**SUPPLEMENTARY MATERIAL**

**Fluid-rock models**

 Reaction path models for the fluids at E2 were modelled using available knowledge of the processes forming these fluids (previous sections). Fluid chemistry predicts that the hydrothermal fluids at E2 are forming because of high-temperature fluid rock interactions with the host rock. To model this, bottom seawater (BSW) was heated (400 °C) and allowed to react with basaltic andesite until the fluid became rock buffered (Model 1, **Supplementary Table 3**). The fluids at E2-S are a result of conductive cooling of a high temperature fluid at a w/r of 2. Similar conditions were simulated, and the fluid was conductively cooled to 344 and 320 °C simulating Tmax of the measured fluid (**Supplementary Figure 5**).

 Conductive cooling of the seawater-derived hydrothermal fluid results in enrichment and depletion trends in certain elements. K and Ca in the fluids show an enrichment trend with increasing conductive cooling (**Supplementary Table 3**). A similar trend is observed in the natural fluids, ‘Iced Bun’ with a higher degree of conductive cooling has a higher K and Ca concentration relative to ‘Dog’s Head’ (**Table 3A**). The predicted K concentrations by modelling are close to endmember fluid concentrations.

 Aqueous SiO2 concentrations are underpredicted by the models as compared to endmember fluid composition. The lower concentrations are likely a result of lower temperatures used while modelling due to database limitations. The fluid-rock models were constrained at 400 °C, however fluid chemistry predicts that the hydrothermal fluid is formation at temperatures >400 °C. The effect of temperature can be further related to dissolved Fe, H2 and H2S concentrations, which are under-predicted. Dissolved CO2 concentrations predicted by the models are lower in concentration as compared to endmember fluids. The excess aqueous CO2 present in the endmember fluids is likely a result of magmatic CO2 which was not accounted for in this model. Conductive cooling models predict an assemblage of montmorillonite + spherite + chalcocite + bornite.

 The fluid at E2-W is fed by a single source fluid as E2-S, which has undergone conductive cooling and mixing with seawater at EM: SW of 1:5. Furthermore, isenthalpic mixing predicts a temperature of 273 °C for the fluid. Using these details, conductively cooled fluid at 300 °C was mixed with seawater at a ratio of 1:5 and allowed to cool to Tmax at E2-W. An increase in Mg, SO4 and pH is observed in the modelled fluid, which generally matches observations in the measured fluid. Sharp decreases in Fe, H2 and H2S are also observed. At Tmax of 53 °C E2-W the model predicts an assemblage of quartz + barite + sphalerite + bornite (**Supplementary Figure 5**).

**Supplementary material- Figures and Tables**

**Supplementary Figure 1:** Temperature (Tmax) plotted against aqueous Mg. The solid lines indicate isenthalpic-isobaric mixing, considering a temperature and salinity dependent heat capacity of the fluid (Driesner 2007). The thermodynamic data for NaCl-H2O fluids are calculated according to thermodynamic data by pure water from Haar et al. (1985).

**Supplementary Figure 2:** Plot of depth vs temperature of the vent fluids at E2. The solid line indicates the phase boundary for a 3.2 wt.% NaCl solution (from (Driesner and Heinrich 2007) and critical point of seawater (Bischoff and Rosenbauer 1985)

**Supplementary Figure 3:** Results of the microthermometric investigation on anhydrite from ‘Dog’s Head’ Chimney sample. A) Histogram of salinity equivalent (Seq) calculated from 26 measurements of freezing point depressions. B) Histogram of entrapment temperatures (Te) calculated from salinity equivalents and homogenization temperatures in 22 fluid inclusions. C) Salinity vs temperature for fluid inclusions and hydrothermal fluid samples. Grey (subcritical) and black (supercritical) lines denote isobaric intersections of the vapor + liquid surface (after Driesner and Heinrich 2007). The vertical red line denotes seawater salinity. SW marks bottom seawater properties. The large arrows indicate mixing paths of phase separated fluids with cold bottom seawater. Note that mixing of cold seawater with subcritical fluids is not suited to account for the variability of the observed fluid compositions.

**Supplementary Figure 4**: Water isotopes of hydrothermal fluids from various MORs and BABs. The solid lines indicate calculated reaction paths for oxygen and hydrogen isotopic composition after Shanks et al. (1995). The yellow points are data from this study. Data for Lau basin, ESR (East Scotia ridge), Okinawa trough, Manus basin, MAR (mid-Atlantic ridge), EPR (East Pacific rise) taken from Mottl et al. (2011), James et al. (2014), Toki et al. (2016), Reeves et al. (2011), Schmidt et al. (2010) and Von Damm et al. (2003) respectively.

**Supplementary Figure 5:** Thermodynamic models for fluid rock interactions. The figure represents reactions of heated seawater with basaltic andesite followed by conductive cooling to represent formation of E2-S fluid and mixing of cooled fluid with BSW to simulate formation of E2-W fluid.

|  |
| --- |
| **Supplementary Table 1**: Fluid inclusion data from anhydrite crystals retrieved from a chimney at 'Dog's Head' hydrothermal vent field at the East Scotia Ridge |
|  |  |  |  |  |  |  |  |  |  |  |  |
| **Inclusion Type** | **n** | **Tm, min-max** | **Tm, mean** | **Seq, min-max** | **Seq, mean** | **Thom, min-max** | **Thom, mean** | **Te, min-max** | **Te, mean** |  |  |
| Type IIa | 22 | (-2.0) - (-1.6) | -1.8 | 2.7-3.4 | 3.1 | 211-314 | 261 | 226-330 | 277 |  |  |
| Type IIb | 4 | (-2.1) - (-1.6) | -1.9 | 2.7-3.6 | 3.2 | 284-317 | 299 | 300-333 | 316 |  |  |
| All | 26 | (-2.1) - (-1.6) | -1.8 | 2.7-3.6 | 3.1 | 211-317 | 268 | 226-333 | 284 |  |  |

Where, Tm = ice melting temperature, Seq = Calculated salinity, Thom = homogenization temperature and Te = entrapment temperature.

**Supplementary Table 2:** E2-W fluid conservative mixing calculation. 'Calculated E2-EF' is the average extrapolated value of the EF at Iced Bun and Dog's Head. 'Calculated E2-W' fluid represents conservative mixing of 'calculated E2-EF' fluid with BSW up to measured E2-W Mg values. 'Measured E2-W' fluid represents actual concentrations measured from the E2-W fluid. '-' indicated that the fluid calculation was not considered due to measured E2-W fluid values like BSW. Red digits indicate values within analytical errors.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|   | Mg | H2 | CH4 | CO2 | H2S | SO4 | Cl | Br | K | Ca | Si | Na | Sr | Fe |
|   | mM | µM | µM | mm | mM | mM | mM | µM | mM | mM | mM | mM | µM | µM |
| calculated E2-EF  | 0 | 56.72 | 44.45 | 10.26 | 4.21 | 0.31 | 503 | 786 | 34.5 | 29.7 | 16.97 | 401 | 88.9 | 930 |
|   |  |  |  |  |  |  |  |  |  |  |  |  |  |   |
| calculated E2-W fluid | 42.5 | 9.11 | 6.86 | 3.70 | 0.81 | 23.13 | 533 | 811 | 14.3 | 12.9 | 3.15 | 451 | 83.0 | 199 |
|   |  |  |  |  |  |  |  |  |  |  |  |  |  |   |
| Measured E2-W | 42.6 | 0.66 | 1.59 | 3.4 | 0.0002 | 25.4 | 543 | 823 | 13.4 | 13.2 | 2.12 | 468 | 85 | 12.1 |
|   |  |  |  |  |  |  |  |  |  |  |  |  |  |   |
| Enrichment (+) or Depletion (-) relative to calculated fluid | 0.1 | -8.4 | -5.27 | -0.30 | -0.811 | 2.27 | - | - | -0.91 | 0.3 | -1.03 | - | 1.98 | -187 |

mM= mmol/L fluid, μM= μmol/L fluid, mm= mmol/Kg fluid, EF= Endmember Fluid

**Supplementary Table 3:** Thermodynamic computations of hypothetical hydrothermal fluid compositions. Model 1 represents fluid-rock interactions between heated seawater and basaltic andesite. Model 2 represents conductive cooling of model 1 fluid to reach measured temperatures of the fluid sampled at E2-S. Model 3 represents the result of a reaction path model of mixing model 2B fluid with bottom seawater (BSW). Minerals were allowed to precipitate along the reaction paths. Where mM= mmol/L fluid, μM= μmol/L fluid

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Start Fluid** | **Model 1** | **Model 2** | **Model 2** | **Model 3** |
|  |
| **BSW** | **Formation of hydrothermal fluid** | **Conductive cooling (a)** | **Conductive cooling (b)** | **Sub-surface mixing of seawater** |  |
|  |  |  |  |  |   |  |
| **Temp (°C)** | 0.5 | 400 | 344 | 320 | 53 |  |
| **W/R** |  -  | 2 |  |  |   |  |
| **pH(25°C)** | 7.67 | 4.7 | 4.2 | 3.63 |   |  |
| **pH(in stu)** | 7.94 | 5.8 | 5.2 | 4.9 | 5.9 |  |
| **K (mM)** | 10 | 29.6 | 35.0 | 36.9 | 16.6 |  |
| **Ca (mM)** | 9.56 | 4.34 | 5.13 | 5.4 | 9.17 |  |
| **H2S (mM)** | 0 | 1.34 | 1.6 | 1.6 | 0.19 |  |
| **H2 (µM)** | **0** | 113 | 23 | 11 | 0.001 |  |
| **SiO2 (mM)** | 0.10 | 9.52 | 11 | 12 | 0.690 |  |
| **Fe (µM)** | **0** | 1.14 | 0.62 | 0.27 | 0.000000119 |  |
| **Mg (mM)** | 51.6 | 0.0024 | 0.0024 | 0.003 | 42.9 |  |
| **SO4 (mM)** | 28 | 1.64 | 1.89 | 2 | 23.6 |  |
| **CO2 (mM)** | **2.3** | 3.66 | 4 | 5 | 3 |  |
| **Li (µM)** | 25.1 | 358 | 423 | 448 | 100 |  |
|  |  |  |  |  |   |  |
| **assemblage** |  - | Basaltic andesite | Figure S1 | Figure S1 | Figure S1 |  |

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