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Volcanic ash dating from the Mejillones Peninsula (23°S): Implications for the Neogene outer fore-arc stratigraphy, tectonics and volcanic relationships

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Introduction

The northern coast of Chile includes the most westward parts of the emerged Southern Central Andes fore arc. Throughout the coastal plains and the Coastal Cordillera, ash deposits are intercalated in alluvial, littoral and shelf Neogene series. The Mejillones Peninsula (23°S) is one of the best places to study these sequences and their deformation history; this is due in partly to the excellent preservation of deposits, because of the hyper aridity that characterizes the coastal Atacama Desert in this latitude. In order to improve our understanding of the chronostratigraphy of coastal sequences and their tectonic implications, we obtained Ar/Ar ages from volcanic ash deposits in this area. The tephrochronology and sedimentological characteristics of those deposits allow us to infer possible volcanic processes involved in their origin.

Ash description

Discontinuous white layers and/or lenticular bodies of non-consolidated ashes are studied. These ash deposits are on average 0.5 m thick, reaching up to 2 m. They are made up of juvenile pumices and glass shards (80-90%), quartz, biotite, sanidine, plagioclase, amphibole crystals (10-20%) and angular and rounded accidentally lithics (10%). Generally they display good selection and laminar stratification as described for ash fall or surge, in spite of the high-energy environment of the enclosing sediments. In some cases, the occurrence of angular lithic debris included in the bottom, at the top and even contained within some of these deposits, implies a moderate reworking by sporadic laminar debris flows and mud flows that, in modern conditions, are associated to very rare heavy rainfall events.

Samples locations

Ten samples were analyzed from the Mejillones Peninsula, including two samples from the coastal plains and Coastal Cordillera (Fig. 1). The samples obtained from the marine La Portada Formation (Miocene-Pliocene) allow us to determine the maximum age of two units, observed in the Tiburón Basin (PMC-28.1c) and Jorgino Horst (PMMC-73, PMC-27.3e) (fig 2 A and B). In this last area, the lower unit, unlike the upper one, displays a greater degree of deformation, most probably associated to the Miocene-Pliocene activity of the Caleta Herradura Fault. In the Jorgino Horst an ash layer (PMC-13.5a) is intercalated within Pleistocene alluvial fans which overlie marine terraces, also of Pleistocene age (fig 2 A). These fans are affected by the recent extensional activity of the Caleta Herradura Fault (< 2 m of vertical displacement). Two samples were obtained from an

alluvial fan at Mejillones Horst (fig 2 C): the first one (PMC-21.5) from the oldest marine terrace of this horst (580 m a.s.l.), the second one (CH-99-I) from the foot of this horst, in the El Rincon area, in an alluvial fan probably formed during the last glaciation (< 20 ka). These last deposits are affected by the recent extensional activity of the Mejillones Fault (< 2 m of vertical displacement). In the Coastal Cordillera, to the east of the peninsula, an ash layer (PMC-33.1a) was observed in the deformed base of an alluvial gravel sequence, up to 750 m a.s.l. (fig 2 D). On the High Cliff foot (western limit of the Coastal Cordillera) another ash layer (PMC-10.1) was observed in an alluvial fan that covers Pleistocene marine terraces, up to 180 m a.s.l. in the coastal plains (fig 2 E).

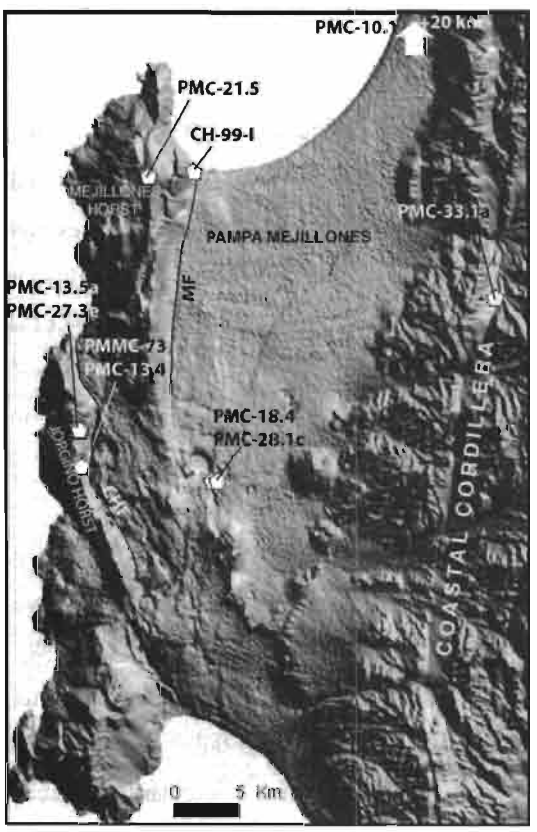

Figure 1. Grey-shaded digital elevation model (iluminated from NE) of the Mejillones Peninsula. CHF: Caleta Herradura Fault. MF: Mejillones Fault.

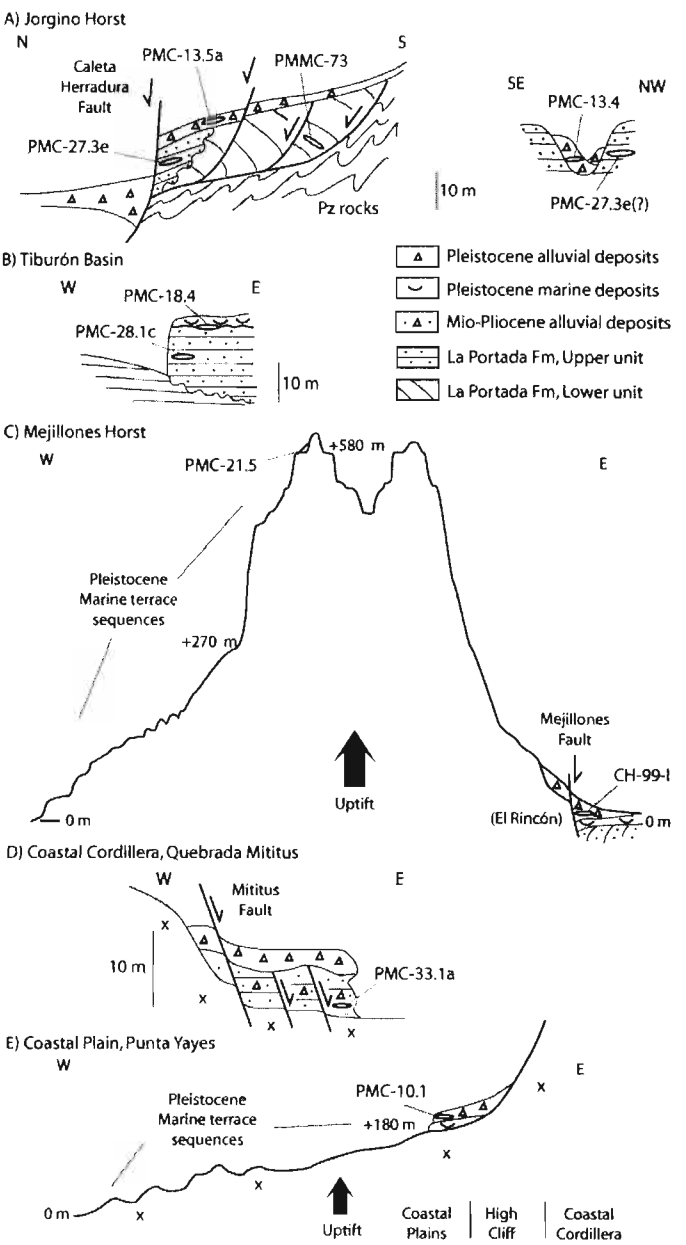

Figure 2. Schematic geological profiles and ash samples localization

Ar/Ar dating results and geodynamic implications

Ar/Ar analyses were performed through laser fusion on single sanidine and biotite crystals. Examination under

the binocular microscope permitted to select fresh minerals directly from pumices whenever possible. When minerals with different aspects were found in a sample, each occurrence was irradiated and dated. In all cases several (3 to 10) fusions were performed in order to check for homogeneous sample population (data in table 1). Actually, several cases of sample heterogeneity occurred, e.g. in PMC-18.4 dated in 0.79 ± 0.03 Ma, a sanidine grain yield an age of 131 Ma, corresponding to a crystal reworked from the coastal plutons.

Sanidine was used where possible due to the probable young age of some of the deposits. Other samples were dated using biotite, in order to easily separate primary volcanic crystals from accidental crystals introduced by reworking (fresh and altered biotite grains). Sample PMC-10.1 was dated using both sanidine and biotite, with a significantly older age from the last one. Thus, all biotite data presented here should be considered as possible maximum ages, except in sample PMC-27.3e where two individual sanidine and biotite minerals yielded concordant ages of 5.67±0.14 Ma.

The age of 19.35±0.04 Ma, obtained from the La Portada Formation lower unit ash (PMMC-73), is consistent with the Lower Miocene age suggested by microfossils present in the base of this formation in the Caleta Herradura area. The ages obtained for the upper unit indicate an Upper Miocene-Lower Pliocene age for this unit. These last deposits provide an upper limit for a period of intense tectonic activity that affected the lower unit, between 5.6 and 19.35 Ma.

Sample	Locality		Material	Age	Error
	UTM N	UTM E	Dated	My	2σ
Mejillones Peninsula					
La Portada Formation (Miocene - Pliocene)					
PMMC-73	7425918	339405	sanidine	19.35	0.04
PMC-27.3e*	7425862	339458	sanidine	5.67	0.14
PMC-27.3e*	7425862	339458	biotite	5.67	0.14
PMC-28.1c*	7422170	349599	biotite	4.17	0.12
Marine terraces deposits (Pleistocene)					
PMC-18.4	7422123	349934	sanidine	0.79	0.03
Alluvial deposits (Pliocene)					
PMC-21.5	7444810	344697	biotite	3.25	0.17
Alluvial deposits (Pleistocene)					
PMC-13.4	7425918	339405	sanidine	5.68	0.02
CH-99-I*	7445207	348191	sanidine	3.82	0.09
CH-99-I*	7445207	348191	sanidine	2.9	0.1
PMC-13.5 a*	7423198	339607	biotite	0.78	0.19
Coastal Cordillera					
Gravels deposits (Miocene - Pliocene)					
PMC-33.1a*	7435755	371142	biotite	12.74	0.13
Coastal Plain					
Alluvial deposits (Pleistocene)					
PMC-10.1	7477841	367586	sanidine	2.04	0.03
PMC-10.1	7477841	367586	biotite	2.61	0.14

Table 1. Summary of Ar/Ar age determinations from ash deposits. These ages are weighted mean of several total laser fusion analyses, when all are concordant at the 2-sigma level. Otherwise the youngest age is indicated by a star (*).

In the El Rincón area, the ash (CH-99-I) within a Pleistocene alluvial fan yielded five sanidine ages ranging from 2.9±0.1 to 3.82±0.09 Ma. These ages are not consistent at the 2-sigma level but the minimum age for the ash is of 3 Ma. This minimum age is similar to those obtained for the high terrace of the Mejillones Horst (PMC-21.5). This indicates that the ash of El Rincón area could be reworked from the ash of the high terrace of the Mejillones Horst. The same probably occurs with the ash layers in the fans that cover the Pleistocene marine terrace of Punta Yayes (PMC-10.1) and Jorgino Horst (PMC-13.4). These may be the product of reworking of a Neogene ash from an intramountain basin of the Coastal Cordillera and Jorgino Horst (PMC-27.3e), respectively. Biotite from the sample PMC-33.1a yielded an age of 12.74±0.13 Ma. The ash is interbedded in an alluvial fan on an intramountain basin of the Costal Cordillera.

The 3.25±0.17 Ma age obtained from ash (PMC-21.5) of the highest terrace of the Mejillones Horst (+580 m a.s.l.), indicates that this peninsula was emergent during the Middle Pliocene. If it is assumed that sea level at that time (3.25 Ma) was close to present datum, a long-term uplift rate of 0.18±0.02 m/ka can be estimated.

Only two samples (PMC-18.4 and PMC-13.5a) furnished ages younger than 1 Ma. They both contain sanidine and biotite xenocrystals of Mesozoic age (131-153 Ma). The young ages of 0.79±0.03 Ma on sanidine and

0.78±0.19 Ma on biotite, each corresponding to a single analysis, are compatible with the morphostratigraphical position of the deposits. PMC-18.4 corresponds to the limit between the higher beach ridge sequence (older than 0.4 ka) of the Pampa Mejillones and the La Portada Formation deposits (>1,8 Ma) (Fig. 2B). The ages of these ash layers suggest that material from a Pleistocene volcanic event is preserved in this coastal region westward from the Andean eruptive centers.

Discussion: Regional volcanic events and ¿westward dispersion of ash?

These ages together with other ages compiled from the SERNAGEOMIN data base (fig 3), highlight the occurrence of ash layers or lenses in the Coastal Cordillera and along the Pacific shores of northern Chile (17°-31°S), at more than 100 km westward from the neogene volcanic arc. Five major depositional periods are presumed (Fig. 4): (i) 18-23 Ma, (ii) 11-16 Ma, (iii) 4.4-11 Ma, (iv) 1.8-4.1 Ma and (v) < 1 Ma.

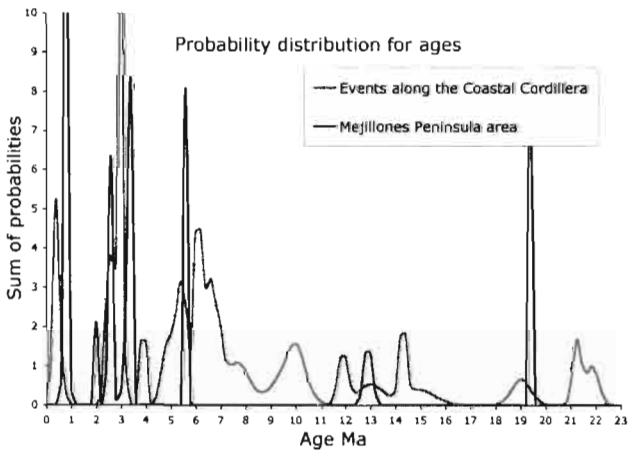

Figure 3. Sum of Gaussian curves or probability distribution for ages from the Mejillones Peninsula area and along the Coastal Cordillera between 18° - 32°S.

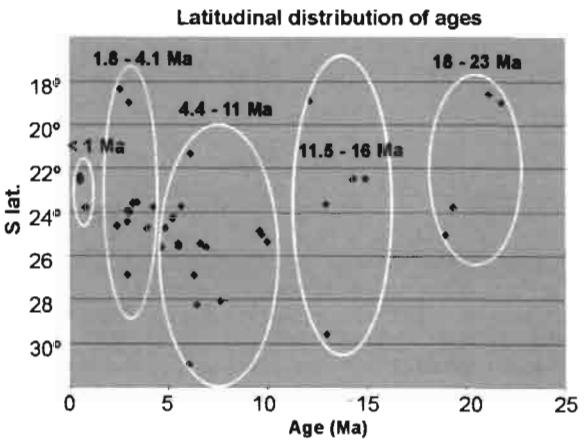

Figure 4. Latitudinal distribution of ash radiometric data between 18° and 32°S (data from Sernageomin data base).

We interpret that the explosivity of some eruptions, which occurred during these periods, was strong enough to allow the deposition of ash at least 100 km westward from the volcanic centers, located within the Central Andes volcanic arc. Most of these Neogene ashes are similar in age with large volume ignimbrites located throughout the arc. So, we propose two hypothetical models for the ash dispersion: (1) the ash deposits could be associated with westward transport of ash clouds (co-ignimbrite ash-fall) coeval to precordilleran Neogene ignimbrites; and/or (2) westward dispersion of ash clouds during plinian eruptions. It is possible that the coastal ash deposits are associated with westward dispersion of ash during episodes of eastern winds that occurred at the base of the stratosphere concomitantly with regional climatic conditions associated to zonal atmospheric circulation. The plinian or ultraplinian columns are likely to have been generated during the early stages of the eruptions, which later produced large-volume ignimbrites. We suggest also that later local reworking of those ash deposits is possible due to cohesive properties of ash material within laminar alluvial flows, which is an ongoing subject of research.