The Windsor esker, lying in the St. Francis River valley north of Sherbrooke, Quebec, has been the subject of recent detailed sedimentological study (McDonald, 1971; Banerjee and McDonald, in press). Numerous borrow pits along the 14-km length of the esker provide good exposure. The esker begins just south of a mass of serpentinized peridotite, and similar ultrabasic rocks outcrop a few kilometres southwest of the esker (Fig. 1). The location of the esker affords a good opportunity to compare ultrabasic dispersal patterns in glaciofluvial sediment to those for till derived from similar ultrabasic rocks in the Thetford Mines area (Shilts, 1973), 80 km northeast. In 1970 a study was made of the variation along the esker of lithologic composition of pebbles. This study has been complemented in 1974 by a study of the distribution of chromium, nickel, cobalt, copper, lead, zinc, and magnetic minerals in different size and mineralogical fractions and in different facies along the esker.

Geology

The Windsor Esker was deposited in contact with the Lennoxville glacier (McDonald and Shilts, 1971), the front of which retreated northward down the St. Francis River valley while standing in a deep (100 m ±) proglacial lake. The earliest ice flow recorded here was toward the west. In late Wisconsin time, ice flow near the glacier margin in the St. Francis Valley was generally towards 115 to 150 degrees (Fig. 1). Late-glacial perturbations are described by Lortie (see this publication, report 114) and Lamarche (1974).

The esker lies on or near bedrock throughout its length. Bedrock consists of quartzite, trachyte, and black slate (Cooke, 1950) except near the northern end of the esker where serpentinized peridotite outcrops.

Morphology and Sedimentology

Windsor Esker consists of three different morphologic types: a) between sites 0 and 10 there are 20 beads, and samples 0 to 15 are located mostly in beads that are 10 to 20 m high and about 285 m apart; b) samples 16 to 22 and 27 to 28 are located in a continuous steep-sided ridge, 10 to 20 m high; c) samples 23 to 26 are from a complex double ridge. Most exposures reveal a 1- to 2-m-thick capping of fine sand and silt that is interpreted as a zone of lacustrine or fluvial reworking. Sedimentology of the Windsor esker is discussed in detail by Banerjee and McDonald (in press). A wide variety of facies are present. Although the predominant grain size is sand, grain sizes of individual units vary from silt to coarse cobble gravel. Sedimentary structures vary from parallel lamination and parallel bedding to cross-lamination and large-scale crossbedding. Hundreds of paleocurrent measurements clearly indicate southeasterly flow of meltwater during all phases of esker deposition. The beads have been interpreted as subaqueous fans deposited during yearly stillstands of the ice front; the ridges are interpreted as having been deposited in subglacial tunnels.

Sampling and Analysis

Sand

Channel samples were collected from 34 sites in the crossbedded or ripple-laminated sand facies, each from fresh gravel pit exposures. In about half of the pits, additional samples were collected for comparison from other exposures of the same facies or from other facies. On Figure 1, each result is related to one of four facies types.

Samples were sieved to -64µ (-250 mesh). Magnetic grains in the fine and very fine sand fraction (64µ to 250µ) were separated by hand magnet from the methylene iodide heavy mineral fraction (SG > 3.3). Weight percentages for the magnetic fractions were calculated as a per cent of the total methylene iodide separate. The -64µ and the magnetic fractions were then digested in perchloric acid and analyzed for Cu, Pb, An, Cr, Ni, and Co by atomic absorption techniques.

Pebbles

Samples of 100 pebbles each were collected from 25 sites along the esker. At several sites additional samples were collected to study 'within-site variation' in pebble composition. Pebbles sampled varied from 2 to 5 cm intermediate diameter. Samples were taken from particular facies, and the pebbles were identified in the field.

Discussion

Figure 1 summarizes the concentrations noted for the most important ultrabasic components. Where more than one sample has been collected from a pit, the data show considerable variation. In pits 18, 21, and 25, for example, Ni is almost as variable among the various facies in the pit as it is from one end of the esker to the other. The magnetic fraction shows similar variation in pit 4. Chromium and nickel values for the magnetic fraction are extremely variable in some pits (21) but very close together in others (4). Compared to similar analyses of many hundreds of till samples from the Thetford Mines area, the esker analyses are quite variable and give little hint of a dispersal pattern. This variability is presently attributed to primary depositional factors in the esker (such as the differing hydraulic behaviour of mineral grains of highly variable specific
Figure 1. Windsor esker, showing distribution of ultrabasic pebbles, magnetite, Ni, and Cr. Meltwater flow in the esker stream was southeastward.
Table 1

Trace element concentrations (ppm) in -64μ (-250 mesh) portions of esker samples

<table>
<thead>
<tr>
<th>Locality Number</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ni</th>
<th>Co</th>
<th>Cr</th>
<th>Facies</th>
</tr>
</thead>
<tbody>
<tr>
<td>210</td>
<td>100</td>
<td>78</td>
<td>174</td>
<td>78</td>
<td>42</td>
<td>62</td>
<td>fine, ripple-laminated sand</td>
</tr>
<tr>
<td>8</td>
<td>190</td>
<td>117</td>
<td>240</td>
<td>191</td>
<td>62</td>
<td>76</td>
<td>coarse, pebbly sand</td>
</tr>
<tr>
<td>18</td>
<td>281</td>
<td>184</td>
<td>230</td>
<td>277</td>
<td>84</td>
<td>84</td>
<td>coarse, pebbly sand</td>
</tr>
<tr>
<td>21</td>
<td>190</td>
<td>115</td>
<td>169</td>
<td>269</td>
<td>48</td>
<td>73</td>
<td>coarse, pebbly sand</td>
</tr>
<tr>
<td>22</td>
<td>190</td>
<td>139</td>
<td>128</td>
<td>284</td>
<td>79</td>
<td>76</td>
<td>coarse, pebbly sand</td>
</tr>
<tr>
<td>25 (A)</td>
<td>94</td>
<td>79</td>
<td>100</td>
<td>174</td>
<td>34</td>
<td>67</td>
<td>coarse, pebbly sand</td>
</tr>
<tr>
<td>25 (B)</td>
<td>104</td>
<td>74</td>
<td>135</td>
<td>146</td>
<td>42</td>
<td>78</td>
<td>fine, ripple-laminated sand</td>
</tr>
</tbody>
</table>

Mean value for esker (exclusive of samples above) N = 44

Range for esker (exclusive of samples above) N = 44

<table>
<thead>
<tr>
<th></th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ni</th>
<th>Co</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22</td>
<td>37</td>
<td>65</td>
<td>69</td>
<td>26</td>
<td>57</td>
</tr>
<tr>
<td>6-72</td>
<td>27-70</td>
<td>40-112</td>
<td>24-250</td>
<td>16-46</td>
<td>26-156</td>
<td></td>
</tr>
</tbody>
</table>

In pits 0, 01, 8, and 19 to 27 ultrabasic pebbles and other ultrabasic components appear to be high. The ultrabasic components at pits 6 and 01 probably are derived from glacial or glaciofluvial erosion of the main ultrabasic mass at the north end of the esker. There, fluvial transport does not seem to have been more than a few kilometres. The origin of the sporadic but relatively high values at pit 8 is unknown. High values in pits 19 to 27 probably are related to glacial transport southeastward from the second ultrabasic outcrop west of the esker (Fig. 1). A train of ultrabasic debris, similar to that outlined in the Thetford Mines area (Shilts, 1973), probably existed in the basal and englacial load of the Lennoxville glacier at the time of formation of the esker and was intercepted by the esker stream. The esker probably derived much of its sediment from debris in the basal portion of the glacier or from underlying till.

In order to use compositional variations in esker sediments as an indication of bedrock composition in areas where bedrock outcrops are sparse, it would be of interest to know the distance back from the terminus of an active glacier that the escaping meltwater was localized in basal tunnels. The length and time-transgressive character of most eskers indicates that subglacial tunnels extend themselves headward as the ice-front recedes, so the length of the esker per se is no guide to this problem. The combination of known bedrock distribution near the Windsor esker and compositional variations within the esker (Fig. 2) can be used to obtain a crude answer to this problem, and this might assist in understanding the problem elsewhere. The following simplifying assumptions could be made:

(a) All esker sediment is derived from erosion of underlying material, and the concentration of a particular material in the esker is directly proportional to the length of esker stream located over the source of that material;

(b) Deposition of esker sediments takes place primarily at the ice front (this must be verified first by field study; in the case of the Windsor esker, beads give this indication); and

(c) The esker stream extends headward at the rate of ice-front retreat, i.e. the length of the esker stream remains constant.
Figure 2. Distribution of pebble lithologies relative to bedrock outcrop along Windsor esker. (Circles with dots at three locations show pebble compositions in till adjacent to the esker.)
The question of the nature of the underlying source material is an important one; if glacial sediments are thin, then this material is probably bedrock; if glacial sediments are thick, then the underlying material could be till and a compositional peak in the esker could reflect the existence of a glacial train in this till. Thus the nature of this source, or "target", will have to be determined. The portion of the Windsor esker that best satisfies assumption (b), while traversing an area of thin drift, is that part of the esker upstream (northwest) of locality 15.

It follows from the above assumptions that the shape of the concentration curve in the esker is a function of the length of the esker stream relative to the width of the outcrop. Three cases are possible:

(a) Esker stream longer than outcrop width:
This generates a broad peak that reaches a maximum at the downstream edge of the outcrop belt and maintains that maximum for some distance downstream from the outcrop belt;

(b) Esker stream same length as outcrop width:
This generates a relatively sharp peak at the downstream end of the outcrop belt; and

(c) Esker stream shorter than outcrop width:
This leads to a broad peak over the downstream portion of the outcrop belt.

Turning to Figure 2, it is possible to examine the distribution of trachyte and black slate upstream from locality 15 in terms of this admittedly crude model, as the esker stream completely traversed relatively well known outcrop widths of these rocks. In the case of black slate, the esker stream crossed an outcrop width of 3 km between localities 1 and 10. A sharp peak is visible at locality 9, near the downstream edge of the outcrop belt. This would appear to fit case (b), above, and leads to a suggested length of 2.5 to 3.5 km for the esker stream. In the case of trachyte, the esker stream crossed an outcrop width of 1.5 km near locality 1. A broad, multiple peak may be present, the downstream edge of which is at locality 7. This configuration appears to fit case (a), above, where the distance from the upstream limit of the trachyte outcrop to the downstream edge of the peak is 3.5 to 5 km. On the basis of these two cases it can be suggested that the esker stream was 3 to 4 km in length. These suggestions must be regarded as extremely tenuous in view of within-site variation, the spacing between sample sites, and the apparent inability of the model to explain the peak in peridotite pebbles at locality 8.

Conclusions

1. Hydraulic sorting and considerable lateral and vertical variation of depositional environments greatly complicate the study of dispersal of trace elements and clasts in an esker.

2. In the Windsor esker, downstream fluvial transport apparently is restricted to between 3 and 4 km.

3. Some relatively high concentrations of ultrabasic components probably are related to erosion, by the esker stream, of a glacial train derived in turn from ultrabasic outcrops occurring some distance laterally from the esker.

4. Some high nickel values may be related to base-metal mineralization in slates or trachytes rather than to silicate nickel typical of the ultrabasic rocks.

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