European Journal of Science, Innovation and Technology

ISSN 2786-4936

Vol. 2 No. 3 (2022)

Field Aspects of Ulindakonda Vent Agglomerate of Gadwal Greenstone Belt, Andhra Pradesh and Telangana State, India

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Abstract. Ulindakonda of Gadwal Greenstone Belt in the Eastern Dharwar Craton (EDC) has a unique type of conglomerate that is not sedimentary in nature like Quartz Pebble Conglomerate (QPC) of Western Greenstone Belts. This polymict conglomerate has mainly the clasts of granodiorite and trachyandesite set in a volcanic matrix of trachyandesitic composition. Generally, granitoid clasts are rare in conglomerate of sedimentary origin. Most of the Greenstone Belts in the Eastern Dharwar Craton are characterized by similar type of conglomerate. But the best amongst them is seen at Ulindakonda of Kurnool district (Andhra Pradesh) in the Gadwal Greenstone Belt that occurs mainly in Andhra Pradesh and partly in Telangana State. The field study has indicated that the majority of outcrops of the conglomerate have granodiorite clasts that are sub-rounded to well-rounded in shape and a few cms to tens of cms in diameter representing volcanic bombs. Some outcrops as seen east of Ulindakonda in a quarry have alternative banding of leucocratic granodiorite and melanocratic trachyandesite reflecting layering/stratification of the two units. There are number of shear planes that have caused the stretching of clasts into a spindle shape. Further, east of Ulindakonda, on the obsequent slopes of the hills of Jagannadhagattu, quartz lapilli tuffs and ash beds have been identified. The field characteristics like clast size, shape, shearing, flow banding, etc. are described in detail. The geomorphic setup of the area under report reflects a broad crater like feature that points to a possible vent agglomerate. The Gulcheru Quartzite of Cuddapah Supergroup overlies the volcanic conglomerates/agglomerates with a marked nonconformity representing ‘Eparchaean unconformity’. All the field characters of this most interesting geological setup are documented. A tectonic model on the possible origin of the conglomerate is also proposed.

Keywords: Eastern Dharwar Craton, Gadwal Greenstone Belt, Vent agglomerate, Granodiorite clasts, Trachyandesite, Eparchean unconformity

Introduction

Ulindakonda polymict conglomerate is located 34 km south of Kurnool and covers an area of nearly 65km^{2}to 70 km^2 with the outcrops seen along the margin of a roughly circular body, with a gentle depression in the center. The specialty of this conglomerate is that it has sub-rounded to well-rounded hornblende granodiorite clasts set in a fine-grained melanocratic volcanic matrix i.e., intermediate in composition of trachyandesite. The granodiorite clasts represent volcanic bombs with the longer axes measuring from a few cms to 86 cms. Adjacent to Ulindakonda village extensive quarrying of melanocratic trachyandesitic volcanic material is being done. It has exposed alternating layers of granodiorite material (plutonic) and volcanic material. This type of stratification is very interesting and appears to be unique to the Gadwal Greenstone Belt compared to others. Most of the clasts, other than the ones that are present

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Funding Information: Department of Science and Technology, Grant/ Award number: DST/ INSPIRE Fellowship/ 2017/ IF170954

near the village Ulindakonda are subjected to tectonism, resulting in the stretching of the clasts. The stretching may also be due to their rotation in flight, which makes the volcanic bombs elongated (Bonewitz, 2012). The intermixing of both the material and the clear transition between the clasts and matrix can be seen in a quarry adjacent to the National Highway No. 44. It has been observed that a thick pile of quartz lapilli tuffs and ash beds also form a mappable lithological unit of the conglomerate. The presence of andalusite in the volcaniclasts reflects low pressure (andalusite-sillimanite type) metamorphism. The conglomerate and the thick pile of volcaniclasts form the basement of the Proterozoic Cuddapah Basin.

The details of this conglomerate will help in the identification of the tectono-environment of the formation of the unit that will be useful in the correlation of the Eastern Greenstone Belts. The Palkanmaridi conglomerate of the Hutti-Maski Greenstone Belt is to a certain extent similar to this. The origin of these conglomerates will be of immense use in understanding the Eastern Greenstone Belts.

The perusal of literature indicates that a similar set up i.e., type of conglomerate was observed by Kroner in a Greenstone Belts in Finland. He called it a ‘volcanic conglomerate’ (Kroner et al., 1981). He further added that a similar type of volcanic conglomerate occurs within the ‘Champion Gneiss’ of the world-famous Kolar Greenstone Belt yet another Eastern Greenstone Belt. In the Dharwar Craton, in Kadiri Greenstone Belts also similar setup exists but of very minor magnitude (Nagaraja Rao, personal communication; Dey et al., 2015). The fieldwork was done in connection with the research programme under the INSPIRE-Fellowship (IF170954). Further work is in progress. Two new ‘Formations’ have been identified that are mappable on 1: 50,000 scale and are added to the existing stratigraphic column. The unique geological setup of the area is being disturbed by human activity.

Geological Setting

Gadwal Greenstone belt is located in the Eastern Dharwar Craton (EDC), trending NNW-SSE covering a distance of 85 km with 1-15 km width extending from Narayanpet in the north to Veldurti in the south and beyond Veldurthi, the belt disappears below the Mesoproterozoic Cuddapah basin. The litho-units of Gadwal Greenstone Belt are represented by quartz-chlorite-sericite-actinolite schist, agglomerate, meta-andesite, and dacite to rhyo-dacite, meta rhyolite, and banded iron formation (Srinivasan & Nagaraja Rao, 1992). The basal Quartz pebble conglomerate (QPC) of the Cuddapah basin is directly resting on this belt and adjoining gneisses and granitoids (Ramam & Murty, 1997; Manikyamba et al., 2004).

The modified lithostratigraphy of the Gadwal Greenstone Belt is presented below.

Table 1. The lithostratigraphic succession of Gadwal Greenstone Belt (GGB) (modified after Srinivasan & Nagaraja Rao, 1992)

Cuddapah basin (Gulcheru Quartzite of the Papaghni Group)	
-------------------- Eparchaean Unconformity --------------------	
Quartz veins/reefs	
Mafic dykes	
Younger granites	
--------------------------------Intrusive contact-------------------------------------	
Veldurti Formation	
Ulindakonda Formation	Quartz lapilli bedded tuff Vent Agglomerate (Volcanic conglomerate) Dacite rhyodacite-rhyolite
Chetlamallapuram Formation	
Sangala Formation	Metabasalts (Andesite)/amphibolite
-------------------- Unconformity/tectonic contact --------------------	
Banded gneiss (basement) (Tonalities Trondhjemite Granodiorite)	

An outcrop geological map reflecting the different outcrops of the Ulindakonda conglomerate area has been prepared (Figure 1). This has helped the author in recognizing two 'New Formations' that are shown in bold and italics on the geological map (Figure 1).

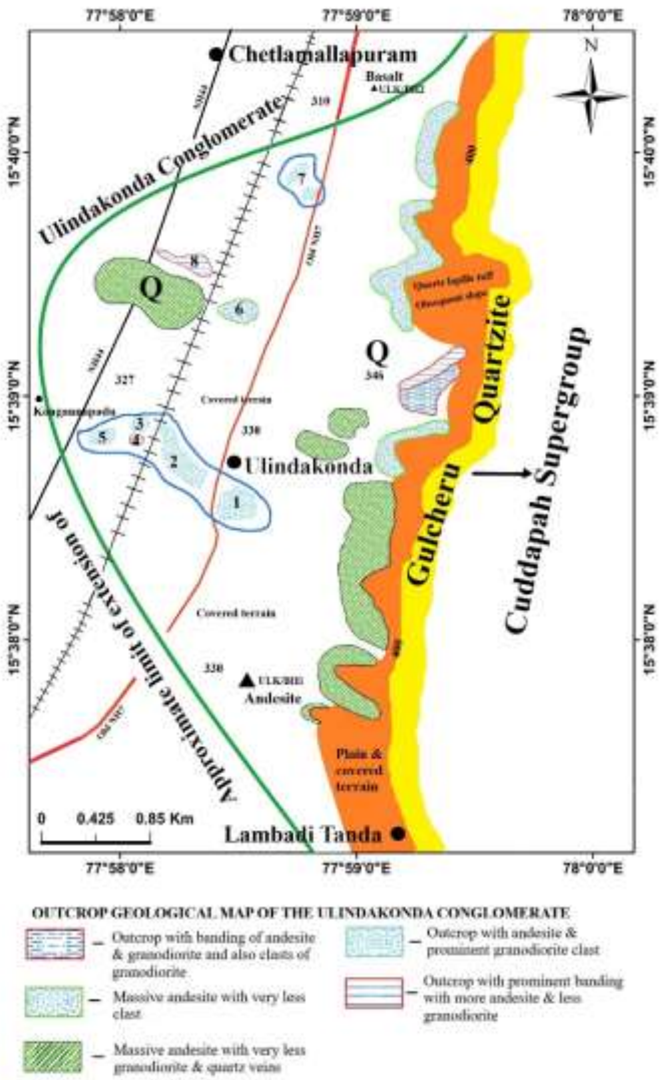

Figure 1. Outcrop geological map of the Ulindakonda Conglomerate

Field Setup

The vast area covered by Ulindakonda Conglomerate reflects a flat or gently undulating topography. There are nearly 8 outcrops of the volcanic conglomerate in and around the Ulindakonda village that show positive relief and a few smaller outcrops are located near Chetlamallapuram village without any positive relief. The field setup reflects a spherical shape with a crater-like depression with extensive volcanic material points to a vent.

The approximate limit of extension of the Ulindakonda conglomerate is confined by basalt towards the west. 28 samples were collected from the study area, in which two samples are from subcrop i.e., boreholes, and the remaining 26 are from outcrops comprising of different characteristics for further work.

The outcrops are divided into, i) outcrop with sub-rounded to rounded granodiorite clasts, ii) outcrops with spindle shaped granodiorite clasts, and iii) outcrops with stratification of granodiorite and trachyandesite.

The details of the outcrops are documented below.

Outcrops with Sub-Rounded to Rounded Granodiorite Clasts

There are 4 outcrops i.e., outcrops-1, 2, 3, and 6 (Figure 1) that reflects a similar setup. The main outcrop (N15^{0}38′34″ E77^{0}58′17″) is located by the side of village Ulindakonda. This (Figure 2a) has well-rounded to sub-rounded granodiorite clasts (A) of various sizes. These clasts exhibit a typical igneous look without any imprint of metamorphism. The longer and shorter axes of the clast are approximately 86 cm and 66 cm respectively. A few clasts of trachyandesite (B) are also observed.

The outcrop-2 (Figure 2b) (N15^{0}38′45″ E77^{0}58′02″) is at a distance of 500 meters NW of the main outcrop, i.e., the outcrop-1, outcrop-3 (Figure 2c) (N15^{0}38′50″ E77^{0}58′01″) is located 200 meters NW of the outcrop-2 and outcrop-6 (Figure 2d) (N15^{0}38′49″ E77^{0}57′41″) lies west of outcrops 4 & 5 at a distance of 230 meters All these outcrops exhibit similar characters as seen in the main outcrop with minor variation in the clast size as reflected in Figure 2d.

Figure 2. Field photographs of sub-rounded to rounded granodiorite clasts a) outcrop-1, b) outcrop-2, c) outcrop-3 and d) outcrop-6
(Note the difference in the clast size)

Outcrops with Spindle-Shaped Granodiorite Clasts

There are 4 outcrops i.e., outcrops - 4, 5, 7, and 8 (Figure 1) that reflect spindle-shaped clasts. The outcrop-4 (Figure 3a) (N15^{0}38′52″ E77^{0}57′53″) is located NW of the main outcrop, i.e., the outcrop 1 at a distance of 920 meters (roadside) towards Kongannapadu village. The outcrop-5 (Figure 3b) (N15^{0}38′49″ E77^{0}57′53″) is situated nearer to the outcrop-4 at a distance of 100 meters, outcrop-7 (Figure 3c) (N15^{0}40′01″ E77^{0}58′35″) is 2 km away from Chetlamallapuram village and outcrop-8 (Figure 3d) (N15^{0}39′27″ E77^{0}57′34″) is located by the side of NH44 i.e., Bangalore-Hyderabad National Highway shows similar features as seen in the outcrop-4 and it has intermixing of both clast and matrix. All the outcrops exhibiting elongated coarse-grained leucocratic rock of granodiorite in composition reflect spindle-shaped clasts. Flow banding is more conspicuous in the fine-grained melanocratic rock i.e., trachyandesitic matrix indicating the ductile deformation (Figure 3b). The granodiorite clasts are very less and the banding of clasts and matrix material is faintly observed in outcrop-7 (Figure 3c).

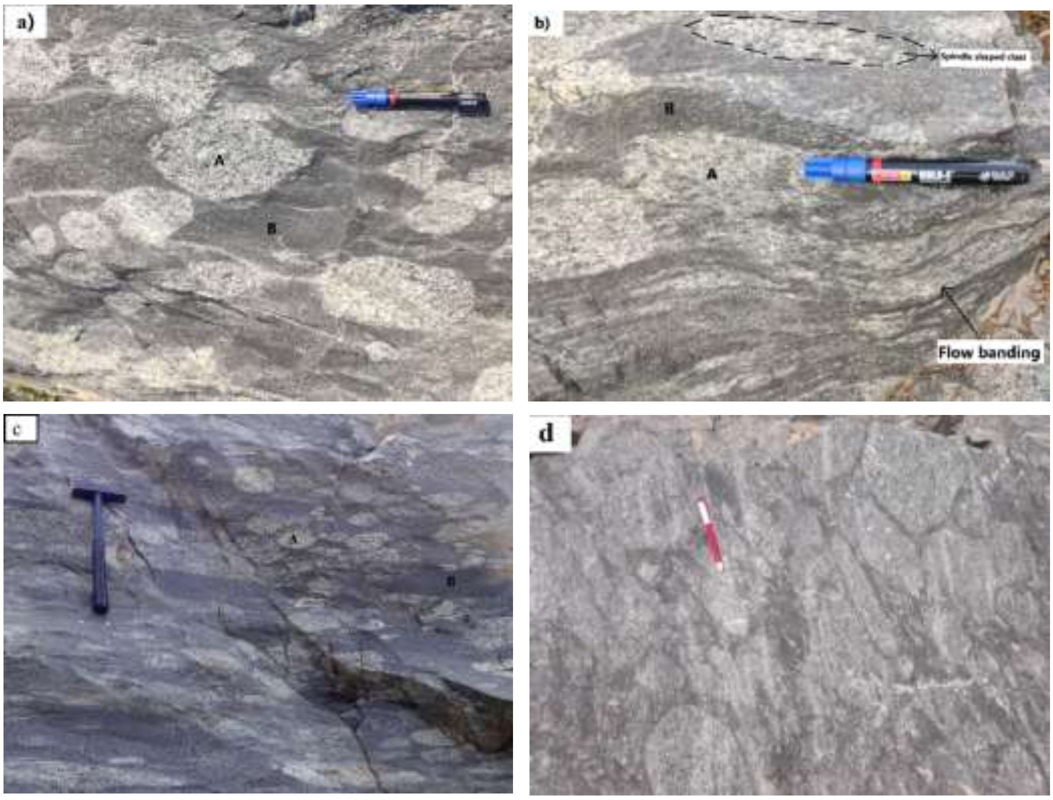

Figure 3. Field photographs of spindle-shaped granodiorite clasts a) outcrop-4, b) flow banding of matrix observed in outcrop-5, c) outcrop-7 and d) outcrop-8
(Note the shape and fluidization of the matrix)

Outcrops with Stratification of Granodiorite and Trachyandesite

Adjacent to the village Ulindakonda, two quarries are located away from the main outcrop i.e., outcrop-1, one in the east (N15^{0}38′49″ E77^{0}58′54″) and the other in the west (N15^{0}39′23″ E77^{0}58′04″) at a distance of 1 km, 2 km respectively. The lithological units in these quarries exhibit alternating bands of granodiorite and andesitic material (Figure 4a) with a few quartz veins traversing the units. Further, granodiorite clasts are almost absent in the eastern quarry. In the western quarry, few quartz-veins trending East-West exhibit parallelism with the banding (Figure 4b). The quartz veins vary in length from a few cms to tens of meters and are 10 cm to 45 cm in width. The presence of quartz veins points to the mild tectonic activity (Figure 4c). At some places in the quarry, granodiorite reflects a gentle upwarp along with the trachyandesite (Figure 4d). The approximate percentage of granodiorite and trachyandesite is 20:80 respectively.

All the above-stated outcrops are easily accessible by the NH-44 and also by the old NH-7.

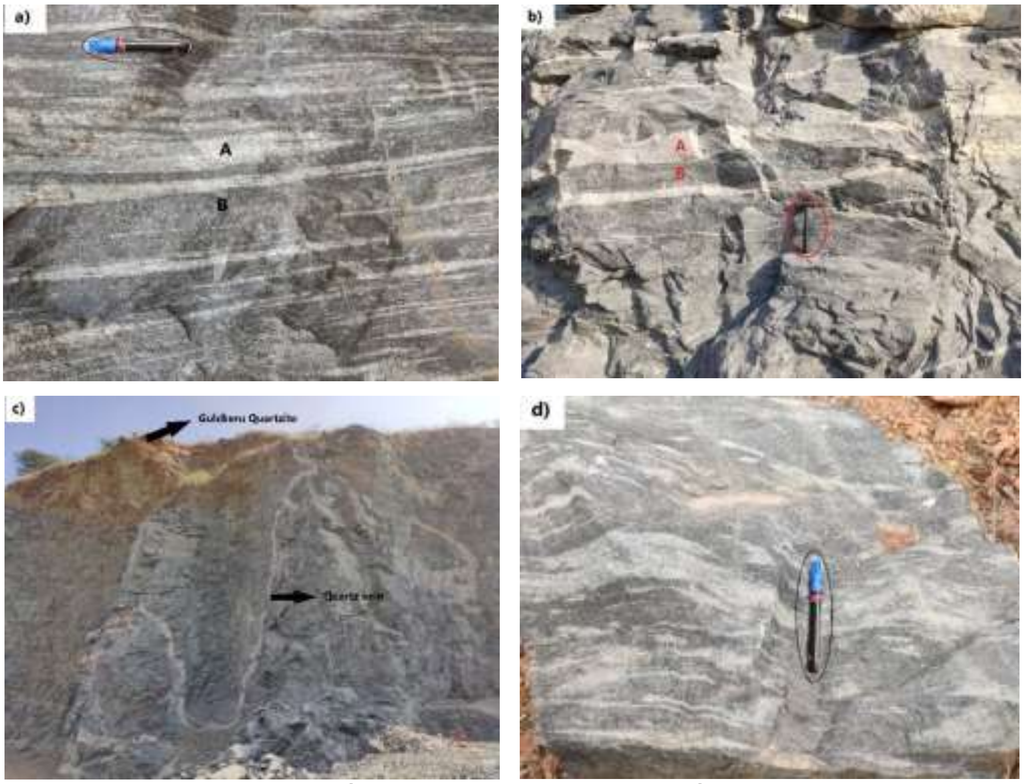

Figure 4. Field photographs of a) alternating banding of granodiorite and andesitic material in the western quarry, b) quartz veins in the eastern quarry c) upwarp of quartz veins, and d) granodiorite (Marker pen length 13.5cm and hammer length 30cm)
(Note the conspicuous banding or layering)

Tuff Sequence

A thick sequence of nearly 85m tuff sequence is observed on the obsequent slope of Jagannadhagattu hill range i.e., east of Ulindakonda. The entire sequence that is resting on the agglomerate is divided into six units. The basal unit is a grey quartz lapille tuff that has the development of andalusite (Figure 5A). This is followed by light-colored fine-grained tuffaceous material that shows schistose character striking NW and dipping NE at 35° (Figure 5B). This also has the development of prominent andalusite. Further, it is overlain by yet another tuffaceous rock having coarse-grained andalusite crystals (Figure 5C). This is followed by quartz lapille tuff that is conspicuous on the outcrop reflecting sub-rounded nature of quartz lapille (Figure 5D). This in turn is succeeded by fine-grained dark gray rock having andalusite crystals (Figure 5E) and over this unit is the light gray rock with well-developed andalusite crystals and quartz (Figure 5F). The topmost unit of the tuff is fine-grained dark grey with andalusite crystals segregated in the form of bands (Figure 5G). This is unconformably overlain by quartz pebble conglomerate (QPC) of the Gulcheru Quartzite of the Cuddapah Supergroup (Figure 5H).

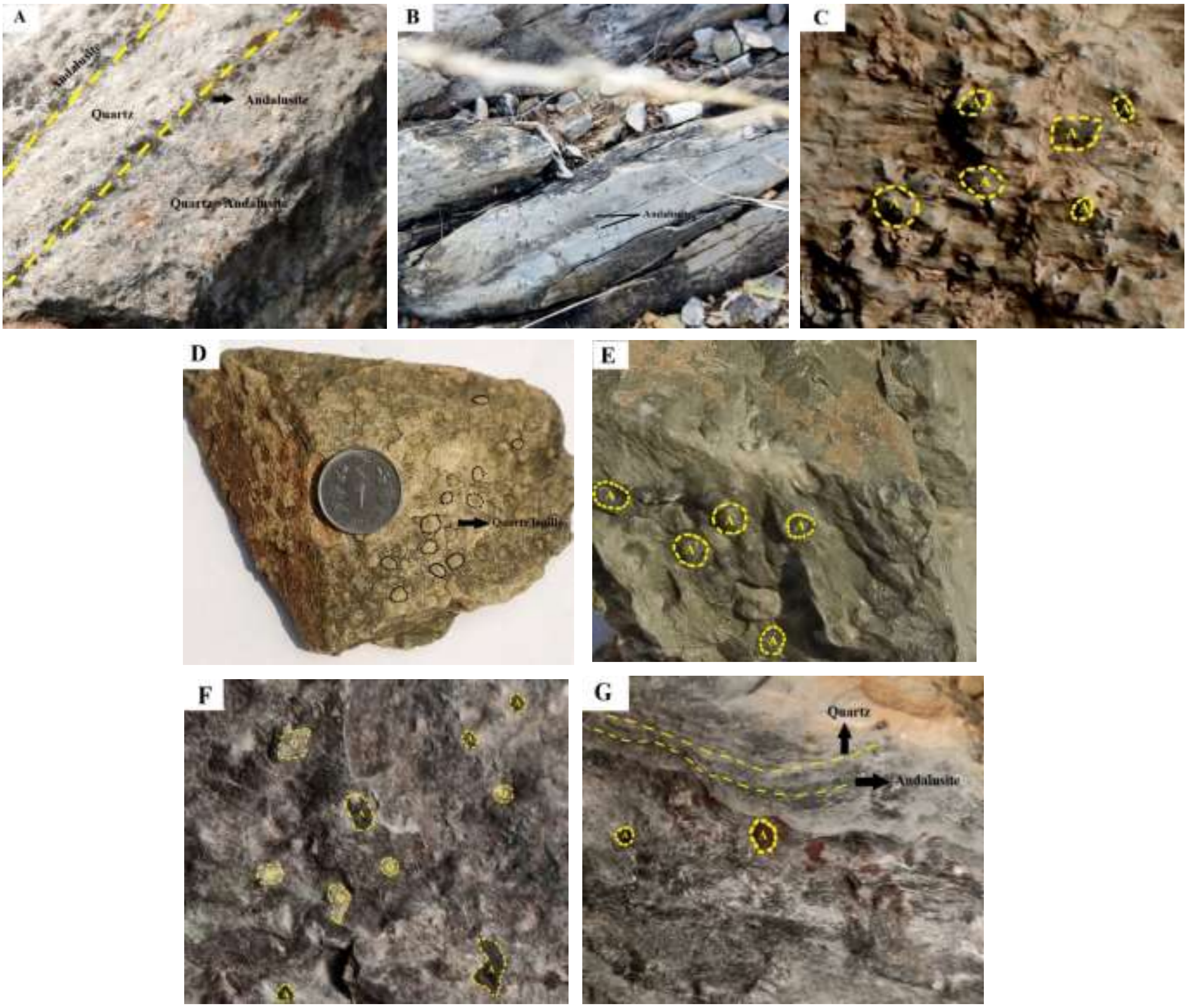

Figure 5. Field photographs of A) Quartz-andalusite tuff, B) Andalusite tuff, C) Andalusite tuff with banding, D) Quartz lapille tuff, E) Andalusite tuff, F) Quartz-andalusite tuff (Diameter of the coin is 2 cm), and G) Quartz-andalusite tuff with banding

The critical perusal of the field setup indicates that the Ulindakonda Conglomerate has all the characters of vent agglomerate that are presented below.

Vent Agglomerate

- The clasts of granodiorite composition and trachyandesitic matrix (Figure 2) do not reflect the characteristics of a sedimentary conglomerate. The clasts of coarse-grained leucocratic granodiorite are rounded to sub-rounded with varying dimensions occur as bombs in agglomerate set in the fine-grained melanocratic matrix of intermediate volcanic rock i.e., trachyandesite.
- Normally in a sedimentary terrain granitoid breaks into smaller fragments which is not the case in the present setup. The matrix of trachyandesitic composition indicates intermediate volcanic nature. In the present setup, the clasts are of plutonic origin.

- The alternate banding of granodiorite and trachyandesitic composition reflects stratiform nature of the two (Figure 4a). It is opined that during an eruption, due to buoyancy, the upcoming mantle material got intermixed with crustal rocks and formed alternate bands of both granodiorite and trachyandesite material.
- The outcrop distribution i.e., the geomorphology of the conglomerate outcrops reflects a slightly distorted circular/semi-circular feature, the eastern side is partly covered by the younger Paleoproterozoic rocks of the Cuddapah Supergroup. The central part of the area under study is a semi-circular depression. In other words, the cross-section of this is a small crater-like with the edges elevated and with depression at the center.
- Further, the tuffaceous sequence (Figure 5) supports mainly the acidic volcanism of the area under study. There are nearly 6 variegated tuffaceous rocks having andalusite and quartz as essential minerals with agglomerate as the basement.
- In all, it has three volcanic suites of rocks, i) represented by basic volcanism like basalt (seen mostly beyond the Western limit of the conglomerate and a little in the center of the area as subcrop), ii) intermediate volcanism indicated by trachyandesites, and iii) acidic volcanism represented by rhyolites.
- The emplacement of this possibly could be in the tectonic setup that has a thin granitoid crust into which the trachyandesitic magma made its way. This might have broken a crust and also partially melted. Where it has broken the granitoid clast/granodiorite clast has developed a sub-rounded to rounded nature mainly due to the ball mill-like setup in a magma chamber (Figure 6B). Further, when partially melted, it might have given rise to the banding of granodiorite and trachyandesitic units (Figure 6B). The proposed tectonic model is given as Figure 6A. Further, there is a clear fusion of these units (Figure 6B).
- The model of Tamura et al. (2016), is used as a base for the proposed tectonic emplacement of the body.
- Thus, the field setup clearly reflects a possible vent agglomerate nature of the Ulindakonda conglomerate.

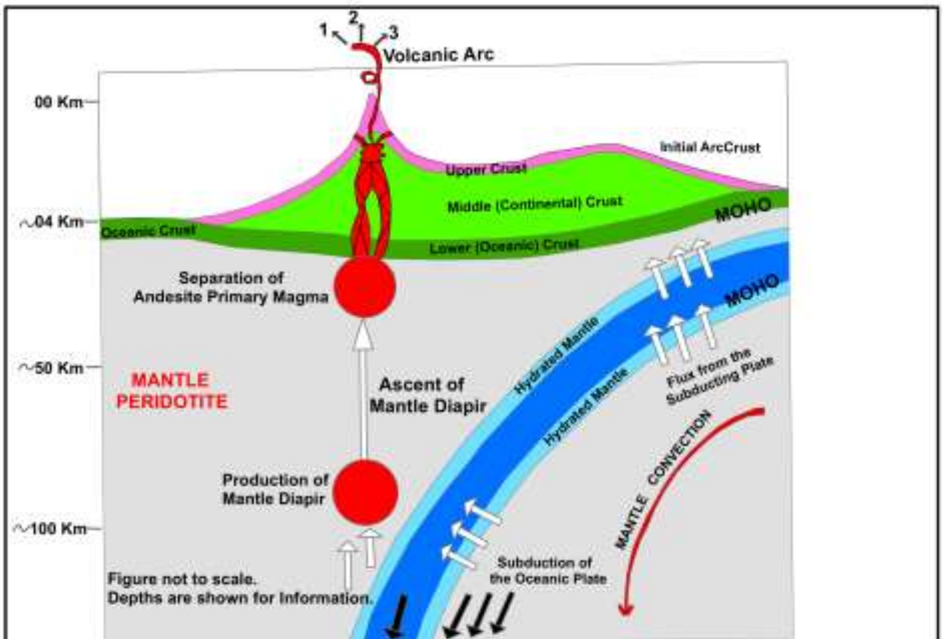

Figure 6 A. Praposed tectonic Model for the emplacement of andesite magma and the resultant vent agglomerate in the Ulindakonda area. Base model is after Tamura Y., et.al, 2016.

Figure 6B. Field photographs of the behaviour of two different lithologies after the volcanic eruption, i.e., 1) sub-rounded to rounded granodiorite clast set in a trachyandesitic matrix, 2) alternate layering of two litho-units, and 3) intermixing of both reflects transitional contact

Rounding of Clast

- In the Ulindakonda conglomerate, the granodiorite clasts are rounded as observed in many vent-agglomerate (Bonewitz, 2012). It is opined that the rounding is mainly due to the action between the clasts and the magma in the magma chamber. This is designated as agglomerate due to the geological setup and the rounding of the clasts.
- Generally, agglomerate plugs, either through the main vent or a satellite vent of a volcano (Bonewitz, 2012). The outcrop of this rock will have a limited extent and appears to be spherical on a geological map. The vent agglomerates are constituted by clasts of various dimensions, shapes, and compositions from the lava, other volcanic rocks, or country rocks (Bonewitz, 2012) as observed in the Ulindakonda conglomerate.
- The Ulindakonda conglomerate exhibits all the three types of size of clasts, viz., i) bombs, that are represented by larger than 64 mm in diameter (Figure 2a), ii) lapille, that are represented by 2- 64 mm in diameter (Figure 5D), and iii) ash, that is less than 2 mm in diameter (Figure 5E; Bonewitz, 2012).
- According to Bonewitz (2012), the clasts that represent volcanic bombs can be divided into various types based on their outward aspects and shape. They are i) The spheres of fluid magma are called spherical bombs, which get into those shapes by the influence of surface tension, ii) The formation of the spindle shaped bombs is also similar to above, but their rotation in flight makes them elongated, and iii) The exterior of the lava bomb solidifies due to flight results in a cracked outer surface while the interior remains to expand forms a bread crust bomb. All the above-stated types can be seen in the Ulindakonda vent agglomerate.
- The difference in their shape is due to eruption phases and the sharp contact between the lithologies represents the variation in temperature (Bonewitz, 2012).
- Quartz lapilli tuff and andalusite tuffs are also observed away from the vent on the obsequent slope (Figure 5D& E).

Formation of Banding/ Stratification

Following the model proposed by Tamura et al. (2016), it is proposed that the andesitic magma made its way out through thin crustal rocks with low pressure. This at places might have broken the crust into smaller fragments that could become bombs (Figure 2), the incomplete mixing of both i.e., crustal rocks and trachyandesitic magma might have led to the formation of alternate bands/ stratification within the igneous rocks. It is due to double diffusive convection, represented by variation in density and temperature, which leads to the cryptic layering i.e., variation in chemical composition (Namur et al., 2015; Irvine, 1982).

Conclusions

The Gadwal Greenstone Belt has a history of multi-variant volcanic episodes represented by basalts, trachyandesites, and rhyolites, and also tuffaceous sequence. The Ulindakonda Conglomerate has the typical characters of vent agglomerate. It has involved the thin upper crust. The modal clearly indicates that the andesitic magma through its passage has broken the granitoid crust and the minor fragments of the crust and to some extent andesite have formed the volcanic bombs embedded in trachyandesite matrix. The same process is also responsible for rounding of the clasts. The stretching of the clasts into spindle shape could be due to later tectonism and also could be due to the rotation of the clasts during their flight. The layering in the conglomerate may be due to crustal fragments mixing with the trachyandesitic magma and due to variation in density and temperature.

Acknowledgements

One of the authors Ms. S. N. L. R. Rajeswari wish to express her sincere thanks to the Department of Science and Technology for providing DST-INSPIRE Fellowship (IF170954) to pursue Ph.D. The authors express their gratitude and sincere thanks to Dr. B. K. Nagaraja Rao, former Director of Geological Survey of India (GSI) for suggesting a thought-provoking problem and also for his guidance in the field.

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