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Pre-Sturtian (800–730 Ma) depositional age of carbonates in sedimentary sequences hosting stratiform iron ores in the Uppermost Allochthon of the Norwegian Caledonides: A chemostratigraphic approach

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ABSTRACT

Carbon and strontium isotope chemostratigraphy (52 $\delta^{13}C_{carb}$ and $\delta^{18}O$, and 50 $^{87}Sr/^{86}Sr$ analyses of carbonate components in whole-rock samples) was applied for constraining an apparent depositional age of the carbonate protolith to amphibolite-grade, calcite marbles occurring in siliciclastic sedimentary sequences hosting iron formations (the Dunderlandsdalen type iron ores) of previously unknown age in the Rödingsfjället Nappe Complex of the Rana region, Nordland, Norway. The least altered $^{87}Sr/^{86}Sr$ (0.70676) and $\delta^{13}C$ (+2.5 to +5.6‰) values of the marbles (Dunderland Marble 2a) in the hanging wall sequence of the Stensundtjern iron formation in the Rana region are consistent with seawater composition in the time interval 800–730 Ma, hence the Middle Cryogenian (pre-Sturtian). The least altered Sr- and C-isotopic values obtained from two other marbles units (Marble 3 and 4) of the Rödningsfjället Nappe Complex are consistent with the Late Cryogenian (c. 660 and 670–700 Ma, respectively). The ages obtained provide the first insight into the depositional time of sediment-hosted iron formations of the Uppermost Allochthon in the North-Central Norwegian Caledonides. The Middle Cryogenian-age of marbles associated with iron formations in the Rana region and those located c. 250 km to the north (the Håfjellet iron ore horizon) share similar $^{87}Sr/^{86}Sr$ and $\delta^{13}C$ ratios and hence similar chemostratigraphic ages. These iron formations were originally accumulated outside of Baltica, on a glacially influenced carbonate-siliciclastic shelf, apparently on a margin of an unknown microcontinent. The Scandinavian Dunderlandsdalen and the Håfjellet iron ores of Middle Cryogenian age (800–730 Ma) were accumulated in an open marine environment distant from volcanic centres, and hence represent an outstanding exception to other reported Neoproterozoic iron formations which were all accumulated in volcanically active continental rift settings.

1. Introduction

The stratiform iron formations within mica schist–marble successions in the Northern and North-Central Norwegian Caledonides are known as the Dunderlandsdalen ore type (e.g. Foslie, 1949; Bugge, 1978). Such deposits occur between latitudes 65°20′ and 69°40′, hence stretching over a distance of c. 550 km. This ore type constitutes important economic deposits in the Rana region where they have been mined for nearly a century.

The depositional age of the sediment-hosted Dunderlandsdalen ore type has previously been suggested to range from the Upper Cambrian to the Lower Ordovician (e.g. Bugge, 1948) or from the Late Precambrian to the Cambro-Ordovician (e.g. Søvegjarto et al., 1988). In general, banded iron formations (BIF) and iron formations (IF) are a characteristic feature of the Archaean–Palaeoproterozoic time, although younger IFs also occurred in the 800–600 Ma interval, i.e. during the Neoproterozoic. However, none of the most recent compilations has included any of the Neoproterozoic IFs in Norway (e.g. Trendall, 2002; Cox et al., 2013).

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The iron formations in the Caledonides of northern Norway are invariably associated with schist–marble successions occurring in the Uppermost Allochthon (UmA) and locally in the Upper Allochthon (UA). In the Ofotfjorden region (for the geographic and geological locations see 'Outline of Fig. 12' in Fig. 1A), isotope chemostratigraphy has been already employed to constrain apparent depositional ages of such schist–marble complexes, hence providing the first insight on the depositional time of sediment-hosted IF (the Håfjellet iron ore horizon) which was linked to Middle Cryogenian (pre-Sturtian) time (Melezhik et al., 2002a, 2003). The main goal of this contribution is to constrain an apparent depositional age of major marble formations known in the UmA of the Rana region (Fig. 1B; Gustavson and Gjelle, 1991) including those associated with IFs and commercially exploited iron-ore bodies (Fig. 1A).

2. Geological background

The main structure of the Scandinavian Caledonides has been described over the past few decades as a succession of four allochthons originating from different geological environments (Gee and Sturt, 1985; Roberts and Gee, 1985) thrust upon each other both prior to and during the collision between Laurentia and Baltica in Silurian–Devonian time. Consequently, the bedrock geology of the study area is represented by parautochthonous, Precambrian crystalline basement (the Nasafjellet and Høgtuva tectonic windows; Fig. 1B) and overlying Caledonian nappes. The Lower Allochthon (LA), UA and UmA are present in the Rana region but the Middle Allochthon (MA) is apparently missing (Figs. 1B and 2). The studied marble formations are located within the UA (the Bjoråga Nappe) and UmA (Ravnålia and Plura nappes), whereas schist–marble–hosted iron ores are known only in the UmA (the Ravnålia Nappe) (Fig. 2).

The UA seems to rest directly upon the Gargatis Nappe of the LA (Thelander et al., 1981) and is represented by the Köli Nappe Complex (Figs. 1B and 2). It originated outside of Baltica (Grenne et al., 1999 and references therein). The nappe complex is characterised by the presence of low- to medium-grade sedimentary rocks among which mica schists, phyllites and carbonate rocks are the dominating lithologies. Volcanic rocks and some plutonic rocks, mainly of mafic and ultramafic composition, are also present. In the Rana region, the Köli Nappe Complex is divided into three nappes, but only two of them occur in the map area (e.g. Gjelle et al., 1991; see Fig. 2). The UmA *per se* is represented by the Rödingsfjället and the Helgeland nappe complexes. The Helgeland Nappe Complex, which is the highest structural unit of the Caledonian nappe pile (Gustavson, 1978), is situated outside the study area. The Rödingsfjället Nappe Complex covers most of the Rana region and was divided into six nappes (Søvegjarto et al., 1988, 1989; Gjelle et al., 1991; Marker et al., 2012; see Fig. 2) whose volcano-sedimentary successions are interpreted to have been formed along the continental margin of Laurentia, or eventually on the margin of microcontinents in the ocean area, that ultimately became part of the Scandinavian Caledonides during the closure of the Iapetus Ocean in late Silurian time (e.g. Roberts et al., 2007). The main component of their geology is characterised by extensive development of medium- to high-grade metasedimentary rocks of which marbles make up a considerable part. Among the tectonic units of Rödingsfjället Nappe Complex only those containing schist–marble-hosted stratiform iron ores (the Ravnålia Nappe) and marbles (the Plura Nappe) will be considered in the current contribution.

The Ravnålia Nappe includes three informal lithostratigraphic units: (i) the Kjerringfjellet group, (ii) the Dunderland formation, and (iii) the Ørtfjellet group (e.g. Gjelle, 1978; Gjelle et al., 1991; Søvegjarto et al., 1988, 1989). The Kjerringfjellet group is situated at the bottom of the Ravnålia Nappe and consists mainly of paragneisses intruded by granitic plutons post-dating the amalgamation of the nappes. The Dunderland formation comprises a large, complicated, antiformal structure (the Dunderland antiform hereafter; Figs. 1B and 3). Main lithologies of the formation are amphibolite-facies dolomite and calcite marbles and schists. The latter include mica schists, graphite-, pyrite- and pyrrhotite-bearing mica schists, quartz–feldspar–mica schists, calcareous hornblende–mica schists, and quartz–garnet–mica schists. In the Dunderland antiform, the quartz–feldspar–mica schists contain small lenses of magnetite-rich IF, whereas the calcareous varieties contain lenses of dolomite marble. The formation also contains minor black, fine-grained amphibolites of assumed intrusive origin (e.g. Bugge, 1948). This amphibolite facies sequence hosts abundant dismembered units of stratiform IF. Psammitic components gradually increase westwards in schist successions which is accompanied by the disappearance of marble and IF. Here, the Dunderland formation becomes indistinguishable from the Ørtfjellet group composed of mica schists, quartz–feldspathic gneisses and subordinate marbles.

The Plura Nappe has not been subdivided in to smaller tectono-stratigraphic units and is composed solely of the Plurdalen Group whose lithologies include various amphibolite-grade mica schists and gneisses, quartzites, amphibolites, meta-keratophyres, dolomitic and calcitic marbles as well as phosphorus-rich magnetite-hornblende schists and Mn-silicate-rich units (Gjelle, 1978; Gjelle et al., 1991; Søvegjarto et al., 1988, 1989; Marker et al., 2012). The latter two units bear some resemblance with units in the Dunderland formation, although the Plurdalen Group appears to be richer in rocks interpretable as meta-volcanites (e.g. meta-keratophyres).

3. The stratiform iron ores of the Dunderland formation

The stratiform iron ores of the Dunderland formation occur in a complexly folded and imbricated carbonate-schist sequence containing minor amphibolites assumed to be of intrusive origin (Bugge, 1948). Due to complex folding, the stratigraphic base or top of any given lithological unit cannot be confidently identified. The main host-rock lithologies comprise different types of amphibolite-facies mica schists and quartzo–feldspathic mica gneisses grading into hornblende-bearing calcareous types or siliceous and aluminous schists such as quartz–garnet–mica schists. The schists contain abundant units of dolomite and calcite marble that occur commonly in close proximity to the IFs. The IFs occur in contact with calcareous schists, marbles and diamictites (Fig. 4A–C). The contact of IFs with the host rocks is either tectonic, especially towards competent units of dolomite marble, or conformable. The conformable contact is characterised by a thin interval of carbonate–mica schist that separates the IFs from the marbles, schists and diamictites. This interval is thinly banded, low in Fe-oxide and rich in Mn-carbonates and Mn-silicates (Fig. 4D). In the western part of the Dunderland antiform, in the mine area at Ørtfjellet-Kvannvatnet (Fig. 3), the IFs show a conformable contact with a diamictite unit in their structural base (for details, see section below) and calcite marble in their structural top (Fig. 5).

In general, the IFs occur as a series of tectonically dismembered and densely spaced segments rarely exceeding 4 km in length. They occur both as up to 30 m thick linear units and as detached isoclinal folds with ore horizons doubled to tripled in thickness in the hinge zones. The iron ores are generally fine-grained (<1 mm) and show a banded distribution of Fe-oxides in a carbonate-bearing quartzitic to pelitic matrix (Bugge, 1948). Thus the gangue minerals are mainly quartz, dolomite, calcite, muscovite, biotite, chlorite and/or oligoclase. In addition, the magnetite-dominated ores are commonly characterised by the presence of amphibole, Fe–Mn–garnet