Rock quality designation and drilling rate correlated with lithology and degree of alteration in volcanic rocks from the 1979 Surtsey drill hole

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ABSTRACT

The Surtsey hyaloclastite was examined to see if geotechnical parameters depend on lithology. Measurements of rock quality designation (RQD) and rate of drilling are compared to degree of alteration, lithology and porosity. The RQD correlates well to alteration. It is shown how this result can contribute to the interpretation of the alteration process in Surtsey. Although drilling rate depends on many factors the main features may be explained by lithological and porosity differences. Results of density and porosity measurements on 22 core samples and 2 samples of incoherent tephra are presented together with quantiative determinations of the authigenic calcite content.

INTRODUCTION

In the course of research project in engineering geology including petrographical influence on rock strength and other geotechnical parameters, the author was able to obtain rock cores from a drilling investigation in Surtsey. Since the main part of this work is restricted to Icelandic volcanics in subaquatic facies, the availability of cores of similiar rocks from the Surtsey drill hole is used to extend the investigation over a wider range of petrological types.

One of the most obvious but rather surprising features of the Surtsey core is the mechanical consistency of what was originally loose hyaloclastic material. This is believed to be a result of a still active alteration process known as palagonitization (Jakobsson 1972, 1978). The rocks are monogenetic and known to have originated from the tephra eruption in Surtsey during November 1963 through March 1964. The variable degree of alteration together with variations in primary lithology must influence geotechnical parameters and it seemed worthwhile to study this relationship as it seemed likely that it has some practical value.

As a first attempt to examine this problem for the core as a whole, rock quality designation (abbr. RQD) and drilling rate are appropriate. The porosity was also evaluated during preparation for rock mechanics experiments. The results should be regarded as an extension to the drill log described in this volume (Jakobsson & Moore 1982) and are published here as they may be of interest to other scientists working on the palagonitization process.

METHODS

The RQD was introduced by Deere for the purpose of increasing information on in situ rock properties from boreholes (Deere 1968, Deere et al. 1969). It is defined as a percentage of core bits longer than 10 centimeters in the total well length in some specific part of a borehole. In other words this can be calculated from the core recovery by deleting all cores shorter than 10 centimeters. Clearly this parameter can only be a limited measure of rock quality, but it does give some idea of joint frequency and rock hardness. To reach a more realistic idea of the properties of rock mass more advanced methods including other important features have been developed (e.g. Barton et al. 1974). Since these methods are often based on RQD it is often preferred over other measures of joint frequency and has become a routine technique in geotechnical core logging. The measurement of RQD for this paper is according to the above definition.

Drilling rate is defined as a rate of advance of the core bit during drilling (Moore 1963). It is usually expressed as the time required to drill a certain standard length of a hole, or as prefered here as the real velocity of the drill hole advance. Several factors of different origin may affect drilling rate. Some of these relate to properties of the rocks encountered, others depend on mechanical factors of the drilling process and human ability and endeavor (Wirth GmbH 1979). Only in controlled and reproduceable conditions can it therefore be a measure of absolute hardness or abrasivity.

Observation of drilling rate is especially useful in rotary drilling as it is the first encountered data which is available even while boring before the hole is completed. Another advantage of this technique is that the log can be recorded over the entire length of the well as other methods of data logging e.g. some geophysical procedures may be incomplete or unfeasible.

In Surtsey the drilling rate was measured with a stop clock and all breaks caused by technical problems were noted and eliminated from the effective drilling time (National Energy Authority, drilling report, geological observations, Surtsey I, 1979).

Lithology and degree of alteration were used a basis of comparison (Jakobsson and Moore 1982). They used the thickness of the palagonite rim in large grains of sideromelan and the alteration rim on olivine phenocrysts as determined under the microscope as a value of alteration. According to this definition the alteration grade does not necessarily need to be identical with the state of rock hardness.

Porosity and alteration are often interconnected and in fact porosity may govern the process of alteration (Furnes 1974, Jakobsson 1978). Porosity of rocks was measured according to DIN 52102 (Deutsche Normen, 1965). This is based on measure of volume from core dimensions (length = 2 x diameter), dry core weight and specific density of pulverised rock determined in a pyknometer. The densities of incoherent materials sampled for soil mechanics testing were measured in situ by sand cone method (ASTM standards 1976).

It should be emphasized that all porosities mentioned here are total porosities, containing both intergranular porosities and vesicles within individual grains. As yet no attempt has been made to evaluate the proportions of initial porosity attributable to overburden load consolidation and authigenic minerals precipitating during palagonitization.

RESULTS AND DISCUSSION

In Fig. 1 RQD and drilling rate are compared with lithology and degree of alteration. The RQD was measured at 3 meter intervals. The drilling rate was also calculated over the same well lengths, although in some shifts where drilling was interrupted by technical problems shorter lengths were employed. Drilling sections where measurements were inobtainable are indicated by gaps in the drilling rate curve. In the analysis of the data it was found that 6 meter intervals could be used for the graphical representation without loosing the main information.

Figure 1 shows that RQD correlates with alteration grade, as RQD is usually high where palagonite rims are thick. This correlation is further emphasized in the lithology log. The low values between 72 and 84 meters are not only due to somewhat highly jointed basaltic dikes but also to the development of irregular contacts and to the rather loose nature of the hyaloclastite in this section. Extremely low values towards the bottom of the hole are due to two thick sections consisting nearly entirely of incoherent tephra.

TABLE I.

Dry density, specific density and total porosity of the Surtsey hyaloclastite.

Sample no	Depth (m)	Dry density (g/cm 3)	Specific density (g/cm 3)	Porosity (%)
1	4.2	1.39 ±0.02	2.78 ±0.01	49.9 ±0.5
3	8.2	1.46	2.78	47.4
5	12.1	1.49	2.79	46.8
7	19.0	1.39	2.77	50.0
8	21.0	1.61	2.78	42.2
10	24.9	1.39	2.78	50.1
12	33.4	1.66	2.78	40.3
14	41.1	1.51	2.80	46.0
15	52.1	1.52	2.79	45.7
20	58.2	1.54	2.78	44.6
22	68.3	1.55	2.77	43.9
25*	74.0	2.82	3.08	8.5
26*	77.6	2.81	3.08	8.8
27	88.3	1.59	2.78	42.6
30	98.0	1.73	2.77	37.5
33	108.7	1.71	2.76	38.0
34	110.5	1.68	2.76	39.2
35	125.3	1.88	2.77	32.2
37	132.7	1.75	2.78	37.0
38	147.5	1.74	2.79	37.8
40	150.0	1.52	2.78	45.2
43	155.3	1.89	2.77	31.9
SB 1**		1.4 ±0.05	2.84	49.5 ±1.0
SB 2**		1.5	2.85	46.8

* Basaltic dike.

** Measurements made on incoherent hyaloclastite in natural openings.

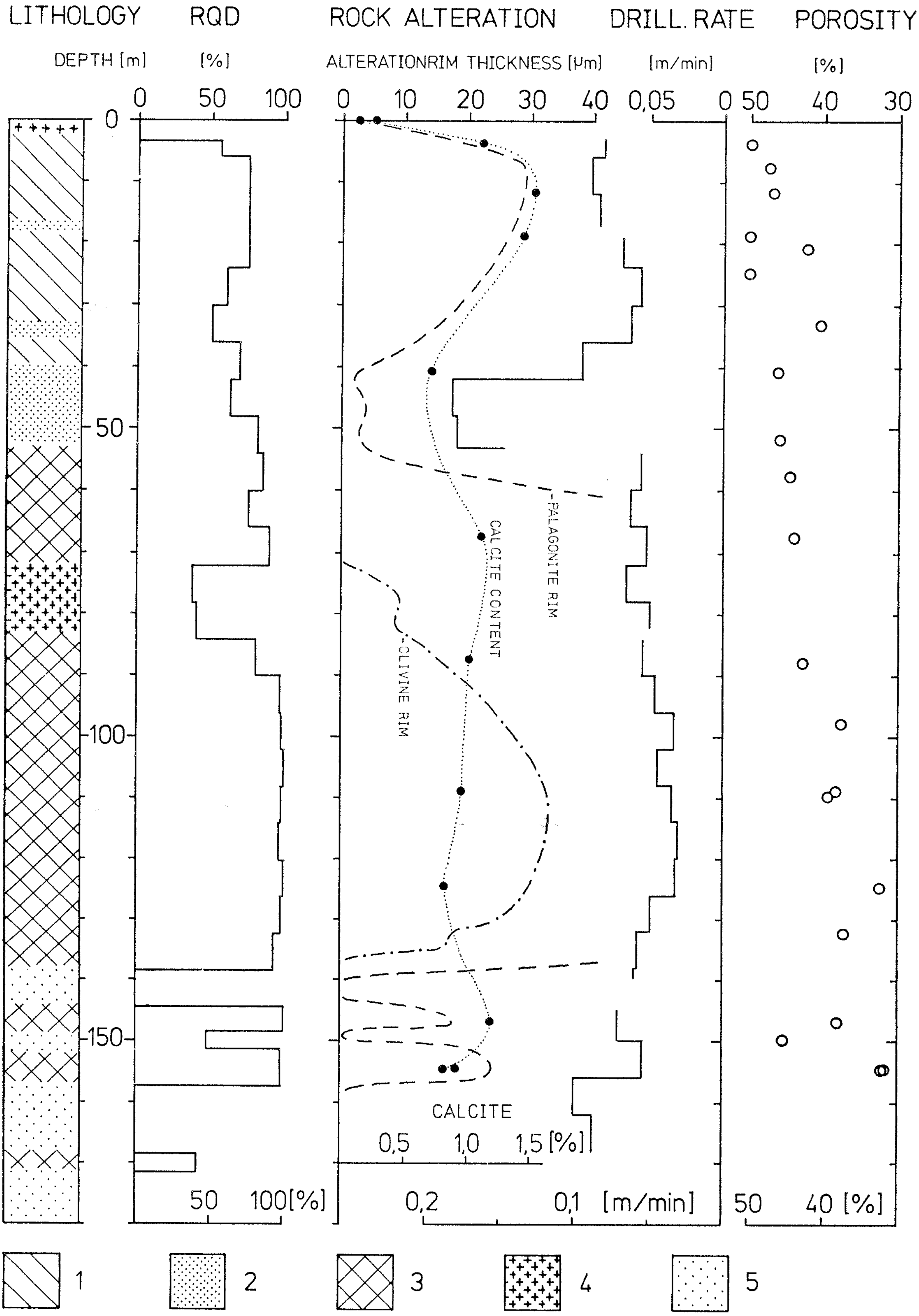

Fig. 1. Lithology and alteration rim curves, average values, pers. comm. Jakobsson and Moore, 1982. Explanation to lithology: 1) brown-black, poorly altered hyalocastite. 2) black, coarse and poorly graded hyaloclastite. 3) grayish-green sound hyaloclastite. 4) basaltic dikes and lava flow at top. 5) incoherent tephra.

The significance of these conclusions is further strengthened by the fact that the different measurements were made by different investigators, eliminating observational subjectivity.

As low RQD value correlates with either highly jointed rock or the presence of incoherent rock material such as the hyaloclastite initially was at the time of deposition, it can be concluded that the material was subsequently cemented and that discontinuities are healed during alteration processes. The hardening effect seems at least to some extent to be caused by growth of authigenic minerals during palagonitization. The non-linearity of changes of RQD with alteration indicates implicitly that the alteration system is in a part open as chemical constitutents of authigenic minerals may move within the rock mass prior to precipitation. This deduction is in good agreement with Jakobsson's theory of an alteration mechanism whereby cold seawater seeps under the island where it becomes heated and move upwards through the overlying rocks (Jakobsson 1978 and Jakobsson & Moore 1982). It is clear that petrographical examination could provide a solution to this problem. First results of high accuracy coulometric measurements of the amount of authigenic calcite (method described by Sixta 1977) show this feature directly (see Fig. 1).

The drilling rate curve shows one main peak in the upper part and another less obvious peak further down (Fig. 1). A comparision of drilling rate with palagonite thickness does not reveal obvious relationship of the details. The drilling rate peaks correlate however very closely with lithology and the curve also seems to follow the porosity trend. The main peak coincides with a rather coarse and poorly graded hyaloclastite which, in spite of the presence of large intergranular voids, has not an abnormally high porosity (see also Table I). The second high drilling rate section is most probably related to incoherent sand and tephra. It is though emphasized that there are many unkown mechanical factors which influence drilling rate in addition to lithology and porosity differences.

In the section of sound basalt an expected negative drilling rate anomaly was not found. This was probably caused by a compensation effect arising from the presence of rather incoherent and porous hyaloclastite of low alteration grade at the contacts of dykes which were thinner than the interval chosen to record the rate. It seems likely that a mechanical drilling time recorder would have greatly improved the reliability of the results.

Direct comparision of RQD with drilling rate is not suggested. High drilling rates can be caused by low RQD only in very fissile or incoherent rocks.

The results of this paper suggest that the more advanced rock mechanic experiments will add useful information on how rock hardening is related to palagonitization. Work is continuing along these lines and the author hopes to present more detail on this in a later paper.

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