BEFORE THE FRANK SLIDE: PREPARATORY AND TRIGGERING CAUSES FROM MAPS AND PHOTOGRAPHS

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ABSTRACT
The Frank Slide occurred on the east limb of the Turtle Mountain Anticline which was thrust up along the folded and splayed Turtle Mountain Fault. Easterly-dipping, Palaeozoic limestones and dolomites then rested on sheared, weaker, Mesozoic clastics and coals. Cordilleran glaciers steepened the eastern flank of Turtle Mountain but left buttressing kame moraines. These were eroded by the Crowsnest River which was pushed against Turtle Mountain between its North and South Peaks by the growth of the alluvial fan of Gold Creek. The Blairmore Group mudstones and shales beneath the moraines were susceptible to toppling. Photographs of the east slope of Turtle Mountain before the Slide show disturbed vegetation, uneven topography, steep slopes and rock fall deposits. The Slide may have been triggered by the freezing of melting snow in rock joints and by coal mining.

RÉSUMÉ
Le glissement Frank s'est produit sur le flanc est de l'anticlinal de la montagne Turtle qui a été poussé le long d'une faille pliée et évasée de la montagne Turtle. Les calcaires de Palaeozoic et les dolomites, avec des inclinaisons vers l'est, s'appuyaient alors reposés sur les roches clastiques et les charbons mésozoïques, plus faibles. Les glaciers cordillères ont rendus plus raide le flanc oriental de la montagne mais ont laissé des moraines étayantes. Celles-ci ont été érodées par le fleuve Crowsnest qui a été poussé contre la montagne Turtle entre ses Crêtes du Nord et du Sud par la croissance du cône alluvial de Gold Creek. Les argiles du groupe Blairmore sous les moraines étaient susceptibles du renversement. Des photographies de la pente est de la montagne avant le glissement nous montrent une végétation dérangée, une topographie inégale, des pentes escarpées et des dépôts d'éboulis rocheux. Le glissement aurait pu être déclenché par la congélation de la neige fondue dans fissures de roche et par l'exploitation des mines de charbon.

1. INTRODUCTION

"Mechanism of landslides", one of Terzaghi's more influential articles on landslides (Bjerrum et al., 1960, Terzaghi, 1950), devoted one of 40 pages to the 1903 Frank Slide and Figure 5 of 15 figures. Terzaghi himself made "Mechanism of landslides" the only reading assignment for his lectures on slope movements in his Harvard course on Engineering Geology (Ferris, 1996). Figure 5a from this paper is an almost exact tracing of McConnell and Brock's much reproduced section across the Frank Slide (McConnell and Brock, 1904, Cruden, 2003) but Figure 5b is original, a "diagram illustrating the writer's concept of the changes of the safety factor of the slope prior to the slide" (Terzaghi, 1950, p. 95). The factor of safety on the vertical axis is plotted against time on the horizontal axis. The time scale, presumably linear, is set by 2 vertical lines, one marking the beginning of coal mining operations and the other, the slide. While neither McConnell and Brock (1904) nor Terzaghi's other source on the Frank Slide, Sharpe (1938), gave a date for the mine opening, the local Mines Inspector (Smith, 1903) was familiar with the mine's 2 years of operations before the Slide. So Terzaghi's concept implied a decrease in the factor of safety of the east slope of Turtle Mountain from about 2.5 to 1 in less than 3 years. "In hard, jointed rocks resting on softer rocks, a decrease of the cohesion of the rock adjoining a slab may occur on account of creep of the softer rocks forming their base….the limestones, forming the bulk of the peak, rested on weaker strata which certainly crept under the influence of the unbalanced pressure produced by the weight of the limestone and the rate of creep was accelerated by coal-mining operations in the weaker strata" (p. 95-96). Terzaghi's remarks have been accepted by others (Voight, in Cruden and Krahn, 1978, Leroueil, 2000, p. 224, Petley and Allison, 1997) without, perhaps, a full appreciation of their speculative nature. While Terzaghi visited the Canadian provinces to the east (as a member of the Review Board of the Gardiner Dam, Goodman, 1999, p. 272) and to the west (as a consultant to British Columbia Hydro, Goodman, 1999, Chp. 18) there is no record in Goodman's detailed and careful biography that Terzaghi ever visited the Frank Slide or even set foot in Alberta.

Here, we review the postglacial geological history of the east slope of Turtle Mountain and show that the slope was unlikely to have had a factor of safety as high as 2.5 in 1900. The review identifies additional processes tending to destabilize the slope and shows the localization of river erosion at the toe of the Slope by the bedrock structure and by the fan of Gold Creek contributed to restriction of the width of the Slide.

2. FLUVIAL EROSION

2.1 The Influence of Gold Creek

McConnell and Brock's map in their 1904 Report shows the pre-Slide course of Gold Creek. South-west of the bridge carrying the Crow's Nest Pass Railway across the Creek, the pre-slide creek turned southwards to join the Crowsnest River, ¼ mile (400 metres) downstream of its present junction. Boyd, who drew the map, had at least 2 sources for the pre-slide course, Leach's map (1903) at 1:142,560, based on his field work in 1901 and 1902, and the Department of the Interior's Township Map, at 1:31,680, a third edition of which was published in June 1902 based on Woods' mapping in 1900 and 1901. As the Township and Range boundaries on Boyd's map were from Woods (1902) and Leach accompanied McConnell and Brock on their survey, both sources were probably used. The Creek flowed through the planned extent of the Village of Frank shown on McConnell and Brock's (1904) map; plans of the Village were probably available from the Mine and may have included the Creek.

Photographs (Plates 1, 2) in the 1904 Report confirm the position of Gold Creek, east of the existing Village of Frank (Plate 2), and flowing down an incised valley to meet the Crowsnest River at an acute angle. Gold Creek flowed into the inside of a bend of the Crowsnest River (then named the Middle Fork of Old Man River). Other similar tributaries of the Crowsnest immediately upstream, Lyons Creek and Blairmore Creek, or downstream, Drum Creek and Byron Creek in Hillcrest, have built extensive alluvial fans from sediment derived from their incision. Such fans divert the Crowsnest River around the accumulating sediment in the fan. Gold Creek fan may have been responsible for causing the Crowsnest River to erode the toe of the east slope of Turtle Mountain.

The terrace shown in the pre-slide photograph, McConnell and Brock (1904, Plate 2), behind the north end of the Village of Frank on the west bank of the Crowsnest River is conspicuously absent from pre-slide views through the Village to the southwest (McConnell and Brock, 1904, Plates 4, 5). The terrace resumes beyond the southern margin of the Slide (McConnell and Brock, 1904, Plates 1, 11). If the terrace were once continuous along the west bank of the Crowsnest River, its erosion is likely due to the River's activity. The southerly continuation of the terrace from west of the Village of Frank stops short of the north margin of the Slide (McConnell and Brock 1904, Map). It resumes "just west of the lower lake at the south end of the slide, where a boulder clay terrace is partially buried under and partially cut away by the slide. The cutting appears to have been done by huge flying boulders, which shot through it. At one point a column of boulder clay has been left standing alone" (McConnell and Brock, 1904, pp. 10-11). Such evidence of the survival of the terrace through aerial bombardment by displaced rocks suggest that removal of the terrace, if it had originally been deposited on the west side of the River, was by fluvial erosion stimulated by the deposition of the Gold Creek fan.

2.2 The Influence of Rock Structure

McConnell and Brock's map (1904, Cruden, 2003) showed the Turtle Mountain Thrust trending northwards towards the Crowsnest River and, perhaps, 30 m above it, directly west of where the northern lateral margin of the Slide deposits entered and crossed the River. Clearly, one factor in the location of the northern margin of the Slide is the relationship between the Turtle Mountain Thrust and the Crowsnest River.

North of the Slide's north margin there is no reliable exposure of the Kootenay Formation or the Fernie Group rocks west of the Crowsnest River. Despite its absence, Cruden and Krahn (1973, Figure 5) had followed Norris (1955) in locating the Turtle Mountain Thrust west of the Crowsnest River. Norris (1993) assumed the Thrust to be west of the River till it crossed the east trending course of the River in the Gap between Frank and Blairmore. However, the Cold Sulphur Spring on the west bank of the Crowsnest River south of the Gap exposes limestone east of Norris' trace of the Thrust and suggests that the River is locally following the broken and weakened bedrock along the Thrust trace. The steep slopes on the west bank of the River between the kame moraine and the north margin of the Slide are consistent with this hypothesis.

On the south margin of the Slide the River is confined as Frank Lake by an east-west trending cliff of flat-lying Blairmore Group sandstones. The west end of the cliff terminates against another, more easterly, thrust fault, called here, the Frank Lake Fault, which brings up the steeply dipping mudstones of the Blairmore Group (MacKay, 1932, Figure 5). These subvertical rocks formed the west bank of the Crowsnest River northwards up to the outcrop of the coal seam at the top of the Kootenay which marked the mine entrance, a little south of the north margin of the Slide. All the mine workings were in the sub-vertical, number 1 coal seam. (MacKay, 1933 Table 1 p. 37B).

The trend of the west bank of the Crowsnest River makes an angle of about forty degrees with the more southerly trend of the coal seam. So the azimuth of the slope into the River diverges considerably from the strike of the bedding in the Blairmore Group rocks. Early work on toppling (Goodman, 1989) had suggested arbitrary limits of up to thirty degrees for this angular divergence. Beyond these limits, toppling was unlikely. Cruden (1989, Table 1) demonstrated that slopes with azimuths making angles as much as eighty degrees with the strike of bedding might topple if they were sufficiently steep.
Goodman and Bray's kinematic criteria for toppling (Norrish and Wyllie, 1996, Equation 15:7) simplifies to the condition,

$$\phi \leq \beta \qquad [1]$$

for vertically dipping rocks with a friction angle, ϕ, on a slope, β. If the slope direction diverges by an angle, d, from the dip direction of the beds, then Cruden (1989, Equation) suggested that equation (1) would become

$$\tan\phi \leq \tan\beta \cos d \qquad [2]$$

At Turtle Mountain, d is about 40°. The slope β, at the toe of the east face of Turtle Mountain before the Slide was not surveyed. Locally, as Cruden and Hungr (1986) have pointed out, the Slide deposits form only a thin veneer over the bedrock; on the steep west bank of the Crowsnest River, there are even small exposures of the vertically-dipping beds. So the present western bank of the River through the Slide, stripped of its colluvial blanket, might give a reasonable lower bound estimate of β as thirty degrees.

Friction angles, ϕ, in the Kootenay and Blairmore Group rocks, shales, siltstones, sandstones, conglomerates and coals (Norris, 1993) would cover a wide range (Wyllie and Norrish, 1996, Table 14-1). Flexural slip surfaces, at close to residual friction angles, have been described from the limestones above the Turtle Mountain Thrust, (Cruden and Krahn, 1978); similar surfaces, with natural shearing producing residual friction angles, might be predicted below the Thrust. A very detailed examination of similar but less deformed rocks at the Oldman Dam (Davichi et al., 1991) found surfaces with friction angles as low as eleven degrees.

Substitution in equation (2) with β, 30 degrees and d, 40 degrees, suggests that bedding surfaces with friction angles below 24 degrees may begin the flexural slipping that leads to toppling. Several such surfaces would be expected in these vertical Mesozoic clastics. The western bank of the Crowsnest River might have been toppling into the river before the Slide.

The most detailed published view of the toe of the east slope of Turtle Mountain before the Slide is in the middle distance of Mark and Buchanan's, the local photographers, picture of the "Mouth of the Canadian American Coal and Coke Company's mine…" (McConnell and Brock, 1904, Plate 4, Cruden, 2004, Figure 2). Toppling of the slope is suggested by uphill-facing scarps in the photograph. What Terzaghi (1950) and Sharpe (1938, Figure 2) called "creep", is demonstrated by "trees with curved trunks concave upslope". The curved mature trees predate the coal mining which had begun a year earlier in 1901. The photograph, on the evidence of the construction of coke ovens in the foreground, dates from the fall of 1902. Other evidence of slope instability includes what appear to be rock fall deposits on the slope. Discontinuities in the tree cover around the positions of the lateral margins of 1903 Slide are also apparent on the 1902 photograph. These observations are then consistent with downslope movement of the vertically dipping rock slice between the Turtle Mountain Fault and the Frank Lake Fault; the intersections of the two faults with the toe of the east slope of Turtle Mountain and the Crowsnest River (eroding that toe) may also "correspond very closely" with the lateral margins of the Slide.

3. MINING

The contribution of coal-mining to the Frank Slide has been an enduring topic of discussion (Krahn and Morgenstern, 1976; Benko and Stead, 1998). McConnell and Brock (1904, p. 13) made the following points "It is almost impossible to avoid the conclusion that these great chambers, 130 feet long, 250 to 400 feet high and 15 feet wide, situated directly under the foot of the mountain must have weakened it, even it, as the management assert, little of the loose coal had been drawn from them. The pressure on them must have been considerable. The loose coal, being less resistant than the unmined, would allow slight-slips or readjustments in the hanging wall, and the jar produced by these may have been sufficient to snap some of the few remaining supports, which held the unbalanced mass in place….it is a significant fact that the edges of the break correspond very closely with the limits of the big chambers and mined coal."

McConnell and Brock (1904, Diagram 1) showed the southern lateral margin of the Slide coincided with the southern edge of 8, 400 foot (120m) high rooms and the northern edge of 10 rooms, which diminished from 160 feet (48 m) high southwards. About 250 feet (75 m) of coal hung above the high rooms at the southern lateral margin of the slide. The northern lateral margin of the Slide is 300 metres north of the mine mouth. While Diagram 1, (reproduced as Figure 12 in Cruden 2003) documented room development close to the mine entrance, Figure 11 in the 1910 Royal Commission Report (Daly, et al., 1912) indicated that intact coal remained above the first 1200 feet (366 metres) of the Main Entry. This more accurate information showed the north margin of the Slide extended over a quarter of the Slide's width beyond the mined area. The limits of the big chambers corresponded only with the south margin (where the influence of the cliff at the south end of Frank Lake should also be considered).

The Survey geologists left Frank before the mine re-opened (Cruden and Langenberg, 2003). However, they were able to report the testimony of the miners at work underground during the Slide. It "contains nothing that would indicate that the bursting of the last bond, by which the mass was upheld was caused by movements in the mine. It indicates rather that anything which occurred in the mine was due to the slide…..The mine appears to have escaped with little damage, much less than might be expected when the weight and force of the material which passed over it is taken into consideration" (McConnell and Brock, 1904, p. 14). The Winnipeg Free Press' correspondent in Frank (probably D.A. Stewart) reported that Brock visited the Mine again with the manager Gebo on July 25, 1903, 3 months after the Slide, examining the first 1200 feet of the Main Entry (Winnipeg Free Press, July 27, 1903).

In numerical modeling of the mining, activity sufficient to initiate the Slide (Benko and Stead, 1998) appears to be accompanied by appreciable movements of the mine walls. However, modeling did not consider that water and gas was likely drained from the rock mass above the Main Entry by 2 years of aggressive ventilation. Pore pressures within the mined rock mass were presumably substantially reduced while a perched water table remained in the limestones supported by the relatively impermeable shales.

Again, numerical modeling of mining excavation on cross-sections through the centre of the mine assumed that mining proceeded down from the ground surface (Benko and Stead, 1998, p. 305). Actually, mining proceeded upwards from the Main Entry adit, leaving both substantial pillars above the rooms and loose coal in the rooms as platforms for further mining. The hanging wall and the footwall of the coal seam were thus in mechanical contact over most of the extent of the rooms in the mine. In the timbered manways and pillars between the rooms, stiffer contacts would have been maintained. So loads on the hanging wall would have been transmitted to the footwall and flowed around the mine.

Future numerical modeling of the effect of mining on Turtle Mountain should incorporate both the effects of drainage and hanging wall support to more accurately assess the significance of mining. Krahn and Morgenstern's (1976) estimate of a 1% reduction in Factor of Safety by mining may then prove to be high.

The effects of mining after the Slide to 1910 (Daly et al., 1912) and until fire closed the mine in 1918 are discussed Read (2003). The volume of coal removed after the Slide was more than double the volume taken before the Slide. Allan (1933) documented cracking in the limestones that he believed was induced by subsidence after the Slide. Further coal consumption by the fire in the seam, perhaps, continues to the present day with, presumably, proportionate effects which are under investigation (Read, 2003).

4. WEATHER

4.1 Preparatory Effects

Stupart, the then Director of the Meteorological Service of Canada, reviewed available records in McConnell and Brock (1904, p. 14). The nearest station was Calgary 250 km to the north east.

"The average annual rainfall, exclusive of snow at Calgary is 12.54 inches (320 mm). In 1899, it was 21.61 inches, 1900 was nearly average, 1901 was heavy, being 15.78 inches and in 1902 it was phenomenal as 28.90 inches fell." He summarized, "During several of the past few years the summer rainfall in Southern Alberta has been abnormally heavy".

David Stewart, who had spent the summer of 1902 at Frank, (Sharpe, C.F.S., personal communication, July 24, 1989), noticed, "There can, however, be no doubt that the ordinary action of the elements had much, if not everything, to do with preparing for the recent slide. During wet seasons, streams of water whose inlet must have been very far up, were found in many places gushing from the base of the mountain" (Stewart, 1903, p. 230). The best-documented of these gushings is "a sulphur spring reputed to be of great medicinal value" (Stewart, 1903, p. 230) whose position prior to the Slide is mapped by Leach (1903). Borneuf's (1983) description of the spring placed it among other better-known springs in active karsts in the Rockies. Other evidence of karst activity was documented by Prosser and Cruden (1982). We should assume then, that both before and after the Slide, the limestones above the Turtle Mountain Fault were subject to active solution along joints and bedding planes. Weather triggers of the Slide might be expected to impede the easy drainage of the limestone rock mass.

4.2 Weather Triggers

The miners at Frank commented on the weather immediately prior to the Slide (McConnell and Brock, 1904, p. 14). "The night of the slide was excessively cold… colder than any night during the winter. Those outside stated that the temperature was down to zero. The day before and the preceding days had been very hot, so that the fissures in the mountain must have filled with water on which the frost would act with powerful effect".

Temperatures in the Report are in degrees Fahrenheit; the overnight low on April 28-29 was -18°C, down about 40°C from the highs registered in Calgary 3 days previously. Such rapid drops in temperature are not uncommon in the Foothills of the Rockies in the Spring. Westerly air flows from the Pacific may be rapidly replaced by cold air masses from the Arctic.

"Snowfall in the winter of 1902-03 was less than average… although March was somewhat in excess" (McConnell and Brock, 1904, p.14). So, sufficient snow was available to melt in the earlier warm spell and infiltrate cracks and fissures widened by the heavy rains of previous summers. Snow is visible in McConnell and Brock's Plate 5 (1904) down to 600 m or more below the North Peak of Turtle Mountain. This well-known photograph taken by Marks and Buchanan, is precisely dated by the procession of escaped miners it records from the afternoon of April 29. Other plates of the North Peak (Plates 12, 13) showed substantial snow accumulations persisting till McConnell and Brock (1904) recorded them after May 8, 1903 (Cruden and Langenberg, 2003).

Terzaghi's comments on the seasonal variation of rock fall and slides on slopes in Norwegian fjords may be relevant "….the slide frequency was greatest in April, during the time of the snow melt, and in October within the period of greatest rainfall. However, most of the major slides have taken place in April because at that time of year, the exits of the joints are still plugged with ice while the snow melt is feeding large quantities of water into the joints of the rock…." (Terzaghi, 1962, p. 262).

Slopes low on the eastern side of Turtle Mountain would be in shade for much of an April day, more so before the Slide with the sheltering bulk of the Centre Peak in place. In contrast, the upper portions of the Turtle Mountain Ridge would be sunlit, allowing snow to melt into the karst-widened joints in the limestone forming the Ridge. So, to McConnell and Brock's suggestion, quoted above, of triggering by freezing of water in fissures, should then be added the elevated cleft-water pressures (Terzaghi, 1962, p. 262) caused by ice plugging the exits of joints and bedding planes on the lower east face of Turtle Mountain.

5. DISCUSSION

Leroueil (2001, p. 224) attributed the apparently trivial but very significant statement "The slope failed when it was ripe for failure" to Terzaghi (1950, p. 96). However, McConnell and Brock (1904, p. 12) had already commented "Turtle mountain…..was ripe for a slide". They continued, "The steep slopes, the shattered and fractured nature of the rocks…coupled with unusually heavy precipitation are causes which in themselves are quite sufficient to have produced the slide". Clearly McConnell and Brock envisaged a much longer ripening than the few years of mining-induced cohesion reduction that Terzaghi (1950, Figure 5) hypothesized. The steepening of slopes had occupied much of the Holocene rather than a small part of the Technogene.

The shattering and fracturing of the rocks began much earlier with the building of the Rocky Mountains, and the folding and thrusting of the sedimentary rocks that form the Turtle Mountain Anticline. Both conditions are preparatory causal factors which make the slope susceptible to movement (WP/WLI, 1994). In the Working Party's terminology, preparatory ground conditions included "jointed or fissured material" and "adversely – oriented mass discontinuities". Preparatory geomorphological processes, "fluvial erosion of the slope toe" and "subterranean erosion" also moved the slope from stable conditions, when the slope was buttressed by the kame terrace, to marginally stable conditions as fluvial erosion of the vertical Mesozoic rocks commenced.

The sparse photographic evidence suggests that the east slope of Turtle Mountain may have been moving slowly before coal mining began. The slope had reached "active instability". Causes triggering movement would then include continuing erosion, to which might be added the physical processes we have identified that occur in the short, violent Springs in the Canadian Rockies. The contribution of the man-made process, mining, to the triggering factors remains to be precisely evaluated. It is unlikely to be large.

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