CONTOURITES IN THE UPPER JURASSIC-LOWER CRETACEOUS VACA MUERTA FORMATION: IMPLICATIONS FOR THE DEPOSITIONAL MODEL AND SEQUENCE STRATIGRAPHY

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In the stratigraphic record, contourites are traditionally described in deep water systems associated with global wind- or thermohaline-driven circulation. However, modern systems show sedimentary bodies deposited by contour currents also in shallow waters (e.g., on the shelves and slopes of the Mediterranean Sea). The Upper Jurassic-Lower Cretaceous Vaca Muerta Formation (Neuquén Basin, Argentina) represents the bottomset and foreset of a mixed carbonate-siliciclastic, shelf-margin, subaqueous clinoform system deposited in a shallow, marginal sea. This formation is host to bottom current deposits that we interpret as contourites. This interpretation is based on sedimentologic, ichnologic, and sequence stratigraphic studies of the lowermost third-order sequences (Units 1 and 2, Tithonian) analyzed in detail in one outcrop (Yesera del Tromen) and cores from nine wells (in the Neuquén Embayment). The Vaca Muerta Formation can be subdivided into five facies associations, namely marginal-marine, basin, drift, slope, and outer ramp (from base to top).

Bottom current deposits are mainly included in the drift facies association, which is constituted by massive (bioturbated), cross-bedded, parallel-, low angle- and wavy-laminated, crinoidal mudstone, crinoid-rich lenses, coarse mudstone laminae encased in fine mudstone, massive (bioturbated), parallel-, low-angle and current-ripple cross-laminated, coarse mudstone, and massive, normal-graded and composite beds of calcareous, fine to coarse mudstone. The relatively deep location of this facies association (at the bottomset, *ca.* 270-400 m water depth, Minisini *et al.*, 2020) points toward deposition below storm-wave base. Sediment-gravity flows (turbidity currents, hyperpycnal currents, and wave-enhanced sediment-gravity flows) are excluded as a trigger for this association because the low-angle foresets (0.2-0.3°) would not be able to sustain the transport of low-density flows capable of producing abundant traction structures. Instead, bottom currents originated the sediment drifts, ventilating the seafloor during discrete events of dominantly dysoxic and oxic conditions. A wind- and thermohaline-driven circulation system is the likely origin of bottom currents (*i.e.*, contour currents). Enhanced cascading of surface waters from the shelf (topset) may have intensified the circulation system during times of cooler climates.

The sedimentary processes resulting in the five facies associations can be further analyzed in terms of basin circulation and sequence stratigraphic patterns, which were likely controlled by climatic oscillations (*e.g.*, cyclostratigraphic models of the Agrio and Vaca Muerta Formation; Sagasti, 2005; Kietzmann *et al.*, 2020). In the study area, during the Transgressive Systems Tract (TST) and the Highstand Systems Tract (HST) of Unit 1, warmer climates and an equatorward migration of the arid belt generated high sea levels and humid conditions, producing high freshwater winter discharges. Warm and brackish waters enhanced water stratification and originated estuarine basin circulation, producing anoxic conditions in the bottomset of the clinoforms. Organic matter and siliciclastics are abundant due to eutrophication and increased fluvial discharge. In contrast, during the following third-order systems tracts (Falling Stage Systems Tract, FSST of Unit 1, and the Lowstand Systems Tract, LST of Unit 2) or regressive hemicycles of fourth-order sequences (associated with TST and Regressive Systems Tract, RST of Unit 2; RST *sensu* Catuneanu, 2006), colder climates and poleward migration of the arid

belt resulted in dominantly arid conditions, low sea levels, and enhanced cascading of dense, cold waters due to stronger winter convection and increased salinity of the surface waters by evaporation in summer. The cascading currents triggered weakened estuarine to anti-estuarine circulation, generating contour currents, and oxygenating the bottomset and foreset of the clinoforms. Organic matter content decreased, and carbonate content increased because of higher bottom water oxygenation and lower siliciclastic dilution, respectively. The shelf constituted by the Picún Leufú Formation represents the area of denser (colder) water production due to its southern location (Rodríguez Blanco *et al.*, 2020). Lower temperatures might be associated with the development of the Picún Leufú Formation (late Tithonian; Brysch, 2018; Alberti *et al.*, 2020), demonstrating that carbonate deposition occurred during times of cooler climates. The return towards dominantly estuarine circulation occurred during transgressive or early regressive hemicycles of TST and RST of Unit 2, generating anoxic and dysoxic conditions from bottomset to middle foreset locations. This depositional model combining sedimentary processes and bottom water oxygenation provides a robust framework to understand sediment partitioning and its relationship with sequence stratigraphy in the Vaca Muerta Formation. However, it also highlights the need for further sedimentologic analysis correlating bottomset and foreset locations with topset facies (Quintuco and Picún Leufú formations) to improve sequence stratigraphic models that aid in the delineation and characterization of unconventional reservoirs.

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