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Palaeoenvironmental reconstruction from redeposited weathered clasts in the CIROS-1 drill core

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Abstract: The occurrence and nature of weathered clasts in the CIROS-1 drill core from McMurdo Sound was recorded. These data showed both associations of weathered material with particular lithofacies and that certain lithologies were preferentially weathered. XRD analysis of weathering rinds from two lithostratigraphic core units suggest that such weathering data can provide evidence of terrestrial palaeoenvironmental conditions that may be otherwise unobtainable.

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Introduction

The CIROS-1 drill hole reached a depth of 702 m in western McMurdo Sound (77°34'55"S, 164°29'56"E), 12 km offshore from Butter Point (Fig. 1). Excellent core recovery (98%) facilitated its division into 22 lithological units (based on marked changes in lithofacies associations) the oldest of which is late Eocene/early Oligocene (Robinson *et al.* 1987). Indications of glacial activity were found throughout the core, including evidence suggesting that ice had advanced close to or over the present drill site on a number of occasions. Evidence for Cenozoic vegetation growth on the Antarctic continent was provided by the occurrence of a *Nothofagus* leaf impression between two glacial beds at 215 m depth (estimated age 30 Ma). Details of the stratigraphy (Hambrey *et al.*, in press), texture (Barrett, in press), clast fabric (Hambrey, in press), clast shape (Hall, in press), and clay mineralogy of the core matrix (Claridge & Campbell, in press) are available.

During the study of clast shape it became apparent that a number of clasts showed clear signs of weathering. Weathering rinds (Fig. 2a) and red-stained cracks in the rocks were observed together with the localized rotting of granites (Fig. 2b); some of the latter displayed the selective loss of feldspars. No data on clast weathering were obtained from either the CIROS-2 (Pyne *et al.* 1985) or MSSTS (Pyne & Waghorn 1980) cores that were obtained from the same area. The data presented here on clasts from two positions in the core add to the knowledge of palaeoenvironmental conditions in the McMurdo region during the Cenozoic. The clasts studied constitute redeposited material which distinguishes this study from most others on weathering rinds (e.g. Chinn 1981, Colman 1981*a*, 1981*b*, 1982, Colman & Pierce 1980, Birkeland 1973) which have focussed on clasts weathered at the site under investigation e.g. in a soil or a moraine. Changes due to diagenesis do not confuse the picture in the present study.

Methodology

Field procedures were confined mainly to visual appraisal of clast weathering seen in the core after it had been cut in half (Hall, in press). At two positions where clast frequency was

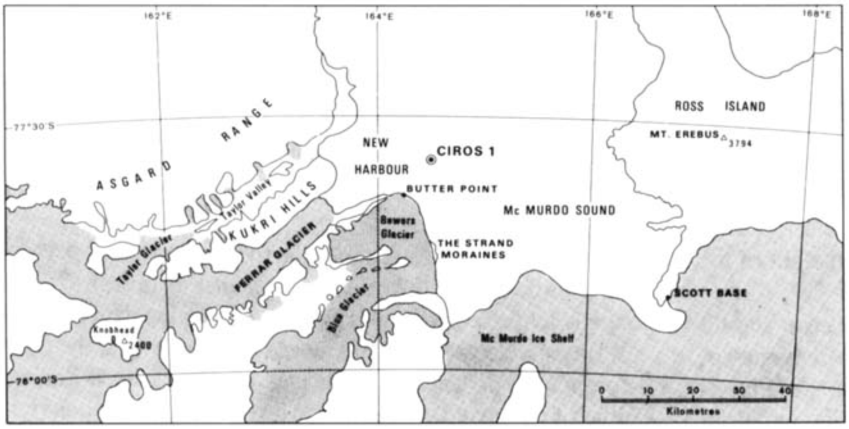

Fig. 1. Map showing location of CIROS-1 drill site.

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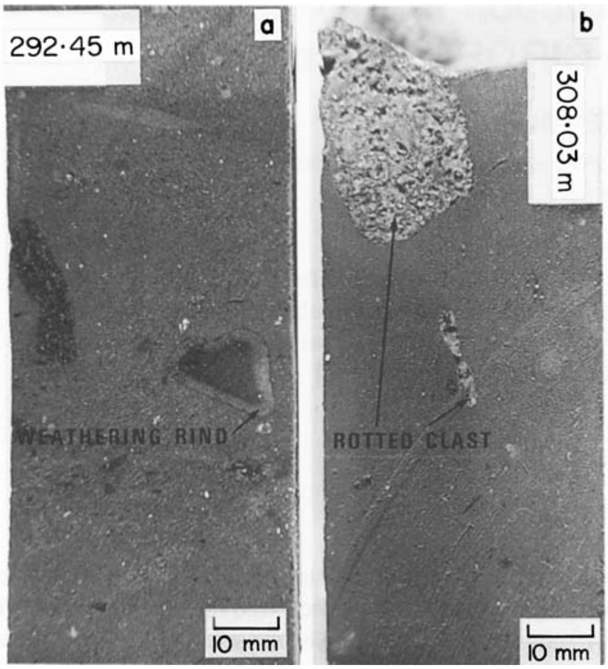

Fig. 2. Two examples of weathered clasts found in the CIROS-1 core: **a.** weathering rind on a dolerite clast, **b.** rotted granitic clast with feldspars weathered out.

high weathered clasts were extracted from the core for mineral analysis of the weathering rinds by bulk analysis X-ray powder diffraction (XRD). Four samples from unit 12 and three from unit 20 were used. The rinds were separated from the rest of the rock on the basis of colour and the crushed samples were packed into the shallow cavity of an aluminium holder so as to minimize preferred orientation. XRD data were obtained from a Philips X-ray diffractometer and Fe-filtered CoKα radiation generated at 40 kV and 40 mA. The specimens were scanned at 1° 2θ/min over the range 2°–75°2θ.

Results and discussion

Although clasts exhibiting signs of weathering were recorded for 14 of the 22 defined units (Fig. 3), this obscures within-unit variability. For instance, of the 215 clasts in unit 17 only 13 showed signs of weathering, and 11 of these were found in a single 3.19-m thick lithofacies. Again in unit 18 (163.29 m thick), although there were only six weathered clasts five were found in the uppermost 10 m of one diamictite lithofacies. Information regarding the lithofacies-specific concentration of weathered clasts that occur in eight of the units are detailed in Table I.

The distribution of weathered clasts in the core should relate to other geomorphological data. The low frequency of occurrence of weathered material in units 3 to 11 (Fig. 3) agrees with the interpretation of these units as distal

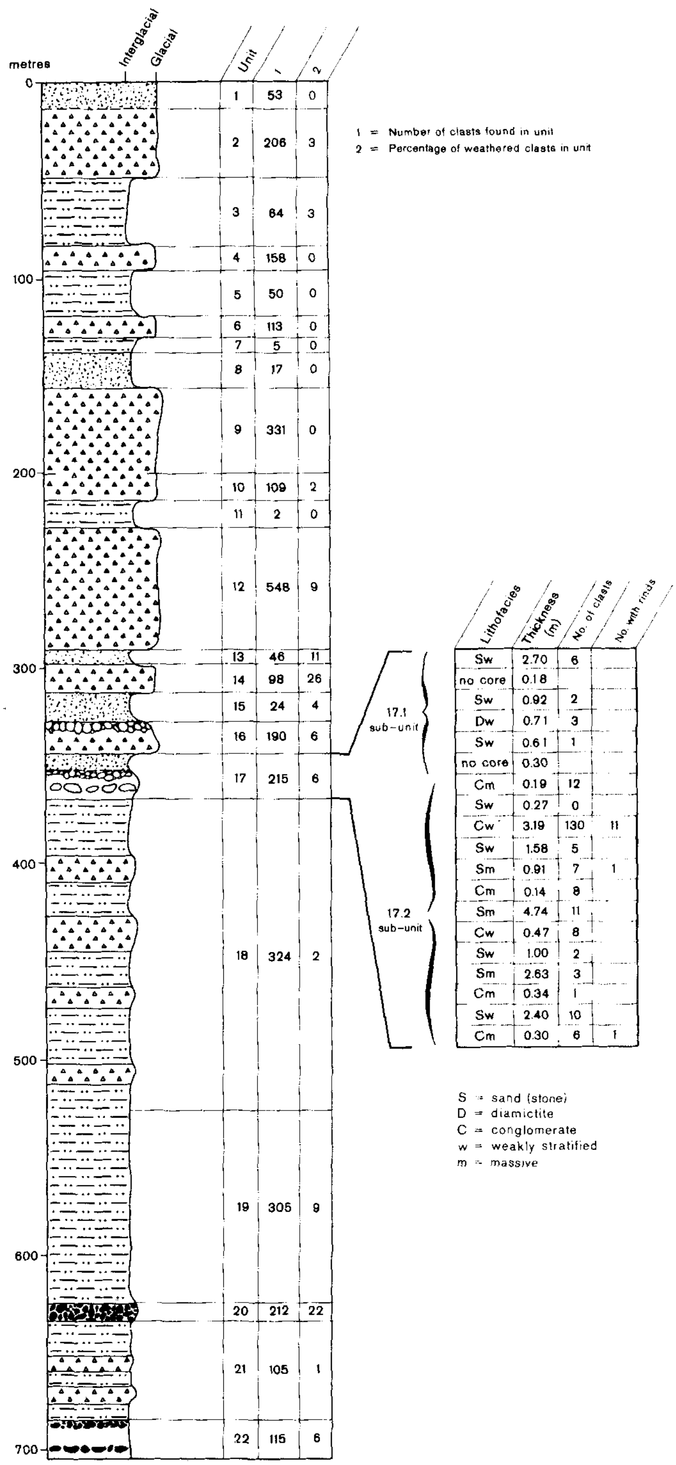

Fig. 3. Generalized data regarding the occurrence of weathered clasts in the 22 core units together with details for unit 17.

glaciomarine or waterlain tills (M.J. Hambrey, personal communication 1987, Hambrey *et al.*, in press). If clast supply to the sediment was distal glaciomarine the probability of finding weathered clasts would be very low. If the debris component of waterlain tills was basally-derived during a time of extensive terrestrial ice cover the clasts would have

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Table I. Occurrence of weathered clasts according to lithofacies.

Unit	Thickness (m)	No. clasts	No. weathered clasts	% weathered clasts	% lithofacies composition of unit S	M	R	C	D	% weathered clasts in each lithofacies S	M	R	C	D
12	62.25	548	51	9	30.6	14.3	10.2	2.0	42.9	4	0	4	0	92
13	8.18	46	5	11	75	0	25	0	0	100	0	0	0	0
14	13.15	98	25	26	0	50	0	0	50	0	0	0	0	100
16	16.30	190	11	6	50	0	0	25	25	27	0	0	0	73
17	23.58	215	13	6	58.8	0	0	35.3[1]	5.9	7.7	0	0	92.3	0
19	93.90	305	28	9	52.3	46.5	0	1.2	0	60.7	28.6	0	10.7	0
20	6.85	207	47	22	50.0	0	0	37.5	12.5	0	0	0	100	0
22	16.32	115	7	6	38.2	32.4	0[3]	26.5	0	0	0	0	100[2]	0

S = sand(stone), C = conglomerate, M = mudstone, R = rhythmites, D = diamictite
[1] 84.6% of weathered clasts in only one C lithofacies
[2] all weathered clasts in one 0.8 m thick C lithofacies
[3] a breccia comprised the final 2.9%

had little opportunity to weather.

The converse must also be true. Units 12, 16, 17, 20 and 22 are all interpreted (Hambrey *et al.*, in press) as being associated with a terrestrial environment within which glacial, fluvioglacial and fluvial conditions conducive to weathering prevailed. Higher concentrations of weathered clasts occurred in all these units. Clear indication that diagenetic alteration did not occur after deposition is indicated by the presence of unweathered clasts residing next to weathered clasts of the same lithology. This is thus quite different to the situation where further change can occur after deposition, as for instance in the weathered talus on rock glaciers cited by Birkeland (1973).

Additional weathering information can be obtained by examining both lithological susceptibility to weathering, and the mineralogy of the weathering rinds. The basalts appear to be preferentially weathered in many but not all units. Weathered material in unit 13, with 51% granitic and 20% basaltic rocks, comprised 66% weathered basalts and 20% weathered granites. In unit 15, where only granites showed signs of weathering, the granites actually comprised only 20% of the clast lithologies present. Quite what the lithological variation in clast weathering indicates is not clear. Basalts generally exhibit more weathering than granites according to the ranking of Gerrard (1988). He ranked the ease of chemical weathering in igneous rocks as: basalt > gabbro > diorite > syenite > granite. Where the granites show the greatest amount of weathering it may be due to mechanical processes. Thus units which show a preponderance of weathered granites (physical weathering) could be indicative of differential environmental conditions to those in which weathered basalts (chemical weathering) predominate. Whatever the case, the imbalance in weathering effects must reflect changes of some sort in the terrestrial environment.

Mineral analysis of the weathering rinds on the basaltic clasts from unit 12 indicated the presence of siderite. Siderite forms in a reducing environment aided by the presence of organic matter (Sokolova 1964). The sedimentological interpretation of unit 12 is that it is proximal glaciomarine to waterlain till, conditions that would produce a reducing environment. In addition, a *Nothofagus* leaf impression found within this unit close (3 m) to where the weathered samples were collected indicates the possibility of some organic matter being present (although the core was not specifically analysed for this). The lack of clay minerals developed in the weathering rinds of these clasts suggests that the environment at that time was not particularly conducive to chemical weathering, although Colman (1982) has shown that clay minerals form only slowly in weathering rinds. Nevertheless, the basalts in the other units show rinds with some clay minerals indicating that environmental conditions for chemical weathering were better at other times.

The rinds from clasts in unit 20 all show the presence of smectite (Fig. 4), normally indicative of chemical weathering within a semi-arid environment. Higher smectite contents in the basaltic rinds than the granitic rinds is not unexpected as the acidic environment generated during weathering of granite inhibits smectite production. The sedimentological interpretation of unit 20 is that it represents a terrestrial environment within which both glacial and fluvial processes were operative. This suggests a cold, but relatively wet subaerial situation, quite unlike that within which the weathering and deposition of the clasts in unit 12 took place. Independent interpretation of the mineralogy of the matrix (Claridge & Campbell, in press) also suggests a terrestrial environment within which podsolized soils formed under forest or scrubland in a cool or cold temperate climate. The smectite found in both the core matrix (Claridge & Campbell, in press) and the clast rims is thought to be allogenic as not only do weathered and unweathered clasts reside next to each other but the absence of smectite/mica interstratification indicates diagenesis must have been low as temperatures could not have exceeded 60°C.

Weathering rinds on clasts from Antarctic offshore drill cores appear to offer direct information on terrestrial palaeoenvironments. Based upon the study of the CIROS-1 core, these constitute three types of data:

a. the nature of the lithofacies in which the weathered

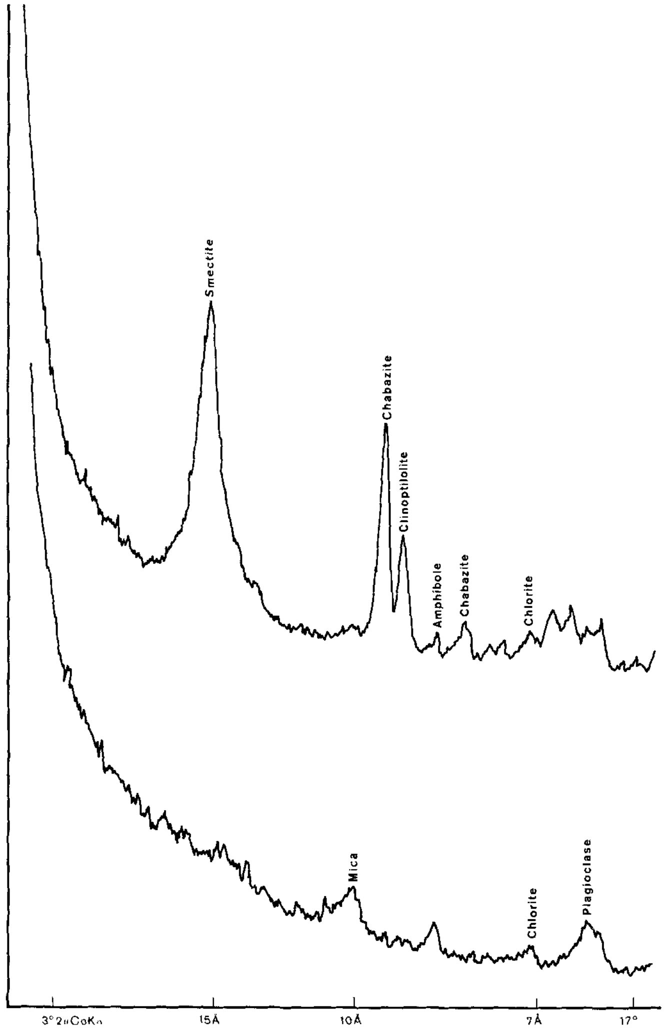

Fig. 4. XRD for basaltic clasts from unit 12 (below) and unit 20 (above).

material is found,

b. the lithological composition of the weathered component, and

c. analysis of the weathering rinds themselves.

Whilst none of these approaches alone is definitive, together they provide what may be otherwise unobtainable data on palaeoenvironmental terrestrial conditions.

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