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Isotopic dating of samples from Shallow Drilling Bjørnøya West 1989. Supplementary studies.

REPORT NO.: 21.3409.04/01/90

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Isotopic datings by Robert A. Duncan

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Institutt for kontinentalsokkelundersøkelser og petroleumsteknologi A/S
Continental Shelf and Petroleum Technology Research Institute

S.P. Andersen veg 15 b * N-7034 Trondheim, Norway
Tel.: + 47 7 591100 * Telex: 55 434 iku n * Telefax: + 47 7 591102 (aut.)

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SUMMARY:

Volcanic debris from core 7316/03-U-01 has been dated isotopically in order to determine the age of deposition. K-Ar dates for five samples give an unrealistic age spread (Bugge et al. 1990) which has been tested in this study by an independant method. $^{40}Ar/^{39}Ar$ dating of two of the samples suggests that the apparent age variation is due to the presence of variable amounts of excess argon in the samples, and that the youngest of the dates are closest to the age of the volcanics. The results are discussed in relation to petrographic features and environment of deposition.

See abstract on page 2.

KEY WORDS:

K-Ar dating	Basaltic glass
$^{40}Ar/^{39}Ar$ dating	Sediment depositional age
Cenozoic volcanism	Debris flow deposits

Skjnnes

ABSTRACT

Core 7316/03-U-01 is characterized by frequent occurrence of excellently preserved glassy volcanic material of relatively uniform basaltic composition. Five samples of lapilli and block sized clasts were dated with the K-Ar method. This resulted in a total spread between 2.3 and 10.2 Ma (Bugge et al. 1990). However, for petrological and geological reasons this age difference was not believed to be real. In order to examine the possible presence of excess argon, two of the samples with different ages have been redated with the Ar-Ar incremental heating method.

The resulting Ar-Ar plateau and isochron dates are similar for the two samples (2.2 - 2.4 Ma). The sample with an old K-Ar date (7.4 Ma) showed the presence of excess "old" argon in the low temperature incremental heating fractions. This suggests that the older K-Ar ages are due to mixing with different amounts of excess argon, and that the 2.2 - 2.4 Ma age is closest to the cooling age of the volcanics. The possiblity of different degrees of excess argon retention in the samples is supported by petrographic observations of the basalt matrix/glass relations; preservation of excess argon being favoured in rapidly chilled glass at subaquatic or subglacial conditions.

Redeposition of the volcanic material by rapid transport mechanisms (debris flows, gravity currents) appeared shortly after the eruption. Dating of the volcanics therefore also gives an absolute age for the deposition of the sediments. The new data suggest that the sediments were deposited in the Pliocene and thus that even the Miocene fossils have been reworked and redeposited.

INTRODUCTION

IKU's Shallow Drilling Bjørnøya West 1989 (Bugge et al. 1990) included four cores that were drilled in the Cenozoic rocks below the clastic wedge southwest of Bjørnøya. Biostratigraphic datings give ages from Paleogene to Miocene with a major hiatus from Late Eocene / earliest Oligocene to early Miocene. The appearance of well preserved volcanic material in the youngest core (7316/03-U-01) has made it possible to use conventional isotopic dating methods to determine absolute ages for the volcanics. In the general case the crystallization or cooling age for volcanic clasts give a maximum age for the deposition of the sediment. In the present case the volcanic material is thought to have erupted shortly before or simultaneously with the deposition of the wedge. Dating of the volcanics therefore gives a possibility to date the deposition of the sediments.

During the main project (Shallow drilling Bjørnøya West 1989; Bugge et al. 1990) five samples of volcanics were selected for K-Ar dating. This resulted in surprisingly young (Late Tertiary) ages which stimulated more detailed reexamination of the core, and some fossil material of Miocene age was detected. However, due to the spread in the K-Ar age data it was decided to test some of these by an independent dating method, and two of the dated samples were selected for Ar-Ar dating. The results from both methods are reported here.

GEOLOGICAL BACKGROUND AND SUITABILITY OF SAMPLES

Geological descriptions and interpretations were given in the Main Report (Bugge et al. 1990) and only a brief summary is given here.

Core 7316/03-U-03 has been divided into six subunits (A-E). Volcanic material occurs at ca. 20 different intervals in the core between 154 m and 32 m within subunits B, D and F (Fig. 1a). The volcanic material consists of ash, lapilli and a few block sized fragments, all of similar basaltic composition. The sediment - volcanics associations are interpreted as debris flow and turbidity current deposits. The volcanic material is thought to represent phreatomagmatic volcanism by the presence of eruption products of subaquatic and of subaerial origin. The possibility of eruption under ice has also been introduced. The interpretation of rapid chilling of the erupting magma under water, wet sediments and/or ice is utterly enhanced by the present study. However, the high vesicularity of some clasts cannot totally exclude that some of the eruption products formed subaerially.

Detailed petrographic, chemical and isotopical analyses of the volcanic material has been performed in order to examine if it represents petrological different types or if all belong to a single volcanic system. This is essential for interpretation of the isotopic dates. Samples from 18 different levels throughout the core have been analysed for major elements (137 electron microprobe glass analyses and 2 XRF whole-rock analyses).

It has been concluded that the volcanics all belong to the same volcanic system and possibly also to the same eruption, on the basis of the following observations:

1) Ash and lapilli clasts have similar chemical composition all showing olivine basaltic composition with relatively high contents of SiO_2 (ca.51%), Na_2O (ca.3.5%) and K_2O (ca.0.9%)(Table 3.4.5; Bugge et al. 1990).

2) There is no variation in petrography and chemistry of the volcanics with core depth, but different developments of grading with respect to size, orientation and density is seen in different debris flows.

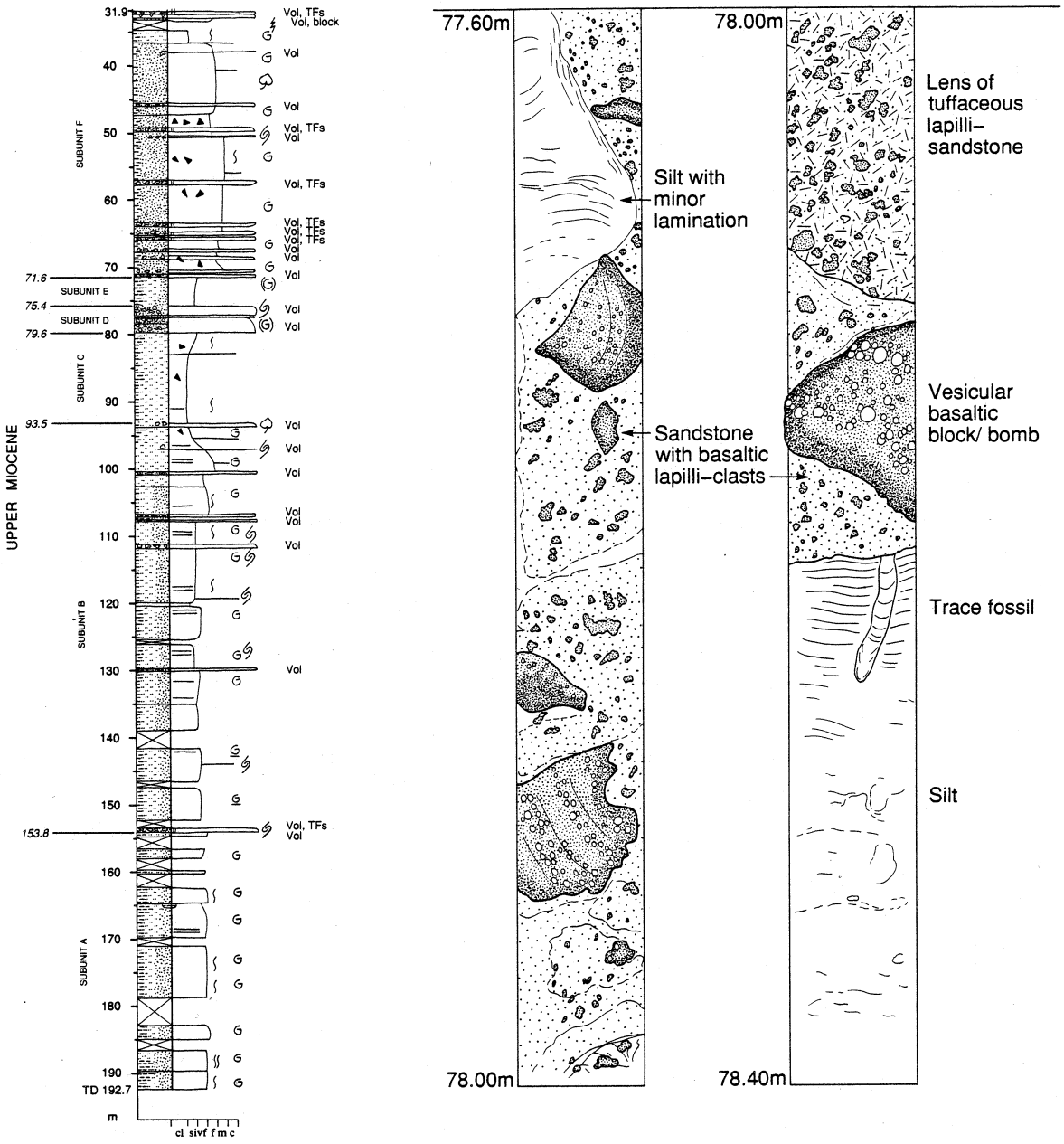


Figure 1

a) Sedimentological log for core 7316/03-U-01 showing the occurrence of layers with volcanic debris (VOL).

b) Details of the core between 77.60m and 78.40m showing the appearance of lapilli sized and block sized basaltic clasts. From Bugge et al. (1990).

3) Olivine phenocrysts have similar composition and appearances in microcrystalline massive blocks and homogeneous glass fragments (ash), and with no distinct chemical variation throughout the core.

4) Sm-Nd isotopic ratios are similar for a massive basaltic block and for carefully separated homogeneous glass fragments.

From this a similar age for the volcanic fragments is to be expected, and the volcanics are thus suitable for timing of the sediment deposition. However, the applicability is also depending on the degree of preservation from secondary alteration.

In general, the volcanics in this core have been excellently preserved. Ash and lapilli show homogeneous pale brown and darker brown glasses with minor contents of olivine phenocrysts, while the more massive blocks of lava show presence of submicroscopic plagioclase microlites and very minute clinopyroxene in a darker glassy matrix. A dark colouring of glass appears in the largest lapilli clasts as well as in the matrix of the blocks. Secondary minerals are absent, except for some consolidated zones with opal and minor appearances of calcite in vesicules in some horizons. Absence of hydration of the glasses is supported by the general high sums in the quantitative chemical glass analyses and by the low content of H_2O (L.O.I.) for two whole-rock samples (Table 3.4.5, Bugge et al. 1990). Comparison of the mean values of K_2O for light brown, dark brown and black oxidised glasses also supports that the observed darkening of colour was not associated with secondary supply of potassium.

It is also of importance that the samples have never been subjected to elevated diagenetic temperatures and that the core has been situated at a shallow level in an arctic climate, locally sealed from percolating waters by clay horizons and opal cemented parts. These are factors that inhibit diffusion disturbances of the isotopic compositions within minerals, glass and sealed pores.

K-AR AND AR-AR DATING METHODS

The K-Ar method has been the common method for dating of volcanic rocks through the last decades. It is based on the decay of naturally occurring ^{40}K to stable ^{40}Ar; $t = \lambda^{-1} \ln ((^{40}Ar^*/^{40}K)(\lambda/\lambda_e) + 1)$ where the age may be

calculated from the measured amount of potassium and the amount of radiogenic argon that has accumulated in a K-bearing sample (λ_e = decay constant of ^{40}K to ^{40}Ar = 0.581 x 10^{-10} and λ is the total decay constant for ^{40}K = 5.543 x 10^{-10}). The equation gives the age of a sample if several analytical and geological assumptions are satisfied (Faure 1986). Important geological assumptions are that radiogenic argon was not present in the sample before the crystallization or the closing event we want to date and that the system has been closed to Ar and K during the time t.

Experience with dating of volcanic rocks has shown that the argon retentivity of anhydrous volcanic glass is fairly good, while the Ar retentivity of devitrified glass and of secondary alteration products is questionable. Secondary alteration of glasses results in a lowering of K-Ar dates. By contrast, the presence of excess radiogenic argon in glasses or xenocrysts will increase the calculated K-Ar age. Excess argon is crust or mantle derived argon dissolved in the magma before the closure of the system for isotopic equilibration during cooling. When the basaltic magma is ascending from deeper levels of crust or mantle towards the earth's surface, the solubility of the gas in the melt phase decreases due to the decreasing pressure. This leads to vesiculation and gas release during eruption. At surface pressure the mantle argon content outgasses completely, but in plutonic rocks and in basalts that are extruded on the ocean floor excess Ar in solution in the magma can be trapped due to high hydrostatic pressure and rapid cooling. Studies of ocean floor pillow lavas have shown a decrease in the amount of excess radiogenic argon from the glassy rind of the pillow to the holocrystalline pillow centres. In the latter more slowly cooled parts the excess radiogenic argon had time to escape during cooling (Seidemann 1978, Faure 1986). The presence of trapped argon is common in the chilled glassy rims of pillow basalts erupted at greater depths than 1500 m below sea-level (Dalrymple & Moe 1968). Another environment that lead to the formation of glass by very rapid chilling is by subglacial eruption. Thus trapping of gas within vesicules or glass may result from rapid quenching of magma in contact with water or ice. However, to the author's knowledge the behaviour of argon in subglacially erupted basalt has not been studied in the litterature.

The Ar-Ar method is based on artificial irradiation of the K-bearing sample with thermal and fast neutrons in a nuclear reactor to produce $^{39}_{18}Ar$ from $^{39}_{19}K$ and age calculation on the basis of the measured $^{40*}Ar/^{39}Ar$-ratio; $t = (1/\lambda)\ln((^{40}Ar^*/^{39}Ar)J + 1)$ where λ is the total decay constant for K.

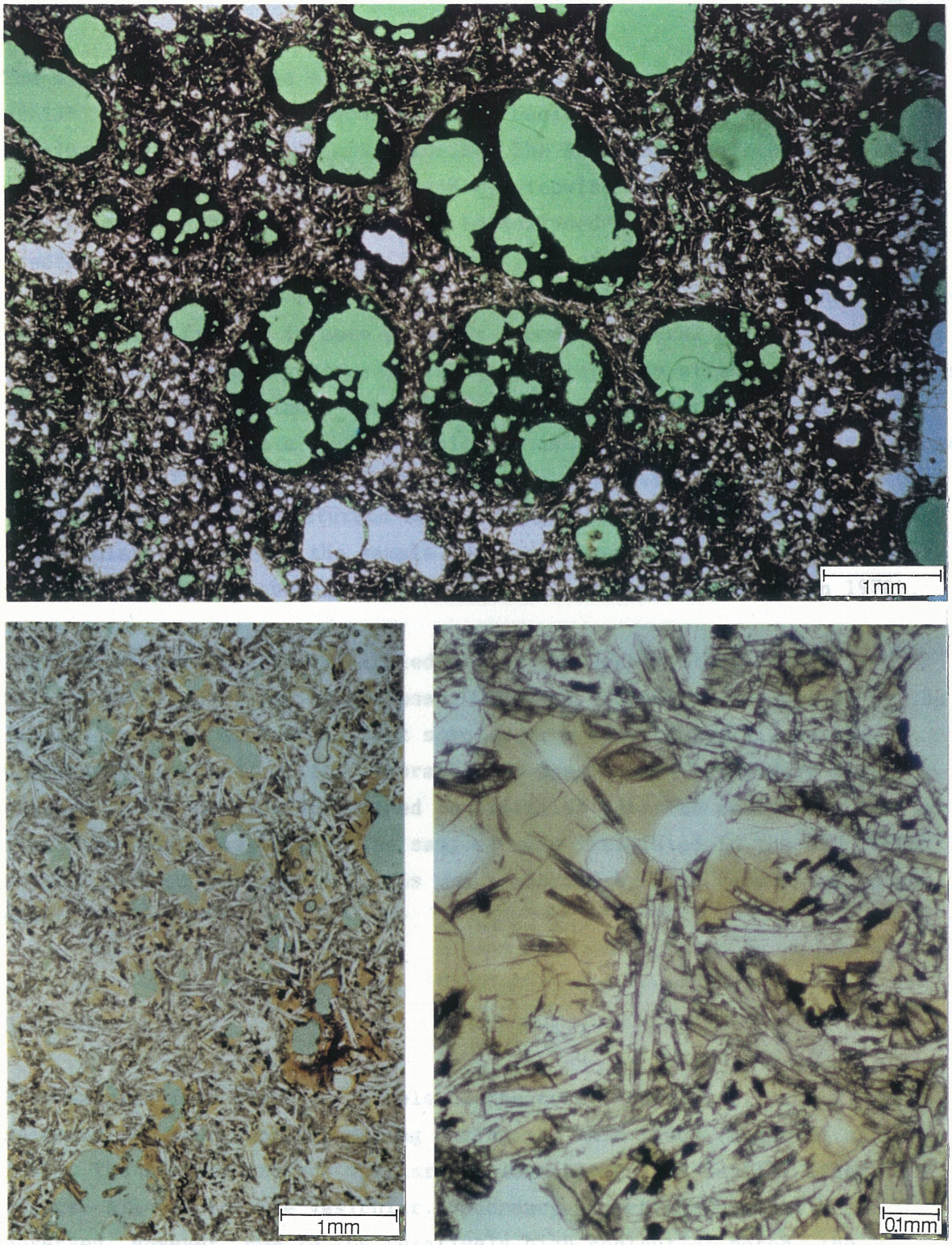


Figure 2

a) Photomicrograph of basaltic lava at 32.05m (parallel polars) showing microphenocrysts of olivine and very thin plagioclase microlites (white) in a dark glassy matrix. Note the appearance of a homogeneous glassy rind around the vesicules and of smaller pores within the larger (pores are coloured by green epoxy. Excess argon may have been trapped within the micropores and glassy rinds.

b) Photomicrograph of basaltic lava with high content of well developed microphnocrysts at 77.70m (parallel polars), dominated by plagioclase microlites (white).

c) Close up of (b) showing plagioclase laths and clinopyroxene within a glassy matrix. Note the frequent appearance of cracks within the pale brown glassy matrix. The absence of excess argon within this sample as compared to sample 32.05m may be caused by Ar-escape related to the more extensive crystal growth during eruption and the formation of microcracks during the rapid cooling of the glass.

The method requires the use of a flux monitor of known age for calculation of "J" and corrections for interfering nuclear reactions with isotopes of calcium, potassium, argon and chlorine. The Ar-Ar dating technique has the adventage that argon can be released by stepwise heating of the irradiated samples, and each fraction can then be analysed isotopically. This gives a spectrum of ages relating to different cites of Ar-incorporation in the sample. Loosely incorporated Ar is released at low temperature and may thus be eliminated from Ar in more strongly bound structural cites (intragranular or homogeneously distributed in glass structure). This gives a possibility to eliminate secondary disturbances. Ar released at high temperatures may form a plateau, which in ideal cases can give a date close to the crystallization age. In addition, the measured $^{40}Ar/^{36}Ar$ and $^{39}Ar/^{36}Ar$ ratios of undisturbed samples define isochrons which can be used to calculate the age of the sample. However, when excess argon is present, "isochrons" with erraneously high ages may be obtained (Seidemann 1978).

The isotopic analyses were carried out at the Oregon State University, College of Oceanography by Professor Robert A. Duncan. As suggested by the laboratory unprepared whole-rock samples were sent. Thus, all sample preparation was done at the laboratory in Oregon. The rocks were first crushed to 0.5 mm size and washed in distilled water to remove dust and break the larger vesicules. The samples were irradiated in the OSU TRIGA reactor, and Ar-isotopic analysis was performed by high vacuum fusion and mass spectrometry.

SAMPLES

Five samples from different levels of the core (subunits B,D and F) were selected for K-Ar isotopic dating during the main study (Bugge et al. 1990). The samples include the largest lava blocks and lapilli sized clasts. All samples are vesicular. Secondary alteration has not been observed. However, due to the relatively high content of pores, the possibility of minor sediment inclusions cannot totally be excluded. Some petrographical details are given as a framework for the interpretation of the K-Ar and Ar-Ar dates discussed later.

Samples 32.05m and 32.10m represent the largest of the basaltic clasts. They consist of vesicular basaltic lava with olivine pheno- and glomerocrysts (up to 1.5 mm long crystals) in a matrix consisting of submicroscopic plagioclase laths (5-19 µm x 100-200 µm) and dark glass.

The occurrence of very minute clinopyroxene (quench textures) in the matrix has been detected only by SEM. Many of the pores show a crystal free glass rind, and in some cases new smaller pores have developed within the circular glassy pseudomorphs after the first generation of pores (Figure 2a). Branching textures of olivine with glass inclusion also suggest rapid cooling of the magma prior to eruption.

Sample 78.08m is from a massive block. The possibility that it represents a volcanic bomb was mentioned in the Main Report (Bugge et al. 1990). An alternative interpretation is that it represents a vesicular part of a pillow or subaqeous/subglacial lava tongue. This sample has similar petrography and development of microlites as the lava blocks described above, except that the pores are less regular and smaller pores are more abundant.

Samples 77.70m and 111.45m represent vesicular basaltic lapilli clasts. Optical microscopy shows that sample 77.70m is the most crystalline of all the samples in this study (Figure 2b), characterized both by a high microphenocryst content, with plagioclase laths (17-62 µm x 170-500 µm) and well developed interstitial clinopyroxene (120-660 µm). Olivine is less abundant than in the samples at 32m. Opaque phases form 20-60 µm wide euhedral crystals. Matrix consists of homogeneous pale brown glass. Small microcracks are visible in the glass matrix, but there are no signs of secondary alteration. The vesicules are less regular and not so spherical as in the samples at 32m. The dated clast at 111.45 m has not been examined optically, but a similar looking clast from the same level shows olivine phenocrysts in a finegrained and mainly glassy matrix.

K- Ar RESULTS

The five samples used for dating show fairly similar contents of potassium (0.90 - 0.94 %K; table 3.4.7 in Bugge et al. 1990). The K - Ar dates vary between 2.3 and 10.2 Ma (Table 1). There is no variation of age as a function of core depth.

The similar potassium values agree with earlier observations of limited chemical variation and a similar origin for the volcanics. The different dates are therefore not believed to represent real age differences. The possibility that some of this discrepancy was due to incorporation of cement was mentioned in the Main Report (Bugge et al. 1990), leading to

erraneously young dates. However, the excellent preservation of the sample with the youngest date (77.70m) and the similar K-compositions of the dated samples shows that secondary supply of K is not likely to have occurred. On the basis of this it was decided to test these results by supplementary studies using the Ar - Ar method to examine the possibility of the presence of excess argon.

Ar - Ar RESULTS

Two of the samples were selected for dating with the Ar - Ar stepwise heating method. Five temperature steps were applied for each sample in the range between 500 °C and 1500 °C, and $^{40}Ar/^{39}Ar$ ages were calculated for each step. Most of the gas is released between 900 °C and 1000 °C.

Both the resulting plateau ages and calculated $^{36}Ar/^{40}Ar$ - $^{39}Ar/^{40}Ar$ isochron ages for both samples are similar (2.2 - 2.4 Ma; Figures. 3a,b and Table 2).

The Ar-Ar date is thus similar to the young K - Ar date for sample 77.70m, while the K - Ar date of sample 32.05m was significantly older (7.4 Ma).

Examination of the age spectrum for sample 32.05m shows that excess argon with an old age has been released in the low temperature fraction (Table 2, Figure 3a). Incorporation of this Ar into a mean age calculation would have resulted in an older mixed age for the sample approaching the K - Ar date. The incremental heating results show that the excess argon was loosely bound, while the more strongly bound argon gave a younger age. The consistency of the young age for the plateau age calculation and the isochron calculation and the similar Ar-Ar age for the two different samples suggest that this age is the primary crystallization/cooling age and not a secondary or "mixed" age.

Table 1 *Comparison of K-Ar (Bugge et al. 1990) and ^{40}Ar-^{39}Ar isotopic dates*

Sample			K - Ar date (Ma)	$^{40}Ar/^{39}Ar$ date (Ma)	
Depth	Sub-unit	Lithology		Plateau age	Isochron age
32.05 m	F	Lava block	7.35 ± 0.15	2.35 ± 0.12	2.31 ± 0.10
32.10 m	F	Lava block	3.19 ± 0.05		
77.70 m	D	4 cm lapilli	2.34 ± 0.08	2.20 ± 0.12	2.21 ± 0.52
78.05 m	D	bomb/block	10.20 ± 0.15		
111.45 m	B	3 cm lapilli	4.39 ± 0.10		

Table 2 *^{40}Ar-^{39}Ar dates for different incremental heating steps.*

Sample 32.05 m

Step 1 15.45 ± 1.39 Ma
Step 2 2.27 ± 0.19
Step 3 2.37 ± 0.18
Step 4 2.82 ± 0.50
Step 5 2.30 ± 0.32

Plateau age : 2.35 ± 0.12 Ma
Isochron age: 2.31 ± 0.10 Ma

Sample 77.70 m

Step 1 0.97 ± 0.88 Ma
Step 2 2.40 ± 0.22
Step 3 2.11 ± 0.15
Step 4 2.22 ± 1.11
Step 5 1.44 ± 1.37

Plateau age: 2.20 ± 0.12 Ma
Isochron age: 2.21 ± 0.52 Ma

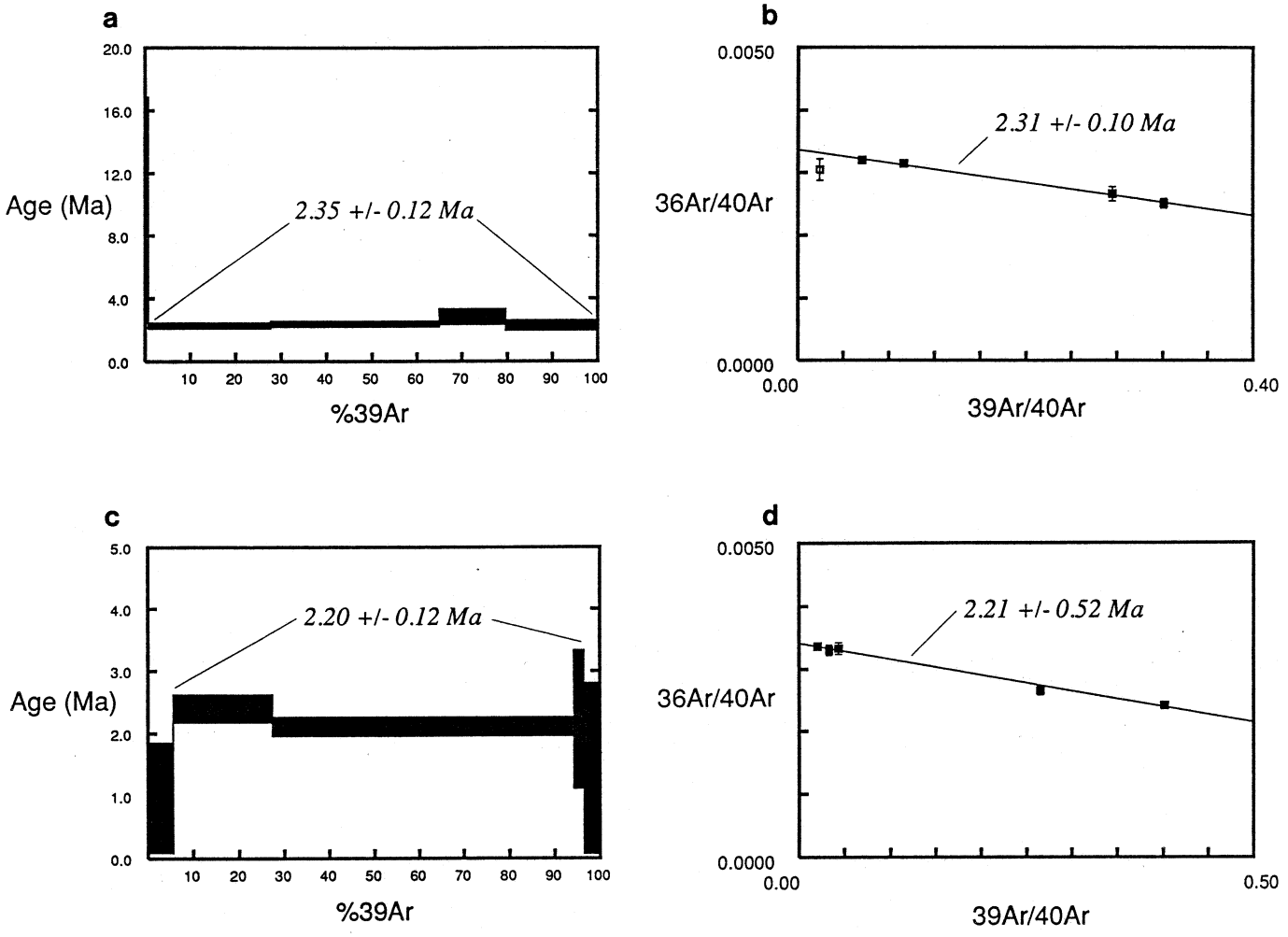


Figure 3 $^{40}Ar/^{39}Ar$ *age spectra and* $^{36}Ar/^{40}Ar$ *isochron plots based on the incremental heating technique for samples 32.05m (a and b) and 77.70m (c and d). Note the old age due to excess argon at very low % of* ^{39}Ar*-release (see also Table 2) in sample 32.05m (a). Small amounts of excess argon have large effects on the age-calculation for these young rocks.*

DISCUSSION

The above interpretation means that the age differences given by the K-Ar method are due to the presence of different amounts of excess argon within the samples. It was earlier mentioned that preservation of excess argon is favoured by rapid cooling of the magma to glassy rocks, which therefore may give erraneously old ages with the K-Ar method. Rocks with higher degree of crystallinity reflect slower cooling with more time for element redistribution and diffusion within the magma and exsolution of excess gas. This relationship between crystallinity and excess argon content is seen for the two samples that were tested by the Ar-Ar method: the sample with the youngest K-Ar age has the best well developed matrix crystals, while the matrix of the sample with excess argon is a mixture of much finer grained quench crystals and glass.

Studies of deep ocean basalts (Marty et al. 1983) have documented the presence of excess argon in vesicules. This argon was released during low temperature incremental heating steps (700-800 °C), while argon from the homogeneous glass was released at higher temperatures (1000-1100 °C) associated with the melting of the glass. Also in the present study it is likely that much of the excess argon has been captured in the vesicules. Possible cites for the excess argon are the small vesicules (< 0.1 mm size) sealed by the homogeneous glass rinds and within the quenched matrix. Excess argon within larger vesicules is likely to have escaped during the sample crushing procedure. The radiogenic argon has been produced by decay of K both within the homogeneous glass (wt.% K_2O = 1) and from plagioclase microlites (wt.% K_2O = 0.2) and released during high temperatures heating steps.

RELATIONS TO THE SEDIMENT DEPOSITION

This study has shown that the volcanic material in core 7316/03-U-01 was erupted around 2.2-2.4 Ma. This redates the deposition of the upper part of the core that contains the volcanoclastic layers (subunits B - F).
The deposition is believed to have occurred shortly after the eruption due to the following:

- Excellent preservation of the glassy volcanics indicating that the metastable products were not subjected to hydrothermal alterations as may proceed in the vicinity of the volcanic fissure.

- The similar composition and appearance of the volcanics throughout the core.

- The volcanics may have erupted into or through the sediments they have been redeposited within as evidenced by rapid cooling (quenching) of the glass in contact with sediment inclusions (fig. 3.4.12 in Bugge et al. 1990).

- The mode of occurrence of the volcanics in debris flow and gravity current deposits indicating rapid transport and deposition. Rapid erosion and deposition may be related to the volcanic activity in terms of tectonic movements (earthquakes, faulting, elevation and subsidence) and buildup of metastable glassy products at the flanks of a volcano.

The majority of the fossils within the core are reworked Cretaceous and Paleogene marine microfloras and only a relatively minor content of younger fossils which indicate a Late Miocene age (Bugge et al. 1990). If the present Ar-Ar dates are correct it means that these are also reworked fossils. However, it has been mentioned that a few of the dinoflaggelate cysts in the core are also known to range into the Pliocene (Bugge et al. 1990 p. 142). The marine affinity of the sediments has been documented by trace fossils. The absence of calcareous foraminifera is therefore peculiar. At the Vøring Plateau calcareous foraminifera are very abundant and particularly around 2.3-? Ma, and would therefore also be expected in the Bjørnøya West sediments if the Pliocene age is true (T. Eidvin pers. comm. 1990, Eidvin & Riis 1989). This is regarded as an argument against the young age. However, it has been pointed out that such fossils are also relatively rare both in the older reworked fossil material, and also in the

Quaternary deposits above the bedrock in the Bjørnøya West area (Bugge et al. 1990). In general, these foraminifera are less abundant in Barents Sea sediments than in the material from the Norwegian Sea (T. Bugge pers. comm. 1990). In the present case, the rapid erosion and deposition of the sediments by debris flow may have disfavoured a high concentration of the calcareous fossils. There is also a possibility of further reduction of the abundance of these fossils by later dissolution processes. The apparent controversy between the biostratigraphic data and the isotopic dates is therefore not necessarily real. On the basis of the Ar-Ar date, the age of the sediment deposition is interpreted as Pliocene (2.2-2.4 Ma) and the Late Miocene and older fossil material as reworked and resedimented fossils.

At the time indicated by the new age the studied area is likely to have been glaciated. Glaciation in nearby areas may have been extensive earlier than 4 Ma with a major increase in glaciation around 2.5 Ma (see references in Bugge et al. 1990). Some evidence for glacial conditions at the time of sediment deposition was already mentioned in the Main Report (Bugge et al. 1990). These include the presence of polished and extrabasinal clasts with possible glacially imposed features throughout the core and the shape of some of the smallest ash fragments. If the sediment source area was glaciated it opens up for alternative mechanisms for the sediment transport and for interpretation of the scarcity of fossils. An interesting relation known from Iceland is the catastrophic water and mass flows called "jøkullaup" which may be caused by subglacial eruption or accumulated melt water from glaciers in areas with high thermal activity.

Additional information of the conditions at the sedimentary source area may be learnt from further studies of the glassy products and the sediments. Due to the large implications for the geological history of the Bjørnøya West area, the Ar-Ar date will be further tested by using a different Ar-Ar laboratory. Attempts are also made to find a laboratory that can date the glass by the fission track method.

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