A new view of the stratigraphy and geological framework of the Amery Group, Radok and Beaver Lake area, northern Prince Charles Mountains, East Antarctica

Pavel I. Lunev, Andrew I. Pogorelsky, and Vladimir F. Ilyin

Polar Marine Geological Research Expedition, Pobedy str. 24, Lomonosov, Saint-Petersburg, Russian Federation. (antarctida2007@mail.ru)

Summary This paper reviews new information on the stratigraphy and distribution of the Permian-Triassic Amery Group strata based on field mapping between 2002 and 2006 by Russian Antarctic Expeditions. The conducted research allowed us to find out new information about the stratigraphy and the character of the relations between the stratigraphic units of the Amery Group. The total thickness of these strata lies between 2865 and 3015 m. The distribution of formations and their members is shown in the accompanying map.

Citation: Lunev, P.I., A.I. Pogorelsky and V.F. Ilyin (2007), A new alternative view on the stratigraphy and the geological framework of the Permian-Triassic deposits of the Amery Group, Radok and Beaver Lake area, northern Prince Charles Mountains, East Antarctica; *in* Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES, edited by A.K. Cooper and C.R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 216, 5 p.

Introduction

Gently dipping sedimentary rocks in the area of the Beaver Lake were first described by Crohn in 1957. He reported a thick sedimentary succession of arkosic sandstones with coal beds and a Permian palynoassemblage as the Amery Formation. These strata were later subdivided into three formations, the conglomeratic Radok Conglomerate, the thick coal-bearing Bainmedart Coal Measures and the coal-free Flagstone Bench Formation, and all included by Mond (1972) in an Amery Group. The age of the Amery Group is limited by the period between the end of the early Permian and the late Triassic (McLoughlin, Lindstrom and Drinnan, 1997).

Since then these strata have been studied by a number of scientists to expand stratigraphic knowledge (McKelvey and Stephenson, 1990; McLoughlin and Drinnan 1997a, b; McLoughlin, Lindstrom and Drinnan, 1997). Other studies focussing mainly on the sedimentology have also been carried out (Fielding and Webb, 1995, 1996). These studies provided the basis for the further work outlined here.

In 2002-2006 the Antarctic Geophysics Department of the Polar Marine Geological Research Expedition undertook special research aimed at a detailed investigation of the geological framework of the area of the Beaver and Radok Lake in the framework of the 48, 49, 50 and 51 Russian Antarctic Expeditions. As a result of this research, a detailed 1:50000 scale map and a complete stratigraphic section representing the deposits of the region from Meso-Proterozoic to modern times were prepared. In this article we consider only the new geological data on the Permian-Triassic deposits of the Amery Group (Figure 1).

Our stratigraphic scheme accepts the formations established by Mond (1972). These are explained as the units are described below. Ages are based on palynological studies of Balme and Playford (1958), Kemp (1969, 1973) and Cantrill et al. (1955). The distribution of these strata is shown in Figure 2.

Radok Conglomerate (P_1 *rd*)

Outcrops stretch along the Eastern coast of the Radok Lake from Panorama Point to the Northern coast. They consist of alternating sequences composed of the layers and lenses of conglomerates with lesser coarse-grained sandstones, siltstones and coal-clay shales. The deposits rest on a clean-cut angular unconformity on middle Neoproterozoic metamorphic rocks. The upper boundary of the formation is observed in the outcrops of Panorama Point, where the coarse quartz-feldspathic sandstones of the Bainmedart Coal Measures rest on the youngest layer of conglomerate. The thickness of the formation is 400 m.

Bainmedart Coal Measures (P_{1-3} *bm*)

The outcrops can be found in the southern and central parts of the mapped area. Exposures extend along the eastern shore of the Radok Lake, the western shore of the Beaver Lake and on both arms of Pagodroma Gorge and Glossopteris Gorge. It is composed of rhythmically alternating sandstones, siltstones, claystones, coal-clay shales and coals. According to their lithological characteristics and the nature of cyclicity the Bainmedart Coal Measures can be divided into 2 subformations - the Upper and the Lower.

Lower Subformation of the Bainmedart Coal Measures (P_{1-3} bm_1)

This directly overlies the Radok Conglomerate and is 265 to 315 m thick. Its characteristic lithology is coarse-grained sandstone forming 70-80% of the unit alternate rhythmically with lenses of conglomerate, siltstone, argillite and coal-clay shales. The strata include rare coal beds as much as 0.2 m thick.

Upper Subformation of the Bainmedart Coal Measures (P$_{1-3}$ bm$_2$)

The Upper Subformation of the Bainmedart Coal Measures differs from the Lower Subformation of the Bainmedart Coal Measures in clay content (the amount of sandstone reaches 50%) and coaliferousity. Depending on the coal content it is divided into 4 members: the First coal poor (P$_{1-2}$ *bm*$_2^1$), the Second coaliferous (P$_{1-2}$ *bm*$_2^2$), the Third coal poor (P$_{1-2}$ *bm*$_2^3$) and the Fourth coaliferous (P$_{1-2}$ *bm*$_2^4$).

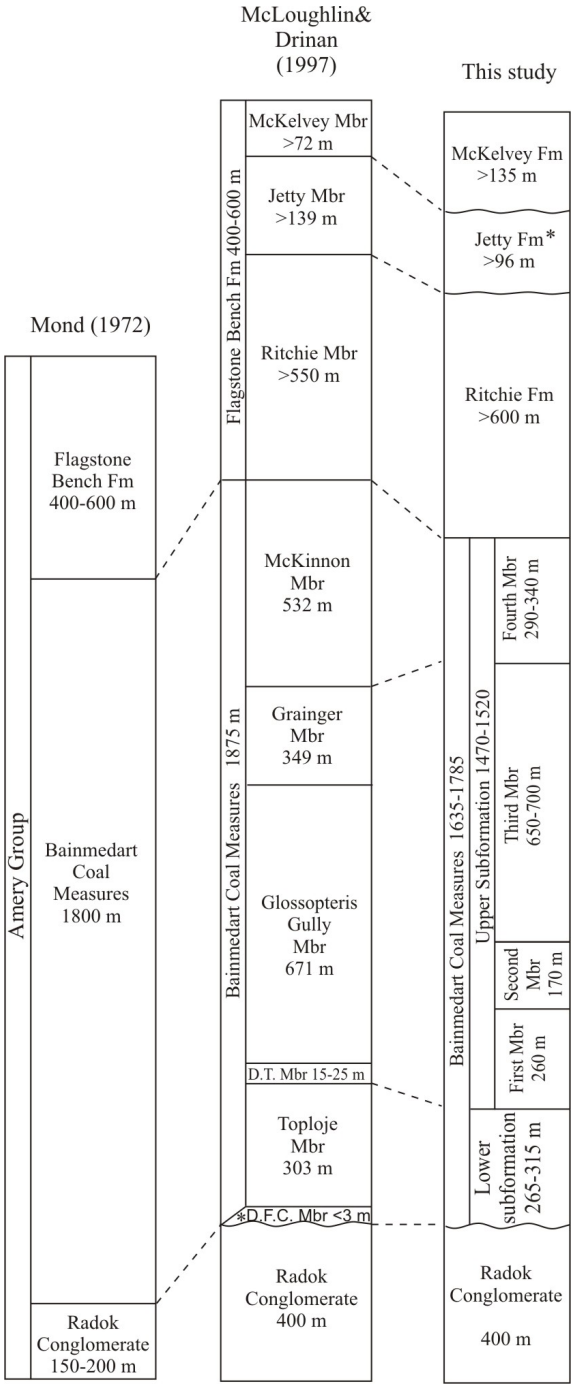

Figure 1. Evolution of Amery Group stratigraphy. *Jetty Mbr defined by Webb and Fielding (1993). Fm – Formation Gl.- Glossopteris Mbr – Member

First (coal-poor) Member (P$_{1-3}$ bm$_2^1$)

This is characterized by a rhythmical alternation of thin beds of laminated fine-grained brown micaceous sandstone, siltstone, claystone and coal-clay shale and beds of coarse-grained cross-bedded quartz-feldspathic sandstone. Eighteen meters of fine-grained thin-slabby brown quartz-feldspathic sandstone atthe base was recognized by Fielding and Webb (1996) as their Dragon's Teeth Member. Rare coal beds up to 0.3 m thick occur throughout. The thickness of this member is 260 m,

Second (coal-rich) Member (P$_{1-3}$ bm$_2^2$)

This is characterized by a cyclic alternation of coarse-grained quartz-feldspathic sandstone, fine-grained micaceous sandstone, siltstone, claystone, coal-clay shale and coal. The thickness of the coal beds reaches 3.5 m, and the total thickness is 13.8 m.

There are two types of cycle determined by the sequence of lithologies – a complete cycle and an incomplete cycle. The complete cycle begins with coarse-grained cross-bedded quartz-feldspathic sandstone, and then follows a thin layer of alternating fine-grained micaceous sandstone, siltstone and argillite. This is followed by a coal bed, which commonly includes layers of claystone and coaly shale. In some cases this layer is entirely coaly shale. Then follows a thin layer of alternating fine lithologies like the second element of the cycle. Coarse-grained quartz-feldspathic sandstone completes the cycle. The characteristic feature of the incomplete cycle is the absence of the upper sandy-clayey element, leaving the coarse-grained quartz-feldspathic sandstone to rest directly on the coal bed. In this case the traces of erosion are observed, and in some cycles the coal bed is absent. Then the cycle consists of coarse-grained sandstones and a member of a thin alternation. The thickness of each cycle varies between 1 and 30 m. The thickness of the member is 170 m.

Third (coal-poor) Member (P$_{1-3}$ bm$_2^3$)

This is divided into two parts. The lower part is characterized by the alternation of the interbedded members of laminated fine-grained brown micaceous sandstone, siltstone, claystone with coarse-grained cross-bedded quartz-feldspathic sandstone that includes beds of coaly shale and coal as much as 0.5 m thick. In the sections one can observe sharp facies changes from fine-grained to coarse-grained sandstone. The coal layers can also be seen to thin along the edges of Pagodroma Gorge and in the outcrops of the southern part of the western shore of Beaver Lake. The upper part of this member is marked by a dominance of coarse-grained sandstone, which constitutes 85-90% of the strata, and edges of Pagodroma Gorge and in

Figure 2. Geological map of Beaver Lake area

description of this formational boundary during this project.

the outcrops of the southern part of the western shore of Beaver Lake. The upper part of this member is marked by a dominance of coarse-grained sandstone, which constitutes 85-90% of the strata, and by an almost complete absence of coal. The member has only three coal layers, the thickness of which is 0.7 m, a number of small lenses only centimeters thick and traces of eroded coal in the form of scattered fragments in pebbly sandstone. The thickness of the member is 650-700 m.

Fourth (coal-rich) Member ($P_{1\text{-}3}bm_2^4$)

The highest member of the Bainmedart Coal Measures is 290-340 m thick and characterized by many coal layers and a wide range of lithologies. Coal occurs largely as 34 separate beds varying from 0.1 to 2.5 m in thickness and totalling 22.4 m, about 7% of the member. However coal beds are almost absent in the southern part of the mapped area, making it impractical to separate the upper two members of the Coal Measures there.

The lower and the middle parts of the member are marked by a cycles of coarse-grained cross-bedded, quartz-feldspathic sandstone, fine-grained micaceous sandstone, calcareous sandstone, siltstone, claystone, coaly shale and coal. Both in the thickness and the constituent elements the cycles are highly variable. As in the First Member, both complete and incomplete cycles are recognized, with the former considered to present the transgressive phase of deposition, while the latter represent the regressive phase.

The thickness of beds within the cycles varies from several centimeters to more than ten meters. Intervals from 30 to 120 m in the middle and upper parts of the member consist of comparatively homogeneous coarse-grained cross-bedded sandstones with beds of pebbly sandstone and conglomerate. These also lack coal beds, the only indications being in the form of small lenses and coal fragments in the sandstone. Cross-bedding is common and varies from 10 cm to 4 m in thickness. The upper boundary of the member and the Bainmedart Coal Measures was taken as the top of the uppermost layer of carbonaceous sandstone, siltstone and clayey rocks. The mapping of these strata led to the discovery and first

Flagstone Bench Formation

Strata forming this formation were found on the eastern, southern and north-western shores of the Beaver Lake. Our mapping has confirmed the division of the formation by McLoughlin and Drinnan (1997b) into 3 members, from the oldest to youngest, the Ritchie Member, the Jetty Member and the McKelvey Member. However, we have found some differences with McLoughlin and Drinnan's work through our work on a continuous section from the upper part of the Ritchie Member, through the total thickness of the Jetty Member, and also the lower part of the McKelvey Member. The main difference between these beds and those of the Bainmedart Coal Measures beneath is the absence of coal. However the top part of the Flagstone Bench Formation (McKelvey Member) contains rocks with coals.

It should be noted that, in our view, the Ritchie, Jetty and McKelvey members have sufficient differences from each other to be considered to rank as independent formations. In this view the Flagstone Bench Formation, therefore, becomes redundant.

Ritchie Member (Formation) (T_{1-2} *rt*)

These strata outcrop on Ritchie Point, the Flagstone Bench platform and in the south of McKelvey Ledge. The deposits of consist of sandstone layers which irregularly alternate with thin variegated close-grained rocks, beds and lenses of gravelstones and conglomerates. The sandstones are light-grey, sometimes yellow, medium- to coarse-grained, gravel, cross-bedded, massive and seldom laminated. The fragmented rocks are mainly represented by quartz and feldspar, sometimes by mica and in small amounts by grains of garnet, amphibole, zircon and sphene. The contact between the Ritchie and the Jetty Formations is characterized with a gradual alternation of the deposits from grey sandstones with rare beds of red silt-clay varieties to mainly red deposits. Thus the boundary of the formations is considered to lie along the surface of denudation present in this sequence. The surface is characterized by deep erosion pockets, pebbles of the lower bedded rocks in the lower part of the overlying deposits..The thickness of the formation is more than 600 m.

Jetty Member (Formation) (T_{2-3} *jt*)

These strata outcrop on the eastern coast of the Beaver Lake on McKelvey Ledge and overlie unconformably the rocks of the Ritchie Formation. The strata are composed of variegated deposits represented by middle-coarse-grained arkoses, silt-sandstones, siltstones and claystone which constitute layers and lenses of different thickness; sometimes one can find conglomerates that make up lenses (to 0.3 m). The fragmented rocks of the deposits are mainly represented by quartz and feldspar, and the ratio of feldspar varies from 20 to 70%. Often there are mica and grains of dark color minerals in the sandstones. The size of the fragmented rocks with the adulteration of gravelstones varies from coarse-grained to close-grained. Small pebbles of quartz and feldspar, and also big (up to 0.2 m) fragments of yellow-grey calcareous siltstones can also be found. The color of sandstones is light-grey with light-magenta, green and lilac spots. The siltstones are commonly light-magenta or green-grey. The siltstones are characterized with polygonal cracks which are filled with sand deposits. The cracks are treated as shrinkage cavities. The claystone as a rule forms thin beds and lenses with a thickness of some centimeters.

Sometimes brown-grey layers (with the size up to 0,5 m) of calcrete – ball stoned clay carbonates – can be seen in the cross-section. Layers less than 1 m thick, and commonly not recurrent along strike, with dense, horizontally developed series of carbonated veins, composed of dark-grey siltstones, sometimes with clay, are found. The contact of the Jetty and the McKelvey Formations which we interpret as unconformable was investigated in five places located on the eastern coast of Beaver Lake. In all cases the boundary is characterized by a sharp rock alternation, rough surface, traces of ferrian impregnation, field stones and pebbles of the deposits of the Jetty Formation in directly overlying rocks along the cross-section. The thickness of the formation is 95 m.

McKelvey Member (Formation) (*T_3 mk*)

This unit is at least 135 m thick and outcrops on the eastern coast of the Beaver Lake around McKelvey Ledge. It is the youngest unit of the Amery Group in the area. The contact of the Jetty and the McKelvey members was investigated in five places on the eastern shore of Beaver Lake. In all cases the boundary is sharp and irregular, with traces of iron impregnation and clasts of Jetty member lithologies in the overlying member.

The rocks are represented by light grey (weathering light yellow) fine- to coarse-grained quartzose and quartzofeldspathic sandstone and siltstone. The sandstones are massive and cross bedded, with sets reaching 1 m in thickness. The foresets dip largely to the north-east. The composition is mostly quartz (60%) and feldspar, with a few grains of garnet, mafic minerals and mica. Pebbles of quartz and feldspar as well as quartzitic rocks as much as 30 cm across can be found, as well as fragments of yellow-grey siltstone up to 15 cm in diameter.

Conclusion

Our surveys show that the total thickness of the deposits of the Amery Group ranges between 2865 and 3015 m, similar to estimates by McLoughlin and Drinnan (1997a, b). The strata described here provide an excellent opportunity for studying Permian and Triassic environments and events in this remote region. Our views on the stratigraphy of these deposits are not unquestionable; however, we think that they are most suitable in geological mapping.

Editor Note The authors advise that the lithostratigraphy proposed herein conforms with the Russian Stratigraphic Code. This code has minor differences with the commonly used Antarctic guide (International Stratigraphic Guide: Wiley, London, 1976).

Acknowledgments. We thank co-editor Peter Barrett and reviewers Chris Fielding and Barrie McKelvey for their comments.

References

Balme, B. and G. Playford (1958), Palynological examination of sediments from Prince Charles Mountains, Antarctica, University of Western Australia Palynology Report, 25, 1-8.

Cantrill, D.J., A.N. Drinnan and J..A. Webb (1995), Late Triassic plant fossils from the Prince Charles Mountains, East Antarctica, Antarctic Science, 7, 51-62.

Fielding, C.R. and J.A. Webb (1996), Facies and cyclicity of the Late Permian Bainmedart Coal Measures in the Northern Prince Charles Mountains, MacRobertson Land, Antarctica, Sedimentology, 43, 295–322.

Fielding, C.R. and J.A. Webb (1995), Sedimentology of the Permian Radok Conglomerate of the Beaver Lake area of MacRobertson Land, East Antarctica, Geol. Mag., 132, 51-63.

Kemp, E. (1969), Palynological examination of samples from the Beaver Lake area, Bull. Bur. Mineral. Res., Geol. and Geophys., Australia, 98, 1-7.

Kemp, E.M. (1973). Permian flora from the Beaver Lake area, Prince Charles Mountains, Antarctica. 1. Palynological examination of samples. Bull. Bur. Min. Res., Geol. Geophys., Australia, 126, 7-12.

McKelvey, B.C. and N.C Stephenson (1990), A geological reconnaissance of the Radok Lake area, Amery Oasis, Prince Charles Mountains, Antarctic Science, 2, 53–66.

McLoughlin, S. and A.N. Drinnan (1997a), Revised stratigraphy of the Permian Bainmedart Coal Measures, northern Prince Charles Mountains, East Antarctica, Geol. Mag., 134, 335–53.

McLoughlin, S. and A.N. Drinnan (1997b), Fluvial sedimentology and revised stratigraphy of the Triassic Flagstone Bench Formation, northen Prince Charles Mountains, East Antarctica, Geol. Mag., 781-806.

McLoughlin. S., S. Lindstrom and A.N. Drinnan (1997), Gondwanan floristic and sedimentological trends during the Permian–Triassic transition: new evidence from the Amery Group, northern Prince Charles Mountains, East Antarctica, Antarctic Science, 9, 281–298.

Mond, A. (1972), Permian sediments in the Beaver Lake area, Prince Charles Mountains. In Antarcrtic Geology and Geophysics, edited by R.J. Adie, Universitetforslaget, Oslo, 585-9.

Webb, J. A. and C.R. Fielding (1993), Permo-Triassic sedimentation within the Lambert Graben, northern Prince Charles Mountains, East Antarctica. In Gondwana Eight: Assembly, Evolution and Dispersal, edited by R.H. Findlay, R. Unrug, M.R. Banks and J.J. Veevers, 357–69. A.A. Balkema, Rotterdam.