Sedimentary Geology 367 (2018) 146–163

Contents lists available at ScienceDirect

Sedimentary Geology

journal homepage: www.elsevier.com/locate/sedgeo

Trace fossils, sedimentary facies and parasequence architecture from the Lower Cretaceous Mulichinco Formation of Argentina: The role of fair-weather waves in shoreface deposits

Lindsey J.N. Wesolowski [a,*], Luis A. Buatois [a], M. Gabriela Mángano [a], Juan José Ponce [b], Noelia B. Carmona [b]

[a] Department of Geological Sciences, University of Saskatchewan, 114 Science Place, Saskatoon, SK S7N 5E2, Canada
[b] CONICET, Instituto de Investigación en Paleobiología y Geología, Universidad Nacional de Rio Negro, General Roca, 8332, Rio Negro, Argentina

A R T I C L E I N F O

Article history:
Received 4 November 2017
Received in revised form 16 February 2018
Accepted 18 February 2018
Available online 21 March 2018

Editor: Dr. B. Jones

Keywords:
Parasequences
Shoreface variability
Fair-weather waves
Mulichinco Formation
Neuquén Basin

A B S T R A C T

Shorefaces can display strong facies variability and integration of sedimentology and ichnology provides a high-resolution model to identify variations among strongly storm-dominated (high energy), moderately storm-affected (intermediate energy), and weakly storm-affected (low energy) shoreface deposits. In addition, ichnology has proved to be of help to delineate parasequences as trace-fossil associations are excellent indicators of environmental conditions which typically change along the depositional profile. Shallow-marine deposits and associated ichnofaunas from the Mulichinco Formation (Valanginian, Lower Cretaceous) in Puerta Curaco, Neuquén Basin, western Argentina, were analyzed to evaluate stress factors on shoreface benthos and parasequence architecture.

During storm-dominated conditions, the *Skolithos* Ichnofacies prevails within the offshore transition and lower shoreface represented by assemblages dominated by *Thalassinoides* isp. and *Ophiomorpha irregulaire*. Under weakly storm-affected conditions, the *Cruziana* Ichnofacies is recognized, characterized by assemblages dominated by *Thalassinoides* isp. and *Gyrochorte comosa* in the offshore transition, and by *Gyrochorte comosa* within the lower shoreface. Storm-influenced conditions yield wider ichnologic variability, showing elements of both ichnofacies.

Storm influence on sedimentation is affected by both allogenic (e.g. tectonic subsidence, sea-level, and sediment influx) and autogenic (e.g. hydrodynamic) controls at both parasequence and intra-parasequence scales. Four distinct types of parasequences were recognized, strongly storm-dominated, moderately storm-affected, moderately storm-affected – strongly fair-weather reworked, and weakly storm-affected, categorized based on parasequence architectural variability derived from varying degrees of storm and fair-weather wave influence. The new type of shoreface described here, the moderately storm-affected – strongly fair-weather reworked shoreface, features storm deposits reworked thoroughly by fair-weather waves. During fair-weather wave reworking, elements of the *Cruziana* Ichnofacies are overprinted upon relict elements of the *Skolithos* Ichnofacies from previous storm induced deposition. This type of shoreface, commonly overlooked in past literature, expands our understanding of the sedimentary dynamics and stratigraphic architecture in a shoreface susceptible to various parasequence and intra-parasequence scale degrees of storm and fair-weather wave influence.

1. Introduction

Shorefaces may display strong sedimentologic (Hart and Plint, 1995; Clifton, 2006; Plint, 2010) and ichnologic variability (MacEachern and Pemberton, 1992; Pemberton et al., 2012). This is the result of alternating and contrasting hydrodynamic energy levels due to overall storm intensity, storm frequency, and relative water depth, resulting in a multitude of stress factors on benthic communities (MacEachern and Pemberton, 1992; Buatois and Mángano, 2011; Pemberton et al., 2012). These varying stress factors at the sediment-water interface are detected by integration of sedimentology and ichnology which aids in detecting variations between strongly storm-dominated (high energy), moderately storm-affected (intermediate energy), and weakly storm-affected (low energy) shoreface facies (MacEachern and Pemberton, 1992; Pemberton et al., 2012). In addition, placement of these deposits within a sequence-stratigraphic framework has been instrumental for refining facies models (Pemberton et al., 2001; Buatois and Mángano, 2011). The use of ichnology to delineate parasequences is facilitated by the fact that trace-fossil associations are excellent indicators of environmental conditions that typically change along the depositional profile (Pemberton et al., 1992).

* Corresponding author.
E-mail address: lindsey.wesolowski@usask.ca (L.J.N. Wesolowski).

https://doi.org/10.1016/j.sedgeo.2018.02.007
0037-0738/

Within the Neuquén Basin of western Argentina, the Mulichinco Formation (Valanginian, Lower Cretaceous) in the vicinity of Yesera del Tromen, consists exclusively of shallow-marine deposits within a large scale progradational succession, typically forming wave-dominated parasequences (Gulisano et al., 1984; Vergani et al., 1995; Schwarz, 1999; Schwarz et al., 2011, 2016) based on superbly exposed outcrops in the locality of Puerta Curaco. Exceptional outcrop quality and a relatively high abundance and diversity of trace fossils provide the opportunity to facilitate characterization of storm-dominated, weakly storm-affected, and two types of moderately storm-affected, shallowing upward parasequences in the upper member. The objective of this study, promoted by examination of distinct types of shallowing-upwards parasequences, is to expand our understanding of the sedimentary dynamics and parasequence architecture in shoreface complexes. Previous schemes have emphasized the importance of storm waves in shaping facies characteristics and sedimentary architecture of shoreface deposits. Our study highlights the importance of fair-weather waves through the recognition of a type of shoreface parasequence, commonly overlooked in past literature.

2. Stratigraphic setting

The Neuquén Basin (Fig. 1) is located east of the Andes in west-central Argentina and comprises approximately 6000 m of Upper Triassic to Paleogene strata formed in a back-arc basin covering over 120,000 km^2 (Leanza et al., 1977; Uliana et al., 1977; Legarreta and Uliana, 1991; Howell et al., 2005; Schwarz, 2012). During the Middle Jurassic to Early Cretaceous, as the Andes formed due to the eastward subduction of the proto-Pacific oceanic crust beneath the western margin of Gondwana (Schwarz et al., 2006), the Neuquén Basin experienced thermal subsidence, interrupted by several episodes of structural inversion (Vergani et al., 1995; Schwarz and Howell, 2005). The basin later evolved into a shallow water epeiric seaway during the Late Jurassic and Early Cretaceous, with ramp type margins in the east and south creating a funnel shaped morphology open to the north and west (Legarreta and Uliana, 1991; Schwarz and Howell, 2005). Within the basin, sedimentary infill alternated from transgressive and regressive successions of the Mendoza Group (Tithonian–Barremian) (Groeber, 1946; Legarreta and Gulisano, 1989; Legarreta and Uliana, 1991; Schwarz et al., 2006), promoted by regional subsidence, tectonic inversion and uplift, as well as fault-controlled subsidence (Vergani et al., 1995; Schwarz et al., 2006). More distal deposits accumulated more proximally during the shoreline transgression, forming retrogradational stacking patterns, and proximal sediments deposited more distally during shoreline regression forming progradational stacking patterns. This infill reflecting the interaction between eustacy and tectonics (Vergani et al., 1995; Howell et al., 2005; Schwarz et al., 2006; Schwarz, 2012), developed an extensive second-order highstand from Tithonian to early Valanginian (Schwarz and Howell, 2005). During the early Valanginian, a tectonic inversion pulse occurred, accounting for a relative drop in sea-level (Vergani et al., 1995; Schwarz and Howell, 2005), which led to deposition of the Mulichinco Formation lowstand wedge in the central part of the basin (Schwarz et al., 2006).

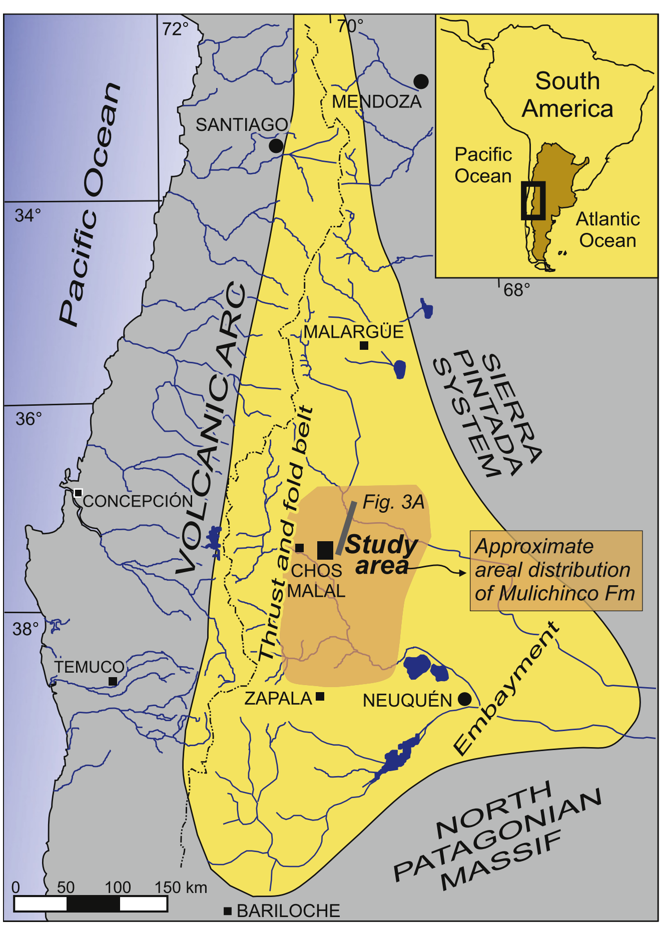

Fig. 1. Location map and approximate areal distribution of the Mulichinco Formation in the Neuquén Basin and study area (modified from Schwarz, 2012).

The study area is located within the central part of the Neuquén Basin (Fig. 1). The succession analyzed is within the second-order lowstand Mulichinco Formation wedge (Fig. 2), with the base of the unit overlying the Intra-Valanginian unconformity, separating the Mulichinco Formation above from the anoxic shales of the Vaca Muerta Formation below (Gulisano et al., 1984; Schwarz and Howell, 2005; Schwarz et al., 2011; Schwarz and Buatois, 2012). The Intra-Valanginian unconformity represents a sequence boundary demarcated by alluvial deposits overlying anoxic shale in proximal settings, and shallow-marine carbonates above anoxic shale and marl in distal settings (Gulisano et al., 1984; Schwarz and Buatois, 2012). Capping the Mulichinco Formation are the dark gray to black, parallel-laminated shales of the Agrio Formation exhibiting a sharp base, directly above tabular or massive carbonates and siliciclastic successions at the top of the measured sections. Subdivision of these formations has been facilitated by detailed biostratigraphic zonations of Lower Cretaceous (Berriasian–lower Barremian) strata through analysis of ammonite biozones and calcareous nanofossil bioevents within the Neuquén Basin (Aguirre-Urreta et al., 2005).

The Mulichinco Formation is composed of three members; lower, middle and upper (Fig. 3A), with as many as fourteen facies associations identified ranging from continental, marginal marine, and shallow to outer-shelf marine settings (Schwarz and Howell, 2005). The lowermost member of the formation is siliciclastic dominated, encompassing from lower shoreface sandstone to offshore mudstone. The middle carbonate member ranges from offshore marl and wackestone to oyster-rich floatstone and boundstone (Schwarz and Howell, 2005; Schwarz et al., 2016). The upper member, subject to the focus of this study, is a mixed siliciclastic-carbonate succession, comprising thin carbonates and thick, siliciclastic, open-marine deposits, stacked forming the parasequences discussed in this paper. In more proximal positions south of the study area, marginal-marine deltaic, as well as, fluvial systems (Schwarz and Howell, 2005), are interpreted to have acted as the sediment source for the uppermost part of the formation (Schwarz et al., 2008, 2016; Liberman et al., 2014).

3. Methodology

Methodology for this research consisted of systematic mapping and standard sedimentary facies analysis based on bed-by-bed measuring of three stratigraphic sections; PCS1 (S 37° 22.577' W 069° 56.846'), PCS2 (S 37° 23.764' W 069° 56.195'), and PCS3 (37° 24.388' W 069° 56.888')