Carbon isotopes as a proxy in tracing carbon mobility in the continental crust of East Antarctica: Implications for carbon geodynamic cycle in orogenic belts

M. Satish-Kumar[1]

[1]*Department of Geology, Faculty of Science, Niigata University, 2-8050 Ikarashi, Nishi-ku, Niigata 950-2181, Niigata Japan*

Organic carbon and carbonate carbon are two important reservoirs that control the carbon geodynamic cycle at convergent margins during plate subduction, arc magmatism and continent building processes. The movement of carbon through different reservoirs in the Earth relating to the global tectonic activities especially, in the convergent margins, is key in understanding the carbon geodynamic cycle. A recent study on Earth's tectonic carbon conveyor belt quantified the fluxes into and out of all reservoirs in the deep oceanic carbon cycle over past 250 million years and provided boundary conditions for future carbon cycle models (Muller et al., 2022). However, a quantitative evaluation of carbon geodynamic cycle at the continental collision zones is not yet carried out. Here, I present a comprehensive synthesis on the different forms of carbon, its movement among various reservoirs in the Lützow-Holm Complex (LHC) of East Antarctica and uses carbon isotopic composition as a proxy to identify the movement of carbon during orogenesis. The results suggest that large volumes of carbon can be stored in the middle to lower continental crust in the form of graphitic carbon and carbonate carbon, as long-term sinks.

Sedimentary carbonate rocks trapped in orogenic belts are of key importance, since they remain stable as metacarbonate rocks for longer time scales, even after subjected to varying degrees of metamorphism up to ultra-high temperature conditions (e.g., Satish-Kumar et al., 2021 and references therein). Metacarbonate rocks are prominent rock units in orogenic belts and form an important carbon reservoir in the continental crust. They occur in large volumes in the Lützow-Holm Complex (LHC) in East Antarctica, which forms a part of the Neoproterozoic to early Paleozoic East African Antarctic Orogeny (Shiraishi et al., 1994; Satish-Kumar et al., 2008a, 2013), with different suits of rocks with varying protolith history, as proposed in a recent subdivision by Dunkley et al. (2020). The LHC, located along the Prince Olav, Prince Herald and Soya coasts (~400 km), in East Antarctica, comprises of a thick pile of metamorphosed pelitic and carbonate rocks associated with granitic and mafic meta-igneous rocks. Deposition of thick sedimentary sequences is considered to have occurred in a continental marginal tectonic setting (Satish-Kumar *et al.,* 2008b, 2010). The closure of Mozambique ocean during the Gondwana amalgamation resulted in extensive accretion of sedimentary sequences, where abundant dolomitic marbles are particularly seen in the Skalleviksshalsen Suite (Satish-Kumar et al., 2008b). Metamorphism during continental collision has resulted in the formation of calc-silicate minerals by decarbonation reactions, which can release a fraction of carbon as CO_2. However, the volume of CO_2 released is limited as evidenced by the preservation of sedimentary carbonate isotopic compositions (($\delta^{13}C$ values near to 0‰; Satish-Kumar and Wada, 2000; Satish-Kumar *et al.,* 1998, 2008b). A comprehensive compilation of carbon and oxygen isotopic composition of orogenic metacarbonate rocks indicate that there is only a minimal effect of decarbonation and CO_2 release from carbonate rocks during orogenesis (Satish-Kumar et al., 2021). Thus, pure carbonate rocks in orogenic belts can act as a long-term sink for carbon.

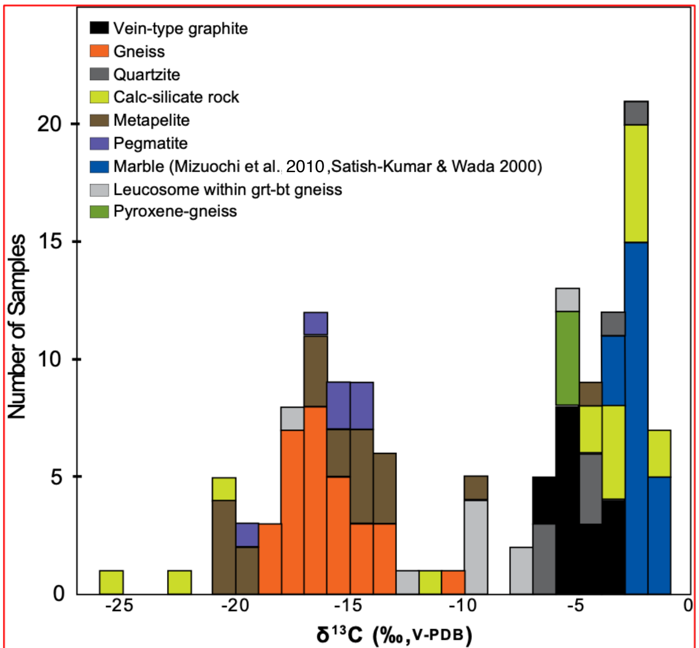

Figure 1. Distribution of carbon isotopic composition of graphite in various rock types in the Lützow-Holm Complex, East Antarctica.

Graphite, the purest form of carbon in collisional orogenic belts, is an important reservoir of carbon in continental crust. Graphite occurs in a variety of rock types in the LHC. Based on the mode of occurrence they were classified into several types, disseminate flakes in gneissic rocks, coarse aggregates in leucosomes, graphite concentration in lithological contacts and as monomineralic graphite veins. At the Skallvikshalsen locality in the LHC, all forms of carbon are observed in a single outcrop scale and thereby movement of carbon within the crust could be traced clearly. Disseminated graphite in pelitic gneisses have the lowest carbon isotopic composition ($\delta^{13}C$ values as low as -25‰, Fig. 1), suggesting sedimentary biogenic signatures, however those in metacarbonate rocks have equilibrated with carbonate during high temperature metamorphism to heavier values ($\delta^{13}C$ values in the range between-3‰ to -1‰, Fig. 1). Carbon isotopic composition of graphite and associated metacarbonate rocks suggest that they are consistent with graphite precipitation from CO_2 fluids locally released through decarbonation reactions. Formation of vein type of graphite is significant, since the veins have penetrated into the felsic gneiss from metacarbonate rocks, suggesting a possible origin from CO_2 fluids released by decarbonation reactions during skarn formation at contact zones.

Coarse-grained graphite is also observed to concentrate in leucosomes in the migmatized meta-pelitic rocks at the Rundvågshetta occurrence. During the high-temperature metamorphism and partial melting of graphite-bearing rocks, graphite decomposes to form COH fluids, part of which, especially the lighter isotope-bearing fluids are supposed to have escaped the system causing a shift toward heavier values ($\delta^{13}C$ values in the range between-18‰ to -10‰, Fig. 1). Based on the field, textural and carbon isotope evidence from Rundvågshetta, biotite dehydration melting of graphite-bearing rocks caused the dissolution of graphite and during melt crystallization graphite has reprecipitated, resulting in carbon remobilization and carbon isotope reorganization, similar to the model suggested by Satish-Kumar et al. (2011). Thus, carbon is recycled and retained as graphite in the continental crust during high-grade metamorphism and anatexis, though its isotopic composition can be considerably modified.

In summary, a comprehensive study of carbon isotopic composition of graphite and carbonate rocks in the Lützow-Holm Complex, East Antarctica has thus revealed the role of recycling of carbon within the continental crust during orogenesis. A detailed synopsis on the movement of carbon from a carbon isotope perspective will be presented to understand the role of carbonate and graphite as "long-term sinks" of carbon during orogenesis.

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