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EVIDENCE OF THE BEDROCK BENEATH THE GREENLAND ICE SHEET NEAR CAMP CENTURY, GREENLAND

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ABSTRACT. Igneous and metamorphic cobbles in sub-ice material recovered from a drill core which penetrated the ice sheet at Camp Century, Greenland, provide a rare look at the geology beneath the ice in the interior of Greenland. The sub-ice material can be correlated, based on petrography, with rocks of the Rinkian mobile belt of the west coast of Greenland; however, preliminary strontium isotopic data suggest such correlation should be made with caution. Chemical analyses and rare-earth element data are given to provide the basis for more rigorous correlations as more data become available on the Rinkian rocks.

RÉSUMÉ. *Observations sur le lit rocheux sous la calotte glaciaire du Groenland près de Camp Century, Groenland.* Des galets volcaniques et métamorphiques ont été trouvés dans le matériel sous glaciaire recueilli lors d'un forage qu'a traversé l'inlandsis à Camp Century au Groenland. Ils procurent un aperçu rare sur la géologie sous la glace dans l'intérieur du Groenland. Le matériel sous glaciaire peut être rapproché, d'après la pétrographie, des roches de la ceinture du Rinkian mobile sur la côte Ouest du Groenland, cependant, les premières données de l'analyse de l'isotope du strontium montrent qu'un tel rapprochement doit être fait avec précaution. Des analyses chimiques et la composition en éléments des terres rares sont données. Elles pourront fonder des corrélations plus rigoureuses lorsqu'on aura plus de données sur les roches du Rinkian.

ZUSAMMENFASSUNG. *Einsicht in den Felsuntergrund des grönländischen Eisschildes bei Camp Century, Grönland.* Vulkanische und metamorphe Gesteinsbrocken in subglazialem Material, gefördert aus einem Bohrloch durch den Eisschild bei Camp Century, Grönland, vermitteln einen seltenen Blick auf die geologischen Verhältnisse unter dem Eis im Inneren Grönlands. Das subglaziale Material kann petrographisch mit Gestein aus dem Rinkian Mobile-Gürtel an der Westküste Grönlands korreliert werden, doch weisen vorläufige Daten von Strontium-Isotopen darauf hin, dass solche Korrelationen mit Vorsicht zu betrachten sind. Chemische Analysen und Daten von seltenen Erden werden vorgelegt, um genauere Korrelationen vornehmen zu können, wenn über das Rinkian-Gestein mehr Daten verfügbar sind.

INTRODUCTION

An ice core, drilled in 1966, for glaciological and climatological studies through the Greenland ice sheet at Camp Century (Fig. 1) penetrated 3.5 m of sub-ice material. The sub-ice part of the core is till-like material (Hansen and Langway, 1966) containing numerous cobbles and fragments of crystalline rock. Debris apparently derived from the sub-ice material is abundant in the 16 m of ice immediately above the ice–sub-ice interface (Herron and Langway, 1979; see Fig. 2). It is probable that the large cobbles are representative of the local bedrock, although the thickness of till underlying the ice sheet at this site is not known. The dynamics of the ice sheet indicate that, if the cobbles are not locally derived, they must have been transported from further inland. The sub-ice material of the Camp Century core thus provides a rare though incomplete look at the geology of the bedrock beneath the ice sheet.

The sub-ice material has received little geological attention as it represents samples of unknown lithologies and structures from beneath the ice. However, similar studies on grab samples from lunar rocks and meteorites have indicated that such investigations are not totally futile. Therefore, a petrographic and geochemical study of the crystalline rocks from the sub-ice material was undertaken in an attempt to characterize the bedrock geology and to provide the basis for possible correlations with the exposed crystalline basement on the perimeter of the ice sheet.

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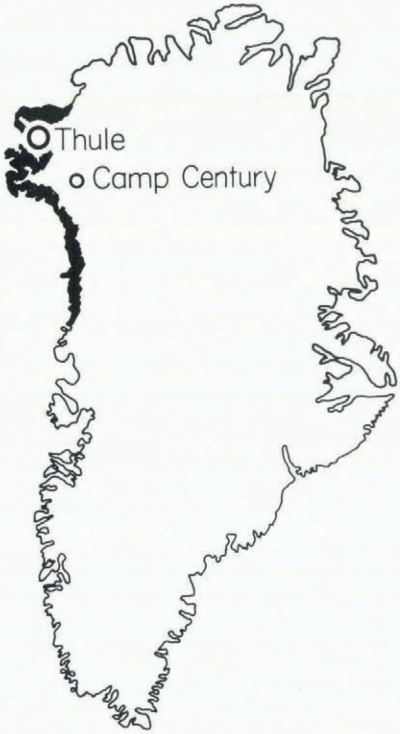

Fig. 1. Location map showing the relative positions of Camp Century and the coastal exposures of the Rinkian mobile belt (shaded area; after Dawes, 1976). Principal exposures are in Inglefield Land, to the north of Thule, and on Melville Bugt, south of Thule.

Sub-ice material

The sub-ice material is a mixture of cobbles, fragments, and dirty ice, and consists of approximately 50–60% crystalline ice. Seventeen rock samples were removed from the ice for this study; these included igneous, metamorphic, and sedimentary specimens. The samples weighed between 4 and 1 132 g, but the weights are unrepresentative as most specimens were cut by the drill bit during coring. Numerous smaller fragments were also observed in the core. The larger samples were relatively fresh with only a small weathering rind, typically rimming the smooth uncut surface. Some of the smaller fragments showed extensive weathering effects. These included a shale fragment that could not be removed intact due to its deteriorated condition.

The densities of the samples were also determined and are listed in Table I. A slight correlation seems to exist between the density and the vertical stratigraphic position of the specimens in the core, with the least dense samples near the top. The cobbles appeared in groupings with depth; no large fragments or cobbles were found in the upper 1.2 m, and none was found between 1.3 and about 2.5 m. The majority of the large fragments were found between 3.0 m and the bottom of the core. No explanation for this distribution is offered.

Petrography

Based on thin-section petrography, the majority of the sampled rock types could tentatively be ascribed to a single metamorphic complex consisting of gneisses, granites, and metabasalts. There are four granodioritic gneisses, six tonalitic gneisses, three granites, a basic amphibolite, and a basic granulite (Table I). If the rocks are considered as part of a metamorphic complex, the mineral assemblages present are not sufficient to delineate accurately the metamorphic regime but, in general, the assemblages fall into the broad category of upper amphibolite facies. Temperatures and pressures are estimated to between 550°C and 650°C, and about 4 kbar.

In addition to the crystalline rocks, there are also a relatively pure sandstone and a silty sandstone, which show minor metamorphic features.

Geochemistry

Ten crystalline rock samples were selected for analysis on the basis of petrography. Chemical analyses were performed using U.S. Geological Survey "rapid" analysis techniques (Shapiro, 1975), except for rare-earth element and isotopic analyses, which were determined by isotope-dilution mass spectrometry.

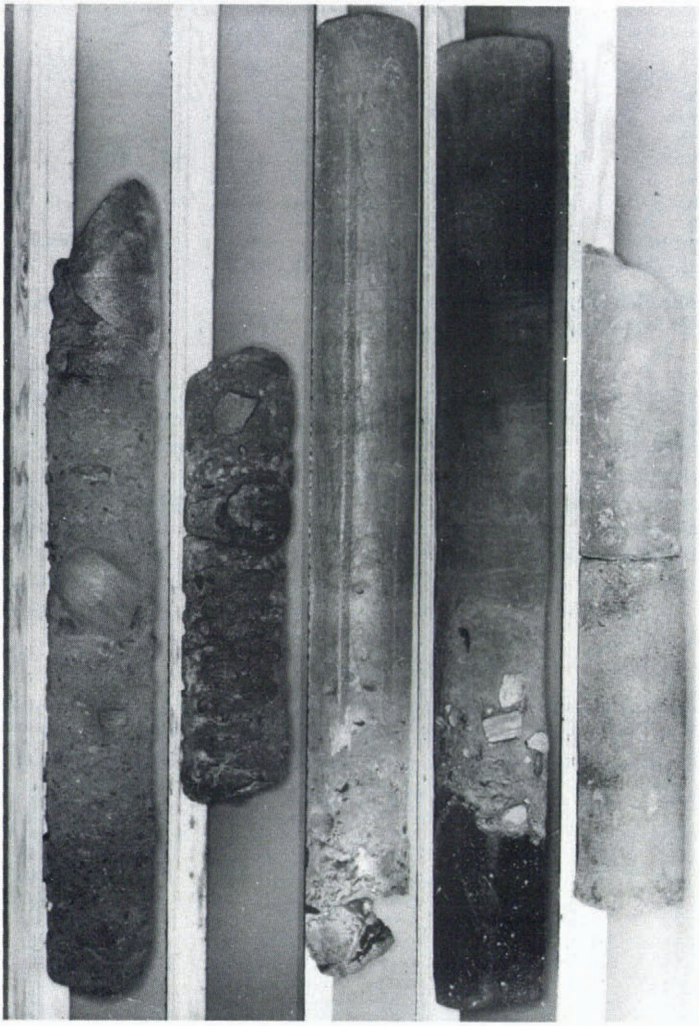

Fig. 2. All of the approximately 3.5 m of sub-ice core and about 25 cm of the "dirty" ice recovered at Camp Century. The sections are in order from right to left: section 1 at the far right is the uppermost section; section 5 at the far left is the bottom section of the core. The top section (1) shows the contact between the main glacier mass and the sub-ice material. Beginning at the contact in section 1, the sub-ice material is sandy, grading to a finer sand (section 2), and still lower, a wedge of very coarse pebbles in a silty matrix. Beneath the wedge and continuing in section 3 is a thick layer of higher ice-content silt-clay that extends almost to the bottom of the section. At the bottom of section 3 is an ice lens nearly 10 cm thick. Sections 4 and 5 show the till-like material containing a heterogeneous assortment of non-stratified cobbles and pebbles in a finer sand–silt–clay matrix. (Photograph by D. Atwood, CRREL.)

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Table I. Modes, densities, core positions, and cobble sizes of samples from the sub-ice material from the Camp Century ice core

Sample No.	*Rock type**	*Depth in sub-ice (from ice–sub-ice interface)* m	*Density* Mg m^{-3}	*qtz*	*K-spar*	*plag*	*bio*	*horn*	*pyrox*	*sphene*	*gar*	*opaques*
				Modes								
1062-1B	Granite	2.39	2.67	40	34.5	17		$\leqslant 1$				2.5
1062-1A	Tonalitic gneiss	2.40	2.68									
1062-2A	Tonalitic gneiss	2.46	2.69	39	2	34	25					<1
1063-1A	Granodioritic gneiss	2.90	2.68	22.2	8.5	59.9	9.4					
1063-2A	Granodioritic gneiss	2.98	2.84	19	20	48		11				
1063-4C	Tonalitic gneiss	3.16	1.79	2.6	41.4	17.9					18.5	1.7
1063-4B	Tonalitic gneiss	3.20	3.06	3.3	0.7	34.8	9.8	51				0.5
1063-4A	Tonalitic gneiss	3.26	2.74	32.3	5.5	44.4	6.0	7.0		4.6		
1063-5D†	Metagabbro	3.34	3.15	4.1		30.1		43.1	19.6			3
1063-6A	Granodioritic	3.40	3.01	16.1	46.1	6.9						0.3

* Igneous classification after Streckeisen (1973).
† Similar sample to 1063-4B.

The results of the chemical analyses are given in Table II. The major-element compositions of the samples are fairly typical of granitoids. There is no regularity in the variation of total iron, MgO, CaO, Na_2O, and K_2O with silica. No regular pattern of variation of either major-element chemistry or modal abundances is evident even within the granitic gneiss.

The abundances and distribution of the rare-earth elements are also typical of granitoids; the light rare earths are highly enriched relative to the heavy rare earths with considerable variation between samples. As in the major-element data, the rare-earth data display no regular pattern of variation with lithology. As the rare-earth elements are believed to be relatively immobile during amphibolite-facies metamorphism, the data should reflect differences in the parental rock compositions of the metamorphic samples.

Table II. The chemical composition of crystalline rock samples from the sub-ice material of the Camp Century ice core. Oxide values in weight per cent; rare-earth abundances in p.p.m.

	1062-1A	1062-1B	1062-2A	1063-1A	1063-2A	1063-6A	1063-4A	1063-4B	1063-4C	1063-5A
SiO_2	69.04	75.91	67.52	65.20	63.60	65.47	70.83	47.35	58.06	70.14
Al_2O_3	17.07	11.97	15.14	18.61	17.44	16.93	15.07	16.94	19.34	15.06
Total iron	2.85	3.56	4.48	2.71	4.41	4.44	3.12	13.12	10.25	3.54
MgO	0.89	0.12	1.54	1.61	1.55	1.62	0.99	6.68	3.49	1.10
CaO	3.01	0.80	2.85	3.43	4.20	2.41	3.45	9.08	2.67	3.81
Na_2O	4.40	3.24	3.81	5.62	3.82	4.32	4.01	3.31	3.33	4.02
K_2O	2.22	4.28	3.29	2.06	3.90	3.91	1.49	1.35	2.29	1.66
P_2O_5	0.11	0.02	0.31	0.22	0.14	0.18	0.17	0.13	0.03	0.23
TiO_2	0.33	0.28	0.78	0.41	0.27	0.47	0.57	1.33	0.98	0.70
MnO	0.04	0.03	0.06	0.04	0.06	0.06	0.05	0.20	0.18	0.07
Total*	99.96	100.21	99.78	99.91	99.39	99.81	99.75	99.49	100.62	100.33
Ce	78.82	84.00	98.85	117.61	51.07	62.63	84.42	35.08	86.32	92.13
Nd	27.35	41.18	40.45	34.05	22.88	23.60	42.44	18.08	33.07	46.48
Sm	3.55	8.67	6.48	3.55	4.02	3.66	7.54	3.96	5.78	8.26
Eu	1.00	2.05	1.31	0.86	1.68	1.05	1.60	1.34	1.90	1.84
Dy	1.01	5.53	3.41	0.99	2.49	1.53	4.79	3.75	4.48	5.33
Er	0.46	2.56	1.55	0.46	1.47	0.75	2.58	2.04	3.15	2.91
Yb	0.34	1.98	1.06	0.39	1.39	0.66	2.39	1.83	3.57	2.75

* Ferrous iron, CO_2, and H_2O were not determined to minimize the amount of sample used.

Two of the samples (1062-1A and 1063-1A) have been analyzed for whole-rock Rb-Sr systematics. These two samples are nearly identical in rare-earth element abundances and therefore may be related. Together they indicate an age of about 1 100 Ma. Individually, they give model ages using a 0.701 initial of 3 660 and 2 760 Ma. Considering the initial of 0.712 associated with the 1 100 Ma age, it is tentatively concluded that these are approximately 3 000 Ma old rocks that were reset to 1 100 Ma during the Carolinidian orogeny. A Hudsonian age (about 1 800 Ma) might be more reasonable, based on exposed rocks of similar lithologies on the north-western coast of Greenland but, even given very large errors, the samples do not approach a line of this age. Therefore, these samples either cannot be used together to define an isochron or they are younger than Hudsonian. Additional work is needed to resolve the ages of the samples from the sub-ice material.

Discussion

Dawes (1976) has described rocks from the crystalline basement complex in the Melville Bugt–Inglefield Land area that are essentially identical to those obtained from the Camp Century sub-ice material. This complex is part of the Rinkian mobile belt (Dawes, 1976) that is exposed for over 700 km along the northern half of the west coast of Greenland (Fig. 1). If the Camp Century samples are associated with the Rinkian mobile belt, then the mobile belt must extend at least 200 km inland to the east. However, the Rinkian mobile belt is Hudsonian in age (1 650–2 000 Ma), while the Camp Century samples are tentatively dated at 1 100 Ma and are associated with the Carolinidian orogeny. The effects of the Carolinidian orogeny are strong on the east coast of Greenland but weak on the west coast. It appears that the Camp Century rocks cannot be simply correlated with the rocks on the west coast of north-west Greenland and the geologic make-up of inland northern Greenland remains an enigma that will not be solved until more samples, preferably of bedrock from beneath the ice sheet, are available.

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REFERENCES

Dawes, P. R. 1976. Precambrian to Tertiary of northern Greenland. (*In* Escher, A., *and* Watt, W. S. *Geology of Greenland.* [Copenhagen], Geological Survey of Greenland, p. 248–304.)
Hansen, B. L., *and* Langway, C. C., *jr.* 1966. Deep core drilling in ice and core analysis at Camp Century, Greenland, 1961–1966. *Antarctic Journal of the United States*, Vol. 1, No. 5, p. 207–08.
Herron, S. L., *formerly* Hoar, S. L., *and* Langway, C. C., *jr.* 1979. The debris-laden ice at the bottom of the Greenland ice sheet. *Journal of Glaciology*, Vol. 23, No. 89, p. 193–207.
Shapiro, L. 1975. Rapid analysis of silicate, carbonate, and phosphate rocks. *U.S. Geological Survey. Bulletin* 1401.
Streckeisen, A. L. 1973. Plutonic rocks: classification and nomenclature recommended by the IUGS Subcommission on the Systematics of Igneous Rocks. *Geotimes*, Vol. 18, No. 10, p. 26–30.