**Geochemical and chronological constraints on interactions between the Yap arc and the Caroline plateau:** **Datasets and Supplementary Materials**

Ji Zhang1,2,3,4, Guo-Liang Zhang1,2,4\*

1 Center of Deep Sea Research & CAS Key Laboratory of Marine Geology and Environment, Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China.

2 Laboratory for Marine Geology, Qingdao National Laboratory of Marine Science and Technology, Qingdao 266237, China.

3 University of Chinese Academy of Sciences, Beijing 100049, China.

4 Center for Ocean Mega-Science, Chinese Academy of Sciences, Qingdao 266071, China.

Corresponding author: Guo-Liang Zhang([zhangguoliang@qdio.ac.cn)](mailto:zhangguoliang@qdio.ac.cn))

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**Introduction**

The supporting information for this paper includes text and tables. The text file is a description of detailed analyses methods (Text S1). Tables give completed data for geochemistry and geochronology results of Yap Arc basement rock samples, which includes: (1) Mineral assemblages of the selective samples (Table S1). We also present the captions for Table S2 (SIMS U–Th–Pb analytical results of titanites in Yap amphibolites), Table S3 (major and trace elements data and Sr-Nd-Pb-Hf isotopes data), Table S4 (40Ar/39Ar VG3600 furnace step-heating analytical results for Y3-9-5 amphiboles) and Table S5(ARGUSVI 40Ar/39Ar laser step-heating analytical results for Y30059-1 amphiboles), which are uploaded separately.

Text S1. Analyses Methods

**Bulk-rock major elements**

Samples were cleaned and crushed into small particles of approximately 3 mm in diameter. The grains with visibly altered parts or secondary minerals were picked out carefully under a binocular. Only the fresh grains with no visible weathered surfaces or secondary minerals were pulverized into powders of 200 mesh with an agate mortar. Major elements were analyzed on fused glass discs with an Axios sequential X-ray Fluorescence Spectrometer at Nanjing University. Samples were fused at 1050 °C using a lithium tetraborate flux (Li2B4O7) in a mixture consisting of 0.5 g of sample and 5 g of lithium tetraborate. The loss on ignition (LOI) of sample powders was determined at a temperature of 1000°C. The measurements were monitored using basalt standards BCR-2, BHVO-2 and GSR-3. The accuracy of the analytical results was controlled by measuring reference material GSR-3 (Table 1).

**Table 1.** Major (wt%) element analyses of standard reference materials. The recommend values for the standards are from Wilson (1997).

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Standard** | **BHVO-2** | | **BCR-2** | | **GSR-3** | | | | | | |
| **Recommend** | **Result** | **Recommend** | **Result** | **Recommend** | **Result1** | **Result2** | **Result3** | **Result4** | **Result5** | **Result6** |
| **SiO2** (wt%) | 49.9±0.6 | 49.94 | 54.1±0.8 | 54.28 | 44.64±0.16 | 44.25 | 44.25 | 44.23 | 44.27 | 44.54 | 44.50 |
| **TiO2** | 2.73±0.04 | 2.71 | 2.26±0.05 | 2.28 | 2.37±0.01 | 2.35 | 2.34 | 2.34 | 2.34 | 2.34 | 2.34 |
| **Al2O3** | 13.5±0.2 | 13.59 | 13.5±0.2 | 13.55 | 13.83±0.2 | 13.78 | 13.74 | 13.74 | 13.77 | 13.77 | 13.84 |
| **TFe2O3** | 12.3±0.2 | 12.30 | 13.8±0.2 | 14.09 | 13.4±0.29 | 13.36 | 13.35 | 13.38 | 13.37 | 13.39 | 13.39 |
| **MnO** | 0.167 | 0.16 | 0.20±0.01 | 0.20 | 0.17±0.01 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| **MgO** | 7.23±0.12 | 7.35 | 3.59±0.05 | 3.65 | 7.77±0.26 | 7.79 | 7.75 | 7.75 | 7.74 | 7.75 | 7.78 |
| **CaO** | 11.4±0.2 | 11.15 | 7.12±0.11 | 6.96 | 8.81±0.14 | 8.73 | 8.71 | 8.72 | 8.72 | 8.73 | 8.75 |
| **Na2O** | 2.22±0.08 | 2.29 | 3.16±0.11 | 3.19 | 3.38±0.07 | 3.33 | 3.39 | 3.44 | 3.26 | 3.32 | 3.37 |
| **K2O** | 0.52±0.01 | 0.52 | 1.79±0.05 | 1.79 | 2.32±0.08 | 2.29 | 2.29 | 2.29 | 2.28 | 2.30 | 2.30 |
| **P2O5** | 0.27±0.02 | 0.26 | 0.35±0.02 | 0.35 | 0.95±0.04 | 0.94 | 0.95 | 0.95 | 0.95 | 0.94 | 0.94 |
| **LOI** | -0.57 | -0.93 | -0.20 | -0.20 | 2.24 | 2.24 | 2.24 | 2.24 | 2.24 | 2.24 | 2.24 |
| **Total** | 99.67 | 99.33 | 99.67 | 100.12 | 99.88 | 99.23 | 99.18 | 99.23 | 99.12 | 99.48 | 99.62 |

**Bulk-rock trace elements**

Trace elements analyses were conducted using inductively coupled plasma mass spectrometry (ICP-MS) (Thermal X Series II) at the Institute of Crust Dynamics, China Earthquake Administration. For trace element analyses, 25 mg of sample powder was precisely weighed and transferred into Teflon beakers. Then 1.5 ml HF and 1.5 ml HNO3 were added in turn and heated in closed Teflon beakers at 50 °C for 24 h. Beakers were opened and heated at 120°C to evaporate the dissolution to incipient dryness. Then 0.5ml HF and 2.5ml 1:1 HNO3 were added, and the sample solutions were transferred into digestion bomb units each consisting of a Teflon capsule and a stainless-steel bomb jacket. The bomb units were heated in oven at 170°C for 72h. Afterwards, the bomb units were cooled down and the Telflon capsules were taken out of the steel jacket, opened and heated on a hotplate at 120°C to evaporate the dissolutions to dryness. The residues were then redissolved using 1:1 HNO3 and Telflon capsules were then closed and heated on hotplate at 120 °C for 30 min. The solutions were diluted by 1000 times using 1% distilled HNO3 and were analyzed by ICP-MS using In, Rh and Re as internal standards. The standard solutions (American Lab Tech Company) were diluted to 1 μg/L, 10 μg/L, 50 μg/L, 100 μg/L and 400 μg/L to produce the calibration curve with linear regression coefficients all above 0.9999. To evaluate the accuracy, BHVO-2 and BCR-2 were run as external standards, and the results are shown in Table 2.

**Table 2.** Trace element results (ppm) of standard reference materials. See Wilson (1997) for recommended values of standards.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Standard** | **BHVO-2** | | | | | **BCR-2** | | |
| **Recommend** | **Result 1** | **Result 2** | **Result 3** | **Result 4** | **Recommend** | **Result 1** | **Result 2** |
| **Be** | 0.99 | 0.98 | 1.00 | 0.98 | 1.02 | 2.17 | 2.93 | 2.07 |
| **Sc** | 32.3 | 32.1 | 32.0 | 32.2 | 32.1 | 33 | 19.2 | 24.1 |
| **V** | 318 | 351 | 347 | 358 | 365 | 416 | 433 | 455 |
| **Co** | 45.0 | 47.9 | 47.1 | 47.1 | 46.9 | 37 | 37.0 | 38.6 |
| **Ni** | 119 | 127 | 126 | 125 | 124 | 12.6 | 13.4 | 13.8 |
| **Cu** | 130 | 131 | 128 | 129 | 128 | 19 | 23.2 | 23.5 |
| **Zn** | 103 | 104 | 103 | 104 | 104 | 127 | 127 | 126 |
| **Ga** | 22 | 22.1 | 22.0 | 22.2 | 22.2 | 23 | 21.4 | 21.8 |
| **Rb** | 9.8 | 9.69 | 9.70 | 9.68 | 9.87 | 48 | 47.7 | 48.4 |
| **Sr** | 396 | 395 | 397 | 391 | 405 | 346 | 343 | 327 |
| **Y** | 26 | 26.1 | 26.0 | 26.4 | 26.4 | 37 | 35.6 | 35.5 |
| **Zr** | 178 | 178 | 177 | 177 | 177 | 188 | 195 | 193 |
| **Nb** | 19 | 19.5 | 19.4 | 19.4 | 19.4 | 12.6 | 12.9 | 13.0 |
| **Ba** | 131 | 130 | 131 | 133 | 130 | 683 | 656 | 658 |
| **La** | 15 | 15.3 | 15.2 | 15.4 | 15.3 | 25 | 20.4 | 21.4 |
| **Ce** | 38 | 38.1 | 37.9 | 37.9 | 38.1 | 53 | 52.7 | 53.1 |
| **Pr** | 5.3 | 5.28 | 5.32 | 5.41 | 5.41 | 6.8 | 6.19 | 6.19 |
| **Nd** | 25 | 25.1 | 24.8 | 25.0 | 25.1 | 28 | 27.2 | 27.7 |
| **Sm** | 6.2 | 6.18 | 6.20 | 6.23 | 6.28 | 6.7 | 6.49 | 6.39 |
| **Eu** | 2.1 | 2.07 | 2.07 | 2.07 | 2.09 | 2.0 | 1.99 | 2.05 |
| **Gd** | 6.3 | 6.28 | 6.30 | 6.28 | 6.37 | 6.8 | 6.92 | 6.91 |
| **Tb** | 0.90 | 0.88 | 0.89 | 0.89 | 0.91 | 1.07 | 1.01 | 0.97 |
| **Dy** | 5.3 | 5.31 | 5.43 | 5.35 | 5.31 | 6.41 | 6.36 | 6.43 |
| **Ho** | 1.04 | 1.02 | 1.03 | 1.05 | 1.04 | 1.33 | 1.38 | 1.33 |
| **Er** | 2.5 | 2.54 | 2.53 | 2.56 | 2.54 | 3.66 | 3.65 | 3.66 |
| **Tm** | 0.35 | 0.35 | 0.35 | 0.35 | 0.36 | 0.54 | 0.56 | 0.55 |
| **Yb** | 2 | 2.02 | 2.07 | 2.05 | 2.00 | 3.5 | 3.42 | 3.32 |
| **Lu** | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 | 0.51 | 0.50 | 0.49 |
| **Hf** | 4.3 | 4.28 | 4.28 | 4.29 | 4.25 | 4.8 | 4.85 | 4.80 |
| **Ta** | 1.4 | 1.40 | 1.39 | 1.40 | 1.38 | 0.79 | 0.95 | 0.93 |
| **Pb** | 1.55 | 1.52 | 1.55 | 1.58 | 1.55 | 11 | 10.10 | 9.90 |
| **Th** | 1.2 | 1.18 | 1.19 | 1.22 | 1.19 | 6.2 | 5.45 | 5.37 |
| **U** | 0.41 | 0.39 | 0.40 | 0.41 | 0.41 | 1.69 | 1.59 | 1.59 |

**Bulk-rock Sr-Nd-Pb-Hf isotopes**

Sr, Nd and Pb chemical separation was performed following a modified procedure described by Pin and Zalduegui (1997), Deniel and Pin (2001) and Míková and Denková (2007). Sr and Pb were purified using Sr-Spec resin, and Nd and Hf were purified using Ln-Spec resin. To eliminate the effects of seafloor weathering, the sample powders for Sr-Nd-Pb-Hf isotope analyses were leached in 6N HCl at 70 °C for 30 mins before digestion. Sr-Nd-Pb-Hf isotopes were analyzed fully automatically by multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS) using a Nu Plasma system at the University of Queensland. The measured 87Sr/86Sr, 143Nd/144Nd and 176Hf/177Hf ratios were corrected for mass fractionation using the exponential law by normalizing to 86Sr/88Sr = 0.1194, 146Nd/144Nd = 0.7219 and 179Hf/177Hf = 0.7325, respectively. Instrument drift was monitored and calibrated with standards. During the analyses, the measured average value for NBS-987 Sr standard is 87Sr/86Sr = 0.710249 ± 11 (n=30, 2SD) (Recommended value for NBS-987 87Sr/86Sr is 0.710244±14(2σ), see Weis et al., 2006), an in-house laboratory standard Ames Nd Metal yielded an average of 143Nd/144Nd=0.511967±5 (n=19, 2SD). This value was used as a calibration reference to monitor instrument drift, which is usually less than 15 ppm. Lead separated from column chemistry was doped with 4 ppb thallium with a 205Tl/203Tl ratio of 0.23875 was used for mass fractionation correction. Repeated analyses (n=26) of SRM-981 yielded average ratios of 208Pb/204Pb=36.7174±23 (2SD), 207Pb/204Pb=15.4942±9 (2SD) and 206Pb/204Pb=16.9409±8 (2SD). Lead isotope data are reported relative to SRM-981 values of 208Pb/204Pb=36.7145±88 (2SD), 207Pb/204Pb=15.4964±29 (2SD) and 206Pb/204Pb=16.9407±36 (2SD) (Weis et al., 2006). The in-house Hf standard monitor was measured between every 6 samples and 22 repeated measurements gave an average 176Hf/177Hf value of 0.282125 ± 4 (2SD), which were used to calibrate the instrument drift to 0.282145 ± 10, corresponding to a mean value of 0.282159±38 (2SD) for JMC-475 standard (Chu et al., 2002).

**SIMS** **U-Th-Pb analyses for titanite**

The SIMS U–Th–Pb analyses were performed using a Cameca IMS-1280HR SIMS at Institute of Geology and Geophysics, Chinese Academy of Sciences (IGG-CAS). The instrument description and analytical procedure for titanite dating is similar to the perovskites (Li et al., 2010) and has been detailed described in Li et al. (2014) and Ling et al. (2015), only a brief summary is described here. The O2− primary ion beam was accelerated at −13 kV, with an intensity of ~9 nA. The ellipsoidal spot is about 20×30 μm in size. The 40Ca48Ti216O4+ peak is used as a reference peak for centering the secondary ion beam, energy and mass adjustments. A mass resolution of ~7000 (defined at 50% peak height) was used. A single electron multiplier was used in ion-counting mode to measure secondary-ion beam intensities by a peak jumping sequence, including isotopes of Pb+, Th+, U+, ThO+, UO+, and 40Ca48Ti216O4+ to produce one set of data. Analyses of the standard YQ82 titanite were interspersed with unknown grains. Each measurement consists of 15 cycles, and the total analytical time is ca. 19 min. Pb/U calibration was performed relative to YQ82 titanite standard (206Pb/238U age = 1837.6 Ma, Li et al., 2016). U and Th concentrations were calibrated against titanite BLR-1 (Aleinikoff, et al., 2007). A long-term uncertainty of 1.5% (1σ RSD) for 206Pb/238U measurements of the standard titanite was propagated to the unknowns, despite that the measured 206Pb/238U error in a specific session is generally ≤ 1% (1σ RSD). A Tera-Wasserburg (Tera and Wasserburg, 1972). Plot was constructed with common lead uncorrected data to deduce the common lead composition. Then a 207Pb-based common lead correction method was conducted to single analysis. Data reduction was carried out using the Isoplot/Ex v. 2.49 program (Ludwig, 2001). Uncertainties on individual analyses in data tables are reported at 1σ level. The finial U-Pb age result is quoted with 95% confidence interval.

**Ar-Ar dating for amphibole**

Hand-picked amphibole grains were treated with 1 N HNO3 60 min. in a warm ultrasonic bath (~50 °C), followed by with demineralised water and acetone. Samples were then weighed and loaded into aluminum packets for irradiation. The packets were placed in a silicate glass tube (Can UM#84), interleaved with packets containing the flux monitor Fish Canyon tuff sanidine (Age = 28.1260 ± 0.0093 Ma (1σ); Phillips et al., 2017). The canister was irradiated for 40 MWhr in the USGS TRIGA REACTOR, USA. After irradiation, the mineral separates of sample Y30059-1 were removed from their packaging and were placed into a custom-designed copper laser sample tray. 40Ar/39Ar step-heating analyses of sample Y30059-1 were carried out on a Thermofisher ARGUSVI multi-collector mass spectrometer following procedures previously described by Matchan and Phillips (2014). Samples were outgassed using the 6 mm beam homogenized beam of a Photonmachines Fusions 10.6 CO2 continuous wave laser operated at low power (1–2%) to remove the bulk of atmospheric argon and were then step-heated over 4–10% laser power. Blanks were monitored routinely and subtracted from sample measurements.

The mineral separates of sample Y3-9-5 were removed from their packaging and were placed into tin foil packets after irradiation. 40Ar/39Ar step-heating analyses of sample Y3-9-5 were carried out on a conventional double-vacuum tantalum resistance furnace attached to a VG3600 mass spectrometer with Daly and Faraday detector. Samples were outgassed at 450 ºC for 2 hours. Following initial outgassing, aliquots were incrementally heating between 500 and 1350 ºC. It takes about 3 minutes to reach the desired temperature and the duration for each heating step was 20 minutes. Extracted gas was purified by multiple SAES Zr-Al getters before expansion into the VG3600 mass spectrometer. Extraction line blanks were measured before the analysis of each sample. After each sample analysis, the furnace was outgassed at 1500 ºC. High-temperature (1450 ºC) furnace blanks contained low levels of the measured isotopes such that blank corrections have a minimal impact on the data.

Mass discrimination and detector intercalibration were monitored by analysis of standard air volumes. Correction factors for interfering reactions, as determined by irradiation of high-purity K-glass and Ca-salt included in Can UM#84 are indicated in the dataset. The reported data have been corrected for system backgrounds, mass discrimination, fluence gradients and atmospheric contamination, assuming the atmospheric argon composition of Lee et al. (2006). Unless otherwise stated, errors associated with the age determinations are one standard deviation and exclude uncertainties in the J-value, age of the fluence monitor and the decay constants. Ages have been calculated using the decay constants of Steiger & Jager (1977).

Table S1. Mineral assemblages of the selective samples.

|  |  |  |
| --- | --- | --- |
| Samples | Essential minerals | Accessory minerals |
| **Group 1** |  |  |
| Y3-9-4 | Amp, Plg (Lab); | Ab, Kf, Ttn, Hem |
| Y3-9-5 | Amp, Plg (By); | Hem, Ap |
| Y3-9-6 | Amp, Plg (Lab) | Ab, Cpx, Lm, Ap |
| Y3-9-10 | Amp, Plg (And, Lab); | Kf, Ab, Cpx, Ttn, Mt, Ilm, Zeo, Ap |
| **Group 2** |  |  |
| Y30059-1 | Amp, Ab, And; | Ilm, Ttn, Ap, Chl, Zeo |
| Y3-9-9 | Amp, Kf; | Ilm, Ttn, Hem |
| Y3-9-14 | Amp, Ab | Cpx, Ilm, Hem, Ttn, Ap |
| **Group 3** |  |  |
| Y30019-2 | Amp, An; | Di, Ab, Ilm, Ttn, Lm, Rt |
| **Abbreviations**: Amp, Amphibole; Lab, Labradorite; Ab, Albite; Kf, Potassium feldspar; Ttn, Titanite; Hem, Hematite; By, Bytownite; Cpx, Clinopyroxene; Lm, Limonite; And, Andesine; Mt, Magnetite; Zeo, Zeolites; Ilm, Ilmenite; Chl, Chlorite; An, Anorthite; Di, Diopside; Rt, Rutile. | | |

Table S2. SIMS U–Th–Pb analytical results of titanite in Yap amphibolites.

Table S3. 40Ar/39Ar VG3600 furnace step-heating analytical results for Y3-9-5 amphiboles.

Table S4. ARGUSVI 40Ar/39Ar laser step-heating analytical results for Y30059-1 amphiboles.

Table S5. Whole-rock major trace elements and Sr-Nd-Pb-Hf isotopes results of Yap samples.

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