Presidential Address

Presidential Address to the Geological Association of Canada, Vancouver, B.C.

Sedimentology: A Tool for Mapping "Mill-Rock"

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Abstract
Mill-rock is a distinctive lithology composed of coarse volcaniclastics, observed close to many massive sulphide deposits of volcanogenic origin. The general consensus of opinion is that strata-bound base-metal sulphide deposits, associated with subaqueous volcanics, are located close to eruptive centres or vents. Volcaniclastics may be important guides to eruptive centres. The aim of the presentation is to review briefly what has been done, and to summarize the principles and techniques which we have used in mapping volcaniclastics.

Grain size and bed thickness are the two properties most often used to establish vertical and lateral variations within the pile. These properties are generally compared within a single event or series of events such that the first mapping problem is one of correlation. The principles are not different from those used in sedimentary rocks. Authors working with grain size have used median, mean, and a representative of the coarsest fragments. In our work we have found that the coarsest grain size gave better results. It is a more reliable measurement of flow conditions and is easier to measure.

The hydrodynamic behavior of pyroclastics should not be different from that of other mass-flow sediments, and by analogy, primary structure sequences, commonly present in volcaniclastics, may be used for paleogeographic reconstruction. Our work in the Noranda region shows that these sequences are a powerful tool, but that bed thickness is not a reliable paleogeographic indicator.

Résumé
"Mill-rock" est composé de matériaux volcaniclastiques grossiers, associés à plusieurs gisements de sulfures massifs d'origine volcanique. Le consensus général étant que ces gisements sont localisés près des cheminées volcaniques, les volcaniclastiques peuvent être un outil important pour les localiser. Nous nous proposons de résumer brièvement le type de travail effectué par le passé sur les volcaniclastiques, ainsi que les principes et les techniques que nous avons utilisés pour les cartographier.

La granulométrie et l'épaisseur des strates sont généralement les deux propriétés utilisées pour déduire les variations latérales et verticales de l'empilement. On compare le plus souvent ces propriétés à l'intérieur d'un ou d'une série d'évènements de sorte que le premier problème de cartographie en est un de corrélation. Les principes pouvant conduire à une solution ne sont pas différents de ceux utilisés dans les séquences sédimentaires. Pour quantifier la granulométrie, les chercheurs ont utilisé le médian, la moyenne, ou la plus grande taille. Nos travaux nous permettent d'affirmer que la quantification de la plus grande taille donne le meilleur résultat. En plus d'être plus facile à mesurer, c'est une valeur plus juste des conditions de l'écoulement.

Le comportement hydrodynamique des pyroclastiques devrait être similaire à celui des autres coulées de masse et par analogie les séquences de structures syngénétiques qui sont souvent observées dans les volcaniclastites, peuvent être utilisées pour la reconstruction paléogéographique. Dans la région de Noranda les mesures sur les épaisseurs des strates n'ont pas donné les résultats escomptés, mais les séquences de structures primaires nous ont permis de trouver une position relative de la cheminée.

Prologue
Historically the presidential address was read at the GAC Luncheon. When the General Chairman of this meeting asked my desires for the address, my first reaction was typically latin: I will not give it at the luncheon. I once came across a study on chimpanzee of the Catarrhinian sub-order which is the most evolved order of monkeys. Our closely related cousins depend on the seasonal availability of fruits and leaves, which form the bulk of their diet. They travel as much as ten miles in a day to get their food. To my surprise, few survive the age of 40 (Goodall and van Lawick, 1936). Although somewhat biassed, my conclusion is that it is not what one eats or does that counts, but the way one eats or does it. I therefore suggested that the address be read at the end of the day and that beer be made available at the door.

I had another problem in preparing the address. As all Councillors will tell you, I am a rather poor politician. I therefore decided to include a little science. Without much competition from this General Meeting I have elected to talk on a sedimentological subject, but in order to make it bearable I shall emphasize processes which can be used in mapping a neglected rock-type.

Introduction
Mill-rock was defined by Sangster (1972) as a distinctive lithology observed close to most massive sulphide deposits of volcanogenic origin. Sangster (1972, p. 3) remarked that whenever he stood on the outcrop containing the largest fragments of acid pyroclastic in any given mining camp, he could invariably hear the mine mill nearby.

You are all familiar, better than I, with exhalite theories, and of the association of a certain number of sulphide deposits with volcanogenic sediments. I don't have to insist at this all-economic meeting on the importance of volcaniclastics. The relationship between the deposits and volcanogenic rocks is well illustrated in Sangster (1972) for the Archean of Canada, and in Jacobsen (1975) for the rest of the world. Honnorez *et al.* (1973) briefly explain the relationship in an actual situation at Vulcano.

Jacobsen (1975, p. 344) states that the general consensus of opinion at present is that strata-bound base-metal sulphide deposits, in sequences of subaqueous volcanics, are products of submarine fumarolic activity, close to centres of volcanism. The problem is stated, geologists have to find the relationship between the various facies of a volcanic pile, and provide an interpretation which determines the position of centres of volcanism.

Volcaniclastics could be an important tool for the reconstruction of the paleogeography, but in spite of their importance in the exploration for massive sulphide deposits, Sangster (1972, p. 4) notes that he was aware "of only one exploration company that was systematically measuring and mapping size of volcaniclastic fragments, and that little work was done by government surveys."

This situation has changed since 1972, and a number of geologists are now working on volcaniclastics in many regions of Canada. My brief survey of the literature, however, did not yield many contributions from the Canadian scene. Volcaniclastics have perhaps not received in Canada the attention that they deserve, though things are improving as more recent literature shows (Smith *et al.*, 1973; Fox, 1977).

The aim of my presentation is to discuss briefly the properties which have been used in the reconstruction of volcaniclastic paleogeography and to summarize the principles and techniques that our team has applied on the Archean volcaniclastics of the Noranda Region.

The Properties

Grain size and bed thickness are the two properties most often used for establishing vertical and lateral variations within volcaniclastic piles. Pettijohn, Potter and Siever (1972, p. 273 and 275), give examples in an "ignimbrite", and in an ash-fall deposit where size and bed thickness decrease with the distance of transport. Primary structures have also been used (Yamada, 1973) in subaqueous pumice flow (Fig. 1). In these examples as with other similar studies, the properties are compared within a single event or series of events, such that the first problem one faces is the correlation of outcrops or sections. The principles are not different from those used in sedimentary rocks. The task may be more difficult due to the lenticularity of the beds within volcaniclastic deposits. The stratigraphic columns from la montagne Pelée described by Roobol and Smith (1976) are a good illustration of the difficulty: the sections are relatively thin (50 to 120 m), and by using carbon-14

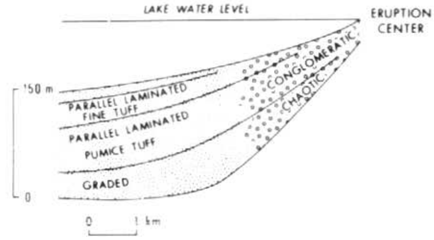

Figure 1
One event of subaqueous pumice flow deposit in the Onikobe Caldera, Japan. Chaotic deposit passes laterally into graded and stratified volcaniclastics. Modified from Yamada (1973).

dates it was shown that no single section can represent the eruptive history of Pelée. Tracing individual beds would be ideal. However, in the Archean deposits the flow deposits are very lenticular and impossible to trace. Many workers confronted with similar problems have used marker beds for correlation. These vary from lava flows, ash falls, to beds with distinctive mineralogical or chemical compositions. Without internal markers one has to compare the volcaniclastic pile from section to section but this may be very difficult in large areas where the possibility of having contributions from more than one vent exists.

Volcaniclastics have characteristic primary structures that are commonly observed in sedimentary rocks of the flysch facies. In the Noranda outcrops which were studied, most beds have a primary structure sequence. Reverse and normal grading, parallel and oblique stratifications are the most abundant structures. They occur in sequences (Fig. 2) which evolve from one end of the deposit to the other. In the flysch facies these sequences have been interpreted as the result of deposition from mass flows, and from turbidity currents, where suspension and/or traction are responsible for the transport. The structure sequences vary as a function of grain size and flow power. As the flow decelerates down-current, grain size decreases and the sequences change (an example is given in Blatt *et al.*, 1972, Fig. 5-3, p. 121). This leads to a lateral variation of primary structure sequences within the deposit which can be mapped and used for the reconstruction of the paleogeography (Walker, 1976). The hydrodynamic behaviour of pyroclastics should not be different from that of other mass-flow sediments, and by analogy we have used primary structure sequences for the reconstruction of the paleogeography.

Figure 2
Primary structure sequence in volcaniclastics of the Noranda Region. The basal graded division is overlain by parallel stratification, dune, and ripple cross-bedding. Photograph courtesy of Normand Tassé.

The primary structure sequences result from the interaction of grain size and flow power. At this stage I should come back to grain size measurements. In working with volcaniclastics authors have used median, mean diameter, or a representative of the coarsest fragments (Scheidegger and Potter, 1968; Walker and Croasdale, 1971; to give two examples). Differentiation of the fragment types gives better results (Walker and Croasdale, 1971). In sedimentary mass-flow and turbidite deposits, grain sizes vary within beds, from base to top. Both mean and coarsest size vary, but the consensus is that the coarsest size is a more sensitive measure of flow variations; if the flow has the competency to transport the coarser material, it should also move the finer sizes. The pyroclastic beds (flows) which were studied at Noranda, show a coarse-grain variation from base to top. The coarsest grain size was documented within each bed, and results were used as a second tool to establish down-current flow directions. In these sections there are two coarsest-size populations, in different bed-types (lapillistone beds, and breccia beds: Figs. 3, 4). If the mean had been used, and the two bed-types grouped in a single sample the lateral variations would have been less evident, and the statistical analysis much less reliable.

Grain size and bed structures can also serve for studying vertical variations within the pile. In flysch sequences up-

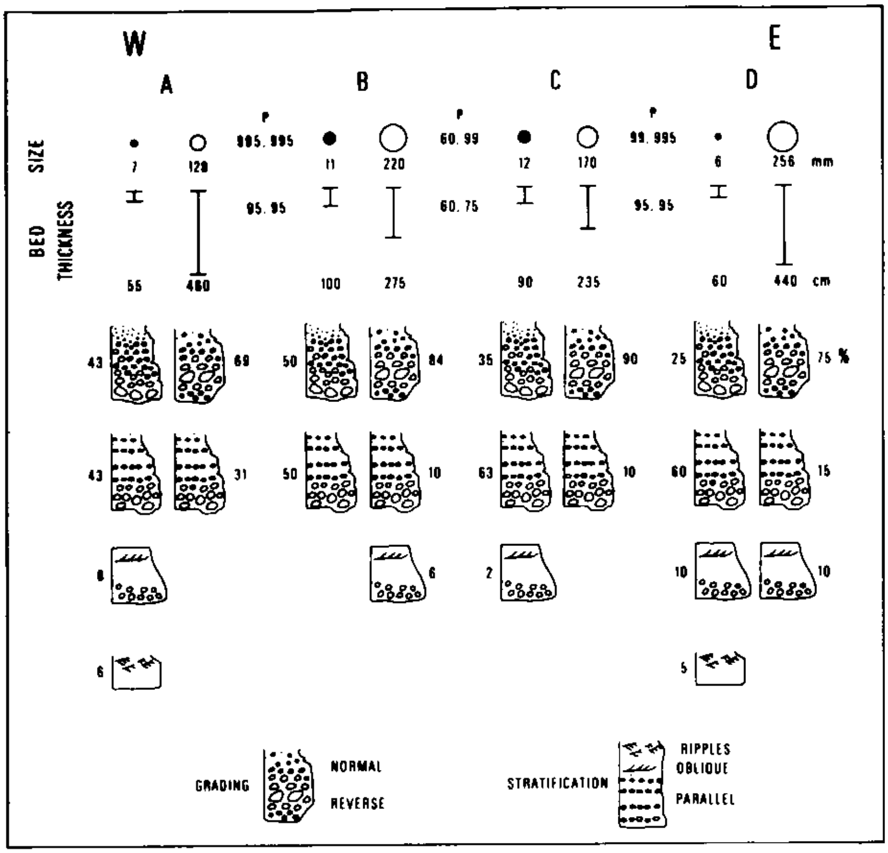

Figure 3
Lateral variations of size, bed-thickness, and primary structure sequence in four sections (A to D) of pyroclastics of the Noranda Region. The figure is briefly discussed at the end of the text. Lapillistone beds on left, breccia beds on right; size in mm, bed thickness in cm. Structure sequence types shown diagrammatically, with per cent frequency in each section indicated. P is the degree of significance. Modified from Tasse (1976).

section variations in bed thickness have been used for the analysis of facies in deep-sea fans (Mutti and Ricci Lucchi, 1972). In pyroclastic deposits clast size and volume of transported material (bed thickness) will be a function of explosion intensity. A sudden increase in size implies an increase in flow power, therefore a new flow (event). These explosions may vary in intensity through time, leading to up-section variations in the coarsest size. The variations occur at the same time in the deposit, although not at the same magnitude. The major variations will cluster around the vent, where the flow power is at its maximum, and sorting worst. Down flow, size decreases and the up-section variations may be less evident (Fig. 5). The result is a series of fining or coarsening-upward cycles that can be used in correlation. The technique was tried in the Noranda pyroclastics and with some success. One gets a clearer image when one treats the two bed populations of coarse sizes in different samples. The beds are very lenticular and bed-thickness data is the least reliable tool to interpret the paleogeography. In ash falls, bed thickness does seem to decrease away from vents, but for flows, as shown in Figure 1, the results are erratic (Yamada, 1973; Schmincke and Swanson, 1967).

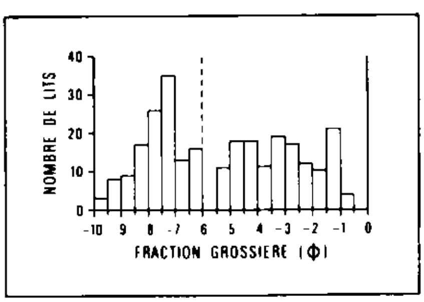

Figure 4
Distribution of coarsest grain size in the three eastern sections of Figure 3. Modified from Tasse (1976).

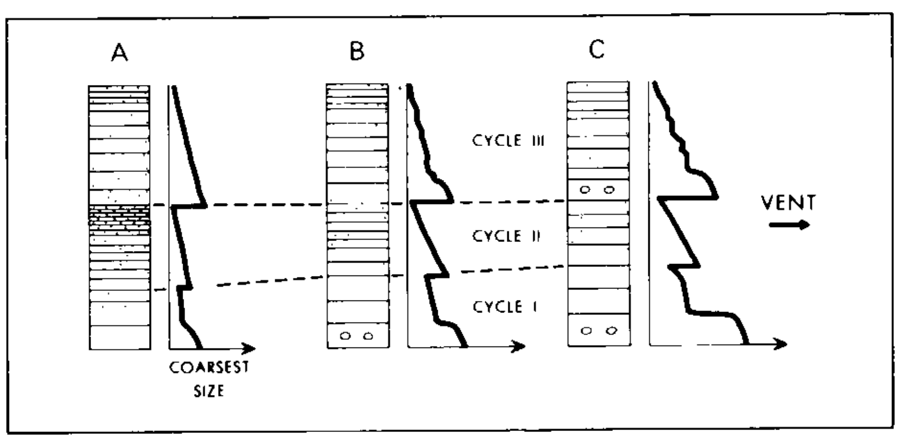

Figure 5
Hypothetical series (cycles) of fining-upward sequences, suggesting possible correlations of the volcaniclastic piles.

Conclusions

La granulométrie maximale est un outil important pour la cartographie des volcaniclastites et qui donne de meilleurs résultats que la taille moyenne. Le traitement statistique doit cependant être fait avec circonspection. Les variations latérales des séquences de structures syngénétiques nous furent très utiles dans une reconstruction paléogeographique. La variation de l'épaisseur des strates peut donner de bons résultats dans l'étude des retombées, mais elle est erratique dans le cas des coulées. La méthode présentée dans cet exposé n'est pas compliquée, mais complète. Lorsque tous les faits sont réunis, les variations latérales et verticales peuvent permettre la découverte de nouvelles cheminées.

Dans l'exemple utilisé en Figure 3, les sections aux deux extrémités W et E sont séparées par enviorn six km et les deux types de lits sont traités dans deux échantillons différents. Les données suggèrent une position relative de la cheminée entre les sections B et C avec des écoulements dans les directions W et E. Un traitement plus élaboré devrait être présenté sous peu.

En résumé, l'utilisation de principes élémentaires de sédimentologie nous a permis de comprendre un empilement de volcaniclastites et j'espère que l'exposé sera utile à ceux qui ont à faire face à des problèmes similaires.

Remerciements

Je ne voudrais pas donner l'impression que je suis responsable de toutes les données et lignes qui furent brièvement présentées à titre d'exemple. Les résultats obtenus dans cet exemple sont dus à un travail d'équipe formée de Normand Tassé, alors étudiant post-grade à l'Université de Montréal, d'Erich Dimroth, professeur à l'Université du Québec à Chicoutimi et de votre humble serviteur.

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