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Sedimentology and high-frequency sequence stratigraphy of a forearc extensional basin: The Miocene Caleta Herradura Formation, Mejillones Peninsula, northern Chile

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Abstract

Facies and sequence stratigraphic interpretation for the 380-m-thick Caleta Herradura Formation (Miocene) are presented, based on detailed and comprehensive outcrop data from the Caleta Herradura half-graben, Mejillones Peninsula, northern Chile. The Caleta Herradura Formation contains an array of lithofacies comprising sandstones, sandy mudstones, diatomites and breccio-conglomerates that are interpreted as the products of inner-shelf to non-marine depositional settings. Complete exposure allows for recognition of a number of distinct and laterally persistent key stratal surfaces that permitted the identification of twenty-five high-frequency (meter to tens of meters-scale) sequences. Based on their internal organization, two main motifs of such unconformity-bounded depositional packages can be distinguished: deepening and deepening-to-shallowing upwards. Transgressive and highstand systems tracts were resolved based on such facies stacking patterns. The origin of sequences is difficult to decipher and remains somewhat uncertain. However, several lines of direct and indirect evidence constrain interpretations for both the sequence architecture and bounding unconformities, and help to discriminate between the various mechanisms that may have driven their development. In essence, these demonstrate that neither tectonically driven sea-level oscillations nor climatically induced changes in sediment supply can adequately explain the distinctive features of unconformities and the facies architecture of sediments they delimit. Instead, these high-frequency changes in relative sea level are best explained as a consequence of glacio-eustatic oscillations. The contemporaneous deep-ocean proxy records appear to support a causal link between the observed stratigraphic cyclicity and glacio-eustatic changes in sea level due to modulation of short-term Milankovitch-scale events by longer-period astronomical variations. However, the type of astronomical forcing remains elusive, hindered by lack of adequate age controls and a poor understanding of pacing mechanisms of high-frequency climate changes during the middle to late Miocene.

Keywords: Miocene; Extensional basin; Northern Chile; High-frequency sequence stratigraphy

1. Introduction

A frequent objective of the investigation of sedimentary successions is the identification and discrimination of the main controls on their accumulation. In tectonically active settings this purpose is commonly hampered by (i) the difficulty in differentiating between

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changes in accommodation (including eustasy and vertical tectonic movement), and (ii) spatial and temporal variations of sediment supply. Within extensional settings, for instance, lateral variability in sediment influx and accommodation have a major impact on basin stratigraphy and produce an array of varied but predictable coeval stratal stacking patterns and key stratal surfaces (e.g. Gawthorpe et al., 1994; Dorsey and Umhoefer, 2000; Sharp et al., 2000). In spite of this complex stratigraphic organization, however, detailed evaluation of unconformity-bounded sediment wedges and lateral features of bounding surfaces within a sequence stratigraphic framework may help to resolve stratigraphic relationships and to distinguish whether relative sea-level fluctuations are a response to eustatic or tectonic controls (Howell and Flint, 1996; Carr et al., 2003; Zecchin et al., 2004). In this paper we present evidence for high-frequency eustatic sea-level changes derived from a detailed sequence stratigraphic analysis from which, owing to the particular climatic setting of the studied area, rates of sediment supply can be confidently eliminated as a variable.

The exhumed Caleta Herradura half-graben basin in northern Chile provides an excellent opportunity to define the prevailing controls on stratal architecture and to unravel the nature of the processes that played the prime role in the development of the impressive succession of unconformity bounded cyclic strata within its Miocene infill. The major intents of this paper are: (i) to define both the sedimentary facies and the depositional settings of the Caleta Herradura Formation, (ii) to examine the high-frequency, highly regular cyclicity within a comprehensive sequence stratigraphic framework, and (iii) to further the understanding of the driving mechanism creating high-frequency sequences in order to assess its possible relation to cycle-producing, astronomically forced sea-level fluctuations.

2. Tectonic, stratigraphic, and regional climatic setting

The Mejillones Peninsula (Fig. 1) is a prominent coastal landmark in northern Chile. It is dissected by a network of northward-striking, high-angle, basement-involved normal faults that generated a series of asymmetric half-grabens located in a forearc position with respect to the Chile subduction system (Armijo and Thiele, 1990; González et al., 2003). The active east–west-directed extensional fault system observed on land continues offshore across the shelf and upper slope (Niemeyer et al., 1996), and is inferred to have been active since at least Miocene time (Hartley and Jolley, 1995). At present, the most widely accepted mechanism for forearc extension along this convergent margin is subduction erosion followed or accompanied by extensional collapse of the leading edge of the South American plate toward the north Chile Trench (Delouis et al., 1998; von Huene et al., 1999; Hartley et al., 2000).

The Caleta Herradura half-graben formed during Miocene time by subsidence along the eastwards downthrowing and southward propagating Jorgino Fault. Deposits of the Caleta Herradura Formation were laid down during initial stages of rifting in a narrow and elongate hanging-wall depocenter. During the Quaternary, regional syn-rift uplift rates have exceeded extensional subsidence rates so that the wedge-shaped Miocene to Pleistocene basin fill experienced net uplift and has been spectacularly exposed on the vertical sea-cliff of the Caleta Harradura de Mejillones Bay (Fig. 1). Here the basin is bounded to the west by the listric, steeply dipping (~70°) Caleta Herradura Fault, a north-striking splay of the Jorgino Fault. Hanging-wall subsidence accommodated a ~500-m-thick clastic wedge composed of three major unconformity-bounded stratal units: the Miocene Caleta Herradura Formation, the early Pliocene member of La Portada Formation (Cerro Bandurrias Member), and the Pleistocene Mejillones Formation (Fig. 2; Krebs et al., 1992; Niemeyer et al., 1996).

Sediments of the 380-m-thick Caleta Herradura Formation, interposed between the Paleozoic metamorphic basement below and the shallow-marine and alluvial fan deposits of the Cerro Bandurrias Member and Mejillones Formation above, display a faulted, westerly dipping monoclinal geometry and comprise a predominantly shallow-marine arenaceous succession with minor intercalations of sandy mudstones, diatomites, and conglomerates. Evidence from the calcareous nannoplankton (Mai, 1984), the faunal composition of the pure diatomite at the top of the Caleta Herradura Formation (Krebs et al., 1992), and from the planktonic foraminiferal content of the entire unit (Ibaraki, 2001), indicate that these strata span from the late early Miocene (Zone N7, with an estimated age of 17.25–16.4 Ma) to the latest Miocene (Zone N17, with an estimated age of 8.3–5.6 Ma) (chronologic calibration of biostratigraphic zones is based on the time scale of Berggren et al., 1995). Moving down the hanging-wall dip slope, the Miocene succession displays a marked stratigraphic expansion characterized by divergent fanning strata produced by syndepositional tilting. These beds onlap onto the underlying unconformities indicating that the fulcrum of the hanging-wall moved away from the fault during sedimentation and that the