Spinel formation by sulphur-rich saline brines from Mansin (Mogok area, Myanmar)

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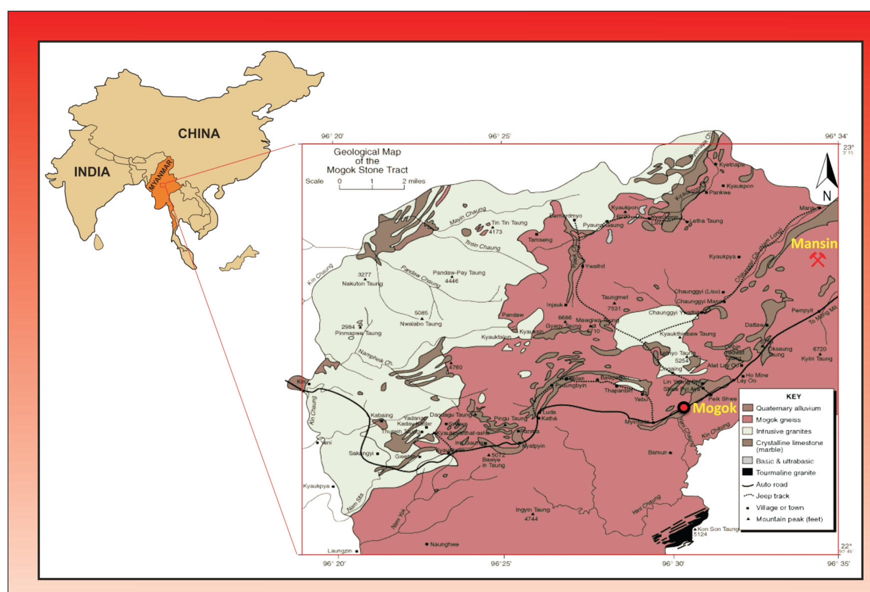


Fig. 1: Geographic position and geology of the Mogok Stone Tract (map after Hughes 1997)

Aims/goals

The Paleogene Mogok metamorphic belt in central Myanmar (Fig. 1) is mainly made up of medium- to high-grade metamorphic rocks and younger intrusions (Metcalfe 1988; Thu et al., 2016). During the last 2 decades, mineral occurrences and assemblages of approximately 100 spinel mines from the Mogok valley (Myanmar) were mapped by Peretti et al. (2007) and Peretti & Tun (2016). Their investigations reveal the co-existence of spinel with ruby and in various types of marble rocks. This investigation presents preliminary results of melt and "fluid" inclusion studies aiming to decipher the chemical conditions under which spinel from Mansin grew at granulite facies conditions of 700-800°C and 7-8 kbar (Phyo et al. 2017).

Methods

Detailed investigations have been performed or are still ongoing by the following methods:

Polarization microscopy, microthermometry (LINKAM table), micro Raman spectroscopy (Bruker Sentrerra), electron microprobe analysis (JEOL JXA-8900), REM (REM Nova NanoSEM 230, Ac c. 20000 V), stable isotope and LA-ICP-MS geochemistry.

Fig. 2: Primary inclusion in spinel

Fluid inclusion typology

Two types of inclusion assemblages are distinguished. Type 1 is a H_2S-rich yellowish inclusion characterized by two immiscible liquids and a vapour bubble (L1 and L2 ~ 10 to 30 vol. %), and a relatively small amount of daughter minerals (Figs. 2&4). Type 2 is represented by a white mineral bearing polycrystalline assemblage of daughter minerals and a small bubble of ~ 5 vol. % (Fig. 5). Both inclusion types are present as primary (Fig. 2) and synchronous trapped secondary fluid inclusions (Figs. 3-5). Nearly all daughter minerals have a rounded "corroded" shape.

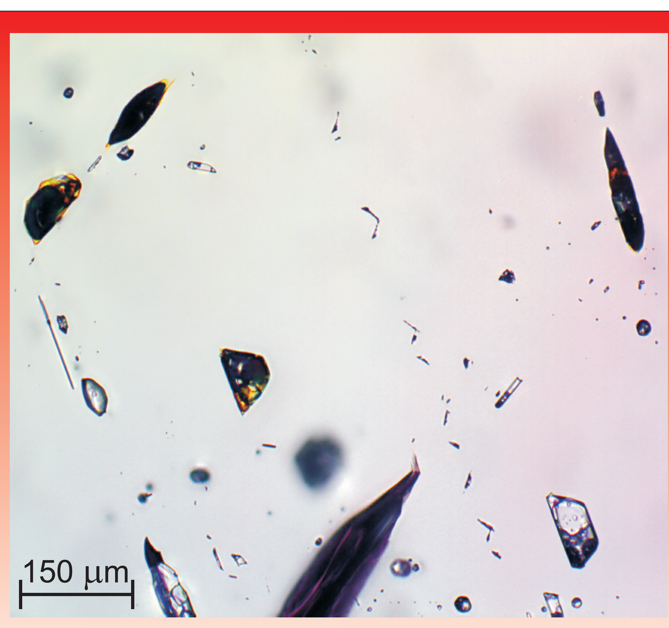


Fig. 3: Secondary inclusions in spinel

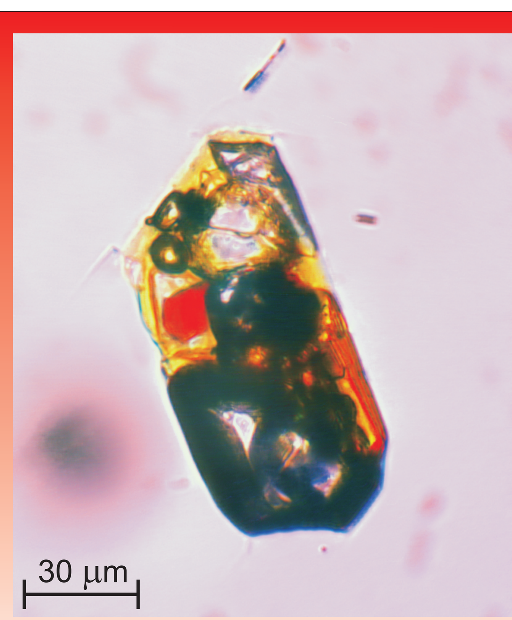


Fig. 4: S-rich secondary inclusion

Fig. 5: White secondary inclusion

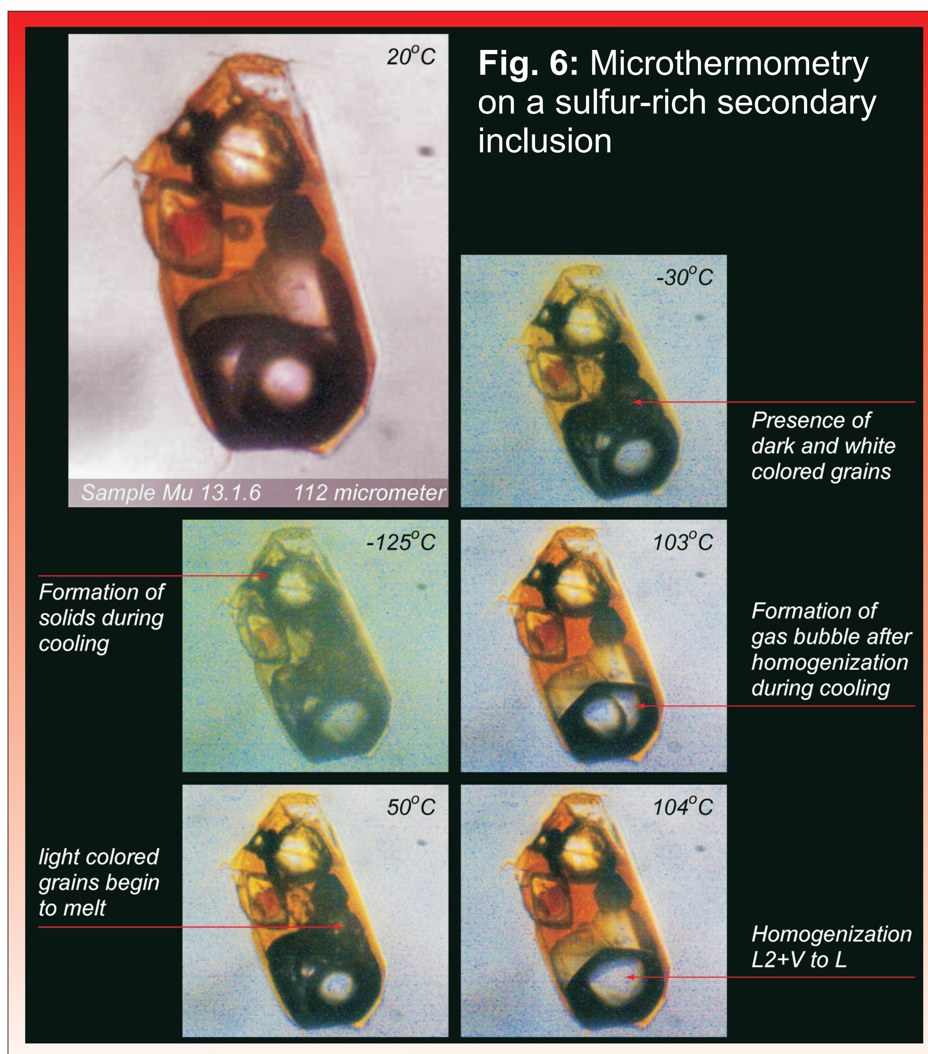


Fig. 6: Microthermometry on a sulfur-rich secondary inclusion

Microthermometry

Several phase transitions were observed during heating by microthermometry, i.e., melting of H_2S at -86°C, dissociation of light coloured grains between 85 and 95 °C, or homogenization of H_2S_L with H_2S_V at 102.5 ± 1°C close to the critical temperature of H_2S (Fig. 5).

Daughter minerals in both inclusion assemblages

Native sulfur, anhydrite, apatite, pyrite, marcasite, sphalerite, chlorides, carbonates, diaspore, brucite, goethite, and very rarely anhydrite and rutile etc.

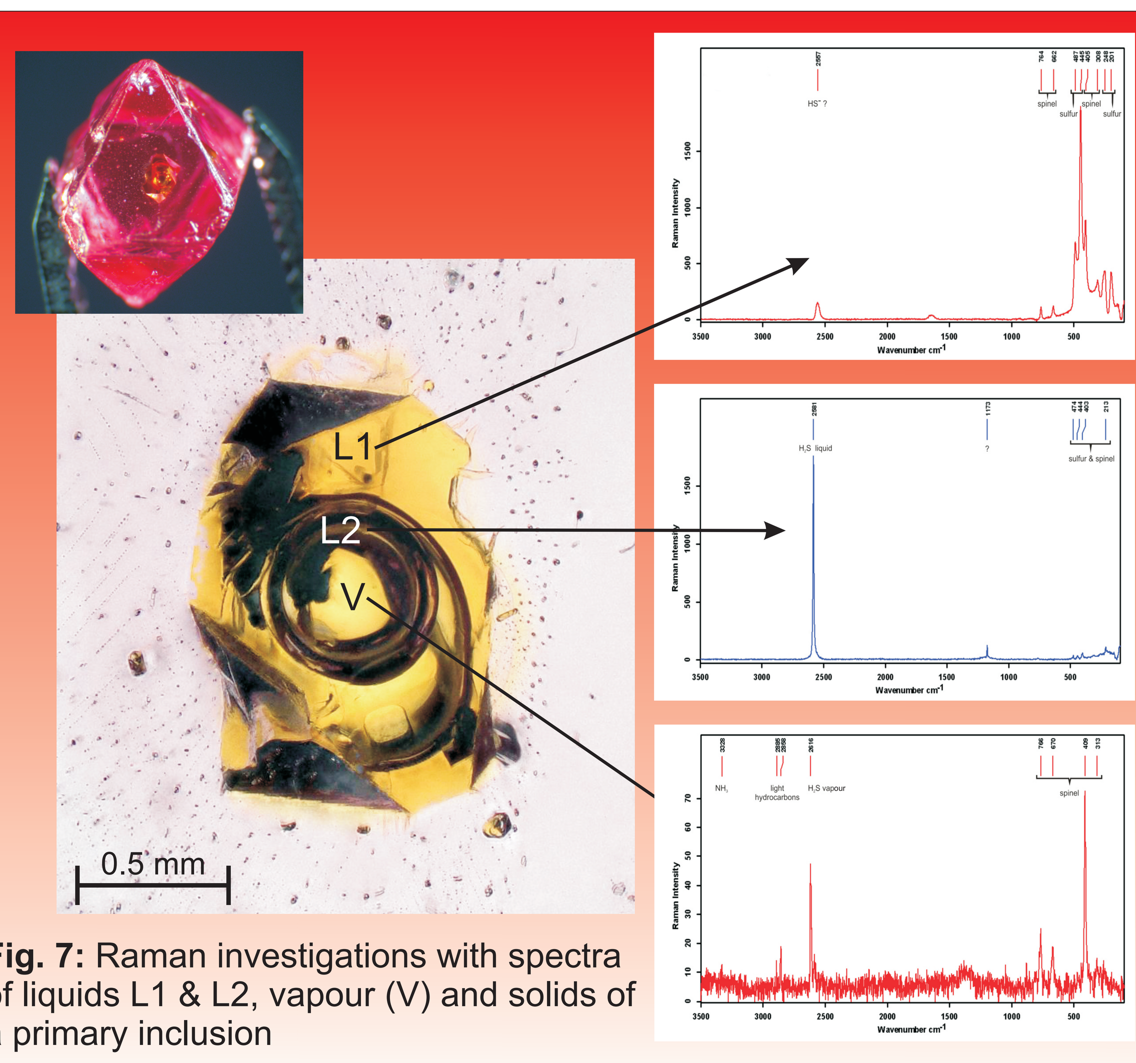


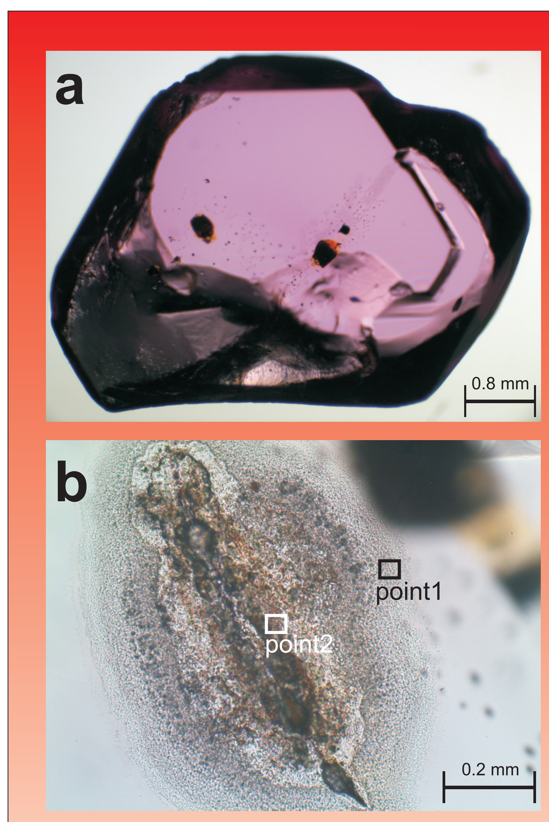
Fig. 7: Raman investigations with spectra of liquids L1 & L2, vapour (V) and solids of a primary inclusion

The striking difference between the two inclusion assemblages is the relative amount of daughter minerals with respect to the liquid volatile bubble. Type 1 and 2 contain two immiscible liquids:

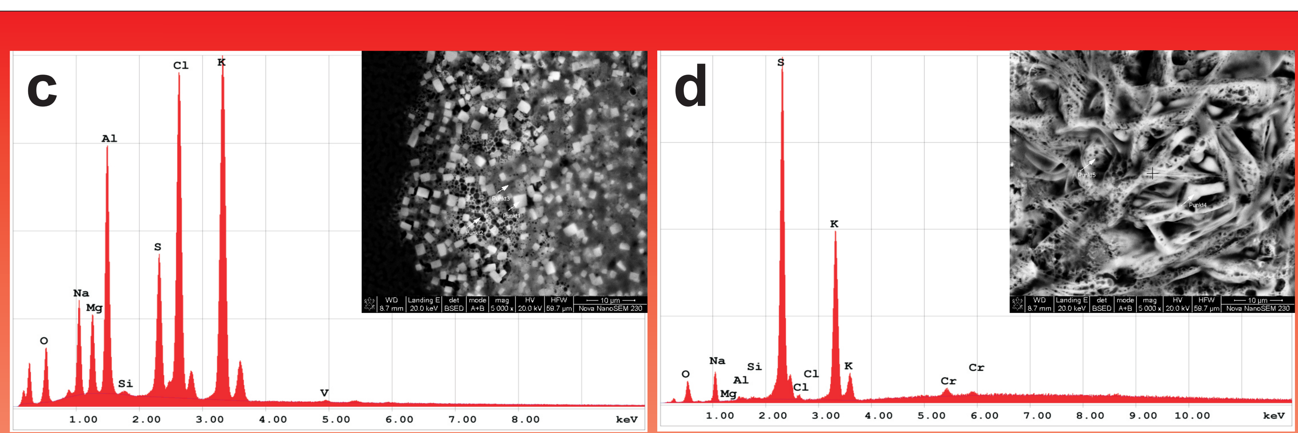
- $L1 = H_2O_L$, HS^-, H_2S_{aq} and some $CO_{2\,aq}$ (Figs. 4&7)
- $L2 = H_2S_L$, H_2O_V (Figs. 4&7)

Type 1 additionally contains:

- native sulfur S_8 within the yellowish liquid H_2O phase, possibly in suspension,
- H_2S_V and some H_2O_V, NH_3, CH_4 and light higher hydrocarbons in the vapour bubble.



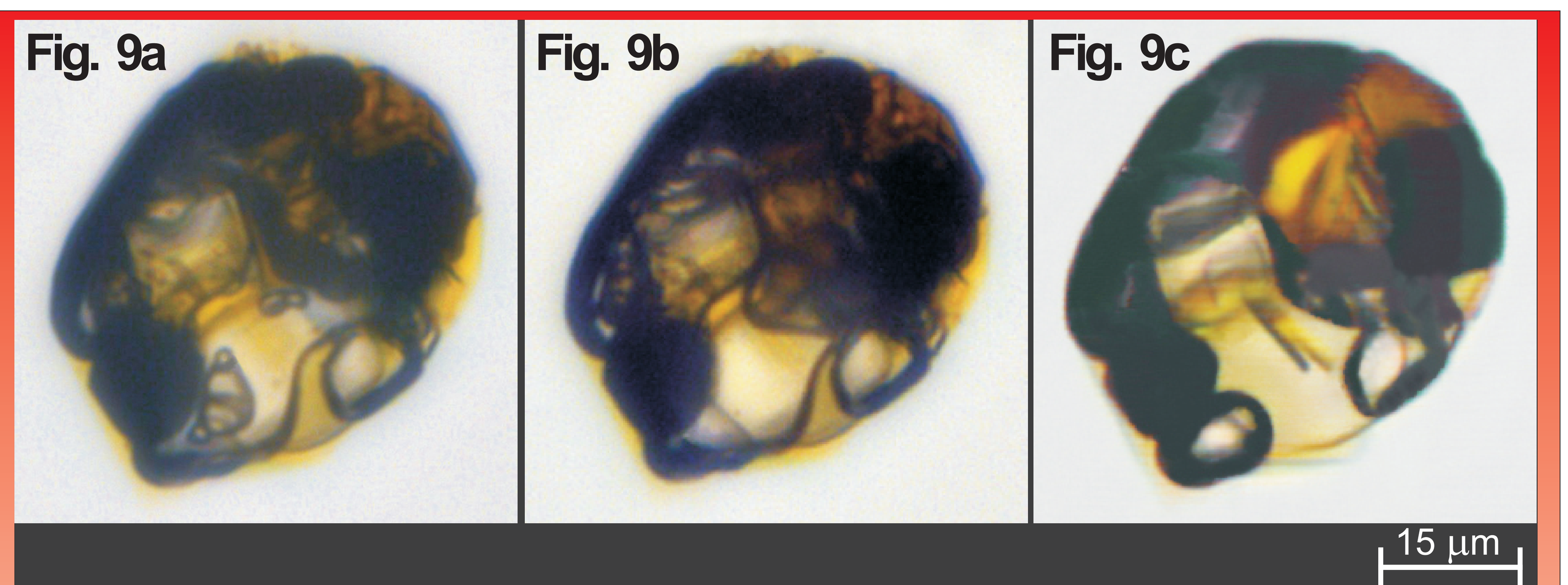
Figs. 8: Decrepitation of an inclusion in spinel (a) and its ejaculate (b) showing halite and sylvine in the external zone and sulfur in the inner zone (see REM spectra c and d with backscattered electron images).



REM

For gaining some chemical and mineralogical informations, a primary Type 1 fluid inclusion (Fig. 8a) has been heated, decrepitated and analysed by REM.

In the external zone of the ejaculate (Fig 8b, point 1) halite or sylvine were detected, and in the inner zone (Fig.8b, point 2), native sulfur were identified. Spectrum c (inner point 1) and spectrum d (external point 2) show the results of the REM analyses.



Problems

All microthermometric investigations on inclusions in spinel from Mansin are accompagnied by the following difficulties: fluid inclusions could change their shape by dissolution and reprecipitation and even form new mineral phases like diaspore, brucite and goethite. Such a behaviour of inclusions can also be observed during Raman measurements within a time space of 10 minutes (Figs. 9a-c).

Preliminary interpretation

The detected daughter minerals are native sulfur, sulfides, carbonates, chlorides, phosphates (apatite), Al-, Mg- and Fe-hydroxides (diaspore, brucite, goethite), and subordinately sulfates and oxides like anhydrite and rutile. The detected volatile species are dominantly H_2S, and traces of HS^-, NH_3, CH_4 and light hydrocarbons. Minute amounts of CO_2 dissolved in aqueous solution indicate that nearly all carbonate anions must have been used for carbonate precipitation. Daughter mineral and fluid phases refer to a sulfur-dominated melt, from which the two inclusion assemblages formed during retrograde conditions. Immiscibility is indicated, leading to the separation to the two inclusion assemblages, as mentioned by Giuliani et al. (2015) for rubies from the same deposits. In addition, most daughter minerals are rounded and changed their shape from one week to the other, even so during Raman measurements. These findings highlight that the Mansin spinel precipitated from a sulfur-dominated chloride carbonate melt in an extremely reduced acid growth environment, in the system Na-K-Ca-Mg-M-Ti-Al-Fe-Cu-Zn-V-C-N-P-S-Cl-F-H_2O.

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