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# The first report on the chemical (Th–U–Pb) monazite age of the Mul granite pluton, Western Bastar craton, central India and its metallogenic significance

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Petrography and the geochemical attributes of the studied Mul granite pluton reveal mixed characteristics of A-type and I-type within-plate granites consistent with an extensional tectonic environment. The dominance of the primary biotite over the primary muscovite suggests its meta-aluminous nature. The dating of monazite from the Mul granitoid pluton by the in situ Th–U–Pb electron probe micro analyser chemical method indicates the tectonomagmatic event around 1602 ± 27 Ma in the western Bastar craton, Chandrapur district, Maharashtra. The age data possibly represent the emplacement of large bodies of grey granite and attendant monazite crystallisation at ∼1600 Ma. This monazite age implies that Mesoproterozoic magmatism is coeval with the formation of the Pranhita Godavari rift in the eastern flank in Maharashtra and associated with the copper and barite mineralisation in Thanewasna and the adjoining areas.

**Keywords.** EPMA; geochronology; Mul; Western Bastar craton; Maharashtra.

Monazite is a rare earth element-rich orthophosphate mineral [(Ce, La, Th, Nd, Y) $PO_4$] and is a common accessory mineral in acid igneous rocks as significant Th and U but negligible common lead incorporation during crystallisation, which both together make monazite suitable for dating (Parrish 1990). Because of the negligible common Pb relative to radiogenic Pb, it can be dated by total Pb methods such as electron microprobe dating (Suzuki and Adachi 1991; Montel *et al.* 1994; Williams *et al.* 2007). The chemical Th–U–total Pb method for the single-grain dating of monazite by an electron probe microanalyser (EPMA) is a powerful technique for determining reliable ages at moderate cost (Suzuki and Adachi 1991; Montel *et al.* 1994; Cocherie *et al.* 1998; Catlos *et al.* 2002), which can be applied to study both igneous and metamorphic rocks. This method has proved to be a valuable tool for geochronologists because of its low cost and high spatial resolution (<5 μm). The high spatial resolution of the method allows carrying out a large number of analyses in a single monazite crystal. However, this method is not reliable due to U-poor but Th-rich monazites which can be easily dated if they are sufficiently old so that a measurable quantity of Pb has been accumulated. Since the granitoids from the western Bastar craton (WBC) are Proterozoic in age based on field characteristics and contain rich $UO_2$ and Th, they are so appropriate for the geochronology study by the EPMA method.

Granitic intrusions make up a substantial component of the continental crust in the Bastar craton, central India. Among the Precambrian granitic rocks of this craton, the granitic rocks in the WBC are especially poorly understood, unlike the granites of Malanjkhand, Dongargarh and Paliam-Darba, which have been extensively studied for their significant metallogenic endowment. The granites in study area cover $\sim$300 km$^2$, located in the Chandrapur district of Maharashtra, WBC (figure 1A). This rock is spatially associated with copper and barite mineralisation and named as the Mul granite. Its geochemistry was well studied by Sashidharan (2007), Mukherjee *et al.* (2007) and Dora (2012). However, the timing of crystallisation of this important granite in WBC is still unknown. In order to know the time of crystallisation, we applied the in situ ‘chemical’ Th–U–Pb dating of monazite with the EPMA to unravel the timing and metallogeny history of the ‘Mul granite’ in the WBC, Chandrapur, Maharashtra.

In the Bastar craton, the granite event (2500–2200 Ma) was well noticed in Malanjkhand, Dongargaon and Kawadgaon-Paliam during the Paleoproterozoic era (Sarkar *et al.* 1981; Ramesh Babu 1993; Panigrahi *et al.* 2004; Stein *et al.* 2004). The regional geological setting of the Bastar craton is provided by previous researchers (Crookshank 1963; Ramachandra 2004; Ramakrishnan and Vaidyanadhan 2008). The granite–pegmatite systems of the Bastar craton host polymetallic Nb, Ta, Sn, Be and Li deposits, which are genetically related to various granitic bodies, locally called the Paliam, Darba (in the SE Bastar craton), Katekalyan (in the central Bastar craton) and Kawadgaon (in the NW Bastar craton) granites (Singh *et al.* 2017).

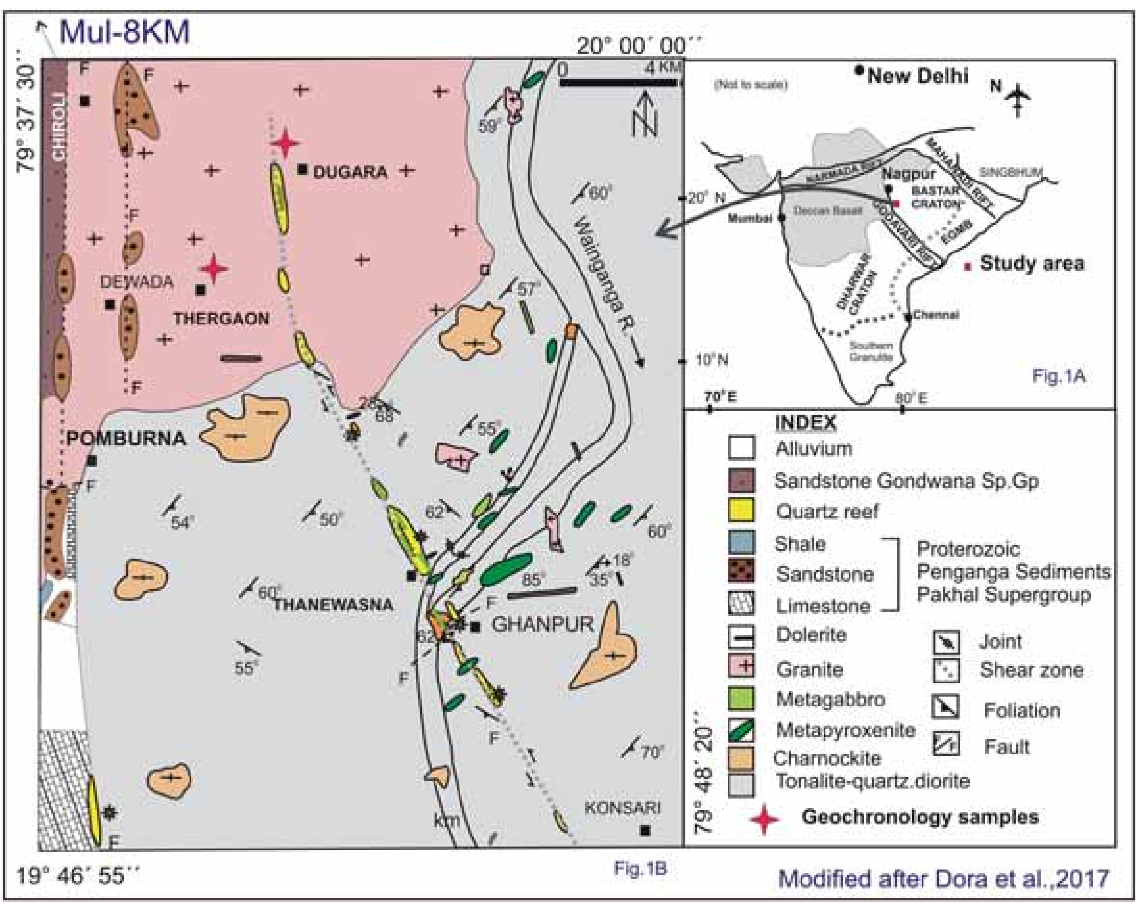


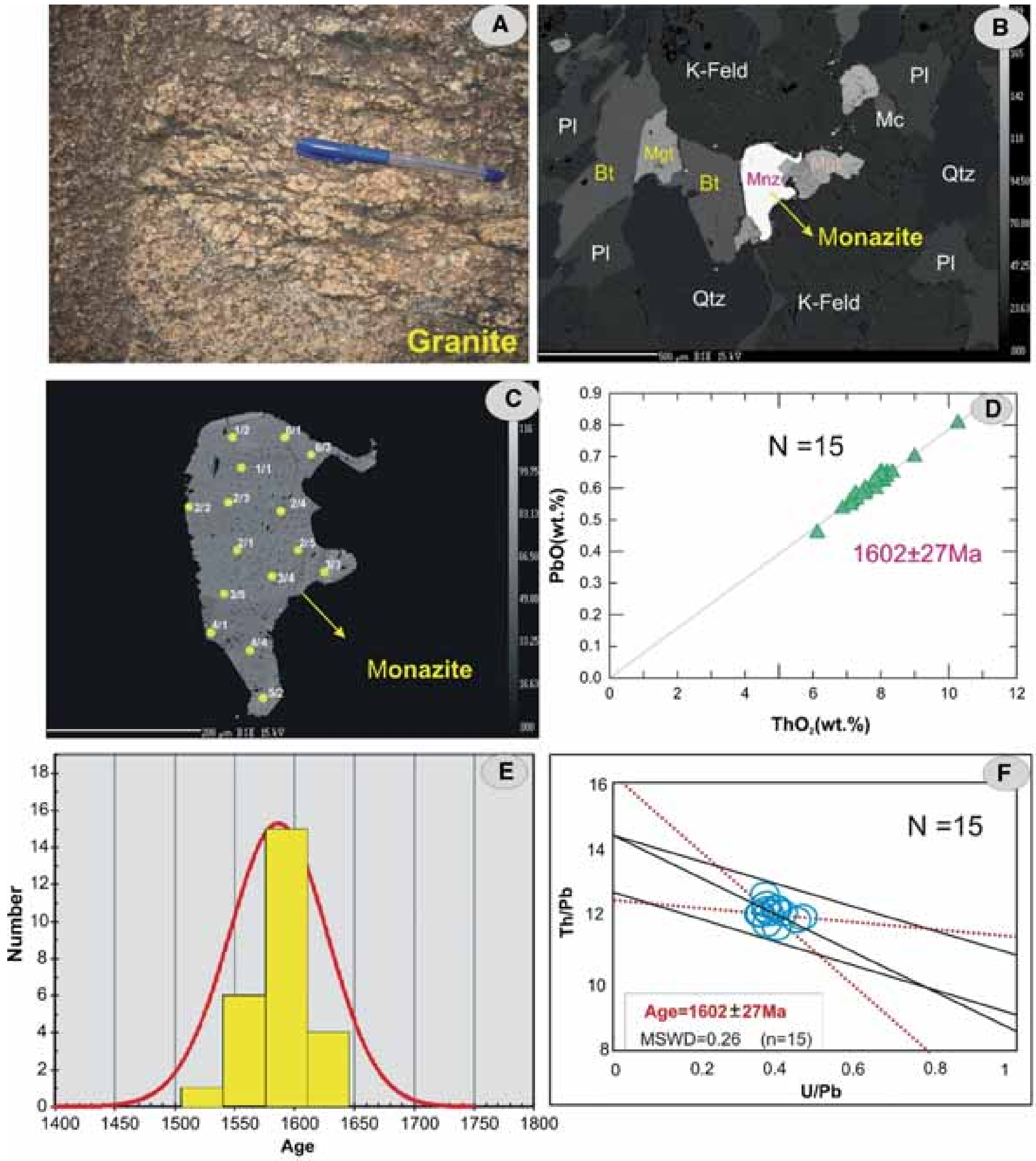

Figure 1. Geological map of the Mul granite pluton, WBC.

The oldest lithologies in the study area are granitic gneisses, which are unclassified. The gneisses contain metamorphosed enclaves of mafic and ultramafic rocks at places. The second dominant rock is charnockite, which occurs as large patches within the TTG gneiss. Charnockite at places is intruded by mafic–ultramafic rocks, mainly comprising pyroxenite, gabbro variants and anorthosite. The entire assemblages in turn are intruded by an undeformed granite named as the Mul granite (Dora *et al.* 2011) and has become the basement for the overlying NW–SE trending rift-bounded Pakhal and Gondwana sediments, which separate the northern Dharwar craton and the southern as well as the south-WBC (Dora *et al.* 2017) (figure 1B). The granite in the study area is exposed over about 300 $km^2$. This rock also occurs in the form of dykes, tongues and apophyses all along the contact zone with the gneiss and mafic rocks and also brought out mafic enclaves indicating its intrusive nature. This rock is heterogeneous and three to four varieties (phases) can be observed near Dugara, Phutana and Lalheti based on the mode of occurrence, colour, texture, structure and cross-cutting relationships, thus displaying a complex nature. They are (i) dark medium-grained grey granite, (ii) pegmatoidal granite and (iii) fine-grained equigranular pink granite. These are massive in the northern part while in the southern part, in contact with the gneisses, they show crude foliation at places probably inherited from gneiss. Several enclaves of basement gneisses are seen in the granite especially near Bimbal and Dewada (figure 2A). Of the two types, the grey granitoids are widespread and form large-scale bodies, whereas the pink type forms small-scale bodies of a limited areal extent. It is likely that the grey and pink varieties of granitoids represent a single episode of felsic magmatism; and the pink colour of granitoids has been caused by flushing the post-magmatic fluids. The well-preserved magmatic fabric and the absence of a strong deformation-induced planar feature with relatively unaltered mineralogy suggest late- to post-tectonic emplacement.

Out of the three varieties of granites, chemical dating of monazite from grey granite was carried out at the EPMA Laboratory, Geological Survey of India, NCEGR, Faridabad. Calibrations were carried out at 20 kV and 20 nA. Pb M was measured using Large polyethylene teraphthalate and the peak counting time was 300 s with background measured on both sides. For uranium, the U Mα line was used in order to avoid interference with the Th Mα line with a peak counting time of 200 s. Thorium Mα peak was also counted for 200 s. Both these elements were measured using a positron emission tomography (PET) crystal. Standards used for Pb, U and Th were PbS, $UO_2$ and $ThO_2$. A synthetic silica-aluminium glass containing 4% rare earth elements was used as the standard for La, Ce, Nd, Pr, Sm, Ho, Dy and Gd. Further details of the analytical procedure are given in Pant *et al.* (2009, 2013). About 14 elements for monazite (P, Si, La, Ce, Pr, Nd, Sm, Gd, Dy, Y, U, Th, Pb and Ca) were analysed to check their structural formulae and total concentration. For individual spot ages, the formulation of Montel *et al.* (1996) was followed, whereas the age probability plots and unmixing of ages were obtained using the software Isoplot3 (v.3.71.09.06.19nx) (Ludwig 2001). Uncertainties in individual analyses in the data table and in the weighted mean ages are quoted at the 95% confidence level (figure 2). Representative monazite chemical compositions are given in table 1.

The granite is coarse- to fine-grained and predominantly porphyritic in nature (figure 2A). It is composed of quartz (28–35%), alkali feldspar (15–30%), plagioclase (10–25%), biotite and hornblende (3–5%) as principal minerals. Secondary minerals are represented by chlorite and sericite. In addition, zircon, rutile, sphene, ilmenite, magnetite and monazite are also present as accessories. At places, the granite hosts subhedral monazite crystals displaying a brown dotted pigmentation. Plagioclase crystals are sub-euhedral and exhibit albite twins. Some crystals underwent sericitisation. Biotite occurs as elongated fine fibres, mostly transformed into chlorite. Some biotite fibres contain opaque inclusions while others are resorbed by quartz. Generally, the rock exhibits a hypidiomorphic granular texture (figure 2B) and at places, perthite and myrmeketic textures, along with a graphic intergrowth of quartz and microcline, are also noticed. The dominance of primary biotite over primary muscovite in the granite suggests that it is meta-aluminous. The granite shows minor post-crystallisation alteration of feldspars to sericite, illite and kaolinite (the last two minerals identified by X-ray diffraction), and biotite to muscovite, hydrated muscovite and chlorite.

Fifteen analyses were carried out on a single grain in order to delineate the age difference between the core and rim of monazite, if any. However, uniform ages were obtained from




A. Field exposure of medium grained grey granite in Mul area
B. Back scattered electron (BSE) image of granite showing the locations of monazite and its textural relationship with other silicates
C. Spot analysis of monazite grain showing age of Mul granite.
D. Pbo vs ThO2 plot of analytical data of monazite grains Mul granite
E. Histogram of age data of Mul granite showing peak around 1600 Ma
F. Weighted average plot with 2 sigma errors of the monazite showing 1602 Ma age in Mul granite.

Figure 2. Field and petrographic description of the Mul granite, WBC.

the rim and core portions of this monazite grain. The $ThO_2$ concentrations of the analysed monazite grains range from 6.12 to 10.27 wt%, while $UO_2$ concentrations vary from 0.18 to 0.31 wt%, and those of PbO lie between 0.45 and 0.80 wt% (table 1). Despite these variations in single grains (core to rim) largely uniform $PbO/ThO^*_2$ ratios were recorded, within the range of 1632–1534 Ma, suggesting monazite formation in a single thermal event (figure 2B–F). Cores and rim analyses were

Table 1. *Microprobe analysis of $ThO_2$, $UO_2$ and PbO of the monazite from the Mul granite, WBC, central India.*

| Analysis no. | Analytical points | $ThO_2$ | $Y_2O_3$ | PbO | $UO_2$ | Age (Ma) | 2-sigma error (Ma) |
|---|---|---|---|---|---|---|---|
| 1 | 1/1 | 6.125 | 0.416 | 0.458 | 0.181 | 1549 | 87 |
| 2 | 1/2 | 8.995 | 0.526 | 0.699 | 0.279 | 1599 | 89 |
| 3 | 2/1 | 8.076 | 0.492 | 0.620 | 0.246 | 1584 | 89 |
| 4 | 2/2 | 7.279 | 0.489 | 0.564 | 0.236 | 1588 | 89 |
| 5 | 2/3 | 7.147 | 0.461 | 0.559 | 0.221 | 1609 | 90 |
| 6 | 2/4 | 7.111 | 0.464 | 0.557 | 0.244 | 1595 | 90 |
| 7 | 2/5 | 8.035 | 0.492 | 0.625 | 0.257 | 1596 | 89 |
| 8 | 3/3 | 10.274 | 0.426 | 0.805 | 0.314 | 1614 | 90 |
| 9 | 3/4 | 8.160 | 0.501 | 0.636 | 0.265 | 1597 | 90 |
| 10 | 3/5 | 8.344 | 0.493 | 0.649 | 0.245 | 1609 | 90 |
| 11 | 4/1 | 7.123 | 0.574 | 0.562 | 0.272 | 1587 | 90 |
| 12 | 4/4 | 8.012 | 0.554 | 0.651 | 0.278 | 1649 | 93 |
| 13 | 5/2 | 7.537 | 0.540 | 0.600 | 0.284 | 1603 | 91 |
| 14 | 6/1 | 7.857 | 0.509 | 0.617 | 0.248 | 1612 | 90 |
| 15 | 6/3 | 7.827 | 0.520 | 0.627 | 0.250 | 1641 | 92 |

acquired for each grain analysed. The results are presented in figure 2(C–F) and show an example of the spot size analysis and age.

The EPMA results define the age of 1602±27 Ma for Mul granites indicating the time of its emplacement. The younger ages (1560–1625 Ma) may be related to further evolution and crystallisation of mineralised granite. Mul granitoid exhibits signatures of the I- and A-type within-plate granites (Sashidharan 2007; Dora 2012). These analogous geochemical and geochronological characteristics of the granite suggest a prominent and widespread early Mesoproterozoic thermal event in the WBC and the mixed I- and A-type nature of this magmatism further implies that these plutons were emplaced in a region undergoing crustal extension. This thermal event is correlated with the extensive magmatism that occurred in the WBC at around 1600–1500 Ma which might have played a significant role in metallogeny. During this period, the emplacement of the Mul granite into basement rocks may cause K-metasomatisim and generated a thermal gradient for driving hydrothermal fluid circulation and also leached K, Fe, Cu and Au, and contributed to the overall metal content. Granite formation during 1602 Ma, faulting took place under an extensional condition during crustal thinning and the hanging wall became a provenance for sedimentary supply and the foot wall became a platform for the deposition of Penganga sediments. After the Mul granite formation and Pakhal sedimentation, quartz–chlorite veins, representing the late stage of hydrothermal solution, were injected along the regional lineament, shear zone, forming copper, gold and barite mineralisation (Dora and Randive 2015), which might have further enriched due to the remobilisation during the periodic reactivation of the shear zone and the basin–margin fault. Subsequent to faulting and shearing, hydrothermal brecciation developed due to the fracture propagation by the intense quartz vein formation associated with base metal and barite mineralisation, hosted by the granite.

Granitic activities in the Bastar craton were studied by many authors for metallogeny (Singh *et al.* 1991; Paul *et al.* 2007; Singh *et al.* 2017). Rb–Sr whole rock determinations for the Dongargarh granite have yielded ages of 2466 and 2270 Ma (Sarkar *et al.* 1981). Malanjkhand pink granitoid yielded $2490 \pm 8$ by Re–Os (Stein *et al.* 2004) and the grey granitoid Malanjkhand by U–Pb yielded $2478 \pm 9$ (Panigrahi *et al.* 2004) but our report of $1602 \pm 27$ Ma by the EPMA technique is the new age of granite formation in the WBC. This bracketed age is more or less matching with the age of the Mosbani and Rakha granite (copper event) in the Singhbhum craton (1.6–1.4 Ga) (Rao *et al.* 1979; Pandey *et al.* 1986; Sarkar *et al.* 1986) and also corroborates with the main events of global metallogeny of iron oxide copper gold (IOCG) (Kaur and Chaudhri 2014); however, the details are beyond the scope of this short communication.

This first report on the age of monazite by EPMA from the Mul granite, WBC possibly indicates the timing of its emplacement and attendant IOCG metallogeny during the subsequent hydrothermal phase. These data are consistent with mineralisation being the result of the hydrothermal fluid and alteration during a period of extensional tectonics during the initiation of the Godavari rift. Understanding the timing of granite-induced mineralisation through the monazite age in the Thanewasna region provides information on the correlation and planning of further exploration work with hydrothermal ore deposits related to the boundary of the Palaeo-Mesoproterozoic granitic rocks of the WBC and elsewhere.

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