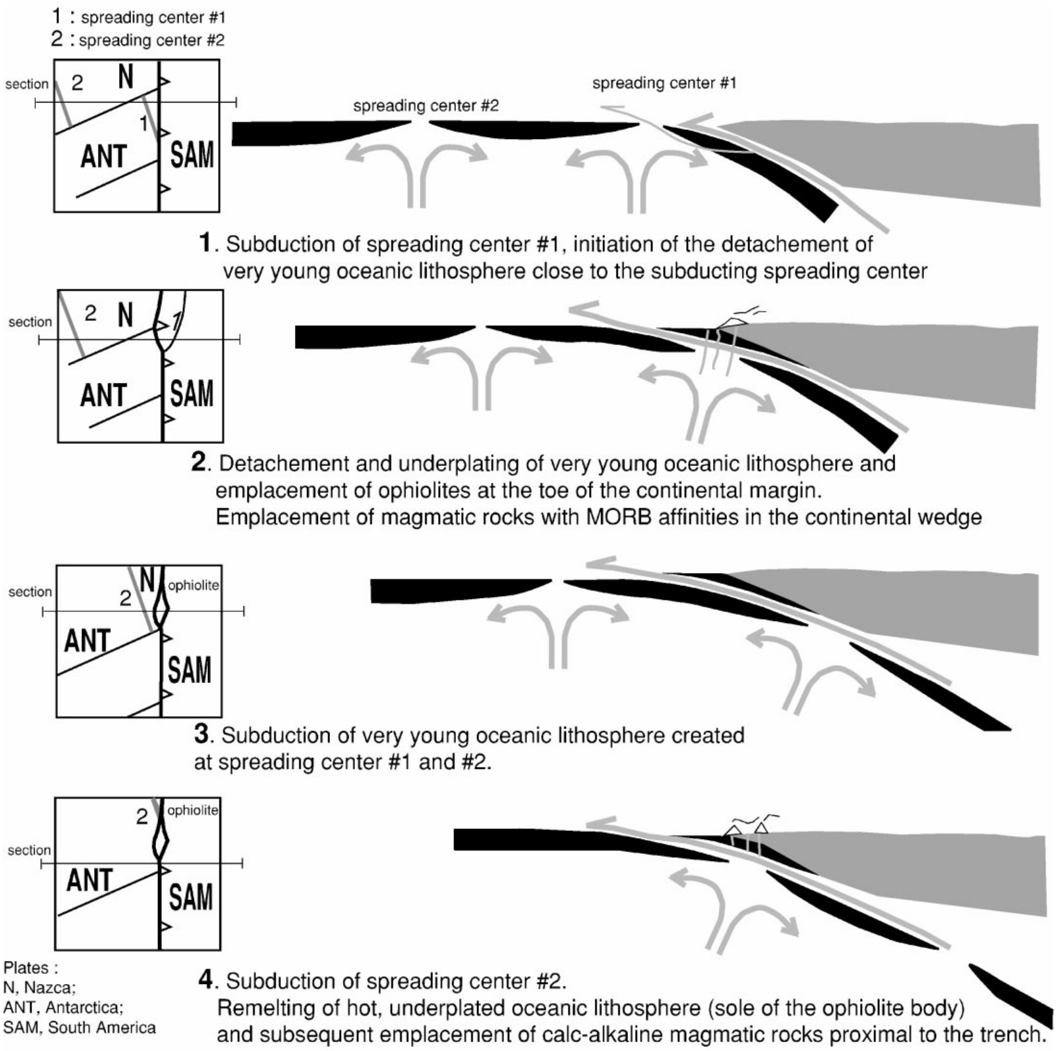


Fig. 7. Theoretical evolution of the Chile Triple Junction with emphasis on two main processes: (1) tectonic coupling during the subduction of active spreading ridge segments, ophiolite emplacement and underplating of young oceanic material at the toe of the continental margin; and (2) repeated subduction of very young oceanic lithosphere and active spreading ridges segments leading to the development of a long-lived thermal anomaly in the forearc and thus re-melting of underplated oceanic material.

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