

# **PS Slope Instability in a Tectonically Active Jurassic Sedimentary Basin, Northwest British Columbia, Canada\***

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## **Abstract**

Sedimentary rocks of the Upper Hazelton Group exposed near Stewart in British Columbia constitute an excellent modern analog of slope processes in siliciclastics-dominated depositional systems. These sediments were deposited over volcanic arc rocks in an evolving extensional basin during the Middle Jurassic. Frequent tectonic activity along basin-bounding faults created significant instability on the slope that resulted in migration of submarine channels along with deposition of debris flows and slumps.

Detailed geological mapping during the summer of 2007 has allowed the identification of multiple amalgamated channel complexes interbedded with finer-grained turbidites. The sand-rich channels can reach thicknesses up to 35 m and be laterally continuous for 200 m. Mudstone rip-up clasts up to 30 cm in diameter are common at the bases of the channels and attest to a high energy environment with great erosion potential. The channels are incised into fine-grained well bedded turbidite successions that display partial to complete Bouma sequences. A broad variety of soft-sediment deformation features, including slump folds, sedimentary dikes and décollements, were also identified within the turbidites. Most of these features are attributed to slope failure during reactivation of normal faults.

Understanding slope dynamics in a tectonically active setting is critical to evaluating the distribution of units with potential reservoir characteristics. A sudden increase in the slope angle is likely to trigger rapid incision by submarine channels, which will tend to be vertically stacked rather than laterally extensive.





# Slope instability in a tectonically active Jurassic sedimentary basin, northwest British Columbia, Canada

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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.

Sedimentary rocks of the upper Hazelton Group exposed near Stewart in British Columbia constitute an excellent modern analog of slope processes in siliciclastic-dominated depositional systems (Fig. 1). These sediments were deposited over rifted volcanic arc rocks in an evolving 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 migration of submarine channels along with deposition of debris flows and slumps (Fig. 2). Comparable features in the overlying Bowser Lake Group to the east are described by Evenchick & Thorkelson (2005)

Detailed geological mapping during the summer of 2007 has allowed the identification of multiple amalgamated channel complexes interbedded with finer-grained turbidites, debris flows and slumps. We investigated the different mechanisms responsible for the distribution of these facies in a Jurassic sedimentary basin in order to evaluate its petroleum potential.

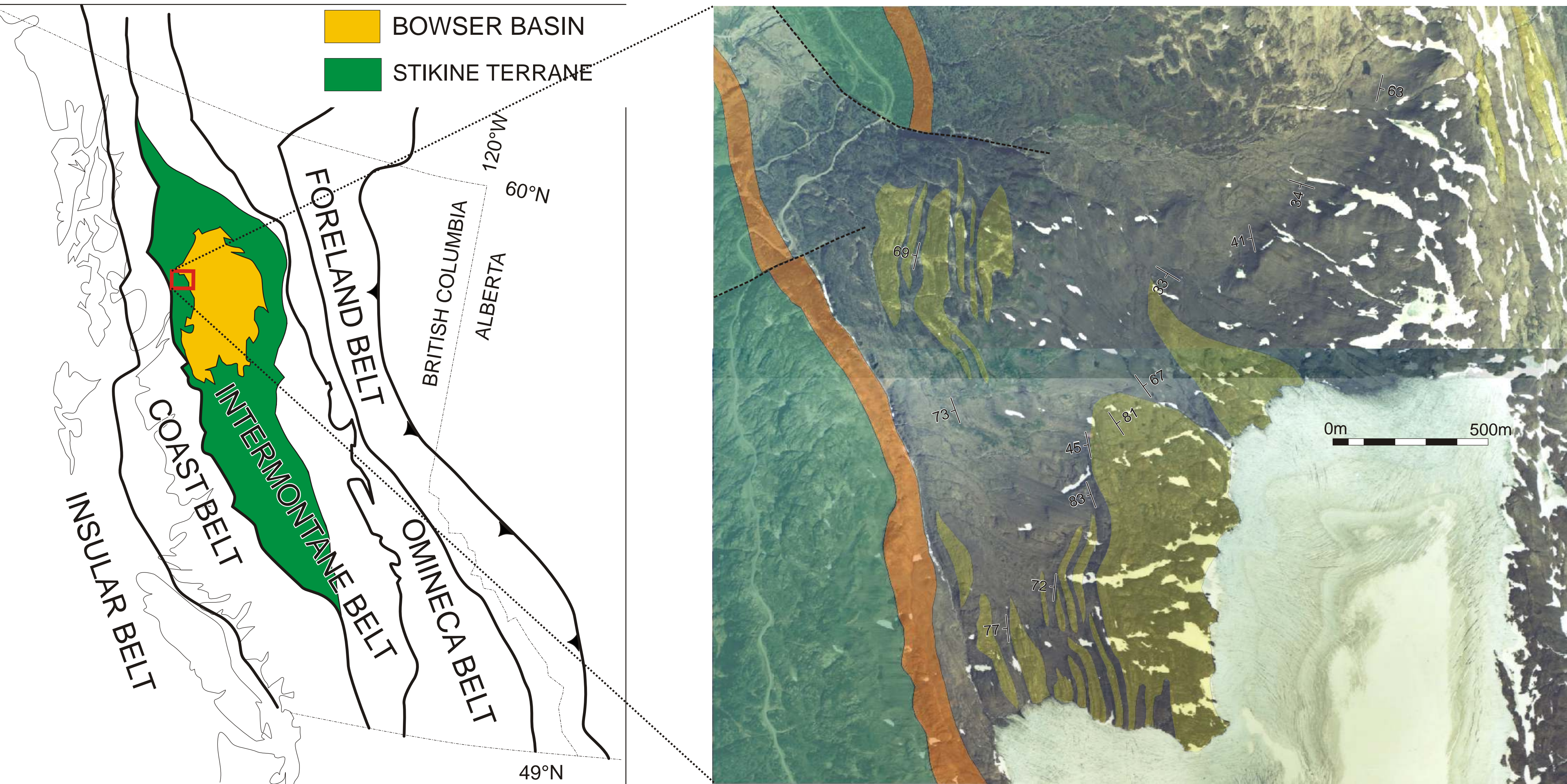


Figure 1 - Location of the Bowser Basin in relation to the principal tectonic belts of the Canadian Cordillera. Red square represents the outline of figure 2.

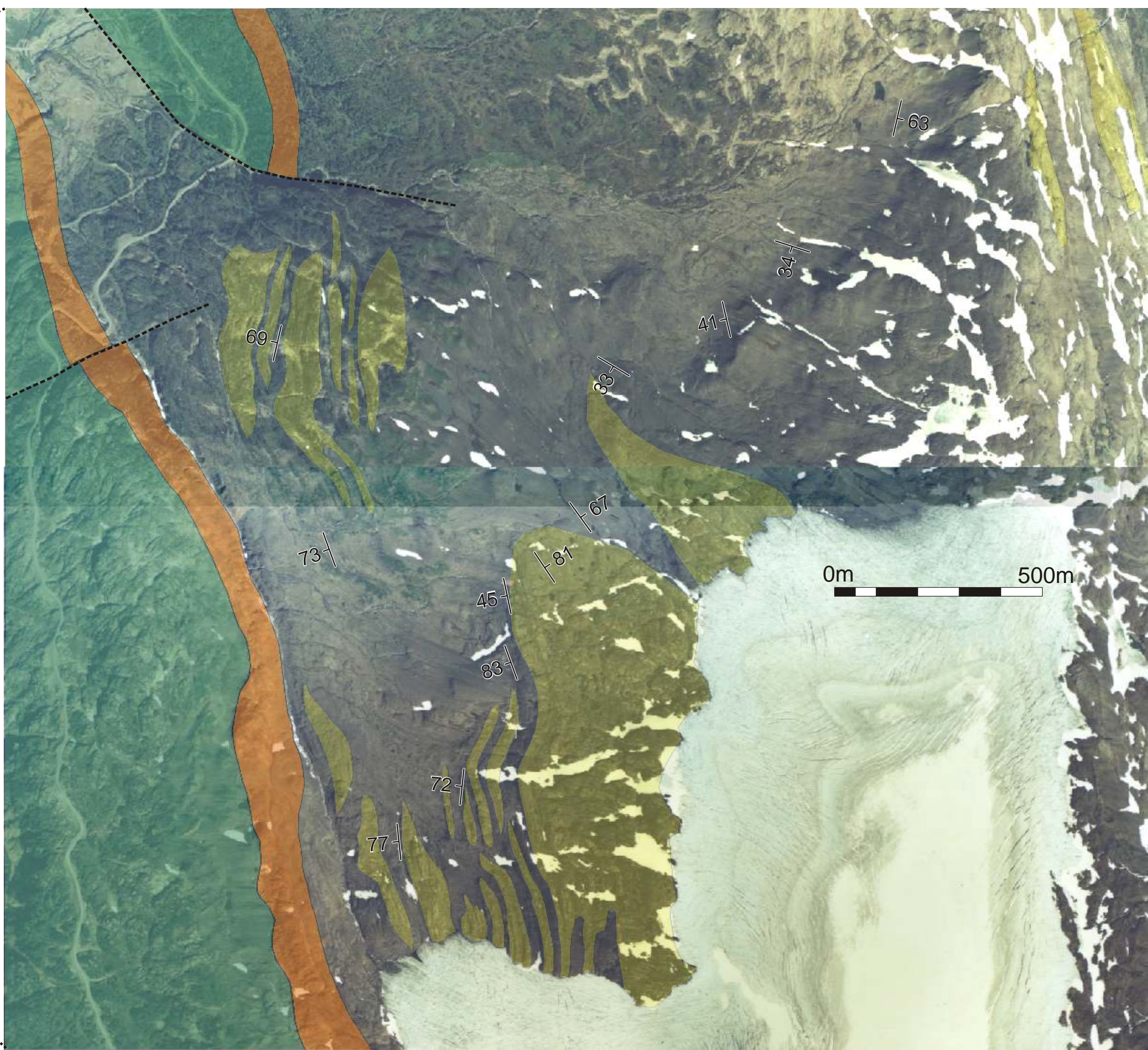


Figure 2 - Simplified geology map of the study area with principal lithostratigraphic units, modified from Grove (1986), Alldrick (1987).

## Legend

- Sandy channel complexes
- Fine-grained turbidites
- Dacitic pyroclastic tuffs
- Volcaniclastic rocks
- Bedding measurements
- Fault

## Submarine channels

Almagamated submarine channel complexes constitute the best reservoir units in the study area. The channels are characterized by medium to very coarse sand with abundant current-generated sedimentary structures such as ripples, planar and trough cross-bedding (Fig. 7). Individual sandstone beds are variable in thickness and can be laterally continuous over 200 metres (Fig. 8).

Detailed mapping has shown that the submarine channels are deeply incised in fine-grained turbidite successions. The turbidites usually contain grazing traces of deposit feeding organisms which suggest more or less stable environmental conditions away from the main sediment input zones (Fig. 3).

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. 9). 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 the basin bounding faults.



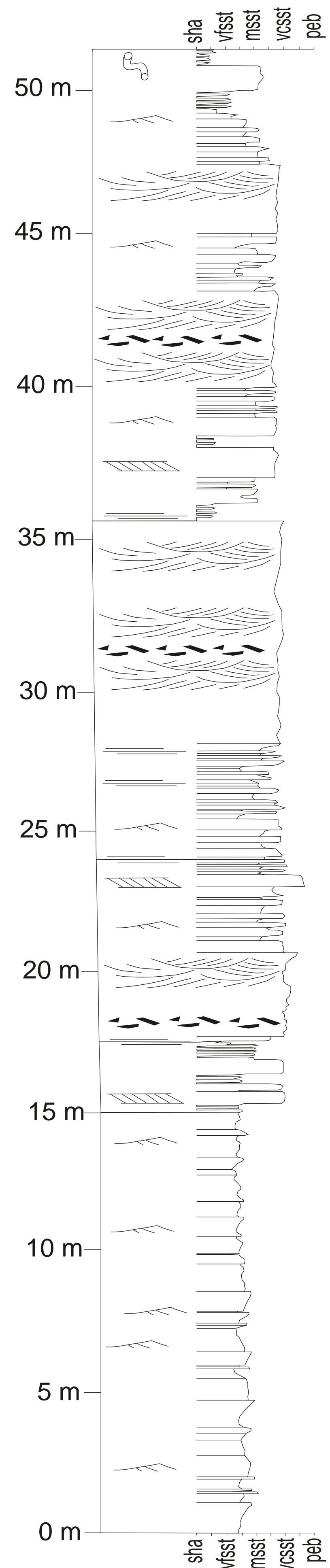
Figure 7 - Thick beds of massive coarse-grained sandstone with well-sorted conglomerate lenses. Located at 23.50 m on the measured section.



Figure 8 - Overturned beds showing a fining upward succession near the top of the channel fill. Exposure corresponds to interval 45-50 m on the measured section.



Figure 9 - 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. Located at 18 m on the measured section. Hammer for scale is 30 cm in length.



## Legend

- Planar cross-bedding
- Parallel laminations
- Asymmetric ripples
- Trough cross-bedding
- Bioturbation
- Mud rip-up clasts

Figure 10 - Detailed stratigraphic section of a submarine channel complex showing sedimentary structures and grain size variation.

## Soft-sediment deformation in turbidites

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 overstepping 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, most of the soft-sediment deformation features are 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 is a common feature observed 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). Eventually, the slump tend to incorporate more fluids during transport and can evolve into a incoherent debris flow.

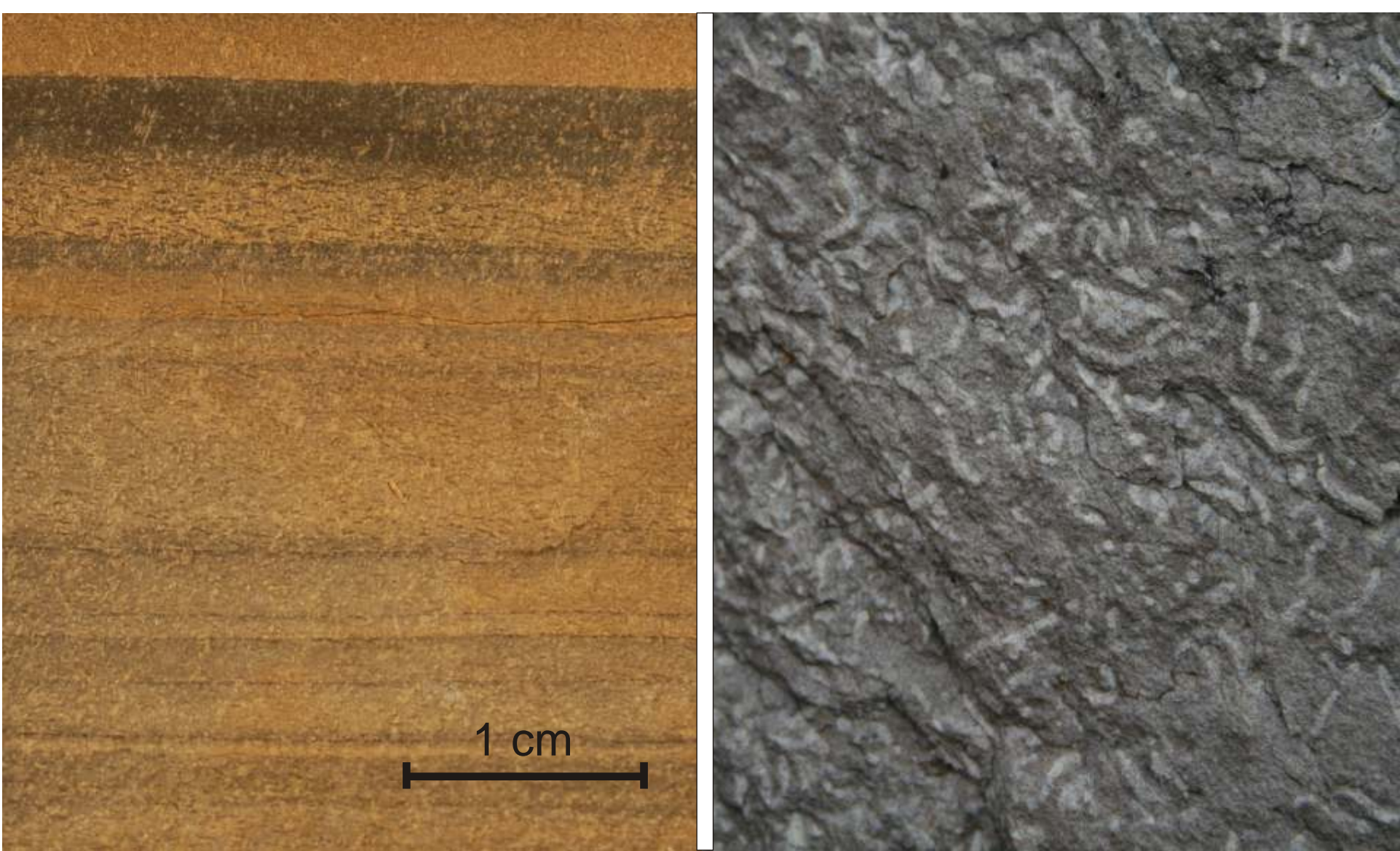


Figure 3 - Trace fossils in fine-grained turbidites dominated by *Anconichnus* / *Phycosiphon*. Left side picture represents cross-section view and right side picture was taken on the bedding plane. Located at 52 m on the measured section of Figure 10.



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.

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 subsequent channel incision in fine-grained successions. Therefore, channel complexes tend to become vertically stacked rather than laterally extensive and can form homogeneous reservoirs.

Extensive biogenic traces in fine-grained turbidites are indicative of slow sediment deposition rates. Turbidites are a combination of gravity-flows, turbidity currents and hemipelagic sedimentation from suspension. The are usually associated with poor reservoir units because of their highly compartmentalized geometry and location outside of the main sediment pathways.

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.

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