The Roles Sheet Structure Minerals, Wetting Fluids and Biological Activities Play in the Development of Bedding-Plane Detachment Surfaces

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Summary

Certain stratigraphic levels are prone to developing detachment surfaces and the thrust faults that result are often observed to follow these beds for tens of kilometres. Development of bedding-parallel detachment surfaces may depend on the presence of alternating layers of parallel aligned platey minerals and a saturating fluid. There appears to be a marked dependence between the weak geomechanical strength of the sedimentary rocks in these stratigraphic levels and: 1) the crystal structure of the minerals that make up the rock, 2) the presence of fluids that saturate the rock, and 3) biological activities that control the deposition of the minerals and organic matter. The natural tendency of flaggy shales to be weak along bedding planes is due to the platey shape of clay minerals, their low interlayer bond strength and their strong affinity for fluids. Biological activities appear to aid in the aligning, deposition and interlayering of clay minerals with organic matter.

Introduction

Thrust faults within the Canadian Rockies preferentially develop within certain stratigraphic units and form long bedding-parallel detachment surfaces (Dahlstrom, 1970, p. 344). The arrows on the right side of the stratigraphic column in Figure 1 identify detachment surfaces in the central Alberta Foothills. There appears to be a link between beds that are recessive in outcrop and detachment surfaces. Detachment surfaces often form in shales and coaly beds that are recessive, whereas carbonates and sandstones that are resistive and cliff-forming in outcrop rarely develop detachment surfaces (see Figure 1).

Results from the San Andreas Fault Observatory at Depth (SAFOD) project suggest that talc is responsible for aseismic slip along the San Andreas Fault (SAF) in the Parkfield California area (Moore & Rymer, 2007). Part of the SAFOD project involved drilling a well that intersected the aseismic portion of the SAF at a depth of about 3 kilometres. The well encountered serpentinite and related minerals including minor amounts of talc as it crossed the active fault surface. The occurrence of talc is significant because it is a soft and weak mineral that may explain the weak nature of that section of the fault. During drilling of the well no evidence was found that high fluid pressures are present at that location of the fault (Gramling, 2007). Identifying the occurrence of weak minerals in detachment surfaces may help in understanding why detachments prefer certain beds.

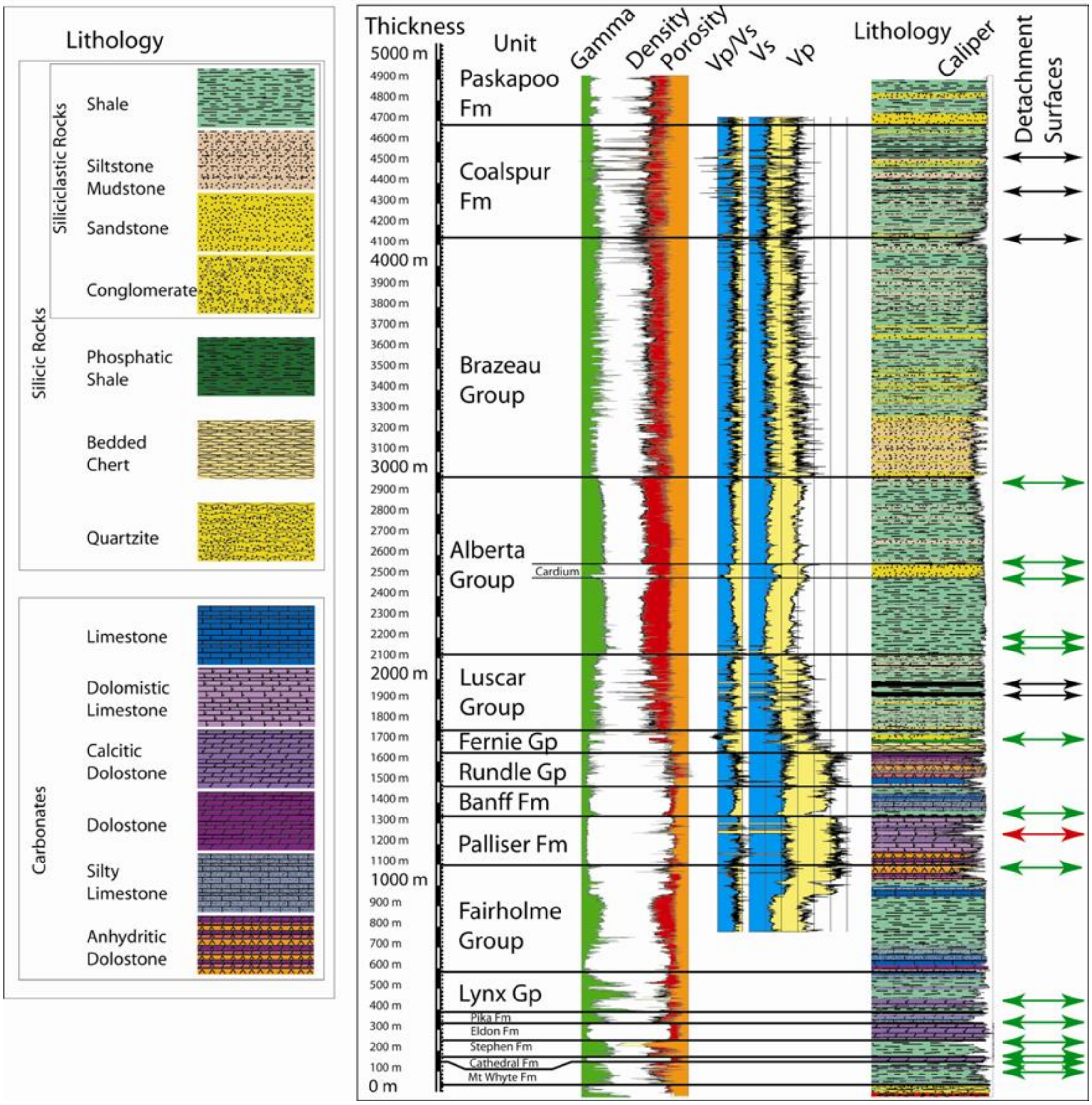

Figure1: Stratigraphic column of the central Alberta Foothills near the Brazeau River area. Wireline logs depict lithologic properties of the stratigraphy. Arrows on right hand side indicate common detachment surfaces in the Central Alberta Foothills.

Shear Strength of Sheet Structure Minerals

A compilation of shear strength measurements of rocks and minerals under confining stress, published by Byerlee (1978), demonstrates that the maximum shear strength, or coefficient of friction, is largely independent of rock or mineral type. Below an effective confining stress of 200 MPa the coefficient of friction for a vast majority of rocks is ~0.85. Two notable exceptions, montmorillonite and vermiculite, both sheet silicates, were found to be significantly weaker, and other sheet-like minerals such as illite and chlorite were found to be somewhat weaker than the rest of the minerals.

The graph in Figure 2, adapted from Moore and Lockner (2004a p. 11), illustrates the low coefficient of friction of sheet structure minerals compared to non-sheet structure minerals. The coefficient of friction for dry sheet structure minerals corresponds to the (001) interlayer bond strength (Moore and Lockner, 2004a p. 8). The slope of the grey trend line suggests the shear strength of the minerals is linearly dependant on the interlayer bond strength, or hardness, of the mineral.

Water saturated test samples consistently exhibit a reduced coefficient of friction compared to corresponding dry samples. The cyan coloured annotations on Figure 2 indicate the coefficient of friction for water saturated samples. It is important to emphasize that pore pressure is not elevated in any of these tests. The reduction in the coefficient of friction observed in these experiments is a chemical bonding process between the minerals and the enveloping water, not a reduction in effective stress (Moore and Lockner, 2004a).

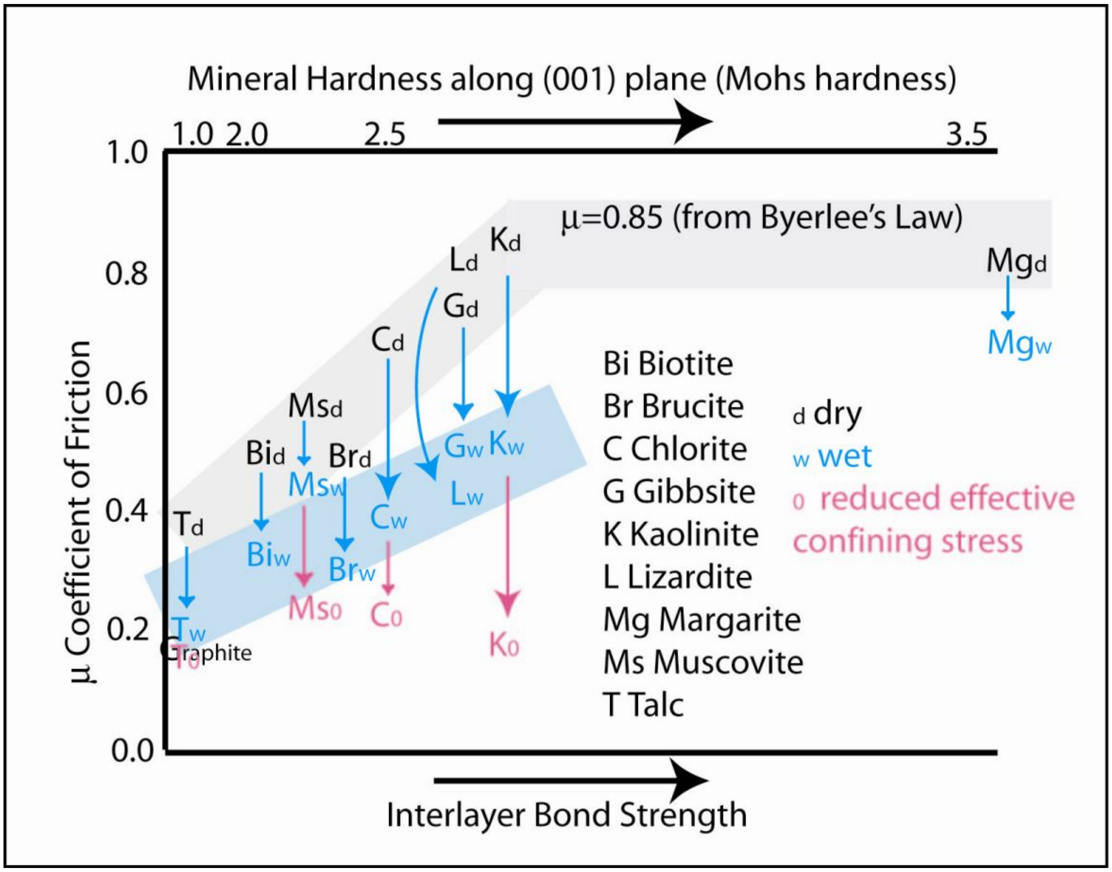

Figure1: Graph adapted from Moore and Lockner, (2004a&b) illustrating the low strength of sheet structure minerals. Note the dependence of strength (coefficient of friction) on hardness and on the presence of water.

Additional factors discussed by Moore and Lockner (2004b) include the dependence on effective confining stress and the ionic concentration. Pink coloured annotations show that the coefficient of friction for some minerals reduces to ~0.2 as the effective stress decreases to zero. For these minerals, increased pore pressure not only reduces the effective stress, but also reduces the coefficient of friction. The results of this work suggest stratigraphic intervals that are rich in platey clay minerals should be prone to developing detachment surfaces.

The Role Biological Activities Play in Controlling the Fabric of Clay Minerals in Shales

A study by Ingram (1953) showed that fissility of a shale rock depends primarily on the fabric of the clay minerals (i.e. the parallel arrangement of sheet structure minerals) which in turn depends on organic content. He found that high organic content leads to flaggy cleavage and parallel orientation of minerals whereas low organic content leads to a massive mudrock without a preferred orientation of the minerals. It appears that humus plays a role in layering clay particles in a parallel orientation and that the weak cementing action of the organic material allows the rock to be plied apart easily along planar surfaces. Hence the dark, organic rich shales of the Exshaw and Pokerchip formations are prone to developing detachment surfaces.

Acknowledgements

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References

Byerlee, J., 1978, Friction of rocks, Pure and Applied Geophysics, Vol. 116, P. 615-626.

Dahlstrom, C.D.A., 1970, Structural geology in the eastern margin of the Canadian Rocky Mountains, Bulletin of Canadian Petroleum Geology, Vol. 18, No. 3, P. 322-40.

Gramling, C., 2007, Talc may reduce friction at creeping fault, Geotimes, October 2007.

Ingram, R.L., 1953, Fissility of Mudrocks, Bulletin of the Geological Society of America, Vol. 64, P. 869-878.

Moore, D.E. & Lockner, D.A., 2004a, Crystallographic controls on the frictional behaviour off dry and water-saturated sheet structure minerals Journal of Geophysical Research, Vol. 109, B03401, p. 1-16.

Moore, D.E. & Lockner, D.A., 2004b, Interpreting the Frictional Behavior of the Smectite Clay Montmorillonite, Poster T41F-1306, AGU Fall Meeting.

Moore, D.E. & Rymer, M.J., 2007, Talc-bearing serpentinite and the creeping section of the San Andreas fault, Nature, Vol. 448, p. 795-797.