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Melt Inclusion Studies of Pb-Zn Ore Deposits of Rajpura-Dariba-Bethumni Belt in District Udaipur, (Rajasthan) India

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Abstract

The Proterozoic Aravalli-Delhi orogenic complex hosts a large number of economically important stratabound base metal sulphide deposits. In the present work, rock samples taken from Outcrop and Underground mines of Sindeskar Kalan, Vedanta Group, Rajpura Dariba-Bethumni Belt which were located at a distance of 76 Kms from Udaipur District (Rajasthan) have been studied. The chief litho units of the group were identified which contain sulfide-bearing calc-silicate and graphite mica schist, dolomite marble, calc-biotite schist and quartzite. Importance to the ore minerals like galena and sphalerite which have been reported in association with the buffer minerals like pyrite and pyrrhotite occurred in the host rocks of the study area. The study of melt inclusion (sulfide melt) of sphalerite showed the maximum temperature of melting which was 923˚C on the Linkam-TMS94 (the maximum temperature limit of the system is up to 1500˚C). The maximum temperature of melting of sphalerite reveals that the dolerite and/or pegmatite intrusion might have supplied sulfide rich melt during the study area in the geological past.

Keywords

Sphalerite, Zn-Pb Ore, Melt Inclusion, Rajpura Dariba-Bethumni Belt, Rajasthan

1. Introduction

Zinc-Lead deposits of various sizes and grades occur throughout the belt in calc-silicate bearing dolomite and graphite mica schist horizons [1], the latter in general containing low-grade disseminated sulfides of large volumes. The ores from the various deposits in the belt have more or less similar mineral assemblage, differing

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mainly in their relative proportions from deposit to deposit. The stratiform ore bodies [2] mainly comprised sphalerite, galena, chalcopyrite, and pyrite-pyrrhotite. The stratiform ores of Rajpura-Dariba are characterized by the presence of different verities of laminated sphalerite such as lemon yellow, light brown, and dark brown, a feature that is absent in other deposit in the belt.

Silicate melt inclusions (MI) are small samples of melt that are trapped during crystal growth at magmatic pressures and temperatures. The MI represent a sample of the melt that was isolated from the magma during host crystal growth. Thus, MI provide a valuable tool for constraining the magmatic history of igneous systems because they provide an unambiguous method to directly determine compositions of melts from which the host crystal grew. The temperature and pressure at which the rocks are formed or the ores are deposited, ranges from about very high at a depth to atmospheric at the surface. Geothermometry is a measurement of estimation of temperatures at which the geologic process takes place, and the indicator which provides this information is known as geothermometry. There are practical as well as theoretical reasons for studying the temperature of ore deposition and the character of trapped melts, beside from the fact that genesis of the minerals cannot be understood until the conditions of depiction and the nature of cooling.

The Archaean basement comprising of gneiss, schist, amphibolite, quartzite and granite dating back to 3.2 to 2.5 b.y. showing unconformable relationship with the Aravalli cover rocks, is clearly marked in and around Udaipur. Stratigraphic succession, established by [3] for the Aravalli Supergroup of the type area around Udaipur and Zawar, shows two major groups separated by an unconformity. The Upper Aravalli Group consists of greywacke-slate-phyllite, quartzite, dolomite and siltyarenite (host for sulphides of zinc and lead) while carbonaceous and pelitic phyllites, dolomite, quartzite, stromatolyte, phosphorite, chlorite schist, amphibolite, quartz arenite and local conglomerate [4] belong to Lower Aravalli Group. In general, Aravalli rocks in Udaipur region show a low-grade metamorphism. The recrystallisation of the silicate minerals suggests the grade of metamorphism to be of greenschist facies [5] (**Figure 1**).

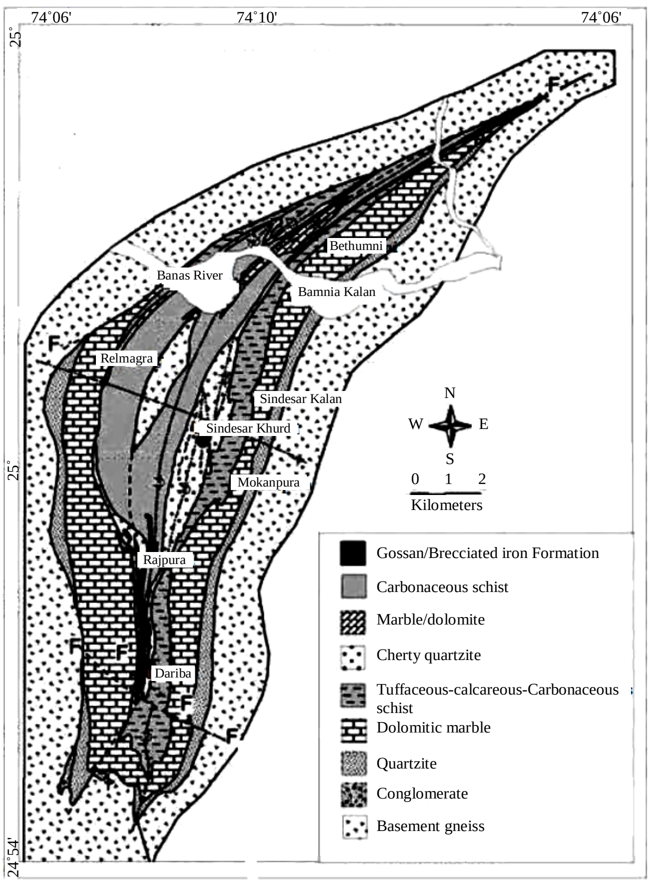

Figure 1. Regional geological map, Dariba Belt. Modified after [6].

2. Geology

The geology of Rajasthan has been studied by many workers [7]-[18] over decades and the different major geological units and prominent faults and lineaments of this region. The crust of the northwestern Indian Craton in Rajasthan comprises the Achaean Banded Gneissic Complex (BGC) forming the basement, overlain by the Proterozoic Delhi Aravalli Fold Belts of Delhi and Malani Igneous Suite, most of which are covered by the Tertiary and Quaternary sediments. Studies by [19] have provided constraints on the ages of the pre-Aravalli basement rocks. Detailed geological mapping by [20] suggests a wide variation in the spatial and temporal evolution of the region through different geodynamic processes.

The Aravalli mountain range in the northwest part of India extends over 700 km in length with a general NE-SW trend It consists of two main Proterozoic sedimentary and volcano sedimentary successions, the Aravalli Supergroup and the DelhiSupergroup, respectively, which are bounded by the Great Boundary Fault to the east and the Western Marginal Fault to the west. These Proterozoic successions rest unconformably on Archean granitoid basement [21], commonly referred to as Banded Gneissic Complex/BGC [22]. The minimum age of the basement rocks is 2500 Ma [23]. The Aravalli Supergroup, a sedimentary succession with minor volcanic flows near the base, developed as a cover sequence on the granitoid basement [21], the BGC of [22]. The existing geochronological data for the Aravalli Supergroup are insufficient to date precisely the opening and closure of the Aravalli Basin. However, the maximum age of the Aravalli Supergroup comes from the Sm-Nd systematics of the basal volcanic indicating 2326 ± 321 Ma [24] and the minimum age is considered to be 1900 ± 80 Ma from the Rb-Sr dating of Darwar Granite that was emplaced synkinematically with the earliest deformation of the Aravalli [25].

Stratigraphy of the study area [26].

Intrusive	Quartz Vein Granite
Rajpura-Dariba Group	Upper Unit: Interbanded quartzite and mica schist/ash bed/ tuffaceous mica schist/graphite mica schist Middle Unit: Limonitised graphite mica schist, silicified/gossanised Ferruginous chert breccia Garnetiferous-magnetite quartzite Graphite ± garnet ± staurolite ± kyanite ± andalusite, mica schist, micaceous cherty dolomite, acid-basic volcanics, tuffaceous/calcareous/carbonaceous/ mica schist Lower Unit: Marble, amphibolite, metamarl, quartzite and conglomerate
------------------ Unconformity ------------------	
Mangalwar Complex	Migmatite Gneisses and schists

3. Material and Methods

A total of 25 samples were collected from the different Levels of underground mine as well as outcrop samples from the selected mine (both of ores and rocks) of the study area, out of which fresher and unweathered samples were selected for melt inclusions studies polished blocks of ores were carried out under transmitted and reflected light respectively.

4. Melt Inclusions Studies

4.1. Introduction

Melt Inclusion in rocks are the vital source of information about the composition of parent magma. Melt inclusions preserve compositions that are different from those of erupted lavas. Melt inclusions are small parcels or "blobs" of melt(s) that are entrapped by crystals growing in the magmas and eventually forming igneous rocks. In many respects they are analogous to fluid inclusions. Melt inclusions are generally small—most are less than 60 micrometers.

Inclusions can act like "fossils" trapping and preserving these melts before they are modified by later processes. They are glassy or crystalline and are found within both extrusive and intrusive rocks because they can form at high pressure and are contained within relatively incompressible hosts, they may retain high concentrations of volatile elements that normally escape from magma during degassing. As such analysis of these inclusions provides direct information on the volatile contents of magmatic systems [27]. [28] was the first to document microscopic melt inclusions in crystals.

4.2. Biphase Inclusions (Figures 2-5)

Main type of Biphase inclusion is:

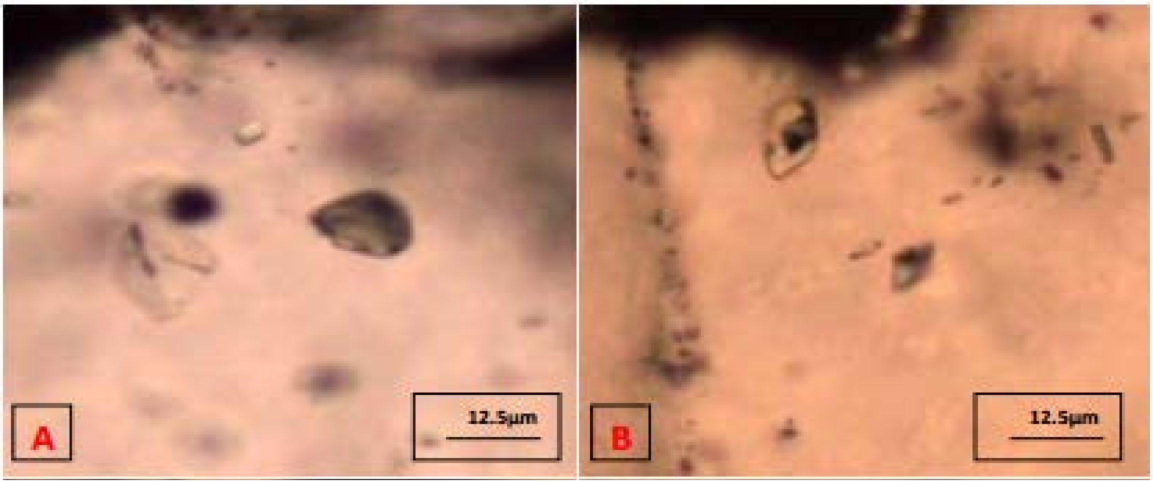

Figure 2. Photomicrographs showing **A** and **B** Biphase melt inclusion, Gas inside the bubble.

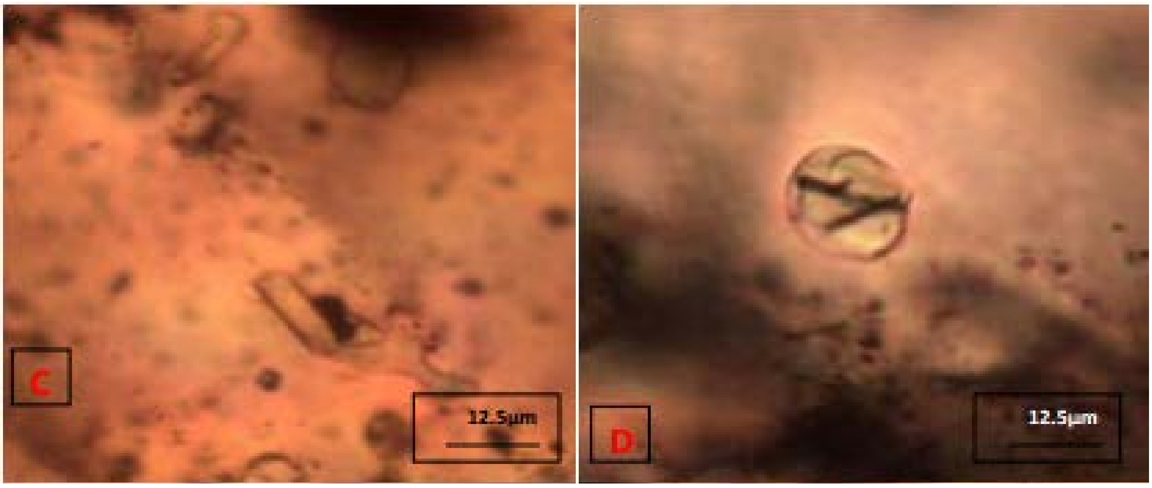

Figure 3. Photomicrograph **C** showing Biphase melt inclusion having microtube, **D** showing Polyphase melt inclusion of globular shape having some rod shape inclusion material.

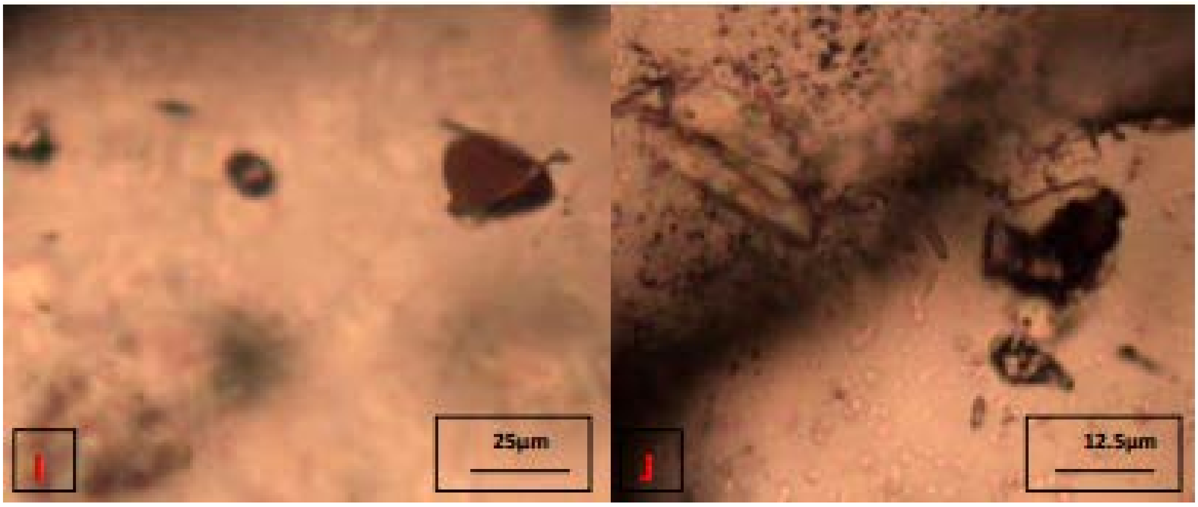

Figure 4. Photomicrograph **I** and **J** Biphase melt inclusion showing negative crystal cavity.

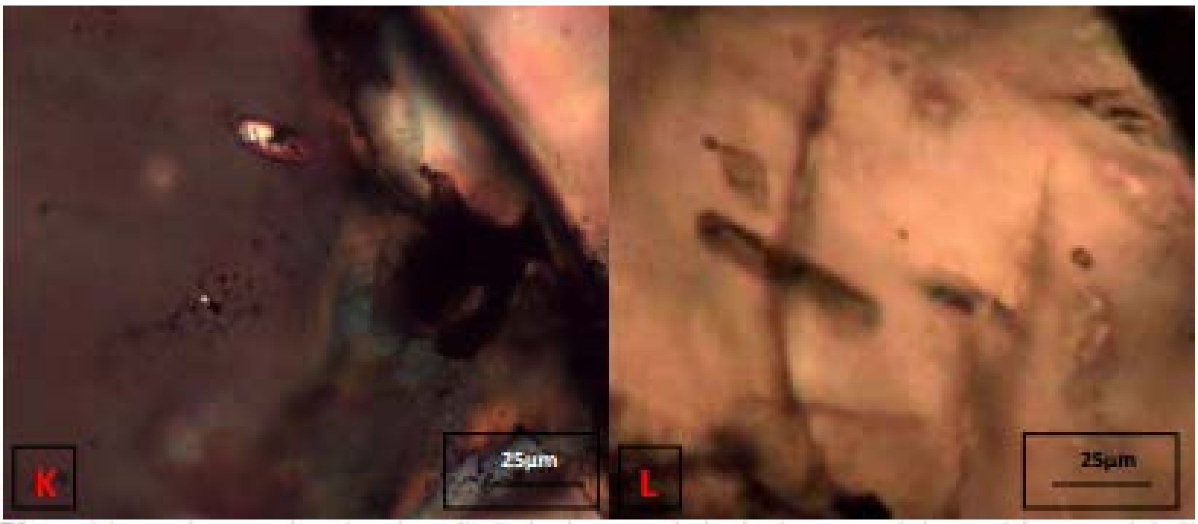

Figure 5. Photomicrograph K Biphase melt inclusion showing open cavity having daughter crystal, L showing Along trail and bottle shaped Polyphase melt inclusion.

- Gas Phase (CO_2) in glass inclusions
- Silicate Phase in glasses
- Opaque Phases in glasses.

These Bi and Mono phase are connected with a microtube called hourglass inclusions.

4.3. Polyphase (Figure 6 and Figure 7)

In this type more than 3 phases occur like gas, silicate phase and other daughter mineral in glasses.

5. Geothermometry

5.1. Introduction

The Melt inclusion microthermometry study was carried out using a Linkam-TMS94 stage attached to a Leitz microscope having CCD camera (**Figure 8**). The stage was caliberated using synthetic CO_2 inclusion supplied by the M/S Linkam Ltd. Analysis was carried out for biphase and polyphase melt inclusion in wafer section of the sphalerite. The maximum temperature limit of the system is up to 1500˚C. At this high temperature oxidation

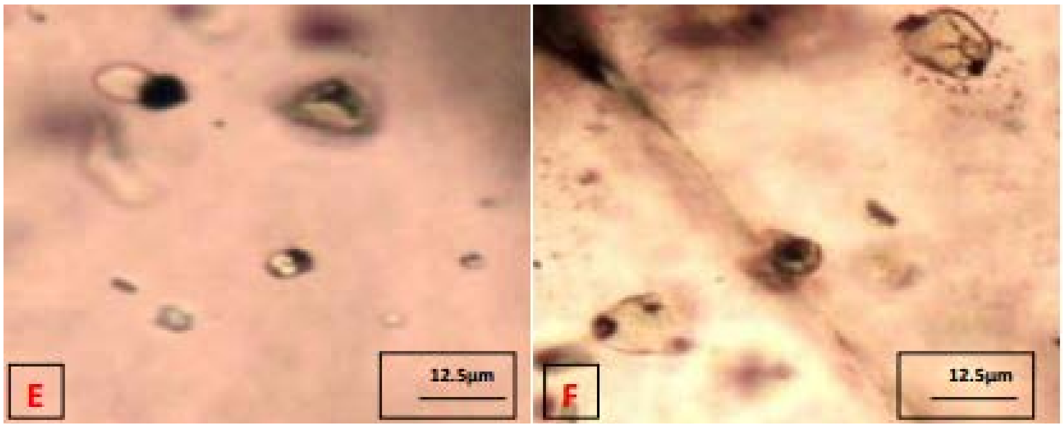

Figure 6. Photomicrograph **E** and **F** showing CO_2 rich Polyphase melt.

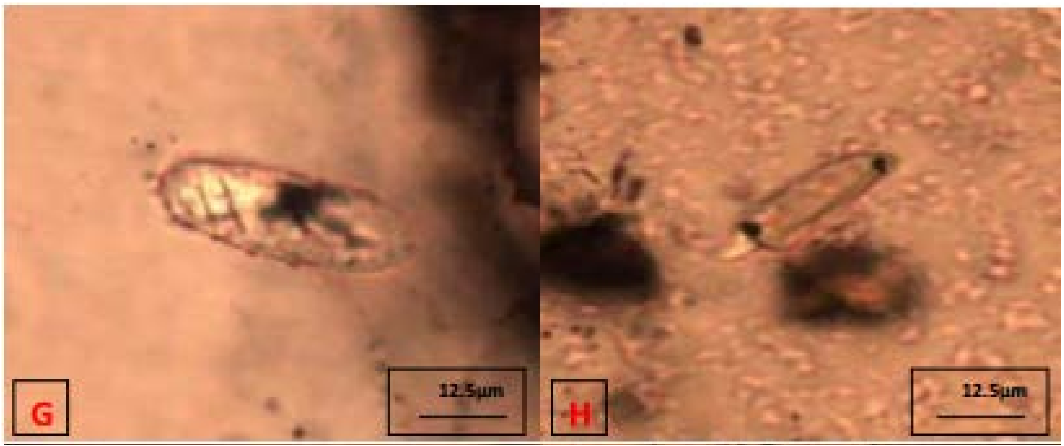

Figure 7. Photomicrographs **G** showing Polyphase melt inclusion containing calsic material, **H** showing Microtube polyphase melt inclusion appearing like airphone.

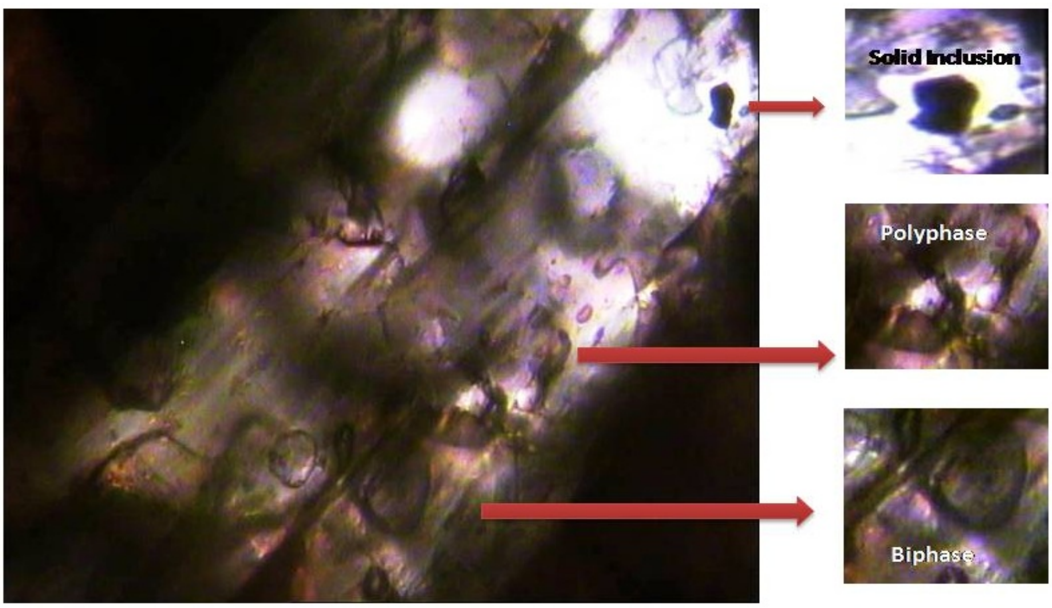

Figure 8. Photomicrograph showing different phases of Melt Inclusion.

may take place. So to reduce the oxidation effect Argon (inert gas) is used. The surrounding environment of the sample should be inert. So, we make it vaccum. Thermo couple is used to know about the temperature of heating (Platinum Radium) thermocouple is used. The sample is placed above a sapphire glass. Water circulation is there to maintain the temperature of vaccum chamber at a constant rate.

5.2. Microthermometric Study

The main aim of microthermometric study is to know the temperature of homogenization of the entrapped inclusion. For the microthermometric study small fragments of already examined doubly polished wafer thin section of sphalerite (Figure 9) is selected. The heating study (Table 1 and Table 2) is carried out on inclusions of large size and primary origin. Heating started at room temperature and pressure.

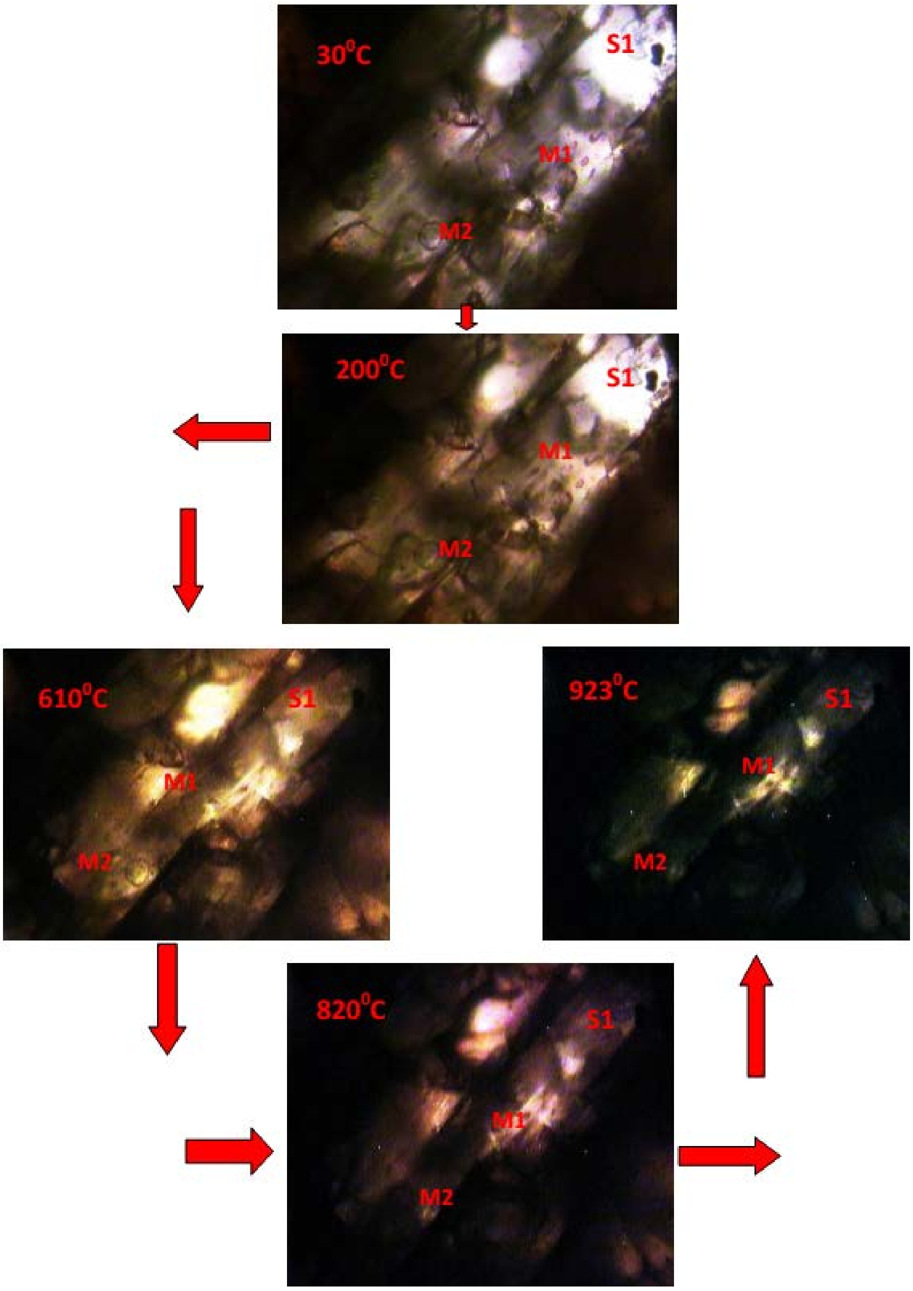

Figure 9. Photomicrograph showing the changes observed during heating.

Table 1. Showing the rate of temperature variation during heating.

Rate of temperature increase per minute	Temperature limit in ˚C	
30	200	
20	500	(Heating)
10	900	
5	1250 Maximum temperature	
15	900	
10	500	(Cooling)
25	200	

Table 2. Observation during heating at different temperature pressure condition.

Vacuum pressure (mbar)	Temperature ˚C	Behavior of melt inclusions description
6	**30**	Heating started
6.5	**200**	No change in melt inclusions
6	**399**	No change in melt inclusions
8	**498**	No change in melt inclusions
10	**594**	No change in the boundary of S1 and slight change in M1 and M2
7.5	**690**	Melt inclusions boundary start merging
9.3	**799**	Merging continues
8	**880**	Partial melting of M1, M2 and no change in S1
14.2	**1020**	Partial melting continues
6	**1110**	Only relict of melt Inclusion
8	**1170**	Complete melting of M1 and M2 but S1 not melt may be some opaque or solid inclusion
9	**1250**	Homogenization temperature of M1 and M2 but S1 still remain

6. Conclusion

Melt inclusion studies result shows that the temperature of complete melting of sphalerite is 1170˚C and maximum temperature of heating is 1250˚C, which is the temperature of homogenization. On the basis of melt inclusions petrography under the ore microscope reveals that the melt inclusions found only at 375 level and little bit at 350 meter level which probably suggest that the pegmatite intrusion occurred up to this level and the recognition of melt inclusion is a proof that a rock was partially melted at some time in its history.

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References

[1] Chauhan, D.S. (1977) The Dariba Main Lode of the Rajpura-Dariba Zinc-Lead-Copper Belt, Udaipur District, Rajasthan. *Journal of Geological Society of India*, **18**, 611-616.

[2] Deb, M., Banerjee, D.M. and Bhattacharya, A.K. (1978) Precambrian Stromatolite and Other Structures in the Rajpura-Dariba Polymetallic Ore Deposit, Rajasthan, India. *Mineralium Deposita*, **13**, 1-9.

http://dx.doi.org/10.1007/BF00202904

[3] Roy, A.B., Paliwal, B.S. and Goel, O.P. (1971) Superposed Folding in the Aravalli Rocks of the Type Area around Udaipur, Rajasthan. *Journal of Geological Society of India*, **12**, 342-348.

[4] Haldar, S.K. and Deb, M. (2001) Geology and Mineralization of Rajpura-Dariba Lead-Zinc Belt, Rajasthan. In: Deb, M. and Goodfellow, W.D., Eds., *Sediment-Hosted Lead-Zink Deposit Modeling Program*, Proceeding, Delhi-Udaipur, 10th-17th December 2001, 177-187.

[5] Gupta, B.C. (1934) The Geology of Central Mewar. *Memoir of Geological Society of India*, **65**, 107-168.

[6] Ameta, S., Das Gupta, S. and Sharma, B.B. (1999) Geology, Structure and Mineralisation in Dariba-Bethumni-Surawas Belt, Rajsamand Dist., Rajasthan. *Records of the Geological Survey of India*, **129**, 22-24.

[7] Deb, M. and Sarkar, S.C. (1990) Proterozoic Tectonic Evolution and Metallogenesis in the Aravalli Delhi Orogenic Complex, Northwestern India. *Precambrian Research*, **46**, 115-137. http://dx.doi.org/10.1016/0301-9268(90)90069-3

[8] Deb, M. (1982) Rare Minerals in Rajpura-Dariba Ores-Some Further Comments. *Journal of Geological Society of India*, **23**, 253-260.

[9] Deb, M. and Kumar, R. (1982) The Volcano-Sedimentary Environment of Rajpura-Dariba Polymetallic Ore Deposit, Udaipur District, Rajasthan. *Geological Survey of India*, *Symposium on Metallogeny of the Precambrian*, IGCP Project 91, Udaipur, 1-17.

[10] Fareeduddin (1998) Single Zircon Age Constraints on the Evolution of Rajasthan Granulite. In: Paliwal, B.S., Ed., *The Indian Precambrian*, Scientific Publishers (India), Jodhpur, 547-556.

[11] Naha, K. and Majumdar, A. (1971) Reinterpretation of the Aravalli Basal Conglomerate at Morchana, Udaipur District, Rajasthan, Western India. *Geological Magazine*, **108**, 111-114. http://dx.doi.org/10.1017/S0016756800051128

[12] Naha, K. and Halyburton, R.V. (1974) Early Precambrian Stratigraphy of Central and Southern Rajasthan, India. *Precambrian Research*, **1**, 55-73. http://dx.doi.org/10.1016/0301-9268(74)90018-7

[13] Poddar, B.C. (1974) Evolution of Sedimentary Sulphide Rhythmites into Metamorphic Tectonites in the Base Metal Deposits of Rajpura-Dariba, Rajasthan. *Golden Jubli Volume*, *Quarterly Journal of Geological Mineral Metamorphic Society of India*, **46**, 207-221.

[14] Poddar, B.C. and Mathur, R.K. (1965) A Note on the Repetitious Sequence of Grewacke-Slate-Phyllite in the Aravalli System around Udaipur, Rajasthan. *Bulletin-Geological Society of India*, **2**, 83-87.

[15] Raja Rao, C.S. (1970) Sequence, Structure and Correlation of the Metasediments and Genesis of the Banded Gniessic Complex of Rajasthan. *Record of Geological Survey of India*, **98**, 122-131.

[16] Ranawat, *et al.* (1988) Metamorphic Character of Rampura-Agucha Pb-Zn Deposit, Rajasthan. In: Roy, A.B., Ed., *Precambrian of the Aravalli Mountain*, *Rajasthan*, *India*, Memoir Geological Society India, Vol. 7, 397-409.

[17] Sharma, R.S. (1988) Patterns of Metamorphism in the Precambrian Rocks of the *Aravalli Mountain Belt*. *Geological Society of India Memoir*, **7**, 33-75.

[18] Sinha-Roy, S. (1984) Precambrian Crustal Interaction in Rajasthan, NM India. *Proceeding of Seminar on Crustal Evolution of Indian Shield and Its Bearing on Metallogeny*, *Indian Journal of Earth Sciences*, 84-91.

[19] Gopalan, K., Trivedi, J.R., Balasubramanyam, M.N., Roy, S.K. and Sastri, C.A. (1979) Rb-Sr Chronology of the Khetry Belt, Rajasthan. *Journal of Geological Society of India*, **20**, 450-456.

[20] Roy, A.B. and Jakhar, S.R. (2002) Geology of Rajasthan, (Northwest India), Precambrian to Recent. Scientific Publishers, India, 412 p.

[21] Roy, A.B. and Kroner, A. (1996) Single Zircon Evaporation Ages Constraining the Growth of the Archaean Aravalli Craton, Northwestern Indian Shield. *Geological Magazine*, **133**, 333-342. http://dx.doi.org/10.1017/S0016756800009067

[22] Heron, A.M. (1953) Geology of Central Rajasthan. *Memoirs of the Geological Survey of India*, **79**, 339 p.

[23] Wiedenbeck, M., Goswami, J.N. and Roy, A.B. (1996) Stabilization of the Aravalli Craton of the North-Western India at 2.5 Ga: An Ion Microprobe Zircon Study. *Chemical Geology*, **129**, 325-340. http://dx.doi.org/10.1016/0009-2541(95)00182-4

[24] Ahmad, T., Dragusanu, C. and Tanaka, T. (2008) Provenance of Proterozoic Basal Aravalli Mafic Volcanic Rocks from Rajasthan, Northwestern India: Nd Isotopes Evidence for Enriched Mantle Reservoirs. *Precambrian Research*, **162**, 150-159. http://dx.doi.org/10.1016/j.precamres.2007.07.011

[25] Ray, J.N. (1980) An Evaluation of the Tectonic Framework of the Rampura-Agucha Zinc-Lead Deposit, Bhilwara District, Rajasthan. *Indian Minerals*, **34**, 19-21.

[26] Gandhi, S.M. (2001) The Ancient Mining and Metallurgy in Rajasthan. *Hindustan Zinc Limited*, **4**, 2-13.

[27] De Vivo, B. and Frezzotti, M.L. (1994) Evidence for Magmatic Immiscibility in Italian Subvolcanic Systems. In: De Vivo, B. and Frezzotti, M.L., Eds., *Fluid Inclusions in Minerals*: *Methods and Applications*, Virginia Tech (VT), Blacksburg, 345-362.

[28] Sorby, H.C. (1858) On the Microscopical Structure of Crystals, Indicating the Origin of Minerals and Rocks. *Quarterly Journal of the Geological Society*, **14**, 453-500. http://dx.doi.org/10.1144/GSL.JGS.1858.014.01-02.44