energy can be utilized efficiently with the existing available equipment for successful operation of different domestic appliances in a pollution-free environment and at minimum operational cost. It is particularly useful for application in rural areas for meeting the power demand. Once the initial cost of installation is met, the electricity generated by solar panels is almost free of cost. In a stand-alone solar power system, one does not have to pay any utility bills. Another positive aspect of installing solar power systems is that the government offers rebates and incentives to cover the initial cost. The system can pave the way for sustainable cultivation in self-sustained greenhouses even in remote areas, where probability of getting conventional grid-connected electricity at a steady voltage round the year is very low.

1. Moharil, R. M. and Kulkarni, P. S., *Renew. Sustain. Energy Rev.*, 2009, **13**, 673–681.
2. Eltawil, M. A. M. A. and Samuel, D. V. K., In Proceedings of Third International Conference on Solar Radiation and Day Lighting, Anamaya Publishers, New Delhi, 2007, pp. 358–367.
3. Al-Shamiry *et al.*, *Am. J. Appl. Sci.*, 2007, **4**(6), 386–389.

Received 31 July 2013; revised accepted 19 December 2013

P. K. SHARMA*
D. V. K. SAMUEL

*Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi 110 012, India*
**For correspondence.*
*e-mail: pks_ageg@iari.res.in*

# Petrographic and XRD studies on a new occurrence of molybdenite within late Archaean mafic enclaves near Hyderabad, eastern Dharwar craton, India

Molybdenum is a group 6 transition metal with an atomic number 42. It occurs in nature only in chemical combination with other elements. The average crustal abundance of molybdenum is 1.2 mg/kg (ref. 1). Molybdenum is extracted from two principal ore minerals molybdenite ($MoS_2$) and wulfenite ($PbMoO_4$); however, molybdenite is a more common ore mineral. Molybdenum is reported from all over the world, though only few countries like China, the United States, Chile and Canada are the main producers[2]. It is an important element in making many types of steel alloys and super-alloys. Due to its ability to survive extreme temperatures without significantly expanding or softening, it is useful in making armor, aircraft parts, electrical contacts, industrial motors and filaments[3]. Generally, rhenium (Re) which is widely used for making super-alloys and as a catalyst, is also found to be associated with molybdenum. Radioisotopes of rhenium $^{188}$Re and $^{186}$Re are used for treatment of liver and pancreatic cancers. Therefore, any new report of molybdenum, by inference molybdenite, from the Indian shield may be an important finding.

Occurrence of molybdenite in India is summarized in the GSI Dossier (Figure 1; Singanenjam *et al.*[4]). A report of molybdenite in granitic plutons from the Pirancheru area near Hyderabad is also documented[5]. Structurally molybdenites are generally associated with shear zones, fracture systems and fold hinges[4]. Most of these molybdenite occurrences are associated with Pan-African to late Proterozoic (500–800 Ma) granites. However, molybdenum occurrences during Neoarchaean to Palaeoproterozoic are also known; for example, Kolar Schist Belt, Andhra Pradesh[4] and Yegavkote near Chintamani, Karnataka[6]. It is important to mention that except one[5], all other[4] molybdenite occurrences are associated with other metal sulphides. The molybdenite occurrence in granite pluton reported from Pirancheru area near Hyderabad is probably primary in nature as it is not associated with any other sulphides[4]. Here we report the occurrence of molybdenite near Taramatipet, about 20 km east of Hyderabad city, which occurs as disseminated-type porphyry deposit in fracture system within the mafic enclaves surrounded by granitoids (Figure 2). The collected molybdenite samples have been studied by ore petrography and XRD to confirm this occurrence and understand possible genesis.

The study area is a part of eastern Dharwar craton (EDC) which consists of Peninsular Gneisses, plutons of potassic granites and granodiorites[7,8] (2.56–2.52 Ga)[9], and Dharwar Supergroup (2.90–2.54 Ga) represented by volcano-sedimentary greenstone sequences[8]. Recent studies have shown that EDC was cratonized at ~2.5 Ga (ref. 8). Besides tracts of different generations of granitoids, a number of Proterozoic mafic dyke swarms are also emplaced throughout EDC[10–12].

The molybdenite occurrence is encountered near the village Taramatipet (17°21′01″N, 78°39′84″E; see Figure 2). This area comprises granitic plutons and widespread mafic enclaves within the plutons. Widespread mafic injections into the crystallizing 2.56–2.52 Ga calc-alkaline to potassic granite plutons at all exposed crustal levels in the EDC are reported[13,14]. These mafic injections occurred during different stages of crystallization of host magmas. The early injections of mafic melts resulted in the formation of mafic enclaves, whereas late mafic injections resulted in synplutonic mafic dykes[15]. The former condition is observed in the study area. There may be two conditions of mafic–felsic mixing during the early stages; the first is a very early stage of crystallization when both felsic and mafic melts form hybrid magmas leading to the formation of slightly mafic calc-alkaline granitoids, whereas during a slightly later stage, the viscosities of the two magmas may be different and permit only slight mingling[15]. During this later stage mafic enclaves are formed. It is suggested that these mafic injections form the terminal event in the 2.56–2.52 Ga magmatism and spatially linked to crustal reworking and cratonization of the Archaean crust[13,14].

Three samples of molybdenite were collected from the fracture system in the mafic enclaves. The locations of these samples are shown in Figure 2. Molybdenite exhibits metallic lusture, thin platy habit and bluish lead-grey colour and streak (Figure 3 *a*). In spite of this, it is essential to confirm its identification by additional characterization studies. Therefore, ore petrography and XRD analyses were done on the collected samples in the present study. Microscopic examination of mafic enclave samples showed presence of either hypidiomorphic or, at places, porphyritic texture. The enclaves are essentially composed of hornblende, plagioclase feldspar, pyroxene, chlorite, ilmenite and apatite, which eventually classify them as meta-gabbro. As molybdenite grains are friable and only concentrated in fracture zones, none of them is seen in thin section of mafic enclaves. Hence, a piece of mafic enclave hosting molybdenite was polished for study under reflected light microscope. It showed extreme bireflectance and strong pleochroism under reflected light. It also showed lamellar twining and contained perfect cleavage (Figure 3 *b*). These characteristics confirm the presence of molybdenite.

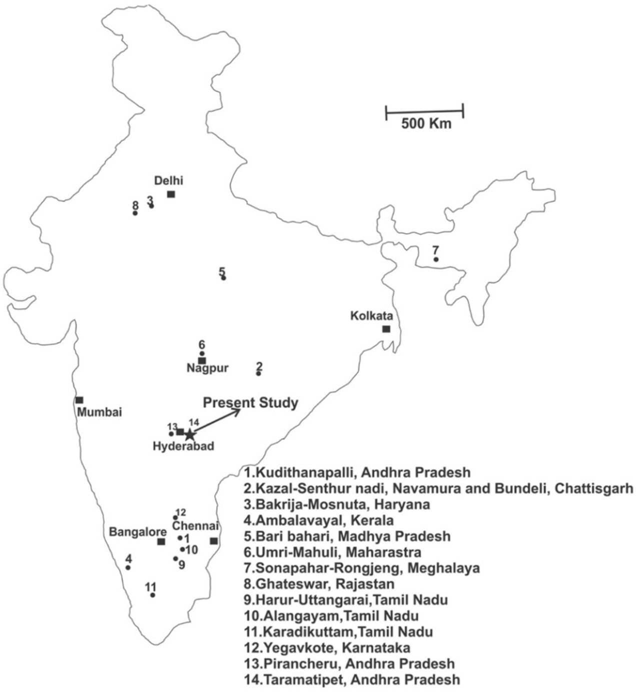



**Figure 1.** Distribution of molybdenite occurrences in India (1 to 11 – after Singanenjam *et al.*[4], 12 – from Vasudev and Jayaram[6], 13 – from Saxena and Sudershan[5]; 14 – from the present study).

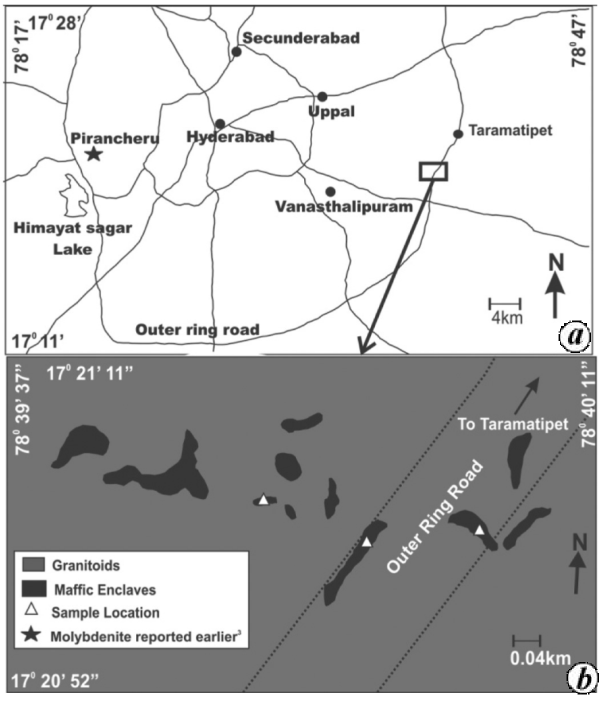



**Figure 2.** ***a***, Location of the study area. ***b***, Generalized geological map of the study area.

XRD study of a sample further confirmed the presence of molybdenite. The diffraction pattern was obtained on a PANalytical X'Pert Pro diffractometer fitted with a copper tube (CuK$\alpha$ radiation) and xenon detector at the Centre of Advanced Study, Department of Geology, Banaras Hindu University, Varanasi. The sample was scanned over a range 5–80° $2\theta$ using a 1/2° fixed divergence slit and 1/4° receiving slit with a step size of 0.0250, 1.20 sec/step and a total run time of 59 min 25 sec at 45 kV and 40 mA. The instrument was calibrated using a silica calibration standard. Phase identification was achieved by comparing the measured data to a reference database, viz. Inorganic Crystal Structure Database (ICSD) in PANalytical X'Pert High Score (Plus) v3.X database. Results are presented in Figure 4. The most significant peaks of XRD analyses at *d* values 6.180 Å (100%), 2.280 Å (30.12%), 1.832 Å (17.25%), 2.052 Å (16.58%), 1.538 Å (16.54%) and 2.743 Å (9.97%) confirm the presence of molybdenite which is of 2H poly-type. A few other minor peaks are also identified; however, these are also of molybdenite. The indexing based on unit cell dimensions $a$ = 3.16 Å and $c$ = 12.28 Å is consistent with the space group $P6_3/mmc$. Therefore, a combination of physical properties, reflected light petrography and XRD data clearly confirms the presence of molybdenite.

Most of the molybdenum deposits are found to be related to granite plutonism[4,16].

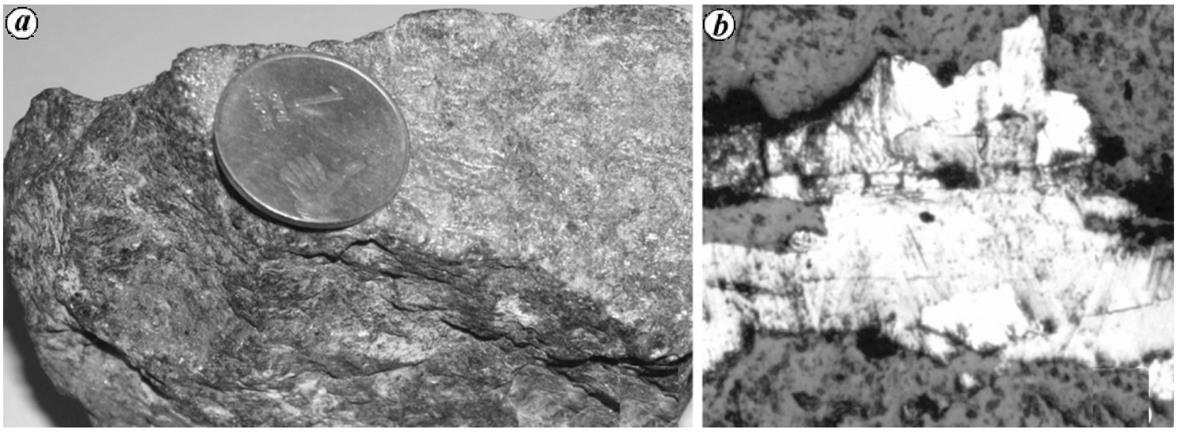
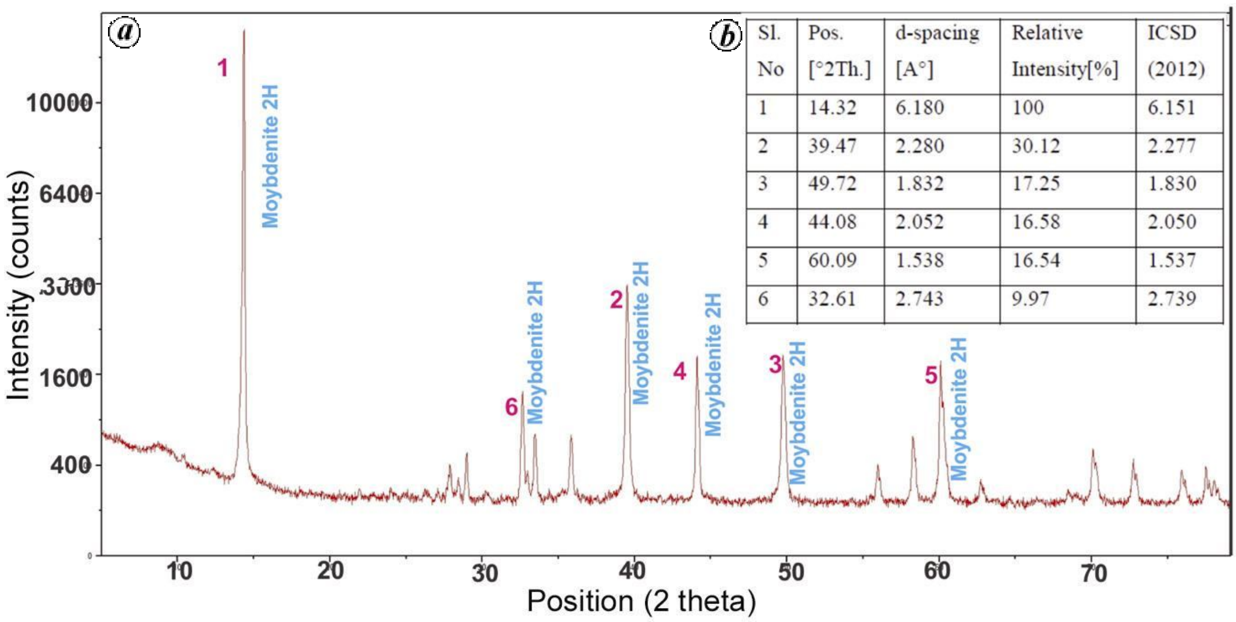


**Figure 3.** ***a***, Molybdenite on a fracture surface of a gabbro specimen. ***b***, Photomicrograph of molybdenite lath under reflected light (magnification 50×).




| Sl. No | Pos. [°2Th.] | d-spacing [A°] | Relative Intensity[%] | ICSD (2012) |
|---|---|---|---|---|
| 1 | 14.32 | 6.180 | 100 | 6.151 |
| 2 | 39.47 | 2.280 | 30.12 | 2.277 |
| 3 | 49.72 | 1.832 | 17.25 | 1.830 |
| 4 | 44.08 | 2.052 | 16.58 | 2.050 |
| 5 | 60.09 | 1.538 | 16.54 | 1.537 |
| 6 | 32.61 | 2.743 | 9.97 | 2.739 |

**Figure 4.** ***a***, XRD scan of the ore sample where six major peaks of molybdenite are labelled. Other visible minor peaks also belong to molybdenite. Numbers are marked at the increasing order of relative intensity. ***b***, *d* spacing data of the analysed ore powder having space group $P6_3/mmc$, $a = 3.16$ Å and $c = 12.28$ Å.

However, their genesis through mafic–felsic magma mingling/mixing is also known[17–20]. Burnham[21,22] suggested genesis of molybdenite through partial melting of Mo-enriched sialic source, whereas Candela and Holland[23,24] recommended its genesis by Mo-enrichment in the magma due to the crystal fractionation of acid magma having low water content. However, the source of hydrothermal fluid containing metal and sulphur is always a matter of debate. Recent publications[17–19] advocate enrichment of Mo through interaction/mixing of felsic–mafic melts. Similar situation is observed for the present case. At several places in EDC there are sufficient evidences to support felsic–mafic magma mingling/mixing[13,14]; all the four stages of felsic–mafic magma mixing and crystallization[15] are observed at all these places, including the present study area. There are evidences which support that the sulphur and metals (Cu ± Mo) of porphyry deposits were transferred directly from mafic to felsic magmas as a result of magma mixing and/or crystallization of underplating mafic magmas[17,18,25–27]. Therefore, by analogy with other fairly well-studied occurrences of molybdenite, the genesis of the Taramatipet molybdenite could be attributed to mixing of sialic magma with injections of deep-seated basic melts.

1. Mielke, J. E., In *Review of Research on Modern Problems in Geochemistry* (ed. Siegel, F. R.), UNESCO Report, Paris, 1979, pp. 13–37.
2. US Geological Survey, *Mineral Commodity Summaries* 2009 (Appendix C), 2009, p. 195.
3. Emsley, J., *Nature's Building Blocks*, Oxford University Press, Oxford, 2001, pp. 262–266; ISBN 0-19-850341-5.
4. Singanenjam, S., Tarafdar, P. and Chattopadhyay, S., Detailed Information Dossier, Geological Survey of India, 2007,

p. 73; http://www.portal.gsi.gov.in/gsi-Doc/pub/DID_Mo_WM.pdf
5. Saxena, P. R. and Sudershan, V., *J. Geol. Soc. India*, 1997, **50**, 347–348.
6. Vasudev, V. N. and Jayaram, S., *J. Geol. Soc. India*, 1979, **20**, 360–380.
7. Ramakrishnan, M. and Vaidyanadhan, R., *Geology of India*. Geological Society of India, Bangalore, 2010, p. 994.
8. Jayananda, M., Peucat, J.-J., Chardon, D., Krishna Rao, B. and Corfu, F., *Precambrian Res.*, 2013, **227**, 55–76.
9. Rogers, A. J., Kolb, J., Meyer, F. M. and Armstrong, R. A., *J. Asian Earth Sci.*, 2007, **31**, 55–70.
10. Murty, Y. G. K., Babu Rao, V., Guptasarma, D., Rao, J. M., Rao, M. N. and Bhattacharjee, S., In *Mafic Dyke Swarms* (eds Halls. H. C. and Fahrig, W. F.). Geological Association of Canada Special Paper 34, 1987, pp. 303–316.
11. Ernst, R. E. and Srivastava, R. K., In *Indian Dykes, Geochemistry, Geophysics and Geochronology* (eds Srivastava, R. K., Sivaji, C. and Chalapathi Rao, N. V.), Narosa Publishing House Pvt Ltd, New Delhi, 2008, pp. 41–56.
12. French, J. E. and Heaman, L. M., *Precambrian Res.*, 2010, **183**, 416–441.
13. Jayananda, M., Miyazaki, T., Gireesh, R. V., Mahesha, N. and Kano, T., *J. Geol. Soc. India*, 2009, **73**, 117–130.
14. Prabhakar, B. C., Jayananda, M., Shareef, M. and Kano, T., *J. Geol. Soc. India*, 2009, **74**, 171–188.
15. Barbarin, B., *Lithos*, 2005, **80**, 155–177.
16. Misra, K. C., *Understanding Mineral Deposits*, Springer – Science + Business Media, 2000.
17. Sotnikov, V. I., *Russ. Geol. Geophys.*, 2006, **47**(3), 355–363.
18. Audétat, A., *J. Petrol.*, 2010, **51**, 1739–1760.
19. Maughan, D. T., Keith, J. D., Christiansen, E. H., Pulsipher, T., Hattori, K. and Evans, N. J., *Miner. Deposita*, 2002, **37**, 14–37.
20. Stavast, W. J. A., Keith, J. D., Christiansen, E. H., Dorais, M. J., Larocque, A. and Evans, N., *Econ. Geol.*, 2006, **101**, 329–345.
21. Burnham, C. W., In *Geochemistry of Hydrothermal Ore Deposits* (ed. Barnes, H. L.), Willey, New York, 1979, pp. 71–136.
22. Burnham, C. W., In *Relation of Deposit in the Southern Cordillera* (eds Dickson, R. W. and Payne, W. D.), Arizona Geological Society Digests, 1981, vol. 14, pp. 71–77.
23. Candela, P. A. and Holland, H. D., *Geochim. Cosmochim. Acta*, 1984, **48**, 373–380.
24. Candela, P. A. and Holland, H. D., *Econ. Geol.*, 1986, **81**, 1–19.
25. Keith, J. D., Shanks, W. C., III, Archibald, D. A. and Farrar, E., *Econ. Geol.*, 1986, **81**, 553–577.
26. Keith, J. D. *et al.*, The role of magmatic sulfides and mafic alkaline magmas in the Bingham and Tintic mining districts. *J. Petrol.*, 1987, **38**, 1679–1690.
27. Hattori, K. H. and Keith, J. D., *Miner. Deposita*, 2001, **36**, 799–806.

ACKNOWLEDGEMENTS. We thank the Ministry of Earth Sciences, New Delhi, for financial support through a scheme MoES/16/10/11-RDEAS and DST, New Delhi for financial support in the form of FIST grant for XRD facility. We also thank the two anonymous reviewers for their constructive comments and Head, Department of Geology, Banaras Hindu University, Varanasi, for providing the necessary facilities. We also thank N. V. Chalapathi Rao, Banaras Hindu University, for useful comments on the earlier version of the manuscript.

Received 30 July 2013; revised accepted 4 December 2013

AMIYA K. SAMAL*
RAJESH K. SRIVASTAVA

*Centre of Advanced Study,*
*Department of Geology,*
*Banaras Hindu University,*
*Varanasi 221 005, India*
**For correspondence.*
*e-mail: amiyasamal007@gmail.com*

## Erratum

# Anomalous silver concentration in volcano-plutonic rocks of Siwana Ring Complex, Barmer district, Western Rajasthan

**Rajeev Bidwai, S. Srinivasan, L. K. Nanda, Atanu Banerjee, P. N. Bangroo, A. K. Rai and P. S. Parihar**
[*Curr. Sci.*, 2014, **106**(2), 159–162]

In the first paragraph, line 7, the dimension should read as *30 km × 25 km* instead of 30 km × 25 m. We regret the error.