A century of risk management at the Frank Slide, Canada

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Abstract: On the morning of April 29, 1903, Canada's deadliest landslide swept down the eastern slope of Turtle Mountain, across the Crowsnest River, the surface infrastructure of the Canadian American Coal Company's Frank Mine, the southern end of the town of Frank and Canada's second transcontinental railway through the Crowsnest Pass. The Frank Slide killed 83 persons and injured 23.

Two experienced Cordilleran geologists, McConnell and Brock, reported that the Slide had several causes: the form and structure of Turtle Mountain, heavy precipitation in the last few years, recent earthquake tremors and, the opening up of large chambers within the mine. The force that severed the last thread was the heavy frost on the morning of the Slide.

The Survey geologists identified the danger of a rock fall from the North Peak of Turtle Mountain with catastrophic consequences for the town and the railway. To mitigate the risk, they recommended that the town be moved beyond the reach of danger. Coal mining continued however. In 1912, a Royal Commission confirmed the risk evaluation and the Federal Government financially supported the town's relocation. Coal mining was halted in 1918 by uncontrollable fires.

A similar risk management process was carried out in the 1930's after the danger of a fall from the South Peak of Turtle Mountain had been identified by Allan. Lime City and the Provincial Highway through the Pass were moved from danger zones. Monitoring of displacements on Turtle Mountain then began a more quantitative risk analysis.

Terzaghi's 1950 comments motivated further landslide characterization and numerical analyses in the 1970's. The monitoring program was updated in the 1980's and again, beginning in 2003. Risk communication was improved by the construction of the Frank Slide Interpretative Centre in 1985. A century's efforts continue.

Résumé: Le matin du 29 avril, 1903, le glissement de terrain le plus mortel du Canada dévalait la pente de la montagne Turtle. Le glissement traversa le Crowsnest, l'infrastructure extérieure de la mine Frank de la Compagnie Canadienne Américaine de Charbon, la limite méridionale de la ville de Frank et le deuxième chemin de fer transcontinental du Canada. Le glissement de Frank tua 83 personnes et en blessa 23.

Deux géologues expérimentés, McConnell et Brock, firent un rapport expliquant que le glissement avait plusieurs causes: la forme et la structure de la montagne Turtle, la précipitation abondante des années précédantes, de petites secousses sismiques récentes et l'ouverture de grandes chambres additionnelles de la mine. La gelée épaisse le matin du glissement fut la goutte d'eau qui fit deborder le vase.

Les géologues identifièrent également un danger de glissement du piton nord de la montagne Turtle pouvant avoir des conséquences catastrophiques pour la ville et le chemin de fer. Pour amoindrir le risque, ils recommandèrent que la ville soit déplacée de manière à se trouver hors de danger. L'exploitation houillère pourtant continua. En 1912, une Commission Royale confirma l'évaluation des risques et le Gouvernement Fédéral soutint financièrement la relocalisation de la ville. L'exploitation houillère fut arrêtée en 1918 suite à des incendies incontrôlables.

Un procédé similaire de gestion de risque fut utilisé dans les années 1930 après que la possibilité d'un glissement du piton sud de la montagne Turtle eut été identifié par Allan. La ville de Lime et l'autoroute provinciale par le Col furent alors déplacées de manière à être mises hors de portée des zones à risque. Le suivi de déplacements de la montagne Turtle eu pour conséquence une analyse de risque plus quantitative.

Les commentaires de Terzaghi en 1950 ont motivé les descriptions supplémentaires de glissement et les analyses numériques des années 1970. Le programme de suivi a été mis à jour dans les années 1980 et de nouveau en 2003. La communication du risque a été améliorée par la construction du Centre d'Interprétation du glissement Frank en 1985. Les efforts d'un siècle continuent.

Keywords: Coal mines, erosion, landslides, highways, railroads, risk assessment

INTRODUCTION

Before dawn on the morning of April 29, 1903, Canada's deadliest landslide swept down the eastern slope of Turtle Mountain, across the Crowsnest River, the surface installations of the Canadian American Coal Company's Frank Mine, the southern end of the town of Frank and Canada's second railway across the Rockies, the Canadian Pacific route through the Crowsnest Pass. In a hundred seconds, 300 hectares had been buried by 14 metres of limestone blocks. The Frank Slide killed 83 persons and injured 23 (Anderson, 1986, p 19).

Two of the Geological Survey of Canada's most experienced Cordilleran geologists investigated. McConnell and Brock (1904), reported that the Slide had several causes: the form and structure of Turtle Mountain, heavy precipitation in the last few years, recent earthquake tremors and the opening up of large chambers within the mine. The force that severed the last thread was the heavy frost on the morning of the Slide.

The Survey geologists identified the danger of a rock fall from the North Peak of Turtle Mountain with catastrophic consequences for the town and the railway. To mitigate the risk, they recommended that the town be moved beyond the reach of danger. Coal mining continued however. A Royal Commission (Daly, Miller, Rice, 1912) confirmed the risk evaluation and the Federal Government financially supported the town's relocation (Whyte, 1987). Coal mining was halted in 1918 by uncontrollable fires.

A similar risk management process, but under the auspices of the Provincial Government, was carried out in the 1930's after the danger of a fall from the South Peak of Turtle Mountain had been identified by Allan (1933). The community of Lime City and the Provincial Highway through the Pass were moved from what were judged to be danger zones. Monitoring of displacements on Turtle Mountain by the Alberta Research Council then began a more quantitative risk analysis (Cruden, 1986).

Terzaghi's (1950) comments motivated further landslide characterization and numerical analyses in the 1970's. The monitoring program was updated in the 1980's and again, beginning in 2003. Risk communication was improved by the construction of the Frank Slide Interpretative Centre in 1985.

Here we review what has been added to our understanding of the causes of the Slide and demonstrate how these additions have influenced the management of the dangers posed by Turtle Mountain.

CAUSES

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 3) 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, 2003, 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.

Fluvial Erosion

Besides adding detail to McConnell and Brock's concerns about the structure of Turtle Mountain, MacKay (1933, p. 32B) added "undermining of the eastern flank of Turtle Mountain by the erosion of Crowsnest River" to their list of causes. Here, we note the influence of Gold Creek on the course of the River.

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.

Mining - The Geological Survey's Views

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).

Mining - Terzaghi's Comments

"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.

Mining - Numerical Modelling

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 until fire closed the mine in 1918 are discussed by Read (2003). The volume of coal removed after the Slide was more than four times the volume taken before 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).

Other Preparatory Effects

Stupart, the then Director of the Meteorological Service of Canada, reviewed available weather records in McConnell and Brock (1904, p. 14). The nearest meteorology 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.

Stupart was also asked to report on seismic conditions but he did "not know of any seismic disturbance….in that part of the country". He relied however on a single seismograph in Toronto, over 2000 km away. McConnell and Brock's conclusion that "Recent earthquake tremors, …..no doubt hastened the time of final disruption" was more then an acknowledgement of Stupart's efforts than a summary of any evidence.

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.

DISCUSSION OF THE CAUSES

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.

RISK MANAGEMENT

The Federal Government

McConnell and Brock's Report had recommended that (the town of Frank) …"be moved a short distance up the valley beyond the reach of danger". However, the underground workings of the mine were little damaged by the Slide and mining resumed. Production peaked in 1906 at 161,402 tons, just exceeding the 1902 total (Daly, Miller and Rice, 1912), and the miners walked to work from their homes in Frank.

McConnell and Brock's Map projected the coal seam mined at Frank northwestwards thru' the western boundaries of the townsite. In 1908 a shaft was sunk 1.2 km north of the entrance of what came to be known as the old or drift mine and production began in the shaft mine from levels driven both to the north and to the south. However the Provincial Government's Mines Inspectorate halted deep levels driven northwards from the Drift Mine and southward from the Shaft Mine when the danger of driving into the water-bearing sediments filling the buried valley of the Crowsnest River became apparent.

Brock, now Director of the Geological Survey, responded to the Mines Inspectorates' request for an opinion (Brock, 1910, 1911) adding his concerns about the stability of the North Peak of Turtle Mountain. In July 1910, the Mines Inspectorate's order for a change in the system of working of the shaft mine led to the shutdown of both shaft and drift mines and a request from the Company's Paris head office for the appointment of a competent investigating committee. The Commission formed a year later concluded (Daly, Rice and Miller, 1912) that a danger area stretched from the southern boundary of the shaft mine to the South Peak of Turtle Mountain and beyond. A map in the report which identified the "area endangered if the North Peak Block should fall" put much of the Town of Frank at risk. Continued mining would require abandonment of the Frank townsite, relocation of the entrance of the drift mine to the south and additional support of the mine openings.

Both the Federal and the Provincial Governments contributed to the costs of relocating buildings in the town to lots provided by the mining company (which went into liquidation). Production resumed during the First World War but the mine was sealed and abandoned in 1918 when fires burning in the drift mine since 1910 became uncontrolled.

The Canadian Pacific Railway occupied some of the abandoned townsite as the Crowsnest Pass route became a more important part of their network. The Railway's concern sent another Geological Survey geologist to inspect Turtle Mountain in the summer of 1931. B.R. MacKay had mapped the mountain in 1910 and 1911. His informal report prompted the Provincial Government (which had assumed responsibility for Alberta's mineral resources in 1930) to send J. Allan to investigate.

The Provincial Government

Allan, Chairman of the Geology Department at the University of Alberta and a founding member of the Alberta Research Council mapped a large danger zone at risk from a 15 million ton fall from the South Peak (Allan, 1931). A small danger zone threatened by a smaller fall included the small settlement of Lime City and a stretch of the main highway through the Pass. Allan recommended the relocation of both of these. Subsequent reports (Allan, 1933) confirmed these recommendations.

In 1933, Allan and his assistants mapped the position of cracks and fissures on Turtle Mountain from South Peak to North Peak at a scale of 1:1200 (Allan, 1933, Plate 1). This map showed the position and width of 18 gauge stations established by red paint marks on opposite sides of gaping cracks. Allan (1933) recommended that the gauge stations be measured a year later and be supplemented by the installation of bench marks on the peaks of Turtle Mountain. The history of subsequent monitoring has been documented by Read et al. (2005).

The Provincial Government carried out Allan's recommendations. In 1976 the Slide's deposits were protected within a Restricted Development Area. The Frank Slide Interpretive Centre was opened in 1986 to help the public understand the Slide (Field and McIntyre, 2003).

SUMMARY

Two communities in the Crowsnest Pass have been relocated in two separate risk control strategies. The second of these, initiated by the identification of the rock slide hazard from the South Peak of Turtle Mountain, began the monitoring of the Mountain which continues today. Risk control options have offered incentives to voluntary compliance by residents, an appropriate risk communication mode when risk assessment, although carried out by experts, was essentially qualitative.

During this last century, advances in geological knowledge and in techniques of numerical analysis have enhanced understanding of the slope movement hazards from Turtle Mountain. Coal mining, arguably a technical hazard on the Mountain, has been abandoned along with railway branch lines serving the mines. However the highway, relocated beyond a danger zone in the 1930s, is now more intensively used. So, the systems whose risks require management change with time. Risk control strategies then require both continual monitoring and optimization.

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