SIGNIFICANCE OF THE MAGNETIC RECORD IN EOCENE-MIOCENE COARSE-GRAINED SEDIMENTS DEPOSITED IN ARID/HYPERARID ENVIRONMENT (< 200 MM YR^{-1}) (ATACAMA DESERT, CHILE)

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ABSTRACT

The magnetic properties of sediments are widely used to understand environmental variability, yet most continental records have been obtained on fine-grained sediments in climatic zones with a mean annual precipitation (MAP) > 200 mm yr^{-1}, while coarse-grained sediments records under arid / hyperarid conditions remain poorly investigated. To test the potential environmental significance of the magnetic record of coarse-grained sediments deposited in a desertic region (MAP < 200 mm yr^{-1}), we selected four sedimentary sequences from the Atacama Desert (Centinela area) and explored their magnetic properties. These sequences were deposited under different climate-environmental conditions from the Eocene to the Miocene. The magnetic properties obtained in the coarse-grained stratigraphic record are mainly controlled by the concentration of (titano)magnetite of detritic origin, which is concentrated in the finest fraction of sediments. The values of parameters related to the intensity of magnetization decrease in the coarse sediments from oldest to youngest following a climatic transition from arid to hyperarid conditions in coincide with changes in the tectonic conditions and/or eventually sedimentary source. In contrast, magnetic-parameters from the fine-grained sediments (wetland deposits) at the top of the sequence are mainly controlled by the concentration of magnetite-maghemite and/or hematite crystals of authigenic origin. These variations are linked to an increase in the authigenic degree, which is related to variations in the depth of the local water table. This study provides one of the first magnetic properties record in coarse grained sediments under arid / hyperarid conditions unveiling the climatic and/or tectonic evolution in the Atacama Desert region.

Keywords: Northern Chile, Paleoclimate, Magnetic properties, Atacama gravels, Palaeoenvironment, Tectonic

RESUMEN

Las propiedades magnéticas en los sedimentos se usan ampliamente para entender la variabilidad ambiental, sin embargo, la mayoría de los registros continentales se han obtenido en sedimentos de grano fino en zonas climáticas con una precipitación media anual (MAP) > 200 mm año^{-1}, mientras que los registros de sedimentos de grano grueso en condiciones áridas/hiperáridas siguen siendo poco investigados. Para probar el potencial para estudios ambienteales del registro magnético de sedimentos de grano grueso depositados en una región desértica (MAP < 200 mm año^{-1}), seleccionamos cuatro secuencias sedimentarias del Desierto de Atacama (área de Centinela) y estudiamos sus propiedades magnéticas. Estas secuencias fueron depositadas en diferentes condiciones climáticas y ambientales desde el Eoceno hasta el Mioceno. Las propiedades magnéticas obtenidas en el registro estratigráfico de grano grueso están controladas principalmente por la concentración de (titano) magnetita de origen detrítico, que se concentra en la fracción más fina de sedimentos. Los valores de los parámetros relacionados con la intensidad de la magnetización disminuyen en los sedimentos gruesos del más antiguo al más joven después de una transición climática de condiciones áridas a hiperaridas y coinciden con cambios en las condiciones tectónicas y / o eventualmente en la fuente sedimentaria. Por el contrario, los parámetros magnéticos de los sedimentos de grano fino (depósitos de humedales) en la parte superior de la secuencia están controlados principalmente por la concentración de cristales de magnetita-maghemita y/o hematita de origen autógeno. Estas variaciones están relacionadas con un aumento en el grado autógeno, que está relacionado con variaciones en la profundidad de la capa freática local. Este estudio proporciona uno de los primeros registros de propiedades magnéticas en sedimentos de grano grueso en condiciones áridas / hiperáridas que revela la evolución climática y/o tectónica en la región del desierto de Atacama.

Palabras claves: Norte de Chile, paleoclima, propiedades magnéticas, gravas de Atacama, paleoambientes, tectónica

1. Introduction

The Atacama Desert is composed of numerous hydrographic basins (Blanco, 2008), mainly filled by gravel flows of alluvial-fluvial origin, deposited under arid conditions and resulting from the erosion of the Precordillera in response to the middle Eocene – Oligocene Incaic tectonic phase (Maksaev, 1990. During the Miocene, the transition to hyper-arid climatic conditions (whose exact timing and conditions remains debated e.g. Riquelme *et al.* 2018) and migration of the deformation to the East, generated a lower sedimentary flow. These arid/hyperarid conditions favor the conservation of the mineralogical signal in the sediments (Pizarro *et al.* 2019).

If magnetic properties have proved their ability to record environmental variations notably in fine-grained continental sediments (*e.g*, Evans, Heller, 2003), the liability of their record in coarse-grained sediment matrixes despite their widespread worldwide distribution remains to be investigated. Pizarro *et al*. (2019) tested the potential paleoclimatic-environmental significance of the magnetic record from paeleosols and a wetland deposit generated in coarse-grained sediments deposited in a desert region with a mean annual precipitation (MAP) < 200mm yr^{-1} and concluded that the fine-grained matrix of the gravels preserved a primary magnetic signal and that variations in magnetic properties could then be interpreted in term of sedimentary provenance changes and/or to tectonic /climatic variations during sediments deposition. However, a longer record was necessary to clarify which of these factors dominated the signal variations in the Atacama gravels. This study therefore investigates the link between the magnetic properties variations and depositional environment in the mid Eocene - Miocene coarse-grained sequence of the Centinela area with the goal to unravel the climatic versus tectonic influences in the sedimentary record of the basin (Fig 1).

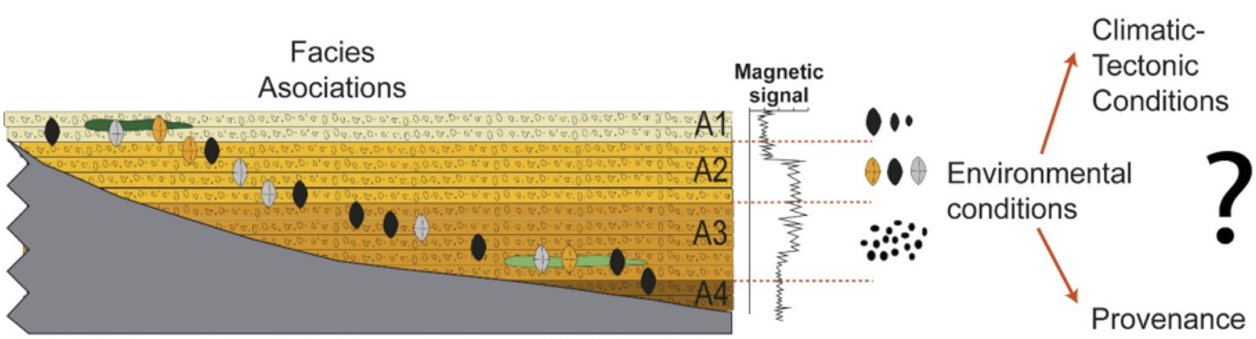

Figure 1. Hypothesis

2. Geological Setting

The study area is located 40 km SSW of the Calama city (22°55’S/69°05’W), on the western slope of the Precordillera. The Centinela basin corresponds to a small basin filled by ca 800 m thick Eocene- Miocene unconsolidated coarse-grained sediments and minor volcanic rocks. According to Riquelme *et al.* (2018), based on stratigraphic relationships, sedimentary facies, paleosols content, sedimentation environment, clasts lithology and thickness, the constructed gravel deposit sequence comprises from oldest to youngest

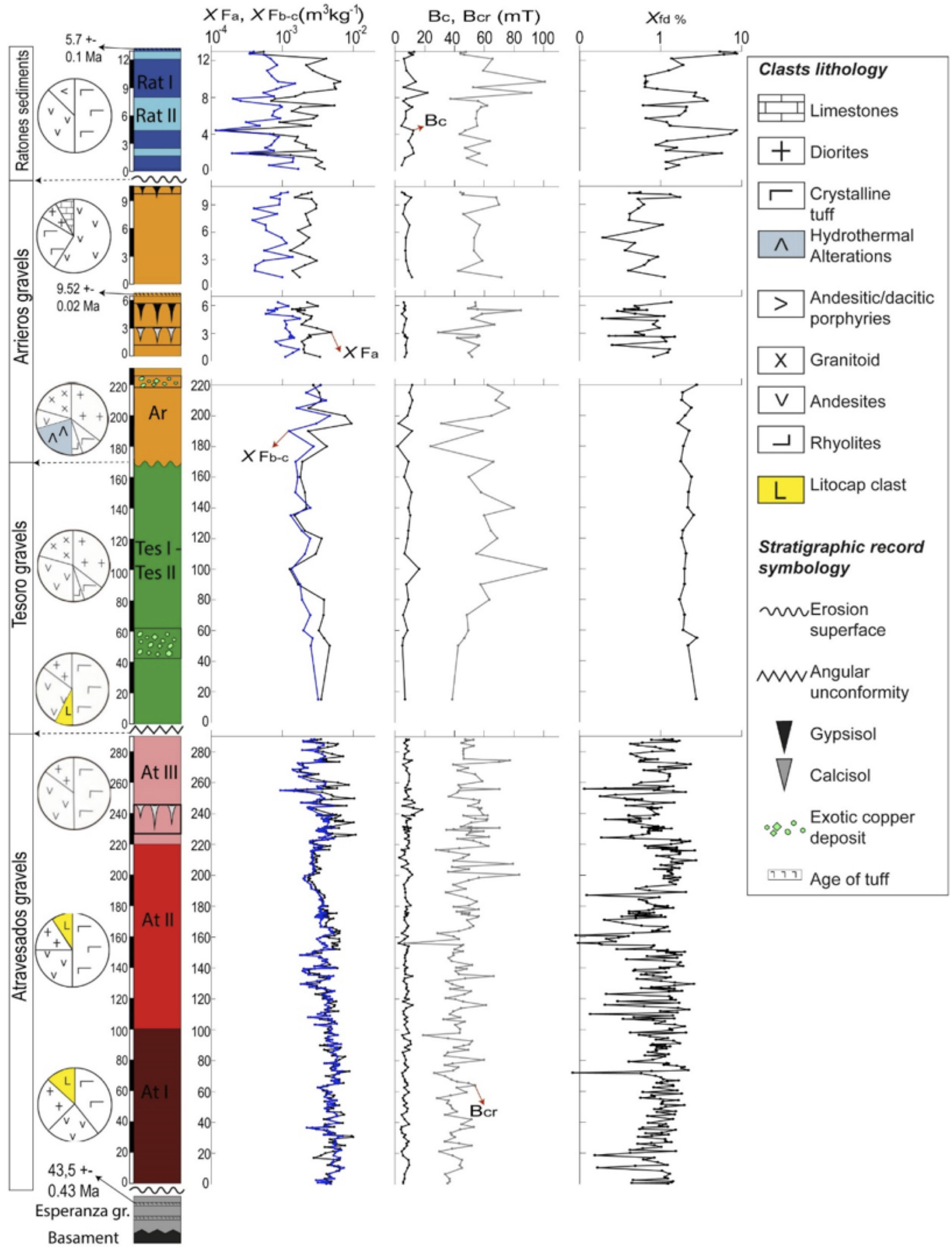

Figure 2. Schematic stratigraphic sequence from Centinela sedimentary records. Left of the stratigraphic Column: Clast-lithologies count of the units investigated in this study. Right of the stratigraphic columns, Magnetic parameters.

as the following units: Esperanza (Esp), Atravesados (At), Tesoro (Tes), Arrieros(Arr) gravels and Ratones Sediments (Rat).

3. Methodology

A total of 442 samples were collected in 5 different sites. The magnetic susceptibility (X) was measured with a Bartington MS2 susceptibilimeter at two different frequencies (470 - 4,700 Hz), to obtain frequency -dependent susceptibility parameter (Xfd%; Dearing *et al.* 1996). The natural remanent magnetization (NRM) and anhysteretic remanent magnetization (ARM) were obtained using a JR- 5A spinner magnetometer and a LDA5-af demagnetizer (AGICO) and a 2G superconducting rock magnetometer. The hysteresis loops and isothermal remanent magnetization (IRM) were obtained using a MicroMag AGM 2900 alternating gradient force magnetometer. Magnetic hysteresis and IRM parameters were calculated with the PmagPy software (available at https://earthref.org/PmagPy/cookbook/ Tauxe, 2010) and the routine of Kruiver *et al.* (2001). Thermomagnetic experiments were realized on a KLY3-CS3 (Curie points were calculated by the method of Hodel *et al.* 2017). Magnetic measurements were suplemented by mineralogical analysis performed with a scan-electron microscope (SEM) with an energy dispersive spectroscopy (EDS). All the experiments were performed at room temperature (*ca* 24° C and 1 atm) at Catolica del Norte University (UCN, Chile) and Géosciences Environnement Toulouse (GET, France) magnetism laboratories.

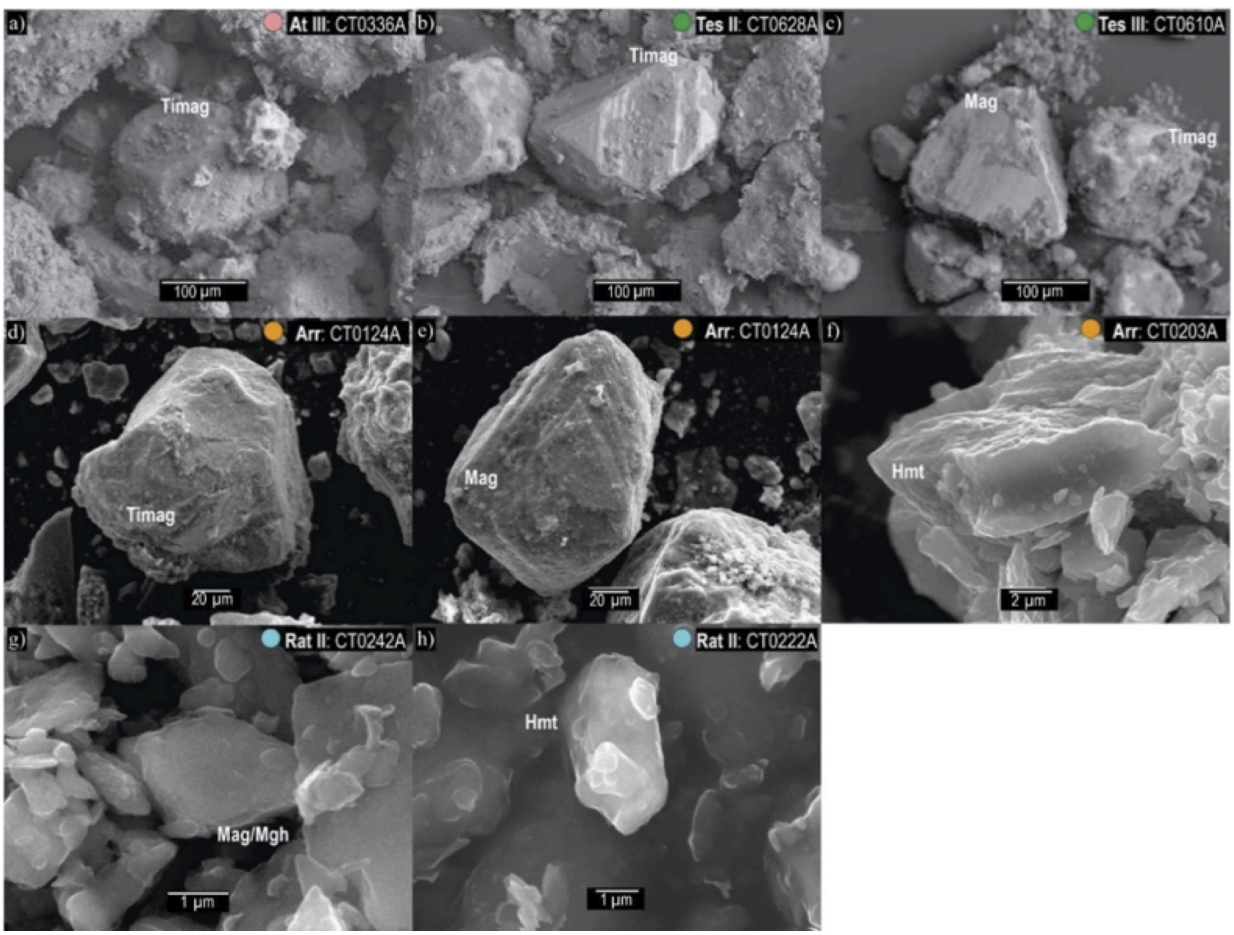

Figure 3. SEM/EDS pictures. a) Atravesados gravels; b) Tesoro gravels; c), and d) Arrieros gravels, e) Fine-grained horizons from Ratones sediments. Mag: Magnetite, Timag: Titanomagnetite, Mgh: Maghemite, Hmt: Hematite.

4. Results

The magnetic parameters χ_{Lf}, χ_{ferry}, χ_{ARM}, M_s and SIRM display relatively similar variations throughout the profile (Fig. 2). Highest susceptibilities (χ_{Lf}) are found in the finest fraction (< 0.5 (A)) and these values display a general decreasing trend from the Atravesados unit, toward the younger Arrieros one with intermediate values in Tesoro gravels. For the Rat sediments, the values are higher in the coarse-grained horizons (Rat I) by comparison to the fine-grained horizons (Rat II). The variations in χ_{hifi} values are less than other parameters, though some fluctuations are registred in the Tesoro gravels. This could indicate a larger proportion of paramagnetic or antiferromagnetic minerals in these horizons. In the Tesoro gravels and Rat II, an inverse relation is observed between the coercivities parameters, B_c and B_{cr}, and the susceptibility parameters variations. Overall, the S-ratio is close to 1 throughout most of the profile, except in some Tesoro and Atravesados gravels horizons where S-ratio is closer to 0, indicating a high proportion of harder magnetic minerals. The χ_{ferry}/ M_s, χ_{ARM}/ M_s, χ_{ferry}/χ_{ARM} and $\chi_{fd\%}$ ratios are rather constant over the whole profile. This indicates that the magnetic grain size variations are not very strong in general, except in the Rat II horizons, where the values of $\chi_{fd\%}$ can be greater than 3%.

In the Atrevesados, Tesoro and Arrieros gravels the magnetic mineralogy consists mainly of subhedral rounded crystals of titanomagnetites and magnetite often above 20 µm in size (Fig. 3) probably of detritic origin. Whereas, in the Rat II we identified subhedral magnetite-maghemite and hematite crystals ca. 1µm (Fig. 3).

The thermomagnetic curves exhibit an irreversible behavior, probably linked to oxidation processes during heating of the sample. All units present maghemite (Increase around 200°- 400° C) and Ti-poor titanomagnetite. Magnetite is found in Tes, Arr and Rat. Tinanomaghemite and/or Titanohematite is found in almost all units. The ARM and demagnetization curves show the presence of low coercivities magnetic minerals (*ca.* at 20 mT). Day plot indicated that Fe-bearing minerals in coarse-grained sediments are mostly PSD/ MD (Fig. 4).

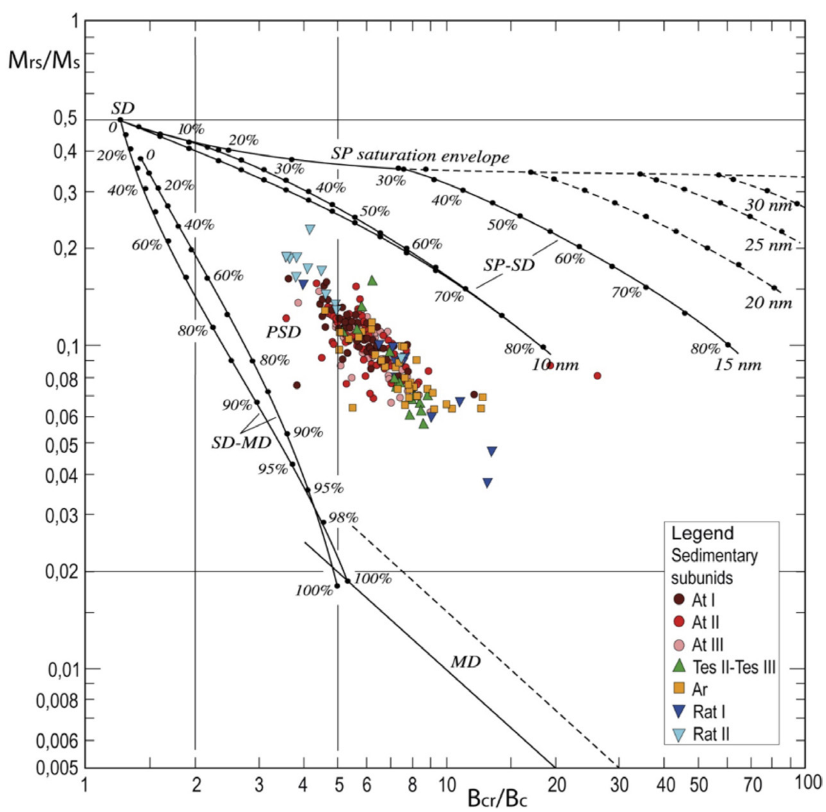

Figure 4. Day plot for magnetite and titanomagnetite from Centinela sedimentary record.

5. Interpretation and Conclusions

- The magnetic signal obtained along with the stratigraphy in the Centinela area, except Rat II horizons, is mainly controlled by the concentration of low-coercivity minerals (*i.e.*, mainly magnetite and titanomagnetite) of detrital origin, which are concentrated in the finest fraction (< 0.5 mm) of the coarse-grained sediments.
- The high $\chi_{fd\%}$ values (> 3%) in the Rat II horizons are linked to an increase in the authigenic degree, which could be related to local water-table variations associated with local, high-frequency, short time scale climatic fluctuations (10–100 kyr).
- The decreasing of magnetization intensity-related parameters from the Atravesados to the Arrieros gravels is linked to a decrease in the input of detrital Fe-bearing minerals, which could be related either to tectonics or to a regional trend in climate aridification
- The χ variations along Atravesados gravels (continuous and long stratigraphic record), where no variations in the source area can be identified, can be used to differentiate between climatic and tectonics conditions, which influenced the sediments deposition.

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