Upper plate deformation and seismic barrier in front of Nazca subduction zone: The Chololo Fault System and active tectonics along the Coastal Cordillera, southern Peru

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A B S T R A C T

The South America plate boundary is one of the most active subduction zone. The recent Mw=8.4 Arequipa 2001 earthquake ruptured the subduction plane toward the south over 400 km and stopped abruptly on the Ilo Peninsula. In this exact region, the subduction seismic crisis induced the reactivation of continental fault systems in the coastal area. We studied the main reactivated fault system that trends perpendicular to the trench by detailed mapping of fault related-geomorphic features. Also, at a longer time scale, a recurrent Quaternary transverse tectonic activity of the CFS is expressed by offset river gullies and alluvial fans. The presence of such extensional fault systems trending orthogonal to the trench along the Coastal Cordillera in southern Peru is interpreted to reflect a strong coupling between the two plates. In this particular case, stress transfer to the upper plate, at least along the coastal fringe, appears to have induced crustal seismic events that were initiated mainly during and after the 2001 earthquake. The seafloor roughness of the subducting plate is usually thought to be a cause of segmentation along subduction zones. However, after comparing and discussing the role of inherited structures within the upper plate to the subduction zone segmentation in southern Peru, we suggest that the continental structure itself may exert some feedback control on the segmentation of the subduction zone and thus participate to define the rupture pattern of major subduction earthquakes along the southern Peru continental margin.

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1. Introduction

The plate boundary between the South American plate and the subducting Nazca plate along the coast of Peru is the site of large destructive earthquakes, including the major June 23, 2001 (Mw=8.4) event (Figs. 1 and 2). This last century, the southern segment of the Nazca subduction zone has undergone 6 major earthquakes, that jumped southward along the subduction plane from 1913 (Mw=7.9), 1942 (Mw=8.2), 1974 (Mw=8.0), 1996 (Mw=7.7), 2001 (Mw=8.4), to 2007 (Mw=8.0). The 2001 earthquake took place within the northwestern part of the rupture zone associated with the 1868 earthquake (Mw=8.8; Dorbath et al., 1990; Tavera and Audin, 2004) but did not break along the part of the seismic gap left by this previous large earthquake (Nishenko, 1985; Tavera et al., 2006). Weak seismicity (either in magnitude or number of events) occurred on the subduction plane or in the continental plate during the 6 months period before the mainshock (Ruegg et al., 2001; Tavera et al., 2006). On a longer time scale, neither the northern Chilean nor the southern Peruvian seismic network recorded crustal events (MI>5) for the 40 years in the forearc, while at least 10 occurred since 2001. The present-day seismic gap along the subduction zone is located right on the Peru–Chile border and in Northern Chile, extending from Ilo to Antofagasta (Fig. 1). The Arequipa earthquake was produced by the rupture of a 400 km long by 150 km-wide segment of the subduction plane (Robinson et al., 2006). The complete pattern of the seismic crisis suggests a southern migration of the rupture. Indeed, modeling the teleseismic broadband P waveforms of this Peru earthquake indicates that the source time function has two pulses of moment release with the larger second one located about 100–150 km southeast of the mainshock hypocenter (Fig. 2, Giovanni et al., 2002; Tavera et al., 2006). This underthrusting main event was followed by the southward spreading of the whole aftershock sequence (Fig. 2; Robinson et al., 2006). The southward migration of the aftershock sequence stopped propagating at Ilo Peninsula, the area that also coincides with the occurrence of the largest aftershock (7 July 2001, Mw=7.5; Figs. 1 and 2).

Although most of the present-day deformation accommodated in the Central Andes is concentrated in the Subandean zone on the Amazonian side of the Eastern Cordillera, we will show that active crustal tectonic and seismic activity are occurring in southern Peru forearc as well. Many faults identified in satellite and aerial images based on the topography and regional geomorphology (Figs. 1 and 3) cross-cut the Neogene detritic formations that cover most of the

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southern forearc (Moquegua Formation, Fig. 4). Although contributions regarding local active tectonics in southern Peru and crustal seismic activity have been published (Engdahl et al., 2006, Macharé and Ortlieb, 1992; Goy et al., 1992, Ortlieb et al., 1996), systematic fault description, geometric and kinematic data are lacking for the large Peruvian portion of the Arica Bend region (Sébrier et al., 1985; Audin et al., 2003; Tavera and Audin, 2004). Likewise, no detailed studies focusing on active tectonics have been conducted in the Coastal Cordillera.

No GPS data are available for the forearc as only one permanent station is installed in Arequipa (in the volcanic arc), thus little is known about the active deformation in the Central Andes Pacific lowlands. McCaffrey (1996) suggest arc parallel extensional strain for southern Peru whereas it’s demonstrated that Northern Chilean forearc suffers arc parallel compressional strain (Allmendinger et al., 2005; Gonzalez et al., 2003). In this study, geomorphic evidence of Quaternary to present-day tectonic activity is described from the Coastal Cordillera to the piedmont of the Western Cordillera (Audin et al., 2006; Sébrier et al., 1985, 1988). Examination of aerial photographs and satellite data in conjunction with focused field work confirms that Quaternary subduction earthquakes related

![Fig. 1. Geodynamic setting of the Nazca subduction zone in Southern Peru, northern part of the Arica Bend. Rupture zones of major seismic events of the last century are reported. The present-day seismic gap extends between southern Peru and northern Chile. The topographic map of Ilo Region outlines the Chololo Fault trace and the other perpendicular to the trench fault systems (Puite and El Abra Faults).](image1)

![Fig. 2. 23rd of June 2001 earthquake and its aftershocks from Peruvian network data, after Tavera et al. (2006). The Nazca fracture zone is reported, being a seismic barrier that stalled the propagation of the main shock rupture as discussed by Robinson et al. (2006) (as on Fig. 1).](image2)
Tectonic activity exists and additionally reveals the presence of undescribed active structures. These undescribed structures must be taken into account in the description of fault kinematics within the Central Andes as these faults participate in the partitioning of the deformation throughout the forearc. Indeed the Coastal area from 17° S to 18°30 S is affected by a network of normal faults, trending perpendicular to the trench that a margin-parallel stretching in contrast with margin-parallel compression observed in Northern Chile (Allmendinger et al., 2005).

We will focus on some of the strong geomorphic signatures, such as active fault traces, scarplets, and river gully offsets, which are all indicative of active motions along the Chololo Fault System at various spatial and temporal scales. Specifically, the Chololo Fault System and a series of similar faults that trend perpendicular to the coast (Fig. 3) near the limit of the 2001 earthquake rupture may indicate that the structure of the upper continental plate plays a role in the segmentation of the subduction plane. We infer that this induced segmentation is due to a strong seismic coupling between the subducting and upper continental plates. We propose here that there may be an influence of the forearc structure on the subduction segmentation.

2. Seismotectonic and geologic setting

The study area extends around the town of Ilo for a distance of 100 km along the coast and towards the town of Moquegua (Fig. 1). The seismotectonic setting of the Peruvian coastal area is largely controlled by the oblique convergence of the Nazca and South American Plates north of the Arica Bend. These two plates are converging at a rate of 78 mm/year (Demets et al., 1990), with the Nazca plate subducting beneath the South American Plate (Bevis et al., 2001). It is now recognized that most of the relative plate motion is accommodated by slip along the subduction interface between these two plates, such as associated with the 2001, 23 June earthquake (Norabuena et al., 1998; Bevis et al., 2001; Khazaradze and Klotz, 2003). The southern Peru earthquake of June 23, 2001 was a Mw of 8.4, which is the largest magnitude earthquake recorded during 30 years prior to the Sumatra earthquakes. Most of the energy release...
and the largest aftershock (Mw 7.6) occurred to the southeast of the hypocenter, in the part of the fault-rupture zone nearest to the town of Ilo (Robinson et al., 2006; Fig. 2). As this part of the subduction plane is interpreted to be highly coupled, a response of the continental plate was highly expected in this Ilo area.

In the Ilo region, the Coastal Cordillera is characterized by large faults or fault systems that are easily observed on the SRTM DEM and aerial photography (Figs. 1, 2 and 3). However, from kinematic point of view, the fault systems trending perpendicular to the trench offset either the Neogene sedimentary formations, Quaternary alluvial fans (Moquegua Fm, 12 to 2.7 Ma; Figs. 2–4), or the intrusive rocks that are part of the Coastal Batholith (Roperch et al., 2006; Audin et al. 2006).

In the Ilo area, the coastal region experienced Plio-Pleistocene uplift, which is evidenced by staircased sequences of marine terraces (Fig. 4; Ortlielb et al., 1996). Near Ilo, at the southern extremity of the Chololo Fault System, the emergent Pampa del Palo region was previously studied by Ortlielb et al. (1996). By combining aerial photo interpretation and stratigraphic observations, Ortlielb et al. (1996) studied a faulted block that periodically moved independently of the rest of the southern Peruvian coast for some time between the Middle and Late Pleistocene (Fig. 4). Since then, the same block is described to be affected by NE–SW trending faults.

The Coastal Batholith plutons yield mostly Middle Cretaceous–Early Eocene ages and define two belts parallel to the coast south of

![Fig. 4. Simplified geologic map of the Ilo area (after INGEMMET, 2001; Roperch et al., 2006). Note the Coastal batholith formations that extend only south of Ilo and the perpendicular fault systems observed equally north or south of Ilo peninsula.](image)

![Fig. 5. Topographic cross sections from SRTM data. The cross section is reported in plane view on the aerial photos. The vertical offset of about 350 m is deduced from geological observations and the offset of stratified fine sediments interbedded with coarse conglomerates preserved at the top of Chololo hill (Fig. 4).](image)
Ilo: one along the Cordillera and one 75 km to the east of Ilo. Northward of Ilo, only one belt concentrates both Plutonic events along the volcanic Cordillera. The single belt extends from Arequipa to Ilo area, and then abruptly split in two belts separated by 75 km that mark a significant migration of the arc in the Late Cretaceous, occurring only south of Ilo area (Fig. 4).

From climatic point of view, some new constraints on erosion rates of pediplains in the forearc of Northern Chile determined using concentrations of terrestrial cosmogenic nuclides (TCNs) indicate that almost no erosion has occurred since the Late Miocene (Dunai et al., 2006; Kober et al., 2007). Indeed, those results suggest extremely low erosion rates of ~0.7 m/Myr on the Costal Cordillera since the Late Miocene. Thus, hyperarid climate enabled the preservation of geomorphic markers offset by fault traces in the Coastal area of southern Peru.

We will focus in this paper on the Chololo Fault System, which has never been the subject of a detailed mapping or seismic history study. The topography is the consequence of geomorphic processes, erosional or tectonic, acting on the regional and local scale. By describing the geomorphic features associated with the Quaternary fault trace, the surface rupture after the subduction earthquake of 2001, and 4 crustal seismic events that occurred in the area during and after the 2001 crisis, we infer that the strong seismic coupling in the coastal area between the subducting Nazca plate and the overriding South American plate is the source of post subduction crustal seismic activity observable in crustal seismicity and active fault geomorphology. Indeed, the active faulting onland coincides with the limit of ruptures on the plate interface.

3. Tectonic geomorphology of the Chololo Fault System

The Chololo Fault System (CFS) as a whole has a surface trace of about 40 km extending from Punta Coles to the Panamerican Highway...
in the north, eventually reaching the Moquegua Valley (Figs. 1 and 3). The CFS consists of various sub-segments, some en echelon, the older and larger segment being transtensional with major left-lateral strike-slip and normal movements; and the smaller and lower segments (with respect to the valley) showing mainly normal movements (Figs. 3 and 4). The CFS trends more or less N55° E, and dips between 50° and 60° to the SE (Fig. 5). The normal scarps are facing southeast and offset either the bedrock piedmont contact (Fig. 4) or the active alluvial fans. Recent alluvial fans and eolian deposits are coalescing along the scarps at various sites along the fault trace. Near one of the topographic profile lines across the fault trace are offset ashes, mostly observed along the youngest scarp (Fig. 6). This ash is typically fine and grey in color, most likely associated with the last Huaynaputina eruption (1600 AD; De Silva and Zielinski, 1998). These grey unconsolidated ashes are observed everywhere in the forearc of southern Peru usually filling the valleys and capping the most recent

Fig. 7. Aerial photo, gullies map and field photos of the fault. The segmentation of the fault trace in surface is compatible with left-lateral movement on the main fault. Also note at a smaller scale, the systematic curving of the river gullies and ridge crest to the West on the Northern side of the fault and to the east on the southern side. On the field photo again some nice triangular facets are marking the fault scarp.
alluvial fans. At this particular site, no geochronologic data are available yet to support this correlation.

4. The normal component

Our detailed study was focused on the northern segment of the CFS (Fig. 3). Vertical offset of about 350 m is observed along the main fault segment between the Moquegua Formation topping the cerro Chololo and the Moquegua Formation/Quaternary infilling down in the valley to the southeastern side of the fault (Figs. 4 and 5). The very flat layers that can be observed on Cerro Chololo, at the top of the foot wall are not folded nor affected by any kind of faulting. Similar outcrops of these deposits composed of undeformed conglomerates and eolian sediments can be seen infilling the canyons cut into the valley.

Narvaez (1964) suggests that the deposits are Quaternary in age. Roperch et al. (2006) compared those deposits to the thin Neogene successive layers described as filling the Moquegua valley in other sites near Moquegua (Fig. 5). In light of these two hypothesis, the deposits are either part of the Moquegua D Formations ranging from Upper Miocene to 2.7 Ma (Roperch et al., 2006) or are younger as suggested by Narvaez (1964).

At the foot of the main scarp, we used kinematic GPS to measure precise topographic profiles, oriented perpendicularly to the fault (Fig. 6). In this way, we made high-resolution measurements of the vertically offset alluvial fan surfaces. Most recent and individual scarps are observed in the river beds or cutting across the youngest alluvial fan (Fig. 6). The main fault system is marked by regular triangular facets illustrating the vertical displacement with vertical offsets reaching at least 20 m (Fig. 6). The smallest recent scarp (1.5 m) is found on the secondary normal fault affecting the last generation of alluvial fans (Fig. 6). It seems to cumulate two events or to be re-eroded.

5. The strike-slip component

The relatively straight trace is indicative of a high-angle, strike-slip fault (Figs. 3, 4 and 6). Additionally, aerial photo analysis allowed us to identify en echelon fault segments (Fig. 3), which indicate normal-sinistral motion. A detailed study of the crest alignments and river offset along the main fault is presented on Figs. 7 and 8. In both plane view or in the oblique field photos, the upper part of the cliff is systematically displaced to the left with respect to the lower part, all along the fault trace, and it works for each crest or dry gullies (Fig. 8). Triangular facets mark the morphology of the cliff next to the main fault trace together with left-lateral offsets of thalwegs. The secondary segment is dominated by a normal offset with no systematic evidences of strike-slip. With white dots to indicate the piercing points used to estimate at least one scale of lateral offsets, we highlight on the aerial photo the similar offset undergone by ridge crests and thalwegs of stream channels on Fig. 8. After faulting, the lower abandoned channel is preserved as in A or B on Fig. 7, and the channel is now facing the cliff, cut off from any water supply. It is impossible to explain this landform of an incised headless stream channel in the upper cliff without invoking a lateral offset along the fault trace. Moreover this type of offset is observed systematically at various sites along the fault (see Figs. 7 and 8).

The respective lateral offsets are measured along the fault trace and support the regular activation of the fault system and a recurrent seismic history. The offset varies from some meters to 480 m (Fig. 8). The maximum offset area along the fault that we were able to reconstruct is presented on Fig. 8. The two best piercing points identified are dry valley walls, two of them being relatively major valleys which are quite distinct with regard to morphology on both sides of the fault. These dry valleys are separated from one another by the same distance d, about 200 m (Fig. 8). This exact same distance between the two valley walls on both the northern and southern sides of the fault trace allows us to confirm that the two sets of valley walls (one on the northern side of the fault trace and the other on the southern side) constitute real recognizable geomorphic features. The best matching of the valley north and south of the fault trace also restores the continuity of other smaller stream channels incised in the mountains farther west. When ridge sideslopes are relatively planar and the fault trace is roughly perpendicular to a narrow ridge crest, such as in the case of the Chololo Fault System; the net slip vector can be measured graphically (Fig. 8). From this reconstruction, we can calculate a lateral slip vector of about 480 m.

6. Others fault systems perpendicular to the trench

The prominent NE-striking fault systems which are restricted in latitudes ranging from 16.5° S to 18.5° S in southern Peru, exist only where the obliquity of the convergence direction is maximal with respect to the trench. Most of the fault scarps face northward, north of Ilo and southward, south of Ilo (Figs. 9 and 10). As scarps are well preserved in such hyper arid regions, we can determine scarp heights from topographic profiles issued from SRTM data (Fig. 9). Most of the scarp heights range between 50 m and 1000 m along very vertical faults. This suggests that a small amount of extension has been accommodated along these fault systems through time and that they

Fig. 8. Note NW–SE streams, crests and alluvial fans misalignment, deviation and offset on 3D Google Earth image. The two biggest and recognizable dry valleys are preserved and offset on each side of the main fault trace by a sinistral movement. The proposed reconstruction suggests the need of extensional NW–SE movement on the main structure.
have been repeatedly activated since at least 4 Ma (Fig. 10, last episodes of sedimentation in the Central valley, i.e. Moquegua D Formation after Roperch et al., 2006). These faults are restricted to the Coastal Cordillera, disappearing below the Moquegua Fm or older sedimentary formations towards the Cordillera Occidental. Finally these faults exist only where the continental plate is more directly committed to the stress of the subduction processes, near the coastal area, above the seismogenic zone (Stern et al., 2002).

7. Seismotectonics and crustal events recorded by the Peruvian national permanent network

During the 2001 subduction earthquake, the Chololo Fault trace that trends across Inalhambica Plain above Ilo, was marked by open cracks striking N30° E. Ruptures occurred along the pre-existing 2 m-high scarps but show no reliable vertical offsets, only open cracks of about 20–30 cm. Most of the houses built on this scarp, which...
corresponds to the southern horsetail termination of the Chololo Fault in Punta Coles near Ilo, were destroyed during the earthquake.

Many microseismic events (M ≥ 4) occurred in Moquegua region after the June 2001 subduction earthquake, whereas really few were even recorded in the whole southern Peru during the last previous 5 years (Tavera et al., 2006). Most (5 of the 9) of the major crustal seismic events that occurred after the subduction earthquake of 2001 have magnitudes higher than 4 and are thus were recorded by the network (Fig. 9). This allowed us to calculate focal mechanisms which could be compared to the regional crustal deformation deduced from tectonic and geomorphic analysis. Each event was recorded by the southern national Peruvian seismic network and thus the P and S waves were analysed from 6 broad band stations and 2 short period stations of the permanent network.

Two of the 4 events are clear aftershocks of the main subduction earthquake (Fig. 9). The last rupturing event is in the upper crust: the 23rd June 2001 (Latitude 17.9251° S, Longitude 71.5791° W, depth = 35.4 km, ML = 5.4); the 25th June 2001 (Latitude 17.4512° S, Longitude 71.1269° W, depth = 19.3 km, ML = 5.1). The most superficial event occurred at a depth of ~20 km and correlates very well with the location of surface offsets long fault systems cutting the Moquegua Fm as observed from field investigations or remotely (DEM, Figs. 3 and 9). This structure appears to be a normal fault base on the tectonic studies, topographic profile (Fig. 9), and the location of the seismic event on the fault system would indicate a vertical fault. This observation suggests that if associated to tectonic deformation, the event should be located right on the fault and the focal mechanism should be compatible with the whole trend of the fault system. Indeed the focal mechanism is also showing a normal sinistral component that fits correctly with the field observations (Fig. 9). The deepest event (about 35 km deep) is located right above the scar of a huge submarine landslide that is affecting the margin in front of Ilo (Fig. 9).

The two other seismic events have occurred almost 2 and 3 years after the subduction crisis of 2001 (26 August 2003, Latitude 17.4246° S, Longitude 71.0835° W, Depth = 19.4 km, ML = 5.8; 30 May 2004, Latitude 17.5849° S, Longitude 71.1523° W, Depth = 54.4 km, ML = 5.0). Since the occurrence of such seismic events was rare or non existent before the subduction earthquake of 2001, they seem to be closely related to the sequence of aftershocks (Fig. 9). The ML = 5.8, 26 August 2003 event, is well located and clearly associated to some crustal deformation right along the Chololo Fault System (Fig. 9). As this structure appears to be transpressive, showing a composite normal-sinistral movement, the location of the seismic event on the Chololo Fault System is coherent with a nearly vertical fault. Moreover, the focal mechanism also shows a normal sinistral component that fits correctly with the tectonic observations. The spatial extension of the fault (about 40 km) suggests that this fault system reaches the lithospheric scale and the depth of this seismic event correlates with this interpretation. The interplate depth is about 20 km to 60 km deep in this part of the subduction zone, beneath the Coastal Cordillera (Tavera et al., 2006). We highlight that the instantaneous deformation traduced by the occurrence of seismic events on this structure is perfectly compatible with the Quaternary deformation at a larger time scale.

8. Discussion

The Chololo Fault System consists of sub-parallel fault segments that form a wide zone at the base of the south-facing front of the Cerro
Chololo, north of the town of Ilo. The fault cuts straight across Quaternary to Holocene alluvium and shows morphologic evidence for normal and sinestral strike-slip motion. We investigated the fault zone at several sites selected from satellite images and field studies. The southernmost of these fault segments is the youngest and shows vertical scarps and lateral offsets. These young scarps are formed on piedmont intermittent alluvial fans that extend from the range-front intermittent gullies. The scarps are poorly developed across the recent fan surfaces, probably as a result of recent erosion or deposition. The youngest movement on the fault is probably Holocene or latest Pleistocene for the southernmost segment. Moreover, numerous normal faults cut the coastal area north and south of the Chololo fault zone, which offset either the crystalline basement, the Neogene pediments or the Quaternary alluvial fans issuing from the foot wall (Figs. 10 and 11).

The purpose of the tectonic geomorphologic work here is to show that prominent geomorphic markers exists along crustal fault systems in the forearc of southern Peru which provide evidence Quaternary tectonic activity. Mapping active fault traces along the coastal area in southern Peru and identifying recent surface offsets can thus be used to determine the key locations where active faulting, either normal or strike-slip, is involved in the deformation of the coastal area.

Some of these markers are robust enough to allow us to characterize the kinematics along the faults, at least for the Quaternary period and show systematic vertical movements associated with a small amount of extension. While surface processes are a much weaker signal than the tectonic signal, with time and strong El Nino events, they gently degrade the traces of active tectonics, possibly creating the segmented nature of the structures we observe in the forearc. Geomorphic observations confirm that despite some segmentation that is observed along the fault systems, crustal seismic events can be expected to occur in this area of the Andean forearc. The fact that perpendicular fault systems are restricted along the coastal fringe suggests that plate coupling plays a role in their formation and activation.

9. The existence and implications of inherited structures of the continental margin

Among these tectonic features oriented perpendicular to the coast, most show a normal component. The detailed CPS is itself associated to transpressive kinematics. Those NE–SW normal fault systems are likely due to seismic crustal activity (accounting for the ongoing Andean tectonic processes) and some to relaxation processes of the stress imposed on the outer forearc after the occurrence of major subduction earthquakes. Indeed if inherited zones of weakness or pre-existing fault systems are present in the overriding plate near this region of increased stress, then such faults may serve to localize the strain.

As discussed by McCaffrey (1996) kinematics of crustal faults in the upper plate can be related to the occurrence of major subduction earthquakes and to the obliquity of the convergence direction with respect to the trench (McCaffrey, 1996).

Seismological data from the Peruvian network and observation of surface ruptures that followed the 2001 subduction earthquake show that several faults are seismically active. For instance, the reactivation of the Chololo fault immediately triggered by the 2001 main shock has been responsible for some of the destructions that affected the upper area of Ilo city. Indeed, on the 25th of June 2001 (Ml=5.1) and 26th of August 2003 (Ml=5.8) two crustal earthquakes occurred right on the Chololo Fault System and its neighbouring fault systems in the Moquegua valley. These events present focal mechanisms compatible with the occurrence of extension on these faults. Related with the strong seismic coupling and the obliquity of convergence between the two plates, this fault system trending perpendicular to the trench, may constitute a barrier to the propagation of the aftershocks along the subduction plane and correlate with the segments that define the subduction plane. These faults could be activated in a particular period of the seismic cycle, for instance at the end of the interseismic period when the horizontal compressive stresses are maximum within the continent. McCaffrey et al. (2000) state that the along strike extensional strain will be larger over the coupled plate boundary where basal active forces are acting. This is supported by the fact that a margin-parallel gradient in the margin-parallel velocity must exist due to the actual bending of the South American plate. Moreover this study illustrates McCaffrey et al.’s (2000) discussion regarding the theoretical spatial correlation that should exist in some cases between interplate coupling and forearc extensional deformation (McCaffrey et al., 2000).

10. Conclusions

The coastal range is affected by a system a normal faults trending perpendicularly to the coast, which may be comparable to northern Chile reverse or normal ones that are trending obliquely to the coast (Gonzalez et al., 2003; Allmendinger et al., 2005). These normal faults are especially frequent on the eastern border of the Central Valley, affecting the Holocene alluvial fans as well as Coastal Cordillera Jurassic to Cretaceous crystalline formations. They show a main normal component and, for at least two of them, a transpressional movement with a left-lateral component. We interpret this motion to be due to the obliquity of the convergence direction of the subducting plate (N79, 77 mm/year, DeMets et al., 1990) with respect to the trench. This type of vector, imposing a 79° N stress from the highly coupled zone to the surface, induces a relaxation compatible in direction with normal sinistral movement on a N55° active fault in the overriding plate.

We speculate that these features may be associated with segmentation of the upper and/or lower plates. This fault set can be interpreted as progressive step faults, that may be triggered by gravitational effects due to major subduction earthquakes. Alternatively, these faults may be susceptible to permanent deformation which prevents the accumulation of the elastic strain energy necessary to sustain seismic rupture and thus constitute a seismic barrier. Recent studies focusing on the aftershock sequence of the 2001 Peru earthquake show that the rupture produced by the subduction seismic event (moment magnitude 8.4) propagated for 70 km before encountering an area of fault that acted as a barrier (Robinson et al., 2006). The rupture continued around this barrier, which remained unbroken for 30 s and then began to break
again, propagating to the south before stopping on Ilo peninsula. 
Robinson et al. (2006) associate this first barrier with the Nazca fracture zone features on the subducting oceanic plate. However, it's also well known that segmentation of the upper plate (Fig. 11) can constrain the propagation of seismic ruptures along the subduction plane (such as in the case of Japan, on upper plate in Nankai subduction zone (Okamura, 1990; Wells et al., 2003)). Here, we interpret the propagation pattern to be mainly associated to margin perpendicular structures as in the case of the Chololo Fault System in southern Peru and to previous segmentation of the Peruvian Coastal Cordillera (Fig. 11). Large, linear magnetic anomalies lie along the coast of southern Peru (INGEMMET, 2001) as presented on Fig. 10. We interpret this map to reflect the crustal structure of the Cretaceous arc in the Coastal area. Negative anomalies also coincide with Miocene sedimentary basins and their limits with the superjacent trace of the active normal fault systems mapped previously in this study. The clear discontinuity observed between the prominent positive and negative magnetic anomaly correlates with seismic stalling of subduction events in the Ilo region as can be seen either in instrumental seismicity with the 2001 earthquake or in historic seismicity for the 1582, 1687 and maybe 1784 events (Dorbath et al., 1990; Fig. 11). Indeed it is striking that historical earthquake ruptures are confined in north or south of the Ilo peninsula (Dorbath et al., 1990; Fig. 12). All of the data gathered in this study suggest that the propagation of major subduction events along the Nazca plate boundary is conditioned in southern Peru by preexisting pronounced features in the geometry of the upper continental South American Plate which localizes the deformation after the occurrence of the subduction earthquakes.

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