Fracture Analysis and use of LiDAR, Turtle Mountain, Alberta

C. Willem Langenberg *
Long Mountain Research Inc., Edmonton, Alberta
cwlangen@telus.net

Andrea Pedrazzini, Michel Jaboyedoff
Institute of Geomatics and Risk Analysis, University of Lausanne, Switzerland

and

Tijmen (Tim) H.D. Hartel
Hartel Consulting, Calgary, Alberta

Summary

The rocks of the Turtle Mountain area are intensely fractured. The Paleozoic carbonates are of most interest regarding the structure of the mountain. Fracture fabrics of these carbonates were measured in outcrop, obtained from image logs in a borehole and subsequently compared to results from slope analysis. The majority of fractures are extensional fractures with accompanying shear fractures related to an anticlinal fold. These investigations identified six fracture sets influencing the slope instability and surface morphology. Three main sets are fold related and the other three appear to be post-folding.

Introduction

Fractures were measured along three scan lines on the crest of Turtle Mountain and collected from an image log in a drill hole (Langenberg *et al.*, 2007). These fracture orientations (Figs. 1 and 2) were compared to results from slope analysis using the COLTOP 3D software (Figs. 3 and 4). This software uses a high resolution Digital Elevation Model (DEM), which was obtained by LiDAR. On this DEM the slope and slope-direction (dip and dip-direction) are represented by specific colors. This process results in a colored relief map where various slope orientations are color-coded. From these maps stereoplots are produced (Pedrazinni *et al.*, in press).

Fracture analysis and LiDAR applications

The rock layers of Turtle Mountain are folded into a large anticline (the Turtle Mountain Anticline) with a steeply dipping to overturned east limb that lies above a fault (the Turtle Mountain Thrust). The timing of movements along this fault is unknown. Movements probably started in the Paleocene and might still continue today, as indicated by small local seismic events along the fault observed by the Turtle Mountain microseismic system (Chen *et al.*, 2005). The main movements might have been around 52 Ma in the early Eocene (van der Pluijm *et al.*, 2006).

Fractures were measured along three scan lines on the western limb of the Turtle Mountain Anticline. Joints along a scan line near a 100m deep borehole have three dominant orientations, dipping moderately to steeply southeast, steeply northeast and steeply southwest. Less common fractures dip to the east-southeast, south-southeast and south-southwest. The steeply northeast-dipping set (observed in the borehole and in the scan line near this borehole) will form the back side of a potential future rock slide from South Peak. The majority of fractures are extension fractures with accompanying shear fractures related to the anticlinal fold.

Two nearby scan lines show dominant fractures dipping 37° northwest, parallel to bedding, but there is another set of northwest-dipping fractures that is distinct and 15 to 20 degrees steeper, yielding the two modes of poles in the SE quadrant. Also frequent are steeply south-dipping and shallowly south-southeast–dipping sets. Less common fractures dip shallowly to the southeast and moderately to the southwest.

All the data from the three scan lines combined provide a sample of the surface data on South Peak near the borehole (Figure 1). The three most frequent orientations seen are the northwest-dipping steeper-than-bedding set, the set dipping steeply northeast sub-parallel to the Frank Slide surface ("scary" joints) and the set that dips ~30° southeast toward Hillcrest. These "scary" fractures are also found in Palliser breccia immediately above the thrust faults. Fractures observed in the borehole (Figure 2) show comparable orientations.

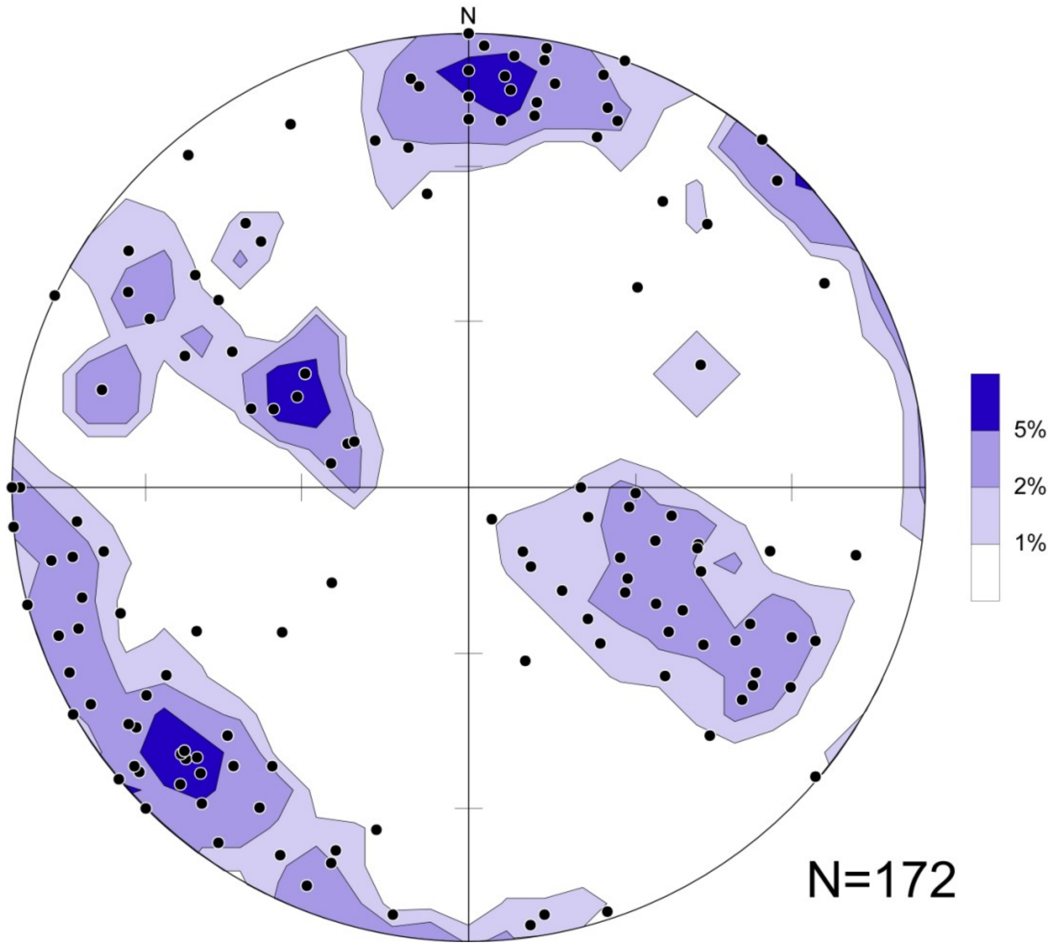

Figure 1: Stereoplot of poles to all surface fractures from scan lines in the South Peak area (western limb). Contours at 1%, 2% and 5% of data per 1% of net.

These fracture orientations were compared with the orientations obtained from slope analyses using the COLTOP 3D software, which are shown in Figure 3 (Pedrazinni *et al.*, in press).

Figure 4 shows the comparable fracture sets from the eastern limb. These investigations allowed the identification of six fracture sets influencing the slope instability. Three fracture sets (sets J2, J3 and J4) have a fixed relation with the fold axis direction and are correlated with the folding/thrusting phase during Paleocene/Eocene. Clock wise rotation of a tectonic horse in the hanging wall of the Turtle Mountain Thrust (Langenberg and Hartel, 2010) is possibly related to dextral movements along the Fraser River/Northern Rocky Mountain Trench Fault Zone (Price and Carmichael, 1986).

The other fracture sets (J1, J5 and J6) are possibly post-folding resulting from unloading movements during Miocene to the present. Stress release during this relaxation period has likely played a role in reactivation of syn-folding structures, such as J2 and J3.

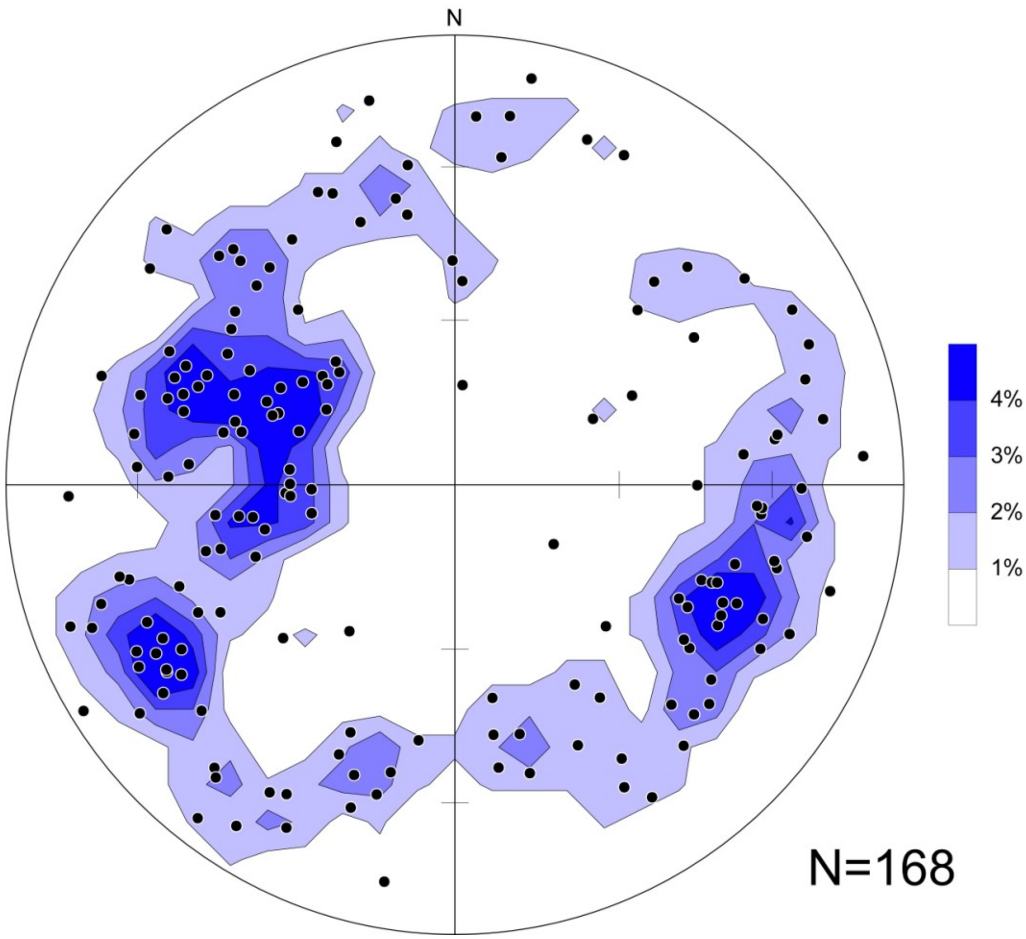

Figure 2: Stereoplot of poles to all fractures and major fractures in the borehole (on the western limb). Contours at 1%, 2%, 3% and 4%.

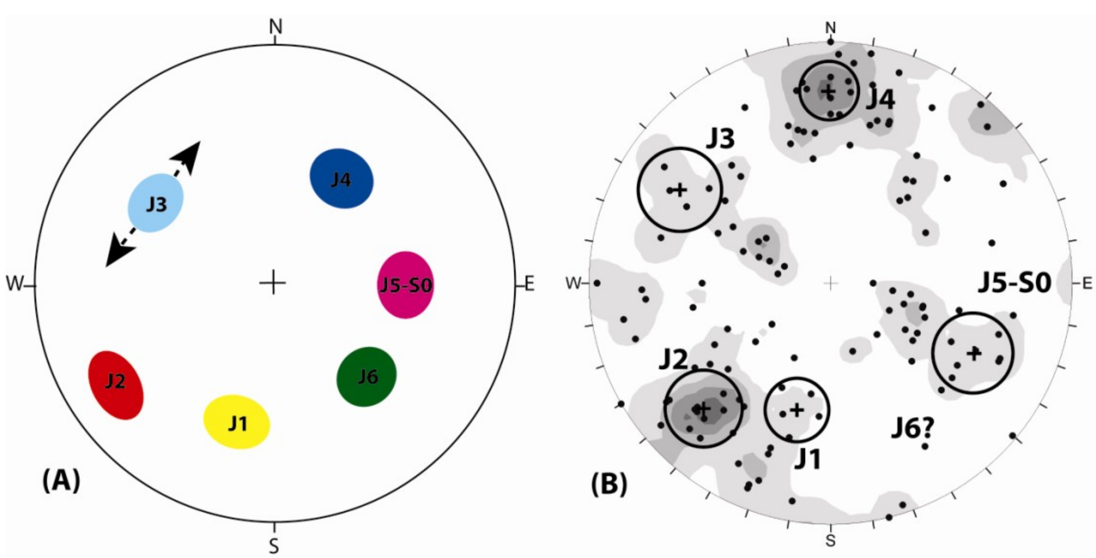

Figure 3: Comparison between the discontinuity sets detected using the COLTOP 3D software (A) and field survey (B) for the western fold limb (from Pedrazzini *et al*., in press).

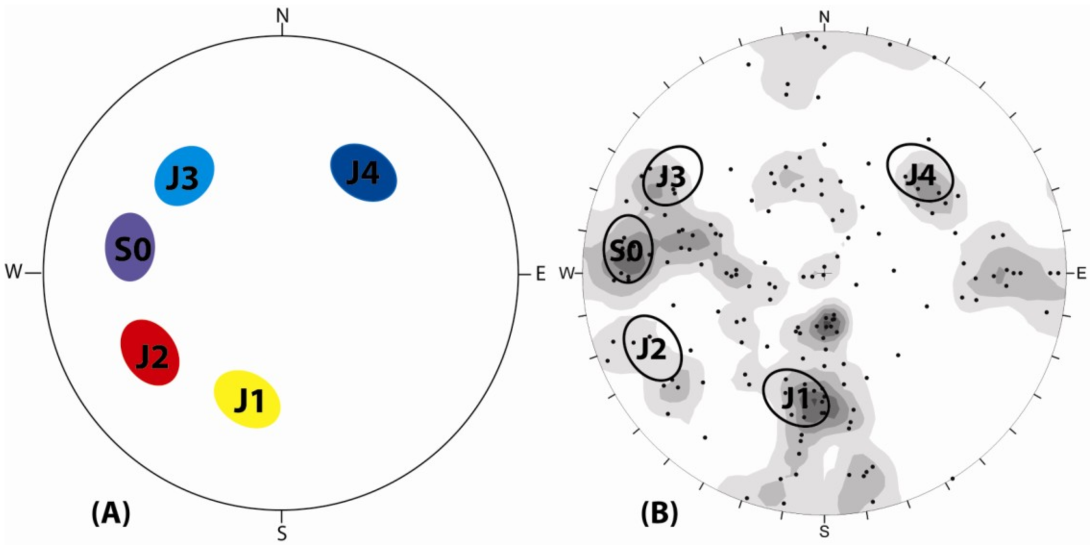

Figure 4: Comparison between the discontinuity sets detected using the COLTOP 3D software (A) and field survey (B) for the eastern fold limb (from Pedrazzini *et al*., in press).

Conclusions

The various fracture discontinuities observed in outcrop, drill hole and slope analysis using high-resolution DEM's from LiDAR surveys can be divided into fold-related fractures and post-folding fractures. Six discontinuity sets can be distinguished of which the three main ones are clearly fold related and the other three appear to be post-folding.

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Debbie Spratt, Dinu Pana and Malcolm Lamb helped with the measurement of surface and borehole fractures. This work is based on studies, which were funded through the Alberta Geological Survey/ERCB. We thank Corey Froese for encouraging this work.

References

Langenberg, C.W. and Hartel, T.H.D. (2010): The rise and fall of Turtle Mountain, Crowsnest Pass, Alberta; Structural geological field trip guidebook, GeoCanada 2010, Calgary, Alberta, May 10-14, 2010.

Langenberg, C.W., Pană, D., Richards, B.C., Spratt, D.A. and Lamb, M.A. (2007): Structural Geology of the Turtle Mountain area near Frank, Alberta; Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2007-03, 30 pages.

Pedrazzini, A., Jaboyedoff, M., Froese, C., Langenberg, W., and Moreno, F. (in press): Structural analysis of Turtle Mountain; origin and influence of fractures in the development of rock slope failures; Slope tectonics, Special publication of the Geological Society of London.

Chen, Z., Stewart, R.R. and Bland, H.C. (2005): Analysis of microseismicity at a mountain site; CREWES Research Report, University of Calgary, v.17, chap. 7, p. 1-28.

Price, R.A. and Carmichael, D.M. (1986): Geometric test for Late Cretaceous-Paleogene intracontinental transform faulting in the Canadian Cordillera; Geology, v. 14, p. 468-471.

van der Pluijm, B.A., Vrolijk, P.J., Pevear, D.R., Hall, C.M., and Solum, J.G. (2006): Fault dating in the Canadian Rocky Mountains: evidence for late Cretaceous and early Eocene orogenic pulses; Geology, v. 34, p. 837-840.