RESEARCH ARTICLE

Malani rhyolite: highly eroded complex crater

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The origin of the Malani beds of India has been construed to an event of anorogenic felsic magmatism that began at ~750 Ma and ended at 650 Ma. No consensus exists regarding their nomenclature, origin and duration of magmatism. These beds have been inferred to have originated due to volcanism but show many features that are unusual for any volcanic formation, such as they are devoid of any penetrative deformation although they are supposed to have resulted due to three phases of igneous activity; they evolved due to 'crustal-volcanism'; they do not show any thrust zone or tectonic melange; their time of evolution does not coincide with any major tectonomagmatic event recognized in the geological history. These features are unusual for a volcanic formation, but are common for an impact crater. The major rock type of the Malani beds is rhyolite, which at places is mixed with sediments and often shows minor fractures and slips. This geology is analogous to Dhala Basin of Madhya Pradesh, India, which has been confirmed as an impact crater. In addition to these features, stishovite has been reported from the Malani beds, which is considered as an unambiguous evidence for impact crater. Thus the area representing Malani rhyolite is a highly eroded, complex, impact crater.

Keywords: Central uplift, impact crater, magmatism, Malani rhyolite.

IN the second half of the 20th century when the concept of plate tectonics revolutionized the understanding of the Earth's mechanism, a group of workers almost simultaneously proved successfully that the collisions of extraterrestrial objects with the Earth have significantly disturbed the Earth's crust and have shaped its surface. Impact cratering is actually a fundamental process, the importance of which lies in shaping all the planets, including the Earth. A complete record of impacts on the Earth is still to be deciphered. Approximately 170 craters have been recognized on the Earth, but several hundred more still remain to be identified. It is important to note that impact craters on other planetary bodies are retained due to lack of an appreciable atmosphere and hence can easily be recognized on the basis of their morphology. In contrast, the Earth is tectonically active and has an atmosphere that causes weathering and deformation of the craters, or leads to their burial under a thick pile of sediments; therefore they are mostly recognized by the occurrence of characteristic shock metamorphic effects.

The origin of the Malani beds of India has been construed to an event of anorogenic felsic magmatism that began at ~750 Ma and ended at 650 Ma, prior to Marwar Supergroup sedimentation. No consensus exists regarding their nomenclature, origin and duration of magmatism. In this article, the unusual characteristics of these beds are discussed and efforts are made to provide a valid explanation for their origin.

Malani beds

Molten volcanic rocks covering an area of ~51,000 sq. km in the western part of India, stretching from Tosham in Haryana to Churu-Jhunjhunu in Rajasthan in the southwest and from Kirana Hills in Punjab to Barmer in Rajasthan and Nagarparkar in Sindh, Pakistan in the west are called the 'Malani beds', a name given by Blanford[1] (Figure 1). Though the Malani beds have been interpreted as volcanic succession[1–3], many of their characteristics enumerated below are unusual and not typical of a volcanic formation: (i) They show sedimentary components such as conglomerate, arkosic sandstone and ash-flow tuffs[4–6]. (ii) Their different components as revealed by detailed petrological and geochemical studies do not constitute a comagmatic series and indicate diverse protolith sources from the mantle as well as from the crust[2,7–11], and at the same time show significant crustal contamination[10,12]. Roy and Jakhar[13] concluded that 'it is not proper to describe rocks of Malani group as constituting a single igneous suite'. (iii) They are dominantly felsic (acidic) in composition, also called as 'Malani rhyolite'[3] (rhyolites or 'acid lava flows' form the major rock type of Malani volcanics, spread over an area of 31,000 sq. km in western Rajasthan). (iv) There is complete absence of any penetrative deformation in the Malani rocks. However three phases of igneous activity have been reported[5,6,11,14–19], viz. (a) bimodal volcanism with initial eruption of basic flows followed by voluminous felsic volcanism; (b) granite intrusions, and (c) emplacement of felsic and mafic dyke swarms. (v) 'Malani magmatic activity' has been dated as 750–680 Ma (refs 20–23). This period of magma genesis does not link with any of the recognized tectonomagmatic events, viz. Pan-African Magmatic Event, Delhi Orogeny, Gondwana Rifting, etc. (vi) Sinha-Roy *et al.*[24] correlated 'Malani magmatism' with Pan-African orogenesis, but that was doubted by many and its

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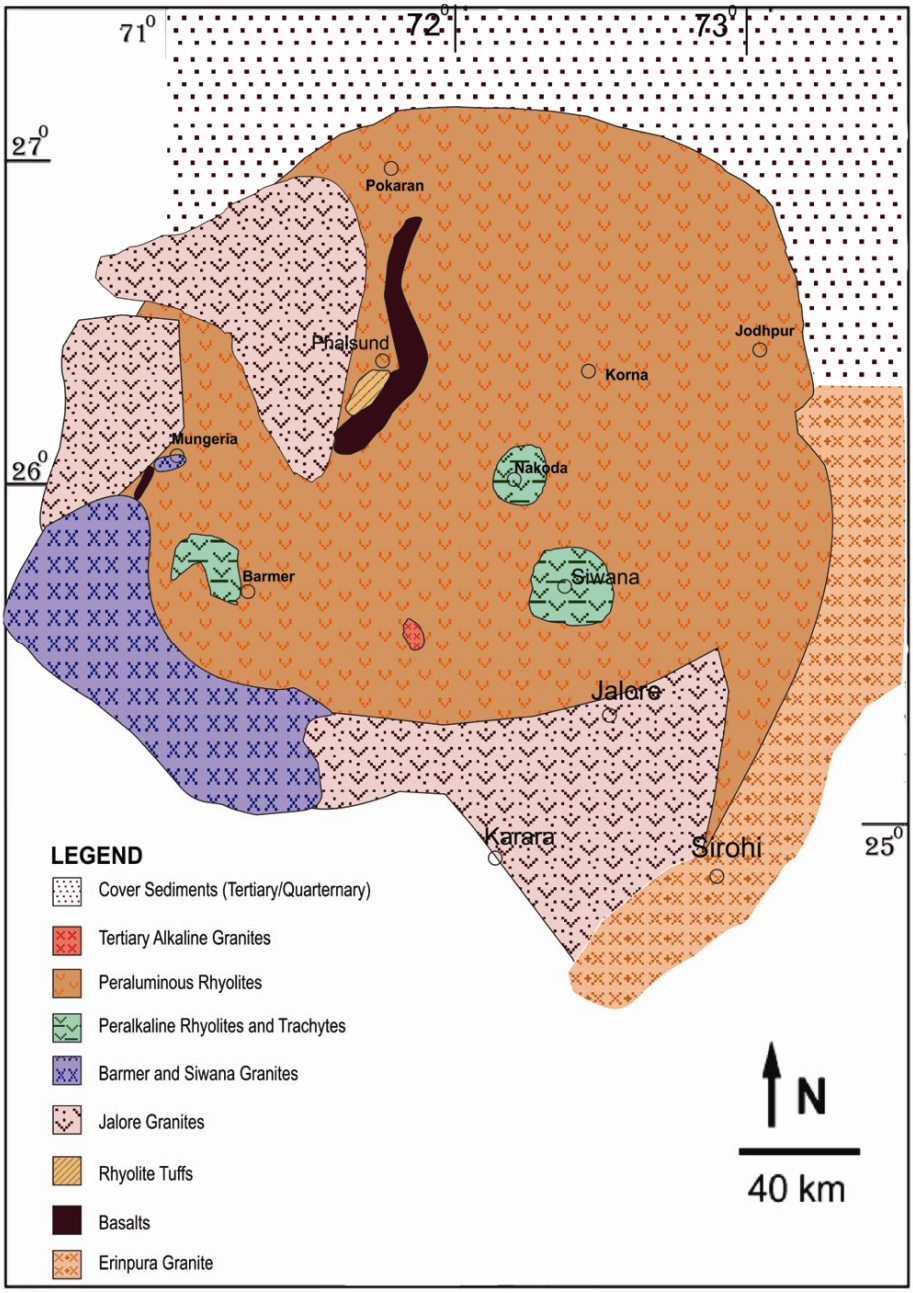

Figure 1. Geological map of the area showing extent of the Malani volcanic rocks (after Bhushan[9]).

anorogenic character is now well established[4,13,25,26]. (vii) The entire Malani area is a basin-like structure[27,28], in which constituent ring complexes of granitic composition are associated with explosion breccia[29] (Table 1). These unusual characters of the Malani beds need a relook and require some valid mechanism that can answer the questions raised during its many-sided interpretations.

Meteorite impacts

Collision of extra-terrestrial objects with the Earth, especially the catastrophic impacts of larger bodies (kilometre or more in diameter), has significantly disturbed the Earth's surface. These catastrophic events are now being studied by a large number of workers. Impact cratering is actually a fundamental universal process that was once considered geologically insignificant. The importance of meteorite impacts on the Earth was recognized largely on the basis of study of other planetary bodies, especially the Moon. Meteorite impacts are now recognized as: a major factor in the geological and biological history of the Earth, imperative triggers for major crustal deformation, large volume of igneous rocks, formation of large circular structures/basins and for the origin of important

Table 1. Important inferences drawn on Malani rocks

Important inferences drawn	Reference
The 'Malani Igneous Complex' consists of a variety of igneous rocks comprising acid, intermediate, basic, ultra basic and alkaline intrusive rocks spread over an area of about 51,000 sq. km in the Thar Desert.	6
The 'Malani rhyolites' (rhyolites of dominantly felsic composition) spread over an area of about 31,000 sq. km in western Rajasthan form the major rock type of the Malani Igneous Complex.	6
The area comprising Malani volcanics is a basin-like structure.	27, 28
The 'Malani Group' is an ensemble of several types of lithology, viz. sedimentary rocks, lava flows, tuffs, pyroclastic material, granitoids and dyke rocks. It does not constitute a comagmatic suite.	4, 13
The Malani volcanic domain has four chemically distinct associations.	64
Rhyolites (peralkaline) and granites (peralkaline) are coeval and cogenetic.	22
Ring complexes of granitic composition that are constituents of Malani igneous rocks are associated with explosion breccia.	29
The Malani volcanics show significant crustal contamination. It indicates diverse protolith sources from the mantle as well as from the crust.	2, 5, 7, 9, 10
There is complete absence of any penetrative deformation, though three phases of igneous activity have been reported. All lavas are free from deformation features.	5, 9, 65
Malani magmatism does not coincide with any recognized tectonomagmatic event; it is emplaced in an anorogenic setting.	4, 14
The rhyolite emplacement is between 771 and 751 Ma.	66
Rhyolite plug at Tosham is dated as 745 ± 20 Ma.	19
The Jalore granite is dated as 727 ± 8 Ma.	12

economic mineral and hydrocarbon deposits[30–46]. Meteorite impacts on the earth leave their signatures in the form of craters and shock metamorphic effects. A bowl-shaped depression with an uplifted rim is called a 'simple crater', whereas structures with an uplifted centre, annular trough and outer faulted rims are called 'complex craters'. The observations on terrestrial complex craters have revealed that they represent a highly modified crater form compared to simple craters, and have considerable smaller depth–diameter ratio. They have relatively shallow excavation leading to retention of greater volume of impact melt[47]. Complex craters have mismatch between volume of the transient cavity and that of the impact melt[48]; the impact melt intersects the base of the transient cavity[49] and affects the final form of the crater[48,50]. The amount of stratigraphic uplift of the complex craters varies, but the target rock units lying stratigraphically above the uplifted material get removed during the cratering process exposing the uplifted molten material[48].

Discussion

On taking into consideration the concept of 'uniformitarianism' propounded by James Hutton and followed by pioneers of modern geology: Charles Lyell, Nicolas Steno, Karl Adolf Von Hoff; it is observed that in most of the cases basic lava is seen emanating from the currently active volcanoes. The origin of volcanoes is generally at the mantle (deep inside the Earth, much below the crust). Hence emanation of acidic lava is not likely and therefore, inferring formation of the Malani rhyolite as a result of acidic volcanism could not satisfy many geoscientists. Siliceous volcanism does occur, but in an entirely different setting. Mantle plume theory can explain the generation of acidic lava as a consequence of melting of the crust. Accordingly, Kochhar[51] attributed Malani magmatism to hotspot activity, but his theory was negated by others[11,52,53] on the basis of the occurrence of Malani volcanism along parallel crustal fractures that supposedly developed as a result of extensional tectonics. If we make an effort to remove the controversies regarding nomenclature and origin of the Malani beds and dwell on the unusual characteristics displayed by the Malani rhyolite as discussed earlier and then try to compare them with the geology resulting due to the formation of a complex crater discussed above, the picture seems to become clearer. The first thing that draws one's attention is the circular outline of the Malani rhyolite (Figure 1), followed by interesting corollaries that can be drawn from the confirmed complex craters on the earth. The Manicouagan crater is one of the proven complex craters of Phanerozoic age in North America[54,55]. Its annular lake is ~70 km in diameter and surrounds an inner plateau capped by impact melt rocks with an emergent central uplift. Its schematic cross-section shows faulted rim area, annular trough and central uplift structure. Shallower depth–diameter ratio and the structural uplift in the centre are noteworthy. A more interesting corollary can be drawn from the Dhala Basin of Proterozoic age in Mohar area, Shivpuri District, Madhya Pradesh, India. Dhala has been confirmed as an impact crater of about 11 km apparent diameter, which has been greatly eroded but its central elevated area is still recognizable[56]. Geomorphologically, the Dhala Basin shows a circular outline with felsic volcanics represented by rhyolites and tuffs. In the central

Figure 2. LANDSAT image of the area under study. Note the ghost lines (circular rim) of the emergent area.

part, rhyolite occurs as a continuous sheet-like body underlying the sediments[57,58]. Drill cores were recently collected from the Dhala Basin. The geology of Dhala Basin on the basis of drill cores has been described by Sinha *et al.*[58]. The drill cores reveal zones of rhyolite intrusion intermingling with sediments. Many of these zones show deformation represented by fractures and minor slips. It is to be noted that the structural uplift in a complex crater occurs when the rocks compressed as a result of energy of the impact, rebound after the release of the shock. (Central uplifts of the craters form due to rebound of the rocks compressed due to energy of the impact.) Rhyolite is blocky or fluidal mixed with partially melted sediments. The mix of the melt and sediments gradually grades into a coherent bed/sheet of rhyolite. This area, would be an ideal location to study the relation between rhyolite and impact melt of sediments; the chemical analysis results will show many similarities. An analogy can be seen in the geology of Malani rhyolite and that of the Dhala Basin. On the basis of this analogy, it can be argued that the area representing Malani rhyolite is a complex crater. The strongest evidence in support of the argument to call this area as a complex crater is the occurrence of stishovite reported from Siwana[59] and from the alluvium[60], which is considered as an unambiguous evidence for the recognition of an impact crater[37,61,62]. Study is under progress to find more impact-related features of this highly eroded crater. The ghost outlines of the emergent area as seen in the imagery (Figure 2) indicate that it is a large crater with apparent diameter of more than 350 km.

1. Blanford, W. T., Geological notes on the Great Indian Thar Desert between Sind and Rajputana. *Rec. Geol. Surv. India*, 1877, **10**, 10–21.
2. La Touche, T. D. H., Geology of western Rajasthan. *Mem. Geol. Surv. India*, 1902, **35**, 116.
3. Heron, A. M., Geology of Central Rajasthan. *Mem. Geol. Surv. India*, 1953, **79**, 339.
4. Sharma, K. K., The Neoproterozoic Malani magmatism of the northwestern Indian shield: Implications for crust-building processes. *Proc. Indian Acad. Sci.* (*Earth Planet. Sci.*), 2004, **113**, 795–807.
5. Bhushan, S. K., Malani Rhyolite – a review. *Gondwana Res.*, 2000, **3**, 65–77
6. Bhushan, S. K. and Chandrasekaran, V., Geology and geochemistry of the magmatic rocks of the Malani Igneous Suite and Tertiary Alkaline Province of Western Rajasthan. *Mem. Geol. Surv. India*, 2002, **126**, 181.
7. Srivastava, R. K., Maheshwari, A. and Upadhyay, R., Geochemistry of felsic volcanics from Gurapratap Singh and Diri, Pali district, Rajasthan. *J. Geol. Soc. India*, 1988, **34**, 467–486, 617–631.
8. Bhushan, S. K., Mineral chemistry and petrographic aspects of Malani volcanics, western Rajasthan. *Indian Minerals*, 1989, **43**, 325–338.
9. Bhushan, S. K., Late Proterozoic continental growth, implications from geochemistry of acid magmatic events of west Indian craton, Rajasthan, India and Antarctica during Precambrian. *Mem. Geol. Soc. India*, 1995, **34**, 339–353.
10. Maheshwari, A., Coltori, M., Sial, A. N. and Mariano, G., Crustal influences in the Petrogenesis of the Malani rhyolites, south-

western Rajasthan, combined trace elements and oxygen isotope constraints. *J. Geol. Soc. India*, 1996, **7**, 611–619.
11. Pareek, H. S., Pre-quaternary geology and mineral resources of north-western Rajasthan. *Mem. Geol. Surv. India*, 1984, **115**, 99.
12. Dhar, S., Frei, R., Kramer, J. D., Nagler, T. F. and Kochhar, N., Sr–Pb and their bearing on the petrogenesis on the Jalore and Siwana complexes, Rajasthan, India. *J. Geol. Soc. India*, 1996, **48**, 151–160.
13. Roy, A. B. and Jakhar, S. R., *Geology of Rajasthan* (*Northwest India*) *Precambrian to Recent*, Scientific Publishers, Jodhpur, 2002, p. 421.
14. Bhushan, S. K. and Chittora, V. K., Late Proterozoic bimodal volcanic assemblage of Siwana subsidence structure, western Rajasthan, India. *J. Geol. Soc. India*, 1999, **53**, 433–452.
15. Bhushan, S. K. and Mohanty, M., Mechanics of intrusion and geochemistry of alkaline granites from Siwana, Barmer district, Rajasthan. *Indian J. Earth Sci*., 1988, **15**, 105–115.
16. Pandit, M. K. and Amar Deep, Geological framework of Sankara dyke swarm forming a part of Malani suit of rocks in western Rajasthan. *Curr. Sci.*, 1994, **67**, 1015–1018.
17. Basu, A. R., Renne, P. R., Dasgupta, D. K., Treichman, F. and Poreda, R. J., Early and late igneous pulses and high He plume for Deccan flood basalts. *Science*, 1993, **261**, 902–906.
18. Kochhar, N. and Dhar, S., The association of hypersolvus and subsolvus granites: A study of Malani Igneous Suit, India. *J. Geol. Soc. India*, 1993, **42**, 449–476.
19. Eby, G. N. and Kochhar, N., Geochemistry and the Petrogenesis of the Malani Igneous Suite, north peninsular India. *J. Geol. Soc. India*, 1990, **36**, 109–130.
20. Crawford, A. R. and Compston, W., The age of the Vindhyan System of peninsular India. *Quart. J. Geol. Soc. London*, 1970, **125**, 351–372.
21. Rathore, S. S., Ventatesan, T. R. and Srivastava, R. K., Rb–Sr and Ar–Ar systematics of Malani volcanic rocks of south-western Rajasthan, evidences for a younger post crystallization thermal event. *Proc. Indian Acad. Sci.* (*Earth Planet. Sci*.), 1996, **105**, 131–141.
22. Rathore, S. S., Ventatesan, T. R. and Srivastava, R. K., Rb–Sr isotope dating of Neoproterozoic (Malani Group) magmatism from south-west Rajasthan, India: evidence of younger Pan-African thermal event ^{40}Ar ^{39}Ar studies. *Gondwana Res.*, 1999, **2**, 271–281.
23. Kochhar, N., Pande, K. and Gopalan, K., Rb–Sr age of Tosham ring complex, Bhiwani, India. *J. Geol. Soc. India*, 1985, **26**, 216–218.
24. Sinha-Roy, S., Mohanty, M., Malhotra, G., Sharma, V. P. and Joshi, D. W., Conglomerate horizons in south-central Rajasthan and their significance on Proterozoic stratigraphy and tectonics of the Aravalli and Delhi fold belts. *J. Geol. Soc. India*, 1993, **41**, 331–350.
25. Roy, A. B., Neoproterozoic crustal evolution and India-Gondwana linkage – An Epilogue. *Gondwana Res*., 1999, **2**, 193–198.
26. Valdiya, K. S., *The Making of India, Geodynamic Evolution*, Macmillan Publishers, India, 2010, p. 816.
27. Mukherjee, A. B., Structure of the Malani rhyolite and a part of the Siwana granites around Siwana, western Rajasthan. *Q. J. Geol. Min. Metall. Soc. India*, 1958, **33**(1), 48.
28. Mukherjee, A. B., Fractional relationship in the peralkaline volcanic complex of Malani, western Rajasthan. 53rd Session Indian Congress, Abstr. 17, 1966.
29. Kochhar, N., Tosham Ring Complex, Bhiwani, India. *Proc. Indian Nat. Sci. Acad*., 1983, **49**, 459–490.
30. French, B. M., Shock metamorphism as a geological process. In *Shock Metamorphism of Natural Materials* (eds French, B. M. and Short, N. M.), Monobook Corp, Baltimore, 1968, pp. 1–17.
31. Soemaker, E. M., Why study impact craters? In *Impact and Explosion Cratering: Planetary and Terrestrial Implications* (eds Roddy, D. J., Pepin, R. O. and Merrill, R. B.), Pergamon, New York, 1977, pp. 1–10.
32. Grieve, R. A. F., Terrestrial impact structures. *Annu. Rev. Earth Planet. Sci*., 1987, **15**, 245–270.
33. Grieve, R. A. F., Impact cratering on the Earth. *Sci. Am.*, 1990, **262**, 66–73.
34. Grieve, R. A. F., Extraterrestrial impact events: the record in the rocks and the stratigraphic column. *Palaeogeogr., Palaeoclimatol., Palaeoecol*., 1997, **132**, 5–23.
35. Nicolaysen, L. O. and Reimold, W. U. (eds), Cryptoexplosion and catastrophes in the geological record with a special focus on the Vredefort structure. *Tectonophysics*, 1990, **171**, 1–422.
36. Pesonen, L. J. and Henkel, H. (eds), Terrestrial impact craters and crater form structures, with a special focus on Fennoscandia. *Tectonophysics*, 1992, **216**, 1–234.
37. Dressler, B. O., Grieve, R. A. F. and Sharpton, V. L. (eds), Large meteorite impacts and planetary evolution II. *Geol. Soc. Am., Spec. Pap.*, 1994, **293**, 348.
38. French, B. M., *Traces of Catastrophe: A Handbook of Shock-Metamorphic Effects in Terrestrial Impact Craters*, Lunar and Planetary Institute, Houston, TX, Contribution, CB-954, 1998, p. 120.
39. Reimold, W. U., Revolutions in the earth sciences: Continental drift, impact and other catastrophes. *S. Afr. J. Geol*., 2007, **110**, 1–46.
40. Reimold, W. U., Catastrophes, extinctions and evolution: 50 years of impact cratering studies. *Mem. Geol. Soc. India*, 2008, **66**, 69–110.
41. Bhandari, N., Collisions with the earth over geologic times and their consequences to the terrestrial environment. *Curr. Sci*., 1991, **61**, 97–104.
42. Bhandari, N., Shukla, P. N. and Pandey, J., Iridium enrichment at Cretaceous–Tertiary boundary in Meghalaya. *Curr. Sci.*, 1987, **56**, 1003–1005.
43. Sisodia, M. S., Lashkari, G. and Bhandari, N., Impact origin of Ramgarh Structure, Rajasthan, some new evidences. *J. Geol. Soc. India*, 2006, **67**, 423–431.
44. Sisodia, M. S., Stratigraphy of Barmer Basin, Rajasthan: implications on Cretaceous–Tertiary Boundary. *J. Geol. Soc. India*, 2006, **67**, 828–829.
45. Sisodia, M. S., Evidences support an extraordinary event, possibly an impact during the Proterozoic for phosphorus abundance on the Earth. *Astrobiology*, 2008, **8**, 360.
46. Sisodia, M. S., Impact during the Proterozoic era possibly inundated the earth with phosphorus. *Int. J. Astrobiol*., 2009, **8**, 179–183.
47. Lange, M. A. and Ahrens, T. J., Impact melting early in lunar history. In Proceedings of the Lunar Planet Science Conference 10, 1979, pp. 2707–2725.
48. Grieve, R. A. F., Terrestrial impact: the record in the rocks. *Meteoritics*, 1991, **26**, 175–194.
49. Melosh, H. J., *Impact Cratering, A Geologic Process*, Oxford University Press, 1989, p. 245.
50. Croft, S. K., Cratering flow fields: Implications for the excavation and transient expansion stages of crater formation. In Proceedings of the Lunar Planet Science Conference 11, 1980, pp. 2347–2378.
51. Kochhar, N., Malani Igneous Suit: Hot spot magmatism and cratonization of the northern part of the Indian shield. *J. Geol. Soc. India*, 1984, **25**, 155–161.
52. Srivastava, R. K., Magmatism in the Aravalli mountain range and its environs. *Mem. Geol. Soc. India*, 1988, **7**, 77–94.
53. Sharma, K. K., The Neoproterozoic Malani magmatism, northwestern Indian shield: Not a plume product. 2003; http://www.mantleplumes.org/
54. Dence, M. R., Dimensional analysis of impact structures. *Meteoritics*, 1973, **8**, 343–344.
55. Grieve, R. A. F. and Head, J. W., The Manicouagan impact structure: An analysis of its dimension and form. In Proceedings of the Lunar Planet Science Conference 13, 1983, p, 807, 818.

56. Pati, J. K., Reimold, W. U., Koeberl, C. and Pati, P., The Dhala structure, Bundelkhand craton, Central India – Eroded remnant of a large Paleoproterozoic impact structure. *Meteorit. Planet. Sci.*, 2008, **43**, 1383–1398.
57. Jain, S. C., Gaur, V. P., Srivastava, S. K., Nabiar, K. V. and Saxena, H. P., Recent find of a cauldron structure in Bundelkhand Craton. *Geol. Surv. India, Spec. Publ.*, 2001, **64**, 289–297.
58. Sinha, K. K., Pandey, P., Bhairam, C. L. and Parihar, P. S., Peperite occurrence and its implications on origin and temporal development of the Proterozoic Dhala Basin, Mohar area, Shivpuri district, Madhya Pradesh. *J. Geol. Soc. India*, 2011, **77**, 183–189.
59. Tripathi, R. P., Mathur, S. C., Sonal, Mathur, Trupti, G. and Chandrashekharam, D., Occurrence of stishovite in the Precambrian Siwana Volcanic Province, western Rajasthan, India. *Curr. Sci.*, 2010, **98**, 30–32.
60. Paliwal, B. S., Shrivastava, K. L., Tripathi, Amita, Yadav, S. K. and Sisodia, H. S., X-ray diffraction reveals the presence of mineral coesite and stishovite in the samples of magnetic particles collected from the Recent Alluvium of Rajasthan. *Curr. Sci.*, 2009, **97**, 481–483.
61. Stoffler, D., Progressive metamorphism and classification of shocked and brecciated crystalline rocks at impact craters. *J. Geophys. Res.*, 1971, **76**, 5541–5551.
62. Stofffler, D. and Langenhorst, F., Shock metamorphism of quartz in nature and experiment, basic observation and theory. *Meteoritics*, 1994, **29**, 155–181.
63. French, B. M. and Koeberl, C., The convincing identification of terrestrial meteorite impact structures: What works, what doesn't, and why. *Earth-Sci. Rev.*, 2010, **98**, 123–170.
64. Srivastava, R. K., Magmatism in the Aravalli mountain range and its environs. *Mem. Geol. Soc. India*, 1988, **7**, 77–93.
65. Pandit, M. K., Shekhawat, S. S., Ferreira, U. P., Sial, A. N. and Bohra, S. K., Trondjhemite and granodiorite assemblages from west of Barmer, probable basement for Malani magmatism in western India. *J. Geol. Soc. India*, 1999, **53**, 89–96.
66. Torswik, T. H., Carter, L. M., Ashwal, L. D., Bhushan, S. K., Pandit, M. K. and Jamtveit, B., Rodinia refined or obscured; palaeomagnetism of the Malani Igneous Suite (NW India). *Precambrian Res.*, 2001, **108**, 319–333.

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