Igneous Petrology of the Tissint Meteorite

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Introduction: The Tissint meteorite has been the subject of multiple studies since its fall in the Moroccan desert during 2011, including characterizing its shock phases, melt inclusions, radiogenic isotopes, and hydrogen isotopes [1-4]. We present the first summary of Tissint's igneous petrogenesis from measurements done on two thin sections (Tissint, 1 and Tissint, 6) obtained from ASU's Center for Meteorite Studies collection.

Fig. 1: Tissint sample at ASU's Center for Meteorite Studies (Lawrence Garvie)

Methods: 2 sections of Tissint were characterized through petrography and electron microprobe at the University of Tennessee for major elements, phase abundances, and crystal size distributions, and through secondary ion mass spectrometry at Arizona State University for trace element abundances.

References: [1] Baziotis I.P et al. (2013) *Nature, 4,* 1404-1408 [2] Brennecka G.A. et al. (2014) *MAPS 49(3),* 412-418 [3] Mane P. et al. (2013), *LPSC XLIV,* #2220 [4] Peters T.J. et al. (2014), *LPSC XLV, #2405* [5] Filiberto J. and Dasgupta R. (2011) *EPSL 304,* 527-537 [6] Crozaz G. and Wadhwa M. (2001), *GCA 67,* 4727-4741. [7] Wadhwa M. et al. (1994), *GCA 58,* (4213-4229) [8] Wadhwa M. et al. (1998), *MAPS 33,* 321-328. [9] McSween H.Y. and Jarosewich E. (1983), *GCA 47,* 1501-1513. [10] Wadhwa M. (2001), *Science 291*, 1527-1530 [11] Symes S.J.K. et al. (2008) [12] Wadhwa M. et al. (2001), *MAPS 36,* 195-208. [13] Balta J.B. et al. (2013), *MAPS 48,* 1359-1382. [14] Burghele et al (1983) *LPSC XIV,* 80-81 [15] Taylor et al. (2002) *MAPS 37,* 1107-1128 [16] Dreibus et al. (1996) *MAPS 31,* A39 [17] Lundberg et al (1990), *GCA* 54: 2535-2547 [18] Ikeda Y. (2004), *Ant. Met. Res. 17* (35-54). [19] Gross J. et al. (2013), *MAPS 46,* 116-133. [20] Sack R. and Ghiorso M. (1994), *Contrib. Min. Pet. 118,* 277-306.

Results

Tissint is an olivine-phyric shergottite (Fig. 2-3). Here we show that its major and trace element chemistry is unique compared to previous shergottites.

Olivine *major elements:*

- Mg# varies from 81 to 29 - largest range, most Fe-rich rims of any olivine-phyric shergottite.
- Coarse-grained olivines are glomerocrysts (Fig. 4)
- Thin sections composed of 27 and 24% olivine, implying 7-10% olivine is cumulate, may represent antecrysts [5]
- Coarse grained olivines free of chromite inclusions, unlike other olivine-phyric shergottites

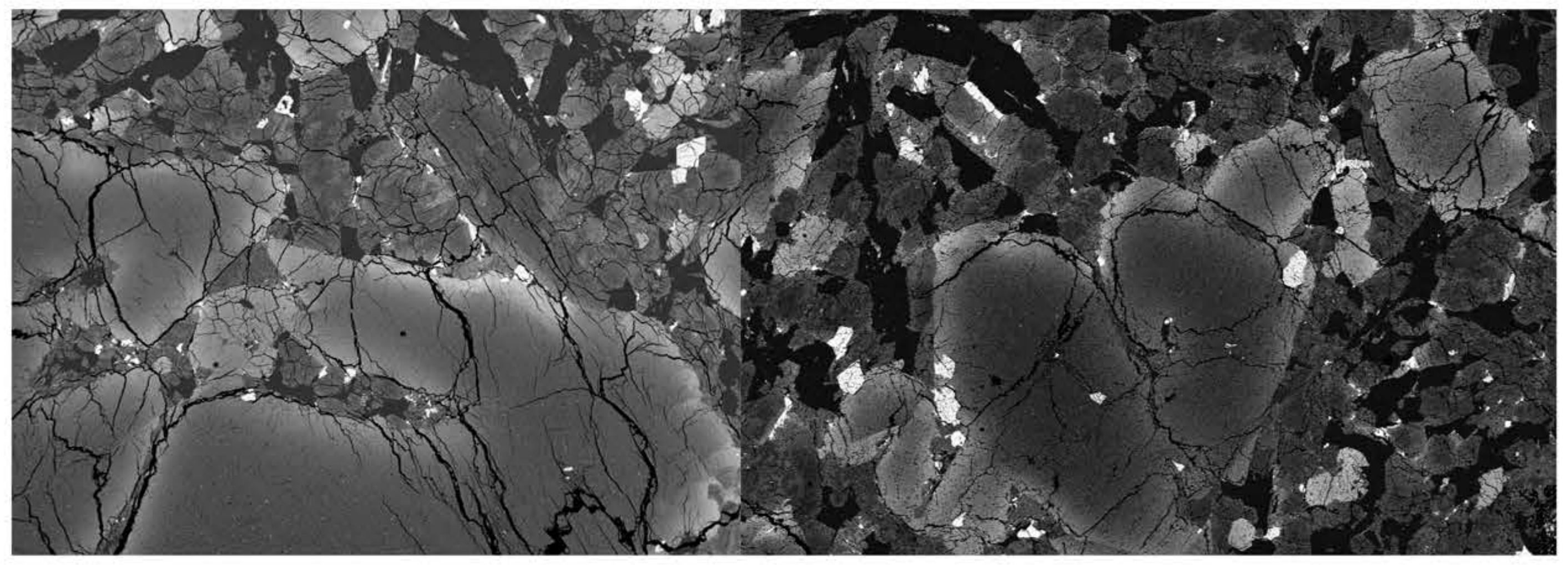

Fig. 4 – olivines with irregular inclusions and internal boundaries, likely glomerocrysts (both images 1.5 mm wide)

Pyroxene *major elements:*

- Range from pigeonite to augite
  - Overlap other olivine-phyric shergottites (Fig. 5)
- Make up 52% of Tissint on average (Fig. 6)

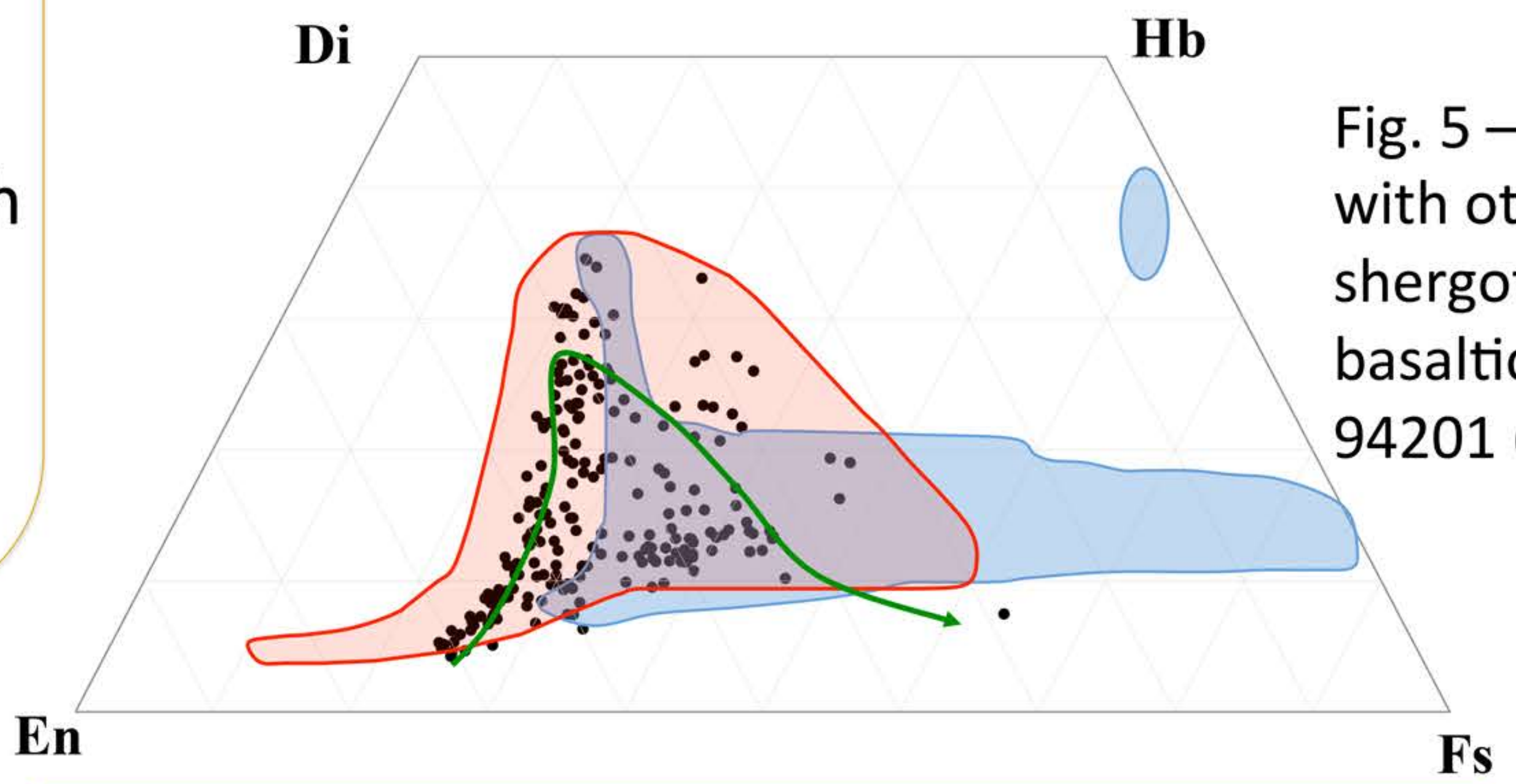

Fig. 5 – Tissint pyroxenes with other olivine phyric shergottites (red) and basaltic shergottite QUE 94201 (blue) [6-7]

Maskelynite *major elements:*

- 20-22% of Tissint
- $An_{68}Ab_{42}Or_1$ to $An_{47}Ab_{48}Or_5$
- Comparable with other olivine-phyric shergottite maskelynites (Fig. 7) [8-9]

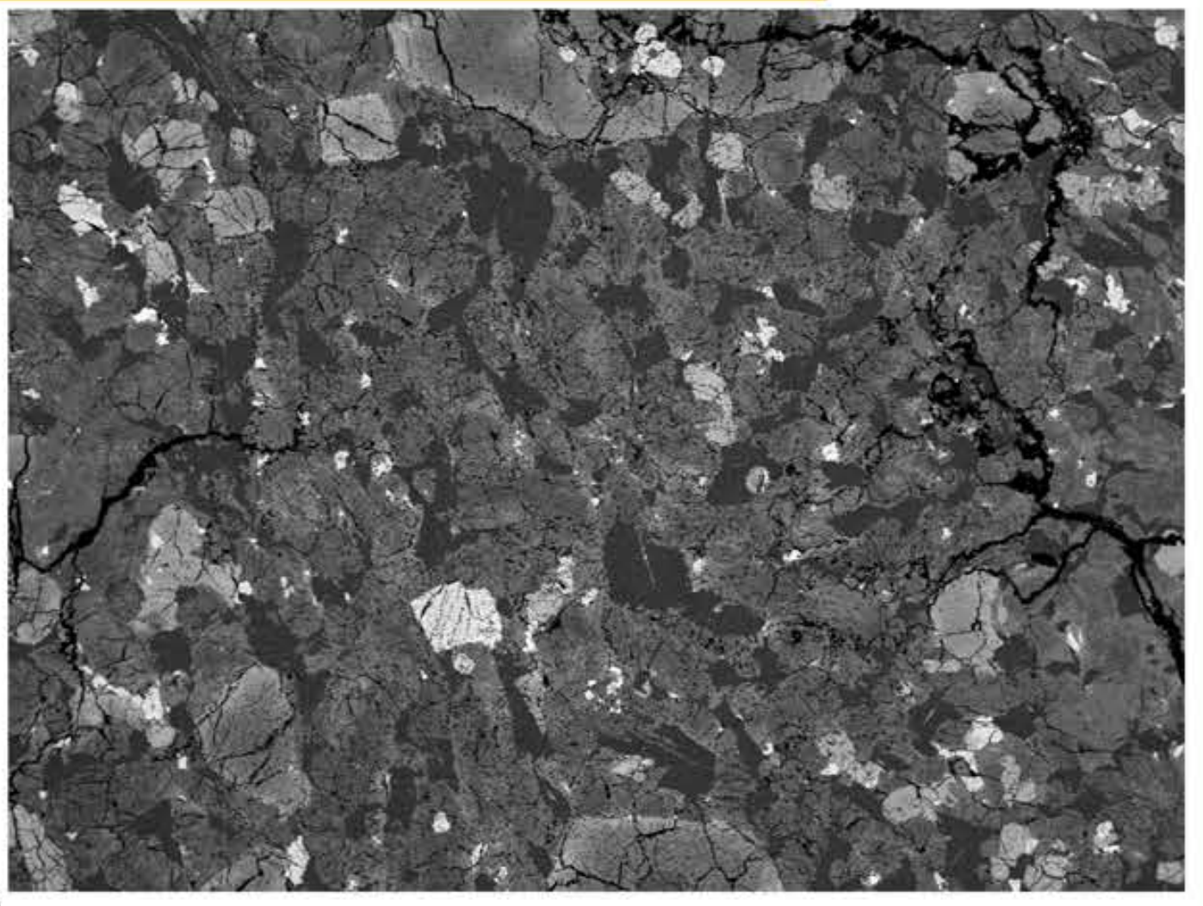

Fig.6 – BSE of pyroxene/ maskelynite rich area (1.5 mm wide)

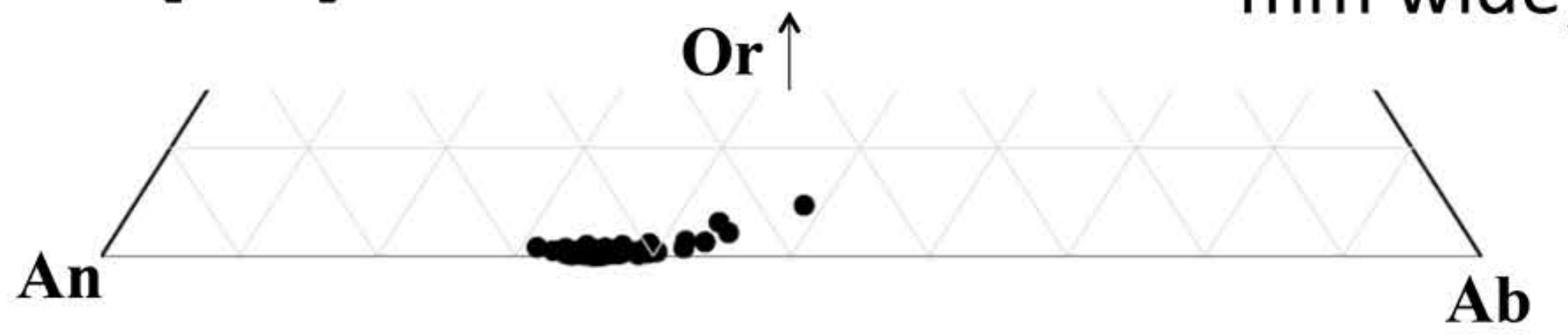

Fig.7 – measured maskelynite compositions

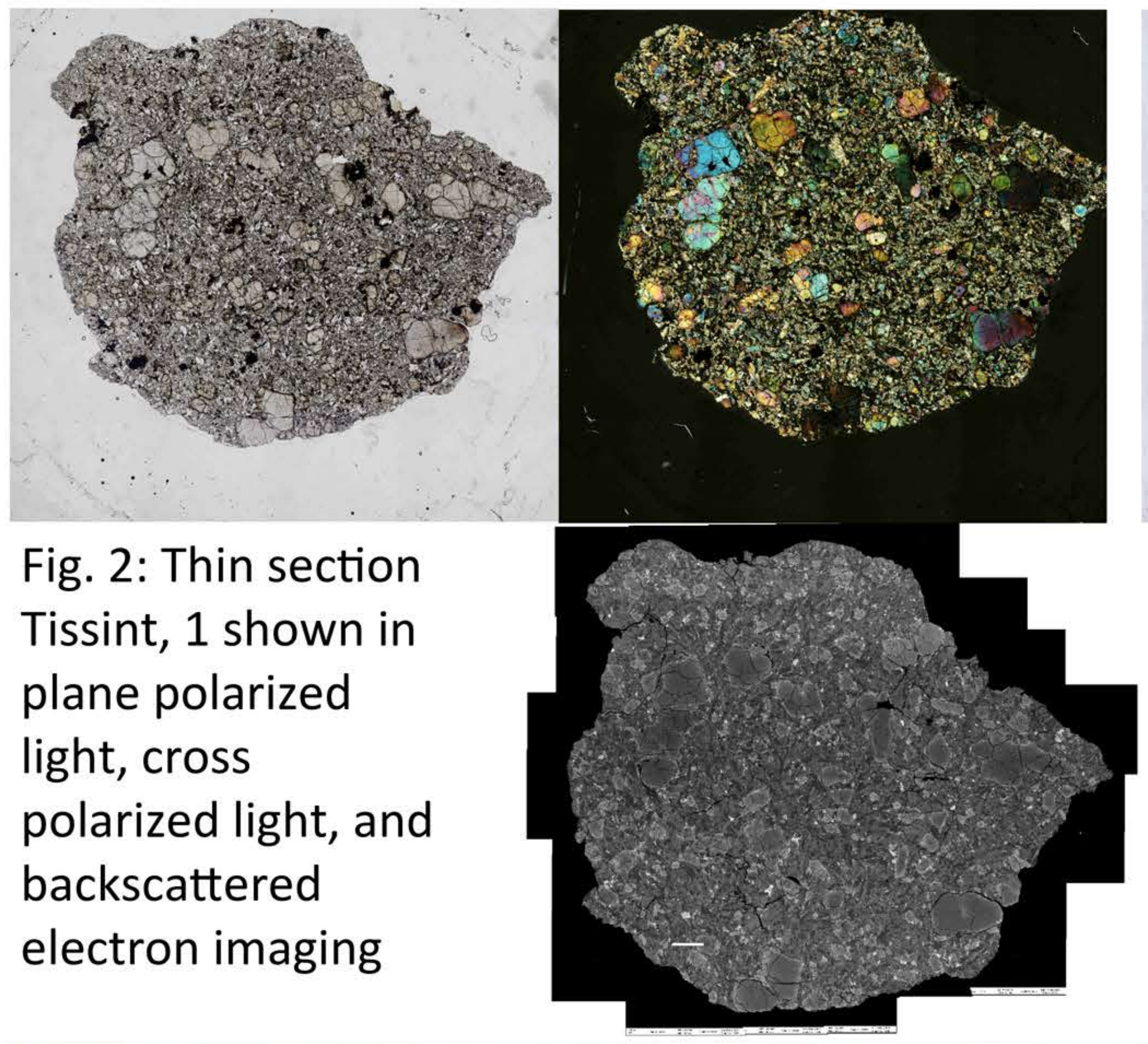

Fig. 2: Thin section Tissint, 1 shown in plane polarized light, cross polarized light, and backscattered electron imaging

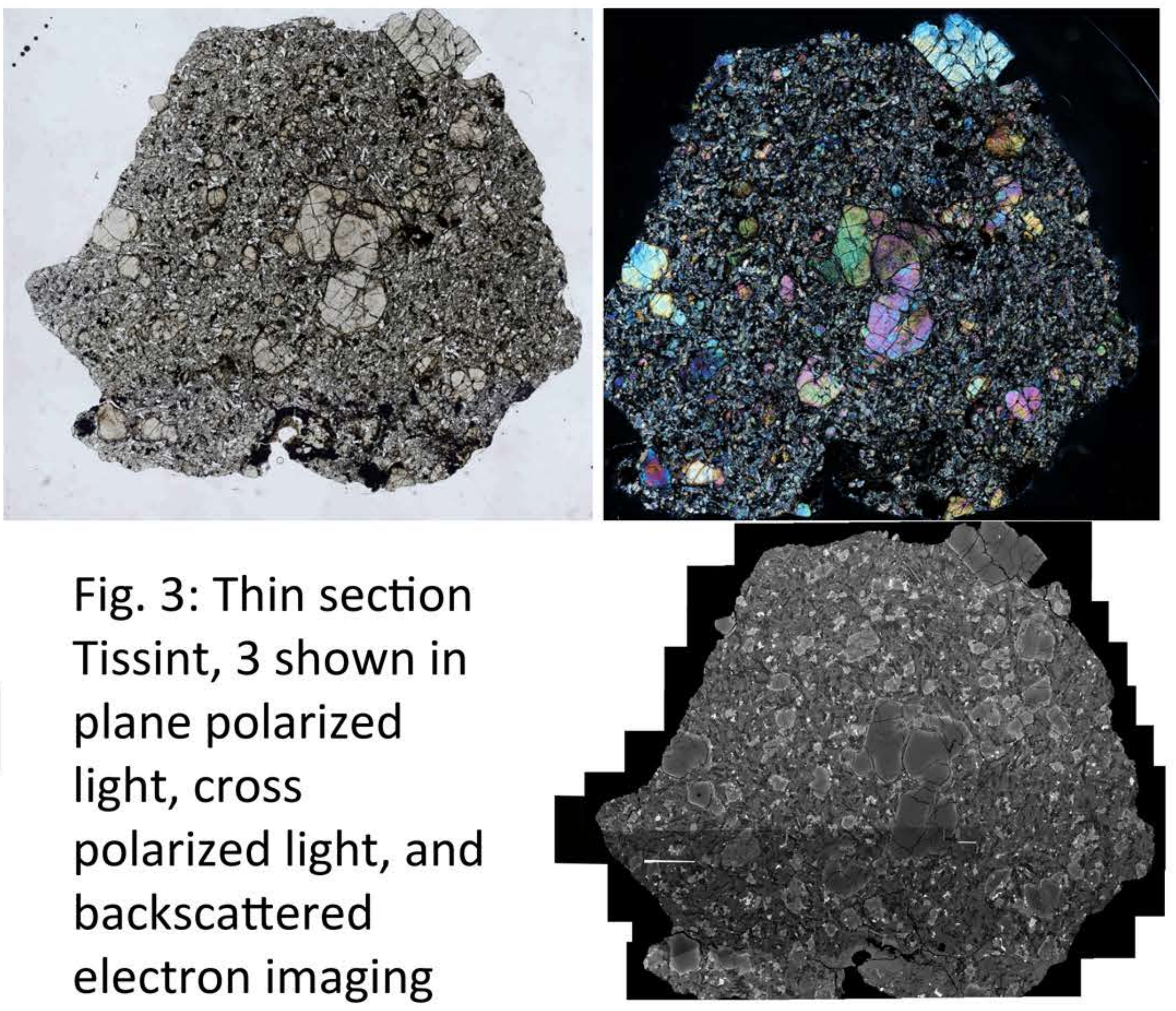

Fig. 3: Thin section Tissint, 3 shown in plane polarized light, cross polarized light, and backscattered electron imaging

Rare Earth Elements (Fig. 8)

- Merrilite is the dominant REE carrier
- Overlaps with depleted shergottites in isotopic compositions [2], but overlaps with intermediate shergottites (EETA-79001A) in REE [11]
- No evidence of open-system processes during crystallization or later weathering
- Eu anomaly allows calculated fO_2 of QFM-2.4 [10]

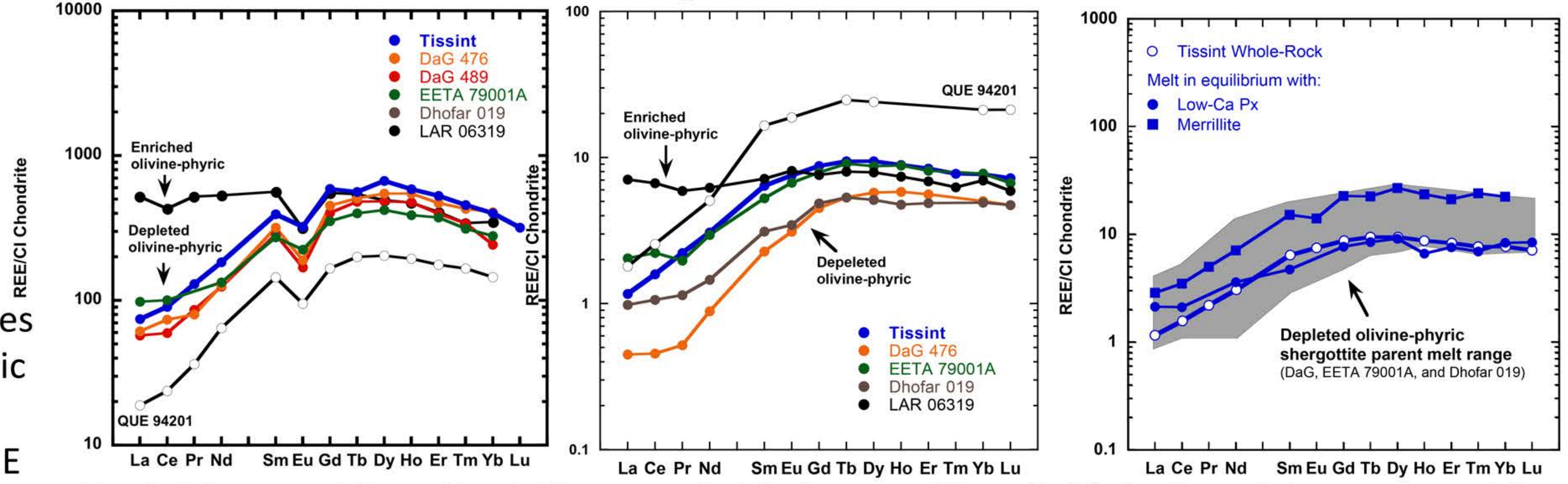

Fig.8: Measured Rare Earth Elements in Tissint merrilites (left), bulk rock (center), and for melt calculated to be in equilibrium with pyroxenes and merrillites (showing no LREE addition) [12-17]

Implications for magmatic processes and Tissint's origin

- Mineral crystallization in Tissint proceeded in the order:
  Olivine→ chromite →maskelynite + pigeonite →augite→ groundmass
- Olivine core Mg # implies near equilibrium with the martian mantle
  - Slightly more Fe-rich than Y-980459 or NWA 5789 [18-19]
- Olivine resided in a cumulate pile or on magma chamber walls where phenocrysts merged into glomerocrysts & Mg # homogenized
- Pyroxene minor elements record decreasing pressure/evolving melt composition
- Crystallization proceeded through highly evolved (Fe-rich) groundmass before final melt crystallized
- Oxygen fugacities calculated from both minerals [20] and REE-in-pyroxenes are low, from QFM-2.4 to QFM-4.
- Could represent an olivine-rich (closer to equilibrium with the mantle) version of depleted basaltic shergottite QUE 94201 [15]

Tissint is a reduced, depleted shergottite derived from an active martian magmatic system