Jurassic sedimentation Patterns and Reservoir Distribution in a Siliciclastic Tectonically-Active Slope Environment, Northwestern British Columbia (NTS 104B/01)

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Introduction

Understanding slope dynamics in tectonically active settings is critical to evaluating the distribution of units with potential reservoir characteristics. Sand-rich channels represent the best reservoir units in a continental slope setting because of their high permeability values. On the other hand, debris flow and mudflow deposits are highly compartmentalized because of their chaotic internal facies, and have poor reservoir properties.

Jurassic sedimentary rocks exposed near Stewart in British Columbia constitute an excellent modern analog of slope processes in siliciclastic-dominated depositional systems (Fig. 1). These rocks were mapped as upper Hazelton Group by Grove (1986) but were later included in the Bowser Lake Group by Evenchick and McNicoll (2002). They were deposited over volcanic arc rocks in an evolving extentional basin during the Middle Jurassic (e.g. Grove 1986, Anderson 1993, Alldrick 1993.) Frequent tectonic activity along basin-bounding faults created significant instability on the slope that resulted in incision of submarine channels along with deposition of thick mass-transport complexes (MTC). Comparable features in the overlying Bowser Lake Group to the northeast are described by Evenchick & Thorkelson (2005)

The succession investigated in this study includes a wide range of gravity flows (Fig. 2). The basal portion is dominated by unconfined thinly bedded turbidites which are overlain by incised channel complexes. This corresponds to progradation of the submarine slope over the basin floor during a normal regression. The proportion of MTCs gradually increases near the top of the succession. Incoherent debris flows are interbedded with amalgamated sandstone beds whereas fine-grained turbiditic intervals are generally absent. The uppermost unit of the succession consists of 500 m of amalgamated slumps and debris flows. Overall, MTCs constitute more than 50% of the entire sedimentary succession.

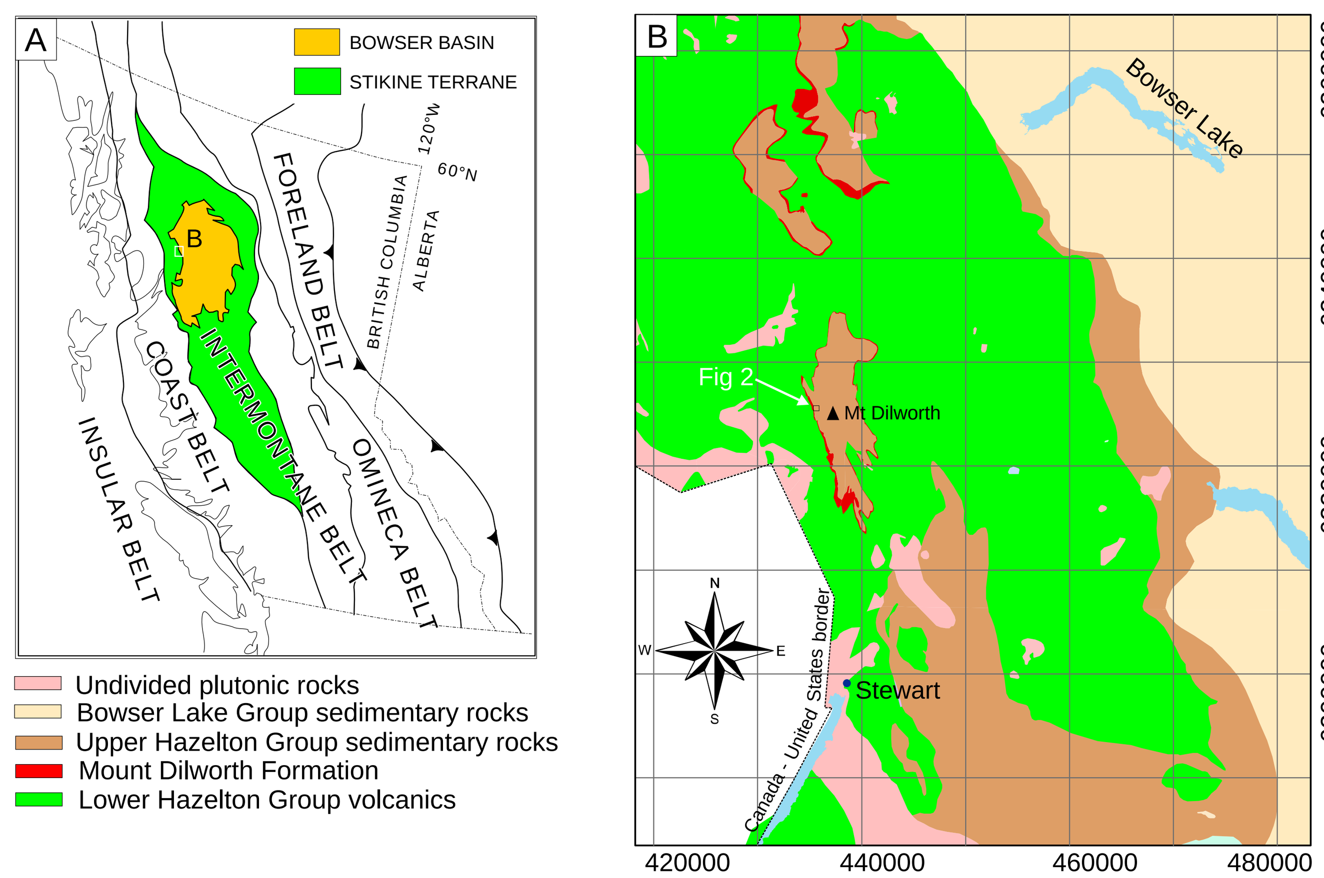

Figure 1 - A) Location of the Bowser Basin in relation to principal tectonic belts of the Canadian Cordillera. White square delineates the extent of the geological map described in figure 1B. B) Simplified geology map showing the principal lithostratigraphic units exposed along the western limit of the Bowser Basin. Projection in UTM NAD 83. Black square represents the outline of the detailed mapping area shown in Figure 2. *Modified* from Grove, 1986; Alldrick, 1987; Anderson, 1993.

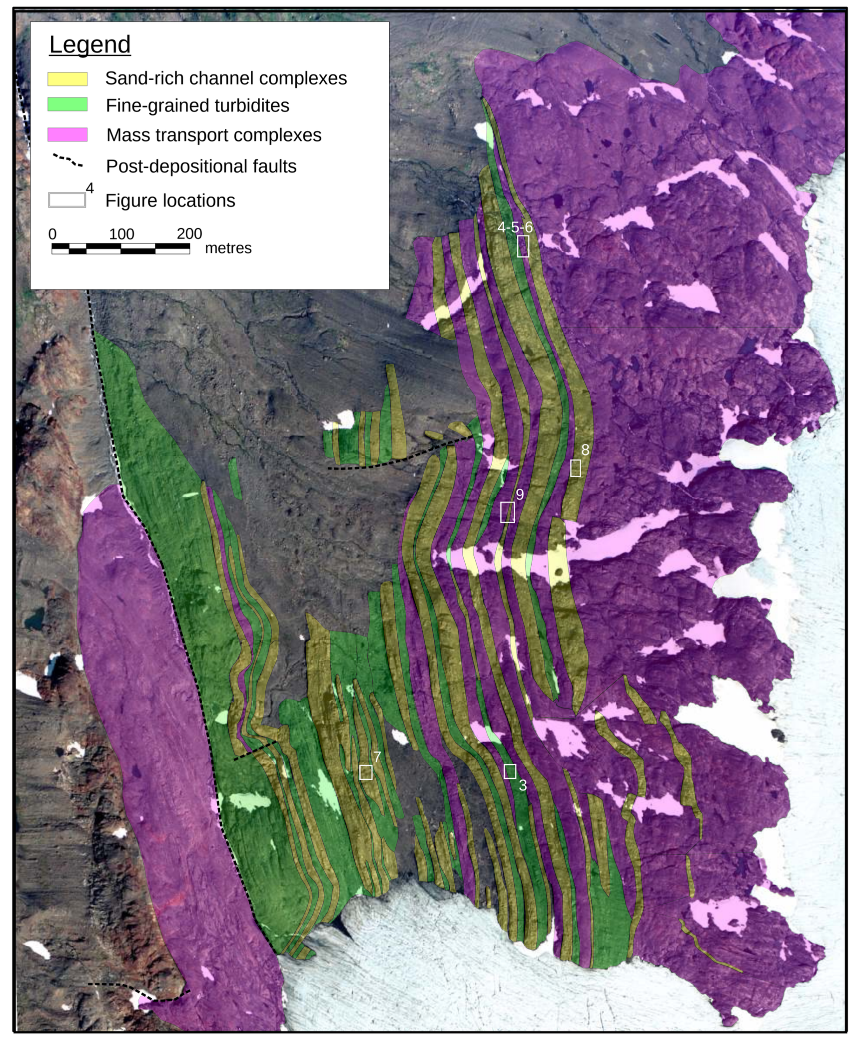

Figure 2- Annotated aerial photograph of the sedimentary succession showing the three main depositional units. Stratigraphic top is to the right.

Submarine channels

Amalgamated submarine channel complexes constitute the best reservoir units in the study area. The channels are characterized by medium to very coarse-grained sandstone with abundant current-generated sedimentary structures such as ripples and planar and trough cross-beddings. Individual sandstone beds are variable in thickness and can be laterally continuous over 200 metres (Fig. 7).

Intervals of semi-consolidated mud rip-up clasts are commonly found at the bases of the coarse-grained units, which attests to the high erosion potential of the channels (Fig. 8). Progradation of shelf-edge deltas on the upper slope was likely the main sediment pathway that delivered sand to submarine canyons. Relative drop in sea-level during lowstands would also lead to an increase of sediment supply to the deep-water setting via sediment by-pass on the shelf. Preservation of the coarse-grained sediments in vertically stacked channels suggests that incision occurred relatively fast and was localized to the main sediment pathways. This could be attributed to the constant readjustment of the slope gradient following tectonic activity along basin bounding faults.

In some cases, distinct sandstone beds become amalgamated along strike and form channelized lobe geometries. Figure 9 shows the spatial distribution of a channel system cutting down into a debris flow unit. The base of the channel is marked by a scoured surface above which a drape of thinly laminated mud and silt accumulated. The absence of coarse material immediately above the scoured surface suggests important sediment bypass prior to accumulation of the fine-grained sediments. The mud-filled channel is truncated by an irregular erosional surface above which a unit of normally-graded, clast-supported conglomerate was deposited. Up-section, the conglomerate gradually passes into moderately-sorted medium to coarse-grained sandstone containing abundant current-generated sedimentary structures. In each measured stratigraphic section, the channel sands are interbedded with laminated silt and very fine sand. These relatively thin finer-grained intervals are interpreted to be levee deposits associated with lateral migration of the channel axis.

Figure 7 - Overturned beds showing a fining upward succession from coarse-grained sandstone to interbedded fine-grained sandstone and siltstone near the top of the channel fill.

Figure 8 - Matrix-supported conglomerate containing poorly sorted mud rip-up clasts. These intervals are common at the base of channel fills and are indicative of a high energy environment with great erosion potential. Hammer for scale is 30 cm in length.

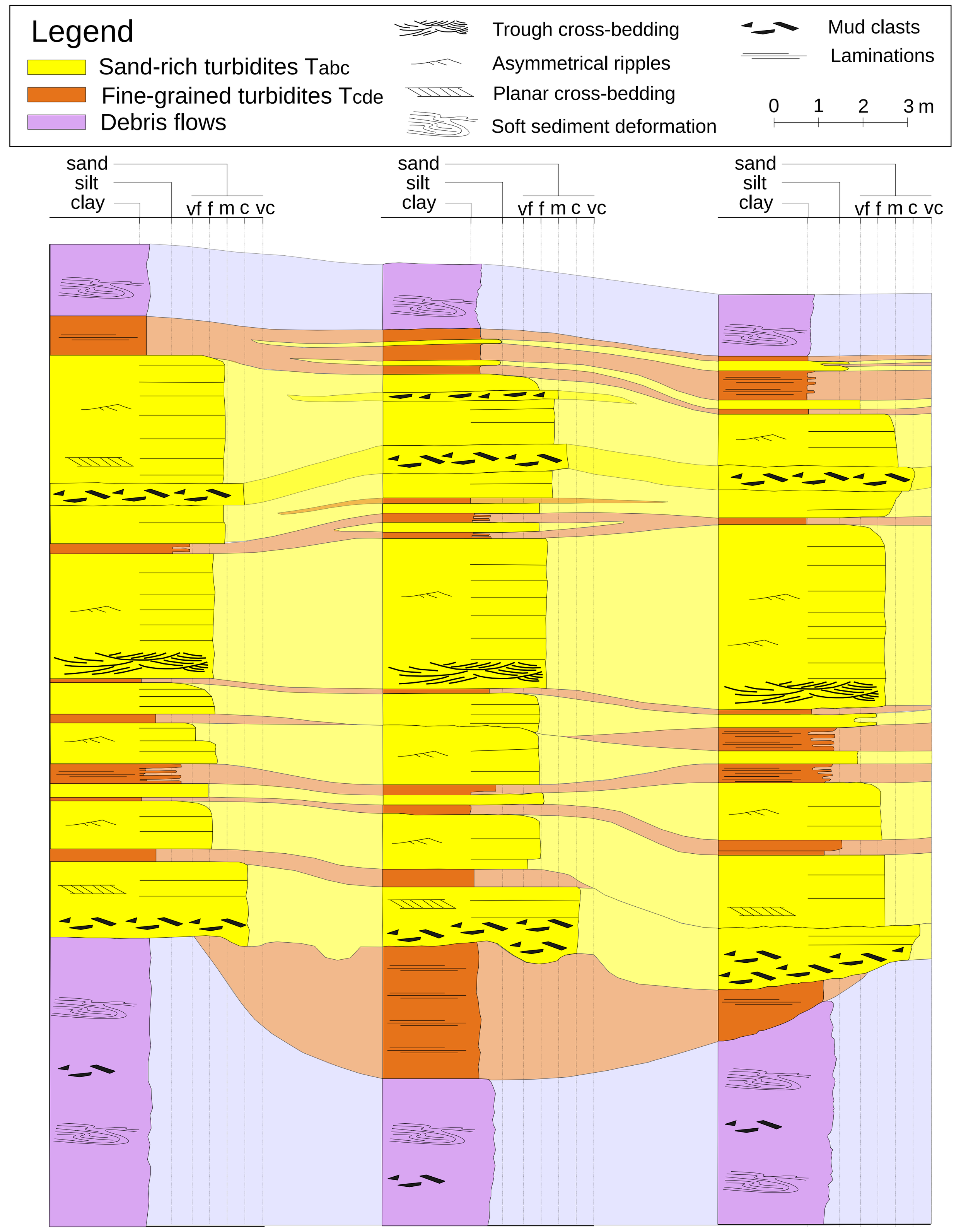

Figure 9 - Stratigraphic cross-section of a mud-filled channel complex showing the lateral variability of depositional units. No vertical exaggeration.

Fine-grained turbidites and mass-transport complexes

Turbidite successions constitute the bulk of clastic sediment accumulation in deep-water environments. They result from a combination of gravity-driven processes and continuous hemipelagic sedimentation from suspension. Slope failure is common in upper slope environments and can be triggered by a variety of processes such as tectonic activity and oversteepening of the slope in areas of fast deposition rates. The omnipresence of biogenic trace fossils in the fine-grained turbidites (Fig. 3) suggests that sediment input was relatively low outside the submarine canyons. Therefore, a significant portion of the soft-sediment deformation features is interpreted to result from tectonic activity in the basin.

Detailed mapping of a slump unit provided better understanding of the deformation mechanisms prevalent during slope failure. Sliding of a cohesive mass of sediments was initiated over a detachment surface underneath which the parallel beds remained undisturbed (Fig. 4). Immediately above the décollement, fine-grained layers were gently folded during compression but retained their original thickness, whereas the softer sand-rich units were subject to ductile deformation (Fig. 4). This feature is consistent with deformation during early diagenesis where muds tend to be more competent than sands and could constitute a reliable criteria to differentiate syn-sedimentary deformation from tectonic deformation.

Extensional features are also common in soft-sediment deformation and can form pull-apart boudins of mud in a sandy matrix (Fig. 5). The slump unit becomes progressively more deformed near its top where disharmonic folding dominates (Fig. 6). This shows that the slump incorporated more fluids during transport and evolved into a incoherent debris flow.

Figure 3 - *Helminthopsis* trace fossil in fine-grained turbidites. These trace are interpreted as grazing trails of worm-like organisms in a low energy depositional environment. Lens cap is 6.5 cm in diameter.

Figure 4 - Thinly bedded turbidite succession with abundant soft sediment deformation features. The slump deposit is located above the detachment surface. Hammer for scale is 30 cm in length. Letter A corresponds to Figure 5.

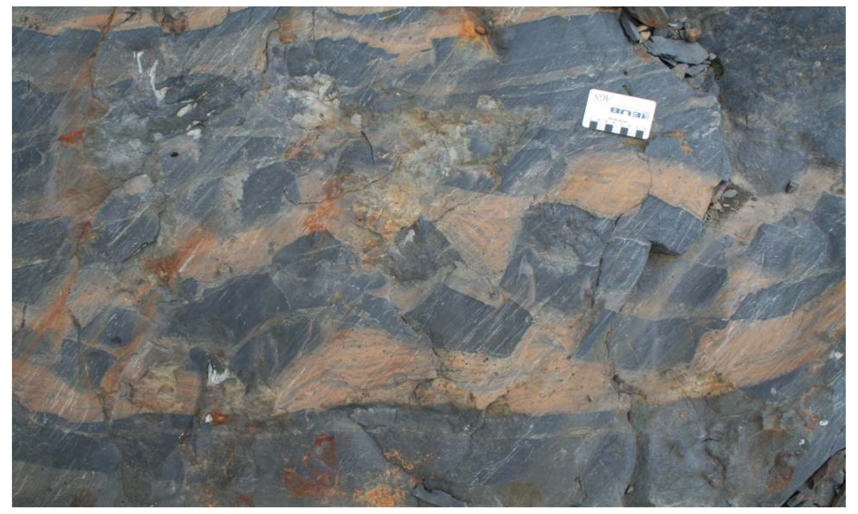

Figure 5 - Close-up of A from Figure 4 showing syn-sedimentary deformation formed by flattening during deposition of the slump. The more competent mud layers tend to pull apart into boudins whereas the surrounding sandy layers flow to fill the remaining available space. Scalebar is 8 cm in length.

Figure 6 - Syn-sedimentary folds located at 2.5m above the detachment surface in the slump unit. Consistent values of fold axis measurements suggest an overprinting of later tectonic deformation with development of axial planar cleavage. Hammer for scale is 30 cm in length.

Conclusions

Sand-filled submarine canyons constitute the primary targets for petroleum exploration on continental slopes. Understanding the tectonic setting of the sedimentary basin can help constrain the lateral distribution and thickness of the channels. Frequent re-adjustments of the slope gradient in a tectonically active sedimentary basin will trigger channel incision in fine-grained successions. Therefore, channel complexes tend to become vertically stacked rather than laterally extensive and can form relatively thick homogeneous reservoirs.

Even though it is difficult to clearly separate the effects associated with shoreline shifts from those driven by tectonic processes, sediments of the upper Hazelton Group near Stewart indicate a strong tectonic influence. Sudden steepening of the slope in response to fault movement is likely to have triggered rapid incision, sediment bypass and deposition of abundant MTCs in the higher portion of the succession. Syn-sedimentary faulting was a major component in determining the nature of the gravity flows. Thick MTCs were deposited during fault reactivation which interrupted the overall regressive cycle responsible for progradation of the slope succession over the basin floor.

Soft-sediment deformation features are abundant in active tectonic basins. They can be distinguished from tectonic deformation processes based on the relative competence of the different lithologies. During early diagenesis, finer-grained sediments such as silts and clays will undergo brittle deformation whereas coarser sands tend to flow in a ductile manner. The opposite is usually observed in tectonic deformation when sediments are completely lithified.

Acknowledgments

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