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Cape Roberts Project: investigating the Cenozoic history of Antarctica

ABSTRACT: Drilling operations of the Cape Roberts Project took place between 1997 and 1999 offshore of Cape Roberts in the western Ross Sea, Antarctica. These were made possible due to a group effort by geoscientists from Australia, Germany, Italy, New Zealand, Great Britain, and the United States. The major goal of this undertaking was the recovery and analysis of sediment core, which was expected to provide a first East Antarctic record of the Early Cenozoic hothouse to icehouse climatic transition. This goal was not attained. Nevertheless, over the three seasons, a 1500 m long composite section was recovered, including a predominantly Early Oligocene to Early Miocene (34–17 Ma) glaciomarine succession. It was analyzed in terms of sediment physical properties, paleontology, tectonic structures, and geophysics. This multidisciplinary investigation allowed detailed reconstruction of a significant portion of local environmental history, spanning a period of highly variable environmental conditions strongly affected by local glacier advance and retreat across the Victoria Land Basin margin.

Key words: Antarctica, Cape Roberts Project, scientific drilling, paleoenvironment, Cenozoic.

Introduction

This report is an extended abstract of a talk given on March 24, 2000 at the Institute of Paleobiology of the Polish Academy of Science, Warszawa. A considerable interest in the discussed issues led to preparation of this article, which summarizes the major aspects of the just concluded Cape Roberts Project (CRP). This was an international undertaking, which took place during three consecutive Antarctic summer seasons in late 1997, 1998, and 1999. The participating countries were Australia, Germany, Italy, New Zealand, the United Kingdom, and United States. The author, a doctoral student at the Ohio State University, took part in the project

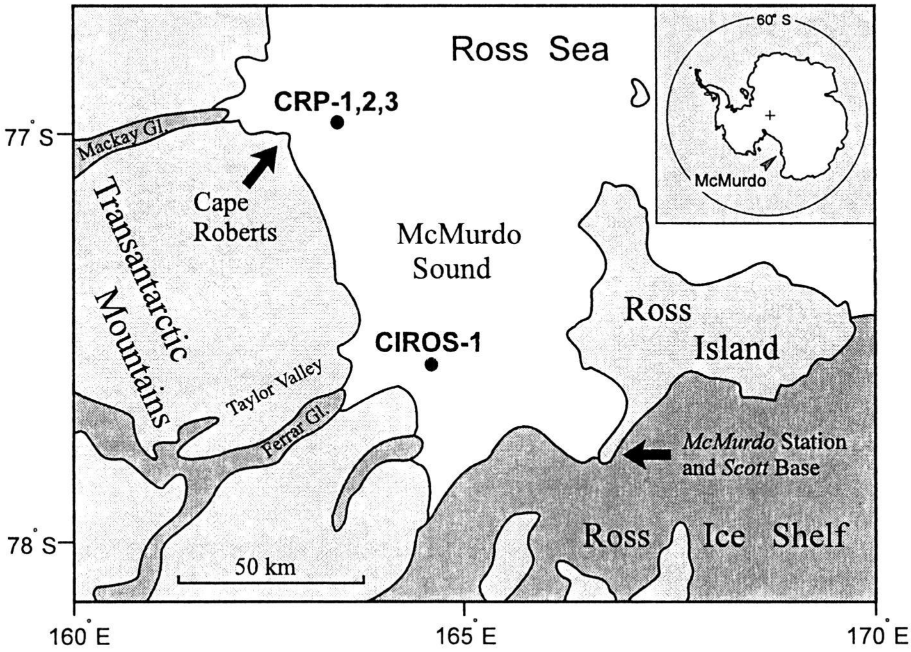

Fig.1. Location of the drill sites CRP-1, CRP-2, CRP-3, and CIROS-1 in the McMurdo Sound, Ross Sea, Antarctica.

during its final season (late 1999) as a micropaleontologist based at the United States Antarctic Program's *McMurdo* Station on Ross Island.

Objectives. — A major objective of CRP was the recovery of sediments that recorded early Cenozoic hothouse to greenhouse climatic transition in East Antarctica. The recovered data were also intended as an aid to comparison of marine and terrestrial climatic records, calibration of geophysical profiles across the Victoria Land Basin, and last but not least, interpretation of the tectonic history of the West-Antarctic Rift System and the Transantarctic Mountains (CRP Science Team, 1998a). Among the non-scientific objectives attained were goals ranging from logistics and improvement of drilling techniques using platforms set on sea ice, to achieving multi-national cooperation during all stages of the project. Another important aspect of the CRP was broad education and improvement of expertise among participants, as well as developing ecological sensitivity to this largely unspoiled polar environment among children in the United States via active correspondence with two American school teachers, who participated in the project (see http://tea.rice.edu).

Drilling sites. — The location of drilling operations (Fig. 1) was chosen so as to satisfy the above-stated scientific goals. Drilling took place off Cape Roberts ~ 30 km east from the mouth of the Mackay Valley, and approximately 125 km northwest from the U.S. *McMurdo* Station and *Scott* Base (New Zealand), both located on the southern tip of the Ross Island.

Fig. 1. Cone of the Mt. Erebus (3795 m) volcano as seen from the Castle Rock Hill near the *McMurdo* Station. *Photo by W. Majewski.*

Fig. 2. View of the CRP-3 drilling platform. *Photo by W. Majewski.*

Fig. 1. *McMurdo* Station on the Ross Island, Antarctica. *Photo by W. Majewski.*

Fig. 2. Peter N. Webb (left) and Percy Strong in the foraminiferal laboratory at the *McMurdo* Station. *Photo by W. Majewski.*

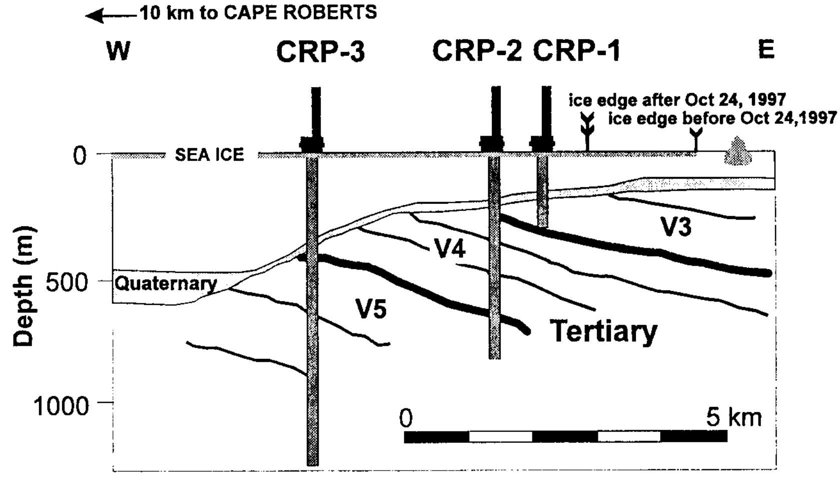

Fig. 2. Cross section through the Roberts ridge along the seismic line NBP9601-89 after CRP Science Team 1998a. Note position of three CRP drill holes as well as marked position of sea-ice edge during the first drilling season. V3, V4, V5 are symbols of seismic units used by Cooper *et al.* 1987.

In geological terms, the sites are located close to the western edge of the Victoria Land Basin, in the western region of the West Antarctic Rift System. Both these structures are believed to have started their development during the Jurassic in association with the initial breaking up of Gondwana, and continued throughout much of Cenozoic (Cooper *et al.* 1987). A remnant of the formerly more active rift zone is the modern Terror Rift Valley, which extends between two active volcanoes, Mt. Erebus (Pl. 1, Fig. 1) in the southeast and Mt. Melbourne at the northwestern end of this structure. Finally, the drill holes were situated on the submarine Roberts ridge, which is a post-Miocene (CRP Science Team 1998b) morphological high located approximately 15 km off Cape Roberts, and where progressively older and eastward dipping strata crop out (Fig. 2).

Methods

Drilling operations and technology. — The operations strategy was dictated by the fact that the drilling platform had to be placed on sea ice ~10 to 20 km offshore on 2 m of sea ice. The length of time during which drilling could take place extended from the beginning of the Antarctic summer season in late August to the weakening and break-up of the sea ice in late November. To shorten the time dedicated for drilling during a single season, the entire coring was divided into three stages; CRP-1, CRP-2, and CRP-3. One hole was completed each year. The drill holes were positioned along seismic section NB9601-89 (Cooper *et al.* 1987) in such way that they provided a combined continuous section with ~50 m of overlap between the three segments (Fig. 2).

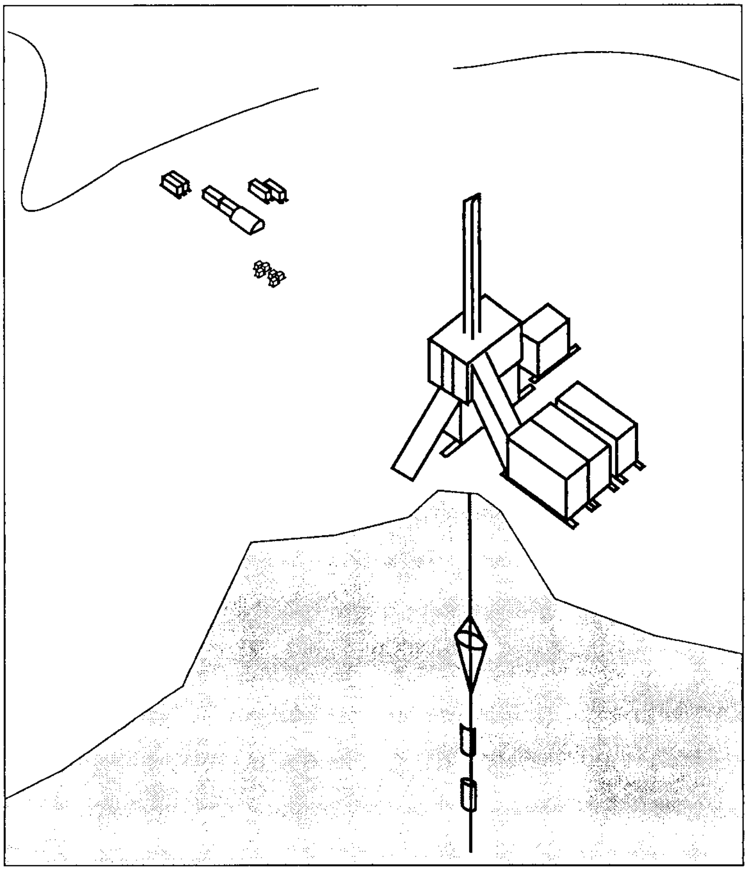

Fig. 3. Cartoon showing the CRP drilling platform set on annual 2 m thick sea-ice, the Cape Roberts camp site, as well as the Cape Roberts itself, from CPR Science Team 1998a.

The 2 m thick sea ice had to support heavy over-ice tractors and sledges transporting drilling equipment and supplies from *Scott* Base and *McMurdo* Station, a drill site camp, and the drilling platform itself. The platform (Pl. 1, Fig. 2) together with a set of drill rods weighed up to 20 ton. The drill string was partly buoyed by two to four 5 ton under-water floats attached to the rods and a pair of 5 ton air pillows placed directly below the sea ice supporting the platform (Fig. 3). The drilling itself was accomplished in a conventional fashion with initial stabilizing of the hole, and a decrease of coring diameter from 61.1 mm to 45.0 mm at ~ 300 meters below sea floor in both CRP-2 and CRP-3. After each drilling season the drilling platform and field camp were transported to shore and stored on the mainland at Cape Roberts until the following season (Fig. 3).

Down-hole logging. — Several types of geophysical measurements were performed inside the drill holes (CRP Science Team 1999a). These were fully completed only in the CRP-3 drill hole due to breakdown of the sea-ice and shortened drilling season at CRP-1 (Fig. 2) and an unstable hole at CRP-2. Measurements of spectral gamma ray emission, gamma ray attenuation (density tool), neutron porosity, sonic velocity, seismic profiling, and magnetic susceptibility were conducted and used to construct a geophysical stratigraphy of the drill holes. Its main purpose was to correlate the three drill holes by using different lithologic proxies. Inclinometer as well as temperature and salinity tools helped in monitoring drill-hole conditions. A dipmeter tool measured dips of strata and structural surfaces. And finally, the televiewer, which recorded images of borehole walls, made possible the orientation of the cores.

Core processing. — Most of the physical properties measurements, which were conducted at the drill site on recovered core, served lithostratigraphic purposes as well. These included quantification of density and porosity, magnetic susceptibility, P-wave velocity, and gamma ray absorption. Direct lithologic description of cores was also conducted at the drill site. Documentation of fracture distribution and density had a special purpose. After separation of fractures developed during drilling operation from those caused by tectonic processes, it was possible to reconstruct former fields of tectonic stress (Wilson and Paulsen 1998).

During good weather periods, cores were transported to *McMurdo* Station (Pl. 2, Fig. 1) from the drill sites each day by helicopters, where more time consuming analyses on selected samples were conducted. Working core-halves were examined lithologically and sedimentologically once more but by a different team, and samples were selected for laboratory processing. This phase included analyzing the petrology of clasts and sediment fine fractions, as well as paleomagnetic and paleontological studies (Pl. 2, Fig. 2). The fossil groups which attracted most attention included diatoms, calcareous nannofossils, foraminifera, marine and terrestrial palynomorphs, and macrofossils.

Dating techniques. — Drillcore chronostratigraphy utilized bioevents (diatoms, and to less extent calcareous nannofossils and marine palynomorphs), paleomagnetics, radiometric and stable isotopic datums. Radiometric methods included $^{40}Ar/^{39}Ar$ measurements on volcanic clasts from both tephra layers and regular sediments; whereas, stable isotopic work utilized $^{87}Sr/^{86}Sr$ ratios of well preserved *in situ* shell material (CRP Science Team 1999b).

Major results

Overview. — The main objective of establishing environmental conditions predating the Eocene/Oligocene climate transition was not met due to failure in penetrating pre-Oligocene sediments. Nevertheless, a near continuous sequence of 1500 m of sediments ranging in age from 34 to 17 Ma (Early Oligocene to Early Miocene) was successfully recovered and analyzed. This core provides a high-

-resolution mid-Cenozoic record of environmental oscillations, occurring in a marine basin at the edge of East Antarctic Ice Sheet. These changes are well documented by a variety of data, and although they probably represent primarily local variations of glacial regime and climate, they do provide information about environmental variability during a long span of middle Tertiary time. The important aspect of CRP, that cannot be overlooked, is multi-disciplinary character of collected data, which provides a rare opportunity to analyze the same phenomena from different perspectives and study the complex web of environmental interactions.

Seismic calibrations. — The pre-Oligocene strata were not reached due to the miscalibration of seismic profiles, which were the original basis for location of the drill sites. One of the reasons for this misjudgment included not accounting for extreme lateral changes of facies within the early and middle Tertiary deposits. These lithologic discontinuities made pointless the seismic-based correlations (*e.g.* Barrett *et al.* 1995) between the Roberts ridge and the CIROS-1 drill hole, which is located almost 70 km to the south (Fig. 1). Unfortunately, insufficient quality of existing seismic profiles did not allow early recognition of these lateral changes, and led also to significant underestimation of Oligocene sediment accumulation rates. Consequently, the age of oldest post-Beacon (post-Devonian) sediments as well as the age of tectonic development of the Cape Roberts margin of the Victoria Land Basin need to be recalibrated from previously postulated Paleocene or even Cretaceous to the earliest Oligocene ages.

Sedimentology. — The mid-Cenozoic succession recovered represents marine deposition under variable glacial influence. The sediments are terrigenous and include mudstones, sandstones, and conglomerates. They represent variable degrees of sorting and commonly contain glacial erratics. Approximately 40 depositional stratigraphic sequences governed by proximity of glacial fronts were identified (CRP Science Team 1998c, 1999c). However, their exact number is unclear due to unresolved difficulties involved with the precise correlation of the three successions: CRP-1, CRP-2, and CRP-3 and potential overlap of successions drilled.

A typical and fully developed sequence begins with coarse grained and poorly sorted basal diamicton containing both mud and sand fractions. It has been interpreted as till deposited during maximum glacial advance. This lithofacies is overlain by glacially distal, finer and better-sorted sandstones and mudstones, which may contain even coarser erratics. Higher in a sequence the sediment coarsens again into sandstone probably as a result of glacial readvance and the top of the sequence is usually truncated by a diamicton of the next succession. The best-developed sequences are 9, 10, and 11 from CRP-2, where biotic changes mimic lithologically recorded oscillations (Webb and Cape Roberts Project Science Team 2000). These three sequences reach 50 to 60 m in thickness each.

Paleobiology. — Micro- and macrofossils although often sparse are present throughout the cored succession, except for the lower part of CRP-3 (the lower-most Oligocene) where only sparse palynomorphs were encountered. Diatoms are the most abundant and diverse group through most of the Miocene–Oligocene succession and provided the majority of biochronological datums (Bohaty *et al.* 1998, Harwood *et al.* 1998, CRP Science Team 1999b). Both benthic and planktonic diatoms are present, however the Oligocene assemblages are dominated by planktonics. Foraminifera are the second most commonly represented microfossil group. These are predominantly benthic calcareous species and, excluding Quaternary strata at the top of CRP-1 and CRP-2, only few poorly preserved planktonic specimens were found in the CRP-1, CRP-2, and CRP-3 drill holes. The vast majority of foraminiferal species are stratigraphically and environmentally cosmopolitan polar-taxa, but they still reflect subtle long-term environmental changes (Webb and Strong 1998, Strong and Webb 1998, CRP Science Team 1999d). Calcareous nannofossils are relatively abundant and diverse only in few intervals within the Oligocene portion of the section and these events apparently reflect brief periods of fully oceanic influence (CRP Science Team 1999d).

Examination for marine palynomorphs resulted in a significant discovery of Early Miocene assemblages including many species of prasinophyte algae, acritarchs, and dinoflagellate cysts, most documented for the first time (CRP Science Team 1998c, Hannah *et al.* 1998). It is the first record of *in situ* Early Miocene marine palynomorph assemblage from the Antarctic region. Terrestrial palynomorphs occur throughout succession, although they are sparse. Oligocene and Miocene assemblages are rather similar and include mainly *Nothofagus* and podocarpaceous conifers (CRP Science Team 1999d).

Tertiary macrofossils are quite common but low in diversity. Oligocene strata contain a few bryozoans, corals and echinoids, as well as relatively abundant mollusks including bivalves, gastropods, and scaphopods (CRP Science Team 1998d). The Lower Miocene assemblage is less diverse and contains serpulids, echinoid spines, bryozoans, and scallops.

The Quaternary section from CRP-1 provided the greatest richness of well-preserved foraminifera and macrofossils. The latter constitute several different epifaunal assemblages dominated by mollusks, bryozoans, echinoids, octocorals, serpulids, and brachiopods of locally rock-forming significance (Taviani *et al.* 1998).

Logistics. — From logistical perspective, the drilling operations achieved all technological objectives, despite sea-ice difficulties. Due to breaking up of sea ice, drilling was postponed in the 1996–97 season and the first 1997–98 season was significantly shortened. Nevertheless, the goal of recovering a 1200 m of core (CRP Science Team 1998a) was not only attained but exceeded. It is apparent that, experiences gained during the earlier CIROS project played a major role in planning operations for CRP. Both field conditions and scientific personnel were much the same for both projects (Barrett 1989). Similarly, technical expertise gained during the three seasons of CRP has opened new avenues for future polar drilling operations.

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Streszczenie

Artykuł zawiera podsumowanie prac i wstępnych wyników Projektu Cape Roberts (CRP). Ten projekt badawczo-wiertniczy zrealizowano w latach 1997–1999 na Morzu Rossa u wybrzeży Antarktydy Wschodniej. Uczestniczyli w nim specjaliści z krajów finansujących to przedsięwzięcie, to jest: Australii, Niemiec, Nowej Zelandii, Stanów Zjednoczonych, Wielkiej Brytanii i Włoch. Głównym celem CRP było uzyskanie szczegółowych danych o charakterze wczesnotrzeciorzędowej zmiany klimatycznej (eocen/oligocen). Niestety, przedoligoceńskie osady nie zostały przewiercone z powodu nieprawidłowej interpretacji danych sejsmicznych, która stanowiła podstawę lokalizacji wierceń. Pomimo tego niepowodzenia, wydobyto rdzeń o długości 1500 metrów, który dostarczył istotnych informacji o charakterze środowiska naturalnego tego rejonu Antarktydy w okresie pomiędzy wczesnym oligocenem i wczesnym miocenem (34–17 mln lat), a więc bezpośrednio po wczesnotrzeciorzędowym ochłodzeniu. Badany rdzeń zawiera osady morsko-lodowcowe, które podzielono na około 40 sekwencji litologicznych. Świadczą one o zmianach środowiskowych wywołanych przede wszystkim dynamiką lokalnych lodowców. Analizy przeprowadzone na Antarktydzie i w macierzystych placówkach badawczych uwzględniły dane sedymentologiczne, paleontologiczne, strukturalne i geofizyczne. Dzięki tej różnorodności dyscyplin uzyskano możliwość odtworzenia środkowotrzeciorzędowego środowiska polarnego. Co więcej, doświadczenia zdobyte przy realizacji CRP mają szansę przyczynić się do dalszego uaktywnienia prac wiertniczo-badawczych na Morzu Rossa i w innych obszarach polarnych.

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