TREND OF THE MAJOR PRIMARY OXYGEN ISOTOPE RESERVOIRS IN THE EARLY SOLAR NEBULA INFERRED FROM ALLENDE CV3 METEORITE

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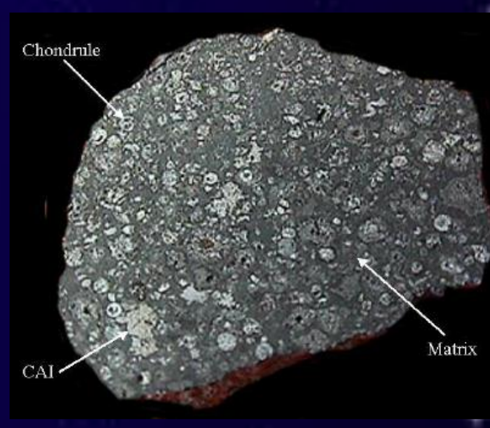
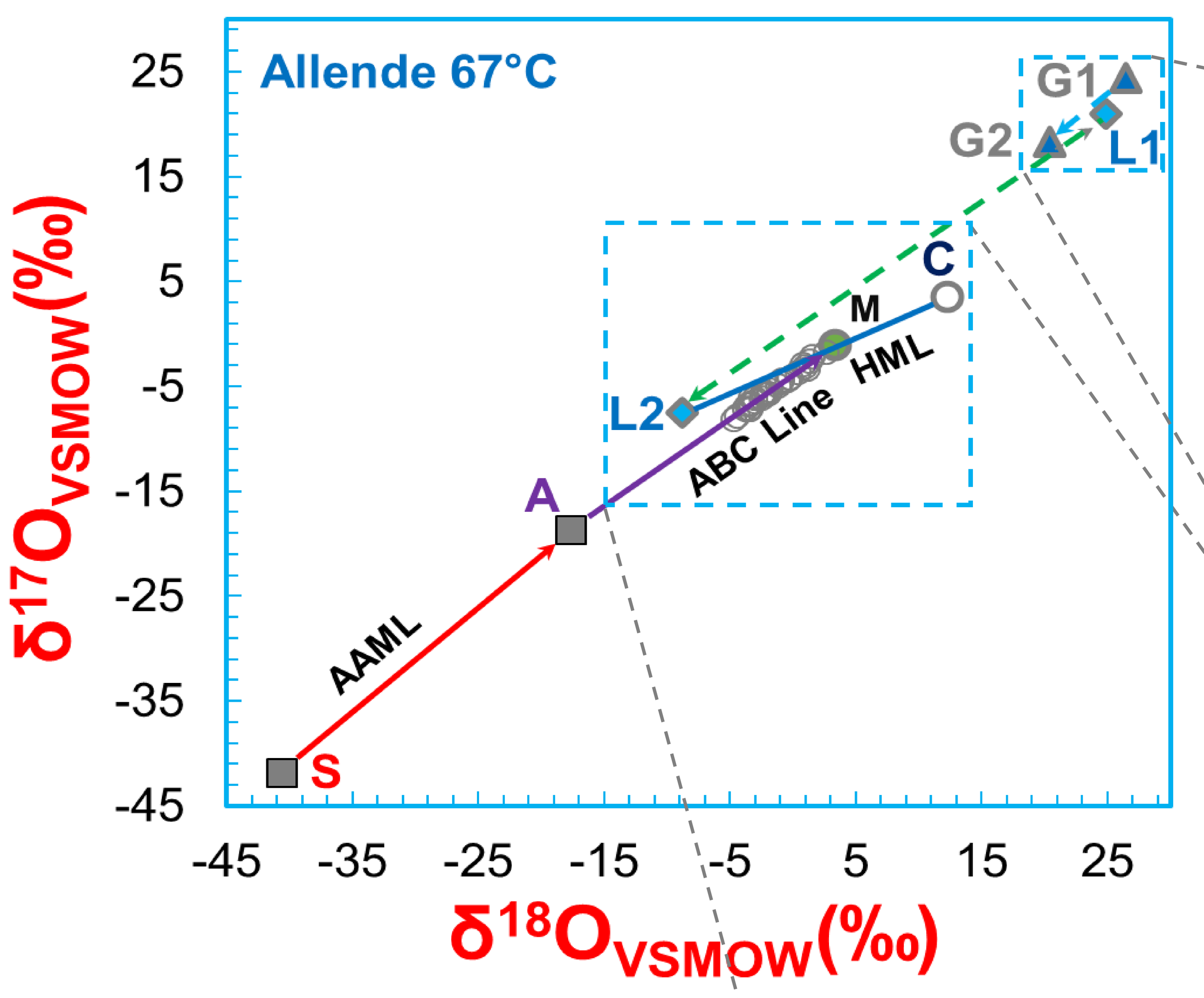


Introduction:

Allende (CV3) meteorite is a carbonaceous chondrite (Krot et al. 2005) which has been considered as the most studied meteorite in history (Snelling 2014 and references therein). The major components of Allende meteorite are: 1) millimeter-sized chondrules (mostly 0.5 to 2.0mm) of various chemical and isotopic compositions (Clayton et al. 1983; Jones et al. 2005; Rudraswami et al. 2011), 2) higher average value of matrix (~60 vol%) compared to other CV chondrites (~42 vol%), 3) relatively higher matrix to chondrule ratios (0.5-1.2; Snelling 2014), 4) high abundance of Ca-Al-rich inclusions (CAIs; MacPherson 2005; Krot et al. 2009) and amoeboid olivine aggregates (AOAs; Scott & Krot 2005). Majority of the chondrules (~94%) in Allende are porphyritic olivine chondrules (PO) comprising of >80 modal % olivine grains that are remarkably uniform in size. The remaining chondrule population in Allende is comprised of barred olivine (BO), porphyritic olivine pyroxene (POP), and porphyritic pyroxene (PP) chondrules (Scott & Krot 2005). The mechanism responsible for making chondrules is still unknown; however, possible scenarios of their formation have been proposed including i) hot solar gas condensation, ii) near the sun following transportation by protostellar jets to the astroidal belt, iii) planetesimals' collisions, iv) shock wave heating, v) due to gravitational instabilities in the solar nebula, vi) by supersonic planetesimals or, vii) electromagnetic heating (e.g., Desch et al. 2012, Johnson et al. 2015). Primitive chondritic meteorites derived from asteroids provide direct constraints on the early solar nebular composition. The slope-1 lines on oxygen isotope diagram (Fig. 1) have been reported to describe the primitive oxygen isotope reservoirs based on the analyses of various chondritic materials (Clayton et al. 1991; Young & Russell 1998; Ushikubo et al. 2012). These lines include equilibrated chondrite line (ECL), Allende anhydrous mineral line (AAML) and primitive chondrule minerals (PCM) line. In this study, we propose a gas-solid mixing (GSM; Fig. 1) line, having a slope of 0.999, to be the basis of mixing trend of extreme primitive reservoirs of the early solar nebula; based on the estimated nebular gas reservoir compositions derived from the oxygen isotope modelling of Allende bulk chondrule (ABC) line (Fig. 2; Jabeen et al. 2018 under review).



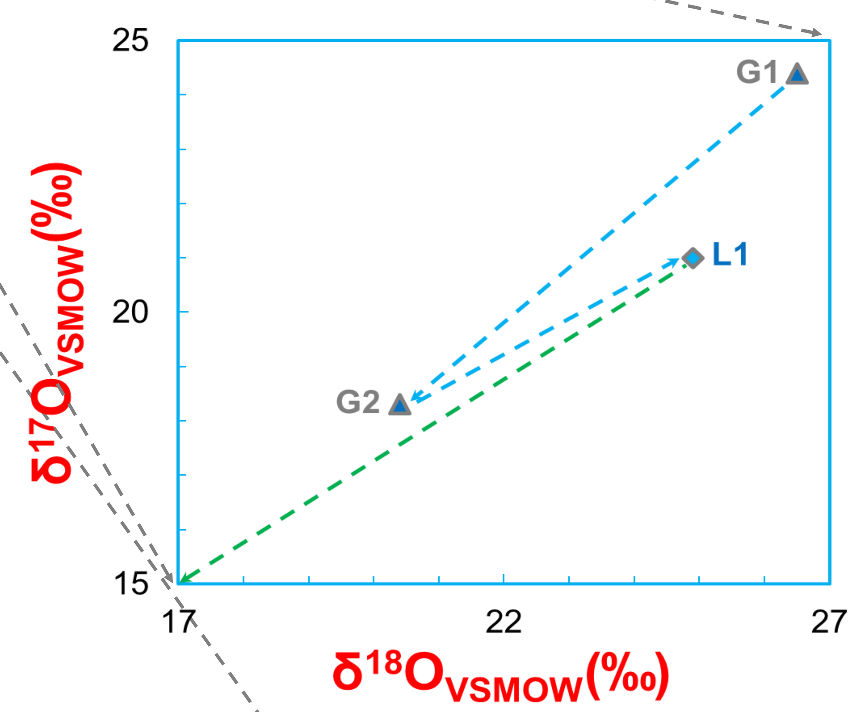


Fig.2. Illustration of the Allende CV3 modelling triple oxygen isotopic compositions of various reservoirs during the aqueous alteration processes occurring on a parent body at ~67°C followed by thermal metamorphism. Nebular gas and initial solid materials are denoted as G (^{17,18}O-rich reservoir; G_1 = initial; G_2 = final; triangles) and S (^{16}O-rich reservoir; square) respectively. The water compositions are represented as L_1 and L_2 (diamonds) during the aqueous alteration processes. Letters A (square), M, and C (circles) represent compositions of solids after

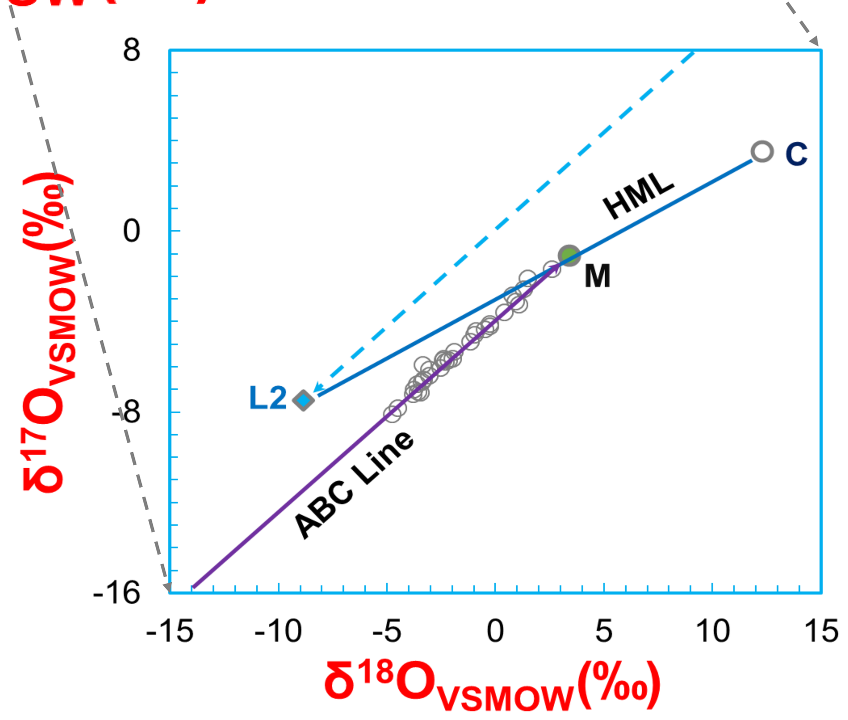


Fig.2. cont'd. isotopic exchange with nebular gas (shift from S to A), matrix, and calcite respectively. Gray open circles represent Allende bulk chondrules data of all types (Jabeen et al. 2018). ABC line = Allende Bulk Chondrule line. HML = hydrous mineral line AAML= Allende anhydrous mineral line (Young & Russell 1998).

Methodology:

A line is constructed from the oxygen isotope values (Fig. 1) derived by mixing the ^{16}O-rich solid component (i.e., CAIs; $\delta^{17}O$ = -41.9 ‰, $\delta^{18}O$ = -40.6 ‰) analyzed by (Young & Russell 1998) and ^{16}O-poor gas component (i.e., $\delta^{17}O$ = 23.6 and 24.4‰; δ18O = 25.0 and 26.5‰; Jabeen et al. 2018) estimated using the C/O = 0.5 (Prieto et al. 2002) and = 0.8 (Onuma et al. 1972) ratios respectively. Isotopic values were calculated by mixing gas: solid components with 1% increment in the gas component (i.e., 1:99 to 99:1).

Results and Discussion:

Various reported primitive trend lines on oxygen isotope plot (Fig. 1) are almost indistinguishable in terms of their slopes (i.e., AAML = 0.992, PCM = 0.987±0.013, GSM-C/O=0.5 = 0.999, and GSM-C/O=0.8 = 0.998) with the exception of a slightly steeper ECL (e.g., 1.074), however, intercepts are variable among all the lines (i.e., AAML = -1.66‰, PCM = 2.70±0.11‰, GSM-C/O=0.5 = -1.36‰, GSM-C/O=0.8 = -1.78‰, and ECL = -1.53‰). Further, AAML, PCM, ECL, GSM-C/O=0.5, and GSM-C/O=0.8 lines intersect the TFL at $\delta^{17}O$ & $\delta^{18}O$ values of 1.8‰ & 3.5‰, 3.0‰ & 5.8‰, 1.4‰ & 2.8‰, 1.5‰ & 2.8‰, and1.9‰ & 3.7‰ respectively. Note that both GSM-C/O=0.5 (based on carbonaceous Allende meteorite) and ECL (based on non-carbonaceous EOCs) lines intersect the TFL at nearly the same point regardless of the difference in their slopes. We interpret our GSM-C/O=0.5 line as the mixing trend of the major primary oxygen isotope reservoirs (Fig. 3).

Conclusions:

Both carbonaceous and non-carbonaceous chondrite components show a close relationship on oxygen isotope diagram demonstrating that the primitive oxygen isotopic reservoirs in the early solar nebula probably had nearly identical trend. We interpret GSM-C/O=0.5 line as the mixing trend of extreme primitive reservoirs (i.e., nebular gas and solids).

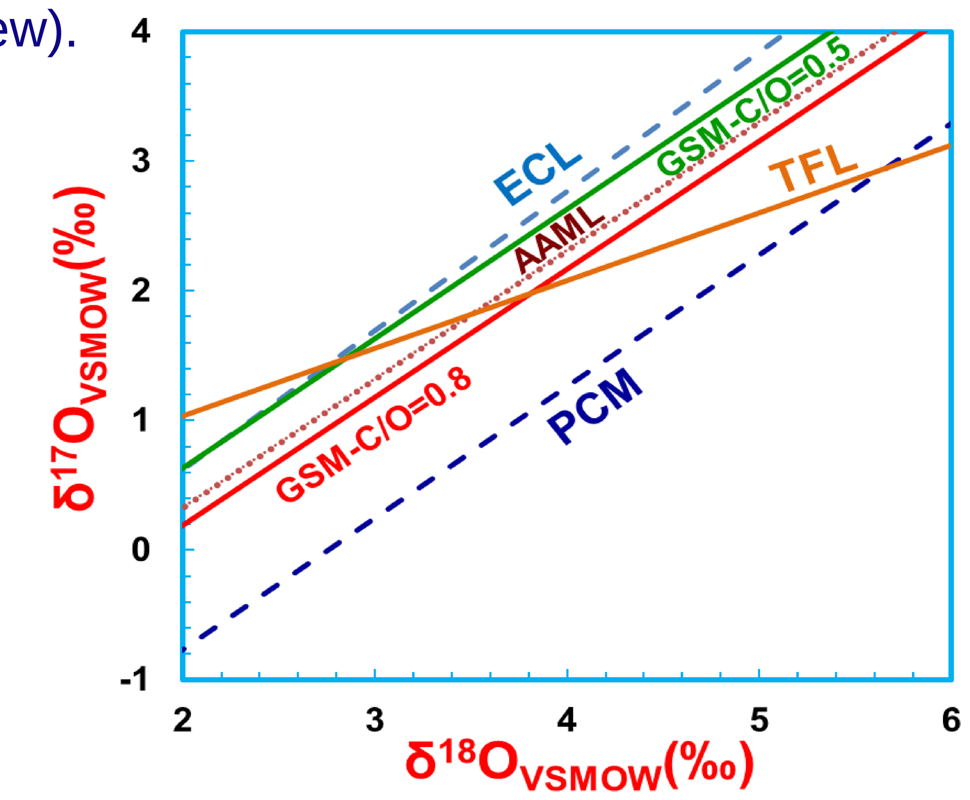


Fig.1. Triple O-isotope diagram showing equilibrated chondrite line (ECL) (Clayton et al. 1991), Allende anhydrous mineral line (AAML) (Young & Russell (1998), and primitive chondrule minerals (PCM) line (Ushikubo et al. 2012), and gas-solid mixing (GSM) lines. Terrestrial fractionation line (TFL) is taken from Ali et al. (2013).

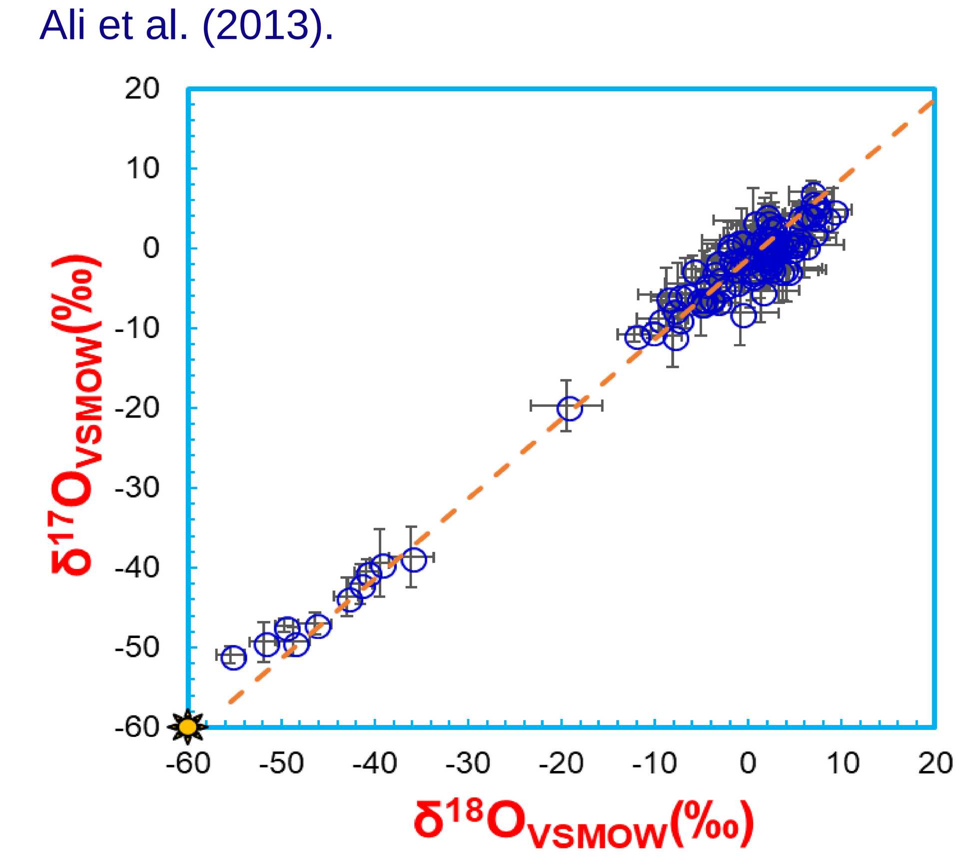


Fig.3. Triple O-isotope diagram showing GSM-C/O=0.5 line along with SIMS/NanoSIMS data (circles; values with precision of <5‰ only) of comet 81P/Wild2 (Stardust Mission; Brownlee et al. 2006) particles and chondritic interplanetary dust particles (IDPs). The star symbol represents the oxygen isotopic composition of the Sun (McKeegan et al. 2008). Data sources: McKeegan et al. 2006; Nakamura et al. 2008; Aléon et al. 2009; Ogliore et al. 2012; Nakashima et al. 2012.

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References:

Aléon et al. (2009) *Geochim. Cosmochim. Acta* 73:4558-4575. Ali et al. (2013) LPS XLIV, Abstract #2873. Brownlee et al. (2006) *Science* 314:1711-1716. Clayton et al. (1983) In Chondrules and their origins. Ed. E. A. King, The Lunar and Planetary Institute, Houston, 37-43. Clayton et al. (1991) *Geochim. Cosmochim. Acta* 55:2317-2337. Desch et al. (2012) *Meteoritics & Planetary Science* 47:1139-1156. Jabeen et al. (2018) *Meteoritics & Planetary Science* (under review). Johnson et al. (2015) *Nature* 517:339–341. Jones (2005) In Chondrites and the Protoplanetary Disk. Ed. A. N. Krot, E. R. D. Scott, B. Reipurth. Astronomical Society of the Pacific, San Francisco, 251-281. Krot et al. (2005) In Meteorites, comets, and planets, Treatise on Geochemistry. Ed. A. M. Davis. Elsevier, Amsterdam, Netherland, 1:83-128. Krot et al. (2009) *Geochim. Cosmochim. Acta,* 73:4963-4997. MacPherson (2005) In Meteorites, comets, and planets, Treatise on Geochemistry. Ed. A. M. Davis. Elsevier, Amsterdam, Netherland, 1:201-246. McKeegan et al. (2006) *Nature* 314:1724-1728. McKeegan et al. (2008) LPS XXXIX, Abstract #2020. Nakamura et al. (2008) *Science* 321:1664-1667. Nakashima et al. (2012) *Earth & Planet. Sci. Lett.* 357-358:355-365. Ogliore et al. (2012) *Geochim. Cosmochim. Acta* 166:74-91. Onuma et al. (1972) *Geochim. Cosmochim. Acta* 36:169-188. Prieto et al. 2002. *The Astro-physical Journal* 573:L137-L140. Rudraswami et al. (2011) *Geochim. Cosmochim. Acta* 75:7596-7611. Scott & Krot (2005) In Meteorites, comets, and planets, Treatise on Geochemistry. Ed. A. M. Davis. Elsevier, Amsterdam, Netherland, 1:143-200. Snelling (2014) *Answers Res. J.* 7:103-145. Ushikubo et al. 2012. *Geochim. Cosmochim. Acta* 90:242-264. Young & Russell (1998) *Science* 282:452-455.