ESTIMATION OF PHYSICAL PARAMETERS OF MacLEAN CHANNEL SULPHIDE-BEARING DEBRIS FLOWS, BUCHANS, NEWFOUNDLAND[1]

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Abstract

Subaqueous sulphide-bearing debris flows were the major transport mechanism for the ore units in the MacLean channel. Measurement of the coarse blocky detritus in the flow deposits allows estimation of the yield strength of the debris flows. Yield strengths for two debris flows in the MacLean channel were estimated to be 1.0 to 1.5 x $10^3 N.m^{-2}$ and 3 to 9 x $10^3 N.m^{-2}$. Paleoslopes an be calculated using the estimated yield strength of the debris. Comparisons between calculated paleoslopes (3 and 10°) and actual bedding attitudes (0 to 15°) in the MacLean Extension orebody suggest present bedding attitudes reflect the paleoslope. Data for the sulphide-bearing debris flows are similar to literature values for non-sulphide flows. Uses of the calculations for mineral exploration include basinal analysis and prediction of locations for high grade, dense debris flow deposits at the bases of steep inclines.

Résumé

Des coulées de d'ébris subaquatiques à sulfures ont été le mécanisme de transport principal des unités minéralisées dans le chenal de MacLean. Le mesurage des débris blocailleux grossiers dans les dépôts permet d'estimer la limite élastique des coulées de débris. Ces limites élastiques sont de 1,0 à 1,5 x 10^3 Nm^{-2} et de 3 à 9 x 10^3 Nm^{-2} pour deux coulées de débris dans le chenal principal. Il est possible de calculer les paléopentes à partir des limites élastiques estimatives des débris. Une comparaison des paléopentes calculées (3° et 10°) et de la disposition actuelle de la stratification (0° à 15°) dans la masse minéralisée de la prolongation de MacLean permet de croire que la disposition actuelle de la stratification reflète la paléopente. Les données sur les coulées de débris à sulfures sont semblables aux valeurs publiées pour les coulées dépourvues de sulfures. Les utilisations des calculs pour l'exploration minérale comprennent l'analyse des bassins et la prévision des emplacements des dépôts riches de coulées de débris denses accumulés au pied de pentes abruptes.

INTRODUCTION

In 1982 and 1983 the author investigated the sedimentology of the transported ore in the MacLean channel, Buchans camp. Newfoundland. Shown in plan and section in Figure 1, the orebodies comprise several lithologically distinct beds within a discrete stratigraphic interval. The focus of the work was the MacLean Extension orebody because it is currently being developed and mined. The adjacent MacLean orebody is mined out and most parts are inaccessible.

Individual beds containing sulphide detritus are poorly sorted with angular to subangular lithic and sulphide clasts as long as one metre or more, set in a sand-sized matrix. The base of some beds is inversely graded but most beds have a random internal fabric. The ore-bearing beds have been interpreted as debris flow deposits (Thurlow, 1977; Walker and Barbour, 1981; Calhoun and Hutchinson, 1981; Binney et al., 1983).

Binney et al. (1983) described the distinctive marginal deposits of a typical debris flow observed in the MacLean Extension workings. The contact is at a high angle between the flow centre, with its matrix of sulphides, barite and fine grained lithic detritus, and the margin of the debris flow, with its coarse (greater than 30 cm) blocks of sulphide, granitic and other lithic clasts in a detrital matrix. Such a contact indicates significant matrix strength, and is diagnostic of debris flow margins (Johnson, 1970, p. 434).

Similar debris flow marginal deposits can be observed at several locations in the MacLean Extension workings, thus confirming previous interpretations that at least some of the ore-bearing beds were deposited by debris flows. Although debris flow deposits comprise most fill in the MacLean channel, turbidity current deposits and landslide deposits have also been recognized.

Middleton and Hampton (1976) defined a debris flow as the sluggish downslope movement of mixtures of granular solids, clay minerals and water in response to gravity. Blocks are supported in the flow by the strength of the matrix and deposition occurs when the shear stress applied to the debris drops below its internal strength and the flow 'freezes' in position.

PHYSICAL PARAMETERS

Using the methods of Johnson (1970, p. 486-490) and Hiscott and Middleton (1979), some of the physical parameters of debris flows can be estimated by measurement of coarse, bouldery detritus in the flows. The debris presumably was at a point of critical equilibrium (shear stress equals yield strength) and was just supported when the flow stopped. For these conditions Johnson (1970, p. 461-487) derived an approximate relation between the yield strength (k) of the debris flow and the thickness of a block (c) supported by the flow. Other considerations are the unit weight of the debris flow (γd) and the block (γb) and the depth of penetration of

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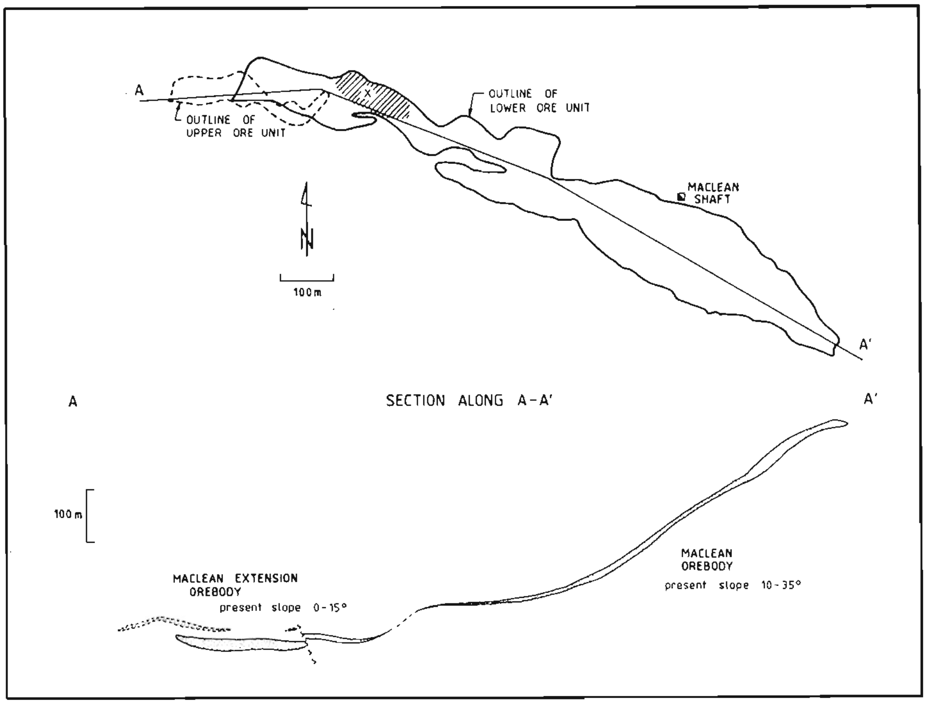

Figure 1

Plan and section of the orebodies of the MacLean channel.

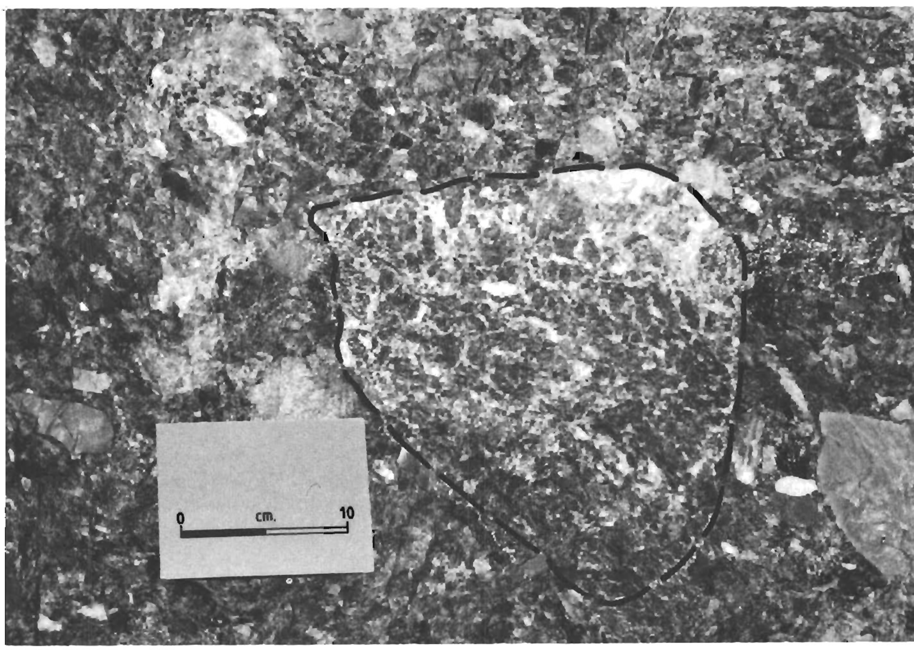

Figure 2

Block of barite-sphalerite-galena completely enclosed by a baritic polylithic breccia-conglomerate bed at the top of the Lower Ore unit, MacLean Extension orebody.

the block into the flow (1/n). The unit weight of a material is the product of its density ($kg.m^{-3}$) and the acceleration due to gravity ($9.80\ m.sec^{-2}$). The depth of penetration (1/n) is expressed as a fraction, for example if a block is 3/4 submerged in the flow then 1/m = 3/4.

$$k \approx \frac{c}{4} \left(\gamma b - \frac{\gamma d}{n}\right)$$

The resultant value for the yield strength (k) of the debris flow is expressed in $N.m^{-2}$ where $1\ N = 1\ kg.m.sec^{-2}$. This relationship is particularly amenable to underground exposures where only the thickness and length of individual clasts can be measured. Difficulty arises, however, in assessing the depth of penetration of a block into the debris flow since the upper limit of individual flows cannot everywhere be identified.

To use the relationship, estimates are needed for the unit weight (density times acceleration of gravity) of both the block and the debris flow. The sulphide blocks observed in the debris flow deposits were sufficiently lithified to break with discrete boundaries so their density is estimated from their mineralogical content. Lithic fragments were transported as clasts and their density is assumed to average $2.7\ g.cm^{-3}$. The density of the debris flow is arbitrarily assumed to be $2.4\ g.cm^{-3}$, at the dense end of the range of 2.0 to $2.5\ g.cm^{-3}$ reported for subaerial debris flow (Fisher, 1971). This is considered a reasonable assumption as the flows were transporting blocks of density 2.6 to $5.5\ g.cm^{-3}$. If the density of the flow exceeded that of the blocks there would be a buoyant effect with the lithic clasts floating to the top. This was not observed. The high percentage of sulphide and barite fragments in the deposits does support a high overall density for the debris flows.

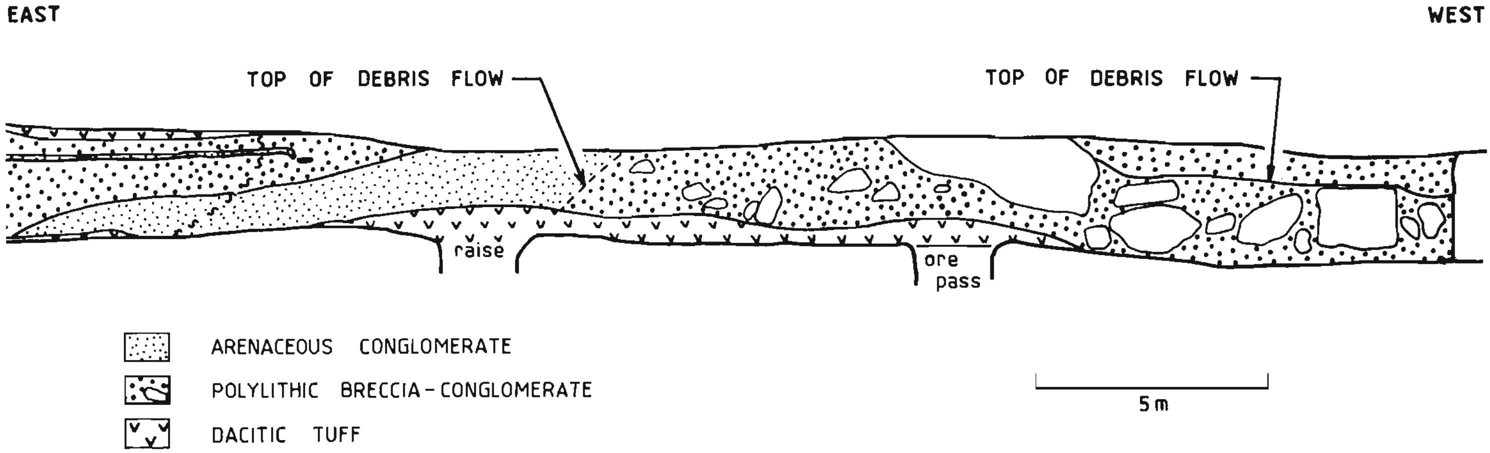

Figure 3. Section of the Lower Ore unit along a sublevel wall (20-6-1), MacLean Extension orebody. Coarse detritus is observed about the snout of the northward flow. The flow is bounded to the east by arenaceous conglomerate deposited contemporaneously with it but outside of the main body of the flow.

Individual flows would have different densities but without measurements taken during flow this cannot be quantified with respect to the deposits observed.

The use of Johnson's relationship can be illustrated with reference to a typical debris flow in the MacLean Extension workings. This flow, located at X in Figure 1, occurs at the top of the Lower Ore unit and is laterally extensive, covering an area in excess of 6000 m^2. Figure 2 illustrates one of the coarser fragments transported by this flow. The thickness of this clast of barite-sphalerite-galena is 0.23 m and it is completely enclosed by the 1.2 m baritic polylithic breccia-conglomerate bed.

$$k \approx \frac{0.23\ m}{4}\left(\left(4.5 - \frac{2.4}{1}\right)(10^3)kg.m^{-3}(9.80\ m.sec^{-2})\right)$$

$$\approx 1.2 \times 10^3\ N.m^{-2}$$

Other blocks of coarse detritus from this bed gave calculated yield strengths for the debris flow in the range of 1.0 to 1.5 x 10^3 $N.m^{-2}$.

Another debris flow deposit (Fig. 3) contains coarse blocks of sphalerite-galena and mineralized stockwork up to 4.4 m in length. The debris flow overlies dacitic tuff and forms the base of the Lower Ore unit at this location. Arenaceous conglomerate marginal to the main body of the flow forms the substrate for similar coarse debris flow deposits to the east. The yield strength for the debris flow was calculated using a sphalerite-galena boulder 1.22 m thick and a stockwork boulder 1.52 m thick, 3/4 submerged in the flow. Yield strengths needed to support these boulders are 9 x 10^3 $N.m^{-2}$ and 3 x 10^3 $N.m^{-2}$, respectively.

Johnson (1970, p. 488) also derived the relationship between the yield strength of the debris in critical equilibrium (k), the slope (δ), the thickness of the flow (Tc) and the unit weight of the debris (γd).

$$k = Tc\ \gamma d \sin \delta$$

This equation was derived using the assumption that the debris flow could be represented as an infinite sheet of plastic material, and is applicable as long as the width of the flow is greatly in excess of its thickness. Knowing the slope, thickness and unit weight of the debris, one can arrive at an independent estimate of the yield strength of the debris. In the case of the MacLean channel, where the amount of postdepositional tilting is unknown, the estimate of yield strength can be used to predict the paleoslope.

For the baritic polylithic breccia-conglomerate which had a yield strength of 1.0 to 1.5 x 10^3 $N.m^{-2}$ based on the maximum clast sizes, the calculated paleoslope is

$$\sin \delta = \frac{1.5 \times 10^3\ N.m^{-2}}{(1.2\ m)(2.4 \times 10^3 kg.m^{-3})(9.80\ m.sec^{-2})} = 0.053$$

$$\delta = 3°$$

The low slope for this bed is consistent with its position as a late debris flow in the filling of the basin. The calculated paleoslope is within the range of the present dip of the bed of 0 to 8° west.

Calculated paleoslopes for the debris flow illustrated in Figure 3 are approximately 10°, in very close agreement with the actual measured dip of the bed which is 12 to 15°.

These results suggest that the present slopes observed in the MacLean Extension area are a reflection of the paleoslopes that existed at the time of deposition of the sulphide-bearing beds. Due to a lack of access, this comparision of actual and predicted slopes could not be extended into the MacLean workings where the Lower Ore unit has a much steeper dip.

If the present attitudes of the rocks in the MacLean orebody are essentially those of the paleoslope, then the yield strength of the debris flows can be calculated. For the sulphide matrix ore, rich in sphalerite and galena;

$$k = (10\ m)(2.4 \times 10^3 kg.m^{-3})(9.80\ m.sec^{-2}) \sin 10°$$

$$= 4 \times 10^4\ N.m^{-2}$$

This result is high compared to the data obtained for debris flows in the MacLean Extension workings. A debris flow with this yield strength could transport boulders in excess of 6 m in diameter. The result indicates one of the limitations of these calculations since no clasts of this size have been recognized in any of the transported orebodies of the Buchans camp. Therefore, the calculated yield strength cannot be confirmed. Sources of error inherent in the calculations are the assumption that sulphide matrix ore was transported by a simple debris flow process and the assumption that the present dip of the bed is identical to the paleoslope.

Using the Hampton number (Hiscott and Middleton, 1979) the velocity (U) that a debris flow would have to exceed for turbulent flow can be calculated. Variables include the strength of the plastic debris flow (k) and the density of the flow (ρd). For turbulent flow;

$$\frac{\rho d\, U^2}{k} \geq 1000$$

For the baritic polylithic breccia-conglomerate bed used throughout this report;

$$U^2 \geq \frac{1000\ (1.5 \times 10^3\ N.m^{-2})}{2.4 \times 10^3\ kg.m^{-3}} = 625\ m^2.sec^{-2}$$

$$U \geq 25\ m.sec^{-1}$$

Compared with velocity values for subaerial debris flows of 1 to 3 $m.sec^{-1}$ (Sharp and Nobles, 1953; Johnson, 1970, p. 512), this is an unrealistic, high velocity for a flow, especially one depositing coarse unsorted detritus. The result confirms the laminar, nonturbulent nature of flow within the debris flows of the MacLean channel.

SUMMARY AND CONCLUSIONS

The data for yield strength of the sulphide-bearing subaqueous debris flows of the MacLean channel is of the same order of magnitude as that presented by Johnson (1970, p. 490) for subaerial debris flows (1.7 to $5 \times 10^3\ N.m^{-2}$) and Hiscott and Middleton (1979) for subaqueous debris flows in the Tourelle Formation ($4 \times 10^3\ N.m^{-2}$). In the MacLean channel the boulders are smaller than in the other studies, but being sulphides, are of much greater density. The variation in yield strength of the flows in the MacLean channel reflects both the diversity of the source area with high density sulphide and lithic detritus to form the flows, and the high local variability of slope in a volcanic environment which has affected the course of the debris flows.

The accuracy of the calculations is subject to the assumptions that Johnson (1970, p. 461-488) made in developing the equations and the fact that a unimodal process of clast support is assumed in applying the equations. Clasts in the MacLean channel have an apparent maximum size based on the author's studies. This may reflect the ability of the debris flows to transport coarse detritus or a limited size range of clasts in the source area.

Even with the limitations outlined, calculations of physical parameters such as debris flow yield strength and paleoslope could be important factors in exploration for sulphide-bearing debris flows such as those at Buchans. Unlike studies of subaerial debris flows, the attitude of preserved subaqueous flows is usually unknown. Even crude estimates of paleoslope may have important implications in basinal analysis and the ultimate success of a mineral exploration program. Changes in paleoslope affect the ability of debris flows with coarse detritus to continue moving downslope. A radical change in paleoslope could result in deposition of debris flows with coarse, high grade sulphide blocks at the base of a steep incline.

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