Application of Fuzzy Clustering and Fuzzy Classification to Evaluate the Provenance of Glacial Till

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To evaluate the provenance of glacial till, the trace element content of magnetite was used. Magnetite was present in all known rock types and all till samples in the area investigated. By using fuzzy-set theory it was possible to group samples of magnetite taken from bedrock into relatively homogeneous and geologically meaningful groups and also, by fuzzy classification, to relate the till samples to the rocks in such a way that the relative contribution of each rock type to the till is estimated. Each rock and till sample is assigned a membership value between 0 and 1 for each rock type. The membership values, for a certain rock type in the till, are then interpolated by kriging onto maps. Magnetites from skarns associated with sulfide ores especially are rather distinct, and so a map of such membership values for till unveils all known ore deposits some 1-5 km “downstream” in the general direction of the ice flow. Other anomalies show up which cannot be related to hitherto known ores or mineralizations.

KEY WORDS: Bayesian classifiers, classification, cluster analysis, cluster validity, fuzzy c means, fuzzy c varieties, fuzzy covariances, geochemical prospecting, glacial till, kriging.

INTRODUCTION

Glacial till has long been used for prospecting, but problems often arise with the methods used. If one tries to quantitatively connect the till to its source rocks the difficulties become considerable since the different mineral grains are selectively weathered, chemically and mechanically, during the course of transport and by time, which leads to a severely distorted picture of the source rocks when, for instance, heavy minerals of till are evaluated.

An attractive method, therefore, would be to analyze the trace element content of some reasonably resistant and abundant mineral which is present in all rock types and till samples in the area under study. The mineral in ques-

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tion should also possess characteristic trace element assemblages for each different parent rock. In this investigation magnetite was used as such a trace mineral for provenance studies. Although other minerals like ilmenite (Parfenoff, 1982) and pyrite (Roberts, 1982) theoretically could have been used, magnetite was chosen due to its universal abundance.

Magnetite has been used in the past as a prospecting medium (Theobald and Thompson, 1962; Theobald, Overstreet, and Thompson, 1967) since it is one of the easiest minerals to separate into a pure fraction and to analyze. But, probably due to difficulties in discriminating between different types of magnetite by classical multivariate methods, its use has been limited.

**DESCRIPTION OF STUDY AREA AND DATA**

The area of just over 1000 km$^2$ is situated N-NW of Falun in Central Sweden. The bedrock consists of older and younger Svecofennian granites, younger Svecofennian migmatites and gneisses and, oldest of them all, the so-called leptite formation consisting of metavolcanics and metasediments. There are also several diorites and gabbros in the area, which stratigraphically belong to the older Svecofennian granite group. The numerous sulfide ores and mineralizations in the area are mostly included in the leptite formation.

The Quaternary features in the area are generally quite straightforward and common glacial till is almost universally present. The general direction of glacial transport for the common till is from about N-NW. An older, fine-grained till, with a more westerly origin, also exists at some places (Eriksson, 1977). Its extent is not known at present, but it is suspected that it might underlie the common till over considerable parts of the area, and thus have contributed to some of the magnetite in the common till.

From the different rock types present, 105 typical bedrock samples were collected and 262 samples were taken from the common till under the c horizon.

The bedrock samples are geographically somewhat unevenly distributed ($R = 0.88$) due to the irregular distribution of outcrops, but the till samples are fairly evenly dispersed ($R = 1.24$), and only minor areas covered by lakes and glaciofluvial sediments were left unsampled. The value $R$ stands for the proportion of the observed mean distance to the expected mean distance between the samples. The larger the $R$ value, the more evenly dispersed the samples (Ripley, 1981).

The magnetites, from bedrock and till, were concentrated by means of separation in tetrabromoethane and the heavy fraction was separated with a hand magnet, finely ground, and then repeatedly separated with a hand magnet again, to obtain as pure a fraction as possible. It was then dissolved in diluted cold HCl, leaving impurities such as ilmenite, hematite, and silicates undissolved.