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Microscopic Observations on the First 300 Metres of CRP-2/2A, Victoria Land Basin, Antarctica

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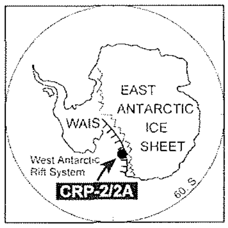
Abstract - From the upper 300 m of CRP-2/2A, twenty-six samples of diamicts and deformation structures have been thin sectioned. These have been analysed for texture, structure, diagenesis and plasmic fabric. The combination of certain microstructures (*e.g.* turbate and linear) and plasmic fabric development is indicative of grounded ice. Clear evidence for two grounded ice events (three samples) was found in the upper Oligocene part of the core. The interpretation of ten more samples is less certain, but as for CRP-1, is taken to point to grounded ice as well. There is a strong correlation between these indications for grounded ice and the basal part of cycles in the sequence stratigraphy.



INTRODUCTION

The Cape Roberts Project is a seven nation effort to study the climatic history of the Antarctic and the tectonic history of the Transantarctic Mountains, by drilling from a floating ice platform into Cenozoic strata in the Western Ross Sea, 14 km E of Cape Roberts (see Fig. 1 in the Introduction). The 624.25 m long core drilled in 1998, CRP-2/2A has an age span from early Oligocene to Pliocene/Quaternary.

As with CRP-1 (van der Meer & Hiemstra, 1998) thin section samples were collected to study the nature of diamicts and distinct deformation structures. All together, 46 samples with a common length of 10 cm were taken (Tab. 1). The samples were selected as representative of the full range of facies described in the Initial Report (Cape Roberts Science Team, 1999) as diamicts, massive diamicts, brecciated or laminated diamicts, deformed sediment, deformed stratification, and furthermore to be representative of structures such as faulted intraclasts, rotated clasts and water-escape structures. Further samples were taken of clastic dykes, some of them for further study together with members of the Cape Roberts Science Team. Details of the samples can be found in table 1. As with CRP-1 the aim of this micromorphological study is to establish which diamicts and structures are the result of grounded ice (van der Meer & Hiemstra, 1998) or of glacier-related processes such as iceberg scour.

METHODS

The thin sections were produced following the method described in van der Meer & Hiemstra (1998). Some stratigraphic higher and less indurated samples were damaged during transport. Thus, in these samples, information can only be derived from the interior of the elements and not from the apparently brecciated nature of the sample.

In this report, only the first 26 samples, covering the top three hundred metres are described. The remaining samples will be reported on at a later stage.

Upon first viewing of the finished thin sections, it appeared that sample C.591 contained a piece of metal, which was demonstrated at the 1999 Post Drilling Workshop. Together with the strongly brecciated nature of the sample this suggested that backwash had occurred during coring. However, further study of the metal in the remaining impregnated sample block revealed it to be a metal hook of a type that is in use in the Amsterdam laboratory, but not at the drill site. This implies that the core section is undisturbed, and that the metal hook must have fallen unto the wet sample surface during impregnation. As this sample consists of a homogeneous sand with floating angular intraclasts, no deformation caused by the metal object could be detected. Given the size of the sample enough undisturbed material remained for a proper description.

DESCRIPTION

In the description, the terminology set out by Brewer (1976) will be followed as this has proven equally applicable to sediments as to soils (van der Meer, 1996). When describing sediments at the microscale, we can distinguish between texture (including size, shape, distribution and composition), structure (including pores), diagenesis and plasmic fabric. These four groups are described here, even though this volume contains more detailed reports on for example grainsize or diagenesis. This full description is presented to allow for full comparison with other samples

Tab. 1 - Sample numbers, core intervals sampled, units and short lithology description (Cape Roberts Science Team, 1999).

sample nr	Lab no	unit	CRP	depth	abbreviated lithology description
VAN.1	C.586	2.1	2	13.61-13.71	brecciated diamict
VAN.2	C.587	2.1		19.23-19.33	massive diamict
VAN.3	C.588	2.2		25.63-25.73	laminated diamict
VAN.4	C.589	3.1		38.09-38.19	deformed diamict
VAN.5	C.590	3.1		40.67-40.77	deformed mixture
VAN.6	C.591	3.1		44.55-44.65	brecciated sand
VAN.7	C.592	3.1		47.25-47.35	brecciated sand
VAN.8	C.593	4.1		48.72-48.82	massive diamict
VAN.9	C.594	4.1/5		53.71-53.81	transition diamict to mud/sandstone; brecciated
VAN.10	C.595	6.1	2A	78.02-78.12	diamict
VAN.11	C.596	6.1		79.66-79.76	disrupted lenses
VAN.12	C.597	6.2		81.08-81.18	stratified diamict
VAN.13	C.598	6.2		86.08-86.18	massive diamict
VAN.14	C.599	6.3		91.20-91.31	deformed stratification
VAN.15	C.600	7.1		96.85-96.95	diamict
VAN.16	C.601	7.1		104.51-104.63	diamict with intraclasts
VAN.17	C.602	7.1		108.70-108.80	laminated diamict
VAN.18	C.603	8.1		121.82-121.92	massive diamict
VAN.19	C.604	8.1		122.37-122.47	deformed mix
VAN.20	C.605	8.1		129.62-129.71	deformed soft sediment
VAN.21	C.606	8.4		184.69-184.79	disturbed bedding, grading to massive
VAN.22	C.607	9.3		196.47-196.55	brecciated diamict
VAN.23	C.608	9.3		203.65-203.75	diamict
VAN.24	C.609	9.3		227.80-227.90	diamict
VAN.25	C.610	9.3		238.80-238.88	diamict with intercalated sandstone
VAN.26	C.611	10.1		298.80-298.92	laminated diamict
VAN.27	C.612	10.1		300.00-300.10	laminated diamict

in the Amsterdam collection, which contains material from other glaciated areas and environments.

In the terminology, one of the main distinctions is between skeleton and plasma. The transition between these two lies at the thickness of the thin section. Anything larger than the thickness of the sample can be studied as an individual particle, while anything smaller can only be seen as an ill-defined unit floating in an undefined groundmass. It should furthermore be kept in mind that thin section studies are effectively 2-dimensional and thus do not allow simple comparison with *e.g.* grainsize data obtained with other methods.

TEXTURE

When looking at the grainsize, the mode in the thin sections under discussion is usually small: less than 150 µm (Tab. 2). Only at some levels does it reach 250 µm. From the point of view of the sedimentary history of the grains, their shape is more interesting. In most samples subangular grains are common. Angular grains have been observed mainly above 79 mbsf (C.595, Tab. 2), while subrounded and rounded grains do not occur above 39 mbsf (C.590, Tab. 2) and occur more frequently going downcore. This in general subangular shape suggests that the majority of the grains is first cycle. The angularity cannot be ascribed to glacial abrasion as grains in tills in sedimentary basins like the North Sea Basin, contain a high proportion of rounded and well-rounded grains (unpublished data).

When looking at the distribution of the grains in the thin sections, in the majority of samples the grains are not distributed at random. Instead, they show some concentration into beds or clusters or wisps (Tab. 2). This will be further dealt with in the section on structure below.

From the point of view of composition we first consider the lithology of clasts. Crystalline rock-types are most prominent in the upper 100 mbsf (Tab. 2). In this case, crystalline is used as a general term, since the clasts can be metamorphic as well as volcanic. Vesicular basalt is present in only a few of the same samples, but has more obviously been observed between 100 and 190 mbsf. On the other hand, minute tephra particles (Fig. 1A) have been

Tab. 2 - Textural observations.

sample nr	CRP	depth mbsf	skeleton																		plasma
			modal size _m	shape				distri		composition											
				A	SA	SR	R	E	U	CR	SA	CS	CA	B	T	IC	MF	F	SP	D	
C.586	2	13.61/71	150		X				X	X	X				X	X	X	X	X		E
C.587		19.23/33	150		X				X	X		X	X		X	X	X	X	X		U
C.588		25.63/73	200		X			X		X	X	X		X		X	X	X	X		E
C.589		38.09/19	100	X	X				X	X	X	X	X		X	X			(		U
C.590		40.67/77	150		X	X	X		X			X			(	X			X		U
C.591		44.55/65	< 50	X				X							X	X			X		absent
C.592		47.25/35	< 50	X											X	X			X		absent
C.593		48.72/82	150		X	X		X		X			X		X	X	X	X			E
C.594		53.71/81	< 100	X	X	X		X		X				X	X	X			(		U
C.595	2A	78.02/12	125	X	X	X			X	X			X	X	X			X			U
C.596		79.66/76	100		X				X	X			X		X	X	X		X	X	U
C.597		81.08/18	150		X				X	X			X		X	X			X		U
C.598		86.08/18	150		X	X		X		X			X		X	X			(		E
C.599		91.20/31	125		X	X			X	X					X	X	(	X	X		U
C.600		96.85/95	200		X	X			X							X	X				U
C.601		104.51/63	not available																		
C.602		108.70/80	200		X			X		X				X	X				X		E
C.603		121.82/92	250		X	X	X		X	X				X	X	X				X	U
C.604		122.37/47	150		X	X	X		X				X	X	X	X	X		X	X	U
C.605		129.62/71	100		X				X						X	X					U
C.606		184.69/79	250		X				X					X	X	X	X				E
C.607		196.47/55	100			X			X							X		X			U
C.608		203.65/75	<100		X	X	X		X		X				X	X	X	X	(	X	U
C.609		227.80/90	<100		X			X								X		X		X	E
C.610		238.80/88	150	X	X	X	X	X								(	X				U
C.611		298.80/92	150		X				X	X						X	X				U
C.612		300.00/10	250		X	X	X		X	X							X		X	C	U

KEY
shape: A - angular, SA - subangular, SR - subrounded, R - rounded
distribution: E - even, U - uneven
composition: CR - general crystalline, SA - sandstone, CS - claystone, CA - carbonates, B - basalt, T - tephra, MF - mollusc fragments, F - microfossil, SP - sponge spicule, D - diatom; X - present, C - p n minor amounts
plasma: E - even, U - uneven distribution

observed in almost every sample above 204 mbsf. The latter is consistent with macroscopic provenance studies (Talarico et al., this volume).

Sandstone and claystone clasts have been observed in the upper 41 m of the core, with the exception of some sandstone in sample C.608 at 203.65/75 mbsf. Carbonate rocks (limestone and possibly marbles) shows a greater depth range. It first occurs at a depth of 122.37/47 mbsf, and is most common between 86.08/18 and 78.02/12 mbsf.

The most common compositional feature observed in the thin sections is the presence of intraclasts (Fig. 1B). These occur in almost every sample, albeit in variable quantities. In general they can be said to be frequently present in most samples. The occurrence of certain structures or the presence of certain constituents within intraclasts will be mentioned separately. It is important to note that, in most cases, the size of intraclasts is measured in the order of millimetres and that many of them are derived from sediments very similar to the host sediment. The only exception to the latter seems to be the very clayey intraclasts (Fig. 1C) for which no real counterparts exist in the core. This similarity may suggest that most intraclasts are of local derivation.

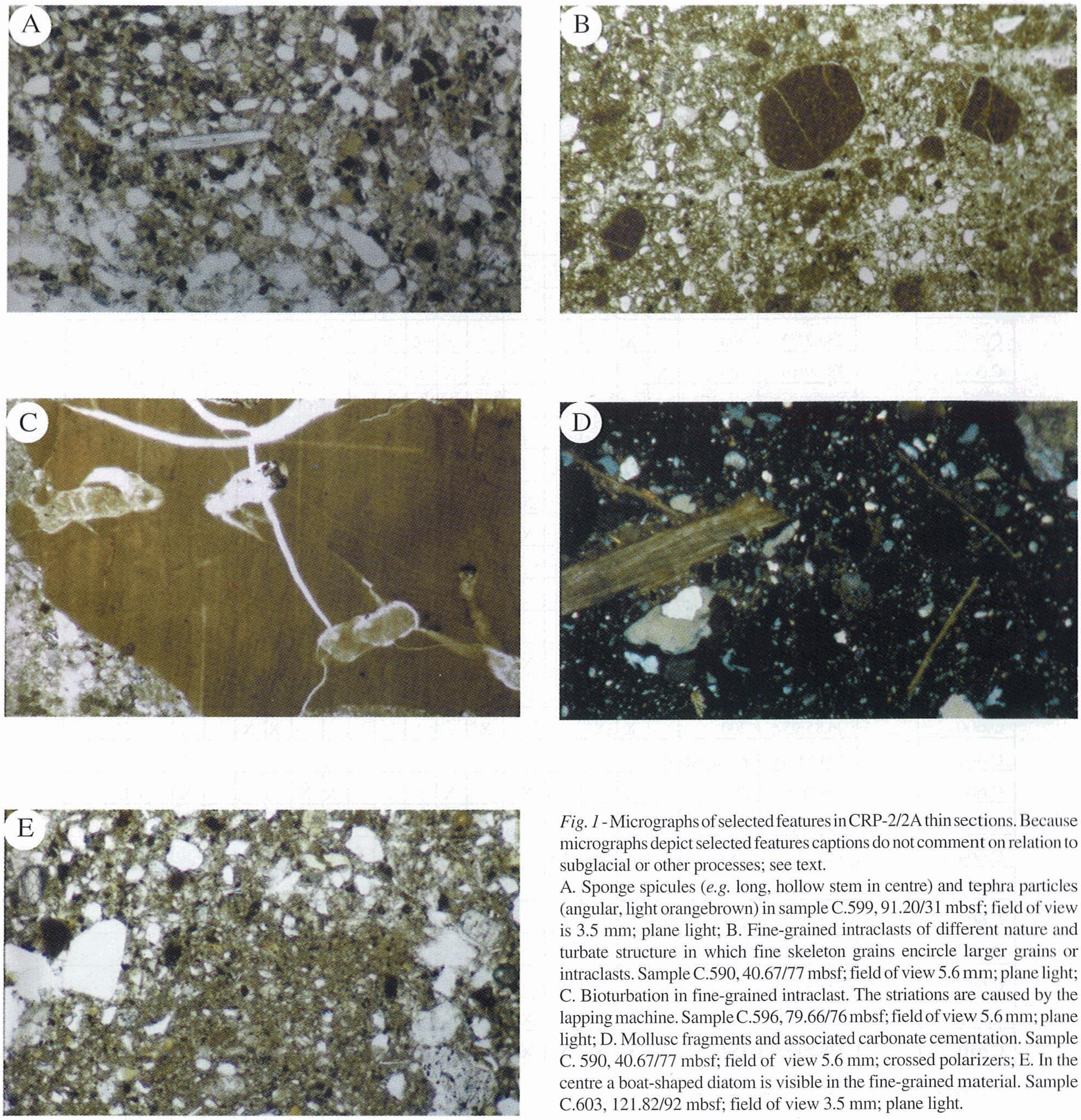


Fig. 1 - Micrographs of selected features in CRP-2/2A thin sections. Because micrographs depict selected features captions do not comment on relation to subglacial or other processes; see text.
A. Sponge spicules (*e.g.* long, hollow stem in centre) and tephra particles (angular, light orangebrown) in sample C.599, 91.20/31 mbsf; field of view is 3.5 mm; plane light; B. Fine-grained intraclasts of different nature and turbate structure in which fine skeleton grains encircle larger grains or intraclasts. Sample C.590, 40.67/77 mbsf; field of view 5.6 mm; plane light; C. Bioturbation in fine-grained intraclast. The striations are caused by the lapping machine. Sample C.596, 79.66/76 mbsf; field of view 5.6 mm; plane light; D. Mollusc fragments and associated carbonate cementation. Sample C. 590, 40.67/77 mbsf; field of view 5.6 mm; crossed polarizers; E. In the centre a boat-shaped diatom is visible in the fine-grained material. Sample C.603, 121.82/92 mbsf; field of view 3.5 mm; plane light.

but under this heading only compound packing voids are mentioned in a few samples. These are all samples in which homogeneous sands are present, either as beds, or as the host sediment. Apart from these, no natural voids have been observed (at low magnification) in the samples. All the samples show voids produced in the production process, albeit by transport, drying, or removal of incompletely impregnated spots. Because these artificial voids provide no useful information they are not indicated in table 3.

Many thin sections show some form of bedding, which occurs most frequently in the lower part of the sequence studied (Tab. 3). In this lower part the bedding is also often more distinct, while diffuse bedding is found higher up in the core. Occasionally, bedding has been observed only in intraclasts and not in the host sediment; in one case (C.594) this enabled the detection of bioturbation in an intraclast (Fig. 1C). Observations on bedding, however, may not be representative for the core, as sample selection was based on other criteria.

Direct evidence of shearing of the sediment has only been found in sample C.611 at a depth of 298.80/90 mbsf, while possible shear structures have been observed in six more samples (Tab. 3). However, in this later group we are dealing with for example lineations (see below) that are not necessarily related to shear. Hence they are indicated with a question mark in table 3.

Brecciation (Fig. 1F) has only been observed above 54 mbsf and is here defined as brecciation *in situ* as demonstrated by the partly jigsaw nature of the fragments. Not included is the structure caused by the falling apart of samples during transport. Although the resulting structure

Tab. 3 - Structural and other observations.

sample nr	CRP	depth mbsf	structure								plasmic fabric					diagenesis			
			voids	other															
				bed	she	bre	tur	par	cas	lin	SK	LA	MA	UN	OM	car	sil	gyp	sul
C.586	2	13.61/71					X			X	C			C	C				
C.587		19.23/33		D					X		X					C			
C.588		25.63/73					X		X	C	X				C				
C.589		38.09/19		C		X										X	X	X	X
C.590		40.67/77				X	(								C	X	X	X	
C.591		44.55/65	CPV			X								C		C		X	
C.592		47.25/35	CPV	C										C				X	
C.593		48.72/82					X			(					C				
C.594		53.71/81		C		X				V						X		X	
C.595	2A	78.02/12	CPV	W												X			X
C.596		79.66/76		I	?					(				C	C	X			X
C.597		81.08/18		I	?		(								C	X	X		
C.598		86.08/18			?		X	(		X									
C.599		91.20/31	CPV	D	?		(			X					C	X			
C.600		96.85/95		D						X				(	C				
C.601		104.51/63	not available																
C.602		108.70/80					X	X								X			
C.603		121.82/92		X	?		(		X		(	(	(	(	C				
C.604		122.37/47	CPV	X	?		X	X+		X					C				
C.605		129.62/71		X			X			X					C				
C.606		184.69/79		X			X			X					C	C		X	
C.607		196.47/55		X											C	X			X
C.608		203.65/75		X			(				(				C				
C.609		227.80/90		D			(		X	(					C	?			X
C.610		238.80/88		X			X			X					C				
C.611		298.80/92		X	X		X			X	X			X	C				
C.612		300.00/10		X			X	X		(					C				

KEY
voids: CPV - compound packing voids
other: bed - bedding, she - shear, bre - brecciation, tur - turbates, par - parallel, cas - finegrained casing, lin - lineation; D - diffuse, W - wavy, I - inclined, C - in intraclast, X - present, (- present in minor amounts, ? - not clear, + - comet structure, V - vertical structure
plasmic fabric: SK - skelsepic, LA - lattisepic, MA - masepic, UN - unistrial, OM - omnisepic
diagenesis: car - carbonates, sil - silicium, gyp - gypsum, sul - sulfide

Many thin sections show some form of bedding, which occurs most frequently in the lower part of the sequence studied (Tab. 3). In this lower part the bedding is also often more distinct, while diffuse bedding is found higher up in the core. Occasionally, bedding has been observed only in intraclasts and not in the host sediment; in one case (C.594) this enabled the detection of bioturbation in an intraclast (Fig. 1C). Observations on bedding, however, may not be representative for the core, as sample selection was based on other criteria.

Direct evidence of shearing of the sediment has only been found in sample C.611 at a depth of 298.80/90 mbsf, while possible shear structures have been observed in six more samples (Tab. 3). However, in this later group we are dealing with for example lineations (see below) that are not necessarily related to shear. Hence they are indicated with a question mark in table 3.

Brecciation (Fig. 1F) has only been observed above 54 mbsf and is here defined as brecciation *in situ* as demonstrated by the partly jigsaw nature of the fragments. Not included is the structure caused by the falling apart of samples during transport. Although the resulting structure can be described as brecciation and the breaking up of the sample may have followed existing lines of weakness (and would then demonstrate the presence of a structure), this is not included in the list of observations.

Turbate structures (Figs. 1B, 1G), defined as fine skeleton grains circling around a nucleus of fine-grained material or around a corestone (van der Meer, 1993; 1997a) are common in about half the thin sections. In six samples they occur only in intraclasts and not in the host sediment; in the other samples (Tab. 3) they are usually common. The parallel structure indicated in the next column, relates to a similar arrangement, but in this case small, elongate grains are lined up parallel to the surface of larger grains. Both types of structures are related to rotational movements of the particles (van der Meer, 1993). Special mention should be made of the comet structure observed in sample C.604 and which is similar to the structure described from CRP-1 (van der Meer & Hiemstra, 1998).

The complementary structure, in which fine-grained material is present as a shell around a larger grain, is also present. It is indicated as 'casing' in four samples.

Lineations, structures in which grains show distinct alignments, have been observed in about half the samples, they range from common to rare. In one case (C.588), a lineation was observed in an intraclast. Sample C.594 stands out because of a vertical structure, suggested by strong vertically oriented fracture planes. It is not clear whether this is an original structure, because this sample shows two phases of brecciation, the original phase being overprinted during transport.

Applying the criteria set out in Hiemstra & van der Meer (1997) for the recognition of fractured grains, these have only been observed in sample C.598 (Fig. 1H). The importance of this is that quartz grains do not fracture easily while encased in soft sediment. It takes serious point pressure before this will happen, and such pressures can be achieved in subglacial conditions.

PLASMIC FABRIC

Birefringence patterns caused by the presence of oriented domains of clays are known as plasmic fabric (Brewer, 1976). Their presence is caused by orientation or re-orientation of clay particles in a stress field. It may be assumed that different geological and sedimentological processes demonstrate different stress fields and, consequently, different arrangements of plasmic fabrics. The strength of development of the plasmic fabric must in a complicated way be related to the effective strength of the stress field, the duration of the acting stress field, to the amount of clay present and to the rheology which is related to pore water pressure during the (de-)formational process. However, detectability of plasmic fabric is not always easy, as it may be obscured by the presence of, for instance Fe-staining, which turns the thin section opaque, or by the presence of micrites, which undo the polarising effect of the microscope.

As in CRP-1, plasmic fabric is not well developed in the thin sections of CRP-2/2A. Table 3 shows that in the host sediment it is only present in a few samples. A skelsepic plasmic fabric, assigned to rotational movement of the particles (van der Meer, 1993, 1997a), is present in samples C.587 and C.588, both in the Quaternary/Pliocene part of the core. Lower down it is present in a weak form in samples C.603 (121.82/92 mbsf) and C.608 (203.65/75 mbsf) and it is clearly present in C.611 (298.80/92 mbsf). In sample C.603 it is present in combination with equally weakly developed lattisepic, masepic and unistrial plasmic fabrics (van der Meer, 1993), which makes this the most varied sample with respect to plasmic fabric development. In sample C.611 the skelsepic plasmic fabric occurs in combination with a unistrial plasmic fabric of equal strength. A weakly developed unistrial plasmic fabric has also been observed in sample C.600 (96.85/95 mbsf).

As mentioned above, intraclasts are present in most thin sections. In the majority of samples these intraclasts are characterised by a well developed omnisepic plasmic fabric (van der Meer, 1993), occasionally in combination with a unistrial plasmic fabric (Fig. 1J). In seven samples, all in the upper 109 mbsf of the core, the intraclasts do not show a plasmic fabric development.

The difference in plasmic fabric development between intraclasts and host sediment shows that the stress field to which the intraclasts have been subjected was stronger or more effective than the stress field acting on the host sediment.

DIAGENESIS

In fine-grained sediments birefringence can be produced by crystal growth of neoformations (unpublished). In order to distinguish such 'secondary' microstructures from primary microstructures, a record is made of all diagenetic features encountered in the thin sections. Another reason for paying attention to diagenesis is that the detectibility of microstructures is influenced by staining.

Table 3 first lists the occurrence of secondary carbonates (Fig. 1K); first encountered in intraclasts in sample C.587. Although such an occurrence in intraclasts is found at a few more places in the core, there are further samples in which secondary carbonates occur in the host sediment. Usually cementations are found in irregularly shaped bodies of variable size, without any indication of what caused the precipitation at that particular spot. In sample C.596 (79.66/76 mbsf) secondary carbonates were observed to be intimately intertwined with mollusc fragments (Fig. 1D), suggesting that, in this case, there is a biological origin for the carbonates. However, this is the only sample in which this has been found; all other observations of mollusc fragments show smooth surfaces, without dissolution pits. In sample C.589 (38.09/19 mbsf) secondary carbonates appear to occur side-by-side with siderite. This is the only observation of this kind and it awaits confirmation.

Silica has been observed in three samples, two of which are remarkably shallow as they occur between 41 and 38 mbsf. Care must be taken, however, because Aghib et al (this volume) only found silica cement below 400 mbsf. Gypsum (Fig. 1L) is most common in the same depth range as silica, but has also been observed at a depth of 184.69/79 mbsf (C.606). This mineral occurs as bundles of crystals, whereas the silica appears as a more diffuse pore-filling.

Sulphides have been observed a few times, sometimes as nodules in the sediment, occasionally it fills the chambers of microfossils.

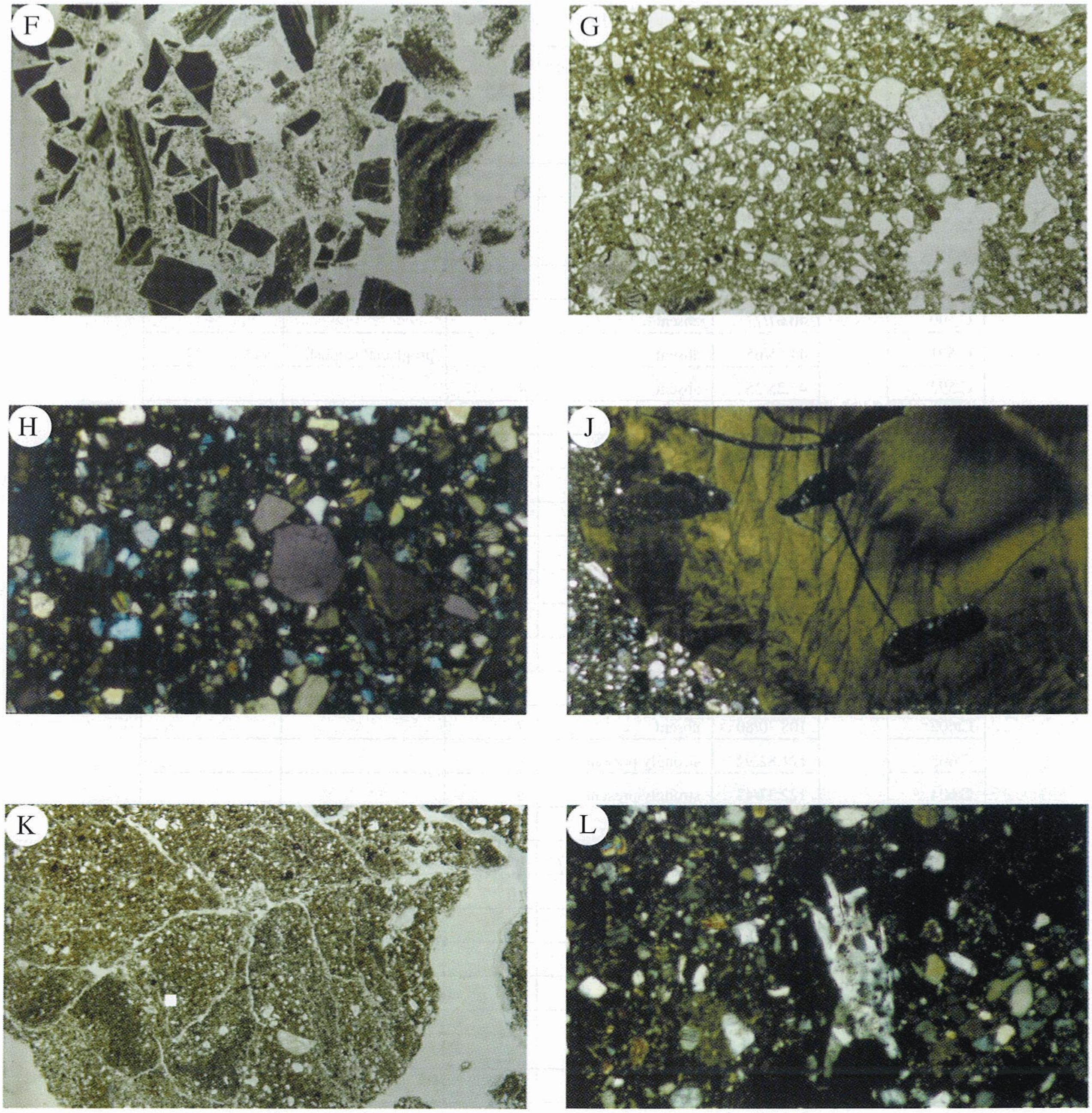


Fig. 1 - continued.
F. Brecciation of fine-grained, laminated material has resulted in angular intraclasts embedded in a very uniform sand host. Sample C.592, 47.25/35 mbsf; field of view 18.0 mm; plane light.; G. Turbate structure, in which fine skeleton grains encircle a common point of origin. Sample C. 586, 13.61/71 mbsf; field of view 9.0 mm; plane light; H. Fractured grain caused by pointloading. Sample C.598, 80.08/18 mbsf; field of view 3.5 mm; crossed polarizers and superposition wedge; J. Strong omnisepic and kinking plasmic fabric (interweaving, vertical black lines; cf. van der Meer, 1993) in the same bioturbated intraclast shown in 1C. Sample C.596, 79.66/76 mbsf; field of view 5.6 mm; crossed polarizers.; K. Folded zone with grey carbonate cement in uniform diamict. Sample C.589, 80.08/18 mbsf; field of view 18.0 mm; plane light.; L. Gypsum crystals (righthand side) in diamict. Sample C. 590, 40.67/77 mbsf; field of view 3.5 mm; crossed polarizers.

deposition, but there may also be a considerable time gap in between. Although cementation has been observed in intraclasts, this is quite rare and the intraclasts were probably produced, transported and incorporated in an unlithified state. The presence of a well developed plasmic fabric in many intraclasts, while such a fabric is absent in the host sediment, suggests that this plasmic fabric was acquired prior to or during production of the intraclasts, possibly during transport, but certainly not during deposition. It is also clear that this happened in a stress-field that was strong enough to cause (re-)orientation of the clays inside the intraclast.

The texture, structures and the widespread occurrence of biological components (Tab. 2) indicate that most, if not all of the sediments originated in a marine environment. However, this does not make them (glacio-)marine by definition. If other processes have restructured the sediments without changing their texture, then it is this later process that provides the genetic label for the sediments. A subglacially restructured marine deposit

Tab. 4 - Indications for grounded ice and correlation with sequence stratigraphy and deformational processes.

sample nr	CRP	depth mbsf	micromorphological indications for grounded ice	sequence nr	deformation acc. to Passchier (this volume)	
					process	depth mbsf
C.586	2	13.61/71	present	1	unknown	12-16
C.587		19.23/33	absent	1		
C.588		25.63/73	present	2		
C.589		38.09/19	absent	3		
C.590		40.67/77	absent	4		
C.591		44.55/65	absent	4	proglacial icepush	44.91-47.87
C.592		47.25/35	absent	4		
C.593		48.72/82	present	4		
C.594		53.71/81	absent	5	subglacial shear	50-71
C.595	2A	78.02/12	absent	6		
C.596		79.66/76	absent	6		
C.597		81.08/18	absent	6		
C.598		86.08/18	present	6		
C.599		91.20/31	present	6	subglacial shear ?	90.67-92.86
C.600		96.85/95	absent	7	in situ fracturing	93.85-96.64
C.601		104.51/63	not available			
C.602		108.70/80	absent	7		
C.603		121.82/92	strongly present	8		
C.604		122.37/47	strongly present	8		
C.605		129.62/71	present	8	in situ fracturing	131-132
C.606		184.69/79	present	9	mass-gravity flow	183.35-185.95
C.607		196.47/55	absent	10		
C.608		203.65/75	absent	10		
C.609		227.80/90	present	10		
C.610		238.80/88	present	10		
C.611		298.80/92	strongly present	11	(clastic dyke) unknown	297.4
C.612		300.00/10	present	11		

extant glacial and marine sediments have been heavily reworked. This reworking may have immediately followed deposition, but there may also be a considerable time gap in between. Although cementation has been observed in intraclasts, this is quite rare and the intraclasts were probably produced, transported and incorporated in an unlithified state. The presence of a well developed plasmic fabric in many intraclasts, while such a fabric is absent in the host sediment, suggests that this plasmic fabric was acquired prior to or during production of the intraclasts, possibly during transport, but certainly not during deposition. It is also clear that this happened in a stress-field that was strong enough to cause (re-)orientation of the clays inside the intraclast.

The texture, structures and the widespread occurrence of biological components (Tab. 2) indicate that most, if not all of the sediments originated in a marine environment. However, this does not make them (glacio-)marine by definition. If other processes have restructured the sediments without changing their texture, then it is this later process that provides the genetic label for the sediments. A subglacially restructured marine deposit becomes a basal till, while a sediment restructured by gravity becomes a mass-flow deposit.

In CRP-1 the combination of rotational (turbate), linear, shear and comet structures, together with the presence of a plasmic fabric, points to a subglacial environment (van der Meer & Hiemstra, 1998). Using the same set of criteria, when looking at table 3, there are three samples that attract attention: C.603 (121.82/92 mbsf), C.604 (122.37/47 mbsf) both in unit 8.1 and C. 611(298.80/92 mbsf) from unit 10.1. In all three samples the development of these structures is strong enough to interpretat them as being the result of subglacial processes, *i.e.* by grounded ice. Given the close proximity of samples C.603 and C.604, and within the same lithological unit (Tab. 1) this

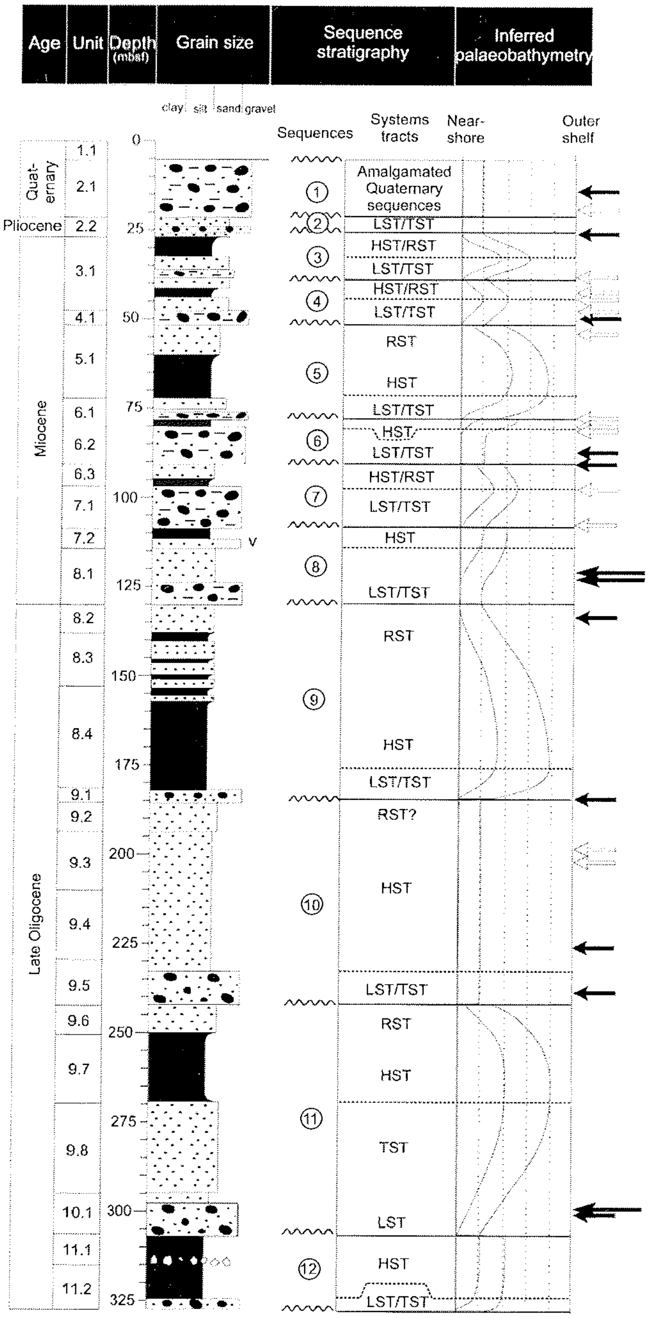


Fig. 2 - Correlation between micromorphology and sequence stratigraphy (see introduction, this volume, for explanation of main diagram). The large black arrows indicate samples with convincing evidence for grounded ice; the small black arrows point at samples with indications for grounded ice; the open arrows locate samples without traces of grounded ice.

must relate to the same event. Because these diamicts are the product of grounded ice, they are thus subglacial tills, even though their glaciomarine origin can still be discerned.

Apart from these three samples, which are very clear, there are a number of samples which show at least some of the structures mentioned. However, the evidence is insufficient to categorically state that they represent grounded ice. Many of these samples also show bedding or traces of bedding, which is sometimes taken to exclude a glacial origin for these sediments. However, bedded or laminated tills are very common, and bedding in tills can easily be the result of tectonism (van der Meer, 1996).

Table 4 lists the interpretation of the thin sections down to 300 mbsf, and relates them to the sequence stratigraphy for CRP-2/2A (Cape Roberts Science Team, 1999) as well as to deformation structures and brecciation as described by Passchier (this volume). A further correlation with the sequence stratigraphy is presented in figure 2. At the two levels where grounded ice has been inferred, *i.e.* around 121-122 mbsf and 298 mbsf, it is obvious that these occur towards the base of sequences 8 and 10, where a nearshore palaeobathymetry related to the glacial advance and glacial maximum is indicated. When we note the position of those samples which appear to non-categorically indicate grounded ice, there is a strong correlation with the same sequence stratigraphic position, *i.e.* towards the base of the sequence. This could be taken to support the indication for grounded ice. There are few exceptions to this correlation; for example C.602 (108.70/80 mbsf), which is situated towards the base of sequence 7, but shows only turbate/parallel structures (see also van der Meer & Hiemstra, 1998). Figure 2 shows the inferred palaeobathymetry in sequences 1 and 10 to be nearshore throughout, suggesting a relation to a glacial cycle of advance and retreat. Thin sections from the higher part of sequence 10 (C.607, C.608) and the lower part of sequence 1 (C.587) show no microstructures indicative of grounded ice. In C.608 there are weak traces of turbation, combined with the presence of a weakly developed plasmic fabric.

In the case of the two events that left the clearest traces of grounded ice, *i.e.* around 121-122 mbsf and 298 mbsf, the thin sections are combined with one thin section each from the lower part of the diamictite. These lower thin sections (C.605 resp. C.612) fall within the group with inconclusive indications of grounded ice. This suggests that the microstructures are better developed higher up in the diamicts, and this could be related to different subglacial conditions during advance and maximum. For a further discussion of the relation between microstructures and position under an overriding glacier see van der Meer & Hiemstra (1998).

Table 4 also shows the correlation with deformational processes inferred by Passchier (this volume). From the top down this starts with an unknown origin for a 'crackle breccia ?', where we find inconclusive indications of grounded ice. It should be stressed that under the microscope the Quaternary sediments give an overall impression of having originated as (glacio-)marine sediments, which have first been restructured by glacial overriding and then remobilised by gravitational processes.

Sample C.591 has been taken just above a zone with chaotic breccias and thrusts linked by Passchier to proglacial icepush. This thin section does not show any microstructures related to glacial proximity, which is compatible with a proglacial setting, while at the microscale it also shows brecciation. More problematic is sample C.594, which according to the interpretation of Passchier, should come from a 21 m thick zone of breccias and cataclastic shearzones caused by subglacial shear. However, in thin section C.594 we have not found any trace of microstructures indicative of grounded ice. The clear vertical structure in this thin section cannot be taken to be indicative either; instead a vertical orientation of clasts is often taken as excluding a subglacial environment.

There is better coherence between sample C.599 where inconlusive indications of grounded ice are present and the indication by Passchier for this interval as a 'subglacial shearzone ?'. Sample C.600, with no indication for grounded ice (although with indications for shearing), was collected just below a zone of *in situ* fracturing, and these data are certainly not mutually exclusive.

Passchier indicates the presence of crackle breccia between 131 and 132 m, just below a diamictite, as being caused by *in situ* fracturing. However, this zone is just below thin section samples C.603, C.604 and C.605, thought to be indicative of one of the two prominent glacial events. In the light of the thin section study, it appears more likely that this *in situ* fracturing is related to the glacial event. Folds and rotated clasts between 183.35 and 185.95 mbsf are ascribed by Passchier to mass-gravity flow, while sample C.606 from the central part of this zone shows the presence of inconclusive indications of grounded ice. Isolated rotational structures are known from for example active subaerial flowtills (Lachniet et al., 1999) and have been described by Kluiving et al. (1999) from Ross Sea sediments interpreted as mass-flow deposits. The presence of non-indicative microstructures for grounded ice and the position towards the base of a sequence has already been taken as strengthening the case for grounded ice deposition. Besides, allowing for some time between the samples, the two interpretations are not mutually exclusive.

Finally the occurrence of a clastic dyke of unknown origin, but occurring directly above our second prominent glacial event (around 298 mbsf), suggests a relation between the two.

The thin sections listed as 'absent' with regard to indications for grounded ice (Tab. 4) must have a different origin. Figure 2 demonstrates that many of these correlate with higher sea level stands in the inferred palaeobathymetry. In so far as these thin sections were taken in diamicts they are most likely to be diamicts resulting from mass-movement, possibly through reworking of previously deposited diamicton. In that case the history may be complicated, as the sediments most likely originated as (glaci-)marine deposits, were restructured by subglacial processes and once again restructured by mass-movement. Comparing table 2 with table 4, does not reveal any compositional relationship between samples and the inferred relation to grounded ice or its absence.

Samples C.591 and C.592 both consist of a host of sand of uniform grain-size, and without any structure. In this host are floating a large number of angular intraclasts, sometimes they are finely bedded, and can partly be reassembled as in a jigsaw puzzle. Here we are obviously dealing with mass-movement, but of a different nature. Both samples are correlatable with the highest inferred sea level within sequence 4 (Fig. 2).

There is a remarkable correlation between indications for grounded ice or absence of such indications and the sequence stratigraphy, see figure 2. There are only a few samples that do not fit into this correlation. Further studies are needed to establish why the latter is the case. Similarly this correlation needs to be tested in the remaining part of core CRP-2/2A, as well as in cores CRP-1 and CRP-3.

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