Isotope and trace element patterns of Cambrian sediments from New Zealand: A record of island arc and SE-Australian continental provenance

F. Wombacher
C. Münker

Institut für Geologie und Dynamik der Lithosphäre and Geochemisches Institut, Goldschmidtstr. 3, 37077 Göttingen, Germany

In this study, we present a complete Sr-Nd-Pb data set from the Cambrian Haupiri Group Sediments of the Takaka Terrane, South Island of New Zealand. 24 samples of the Haupiri Group Sediments were analysed for major and trace elements by XRF. 12 samples were selected for Rb-Sr and Sm-Nd analyses and further trace element analyses (ICPMS). Additional Pb isotope data for seven samples is taken from Münker (1997). The data allows to identify continental provenance and mafic island arc sources.

The Haupiri Group Sediments and the Devil River Volcanics form the Cambrian part of the Takaka Terrane, New Zealand. The Devil River Volcanics show a wide compositional range comprising low to high-K intra-oceanic arc rocks (Benson Volcanics), back-arc rocks (Mataki Volcanics), and boninites. Petrological constraints identify two major sources for the Haupiri Group Sediments, a mafic igneous and a continental source.

Moores (1991) proposed a late Precambrian fit of Western North America with the Australia-Antarctic shield region, the so called SWEAT (**S**outh**w**est U.S.-**E**ast **A**ntarctic connection)-hypothesis. The SWEAT-hypothesis was soon refined (e.g. Dalziel *et al.*, 1994) and is now widely accepted. In the Late Precambrian the Rodinia-supercontinent broke up and Laurentia and Gondwana drifted apart, thus opening the Palaeo-Pacific ocean. Subsequently the Australian/Palaeo-Pacific plate boundary developed into a passive margin (e.g. Glen *et al.*, 1997). Convergence between Southeast Gondwana and the Palaeo-Pacific ocean commenced in the late Early Cambrian (Glen *et al.*, 1997).

It is still unknown whether the Devil River arc originated in a convergent setting within the Palaeo-Pacific ocean, offshore SE Gondwana (Fig. 1) or is an exotic fragment within present-day SE Gondwana (New Zealand, Australia/Tasmania and Antarctica). Our isotope study of sediments intercalated with volcanic rocks of the Devil River Arc infers the palaeogeographic position of the island arc.

Continental provenance

Recalculated to the approximate time of deposition, Sr isotopes do not correlate with Nd isotopes. The presence of significant amounts of seawater-derived Sr in the samples is suggested by a Sr-rich HCl-soluble (~carbonate) component. Isochrons calculated from leachates-whole rocks and silicate residues demonstrate Sr resetting at ages significantly younger than the age of deposition. Since resetting affected silicate minerals and carbonates, the original Sr isotope composition of the clastic component, and thus Sr isotope information on provenance is lost.

An increase of εNd_{Strat} with stratigraphic age is observed for the sediments of the Haupiri Group which is attributed to volcaniclastic input with the onset of island arc activity.

Four samples (Junction Formation and Heath Creek beds) can be shown to be entirely or predominantly

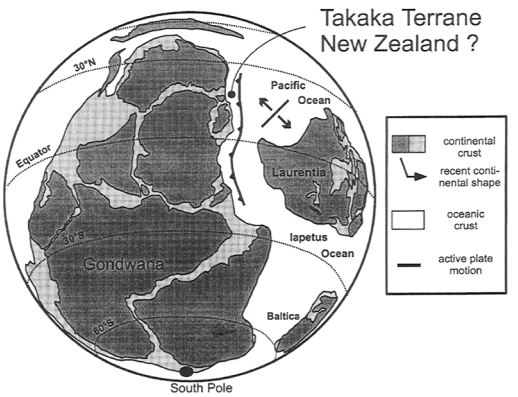

FIG. 1. Palaeogeography of Gondwana at 520 Ma (after Dalziel *et al.*, 1994).

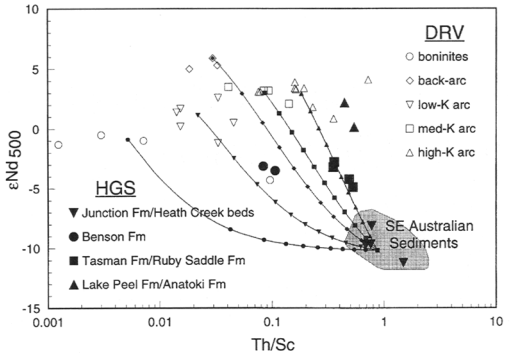

FIG. 2. εNd at 500 Ma versus Th/Sc-diagram. HGS = Haupiri Group Sediments; DRV = Devil River Volcanics. Tic marks at mixing lines indicate incorporation of volcaniclastic detritus in steps of 10 %. The shaded field refers to fine-grained continental reference samples from SE Australia, taken from Turner *et al.* (1993). Data of Devil River Volcanics is from Münker (1997).

derived from 'felsic' continental sources based on major and trace element composition.

Model ages (1.9–2.1 Ga) and εNd_{500Ma} (−8 to −11) of those four continent derived Haupiri Group samples compare well with average values from 20 fine-grained Late Proterozoic to Early Palaeozoic sediments from SE Australia ($T_{DM} \approx 2$ Ga, $\varepsilon Nd_{500Ma} \approx -10$; Turner *et al.*, 1993). This is consistent with a SE Australian crustal source for the Haupiri Group Sediments.

Pb isotope compositions of six Haupiri Group samples recalculated at 500 Ma show a narrow range of $^{206}Pb/^{204}Pb$ = 17.79 to 18.05 and $^{207}Pb/^{204}Pb$ = 15.59 to 15.62 (Münker, 1997). The narrow range in Pb-isotopes for the six samples of different units suggests, that the U/Pb ratios remained unaltered after deposition/diagenesis. One outlier, however, most likely suffered alteration of its U/Pb ratio some time after 500 Ma. Münker (1997) inferred the more radiogenic lead isotope composition of the Devil River Volcanics to be controlled by an Archaean component in the mantle source. Haupiri Group Sediments with a large mafic component indeed exhibit a slight shift towards more radiogenic Pb isotope compositions. The Haupiri Group Sediments, however, exhibit Pb isotope compositions similar to those of the Lachlan Fold Belt/SE Australia ($^{206}Pb/^{204}Pb$ = 17.6 to 18.1 and $^{207}Pb/^{204}Pb$ = 15.56 to 15.65 at 500 Ma, McCulloch and Woodhead, 1993). The high Pb content of the continental component dominates the Pb budget and controls the Pb isotope composition of the arc-related sediments.

Island arc provenance

Within the Devil River Volcanics, low-K volcanic rocks and boninites are restricted to the older part of the arc series, whereas the younger part is characterized by medium-K to high-K rocks. The variable source of the volcaniclastic component in the sediments and the amount of volcaniclastic input is determined by combined Nd isotopes and trace elements (e.g. Th/Sc). In Fig. 2, Nd isotopes and Th/Sc demonstrate that the stratigraphically older Benson Formation samples contain about 85% low-K volcaniclastic material consistent with their deposition during the early low-K/boninitic stage of the Devil River Arc. A significant contribution of back-arc volcanic rocks (Mataki Volcanics) to the Benson Formation samples can be ruled out, since *REE* abundances of the Benson Formation samples are below those of the back-arc rocks. The younger Tasman and Ruby Saddle Formation samples contain 40 to 60% of medium-K to high-K volcaniclastic detritus and reflect the main stage of the island arc activity. The volcaniclastic component in samples of the youngest units, the Lake Peel and Anatoki Formations is solely derived from high-K arc-rocks, consistent with their deposition during the final stage of the Devil River arc.

Conclusions

Nd and Pb isotopes constrain SE Australia as the most likely continental source for the Haupiri Group Sediments. From Nd isotopes and trace element systematics it can be inferred that low to high-K Benson Volcanics (arc affinity) constitute distinguishable mafic sources. Nd isotopes and chemistry of arc-related sediments record the volcanic arc evolution and thus provide a useful tool for reconstruction of ancient arc assemblages.

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