geoconvention
Calgary • Canada • June 20-22 2022

Flow processes and bed-scale characteristics associated with a fault-controlled intra-slope fan deposit, Tres Pasos Formation, Chile

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Summary

Sediment-laden gravity currents are the primary mechanism for delivering coarse-grained material to the deep-sea and their deposits represent one of the most common types of sedimentary rocks (Middleton, 1993). However, turbidity current processes on the seafloor have been notoriously difficult to study due to their inaccessible, unpredictable and destructive nature (Mutti and Normark, 1987). Despite these challenges, early researchers such as Gerard Middleton used integrated approaches including flume experiments and outcrop investigations to understand turbidity current mechanics and deposition (e.g., Middleton, 1967; Middleton and Hampton, 1973; Hiscott and Middleton, 1979). These initial studies noted the possibility that many turbidity currents were Froude supercritical and documented the occurrence of their associated sedimentary structures in deep water strata. Recently, seafloor observations have become more feasible through technological advancements and have further highlighted the importance of the upper flow regime in subaqueous density flows (e.g., Hughes Clarke, 2016). We build off the foundational work of Middleton and others while incorporating recent findings from seafloor investigations to examine the flow processes and products involved when turbidity currents encounter seafloor topography in the form of a fault-bound slope minibasin.

Turbidity currents often traverse complex slopes where seafloor topography can have a major influence on their hydraulic properties and distribution of sediment (McCaffrey and Kneller, 2004; Clark and Cartwright, 2009; Tek et al., 2020). The nature of flow seafloor interactions depends on both the properties of the flow (e.g., velocity, thickness, Froude number, density stratification) and the topography (relief, shape), and can result in distinct stratigraphic expressions (Alexander and Morris, 1994; Kneller and Buckee, 2000; Soutter et al., 2021). Where local changes in gradient and confinement generate accommodation for deposition, sandy intra-slope fans can form and represent attractive hydrocarbon reservoir targets in many basins around the world (e.g., Gulf of Mexico, offshore West Africa, Atlantic Canada; Pr ather et al., 1998; Sinclair and Tomasso, 2007; Rodriguez et al., 2021). Zones upslope of intra-slope and base of slope fans have been interpretated as flow transition zones that separate regions of net erosion and net deposition, and contain enigmatic morphological features (bedforms, scours) attributed to changes from Froude supercritical to subcritical flow regimes (Mutti and Normark, 1987; Wynn et al., 2002; Hodgson et al., 2022). However, relatively few examples of intra-slope fans have been identified in outcrop. As a result, the flow dynamics and depositional processes that produce these successions as well as their sedimentological characteristics remain poorly constrained. In this study, we examined an exceptional outcrop at

El Chingue Bluff in Chilean Patagonia, which reveals an oblique depositional-dip perspective of a fault-bound intra-slope fan accumulation along its entire depositional length (Figure 1; Shultz and Hubbard, 2005). We conducted a bed-scale investigation using classic field methods (including 22 measured sections) and an Unmanned Aerial Vehicle structure-from-motion 3D photogrammetry model to document the sedimentology and architecture of the succession from proximal to distal.

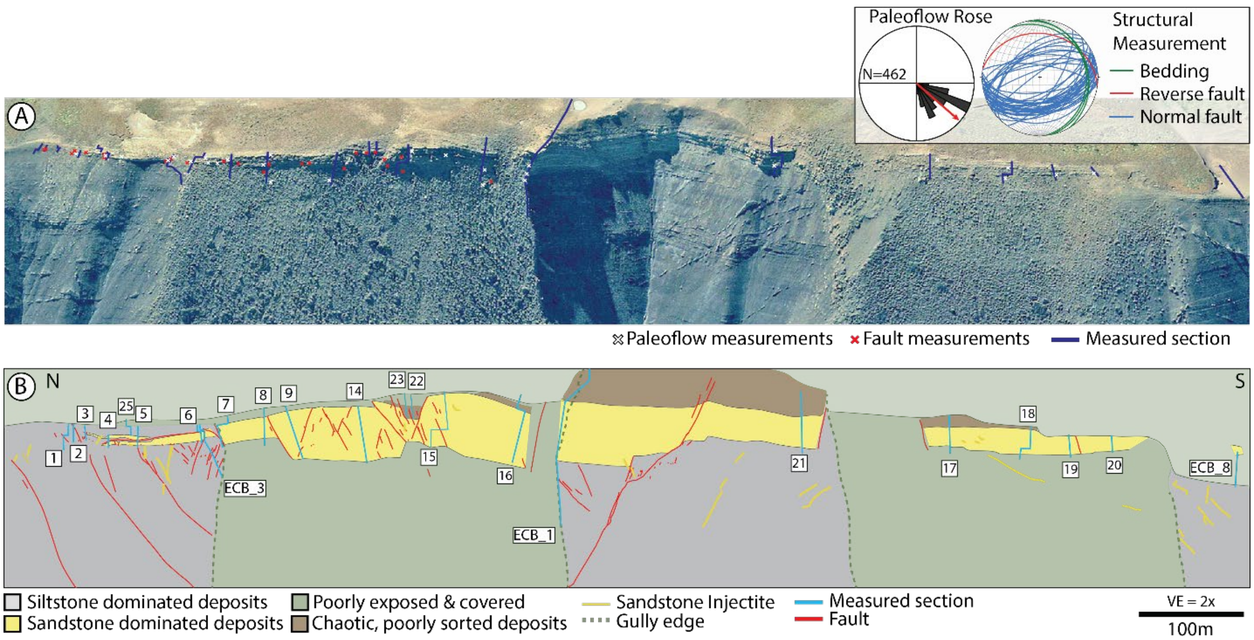

Figure 1: El Chingue Bluff study area and dataset. (A) Google Earth satellite image of the top of El Chingue Bluff. The location of fault and paleoflow orientation measurements are indicated as well as the location of measured sections. Paleoflow and structural measurements for the area are compiled on the rose and stereonet diagrams in the top right corner. (B) Stratigraphic cross-section with 2x vertical exaggeration produced from tracing features on the digital outcrop model. Faults, sandstone injectites, measured section locations and mapped lithology are included.

The intra-slope fan is exposed at the top of El Chingue Bluff and consists of a sandstone-prone package overlying siltstone-dominated, thin-bedded slope strata and capped by a thick poorly sorted debris flow deposit (Figure 1). The succession is cross-cut by several faults, and changes in thickness and character over the ~ 1 km long exposure (Figures 1 and 2). Some normal faults and small localized reverse faults are interpreted as post-depositional tectonic deformation while other normal faults are interpreted to be synsedimentary features based on coincident changes in sandstone bed thickness and abundance that make stratigraphic correlations locally challenging. At the head of the minibasin the succession is siltstone-dominated with discontinuous sandstone beds and steep-faced scours containing backset stratification; features which suggest a region dominated by sediment bypass and supercritical flows that locally underwent hydraulic jumps at normal faults (Figures 1 and 2; Ge et al., 2017). The deposit becomes sandstone-prone downslope and thickens to a maximum of 30 m on the downthrown side of NE-SW oriented normal faults before thinning to the south (Figure 1). The sandy basin fill consists of thick, non-amalgamated, traction-dominated (Tb) sandstone beds; these increase in average bed thickness, net-to-gross, grain size, and proportion of Ta-e turbidite beds downslope (Figure 2). We document a gradual transition from bypassing, Froude supercritical to depositional flow conditions where relatively small-scale seafloor fault topography interacted with and partially confined the lower portion of stratified flows. These findings provide bed-scale characterization of an intra-slope fan; data which is difficult to obtain from modern and experimental investigations but highly relevant to assessing the quality, continuity, and up-dip pinch-out of comparable deposits that comprise hydrocarbon reservoirs.

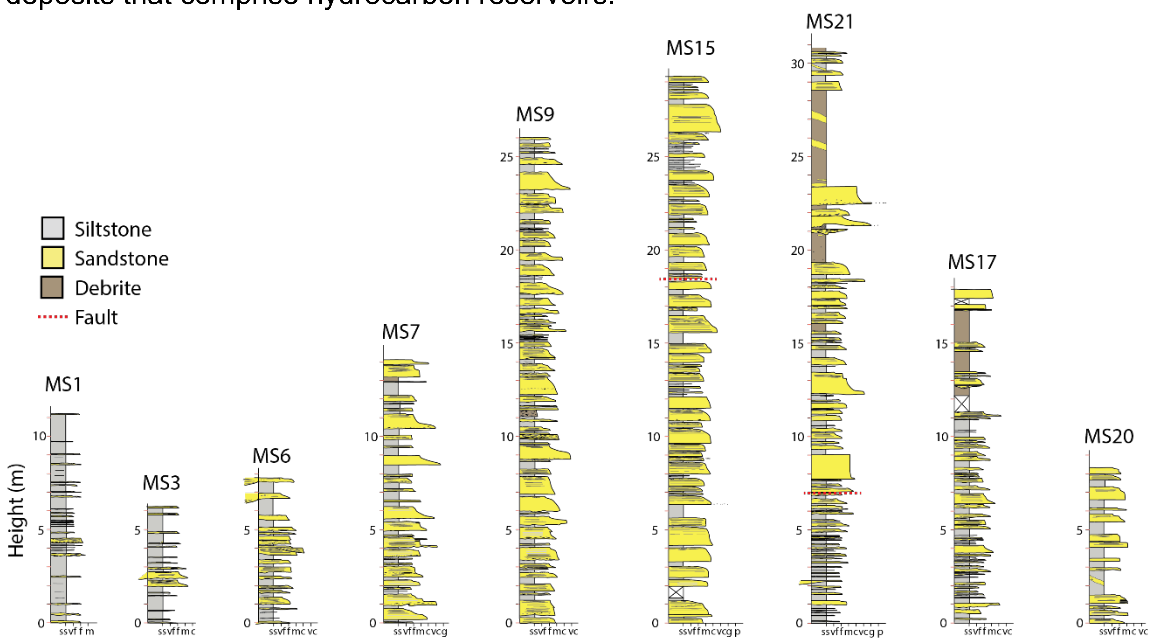

Figure 2: Examples of measured sections through the intra-slope fan deposit on El Chingue Bluff ordered from proximal (left) to distal (right). Section locations are in Figure 1. D90 grain sizes are displayed in sections and are (from left to right) ss = silt, vf = very fine sand, f = fine sand, m = medium sand, c = coarse sand, vc = very coarse sand, g = granule, p = pebble.

Acknowledgements

The funding for this work was generously provided by the industry sponsors of the Chile Slope Systems Joint Industry Project. The authors would also like to thank Benjamin Daniels, Sophie Hage, Arne Fuhrmann, Noah Vento, Andrew Ruetten and Zane Jobe for assistance with field work.

References

Alexander, J., and Morris, S., 1994. Observations and experimental, nonchannelized, high-concentration turbidity currents and variations in deposits around obstacles: Journal of Sedimentary Research, v. A64 (no. 4), p. 899 – 909.

Clark, I.R., and Cartwright, J.A., 2009. Interactions between submarine channel systems and deformation in deepwater fold belts: Examples from the Levant Basin, Eastern Mediterranean Sea: Marine and Petroleum Geology, v. 26, p.1465 – 1482.

Hiscott, R.N., and Middleton, G.V., 1979. Fabric of coarse deep-water sandstones, Tourelle Formation, Quebec, Canada: Journal of Sedimentary Petrology, v. 50 (no. 3), p. 703 – 722.

Hodgson, D.M., Peakall, J., and Maier, K.L., 2022. Submarine channel mouth settings: Processes, geomorphology, and deposits: Frontiers in Earth Science, v. 10, 790320.

Hughes Clarke, J.E., 2016. First wide-angle view of channelized turbidity currents links migrating cyclic steps to flow characteristics: Nature Communications, v. 7, 11896.

Ge, Z., Nemec, W., Gawthorpe, R.L., and Hansen, E.W.M., 2017. Response of unconfined turbidity current to normal fault topography: Sedimentology, v. 64, p. 932 – 959.

Kneller, B., and Buckee, C., 2000. The structure and fluid mechanics of turbidity currents: A review of some recent studies and their geological implications: Sedimentology, v. 47, p. 62 – 94.

McCaffrey, W.D., and Kneller, B.C., 2004, Scale effect of non-uniformity on deposition from turbidity currents with reference to the Grès d'Annot of SE France, in Joseph, P., and Lomas, S.A., eds., Deep-water sedimentation in the Alpine Basin of SE France: New perspectives on the Grès d'Annot and related systems: London, Geological Society, Special Publications, v. 221, p. 301–310.

Middleton, G.V., 1967. Experiments on density and turbidity currents: III. Deposition of sediment: Canadian Journal of Earth Sciences, v. 4, p. 475 – 505.

Middleton, G.V., 1993. Sediment deposition from turbidity currents: Annual Review of Earth and Planetary Sciences, v. 21, p. 89 – 114.

Middleton, G.V., and Hampton, M.A., 1973. Part 1. Sediment gravity flows: mechanics of flow and deposition, in Middleton, G.V., and Bouma, A.H., eds., Turbidites and Deep-water Sedimentation, SEPM Pacific Section, Short Course Lecture Notes, p. 1–38.

Mutti, E., and Normark, W.R., 1987. Comparing examples of modern and ancient turbidite systems: problems and concepts, in Leggett, J.K., and Zuffa, G.G., eds., Marine Clastic Sedimentology; Concepts and Case Studies, Graham and Trotman, London, p. 1 – 38.

Prather, B.E., Booth, J.R., Steffens, G.S., and Craig, P.A., 1998. Classification, lithologic calibration, and stratigraphic succession of seismic facies of intraslope basins, deep water Gulf of Mexico: AAPG Bulletin, v. 82, p. 701–728.

Rodriguez, C.R., Jackson, C.A.-L., Bell, R.E., Rotevatn, A., and Francis, M., 2021. Deep-water reservoir distribution pn a salt influenced slope, Santos Basin, offshore Brazil: AAPG Bulletin, v. 105 (no. 8), p. 1679 – 1720.

Shultz, M.R., and Hubbard, S.M., 2005. Sedimentology, stratigraphic architecture, and ichnology of gravity-flow deposits partially ponded in a growth-fault-controlled slope minibasin, Tres Pasos Formation (Cretaceous), Southern Chile: Journal of Sedimentary Research, v. 75 (no. 3), p. 440 – 453.

Sinclair, H., and Tomasso, M., 2007. Depositional evolution of confined turbidite basins: Journal of Sedimentary Research, v. 72 (no. 4), p. 451 – 456.

Soutter, E.L., Bell, D., Cumberpatch, Z.A., Ferguson, R.A., Spychala, Y.T., Kane, I.A., and Eggenhuisen, J.T., 2021. The influence of confining topography orientation on experimental turbidity currents and geological implications: Frontiers in Earth Science, v. 8, 540633.

Tek, D.E., Poyatos-moré, M., Patacci, M., McArthur, A.D., Colobera, L., Cullen, T.M., and McCaffrey, W.D., 2020. Syndepositional tectonics and mass-transport deposits control channelized, bathymetrically complex deep-water systems (Ainsa depocenter, Spain): Journal of Sedimentary Research, v. 90, p. 729 – 762.

Wynn, R.B., Kenyon, N.H., Masson, D.G., Stow, D.A. and Weaver, P.P., 2002. Characterization and recognition of deep-water channel-lobe transition zones: AAPG Bulletin, v. 86, p. 1441–1462.