CONSTRAINTS ON CHONDRULE FORMATION FROM INVESTIGATIONS OF METEORITES: A SUMMARY OF THE WORKSHOP ON CHONDRULES AND THE PROTOPLANETARY DISK HELD IN LONDON IN FEBRUARY 2017. S. S. Russell[1], H. C. Connolly Jr.[2], and A. N. Krot[3]. [1]Department of Earth Sciences, Natural History Museum, Cromwell Road, London, SW7 5BD, UK (sarr@nhm.ac.uk). [2]Dept Geology, Rowan University, 201 Mullica Hill Road, Glassboro, New Jersey, USA. [3]University of Hawai'i at Manoa, HIGP, Honolulu, HI 96822, USA.

Introduction: On 27th and 28th February 2017 a conference on "*Chondrules and the Protoplanetary Disk"* was held at the Natural History Museum, London, UK. The two day meeting brought together meteoriticists and astrophysicsts to discuss observations on chondrules and the constraints they provide on chondrule forming mechanisms.

The topics included the following:

Complementarity: A key discussion point at the conference was whether there is complementarity between chondrules and matrix- i.e. whether the chondrules and matrix have different chemistries and isotopic compositions that are both required together in order to create a chondritic whole rock [1,2,3]. Complementarity appears to exist in several elements and also in the tungsten isotopes: chondrules have a ^{183}W excess and matrix has a ^{183}W deficit; a mix of the two is required to make the same composition as the Earth, and bulk meteorites [4].

Chronology: Petrographic observations show that while chondules are occasionally observed in CAIs, the reverse is not true, except when a CAI has become swept up into a chondrule melt. This suggests that while CAIs were present when chondrules formed, chondrules were not present when CAIs formed [5]. Al-Mg systematics of chondrules show chondrules are consistently younger than CAIs, assuming a homogeneous initial distribution of $^{26}Al/^{27}Al$ [6]. This constraint is disallowed if $^{26}Al^{27}Al$ was higher in the CAI forming region than in the chondrule forming region. Pb-Pb isotopes, in contrast, show chondrule formation starting at the same time as CAIs and continuing for 3.6 Myr [7].

Cooling Rates and Pressures: While classic experiments have been performed to determine the cooling history of chondrules using sillicates, new work on chondrule glass and opaques is offering a new view, suggesting even more rapid cooling rates are required for chondrules at the lower end of the cooling tail, near to the subsolidus [8]. The high abundance of volatiles in chondrules provides important and clear constraints on chondrule formation, although a systematic study of chondrules in all groups has not been undertaken [9].

Magnetic Properties: These are providing new and important constraints on chondrule formation. Ordinary chondrites have experienced a strong field and CR chondrites a weak field which may indicate that CR chondrules formed further out in the disk [10].

Outstanding questions

The conference highlighted several outstanding questions, including:

- What is the role of giant planets and their migration in the formation of chondrites and their components?
- How common were chondrules in the protoplanetary disk?
- How were chondritic components stored since they appear to have formed over several millions of years?
- Where there several chondrule forming mechanisms, and if so what is their relative importance?

At straw poll at the end of the conference, the majority of delegates favoured a 'nebular' mechanism for chondrule formation, although 'planetary' models were also popular. Many delegates remained unsure of how chondrules formed.

The conference highlighted a continued need for a combination of sample analysis, experimental petrology and theoretical modeling and communication between these communities. Some of the questions may be answered by the sample return missions to primitive asteroids that are currently in flight: Hayabusa2 and OSIRIS-REx.

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