Natural diamonds, because of their great physical resiliency, can preserve information about their formation, storage, and transport conditions for billions of years. Diamond samples therefore provide a unique opportunity to directly study ancient samples of the Earth’s deep interior. To correctly interpret the information diamonds provide, it is essential to accurately constrain the depth of their origin. This depth provenance is usually identified using coexisting minerals that are trapped as inclusions within diamonds during their growth. Comparison of an inclusion’s composition and mineralogy with experimental phase equilibria allows the diamond’s growth conditions to be estimated. While the majority of diamonds likely originate from depths of 140–220 km in cratonic mantle, a small subset appears to have been exhumed from depths extending to >800 km, called “superdeep” or “ultradeep” diamonds (e.g., Walter et al. 2011; Pearson et al. 2014). Inclusions of magnesiowüstite are among the most commonly described in sub-lithospheric diamonds and have often been assumed to indicate diamond provenance in the lower mantle because [Mg,Fe]O is not stable at upper mantle conditions in a subsolidus mantle compositions (Trønnes 2009). This is despite the stability field of [Mg,Fe]O extending to ambient pressure conditions and experimental evidence of magnesiowüstite stability in equilibrium with diamond throughout the upper mantle (Brey et al. 2004; Thomson et al. 2016). A new study by Uenver-Thiele et al. (2017) in American Mineralogist places important new constraints on the formation and uplift history of inclusions containing magnesiowüstite.

Studies of magnesiowüstite inclusions in diamonds from the Juina region of Brazil often report observation of nanometer-sized crystals of magnesiowüstite ([Mg,Fe]Fe2O4), which supposedly “confirm” the lower mantle origin of these samples. The magnesiowüstite precipitates can occur at the interface between the diamond and [Mg,Fe]O inclusion, or as evenly distributed dislocation “necklaces” within the inclusion interior (Harte et al. 1999; Wirth et al. 2014; Palot et al. 2016). Wirth et al. (2014) describe chains of globular [Mg0.5Fe0.5]Fe2O4 crystals, ~75 nm in size, making up 6–11 vol% of the entire [Mg2–Fe2]O inclusion. This suggests the original inclusion had an Fe3+/ΣFe of 11–14%, compared with 7 ± 2% in the recovered magnesiowüstite (McCammon 1997). Wirth et al. (2014) also identified the magnesiowüstite is accompanied by small, ~30 nm, cubic voids, Al-bearing spinel and Ni-Fe metal blebs. Palot et al. (2016) describe isolated 10–20 nm octahedra of Mg[Fe0.5Cr0.17Al0.08]2O4 throughout a [Mg84Fe16]O host with a recovered Fe3+/ΣFe content of 1–2% that also contains ~30 ppm H2O in brucite precipitates. The bulk inclusion composition reported by Palot et al. (~[Mg2Fe3]O ignoring minor elements) implies the original magnesiowüstite must have had an Fe3+/ΣFe of approximately 10–12%. Wirth et al. (2014) and Palot et al. (2016) both observe a topotaxial relationship between magnesiowüstite lamellae and the [Mg,Fe]O host, confirming the magnesiowüstite must have formed during exsolution from a homogenous magnesiowüstite grain. Using different arguments both studies concluded that the magnesiowüstite lamellae are indicative of the lower mantle provenance of these diamonds. Wirth et al. (2014) suggested the highly non-stoichiometric magnesiowüstite inclusion sampled the high-spin–low-spin transition in the iron stability field, promoting high Fe3+ contents. This would place inclusion, and diamond, formation near the very base of the mantle. Alternatively, Palot et al. (2016) interpreted the conditions of magnesiowüstite exsolution using a phase diagram constructed from atmospheric-pressure experimental data in the MgO–Fe2O3, MgO–Al2O3, and MgO–Cr2O3 systems. This approach suggested that the onset of exsolution occurred at a temperature of ~1700°C, which corresponds to ~25 GPa on the mantle adiabat (Palot et al. 2016). Both approaches make many assumptions and lack experimental verification that magnesiowüstite exsolution unambiguously indicates a diamond exhumation from the lower mantle. Indeed, as outlined below, the high ferric iron contents of the inclusions and new phase relations of magnesiowüstite (Uenver-Thiele et al. 2017) instead point to a much shallower origin.

At low pressures (<5 GPa) it is well understood that magnesiowüstite can incorporate significant ferric iron, up to Fe3+/ΣFe of 70%, mainly charge balanced by negative cation vacancies (e.g. Hazen and Jeanloz 1984; Dobson et al. 1998). With increasing pressure and decreasing oxygen fugacity the ferric iron capacity of magnesiowüstite decreases, due to a high-pressure phase transition of Fe3O4 (Huang and Bassett 1986; McCallum et al. 1998). Since the mantle becomes more reduced with depth, from ~1 log unit above the nickel-nickel oxide buffer (NNO+1) at 200 km to 1.5 log units below the iron-wüstite buffer (IW-1.5) at 660 km (Rohrbach and Schmidt 2011), it is expected that ferric iron concentration of [Mg,Fe]O will fall rapidly with increasing formation pressure. Indeed experiments confirm at conditions just within the lower mantle the maximum Fe3+/ΣFe in [Mg2Fe3]O, similar in composition to the inclusion observed by Palot et al. (2016), is <2% at NNO and ~0.5% at IW (Otsuka et al. 2013). Similarly [Mg2Fe3]O, similar to that observed by Wirth et al. (2014), would have a Fe3+/ΣFe capacity of ~7–14% at IW and NNO, respectively. These ferric iron capacities provide an upper bound, because “normal” lower mantle conditions are more reduced and extend to higher pressure than the experimental conditions. Thus, the bulk composition of diamond-hosted inclusions displaying magnesiowüstite exsolution appears inconsistent with formation under lower mantle conditions, unless exceptionally oxidized conditions are present.