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Micromorphology of Miocene Diamicts, Indications of Grounded Ice

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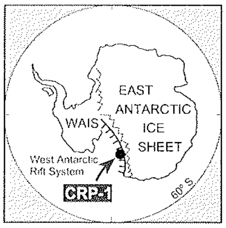
Abstract - Five samples of diamicts from different levels of the Miocene part of the CRP-1 core have been thin sectioned. Observations in the thin sections relate to texture, diagenesis, structure and plasmic fabric. The combination of observed microstructures leads to the interpretation that three samples are certainly indicative of grounded ice, *i.e.* they are basal tills, whilst the other two samples also possibly represent the same environment.



INTRODUCTION

Five samples were analysed micromorphologically in order to give a more specific answer concerning the origin of some of the diamicts in the Miocene section of CRP-1. Details on the sample intervals are presented in table 1. CRP-1 is a core drilled in 150 m of water at 77.008°S and 163.755°E, in the Ross Sea, Victoria Land Basin (see Fig. 1 in Introduction).

Thin sections were prepared following the method outlined in van der Meer (1996), except that acetone was used as a thinner instead of monostyrene, and that the samples were washed with acetone first to replace interstitial water. The thin sections are not of perfect quality, because of partial impregnation problems. However, enough material was available for analyses and for comparison with other thin section samples of Antarctic core material (Hiemstra & van der Meer, 1998; van der Meer et al., 1998).

The five samples come from diamict layers that have all been described by the Cape Roberts Science Team as closely related to glaciers, *i.e.* proximal glacimarine (Unit 5.3), fluctuating volumes of ice-rafted debris (Unit 5.6), high density iceberg sedimentation near fluctuating ice margin (Unit 6.1) and high density iceberg or grounding-line sedimentation (Unit 6.3). However, lithologically there is no clear evidence of grounded ice at the locality of CRP-1. In this paper we examine the microstructures of the diamicts for evidence of direct glacial influence on the sediments.

Tab. 1 - Sample depths as indicated in the paper, core intervals, units and lithology description (Cape Roberts Science Team, 1998).

Sample depth (mbsf)	Interval (mbsf)	Unit	Log description
63.05	63.03 - 63.07	5.3	fine sandstone, associated with sandy diamictite
78.99	78.94 - 79.04	5.6	clast-rich sandy diamictite
105.58	105.53 - 105.63	6.1	clast-poor sandy diamictite
123.25	123.19 - 123.30	6.3	clast-poor muddy diamictite
134.45	134.40 - 134.50	6.3	clast-poor muddy diamictite

DESCRIPTION

The terminology used here was originally developed for soil micromorphology by Brewer (1976). Previous work showed however that the nomenclature is also appropriate to sediments (van der Meer, 1996).

In describing thin sections, observations fall into four groups: texture, diagenesis, structure and plasmic fabric (van der Meer, 1996). Each of these headings can be subdivided as is desired. As such, a selection of features recognised in this study is listed in table 2.

Tab. 2 - Selected micromorphological observations.

Sample (mbsf)	Texture (intraclasts)		Diagenesis (cementation)	Structures		Plasmic fabrics		
	diamict	clay		rotational	linear	'comet'	unistrial	omnisepic + unistrial (in intraclasts)
63.05	*		***	***	*			
78.99	**	**	*	***		*	*	**
105.58	**		*/**	*	*			
123.25	**	**		**	***	*	*	**
134.45	**	**		***	**			*

Note: *** = abundant; ** = common; * = rare.

TEXTURE

Micromorphologically we distinguish a decrease in modal grain-size going down core, the only exception being the sample from 78.99 metres below sea floor (mbsf). It must be realised that this is based on 2-D visual estimations and measurements in the thin sections, and that they cannot be automatically compared with grain-size data as determined by other techniques. For more detailed information regarding grain-size we refer to De Santis & Barrett (this volume). We observed that the grain-shape of the skeleton grains in the diamicts varied between subangular to subrounded without any apparent trends with depth or with grain size. The distribution of the skeleton grains is random in most samples, only the central part of the sample from 123.25 mbsf contains an irregular shaped, non-uniform coarser zone, consisting of diffusely bounded, differently sized bands. The sample from 63.05 mbsf contains a thin band of sandy-silty material at the top, but because it is not known whether this is part of a larger unit, nothing much can be said about its character. Of particular importance is the common to abundant presence of intraclasts in the samples. These are mostly rounded and either of a diamictic or clayey nature (Fig. 1). The latter could be claystone fragments, as suggested by a dark staining. The intraclasts appear to be composed of 'foreign' material, which has been incorporated in the host sediment.

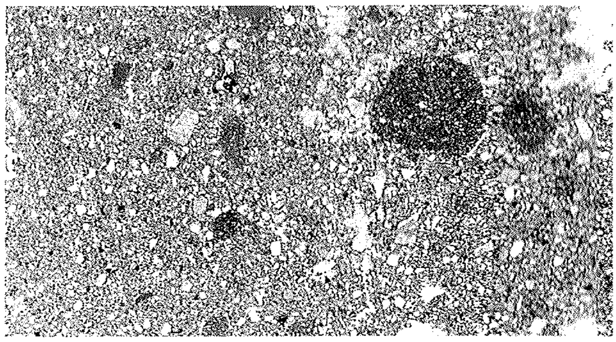


Fig. 1 - Thin section from 123.25 mbsf; general view of the diamict. Note the high grain density and the large number of intraclasts, either of a diamictic or of a clay nature. Plane light, width of view is 12.0 mm.

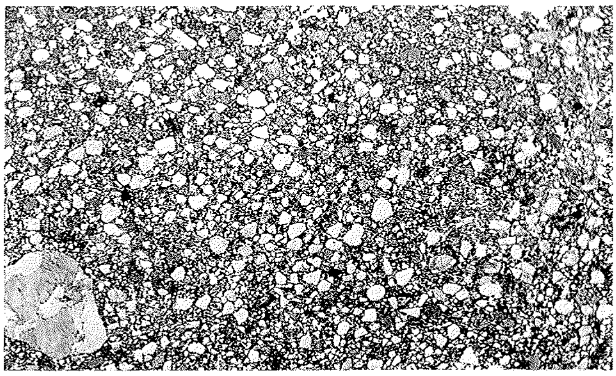


Fig. 2 - Thin section from 63.05 mbsf; rotational structure depicted by circular alignment of skeleton grains. Plane light, width of view is 18.0 mm.

DIAGENESIS

The samples from 63.05, 78.99 and 105.58 mbsf all contain patches of carbonate precipitation. The occurrence of carbonate cement being most abundant in the shallowest sample. The cementation appears non-uniform, and shows irregular boundaries with non-cemented parts of the sample. In the 105.58 mbsf sample patches of cement occur either as a rim around clasts or as augen-shaped lenses which follow the overall dipping structure within this sample. Carbonate concretions are described in more detail in Claps & Aghib (this volume).

STRUCTURE

Three types of structures are indicated in table 2. The first column indicates the presence of rotational structures, one of the most common microstructures in glacial sediments (van der Meer, 1993). These structures, in which fine grains form circles around either a larger grain or around a stiff nucleus, typically form through shearing by grounded ice (van der Meer, 1997). In the five samples presented here, only the sample at 105.58 mbsf shows a weak development of this structure; in the others it is strong to very strong. Although rotational structures can also occur in mass movement deposits like flowtills (Menzies & Zaniewski, pers. comm.), they appear to occur mainly as isolated features in such deposits. In the samples presented here they occur as continuous structures throughout the samples, where individual circles seem to be 'in contact with each other' (Fig. 2).

Another second structural feature indicated in table 2 is the presence of lineations in the thin sections. These appear as lines, centimetres long, that are mainly made up of aligned grains, in contrast to the typically random grain distribution. Lineations are present in four of the five samples, and appear most strongly in the lower ones. In the sample from a depth of 123.25 mbsf the lineations occur in a band, up to 5 cm wide, that runs obliquely through the sample (Fig. 3). Although there are a few cross-cutting lineations, most of them dip parallel and in the same direction as the band. It is noticeable that in the zones above and below this band rotational structures dominate, whereas only a few of them are present in between more widely spaced lineations. In the other samples where such lineation structures are present, they occur less systematically and more widely distributed.

The third and last indicated structure in table 2 occurs in the samples from 78.99 and 123.25 mbsf. Both demonstrate an example of a 'comet' structure (Menzies, in van der Meer & Menzies, 1998), in which a clast acts as a core from which tails of fine-grained materials and/or lineations originate (Fig. 4). In the sample from 78.99 mbsf the fine-grained material at the head of the structure consists of clays which show a clear plasmic fabric (see below). The same sample is the only one in which wisps of clay have been deformed as shown by the skeleton grains that have been pressed into them. These wisps are very small (<2 mm) and occur dispersed throughout the sample.

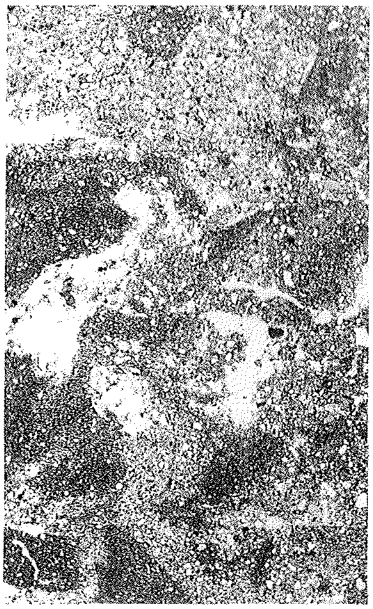


Fig. 3 - Thin section from 123.25 mbsf; lineations. Plane light, width of view is 18.0 mm.

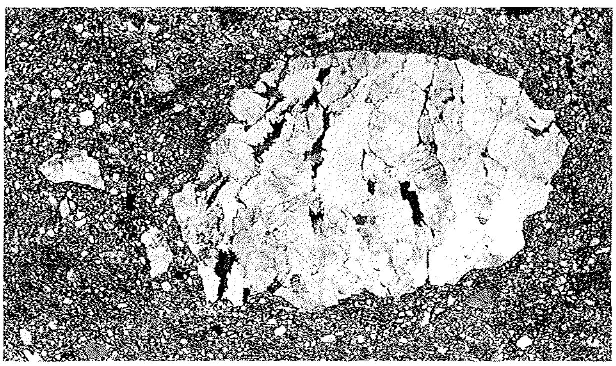


Fig. 4 - Thin section from 123.25 mbsf; comet structure consisting of a crystalline clast with tails of fine-grained material. Plane light, width of view is 18.0 mm.

Although the thin section from 105.58 mbsf only shows a minor development of the linear and rotational structures, it is nevertheless a sample with a very clear overall, macroscopic structure. This is outlined by a consistent dip of all elongate elements: clasts, fine-grained patches and augen-shaped areas of cementation.

PLASMIC FABRIC

Plasmic fabric is defined as 'birefringence models of the plasma, based on the optical properties of the particles as well as the optical properties caused by the orientation of particles relative to each other'. In this definition plasma can be regarded as all material that is finer than the thickness of the thin section (about 25 μm) and which, consequently, can no longer be seen as individual particles. A number of such models can be recognised (van der Meer, 1996), of which only two have been observed in this set of samples.

Birefringence is present in the clay intraclasts as omnisepic and unistrial plasmic fabric. Omnisepic indicates that all clay particles are oriented and show a clear birefringence when viewed under crossed polarisers. Unistrial plasmic fabric indicates that relatively long, continuous lines of birefringence are present; these can also be indicated as discrete shears (van der Meer, 1993). However, the fact that both plasmic fabrics are present in intraclasts indicates that these have been subjected to stress sometime in their history. Most likely this fabric was developed during break-up and thus has no relation to the stress history of the host sediment.

In the sample from 78.99 mbsf a unistrial plasmic fabric has been observed in the clayey material in the head of the comet structure. Thin, parallel lines of birefringence can be seen to curve with the overall shape of the structure. Furthermore a distinct omnisepic plasmic fabric is present in the minute wisps of clayey material that occur dispersed throughout the sample. Thus there is good evidence that this sample has been subjected to considerable stress.

In the sample from 123.25 mbsf a weak presence of unistrial plasmic fabric is indicated. There it has been observed within some plasma-rich areas and parallel to the lineations indicated in the previous section. Besides there was at least a suggestion of plasmic fabric development in some of the diamictic intraclasts.

The visibility of the plasmic fabric is also influenced by the carbonate content of the sediment (van der Meer, 1993). As some of the samples, *e.g.* 63.05 and 105.58 mbsf, demonstrate the presence of carbonate cements, it may well be that the actual reorientation of the clays is stronger than detected.

DISCUSSION AND CONCLUSIONS

We start this section by emphasising the high number of intraclasts in most of the samples presented here. Their frequency suggests that we can expect these in many other parts of the core as well. The importance of this observation is that bulk samples taken for grain size, clay mineralogy or siliceous microfossils, for example, may give biased results as long as intraclasts are not removed or their composition tested. Micro-morphological analyses of the intraclasts (composition, roundness, plasmic fabrics) seem to indicate that most of them have been incorporated from a different source into the host sediment.

The interpretation of micromorphological observations is not a matter of looking for single diagnostic criteria (van der Meer, 1993). Instead, it is the occurrence of combinations of observations that point at a certain origin (van der Meer et al., 1994). Fluviatile sediments show different deformational microstructures (van der Meer et al., 1996) from lacustrine sediments (van der Meer & Warren, 1997), from glacimarine sediments (Solheim & van der Meer, unpublished data) or from marine mass-movement sediments (Hiemstra et al., unpublished data), because each type of sediment has been subjected to different types of stress-fields or combinations thereof. It should also be noted that, when looking for indications of sedimentary or deformational history of the deposits, the micromorphological observations on texture and diagenesis are usually of little help. These are more descriptors than anything else.

In the five samples presented here, the overall set of microstructures points to a subglacial environment. However, in the sample from 63.05 mbsf it almost comes down to a single criterion interpretation, an undesirable situation. It should be noted, however, that the rotational structure in this sample is very well developed, more strongly than in samples (in our reference collection) from any other known sedimentary environment. Nevertheless, we have reservations regarding the interpretation of this sample. The same holds for the sample from 105.58 mbsf, because in this sample the microstructures are even more weakly developed while, on the other hand, it possesses a strong overall (macroscopic) structure.

Regarding the interpretation of the samples from 78.99, 123.25 and 134.45 mbsf, we feel more confident. From the occurrence of a combination of microstructures, which we only know from basal tills, we infer that these samples represent subglacially deformed diamicts. With respect to the latter, two samples, both from Unit 6.3 (119.28-141.60 mbsf), some refinement is required. Although tills with a thickness of several tens of metres are not uncommon, our interpretation does not mean that we automatically assume that all of Unit 6.3 is a basal till. Studying 20 cm out of 20 m would stretch the interpretation too far.

Furthermore, these diamicts are not basal tills in the sense of units that have been deposited by and from the ice. Rather, we envisage the diamicts to be primary glacimarine deposits that have been thoroughly remoulded during an ice advance. In this way the diamicts retain most of the sedimentary characteristics of the original glacimarine deposits, while structurally they have the characteristics of a basal till, and therefore should be defined as such. In the continuum of erosion - deformation - deposition in a subglacial setting this is an often overlooked distinction.

The fact that we interpret the samples as basal tills does not mean that we assume the ice margin to have transgressed the site of CRP-1 for a long distance. The fact that the development of a plasmic fabric in the samples, more notably in plasma-rich zones, is either poor or else completely lacking indicates that the effective pressure must have been very low. Basal tills from a large distance behind a tidewater ice margin (Carr, in press) normally show a well developed plasmic fabric and cannot be distinguished from fully terrestrial tills (see also Boulton et al., 1996). Observations in glacimarine sediments that have been subjected to a documented surge of a tidewater glacier lobe in Svalbard (Solheim & van der Meer, unpublished data) seem to indicate that in the presence of large amounts of water, *i.e.* high porewater pressures and consequently low effective pressures, a plasmic fabric does not develop. The combination of well developed plasmic fabrics further upglacier under a tidewater glacier and (almost) no development under the margin of a surging tidewater glacier (in Spitsbergen) is interpreted by us as an indication that the CRP-1 site was subglacial but close to the ice margin. Near the ice margin the amount of subglacial porewater can be expected to be the greatest.

Our interpretation of the thin sections described here confirms the inferences of the Cape Roberts Science Team on the presence of grounded ice over the CRP-1 drillsite at 79 mbsf. Previously unsuspected levels at which grounding of ice influenced primary glacimarine deposits were identified at 123 and 134 mbsf.

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REFERENCES

Boulton G.S., van der Meer J.J.M., Hart J., Beets D., Ruegg G.H.J., van der Wateren F.M.& Jarvis J., 1996. Till and moraine emplacement in a deforming bed surge - an example from a marine environment. *Quaternary Science Reviews*, **15**, 961-987.

Brewer R., 1976. *Fabric and mineral analysis of soils*. Krieger, Huntington, 482 p.

Carr S., in press. The micromorphology of the Last Glacial Maximum sediments in the Southern North Sea. *Catena*.

Cape Roberts Science Team, 1998. Summary of Results from CRP-1, Cape Roberts Project, Antarctica. *Terra Antarctica*, **5**(1), 125-137.

Hiemstra J.F. & van der Meer J.J.M., 1998. Micromorphology of sediments from the Eastern Antarctic continental shelf: selected samples. *Rapport Fysisch Geografisch en Bodemkundig Laboratorium, Universiteit van Amsterdam*, **72**, 27 p.

van der Meer J.J.M., 1993. Microscopic evidence of subglacial deformation. *Quaternary Science Reviews*, **12**, 553-587.

van der Meer J.J.M., 1996. Micromorphology. In: Menzies J.(ed.), *Glacial environments: Volume 2; Past glacial environments - processes, sediments and landforms*, Butterworth & Heinemann, Oxford, 335-355.

van der Meer J.J.M., 1997. Subglacial processes revealed by the microscope: particle and aggregate mobility in till. *Quaternary Science Reviews*, **16**, 827-831.

van der Meer J.J.M. & Menzies J., 1997. Micromorphology of glacial sediments, a workshop. *Handout, Second International Workshop on the Micromorphology of Glacial Sediments*, Brock University, St. Catharines, Canada, 80 p.

van der Meer J.J.M. & Warren W.P., 1997. Sedimentology of late glacial clays in lacustrine basins, Central Ireland. *Quaternary Science Reviews*, **16**, 779-791.

van der Meer J.J.M., Verbers A.L.L.M. & Warren W.P., 1994. The micromorphological character of the Ballycroneen Formation (Irish Sea Till): a first assessment. In: Warren W.P.& Croot D. (eds.), *Formation and deformation of glacial deposits*, Balkema, Rotterdam, 39-49.

van der Meer J.J.M., van Berghem J.W. & van Dreumel P.F., 1996. Microscopische waarnemingen aan doorlatendheid en chemische stabiliteit van vervuilde waterbodems. *H2O*, **29**, 77-80.

van der Meer J.J.M., Hiemstra J.F. & Stroeven A.P., 1998. Micromorphology of two Sirius Group core diamict samples from Mt. Feather, Dry Valleys, Antarctica. In: Wilson G. & Barron J. (eds.), *Mount Feather Sirius Group core workshop and collaborative sample analysis*, Byrd Polar Research Center BPRC, Report No. **14**, 96-108.