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Significance of random illite-vermiculite mixed layers in Pleistocene sediments of the northwestern Atlantic Ocean

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ABSTRACT: The clay mineralogy of Pleistocene sediments of eleven sediment cores at three ODP sites from 30°N to 60°N northwestern Atlantic Ocean has been investigated. The sediments are characterized by the presence of random illite-vermiculite mixed layers (I-V) (up to 32% of the clay mineral assemblage). The I-V clays are much more abundant during interglacial periods than during glacial ones. They are attributed to detrital supply through erosion of high-latitude continental areas from which they are derived mainly from chemical weathering of micaceous phyllosilicates. Their spatial distribution and the specific conditions for their formation through weathering suggest that I-V mixed layers are mainly derived from the Canadian Shield. They were transported from their source to marine deposition areas by rivers, deep water masses or nepheloid layers. Due to the specific conditions required for the formation of I-V, its occurrence and abundance are used as a palaeoclimate and palaeocirculation proxy for northwestern Atlantic Pleistocene sediment.

KEYWORDS: Pleistocene, Atlantic Ocean, glacial/interglacial, illite-vermiculite mixed layers.

Clay mineral investigations of Cenozoic sediments have been performed on numerous North Atlantic Ocean coring and drilling sites starting from DSDP Leg 11 (Lancelot et al., 1972). Drilled and cored holes were studied from: DSDP Leg 43 (Koch & Rothe, 1979), DSDP Leg 44 (Flood, 1978), DSDP Leg 47 (Chamley et al., 1979), DSDP Leg 48 (Cassat, 1979), DSDP Leg 50 (Chamley et al., 1980), ODP Leg 105 (Thiébaud et al., 1989), ODP Legs 150 and 150X

(Deconinck & Vanderaveroet, 1996; Vanderaveroet & Deconinck, 1997), CSS Hudson cruise (Fagel et al., 1996) and Suroit 1990 Paleocinat cruise (Bout-Roumazeilles, 1995).

From Eocene to late Pleistocene, the clay mineralogical trend is characterized by an increase of rock-derived clay minerals such as illite and chlorite associated with random mixed-layer minerals, at the expense of soil-derived minerals such as smectite (Chamley, 1979). In Eocene sediments, smectite-rich assemblages, probably largely reworked from poorly-drained soils, dominated the clay assemblage, reflecting the warm conditions prevailing during this period. Close to the Eocene-Oligocene boundary and during the early Oligocene, a change appeared in the sedimentation: the proportions of clay minerals issuing from mechanical alteration increased in relation to the global cooling induced by the Antarctic glaciation (Robert, 1992). From Oligocene to Pleistocene, percentages of illite and chlorite increased in successive steps whereas proportions of smectite and often of kaolinite decreased (Chamley, 1979).

In the northwestern Atlantic Ocean between 30°N and 60°N and between 40°W and 75°W (Fig. 1), the Pleistocene sediments are characterized by the occurrence of various amounts of random illitevermiculite mixed layers (I-V). The percentages of random I-V mixed layers range from trace amounts to 32% of the clay mineral fraction. Chamley et al. (1983) interpreted the occurrence of the assemblage composed of chlorite, illite and random mixed layers as the result of the late Cenozoic cooling favouring the supply of minerals derived from poorly weathered continental rocks and highlatitude oceanic currents. Fagel et al. (1996) assumed that random I-V mixed layers came from soils developed on muscovite-rich schists throughout the Appalachian region. Vanderaveroet (1996) showed that I-V mixed layers were characteristic of the Pleistocene period and probably resulted from the moderate chemical weathering of illite. Bout-Roumazeilles (1995) revealed that the variations of I-V mixed layers were linked to glacial/interglacial alternations, and seemed to result from modifications in the intermediate water-mass circulation.

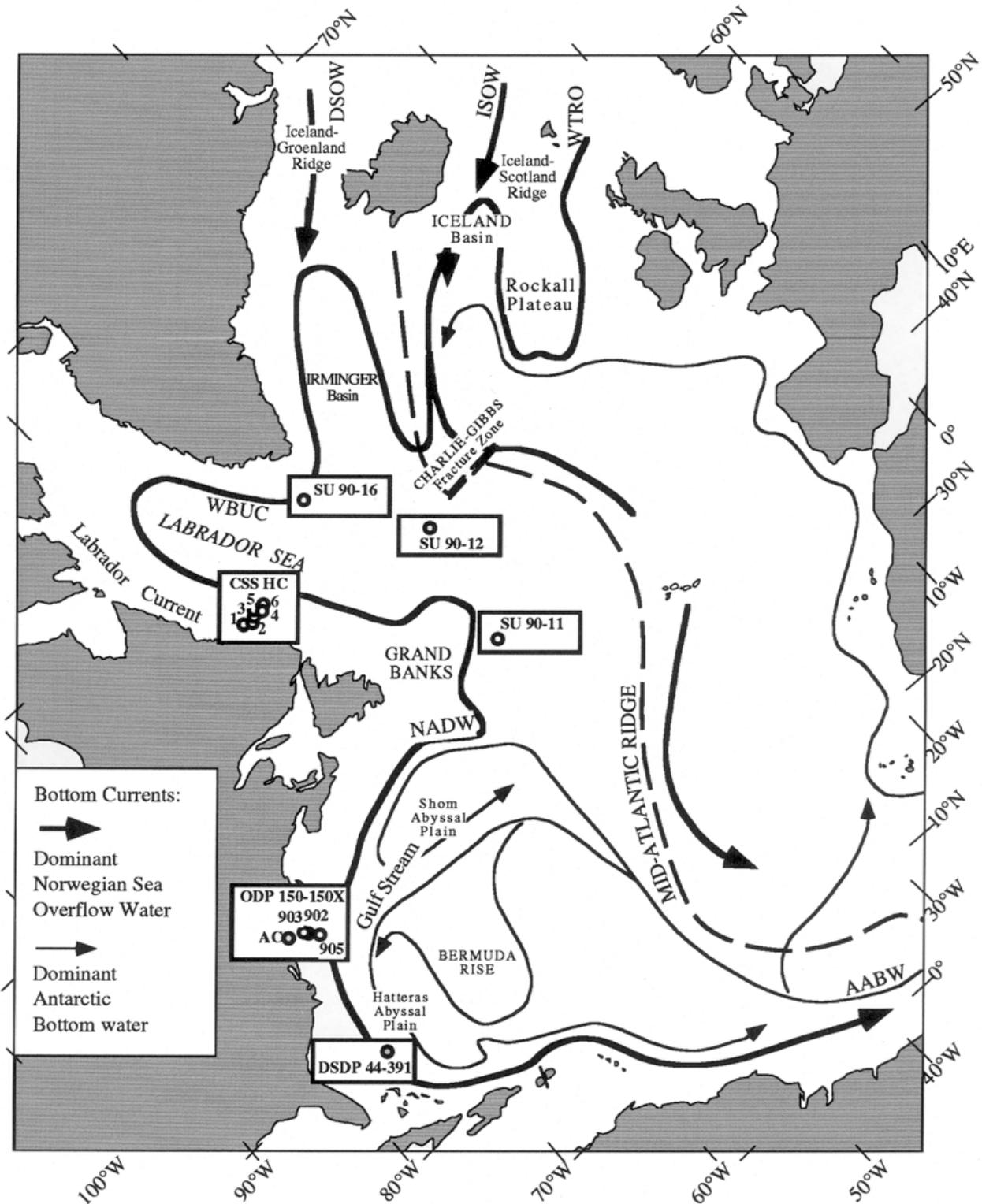


FIG. 1. Location of studied areas and main deep circulation patterns modified from Tucholke et al., 1973; McCave & Tucholke, 1986; Vogt & Tucholke, 1989. DSOW (Denmark Strait Overflow Water), ISOW (Iceland-Scotland Overflow Water), and WTRO (Wyville-Thomson Ridge Overflow Water) combine to form NADW (North Atlantic Deep Water) and WBUC (Western Boundary Undercurrent). AC = Atlantic City Borehole.

The I-V mixed layers are present in some old sedimentary rocks (Cretaceous to Cenozoic sediments) which have been affected by burial diagenesis (e.g. Kafoutine borehole, coastal basin of Senegal; ODP site 652, Leg 107, western Tyrrhenian Basin (Chamley & Debrabant, 1989)) but they have rarely been reported in Pleistocene marine sediments, including those of the North Atlantic Ocean. Various questions therefore arise about the formation, transport and significance of these I-V mixed layers.

In this paper we reassess the formation, the transport and the distribution of illite-vermiculite mixed-layer clay minerals, and their relation to climate changes as well as to deep and surface oceanic circulation during the Pleistocene.

MATERIALS AND METHODS

The analyses were performed on samples from sites 902 to 905 and Atlantic City Borehole (Legs 150 and 150X, New Jersey margin), sites 1, 2, 3, 4, 5 and 6 (CSS Hudson cruise 91-045, Labrador Sea), core SU 90-11 and cores SU 90-12 to 16 (1990 Paleocinat cruise, North American Basin and Labrador Sea).

Deflocculation of clays was carried out by successive washing with distilled water after decarbonation of the crushed sediment with 0.2 N HCl. The clay fraction (<2 mm) was separated by sedimentation and centrifugation (Brown & Brindley, 1980). The clay mineral phase was determined by using X-ray diffraction (XRD) on oriented mounts. The XRD patterns were obtained using a Philips PW 1730 diffractometer with Cu-K α radiation and Ni filter (40 kV and 25 mA). The XRD analyses were performed after air drying, ethylene glycol solvation, and heating at 490°C for 2 h. The goniometer scanned from 2.5° to 28.5°2theta for air-dried and glycol-solvated conditions and from 2.5° to 14.5°2theta for heating conditions. The identification of clay minerals was made according to the position of the 001 series of basal reflections (Brown & Brindley, 1980). Semi-quantitative estimates (Table 1) were based on the intensity and on the area of the main diffraction peak of each mineral (Biscaye, 1965). The reproducibility of the technical work and measurements was tested: five oriented mounts, performed on the same sample, were submitted three times to XRD. The relative error interval is +5%.

X-ray diffraction analyses allowed us to identify, in addition to the common clay minerals, illite, chlorite, smectite, kaolinite and some random mixed-layered I-V. These I-V

mixed layers are characterized in air-dried conditions by a broad peak ranging from 10 to 13 Å°, with a maximum intensity at ~12 Å° (Fig. 2). This peak is not altered in position or intensity by glycol saturation but collapses to 10 Å° after heating.

For each site the time-scale is based on nanofossil and diatom zonations or on the comparison between the benthic and/or planktonic δ18O records and the spectral mapping SPECMAP stack (Martinson et al., 1987).

RESULTS

Spatial distribution of illite-vermiculite mixed layers

Northwestern Atlantic Ocean between 45°N and 60°N. The Pleistocene sediments containing I-V mixed layers were drilled at water depths of 530, 301, 340, 1364, 1984 and 2648 m (Hillaire-Marcel et al., 1991; Fig. 1) and 2100, 2924, 2950 and 3660 m (Bout-Roumazeilles et al., 1997; Fig. 1). From shelf to rise, the surface sediments of the western Labrador margin consist of brown muddy sand to foraminiferal mud (Fagel et al., 1996). The I-V mixed layers are abundant (up to 35%) in the shallowest sites (sites 1, 2 and 3) along the western Labrador margin (Fig. 3). At greater depths, they decrease to 5% at site 4, and to trace amounts at sites 5 and 6. The other clay minerals include chlorite, illite and kaolinite. Smectite is absent in the shallowest sites (sites 1 to 6) whereas its percentage reaches 47% in the deepest sites where I-V mixed layers are absent (Fagel et al., 1996).

The I-V mixed layers constitute 5% of the clay fraction in core SU 90-13 located near the entrance of the Labrador Sea at 3660 m depth, as well as in core SU 90-14 which is located near the southern tip of Greenland at 2924 m depth. The site SU 90-12 is located near the mouth of the Labrador Sea (Fig. 1) at a water depth of 2950 m on a seamount developed up to 1000 m above the seafloor. The Pleistocene- Holocene sediments of core SU 90-12 are composed mainly of dark grey terrigenous muds, interbedded with minor levels of calcareous (nanofossils with foraminifera) muds. The average percentage of I-V mixed layers is 18% (Fig. 3, Table 1). The site SU 90-16 is located at the southern Greenland shelf edge at a water depth of 2100 m (Fig. 3). The Pleistocene- Holocene sediments are composed of terrigenous muds interbedded with silty to sandy layers. Illite-vermiculite mixed layers (11%) are associated with chlorite, illite, smectite and

kaolinite (Bout- Roumazeilles et al., 1997). Holocene sediments are considerably enriched in I-V mixed layers with a maximum of 35% of the clay mineral association (Table 1).

The site SU 90-11 is located off Newfoundland at a water depth of 3645 m. The Pleistocene-Holocene sediments are dark grey terrigenous muds interbedded with grey calcareous (nanofossils with foraminifera) muds. The clay fraction of Pleistocene sediments consists of a mixture of chlorite, illite, smectite, kaolinite and I-V mixed layers (Bout-Roumazeilles, 1995).

No I-V mixed layers were identified in the clay fraction of late Pleistocene sediments drilled in the eastern part of the Atlantic Ocean (Irminger, Iceland and Rockall Basins; Bout-Roumazeilles, 1995; Fagel et al., 1996).

Mid American Atlantic Ocean. Several sites were drilled on the New Jersey passive margin in the Baltimore Canyon Trough along a transect including the coastal plain, the continental slope and the continental rise (Leg ODP 150; Mountain et al., 1994). The Pleistocene sediments recovered at these sites are composed mainly of grey silty clay on the continental slope (site 902, 811 m; site 903, 445 m) and rise (site 905, 2698 m), and unconsolidated sands, silts, clays and gravels on the coastal plain (Atlantic City borehole; Miller et al., 1994). The clay minerals in Pleistocene sediments include illite and chlorite, associated with kaolinite, smectite and randomly interstratified minerals such as I-V. The appearance of chlorite and I-V mixed layers characterizes the clay mineralogy of Pleistocene sediments drilled on the continental slope and rise (Deconinck & Vanderaveroet, 1996; Vanderaveroet, 1996; Vanderaveroet et al., 1999) and on the coastal plain (Vanderaveroet & Deconinck, 1997). The percentages of I-V mixed layers reach 20% (average 15%) on the coastal plain, 30% (average 11%) on the continental slope, and 25% (average 11%) on the continental rise (Fig. 3, Table 1). On the continental slope at site 902, illite and interstratified minerals (I-V and I-S) are correlated negatively. Variable amounts of quartz, feldspars and amphibole are associated with the clay minerals.

Blake-Bahama Basin. The Pleistocene sediments drilled at 4974 m depth at site 391 of DSDP Leg 44 are assigned to the 'Blake Ridge Formation'. This formation is composed of silty clay with a small amount of nanofossil and foraminiferal ooze. The clay assemblage is dominated by primary detrital clay minerals such as chlorite and illite, with lesser amounts of several mixed-

layer minerals (illite- smectite, I-V and chlorite-smectite). The I-V mixed layers, associated with small amounts of smectite, are characteristic of these sediments (Chamley et al., 1983).

Sites	Lat. (°N)	Long. (°W)	Depth (m)	Chlorite (%)	Illite (%)	Smectite (%)	Kaolinite (%)	I-V (%)
Core 1	54°52'9	56°26'9	530	28	52	0	8	12
Core 2	54°44'5	55°35'0	301	25	36	0	7	32
Core 3	54°49'2	53°43'9	340	29	36	0	8	27
Core 4	54°54'0	52°52'0	1364	32	54	0	9	5
Core 5	55°02'0	52°44'7	1984	30	60	0	10	Tr
Core 6	52°07'7	52°07'7	2648	41	59	0	Tr	Tr
SU90-11	44°43'6	40°15'8	3646	20	35	16	12	17
SU90-12	51°52'6	39°47'4	2950	21	34	15	12	18
SU90-13	52°52'4	41°15'7	3660	17	42	20	16	5
SU90-14	57°39'2	46°51'2	2924	12	25	46	12	5
SU90-16	58°13'2	45°10'5	2100	11	21	44	13	11
150X-Atl. City	39°22'7	74°25'4	0	19	26	35	5	15
150-902D	38°56'08	72°46'37	808	27	44	10	8	11
150-905A	38°36'83	72°17'02	2698	23	36	22	8	11

tr = trace amounts

TABLE 1. Core characteristics and average percentages of clay minerals in the fine fraction of sediments from CSS Hudson cruise 91-045 (Fagel et al., 1996), cores SU 90-11 to SU 90-16 from Paleocinat I cruise (Bout-Roumzeilles, 1995) and from ODP sites 150X, 150-902 and 150-905 (Vanderaveroet, 1996; Deconinck & Vanderaveroet, 1996).

DISCUSSION

Clay sedimentation in the northwestern Atlantic Ocean is mainly controlled by detrital supply from the North American continent (Biscaye, 1965). Clay mineral particles are transported from continental masses to the ocean by surface and bottom currents (Heezen et al., 1966), and by winds (Grousset & Biscaye, 1989).

Oceanographic conditions at deep and intermediate depths

In the North Atlantic two important deep currents control the oceanographic circulation, i.e. the North Atlantic Deep Water (NADW) and the Antarctic Atlantic Bottom Water (AABW) (Fig. 1). Most North Atlantic Deep Water is sourced in the Norwegian Sea as overflow both between Iceland and Greenland through the Denmark Strait (Denmark Strait Overflow Water, DSOW) and between Iceland and Scotland (Iceland-Scotland Overflow Water, ISOW) (McCave & Tucholke, 1986). At the southern tip of Greenland, the combination of these deep water masses

(DSOW, ISOW and WTRO) forms a bottom current called the Western Boundary Undercurrent (WBUC) (McCave & Tucholke, 1986).

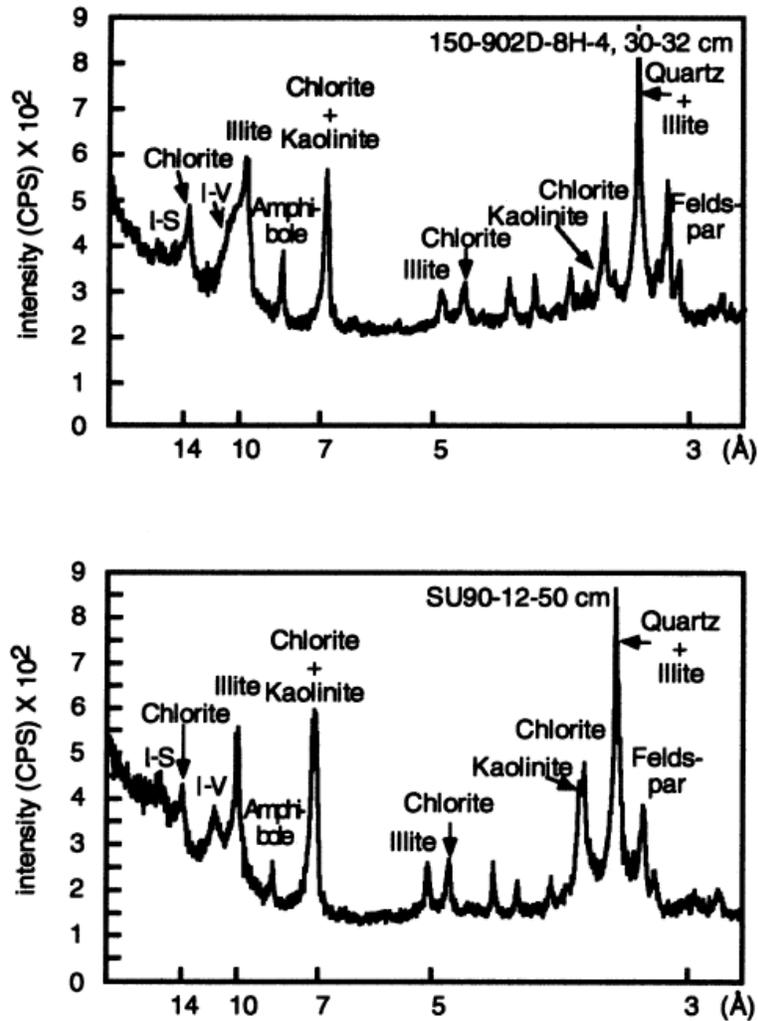
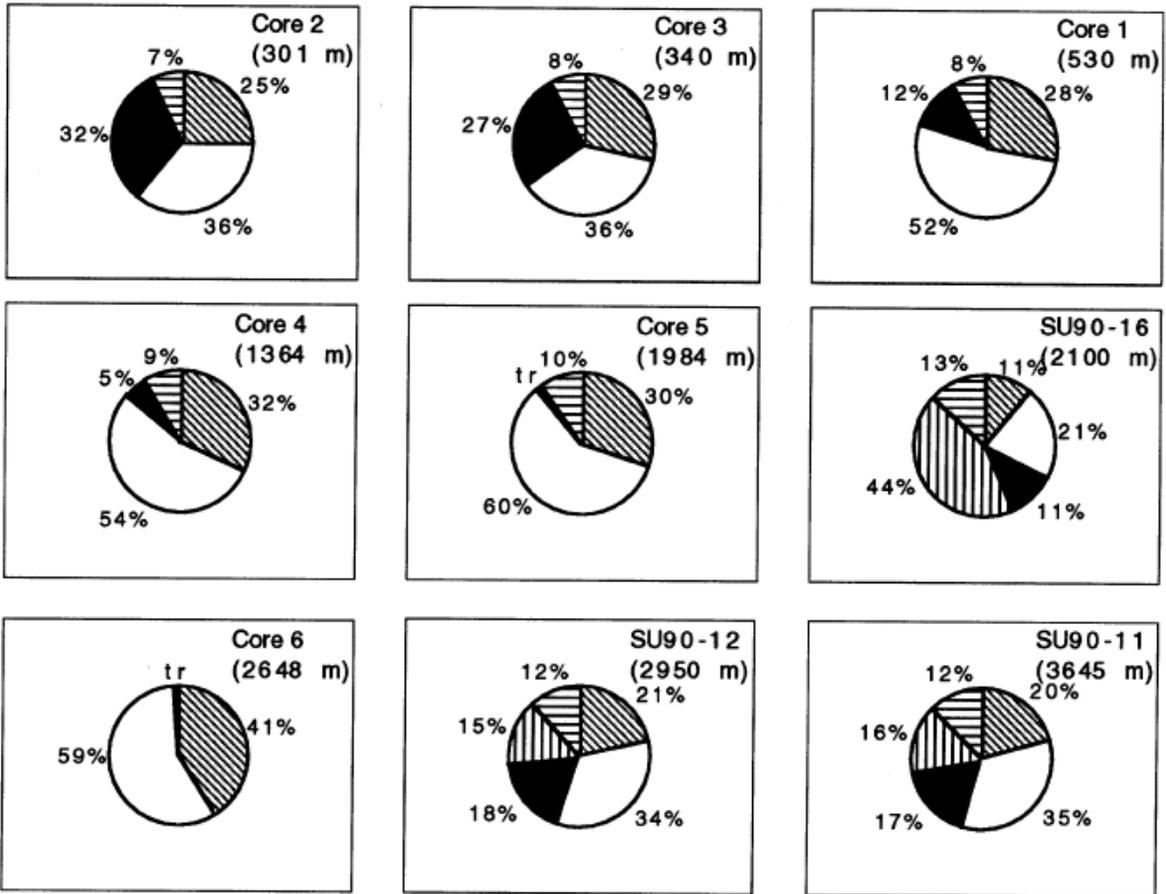


FIG. 2. Typical XRD patterns (glycolated fine fraction) from ODP site 902 (New Jersey continental slope) and Core SU90-12 (Shom Abyssal Plain) sediments. I-S: illite-smectite mixed layers and I-V: illite-vermiculite mixed layers.

Northern Atlantic Ocean



Mid Atlantic Ocean

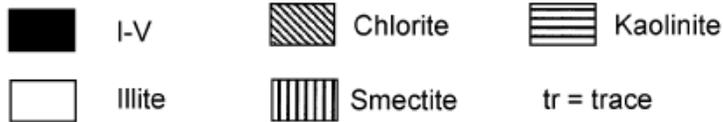
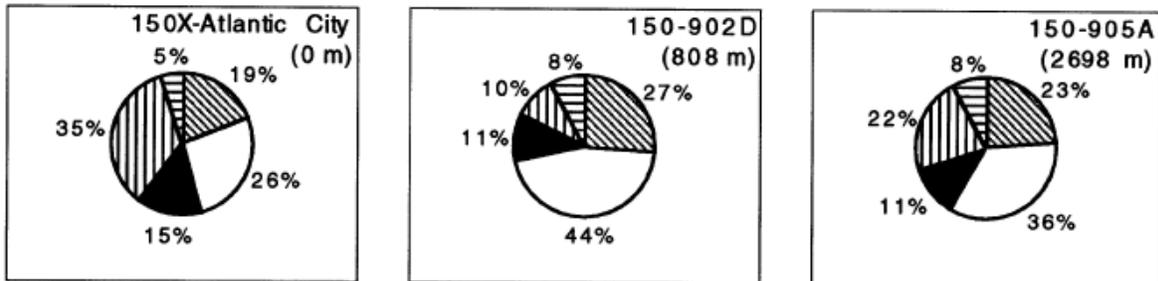


FIG. 3. Charts summarizing the mean percentages of clay minerals in the fine fraction at each site.

The deepest water mass is represented by AABW, entering the western North Atlantic from the south between the Mid-Atlantic Ridge and northern South America (McCave & Tucholke, 1986).

The North Atlantic Ocean is also characterized by important intermediate-depth currents. In the northwestern Atlantic basin, the main intermediate water mass is the Labrador Intermediate Water flowing at depths ranging from 800 to 2500 m (Thiébaud et al., 1989). This current forms in the Labrador Sea, flows eastwards along the slope and then southwards in the basin at intermediate water depths, following the main pattern of deep-water circulation.

Formation of vermiculite and vermiculitic mixed layers through weathering

The origin of interstratified clay minerals such as I-V in continental landscapes has been discussed by various authors. Several hypotheses exist to explain the occurrence of vermiculite or vermiculitic mixed-layered minerals in soils:

(1) The weathering of micaceous minerals in soils under temperate climatic conditions can lead to the formation of vermiculitic mixed layers (Berry & Johns, 1966). The weathering and transformation of a 10 Å mica (biotite or muscovite) into I-V has been observed in Adirondack (April et al., 1986), Greenland (Petersen & Rasmussen, 1980), and Virginia soils (Rich, 1968; McCartan, 1988), and by Harris et al. (1992) in the southern US coastal plain. The random I-V mixed layers are interpreted as having developed as a result of pedogenic processes during the Quaternary under temperate– cool conditions by the transformation of primary minerals, especially of mica-illite, in soils being formed on the Canadian Shield.

The transformation of biotite into a typical Al-rich vermiculite requires a change from a trioctahedral to a dioctahedral structure. This phenomenon has been found for Fe-rich species by Farmer et al. (1971). The removal of the octahedral cations and their replacement by Al, which is especially mobile at low pH, occurs during weathering in acidic soil environments and leads to aluminous, dioctahedral vermiculite. The process involves an exchange of K by hydrated cations associated with a swelling of the mica. During weathering in acid conditions, considerable interlayer K can be removed from micas in the soil (Rich, 1968).

(2) The formation of mixed layers containing vermiculite-like layers can also be derived from weathering of other primary aluminosilicates (April et al., 1986). For example, the vermiculitization of chlorite is a common phenomenon. The experimental vermiculitization of

chlorite can be achieved by a thermal dehydroxylation followed by an acid dissolution of the hydroxide sheets, namely via a transitional chlorite/vermiculite stage (Argast, 1991). In the same way feldspar weathering sometimes leads to the formation of vermiculite through an intermediate micaceous phase (April et al., 1986).

Source areas of illite-vermiculite mixed layers

Illite-vermiculite mixed layers occur in recent northwestern Atlantic sediments, the clay fraction of which is dominated by illite and chlorite (Biscaye, 1965; Hathaway, 1972; Dunn et al., 1987; Deconinck & Vanderaverroet, 1996) which result predominantly from physical weathering and erosion of continental areas (Biscaye, 1965; Chamley, 1979). On the North American Continent, late Cenozoic glaciers transported southwards large amounts of chlorite and illite eroded from Precambrian and Palaeozoic igneous and sedimentary rocks of the Canadian Shield (Dunn et al., 1987). The association of amphibole and feldspars with chlorite and illite is common and supports the interpretation of glaciers, streams and rivers draining crystalline and metamorphic rocks of the Canadian Shield under glacial climate (Thiébault et al., 1989).

The main sources of I-V mixed layers appear to be located in the North American continent. The I-V mixed layers are particularly abundant on land in the Appalachian mountain range. They were also identified in the northeastern Virginia coastal plain and soils (Rich, 1968; McCartan, 1988); in the external domain of the southern Canadian Appalachians (Yang & Hesse, 1991) ; in Adirondack soils (April et al., 1986); and in Indiana (Argast, 1991). They are also considered as reworked material in fluvial sediments of Greenland (Petersen & Rasmussen, 1980).

The negative correlation registered between the abundance of illite and interstratified minerals I-V and I-S in ODP site 902 sediments (New Jersey slope) suggests that both mixed-layered minerals result from weathering of illite (Vanderaverroet, 1996; Vanderaverroet et al., 1999).

Clay mineral transportation

Rivers. The identification of I-V mixed layers in Atlantic City Borehole sediments recovered in the New Jersey coastal plain (Vanderaverroet, 1996; Vanderaverroet & Deconinck, 1997) helps us to understand the transport path of these mineral species. The terrigenous sediments offshore New Jersey are transported towards the ocean by the Hudson and Delaware Rivers (Dunn et al., 1987). The palynological data at site Amcor 6021C located on the upper continental slope off New Jersey show that most Quaternary sediments were transported by the Hudson River and its tributaries draining the area between northern New Jersey and eastern Massachusetts (Groot et al., 1995). The mineralogical composition of sand-sized sediments from the US middle Atlantic shelf demonstrates the dominant influence of the Hudson River from New York to Cape Hatteras (Darby, 1990). During the Quaternary, the Hudson River drained widely glaciated regions to the north (Poag & Sevon, 1989; Poag, 1992) and supplied terrigenous material to the coastal plain, outer shelf and upper slope areas off New Jersey (Saito, 1996). The I-V mixed layers were therefore dominantly transported to the ocean by rivers draining the northeastern part of the American continent.

In the Labrador Sea, the offshore position of sites 1, 2 and 3 facing the mouth of the Churchill River suggests that I-V mixed layers were derived from the Canadian Shield, transported to the ocean by rivers draining this area. This is also indicated by the lateral changes in abundance of this clay species (Fagel et al., 1996). The small amounts of I-V mixed layers in sediments at sites 4, 5 and 6 are attributed to the reworking of sediments from shallower sites.

Intermediate water. The occurrence of I-V mixed layers on seamounts, culminating at 1000 m above the seafloor in the western part of the Atlantic Ocean (i.e. Labrador Sea, SU90-11 and SU90-12), could be explained by their transport by a detached nepheloid layer (Bout-Roumzeilles et al., 1999). The seasonal existence of such nepheloid layers is documented by Biscaye & Eittrheim (1974). Due to the suspended sediment density and the geographical distribution of water circulation, the nepheloid layers flowed southward at intermediate depths along the western Atlantic passive margin. The suspended sediment content of this nepheloid layer must have increased during short-time climatic events like Heinrich Events, during which the growth and fragmentation of the Laurentide icesheet favoured the reworking of sediments deposited on continental shelves. In the Labrador Sea, the shallow sediments were enriched in I-V mixed layers (Fagel et al., 1996) transported to the shelf area by runoff during interglacial

periods. These particles have probably contributed to the formation of nepheloid layers which flowed at intermediate depth because of relatively high density.

First, the variation in abundance of the I-V mixed layers within glacial/interglacial alternations are likely to have been controlled directly by the precession orbital parameter, since insolation and inferred rainfall changes can affect the pedogenic formation of these minerals which form as a result of weathering. The temporal resolution of the chronostratigraphic scale is higher than the gap between continental climatic modifications and their oceanic record. Second, changes in surface and intermediate depth circulation may also have indirectly monitored variations in the mixed-layer I-V supply with a precessional cyclicity (~23000 years). The reworking of this mineral from land masses surrounding the Labrador Sea could have increased during the continental ice-sheet melting induced by precession driven poleward heat transfer. This implies that both insolation and oceanic transport potentially controlled the variations of the mixed-layer I-V supply to the northwestern Atlantic Ocean (Bout-Roumazelles et al., 1997).

The fact that the mixed-layer I-V content is lower in Holocene sediments of core SU 90-13 (5%) relative to nearby core SU 90-12 (20% for sediments of the same stratigraphic level; Table 1, Fig. 1), and similarity of core SU 90-14 (5%) relative to the very near core SU 90-16 (35%), seems to be related to the respective core depths. Core SU 90-13 (3660 m depth) is deeper than core SU 90-12 (2950 m), and core SU 90-14 (2924 m) is deeper than core SU 90-16 (2100 m). The correspondence between the core depths and the mixed-layer I-V abundance in the clay mineral association suggests that this mineral group is preferentially transported by intermediate water which develops at water-depths >2000 m and flows from the Canadian continental shelf area to the Labrador Sea (Bout-Roumazelles, 1995).

Bottom water. Illite-vermiculite mixed layers occur locally at sites in areas under the influence of bottom current. Site SU 90-16, for example, situated at the southern Greenland shelf edge; ODP 905, located on the New Jersey upper rise; and DSDP site 391, drilled in the Blake-Bahama Basin, are under the influence of the NADW/WBUC (Fig. 1). At DSDP site 391, the mixed layers are scoured from the North Appalachian range. At ODP site 905, they are attributed to transport by the WBUC (Vanderaveroet, 1996; Deconinck & Vanderaveroet, 1996), as well as by intense winnowing of the adjacent slope. Submarine barrier. Until now, I-V mixed layers have been identified only in the western basins of the North Atlantic Ocean. The clay mineral analyses performed on Pleistocene sediments from sites SU 90-08 (west limb of the Mid-Atlantic Ridge),

SU 90-33 (off Iceland), and SU 90-38 (off Ireland) (Bout-Roumzeilles, 1995), as well as on surface sediments at sites drilled in Irminger and Iceland basins (Fagel et al., 1996), do not reveal the occurrence of these mixed layers. This suggests that during Quaternary times the Mid-Atlantic Ridge acted as a barrier for the transport of these clay minerals.

Climatic interpretations

It is noteworthy that these I-V mixed layers are especially abundant in interglacial deposits, at the expense of smectite. In addition, the highest mixed-layer I-V percentages are observed in Heinrich levels (Bout-Roumzeilles, 1995; Fig. 4a), which characterize abrupt climatic changes during the last glacial period (stages 2, 3 and 4) and correspond to the instability of the Laurentide ice sheet (Bond et al., 1992). The border of the Laurentide ice sheet fractured and released icebergs bearing detrital particles from the Canadian Shield. These Heinrich levels are expressed by the occurrence of an increase of the coarse detrital fraction in oceanic sediments (Grousset et al., 1993).

As in the eastern North Atlantic Ocean, the highest proportions of I-V mixed layers in Pleistocene sediments drilled on the New Jersey passive margin are recorded in sediments deposited during interglacial periods and especially during isotopic stages 5 and 7 (Vanderaveroet, 1996; Vanderaveroet et al., 1999; Fig. 4b).

CONCLUSION

The clay mineral associations of recent and Pleistocene sediments of the northwestern Atlantic Ocean, investigated from cored and drilled material located at various water depths between 30°N and 60°N and between 30°W and 70°W, comprise, besides common clay species (illite, chlorite, kaolinite, smectite), a random illite-vermiculite mixed-layered mineral characterized by an XRD peak at 12Å when air dried and glycolated, collapsing to 10Å after heating. The comparison of new results with previous data leads to the following interpretations.

(1) The presence of I-V mixed layers is characteristic of northwestern Atlantic basins. It has not been reported so far from northeastern Atlantic basins. The mid-Atlantic ridge seems to

have acted as a barrier and to have prevented the transportation of this mineral into eastern basins.

(2) The I-V mixed layers characterize Pleistocene sediments particularly those deposited during interglacial periods. Since the abundance of I-V mixed-layer minerals are often negatively correlated with those of illite, they are probably derived from the continental weathering of micaceous phyllosilicates, under typically interglacial climatic conditions.

(3) Mineralogical data and geographical distribution indicate that I-V mixed-layered minerals have derived mainly from the Canadian Shield where there were suitable weathering conditions (hydrolysis in rather alkaline environment of old plutonic rocks). The I-V mixed layers may occur in areas submitted to interglacial/glacial variations and where the dominant sediment source comprises micaceous phyllosilicates.

(4) The I-V mixed layers occur in quite different areas and geographical settings and therefore result from different transportation vectors. In the Labrador Sea they are attributed to transfer by intermediate-depth water masses. By contrast the deep to bottom water masses seem to have prevailed in the North American basin because I-V mixed layers are absent from the deepest cores of this region. Further south, the I-V mixed layers result from a direct supply by rivers to the ocean.

(5) Because of their increased supply during interglacial periods, wide transport by intermediate and deep-water masses, and by rivers, the occurrence of these I-V mixed layers can be used as a palaeoclimate proxy in Pleistocene sediments from the northwestern Atlantic Basin.

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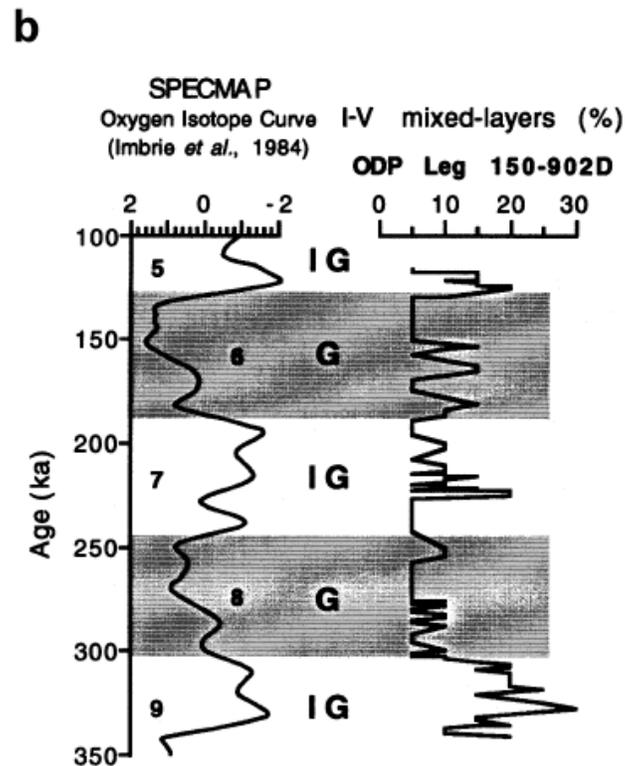
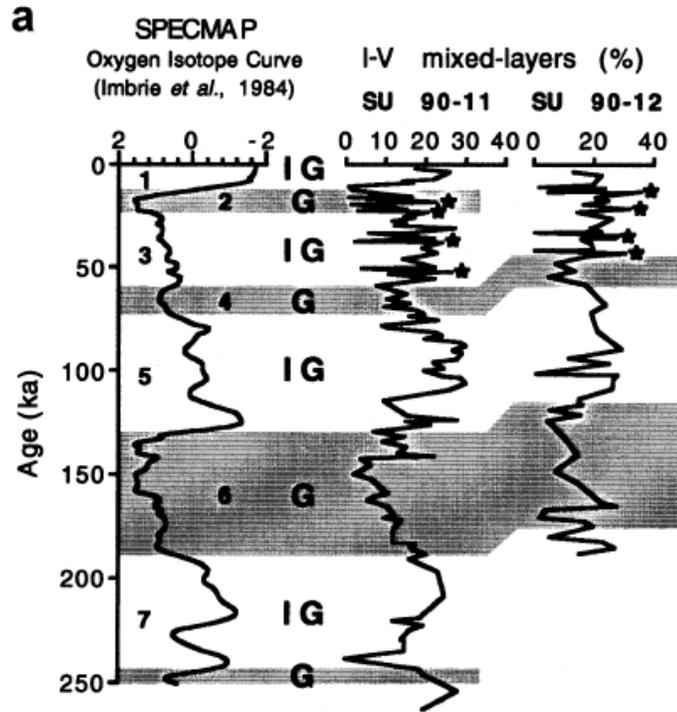


FIG. 4. Correlation between Oxygen Isotopic Curve (SPECMAP, Imbrie *et al.*, 1984) and percentages in the fine fraction of illite-vermiculite mixed layers at (a) Cores SU90-11 (off Newfoundland) and -12 (Shom abyssal plain); and (b) ODP site 902 (New Jersey continental slope). G = Glacial isotopic stage, IG = Interglacial isotopic stage, ★ = Heinrich level.

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