THERMOCHEMICAL MODELLING OF POSSIBLE EUROPAN OCEAN COMPOSITIONS.

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Introduction: Evidence of widespread geological activity on the surface of Europa [1, 2], and perturbations in Jupiter's magnetic field [3–5] indicate that a subsurface ocean likely exists underneath the ice shell. However, the composition of this ocean remains unclear given its inaccessibility to spacecraft and the limited data on plume composition. Determining its composition would provide insight into both the evolution of Europa and its capability to support life.

Data obtained by the Galileo spacecraft indicated that Europa is differentiated and composed of a metallic core, a silicate mantle (referred to as 'mantle' from hereon) and a water-ice layer [6]. If this mantle is in contact with a liquid ocean, water-rock interactions would be occurring on Europa, and a "bottom-up" approach has been used to assess possible ocean compositions[7–9]. These previous studies have predominantly used carbonaceous chondrites as a possible silicate mantle composition [7–9]; however, computer modelling revealed a L/LL chondrite-type composition correlated with Europa's moment of inertia (MOI), and could also be a possible candidate composition [10].

Previous investigations have also predominantly focused on hydrothermal alteration of the mantle using pure H_2O or HCl fluids [7, 9, 11], which could have been accreted as Europa formed in the circum-jovian disk [12]. However, this ignores any potential contribution from ices that may have been captured since Europa initially formed, such as ices from cometary impacts. It has been determined that cometary impacts are expected to have created 90 % of impact craters on the surface [13] so cometary ices may have made a significant contribution to the europan ocean. Therefore, the effects of cometary-type ices on current ocean composition warrants further investigation.

In this study, we used thermochemical modelling to react a range of potential europan mantle compositions with either pure H_2O or a fluid with a composition based on cometary ices to assess their influence on possible ocean compositions.

Methods: The computer code CHIM-XPT and the Soltherm database [14] were used to generate possible ocean compositions.

Mantle compositions: L, LL and CV chondrites were used to simulate the composition of the mantle (Table 1). Owing to the oxidized and reduced subgroups of CV chondrites, two endmembers were used (CV_{red} and CV_{oxi}). To account for the formation of the metallic core [6], Fe and/or FeS were removed from the bulk composition in accordance with abundances detailed in [10].

Table 1. Model input of the four mantle compositions.

	CV_{red}	CV_{oxi}	L	LL
SiO_2	35.21	34.65	42.50	43.89
TiO_2	0.14	0.14	0.13	0.14
Al_2O_3	3.26	3.21	2.41	2.40
Fe_2O_3	0.32	16.95	1.61	3.31
FeO	31.28	15.81	14.03	12.09
MnO	0.23	0.23	0.36	0.38
MgO	22.78	22.42	26.46	27.26
CaO	2.84	2.79	1.98	2.08
Na_2O	0.46	0.45	1.01	1.00
K_2O	0.03	0.03	0.11	0.11
P_2O_5	0.27	0.26	0.24	0.24
Fe(m)	0.43	0.42	2.08	0.00
Ni	0.90	0.89	1.33	1.16
FeS	1.45	1.36	5.56	5.65
C	0.38	0.38	0.17	0.26
NaCl	0.015	0.014	0.017	0.035
Total	100.00	100.00	100.00	100.00
Fe(t)	26.41	25.43	17.65	15.30

Initial fluids: The mantle compositions were reacted with either pure H_2O or a fluid of cometary melt to represent two initial fluid endmember compositions. The composition of 67P/Churymov-Gerasimenko [15] was used to represent the cometary melt.

Models: Hydrothermal alteration within the mantle was expected to occur in the upper tens of kms of the mantle, where a pressure and temperature of 250 MPa and 333.15 K are anticipated [16]. Models were run at water-rock ratios (W/R) of 1-100. Resultant fluids from these hydrothermal alteration models were then cooled and depressurized to conditions expected at the ocean-mantle interface (125 MPa and 273.16 K) [16], which imitated the ascent of hydrothermally altered fluids through the mantle to the ocean.

Results and Discussion: We report the results for models at W/R = 1 as extensive alteration of the mantle is expected for Europa today [17].

Secondary mineral formation: Overall there was limited variation in model outputs between initial mantle compositions. Variations were restricted to the abundance of Fe, which led to differences in the abundance of Fe-bearing secondary minerals. However, the influence of initial fluid composition led to a distinct variation in secondary mineral assemblages. Pure H_2O

models were dominated by serpentine, greenalite and chlorite, with magnetite observed only in CV_{red} and CV_{oxi} mantle compositions. Cometary fluid models resulted in secondary minerals assemblages dominated by talc, carbonate, greenalite, serpentine and chlorite. The high proportion of carbonate and sulfide minerals present in cometary melt models reflected the high C and S present in the cometary melt.

Ocean compositions: The cooling and depressurization of hydrothermally altered fluids did not lead to changes in the absolute concentration of dominant fluid components regardless of mantle or initial fluid composition. The element concentrations presented here are from the models that simulated the subsequent ascent of fluids to the europan seafloor.

These models revealed similar species were dominant (concentrations > 10^{-3} mol kg^{-1}) in both initial fluid compositions (Fig. 1), and limited variation was observed between mantle compositions. Pure H_2O models showed **Σ**Cl, **Σ**C, **Σ**Ca, **Σ**K, **Σ**Na, and **Σ**Al in concentrations > 10^{-3} mol kg^{-1} and within one order of magnitude of each other for all mantle compositions tested. Concentrations of >10^{-3} mol kg^{-1} were reported for **Σ**Si across all mantle compositions; however, the absolute concentrations varied by one order of magnitude or greater between mantle compositions. S was only above 10^{-3} mol kg^{-1} for L and LL compositions and Fe was above it for CV_{red}. Cometary melt models showed **Σ**C, **Σ**Si, **Σ**K, **Σ**Na and **Σ**N were the dominant species for all mantle compositions, and remained within one order of magnitude of each other.

Conclusions: These models indicate that initial fluid compositions have a stronger influence on the dominant fluid species than the mantle composition. This highlights that more work is required to assess the influence of a broad range of possible initial fluid compositions. In particular, the role of cometary ices needs to be explored further to examine the full extent of their impact on Europa's ocean composition.

Furthermore these results also indicate that C would be major component of Europa's ocean regardless of its initial fluid or mantle compositions. Therefore, carbonates, for example hydromagnesite or sodium carbonate, should also be considered when assessing ocean composition through the surface expression of salts.

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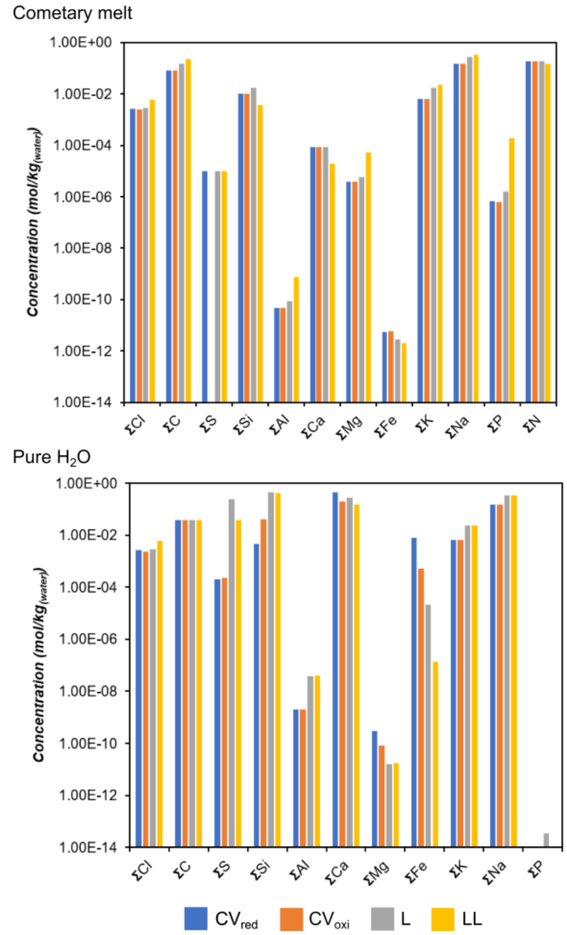

Fig. 1. Ocean compositions generated after experiencing hydrothermal alteration within the mantle and ascent to the mantle-ocean interface for the four mantle and two initial fluid compositions explored.

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