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Detrital silicates in Northeast Atlantic deep-sea sediments during the Late Quaternary: Mineralogical and K-Ar isotopic data

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Key-words: NE Atlantic Ocean, K-Ar dating, detrital minerals, deep-sea sediments, Late Quaternary climate.

ABSTRACT

During the late Pleistocene, sedimentation in the North Atlantic Ocean has been influenced by a varying input of detrital material from the surrounding land masses. The nature and quantity of this supply are controlled by the prevailing climatic conditions. Sixty K-Ar age determinations have been carried out on fine < 2 and 2–16 µm fractions of the non-carbonate residue of 27 samples and 6 ice rafted dropstones from several cores recovered within the framework of the NOAMP project (47°30'N–19°30'W). Detrital mineral assemblages are composed of mica, chlorite, smectite and kaolinite, preferentially concentrated in the clay-size fraction, whereas quartz, K-feldspar, plagioclase, amphibole and some rare zeolite are enriched in the coarser 2–16 µm fraction. The downcore distribution of K-Ar ages does not display significant variations during interglacial (foraminiferal oozes) and glacial (diamictons) periods. The age values are scattered between 350 and 500 ± 7 Ma, apparently reflecting detrital supply from the Caledonian and Precambrian terrains of North-America, Greenland and Scandinavia. However, the influence of detrital input from the Tertiary-Quaternary magmatic provinces of Iceland and South-eastern Greenland is not well resolved by this method. During several phases of enhanced ice-rafting at about 11, 23, 47 and 59 ky, K-Ar ages shift up to 800–1140 Ma. These data more likely reflect an increasing input of older rock sources from Precambrian basements and a concomittant decrease of the basalt-derived supply from Iceland and Eastern Greenland. K-Ar dating and mineralogical study of fine silico-clastic material (< 16 µm) from deep-sea sediments provide substantial data for the reconstruction of the paleoceanographic and paleoclimatic environments of the NE Atlantic Ocean during the last 140,000 years.

ZUSAMMENFASSUNG

Die Sedimentation im Nordatlantik wird im späten Pleistozän von variablem detritischem Eintrag von den umliegenden Landmassen beeinflusst. Die Menge und Zusammensetzung dieses Materials wird von den vorherrschenden Klimabedingungen bestimmt. An pleistozänen und holozänen Sedimenten aus der Westeuropäischen Tiefsee (NOAMP-Projekt, 47°30'N–19°30'W) wurden neben einer detaillierten mineralogischen Analyse 60 K-Ar Datierungen des karbonatfreien Rückstands von 27 Proben (Fraktion < 2 µm, Fraktion 2–16 µm) und von sechs eistransportierten dropstones gemacht. Die Tonfraktion besteht hauptsächlich aus Glimmern, Chlorit, Smektit und Kaolinit, während Quarz, K-Feldspat, Plagioklas, Amphibol und seltener Zeolith in der Kornfraktion 2–16 µm angereichert sind. Die K-Ar Alter zeigen während Interglazialen (foraminiferal ooze) und Glazialen (diamicton) nur geringe Schwankungen. Die Alter variieren zwischen 350 und 500 ± 7 Ma.

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Diese Alter dokumentieren Mischungen von Material verschiedener potentieller Liefergebiete wie den kaledonischen und präkambrischen Gebieten von Nordamerika, Grönland und Skandinavien. Der detritische Eintrag von den tertiären und quartären magmatischen Provinzen Islands und Südostgrönlands kann mit dieser Methode nur unzureichend bestimmt werden. Während einiger Phasen verstärkten Sedimenteintrags durch Eisberge um 11, 23, 47 und 59 ka BP nehmen die K-Ar Alter auf 800–1140 Ma zu. Diese Datierungen dokumentieren den zunehmenden Eintrag von präkambrischen Liefergebieten und eine gleichzeitige Abnahme von jüngerem Material aus den tertiären magmatischen Provinzen Ostgrönlands und Islands. K-Ar Datierungen und mineralogische Analysen von Tiefseesedimenten geben Informationen, die zur Rekonstruktion klimatischer und ozeanographischer Verhältnisse im Nordostatlantik in den letzten 140000 Jahren verwendet werden können.

RÉSUMÉ

Au Pleistocène supérieur, la sédimentation dans l'Atlantique Nord a été influencée par des apports variables de minéraux silicatés détritiques en provenance des continents voisins. La nature et la quantité de ces apports sont contrôlées par les conditions climatiques qui régnaient au moment du dépôt. Une étude combinant des analyses minéralogiques par diffraction X et 60 déterminations isotopiques K-Ar a été effectuée sur les fractions décarbonatées, < 2 µm et 2–16 µm, de 27 échantillons et sur 6 microgalets issus du transport par les icebergs; le tout provenant de plusieurs carottes prélevées dans le cadre du projet NOAMP (47°30'N–19°30'W). Les minéraux détritiques sont essentiellement composés de mica, chlorite, smectite, kaolinite, plutôt concentrés dans les franctions argileuses et de quartz, amphibole, feldspath potassique, plagioclase et parfois zeolite, plus abondants dans les fractions 2–16 µm. La distribution des âges K-Ar le long des carottes ne présente pas de variations significatives entre les périodes interglaciaires (boues à foraminifères) et glaciaires (marnes carbonatées). Les âges mesurés sont dispersés entre 350 et 500 ± 7 Ma. L'origine apparente de ces minéraux se situe dans les terrains calédoniens et précambriens d'Amérique du Nord, du Groenland ou de Scandinavie. Néanmoins les apports de matériel détritique d'origine basaltique sont mal estimés par cette méthode. Pendant certaines périodes où le transport par les icebergs prédomine, vers 11, 23, 47 et 59 ka, les âges K-Ar augmentent jusque vers 800–1140 Ma. Ces valeurs traduisent un enrichissement notable en minéraux plus anciens et la diminution des apports de matériaux d'origine basaltique depuis la plateforme d'Islande et du Groenland oriental. La datation K-Ar de minéraux détritiques dans les sédiments océaniques est une méthode qui peut fournir des données supplémentaires pour les reconstitutions paléocéanographiques et paléoclimatiques dans l'Atlantique Nord depuis près de 140000 ans.

Introduction

During the last few decades many studies have been devoted to the reconstruction of Pleistocene and Holocene climates (CLIMAP 1976 and 1981). Most of these studies are focused on the biogenic component of carbonate sediments, using the distribution patterns of marine organisms and the oxygen isotopic composition of their skeletons (e.g. Emiliani & Shackleton 1974; Duplessy et al. 1981; Sarnthein et al. 1984). These investigations provide information on global climatic changes from the temperature of the water masses and their circulation patterns. The transport of silico-clastic material into deep-sea basins of the NE Atlantic Ocean (Fig. 1) occurs by surface and bottom currents (Grousset et al. 1983), turbidity currents ((Lonsdale et al. 1981), wind (jet streams, westerlies, Folger 1970; Windom 1975), and ice-rafting in high to medium latitudes (Ruddiman 1977). Oceanic and atmospheric circulation patterns do not support significant supplies from the European continent (Grousset et al. 1988). Detrital minerals in marine environments can also be useful indicators of paleoclimatic conditions as terrigenous minerals reflect the weathering conditions of the surrounding land masses (Biscaye 1965; Griffin et al. 1968; Chamley 1989). For example, mica-chlorite assemblages in the clay-size fraction and mica-quartz-amphibole in the coarser fractions suggest rather cold and arid weathering conditions of high-latitude areas (Singer 1984). Kaolinite is a typical

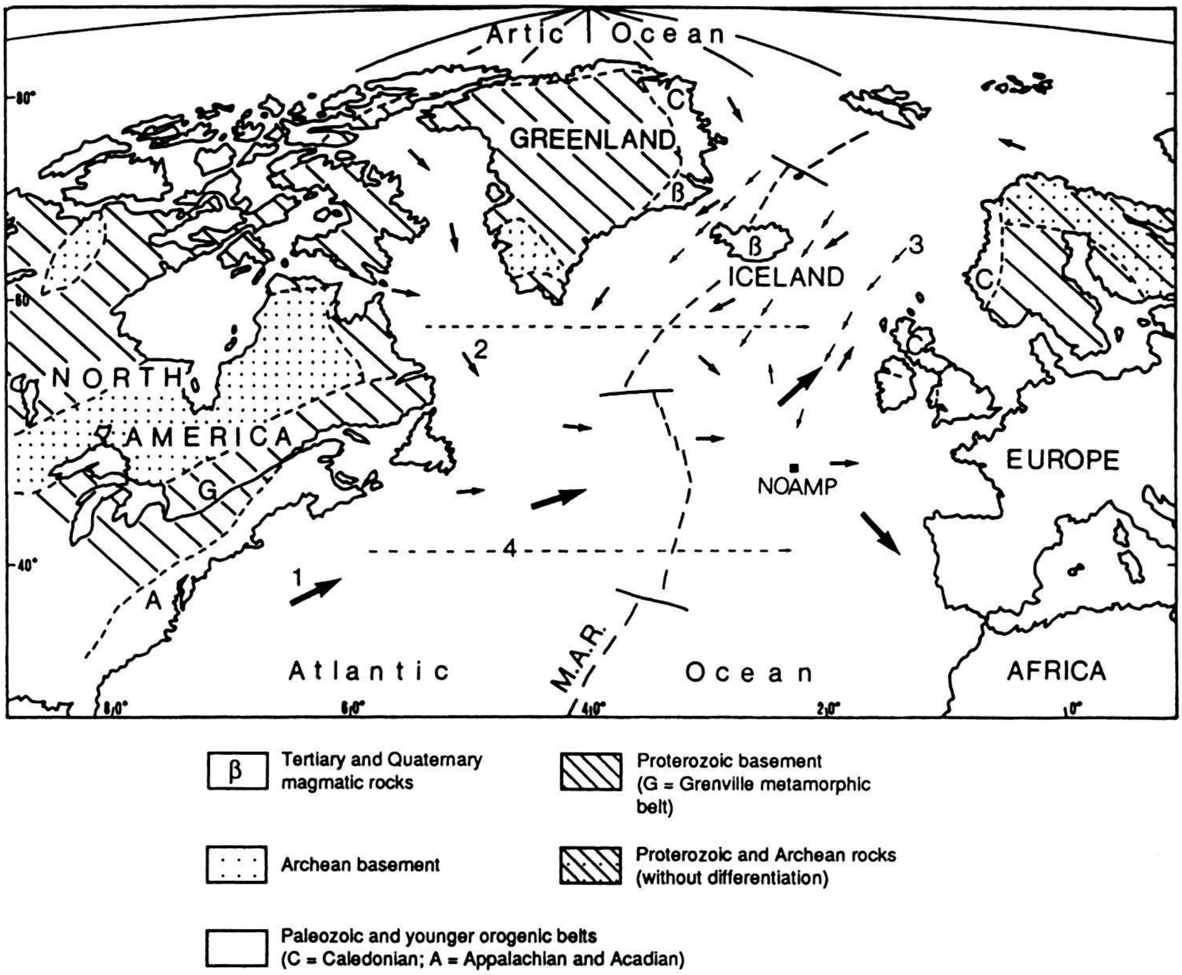

Fig. 1. Location of the NOAMP site in the Westeuropean Basin and schematic geological map of the surrounding land masses, with simplified presentation of oceanic circulation patterns: 1 = Gulf Stream, North Atlantic Drift; 2 = main drift-ice trajectories; 3 = North Atlantic Deep Water (NADW) and 4 = principal direction of eolian fluxes. MAR = Mid-Atlantic Ridge.

alteration product generated in tropical latitudes. Smectite can either be a common weathering product of terrestrial environments with contrasted seasons (Millot 1964) or an alteration phase from basaltic flows (Parra et al. 1985). In the Northeastern Atlantic basin the most probable source of smectite is the volcanic province of Iceland from where it is transported southward by bottom currents (Parra et al. 1985; Grousset & Chesselet 1986). The composition and the quantity of terrigenous material depend on a) the lithologies of terrestrial and/or submarine source areas and b) the oceanic and atmospheric circulation patterns. Both factors can fluctuate according to the prevailing climatic conditions.

The purpose of this study is to determine more precisely potential sources of detrital silicate minerals in deep-sea sediments from the NE Atlantic, through X-ray diffraction analyses and conventional K-Ar dating. This latter method has rarely been applied to detrital marine environments. Most of the radiogenic isotopes studies have been focused on the diagenetic/authigenic processes occuring within sediments or during alteration of submarine basaltic flows (e.g. Clauer 1976). However, early work by Krylov et al. (1961)

or Hurley et al. (1963) already suggested that K-Ar age determinations might be useful for mapping average detrital inputs, for stratigraphic correlations and therefore, would support paleoceanographic and paleoclimatic reconstructions.

Physiographic setting

The location of the NOAMP site (Nord-Ost-Atlantisches Monitoring-Programm) in the NE Atlantic Ocean at 47°30′N–19°30′W provides optimal conditions for the study of a complete sedimentary record of Late Pleistocene climatic changes. This region is crossed by southward shifts of the polar front down to 43°N during cold periods and northward excursions of warmer water masses during interglacial periods (Ruddiman & McIntyre 1976). Therefore climatic fluctuations are well recorded by sediments of this area (Fig. 1). Within the framework of the NOAMP project in the West-European basin, a large set of piston cores, with a total length of about 200 m, was recovered from water depths between 3900 and 4600 m (Meischner 1987; Jantschik & Lohoff 1987; Heinrich 1989). Five cores from a deep-sea mount and the surrounding areas were chosen for a detailed mineralogical and K-Ar isotopic study (Fig. 2). The mount, called the "Grosser Dreizack", is one of the permanent monitoring stations in the Joint Global Oceanic Flux Study (JGOFS). The deep-sea plains in the vicinity are frequently crossed by turbiditic

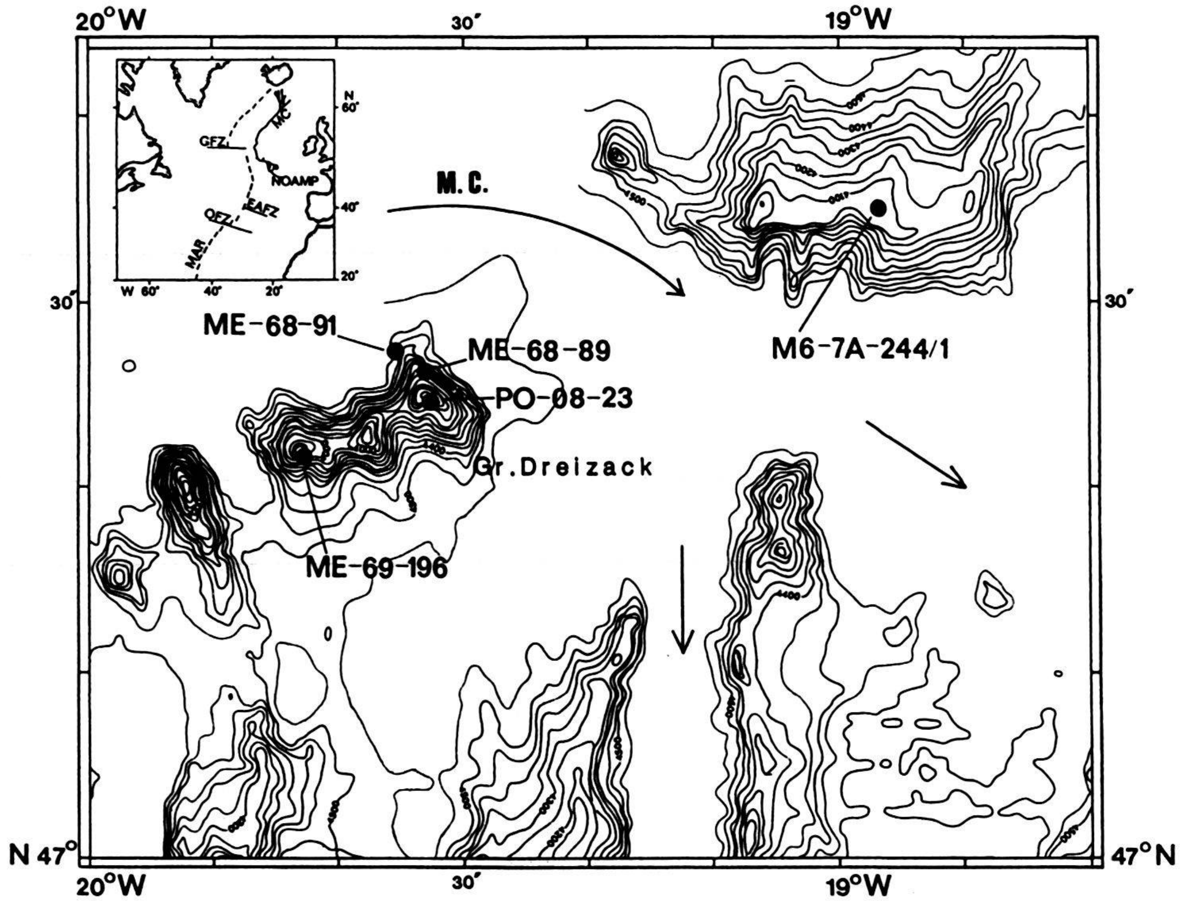

Fig. 2. Bathymetric map of the NOAMP area with core locations. Contour intervals are 50 m and depths below sea level are indicated. M.C. = Maury channel turbidite system.

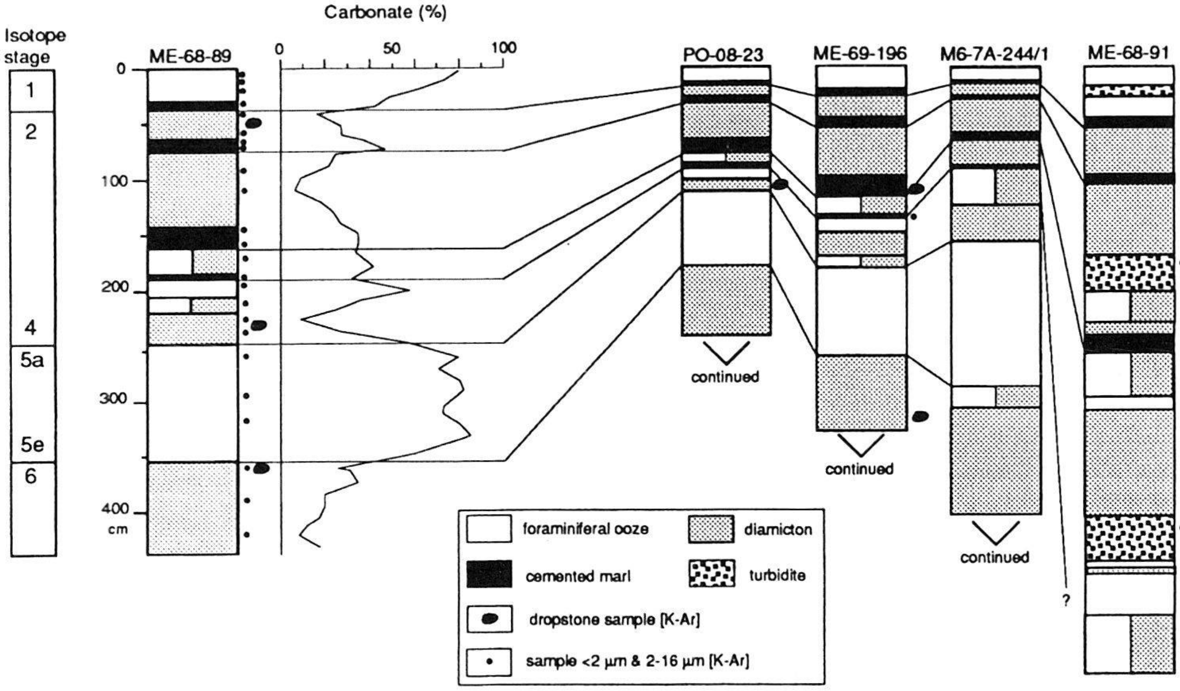

Fig. 3. Lithological correlation of five cores from the NOAMP area. Stratigraphic control is infered by cross-correlation with core ME-68-196 where a stable isotope curve is available (OBERHÄNSLI et al. 1986, HEINRICH 1988). The carbonate curve of core ME-68-89 displays high contents during interglacial periods (isotope stages 1, 5) and low contents during glacials periods (isotope stages 2–4, 6).

currents, transporting volcano-clastic sediments southward from the Islandic shelf in the Maury Channel System (Gabel 1989; Heinrich 1986 a, b). However, away from the proximal canyon system, turbiditic activity is only effective for water depths greater than 4400 m. Turbidite layers can only be seen in core ME-68-91 (Fig. 3). Most of the cores display a complete sediment record back to about 140 ky (Jantschik & Lohoff 1987).

Material and methods

Mineralogical study and K-Ar age determinations were carried out on the non-soluble residue, after dissolution of carbonates in 10% HCl at room temperature and under constant agitation. Two different grain size fractions, < 2 and 2–16 µm, were separated by centrifugation and settling methods. No further grain-size fractionation could be made, e.g. to isolate individual mineral species such as smectite, because the amount of recovered silicate residue rarely exceeded 250 mg. The < 2 µm fraction mainly concentrates clay-type minerals, smectite, kaolinite, mica, chlorite, whereas the coarser 2–16 µm fraction also includes quartz, amphibole, plagioclase, K-feldspar and zeolite grains. The two size fractions generally represent between 50 and more than 80% of the non-carbonate residue, with one mode at about 5 µm (Jantschik 1991). Six centimetric dropstones were also sampled by direct hand-picking from the cores. Qualitative mineralogical compositions of < 2 and 2–16 µm fractions were obtained with a Scintag XDS 2000 diffractometer, on glycolated oriented glass slide specimen. Samples are scanned between 2 and 50° 2θ $CuK\alpha_1$ (40 mA, 40 kV). Semi-quantitative estimations of phyllosilicate content from diffraction peak heights were calculated with correction factors, following the method of Biscaye (1965). In order to compare mineralogical compositions and K-Ar age values, the relative proportions of each K-bearing phase (mica, smectite, amphibole, K-feldspar, plagioclase and zeolite) were calculated with no correction procedure. Bulk mineralogical composition was determined by the powder diffraction technique.

Sixty K-Ar isotopic determinations were carried out using a procedure described by Dalrymple & Lanphere (1969) and Hunziker (1979). Argon was extracted, purified and mixed with a ^{38}Ar spike aliquot in a pyrex line with high-vacuum metal valves. Samples were previously outgassed at 100 °C for several hours, in order to reduce atmospheric contamination. No release of radiogenic argon has been noticed at this temperature. Isotopic ratios were determined with an A.E.I.M.S.10 S. mass spectrometer whose resolution is improved by a 4.1 kG permanent magnet. During the course of this study, equipment reproducibility and spike calibration were checked by sample duplicates and regular analyses of biotite standards (HD-B_1 and KA-3, Fontignie 1982). Potassium was measured by flame spectrophotometry with a reproducibility better than 2%. K-Ar ages were calculated with the decay constants recommended by Steiger and Jäger (1977). All isotopic data are displayed in Tables 1 and 2.

Sedimentary and stratigraphic record

The sediments are composed of alternating foraminiferal oozes (FO), carbonate marls called diamictons (DI) and cemented marls (CM) (Jantschik & Lohoff 1987). Warm climatic conditions are indicated by the presence of light yellow to white-coloured foraminiferal oozes with carbonate contents of up to 90%. Cold climatic conditions are characterized by brownish-coloured diamictons, with substantial amounts of terrigenous material and low carbonate contents (5–40%). Four horizons of cemented marls occur within the diamictons, during the last glacial period and at the Holocene-Pleistocene transition (Fig. 3). These layers display cementation by neoformation of dolomite (Clasen et al. 1990; Jantschik 1991). Thin Sections and SEM observations show rhombohedrical dolomite crystals. Within these layers the water content and the sediment porosity are reduced. Cemented layers can be correlated from core to core. Three of them can even be found in between the turbiditic levels of core ME-68-91. Detailed stratigraphic data of core ME-68-89, which displays a complete sequence down to about 140 ky, and lithological comparisons with other cores are shown in Figure 3. The sampling positions of the < 2 μm, 2–16 μm fractions and dropstones used for K-Ar dating are also indicated. Oxygen isotopic compositions were measured on foraminifera from core ME-69-196 (Oberhänsli et al. 1986; Heinrich 1988). Lithological cross-correlations between cores allowed definition of isotope-stage boundaries down to stage 6. Furthermore, comparison of carbonate curves with published data (McIntyre et al. 1972, Sancetta et al. 1973) yielded a stratigraphic control of the sediments down to about 140 ky.

Results and discussion

Mineralogical data

The dominant clay-size minerals found in the sediments are mica, chlorite, kaolinite and smectite. No significant contribution of mixed-layers was noticed. Very low contents of quartz, K-feldspar, plagioclase and amphibole are also determined. Such composition suggests the mixing of minerals from various continental and/or submarine origins. The downcore distribution of the phyllosilicates is displayed in Figure 4. Mica is the dominant clay mineral with contents of 60–80%. The amount of smectite and kaolinite ranges from less than 5% up to 15%. Chlorite generally represents 10% to 20% of the mineral assemblage. The most drastic changes in the phyllosilicate distribution occur in the cemented marl horizons. Within these layers smectite and kaolinite contents strongly decrease (< 5%), whereas chlorite and mica increase to 15–25% and more than 70%, respectively.

The coarse 2–16 µm fractions are made up of mica, chlorite, kaolinite, negligible amounts of smectite and detrital assemblages consisting of quartz, amphibole, K-feldspar, plagioclase and sometimes zeolite. All minerals display irregular and broken shapes, typical for clastic transort (Plate 1). The amphiboles in the CM, when observed by optical microscope, are predominantly hornblendes from granitic and/or high grade metamorphic rocks. The rare occurence of coarse zeolite (clinoptilolite) grains in the 2–16 µm fraction is limited to some DI levels (core ME-68-89: 100–125, 160–170 cm). The distribution of the non-phyllosilicate minerals in core ME-68-89 is consistent with glacial (high amounts of detrital minerals) and interglacial (low amounts) phases (Fig. 5). These fluctuations are best seen in the quartz distribution. The relative content of coarse-grained silicate material is used to infer drift-ice trajectories during the last glacial and interglacial periods in the North Atlantic Ocean (Ruddiman 1977). The 2–16 µm quartz peaks of core ME-68-89 are consistent with the ice-rafted detritus (IRD) peaks

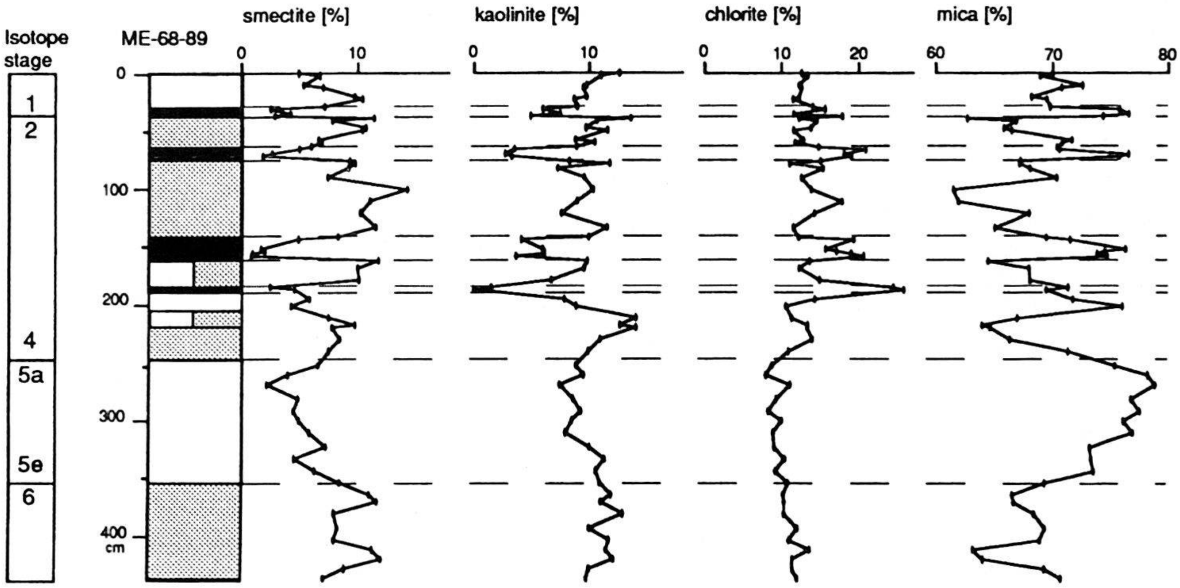

Fig. 4. Downcore distribution (core ME-68-89) of clay minerals (in relative %) in the non-carbonate < 2 µm fraction. Mineral percentages were calculated using the method of Biscaye (1965). (for legend see Fig. 3).

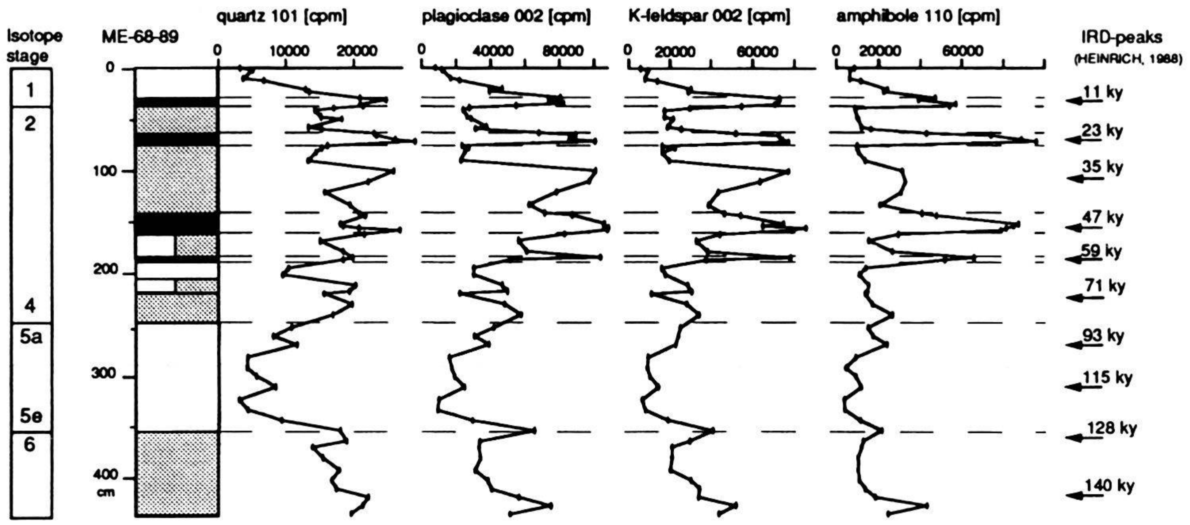

Fig. 5. Downcore distribution of quartz (101), plagioclase (002), K-feldspar (002) and amphibole (110) in the non-carbonate 2–16 μm fraction. Note the enrichment of amphibole in the cemented marl. Unit is cpm (counts per minute); for legend see Fig. 3.

(> 180 μm) reported from the same area by Heinrich (1988). This IRD distribution displays a cyclic variation with a period of about 11 ± 1 ky during the last 140 ky. IRD peaks identified within the last glacial period (isotope stages 2–4) are also characterized by high abundances of K-feldspar and plagioclase (Fig. 5). High amphibole content, however, is restricted to the four cemented marl horizons which correspond to the IRD peaks at about 11, 23, 47 and 59 ± 1 ky.

K-Ar isotopic data

Silico-clastic material transported at the NOAMP site should essentially be dominated by very old detrital minerals. The surrounding land masses of North America, Greenland (actually covered by inland ice), Scandinavia and even the British Isles are predominantly made up of Precambrian and Paleozoic igneous, metamorphic and sedimentary rocks. (Fig. 1). Surface and bottom currents, western eolian fluxes and ice rafting during cold climatic periods should theoretically supply 250–3800 Ma old minerals, according to the weathering conditions prevailing on the continents. But important age differences between coexisting minerals can be generated during the orogenic events, polymetamorphic histories or cooling patterns of old metamorphic rocks (see discussion in Faure 1986). The only available young source is provided by the Tertiary-Quaternary magmatic provinces of Southeastern Greenland and Iceland and, by the Mid-Atlantic ridge (MAR) located on the NW border of the NOAMP site.

Estimation of source rock ages: K-Ar dating of dropstones

Iceberg transport supplies gravels and other fine and coarse rock fragments to deep-sea sediments. K-Ar dating of K-bearing minerals of these detritus can support identification of some of the initial rock sources. However only whole-rock analyses could be performed on these tiny pebbles, therefore only providing average age values.

Table 1: K-Ar isotopic data of dropstones

Core depth (cm)	Dropstone type	Mineralogical content (1)	%K	$\%^{40}Ar$ rad.	[^{40}Ar rad.] (10^{-9} mol/g)	K-Ar age ±2σ (Ma)
ME-68-89	Diorite-gabbro	quartz,epidote, hornblende,chlorite, plagioclase,zoisite.	1.45	94.51	9.09683	1985 ± 25
ME-68-89	Basalt	glass,pyroxene olivine,plagioclase tuff-lapilli.	0.57	9.11	0.00362	3.7 ± 0.1
ME-68-89	Gneiss	quartz,mica, K-feldspar,sphene, plagioclase,epidote.	0.45	79.46	0.34576	400 ± 7.5
PO-08-23	Monzonite	amphibole,quartz, K-feldspar,mica, epidote, apatite.	6.28	98.25	23.17550	1406 ± 21
ME-68-196	Grano-diorite	quartz,biotite, K-feldspar,zircon plagioclase,apatite.	1.18	98.09	10.74700	2460 ± 28
ME-68-196	Basalt	olivine,plagioclase lava flow.	1.31	20.00	0.04717	20.6 ± 0.8

(1)- Determinations from thin section observations

Six dropstones identified as granodioritic, dioritic, monzonitic, gneissic and basaltic rock fragments were analyzed (Table 1). The corresponding K-Ar ages are 2460 ± 28, 1985 ± 25, 1406 ± 21, 400 ± 7, 21 ± 1, and 3.7 ± 0.1 Ma. All these ages are consistent with the potential Precambrian-Paleozoic continental and the Tertiary basaltic sources already mentioned; but precise identification of the provenance of these rocks is difficult.

K-Ar ages in DI and FO sediment types

Potassium-argon apparent ages of clay-size fractions range between 350 and 500 ± 7 Ma for both DI and FO (Table 2). No significant discrimination between these two sediment types is provided by K-Ar age determinations. It is most likely that the clay fractions were derived from comparable sources and that the mixing conditions of the different detritus in sea-water were rather similar. All ages are consistent with the available spectrum of potential source rocks. One has, however, to keep in mind that only the K-bearing minerals are taken into account by this dating method. The same conclusions are drawn for the coarser 2–16 μm fractions. K-Ar ages are slightly higher, scattered between 420 and 620 ± 9 Ma. The age deviations between the two different size fractions of each sample can be attributed to different mass balances of detrital minerals. Older and/or argon-rich phases such as amphibole and K-feldspar are preferentially

Tab.2: K-Ar isotopic data of silicate residues

Core depth (cm)	Sediment type	Grain size (µm)	%K	%^{40}Ar rad.	[^{40}Ar rad.] (10^{-9} mol/g)	K-Ar age ±2σ (Ma)
ME-68-89						
2-4	FO	<2	2.61	76.10	1.99867	395 ± 8
		2-16	2.40	79.20	2.41729	504 ± 9
10-12	FO	<2	2.82	88.69	2.61993	469 ± 9
		2-16	2.46	87.39	2.93577	583 ± 10
21-23	FO	<2	2.90	86.96	2.36528	418 ± 8
		2-16	2.49	70.25	2.50474	503 ± 9
34-36	CM1	<2	3.38	94.00	6.30585	844 ± 14
		2-16	2.84	93.70	5.93961	924 ± 15
38.5-40.5	DI	<2	2.97	81.50	2.48263	427 ± 8
		2-16	2.58	83.30	2.48908	485 ± 9
58-60	DI	<2	3.26	78.60	2.49577	395 ± 8
		2-16	2.70	83.30	2.64952	492 ± 9
65-67	CM2	<2	3.25	90.60	6.38152	879 ± 15
		2-16	2.65	89.70	6.17050	1004 ± 16
69-71	CM2	<2	3.37	81.40	6.70067	888 ± 15
		2-16	2.58	92.20	6.48604	1064 ± 17
89-91	DI	<2	3.19	84.30	3.07671	485 ± 9
		2-16	2.66	78.70	2.79882	523 ± 10
110-112	DI	<2	3.08	87.30	3.04912	496 ± 9
		2-16	2.49	48.30	2.73505	543 ± 10
143-145	CM3	<2	3.36	76.80	5.94436	809 ± 14
		2-16	2.67	88.50	5.39539	899 ± 15
153-155	CM3	<2	3.37	89.40	7.69791	989 ± 16
		2-16	2.57	93.50	7.09056	1141 ± 18
167-169	DI-FO	<2	2.89	77.80	2.05322	369 ± 7
		2-16	2.44	78.30	2.33799	482 ± 11
187-189	CM4	<2	3.34	91.68	7.46176	972 ± 17
		2-16	2.71	96.20	6.90154	1074 ± 18
195-197	FO	<2	3.03	76.73	2.11187	363 ± 7
		2-16	2.59	88.47	2.17045	428 ± 8
211-213	DI	<2	2.70	83.47	1.81096	350 ± 7
		2-16	2.26	74.09	1.87337	424 ± 9
219-221	FO	<2	2.85	88.79	2.10791	383 ± 7
		2-16	2.69	87.99	2.23296	425 ± 8
229-231	FO	<2	3.03	87.32	2.82385	470 ± 9
		2-16	2.46	93.33	3.15753	620 ± 11
261-263	FO	<2	2.73	85.62	2.34484	438 ± 8
		2-16	2.39	91.34	2.65975	549 ± 10
291-293	FO	<2	2.30	45.53	1.59847	362 ± 7
		2-16	2.01	80.03	1.73872	440 ± 8
321-323	FO	<2	2.52	73.61	1.77050	366 ± 7
		2-16	2.24	72.98	2.13021	479 ± 9
362-364	DI	<2	2.93	79.42	2.23195	393 ± 7
		2-16	2.53	91.21	2.38516	475 ± 9
391-393	DI	<2	3.05	49.66	2.13953	365 ± 7
		2-16	2.58	70.49	2.38162	467 ± 9
419-421	DI	<2	2.81	85.82	2.62164	471 ± 9
		2-16	2.72	81.05	2.48829	463 ± 9
ME-69-196						
133-137	CM4	<2	3.26	56.90	6.59664	900 ± 15
		2-16	2.52	94.00	6.04184	1026 ± 17
ME-68-91						
175-177	TU	<2	2.29	79.70	1.55278	354 ± 7
		2-16	1.78	80.30	1.23181	361 ± 7
417-419	TU	<2	1.92	65.10	1.06816	295 ± 6
		2-16	1.56	80.60	0.90535	307 ± 6

concentrated in the coarse size fractions, whereas fine-grained separates mainly contain mica, smectite and other clay-type minerals. No significant correlations between K-Ar ages and mineralogical composition inferred from XRD are observed (Fig. 6). However the relative influence of the K-bearing phases on the K-Ar age values can be estimated

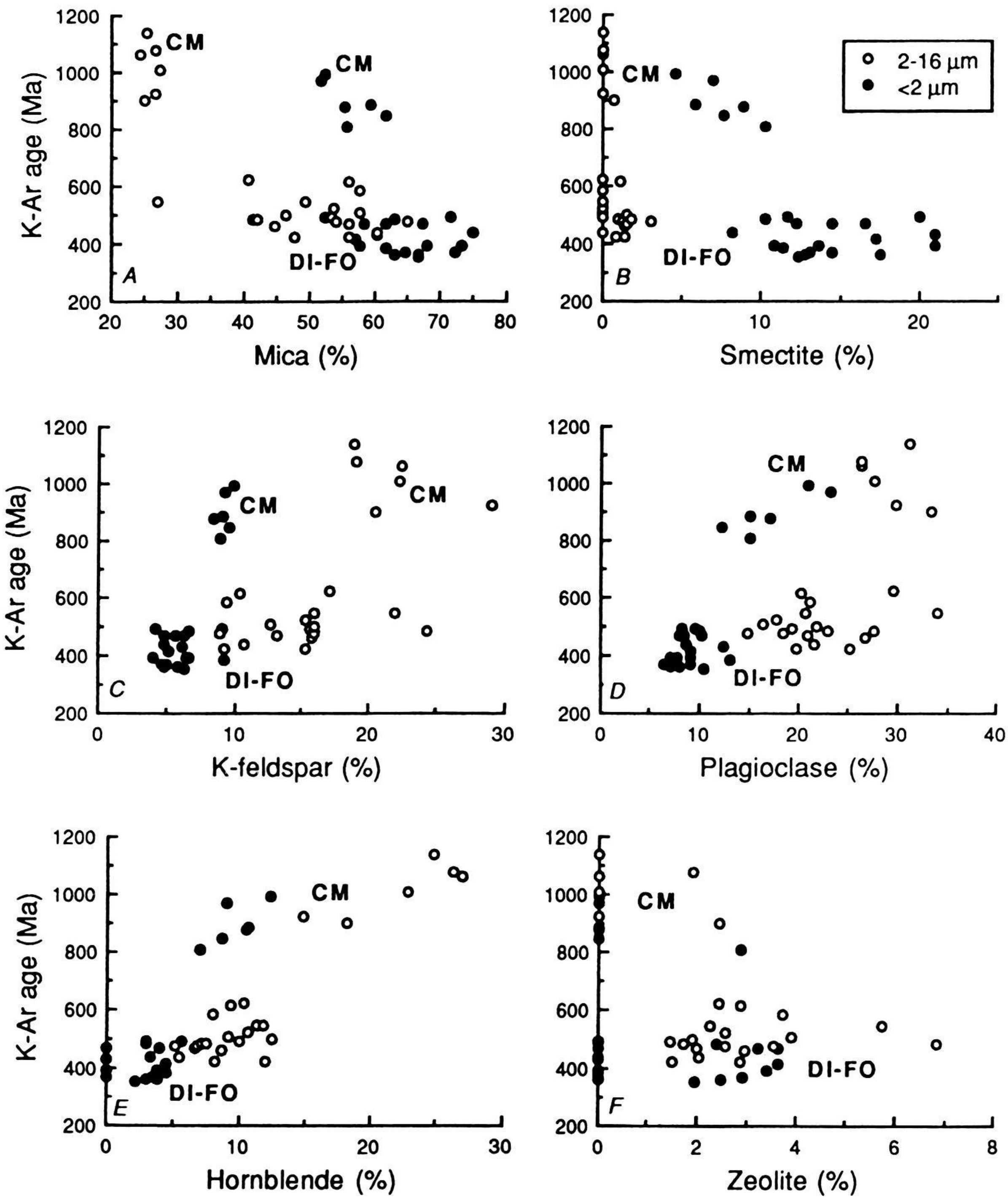

Fig. 6. Plots of K-Ar ages vs. mineralogical contents of K-bearing phases (< 2 and 2–16 µm fractions). Mica (A) and smectite (B) are concentrated in the clay size fractions, whereas K-feldspar (C), plagioclase (D), amphibole (E) and zeolite (F) are enriched in the coarser grain size fractions of the three sediment types. (FO = foraminiferal ooze; DI = diamicton; CM = cemented marl).

by principal components factor analysis, using a varimax rotation procedure. Factor 1 (64% of variance contribution) is dominated by the statistical weight of mica (+ 0.90), amphibole (+ 0.89) and feldspars (+ 0.90) which is roughly opposite to that of smectite (− 0.29). Factor 2 (36% of variance contribution) provides a high loading score for K-Ar age values (+ 0.86) which are preferentially connected to amphibole (+ 0.42), feldspars (+ 0.36), weakly to mica (+ 0.15), whereas smectite is negatively loaded (− 0.82). The increase of K-Ar ages is then more likely related to the relative increase of amphibole, K-feldspar, plagioclase and partly mica, whereas smectite, mainly concentrated in the clay size fractions, has little influence.

Influence of smectite content on K-Ar ages

Previous Rb-Sr and K-Ar isotopic analyses of smectites in deep-sea sediments have been reported by Hoffert (1980), Clauer et al. (1982) and Clauer et al. (1984). These studies emphasized the occurence of authigenic smectites, with special reference to in situ crystallization or to sea water alteration of submarine basalts. In the North Atlantic such processes can be observed along the MAR and the Islandic shelf. Both regions are potential zones of detrital supply to the NOAMP site, according to bottom current transport directions (Grousset et al. 1983; Grousset & Chesselet 1986). A possible way to estimate the influence of this supply on the K-Ar age values is to recalculate the data assuming a mixture of at least two K-bearing components: an "old" detritus composed of mica, amphibole, plagioclase and K-feldspar and a "young" smectite contaminant. The age of the former component was varied from 2500 to 250 Ma, assuming a bulk K-content of 6%. The average age of the smectite component was estimated to be 0.1 Ma, according to the stratigraphical record, with 1% of potassium. This assumed K-content is higher than what is usually reported for pure smectite and therefore accounts for possible small amounts of mica-smectite mixed-layers. Apparent K-Ar age values were calculated for different proportions of 0.1 Ma "smectite" (Fig. 7). In core ME-68-89, the smectite abundances do not exceed 21% of the K-bearing minerals (Fig. 6 and 7). Contamination by 10–20% smectite would only reduce the K-Ar ages by 1.0–2.2% to 1.7–3.8% of the initial value, for 2500 and 250 Ma respectively. Therefore important age reduction could only be caused by high smectite contribution. This is more likely the case for the turbidite layers of core ME-68-91. The apparent age of the clay size fraction at 417 cm (49% smectite) drops to 295 ± 6 Ma. According to the assumed binary mixture, the initial age of the sample should approximatively be of 350 Ma (Fig. 7). The corresponding age reduction is of 15.7%. Quaternary smectites are however not the only possible source of "young" material. A low K-Ar age value (307 ± 6 Ma, Tab. 1) is also measured for the coarser, 2–16 μm, fraction of this sample, probably also reflecting occurence of other young basalt-derived minerals such as plagioclase. A similar line of arguments can be used for clinoptilolite, a marine zeolite, occuring in some coarse 2–16 μm fractions. The very low zeolite contents (mainly less than 4%) will not influence significantly the K-Ar ages. Potassium-argon dating of FO and DI sediment types provides average values for mixtures of various detrital sources of minerals, with respect to the relative radiogenic ^{40}Ar contribution of each component. Consequently the low abundances of potentially "young" mineral phases in the studied core do not change significantly the K-Ar ages.

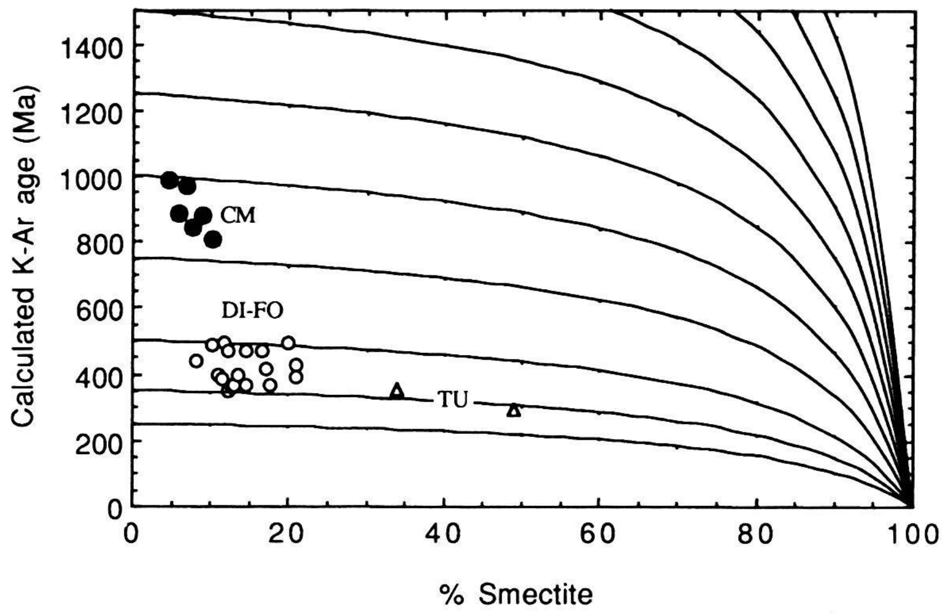

Fig. 7. Variation of calculated K-Ar age values vs. content of "young" (0.1 Ma) smectite component. The curves are calculated for ages between 250 and 2500 Ma, at 250 Ma intervals. Measured K-Ar ages of clay size fractions with their relative smectite contents are shown for all sediment types (FO = foraminiferal ooze, DI = diamicton, CM = cemented marl, TU = turbidite mud).

K-Ar ages in cemented marl horizons

Potassium-argon ages of clay-size minerals are scattered between 800 and 990 ± 15 Ma in the four cemented marl horizons of core ME-68-89 (Tab. 2). Such a high age value is also displayed by the fourth CM layer of core ME-69-196 (900 ± 15 Ma). The 2–16 µm size fractions display even older age values, up to 900–1140 ± 17 Ma. Differences of 300 to 720 Ma, with respect to the corresponding DI-FO fractions, emphasize major changes of source, transport and mixing conditions. Diagenetic effects on the K-Ar isotopic system of the detrital silicates can be excluded, due to very low temperatures and negligible burial conditions. Consequently the shift of K-Ar ages can directly be related to a drastic change of mineral sources and mixing conditions. These data are consistent with the drift-ice trajectories reported by Ruddiman (1977), as the oldest potential sources of minerals are provided by the Precambrian terrains of Greenland and North America, located at high latitudes (Fig. 1). The deviations between K-Ar ages of corresponding fine and coarse size fractions also infer different mass balances of detrital minerals in the cemented marls.

Significance of K-Ar dating of fine-grained detrital minerals in NE Atlantic deep-sea sediments

The downcore distribution of K-Ar ages of all sediment types is reproduced on Figure 8. In FO and DI, clay size minerals display an average age value of about 413 (− 63, + 82) Ma. Coarser, 2–16 µm, fractions yield 494 (− 70, + 126) Ma. These data most likely reflect variable balances of K-minerals such as mica, amphibole, K-feldspar, plagioclase (?) from old continental sources of high latitudes (North America, Green-

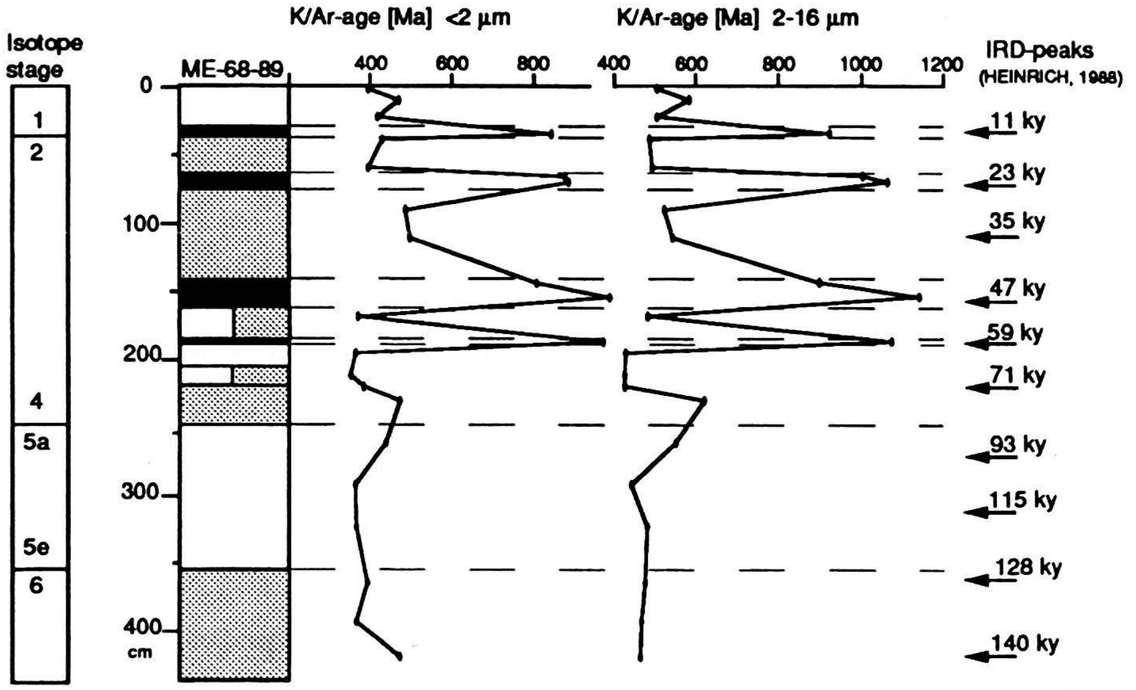

Fig. 8. Downcore distribution of K-Ar ages of the non-carbonate fractions < 2 µm and 2–16 µm of core ME-68-89. The highest age values are restricted to the 4 cemented marl horizons (for legend see Fig. 3).

land, Scandinavia). The contributions of young and/or basalt-derived material, which are represented by smectite, are not adequatly resolved by the K-Ar data. Additional isotopic methods are still required. Potential sources and mixing conditions of detrital minerals in sea water did probably not fluctuate significantly during interglacial and clacial periods of the past 140 ky. Detritus is mainly supplied by wind (westerlies, North-America), surface currents (North Atlantic Drift), North Atlantic Deep Water circulation (NADW, mainly Iceland) and ice rafting during cold climatic phases (North-America, Greenland, Iceland).

Potassium-argon dating of fine detrital minerals within the cemented marl horizons indicates drastic paleoceanographic changes. This indication is supported by distinct mineralogical assemblages with smectite and kaolinite minima in clay size fractions and high quartz, feldspar and especially amphibole contents in coarser 2–16 µm fractions. The K-Ar age values shift up to 800–1140 Ma for both size fractions. It is most likely that young material orginating from the Tertiary-Quaternary magmatic provinces is lacking in the sediments, whereas the influence of old detritus from the crystalline basements of Greenland and North America becomes more important. Such compositions are probably connected to a breakdown or at least a strong decrease of NADW formation in the Norvegian Sea and a subsequent interruption of the deep-water circulation in the Northeast Atlantic (Williams & Fillon 1986; Broecker et al. 1990). This interruption would explain the low contents of smectite, supplied by bottom currents from Iceland. These cemented layers also correspond to four of the IRD-peaks reported by Heinrich (1988, at 11, 23, 47, 59 ky), occuring in periods of increased iceberg supply from the NW Precambrian land masses. Such drastic events must also have occured during former glaciations, as two additional cemented marl horizons were found in core

M6-7A-244/1, at about 250 and 400 ky (isotope stages 8 and 12). The silicate residue of these layers yield high K-Ar ages between 700 and 1340 Ma (Jantschik 1991).

Conclusions

The bulk mineralogical composition of fine silicate detritus (< 2 and 2–16 μm) is approximately constant with time for the past 140 ky. Only the relative amounts of each mineral vary significantly during glacial and interglacial periods. A breakdown, or at least a strong decrease, of the basalt-derived supply occurs during four distinct phases of enhanced ice-rafting (cemented marls). These phases are documented by a strong decrease in smectite-kaolinite and by a concomittant input from crystalline sources characterized by elevated quartz, K-feldspar, plagioclase and especially amphibole contents.

Potassium-argon dating provides average age values, for mixtures of detrital minerals from the various possible sources, according to the relative radiogenic ^{40}Ar contribution of each K-bearing component. Consequently Quaternary sources such as basaltic alteration products from Iceland and the surrounding areas are not resolved by this method, unless their contributions represent a significant part of the mixtures (greater than 50%). Additional geochemical methods are required in order to get a better estimation of the mixtures end-members.

The potential sources of detrital minerals can be assessed by K-Ar dating of ice-rafted dropstones recovered at the NOAMP site. According to the different rock types (basalt, gneiss, monzonite, diorite, granodiorite) and the corresponding age values (3.7 Ma, 20 Ma, 400 Ma, 1406 Ma, 1985 Ma, 2460 Ma), the possible sources essentially include the Paleozoic and Precambrian basement areas of the high latitudes (North America, Greenland, Scandinavia) as well as, the Tertiary-Quaternary magmatic provinces of Iceland and Greenland. The downcore distribution of K-Ar apparent ages of fine grained fractions (< 2 μm and 2–16 μm) displays a background signal of about 400–500 Ma which is roughly constant during warm (Foraminiferal oozes) and cold (Diamictons) climatic periods. These data are compatible with a mixing process, including the various end members represented by the dropstones. Contrasting age values of up to 1100 Ma are reported for the four phases of enhanced ice-rafting, corresponding to the cemented marls. These data emphasize drastic changes in the composition (low smectite, high amphibole contents), the origin (enhanced Precambrian input from North America and Greenland) and the mixing conditions (breakdown or decrease of NADW circulation, NW-SE direction of iceberg transport) of the detrital minerals. During the Late Pleistocene these drastic climatic changes were repeated several times at about 11, 23, 47 and 59 ky and occurred in former glaciations approximately at 250 and 400 ky. Consequently K-Ar dating of fine-grained detrital silicates yields indirect information on paleoceanographic circulation and therefore, can support paleoclimatic reconstructions.

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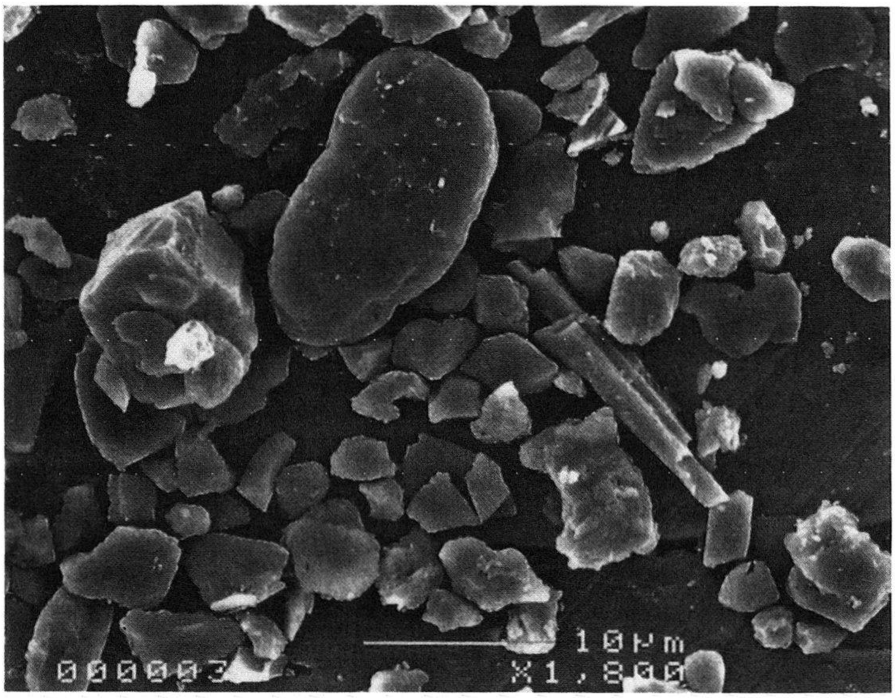
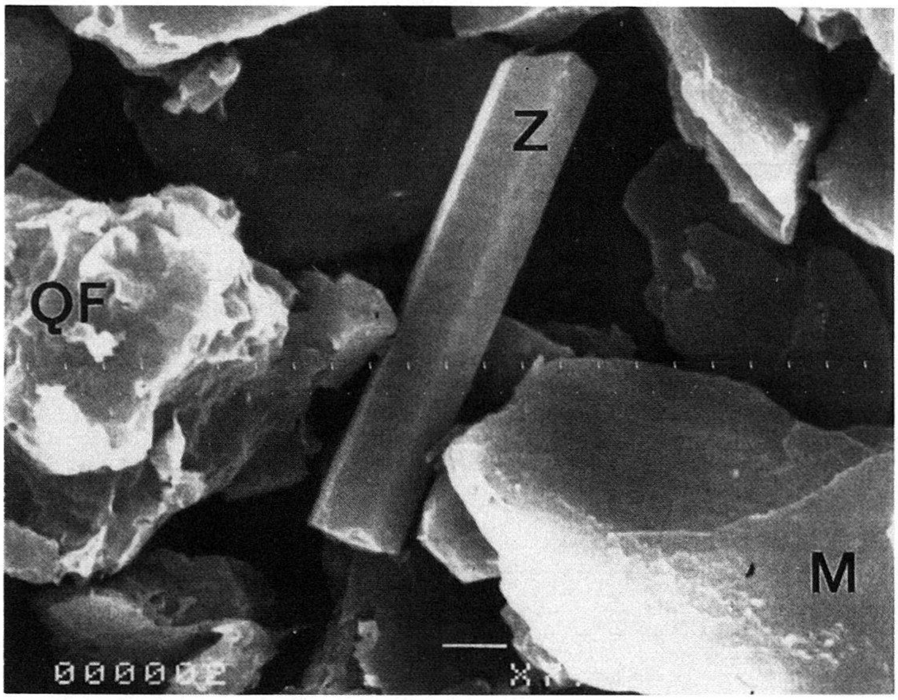
Plate 1



A.
Overview of the non-carbonate 2–16 μm fraction (core ME-68-89, sample depth 110–112 cm) by SEM: note the angular to rounded quartz and feldspar grains, and the platy phyllosilicates. Scale bar is 10 μm.



B.
Detailed view of a coarse zeolite crystal (Z, authigenic?), mica flakes (M) and quartz and/or feldspar grains (QF) by SEM (core ME-68-89, sample depth 110–112 cm, 2–16 μm fraction). Scale bar is 1 μm.