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SLIP RATES OF A LATE QUATERNARY NORMAL FAULT IN MEJILLONES PENINSULA (23°S), ESTIMATED USING ^{10}BE EXPOSURES AGES

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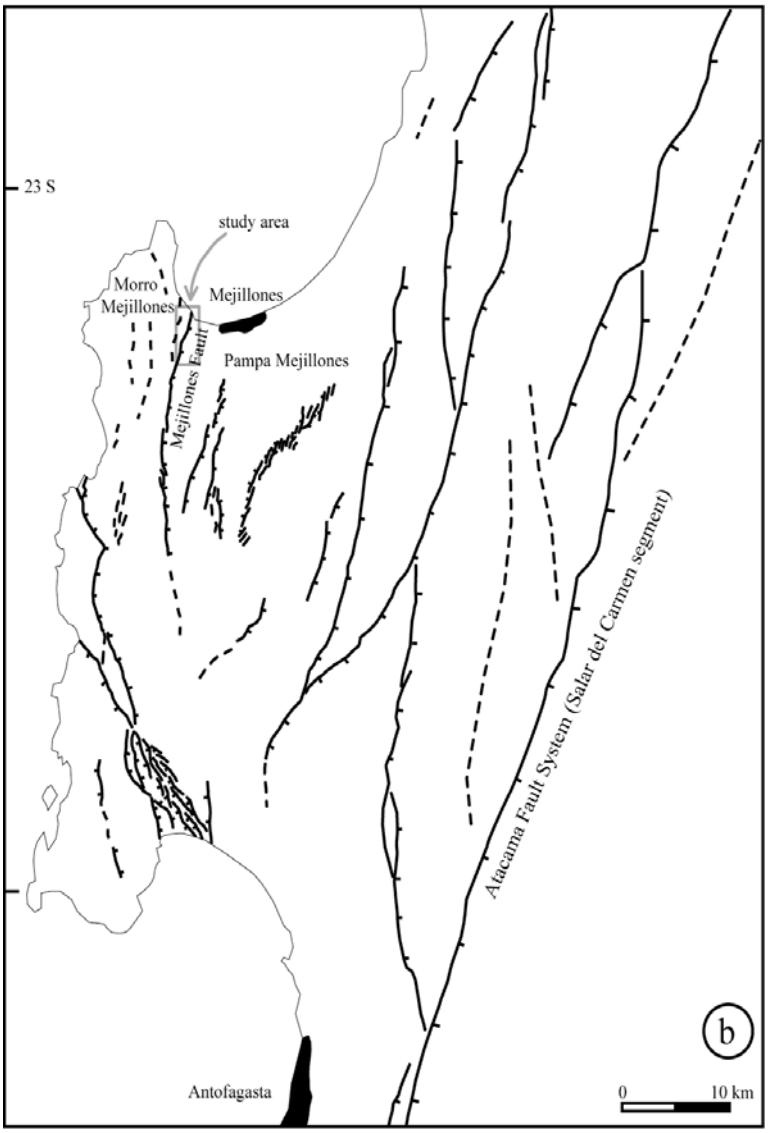
ABSTRACT
In-situ produced cosmogenic ^{10}Be measurements of offset alluvial surfaces have been used to estimate the slip rates along the Mejillones Fault, a Mesozoic fault located at the north-western Mejillones Peninsula in northern Chile, that was reactivated as normal fault during the Upper Quaternary. Average slip rates of 0.29 ± 0.06 m/ka over the last 50 ka were calculated. These results are consistent with the uplift rate estimated from the analysis of morphostratigraphic evolution of this coastal area based on the study of emerged Quaternary marine terraces and beach-ridge sequences. The hypothetical relation between the activity of these faults and subduction earthquakes (co-seismic deformation) suggests that these structures are potential active faults that have to be taken into account in terms of seismic risk analysis.

INTRODUCTION
The Mejillones Peninsula is located along the arid coast of northern Chile and belongs to the Central Andes fore arc. It is the emerged part of the fore arc located closest to the subduction trench. Quaternary alluvial fans and uplifted abrasive marine terraces (with sometimes associated deposits) are well preserved, and both are affected by several normal faults. Our study aims quantify the slip rate along the faults by determining the exposure ages of the displaced alluvial fans surfaces using *in-situ* produced cosmogenic ^{10}Be.

THE MEJILLONES FAULT
Located in the northern-western area of the Mejillones Peninsula, the Mejillones Fault belongs to the Mejillones Faulting System but can also be considered as the westernmost part of the Atacama Fault System which has a Mesozoic origin (Fig. 1). The Mejillones Peninsula displays an E-W extensional deformation during the Plio-Quaternary and is affected by numerous normal faults, tension gashes, tilted blocks and vertical motions (*e.g.*: Okada, 1971; Armijo and Thiele, 1991; Hartley and Jolley, 1995; Niemeyer *et al*., 1996; Delouis *et al*., 1998). This extensional deformation is expressed in the morphology by a series of horsts and grabens.



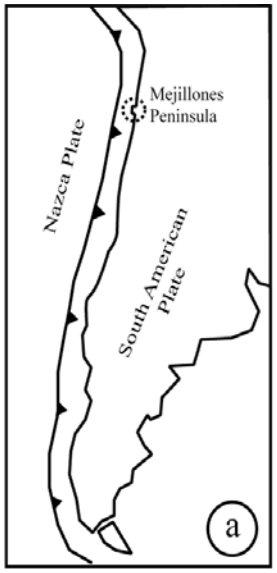


Figure 1.- a) Location map of the Mejillones Peninsula. b) Distribution of the main Quaternary regional faults and the study area.

Quaternary normal faults (certain/probable)

The Mejillones Fault limits to the east the uplifted Morro Mejillones range that displays a staircase morphology corresponding to wave-cut platforms abraded in basement rocks. To the east of the fault, the Pampa Mejillones defines an isthmus filled by Neogene marine deposits and covered by a well-developed Quaternary sequence of beach-ridges. The whole system (Mejillones Fault, Morro Mejillones and Pampa Mejillones) can be described as a half-graben that was formed in Neogene times, in the northern half of the peninsula.

The last movements along the Mejillones Fault affect several generations of alluvial fans at outlets of deep-incised drainage basins developed in the eastern flanks of the Morro Mejillones. These alluvial fans cover Quaternary beach-ridges of Pampa Mejillones formed during the last half million years (Ortlieb, 1995; Ortlieb *et al*., 1996a).

These faults are supposed to have a very recent activity, but no historical seismic activity has been reported. Moreover, no significant crustal seismicity is associated to the fore arc at this latitude.

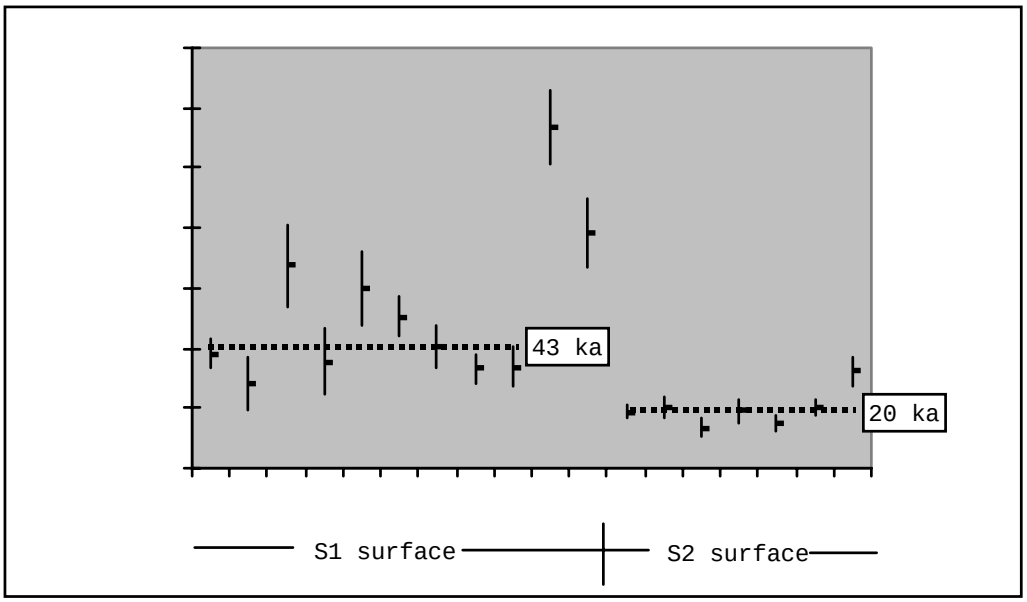
Delouis *et al*. **(**1998) proposed that the state of stress in the outer fore arc was linked to the seismic cycle in the subduction zone. As observed during the 30 July 1995 (Mw = 8.0) Antofagasta earthquake, subduction earthquakes produced coseismic E-W extensional and vertical movements in the coastal area, that would produce the reactivation of some branches of the Atacama Fault System and the formation of cracks.

PRELIMINARY MORPHOTECTONIC AND DATING RESULTS

We surveyed morphotectonic markers along the northern part of the Mejillones Fault where they were the best preserved from erosion. Three sites were selected in order to measure the cumulated displacements along the fault (Fig. 1).

The mean offsets were determined from Digital Elevation Models (DEM) calculated from differential GPS measurements with 1 cm accuracy. Series of cross-sections in DEM allowed us to estimate the mean vertical cumulated offsets. We obtained 13 ± 1 m and 5.5 ± 0.5 m for the offsets of the two surfaces, S1 and S2 respectively (S2 is inset in S1). We collected samples from granitic boulders well inserted in the S1 and S2 alluvial surfaces, on both sides of the fault scarp. For each surface, five boulders were sampled with two or three samples by boulders: one at the top, one in the core and one at the bottom. The exposures ages of these samples were estimated using in-situ produced cosmogenic ^{10}Be concentrations (e.g. Brown *et al*., 1991; Siame *et al*., 1997).

Assumption of negligible erosion rate of boulders allows us to estimate minimum exposure ages using ^{10}Be production rates calculated from the scaling factors of Lal (1991) (e.g. Braucher *et al*., 2000). Preliminary available results give minimum exposure ages of 43,000 ± 3,000 ^{10}Be yr for S1 surface and 20,000 ± 3,000 ^{10}Be yr for S2 surface (Graph and Table 1), which leads to an average slip rate of 0.29 ± 0.06 m/ka. Samples 10 and 11 (see Graph and Table 1) are not considered in the calculation of the exposure age of the S1 surface, since inherited ^{10}Be is suspected.



Sample	10Be (atoms/g)	Uncertainty (atoms/g)	Minimum age (yr)	Uncertainty (yr)
S1 alluavial surface :				
C99-1	174319	20419	38231	4478
C99-2	60851	19329	28378	9014
C99-3	BORE	BORE	-	-
C99-4	305774	61839	67515	13654
C99-5	89897	27239	35481	10751
C99-6	116042	23941	59661	12309
C99-7	187965	24529	50330	6568
C99-8	113455	19213	40666	6887
C99-9	151676	22360	33227	4898
C99-10	94459	19103	33804	6836
C99-11	508351	55159	113432	12306
C99-12	166151	23794	78380	11224
S2 alluavial surface :				
C99-13	86480	10383	18882	2267
C99-14	59561	9585	20435	3289
C99-15	62145	12568	13552	2741
C99-16	47136	9533	19145	3872
C99-17	69121	12394	15079	2704
C99-18	BORE	BORE	-	-
C99-19	93154	13340	20346	2914
C99-20	93630	14237	32423	4930

Graph and Table1.- ^{10}Be calculated minimum exposure ages from S1 and S2 alluvial surfaces. Average ages of each surface are indicated with dashed lines in thousands of years (ka). See explanation in the text.

DISCUSSION

These results, although preliminary, allow us to draw several preliminary conclusions concerning the recent paleoclimatic and tectonic processes along this part of the Mejillones Peninsula.

According to the preliminary exposure ages of S1 and S2 (the oldest well preserved alluvial surfaces), alluvial fan deposition during different paleoclimatic phases of the last glacial period (from ca. 74 to 10 ka) is suggested. This is in agreement with radiocarbon dates on alluvial sediments from Quebrada Las Conchas, at Antofagasta (Vargas and Ortlieb, unpublished) which suggest that rainfalls were strong enough during the last glacial maximum to form alluvial sequences.

The long-term regional Pleistocene average uplift estimated from the study of marine terraces of the Pampa de Mejillones is about 0.2 m/ka while the Morro Mejillones, west of the Mejillones Fault, seems to have been uplifted at an overall rate of 0.4 m/ka (Ortlieb, 1995; Ortlieb *et al*., 1996b). The difference may represent the amount of uplift due to the Quaternary activity of the Mejillones Fault. These calculations are consistent with our results using cosmic ray exposure dating of offset surfaces along this fault.

The features observed along the fault (*i.e.* the two offset alluvial surfaces) are interpreted as the effects of at least two events since the abandonment of the surface S1. The difference of riser heights of the inset secondary surfaces observed within the main S2 surface, on both sides of the fault, suggests that the cumulated displacements are the results of much more numerous events. Moreover, within the most recent alluvial surfaces, inset in S2, we observed a set of cracks trending N-S along the trend of the fault scarp. No surface ruptures were reported in the Antofagasta area during the 30 July 1995 (Mw = 8.0) earthquake (located at the southern part of the peninsula). Nevertheless, tension gashes were described along some faults of the Atacama Fault System (Delouis *et al*., 1998). Therefore, we think that the activity of the Mejillones Fault (and all the fault system of this peninsula) could be related to the occurrence of strong subduction earthquakes ($Mw \geq 8.0$).

CONCLUSIONS

Upper Quaternary deformation in the Mejillones Peninsula is characterised by a regional, long term, coastal uplift and by extensional deformation. Tectonic blocks, which have been submitted to different vertical deformation, are separated by normal faults. Here, we estimate the vertical-slip rate along the Mejillones Fault (calculated for the last 43 ka) at 0.29 ± 0.06 m/ka. This normal faulting is still active and could be closely associated with subduction earthquakes.

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