010458

from "Some Notes on the Stability of Rock Slopes in Open Pits Mines in B.C.", Oct 4th 1962
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available (maximum length of standard rock bolts is 8 feet) thus allowing deeper penetration into the underlying firm rock. On the other hand, the increase of shear strength along the fault plane caused by tightening rock bolts would be lost and the possible effect of tying the whole unstable mass, at least in the critical toe area, into a solid bulwark would be reduced by using steel which could not be tightened down. This probably could be partially overcome by cement grouting loose steel into the drill holes. The effectiveness of a specific number of bolts or other steel increases with a decrease in the slope of the fault plane for a given unstable rock mass with a safety factor equal to unity as shown on Figure 1 (<u>see</u> 30 degree and 45 degree lines) and conversely, decreases with an increase in slope (<u>see</u> 70 degree line). Also, of course, the effectiveness of a specific number of bolts or other steel on a given slope, decreases with increasing size of the unstable mass.

The above analyses, although very much simplified, nevertheless suggest that a relatively few rock bolts or other pieces of steel properly anchored can have a marked effect on stabilizing potential rock slides.

6. <u>Craigmont Mines Limited, Merritt</u>

(Ref.: <u>Minister of Mines, B.C.</u>, Ann. Rept., 1960, pp. 26-40.)

In February 1962 cracks were observed developing on the ground surface above the headwall or west slope of the open pit. Since then a mass of unstable waste rock, very roughly estimated to be 400,000 cubic yards in volume, lying between these cracks and the 3,930-foot berm has slumped several feet downhill. The upper cracks form a rough arc suggesting that the slide is of the rotational shear type such as form when soils fail. Similar arc-shaped cracks have more recently developed on the ground surface above the north pit slope but no major movements have yet occurred in this area. The headwall and north slope of the pit are to be cut back considerably in the near future so all of the failed material will be removed.

The rocks involved in the headwall slide are highly altered, limy and non-limy sediments and volcanics of the Nicola Group. At the mine, these rocks are cut by numerous, generally east-west striking, steeply dipping faults and closely spaced, irregularly oriented fractures. The crack at the top of the slide has occurred along closely spaced fractures which no doubt largely control the shape of the failure surface throughout the slide. The slide is bounded to the north and south by east-west striking, steeply dipping faults, the north boundary fault containing considerable graphite. Water probably played an important part in the formation of this slide. Failure occurred in February when considerable wet snow covered the area and seepage was observed issuing from the graphitic north fault zone just prior to failure.

Prior to failure, the headwall and north slope of the pit had been developed to an over-all slope of about 45 degrees, 6 degrees flatter than originally planned. Following the slide, a relatively wide berm was left at the toe of the slumped mass at the 3,930-foot level and an over-all slope of 43 degrees was developed from that level downward. In order to calculate the safety factor against failure of the 43-degree slopes, assuming classic soil mechanics theory can be applied, it would be necessary to know the following about the headwall slide which would be used for the calculations: the depth and shape of the zone of failure, the shear strengths of the joint and fault materials forming the zone of failure, and the ground water conditions at the time of failure. All these factors for this slide are unknown. However, if we assume that the shear strengths of the materials in the part of the pit to be excavated to a 43-degree slope are similar to that of the slide, a decrease in slope of 2 degrees will obviously increase the safety factor by very little assuming an equivalent water table. A relatively small increase in the elevation of the water table over that of February 1962 would probably cause failure of the 43-degree slopes, other things being equal and therefore any measures taken to lead water away from the general pit area is probably very desirable.

<u>Summary</u>

(a) Costly and/or dangerous rock slides have occurred in several open pit mines in British Columbia and no doubt others will occur in the future. These failures have involved masses of rock varying from small fragments to hundreds of thousands of cubic yards and have varied in speed from instantaneous to slow slumping involving long periods of time.

(b) Stable, vertical pit slopes have been developed in competent rocks having few structural weaknesses whereas slopes as flat as 45 degrees have failed in incompetent rocks containing numerous structural weaknesses.

(c) Most of the slides have occurred in the headwalls or highest slopes.

(d) All of the failures observed have occurred along zones of structural weakness such as faults and joints.

(e) In the open pit iron mines of Vancouver Island, slopes excavated in volcanic rocks are more susceptible to slides than those developed in limestone due to the greater abundance and intensity of structural weaknesses in the former.

(f) Procedures that have been used to stabilize rock slopes in British Columbia mines are:

(i) Scaling of loose rock from pit faces; this is usually done by the loading shovel.
(ii) Blasting of large unstable masses, that is, flattening over-all slopes showing instability.
(iii) Rock bolting and surface cementing.
(iv) "Pre-shearing" prior to main blast.
(v) Drainage of surface water back of the slopes.

Department of Mines and Petroleum Resources
Victoria, B.C.
October 4, 1962.