STM JOURNALS

International Journal of
Mineral

https://journals.stmjournals.com/ijmi.

Volume 3, Issue 1, 2026.
January—June.
DOI (Journal): 10.37591/IJMI.

Review IJMI

Petrographic and Geochemical Characteristics of Deccan Trap Basalts from Belagavi, Karnataka, India

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Abstract

The Deccan Trap volcanic province represents one of the largest continental flood basalt provinces in the world and provides significant insights into magma generation and evolution processes. The present study focuses on the petrography and geochemistry of basalts from the Belagavi region, which forms part of the southern extension of the Deccan volcanic province. Petrographic analysis of thin sections reveals that the basalts are mainly composed of plagioclase feldspar and augite, with minor opaque minerals. Various textures such as ophitic, sub-ophitic, glomeroporphyritic, intergranular, and intersertal textures are observed, indicating different stages of magma crystallisation. Geochemical analysis using X-ray Fluorescence Spectrometry (XRF) shows that the basalts are basic in composition with SiO_2 values ranging from 47.7–49.0 wt%. The TAS diagram classifies the samples within the basalt field, while the AFM diagram indicates their tholeiitic affinity. Trace element ratios further suggest similarities with the Mahabaleshwar formation lavas of the Deccan Traps.

Keywords: Deccan traps; Belagavi basalts; petrography; geochemistry; tholeiitic Basalt; XRF analysis; large igneous province

INTRODUCTION

The Deccan Traps of western and central India represent one of the largest continental flood basalt provinces in the world and form a major geological feature of the Indian subcontinent. These volcanic rocks were emplaced during the Late Cretaceous to Early Paleogene period (~66 Ma) and consist of extensive basaltic lava flows covering nearly 500,000 km^2, with a thickness locally exceeding 2000 m [1]. The Deccan volcanic province is dominated by tholeiitic basaltic lavas, although small occurrences of alkalic basalts and more evolved volcanic rocks have also been reported from certain regions [2,3]. The origin of these flood basalts is commonly associated with mantle plume activity linked to the Réunion hotspot, which produced large volumes of basaltic magma within a relatively short geological period [4].

The Deccan basalts have received significant scientific attention because they provide important insights into mantle processes, magma generation, and the evolution of large igneous provinces. Petrographic studies indicate that these basalts typically contain plagioclase feldspar, pyroxene, olivine, and Fe–Ti oxide minerals, which are characteristic of tholeiitic magma [5]. Geochemical studies suggest that variations in their chemical composition are related to fractional crystallization, mantle source heterogeneity, and crustal contamination during magma ascent [6,7].

Within the Deccan volcanic province, basaltic lava flows are subdivided into several formations and stratigraphic units with distinct petrographic and geochemical features [8]. Detailed petrographic and geochemical studies of basalt exposures are

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Received Date: March 17, 2026
Accepted Date: March 18, 2026
Published Date: March 28, 2026

Citation: Sachin R Kulkarni, Mahadeva M. Petrographic and Geochemical Characteristics of Deccan Trap Basalts from Belagavi, Karnataka, India. International Journal of Mineral. 2026; 3(1): 52–61p.

therefore important for understanding the petrogenesis, magma evolution, and regional correlation of these lava sequences. The present study examines the petrographic and geochemical characteristics of basalts from the Belagavi region of northern Karnataka, which forms part of the southern extension of the Deccan Trap province. Through thin-section petrography and whole-rock geochemical analysis, the study aims to determine the mineral composition, textures, and magma type of these basalts and to understand their relationship with other lava formations of the Deccan volcanic province.

REGIONAL GEOLOGICAL SETTING

The Karnataka craton forms an important part of the southern Indian shield and represents one of the oldest Precambrian geological terrains in the world. The geology of the state is mainly composed of rocks belonging to the Archaean and Proterozoic eras, reflecting a long geological history involving crustal evolution, tectonic activity, and magmatic processes. Among the oldest rock units are the Sargur (Surgur) schist belts, which consist of ancient supracrustal sequences of metamorphosed volcanic and sedimentary rocks [9]. These formations represent early stages of crustal development in the Indian shield.

A major portion of central and southern Karnataka is occupied by the Peninsular Gneissic Complex, composed predominantly of grey gneisses known as Peninsular Gneiss. Although earlier studies attempted to place the gneisses either above or below the schist belts, later interpretations suggest that they represent a complex assemblage formed through deformation, metamorphism, granitic intrusion, and magmatic processes [10]. The complex is broadly divided into older gneissic rocks in the western region and younger gneisses toward the east.

Associated with these gneisses are extensive greenstone belts or schist belts, composed mainly of basic igneous rocks along with minor sedimentary units [11,12]. These rocks are well developed in the Dharwar Supergroup, which includes the Bababudan Group, consisting of basaltic lava flows, orthoquartzites, and banded iron formations, and the Chitradurga Group, mainly composed of sedimentary rocks [13].

Another significant feature is the Closepet Granite belt, a north–south trending body of potassic granites separating older gneisses and schist belts from younger crustal blocks. High-grade metamorphic rocks such as charnockites are widely distributed in southern Karnataka [14,15]. In northern Karnataka, the Archaean basement is overlain by Proterozoic sedimentary rocks of the Kaladgi and Bhima basins, separated by the Great Eparchaean Unconformity. The Kaladgi formations consist mainly of orthoquartzites and carbonates [16], while the Bhima Group includes sandstones, shales, and limestones [17]. Parts of northern Karnataka are also covered by Deccan Trap basalts of Late Cretaceous–early Paleogene age, along with younger lateritic and alluvial deposits.

Geology of the Study Area

The study area forms the southern extension of the well-known Deccan Trap volcanic province located in the northern part of Karnataka, particularly within the Belagavi district as shown in Figure-1. The region is characterized by extensive basaltic lava flows that are part of the Deccan flood basalts of India. These basalt flows are generally described as undifferentiated volcanic flows of the Deccan Trap sequence [18].

Geographically, the study area lies within Survey of India Toposheet No. 48 I/9 at a scale of 1:50,000. The area is located between approximately latitude 15°30'–16°00' N and longitude 74°30'–74°45' E. The region falls within the northern Karnataka plateau and is characterized by basaltic hillocks and plateau topography typical of Deccan Trap terrains.

Reconnaissance field investigations conducted by Hegde, Koti, and Kruger (2014) indicate that the study area consists predominantly of volcanic rock sequences of basic lava composition. The major lithological units identified in the area include basalt, greywacke and meta-greywacke, granitic complexes, limestone–dolomite formations, and younger lateritic deposits.

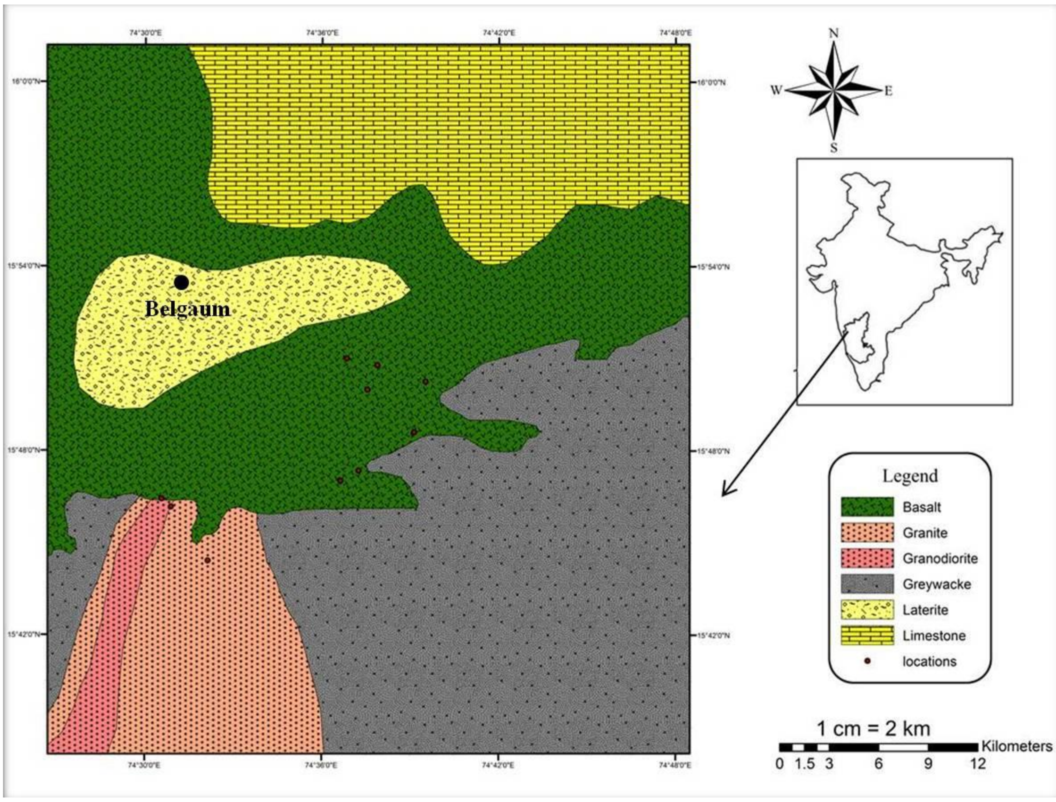

Figure 1. Geological Map of the study area, with stratigraphic order.

Although the basement rocks are not directly exposed in most parts of the study area, geological evidence suggests that different basement units occur in different locations. In some regions, Archaean rocks form the basement, whereas in other areas the Kaladgi formations or granitic complexes act as the basement for the Deccan basalt flows. The Deccan basalts are well exposed in the study area at elevations ranging from approximately 746.76 m to 822.96 m above mean sea level.

The basaltic lava flows are generally horizontally disposed, forming characteristic step-like plateau topography. However, tracing individual flows over large distances is difficult due to extensive vegetation cover, soil development, and weathering processes. The southern part of the Belagavi region is dominated by well-exposed basalt outcrops forming flat-topped hillocks typical of Deccan Trap landscapes. The slopes of these hillocks are often covered by boulders, loose soil, and vegetation.

Detailed geological mapping of the study area indicates the presence of several lithological units, which are described below.

Stratigraphy of the Study Area

The stratigraphic succession of the study area records a long geological history ranging from Archaean basement rocks to recent surface deposits. The oldest rocks belong to the Peninsular Gneissic Complex, which includes granitic gneisses, granites, gabbros, and granodiorites. These rocks form the crystalline basement for the younger formations and represent early crustal components of the Dharwar craton [19].

Overlying the Archaean basement are Proterozoic sedimentary rocks of the Kaladgi Basin, consisting mainly of orthoquartzites, argillites, limestone, and dolomite deposited in shallow marine environments [5]. These formations are separated from the basement by the Great Eparchaean Unconformity, which represents a major break in geological time [8]. Above the Kaladgi formations occur the Bhima Group, composed of sandstones, shales, and limestone deposited during the late Proterozoic period [15].

These sedimentary sequences are overlain by Deccan Trap basalt flows of Late Cretaceous–early Paleogene age [17,20]. In many areas, the basalts are capped by lateritic and bauxitic deposits, followed by recent soils and alluvium, representing the youngest geological units of the region.

Petrography

The basalts of the Belagavi region are mainly composed of plagioclase feldspar and pyroxene, with occasional phenocrysts of olivine. Based on mineralogical and geochemical characteristics, these basalts were classified by Pandith (1985) into three types: olivine tholeiites, quartz tholeiites, and low-calcium quartz tholeiites. Among these, the Belagavi basalts are predominantly represented by quartz tholeiites and low-calcium quartz tholeiites. Petrographic analysis of representative basalt samples was carried out to determine their mineralogical composition, textures, and crystallization history. Thin sections were examined under a polarizing petrographic microscope using both plane polarized light (PPL) and cross polarized light (XPL), which provided insights into the mineral assemblages and cooling history of the Deccan basalt flows exposed in the study area.

The basalts occur as massive lava flows, commonly separated by intertrappean and intratrappean beds. The lower flows are typically massive and compact, whereas the upper flows often display vesicular and amygdaloidal structures, indicating the presence of gas bubbles during magma solidification. Megascopically, these rocks are dark grey to black in colour, fine-grained, and compact. Petrographic observations show that the basalts are composed mainly of plagioclase feldspar and augite (clinopyroxene), with minor opaque minerals such as magnetite or titanomagnetite.

The groundmass is generally fine-grained, consisting of plagioclase laths and pyroxene crystals with scattered opaque minerals. Several important igneous textures are observed, including sub-ophitic, ophitic, glomeroporphyritic, and intergranular textures. In sub-ophitic texture as shown in Figure-2, plagioclase laths are partially enclosed by augite crystals, indicating early crystallisation of plagioclase followed by augite during magma cooling. Ophitic texture Figure-3 and as shown in Figure-4 shows plagioclase laths completely enclosed within augite phenocrysts, suggesting continued crystallization of pyroxene around earlier plagioclase crystals. Abundant opaque minerals as shown in Figure-5 occur as black grains within the groundmass and represent iron oxide phases that crystallized during later stages of magma solidification.

Some thin sections also display glomeroporphyritic texture as shown in Figure-6, where clusters of plagioclase crystals form aggregates known as glomerocrysts. This texture indicates that plagioclase crystals formed early within the magma chamber and later aggregated before final eruption and cooling of the lava. Overall, the mineral composition and textures observed in these basalts indicate that they belong to the tholeiitic basalt series of the Deccan Trap volcanic province. These petrographic features suggest that the basalts were derived from mantle-derived magma and underwent fractional crystallization and cooling during volcanic emplacement.

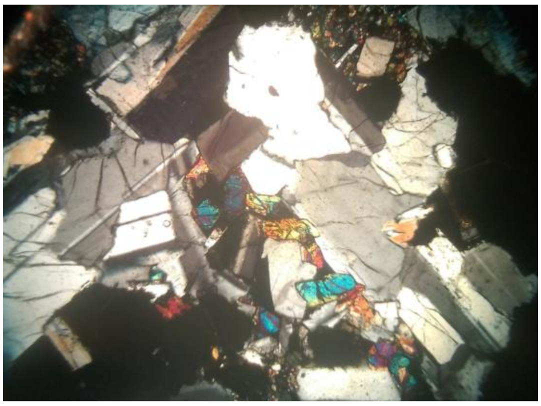

Figure 2. Sub-ophitic texture in basalt (augite partially enclosing plagioclase).

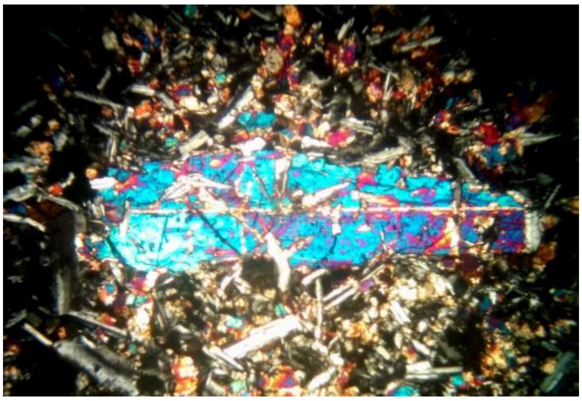

Figure 3. Ophitic texture in basalt showing plagioclase laths enclosed within augite.

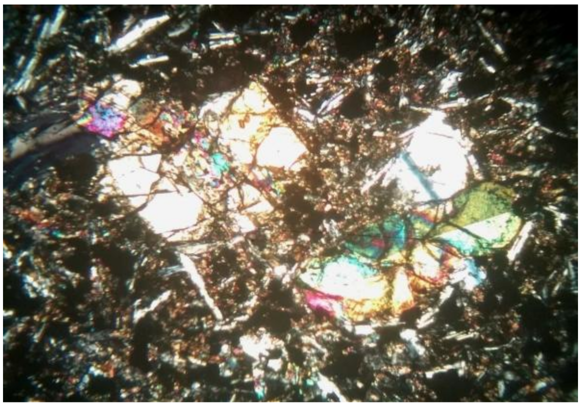

Figure 4. Ophitic texture in basalt with augite phenocryst enclosing plagioclase feldspar.

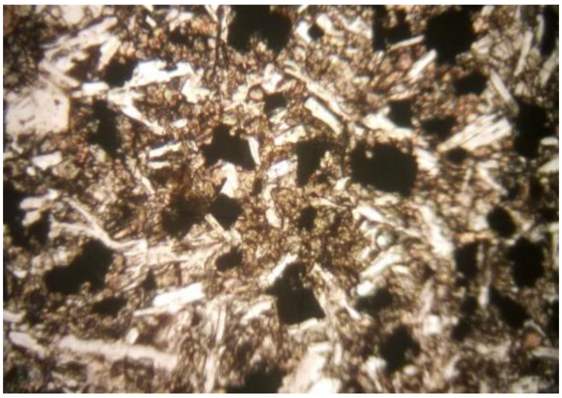

Figure 5. Basalt showing abundant opaque minerals (iron oxides) in the groundmass.

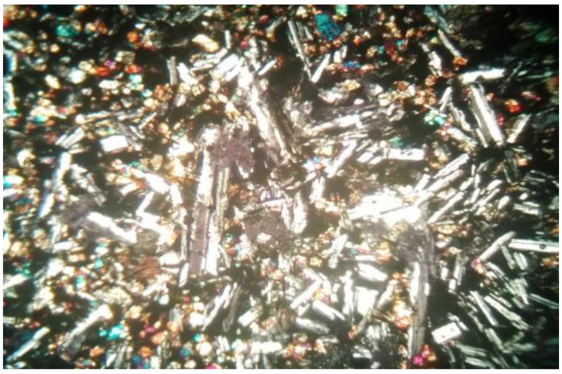

Figure 6. Primary basaltic texture with glomeroporphyritic clusters of plagioclases.

Geochemistry of the Study Area

The geochemical characteristics of the basalt samples from the study area were investigated to understand their chemical composition, magma type, and petrogenetic affinity. Prior to analysis, all collected samples were carefully cleaned to remove weathered surfaces and secondary mineral phases such as vein quartz and calcite, ensuring that only fresh rock material was used. The samples were then broken into small fragments and finely powdered using an agate mortar, which helps minimize contamination that may occur during mechanical grinding. The powdered samples were subsequently analyzed for major and trace element compositions using X-ray Fluorescence Spectrometry (XRF) on pressed powder pellets.

The results of the major oxide and trace element analyses are summarized in Table 1 & 2. The SiO_2 content of the analyzed basalt samples ranges from 47.70 to 49.03 wt%, indicating that the rocks are basic in composition and confirming their classification as basalts. The total alkali content (Na_2O + K_2O) varies from 2.40 to 3.12 wt%, representing relatively low to moderate alkali concentrations. The Na_2O/K_2O ratios, which range from 5.02 to 15, are comparatively high and suggest a sodic affinity of the basaltic magma. The K_2O content is consistently low, remaining below 1 wt%, which is a characteristic feature of tholeiitic basalts.

Moderate variations are observed in the concentrations of Al_2O_3 (13.09–14.64 wt%), MgO (4.22–4.27 wt%), and CaO (9.99–11.63 wt%), indicating differences in the degree of magma differentiation within the basalt flows. The TiO_2 content varies between 1.77 and 3.78 wt%, reflecting enrichment in iron and titanium, which is commonly observed in many Deccan Trap basalts. Trace element concentrations also provide valuable information regarding magma evolution. Elements such as Rb (3–13 ppm), Y (28–41 ppm), Zr (96–202 ppm), Ba (65–172 ppm), and Nb (22.7–24.7 ppm) show enrichment in incompatible elements, a typical geochemical feature of Deccan basaltic rocks.

To further classify the basalt samples, geochemical discrimination diagrams were used. The Total Alkali–Silica (TAS) diagram proposed by Le Bas et al. (1986) was used to determine the volcanic rock type. In this diagram, the combined alkali content (Na_2O + K_2O) is plotted against SiO_2. As illustrated in Figure 7, all analyzed samples plot within the basalt field, confirming their basaltic composition. The relatively low alkali content together with moderate silica values indicates that the basalts belong to the tholeiitic magma series, which is typical of the Deccan Trap volcanic province.

Another important geochemical classification method involves the AFM triangular diagram, which distinguishes between tholeiitic and calc-alkaline magma series. In this diagram, the relative proportions of Fe_2O_3, MgO, and total alkalis (Na_2O + K_2O) are plotted. The AFM plot for the basalt samples from the study area is shown in Figure 8. The plotted data points fall clearly within the tholeiitic field, above the boundary separating tholeiitic and calc-alkaline magma series. This distribution indicates a typical iron-enrichment trend during magmatic differentiation, which is characteristic of tholeiitic basaltic magmas [21]. The AFM diagram therefore confirms that the basalts of the Belagavi region belong to the tholeiitic magma series, supporting the petrographic observations.

In addition to major element classification, trace element ratios provide further insight into the magma source characteristics and petrogenetic relationships of the basalt samples. A Ba/Y versus Zr/Nb diagram was used to compare the Belagavi basalts with other lava formations within the Deccan Trap province. As shown in Figure 9, fields corresponding to major Deccan formations such as Ambenali, Mahabaleshwar, Poladpur, and Bushe are indicated. The Belagavi basalt samples plot mainly within or near the Mahabaleshwar formation field, suggesting a strong geochemical similarity between these lavas and the Mahabaleshwar flows.

The samples exhibit moderate Ba/Y ratios and relatively low Zr/Nb values, which are typical of evolved tholeiitic basalts. Their distribution away from the Poladpur and Bushe fields indicates that the Belagavi basalts are more closely related to the Mahabaleshwar lava sequence (Mahoney, 1988).

Table 1. Major oxide (wt%) and trace element (ppm) composition of basalt samples from the Belagavi region determined using X-ray fluorescence spectrometry (XRF).

Oxides / elements	SiO_2 (wt%)	TiO_2 (wt%)	Al_2O_3 (wt%)	Fe_2O_3 (wt%)	MnO (wt%)	MgO (wt%)	CaO (wt%)	Na_2O (wt%)	K_2O (wt%)	P_2O_5 (wt%)
Sample 1	47.7	1.77	13.09	14.25	0.19	4.27	9.99	2.02	0.40	0.26
Sample 2	48.12	2.45	13.42	14.80	0.21	4.25	10.34	2.14	0.35	0.29
Sample 3	48.56	2.98	13.87	15.32	0.23	4.24	10.68	2.27	0.30	0.31
Sample 4	48.77	3.13	14.01	15.76	0.24	4.23	10.95	2.36	0.27	0.34
Sample 5	48.91	3.45	14.32	16.02	0.26	4.22	11.21	2.48	0.22	0.36
Sample 6	49.03	3.78	14.64	16.41	0.27	4.22	11.63	2.61	0.17	0.39

Table 2. Trace elements.

Trace element (ppm)	Range
Rb	3–13
Y	28–41
Zr	96–202
Ba	65-172
Nb	22.7-24.7

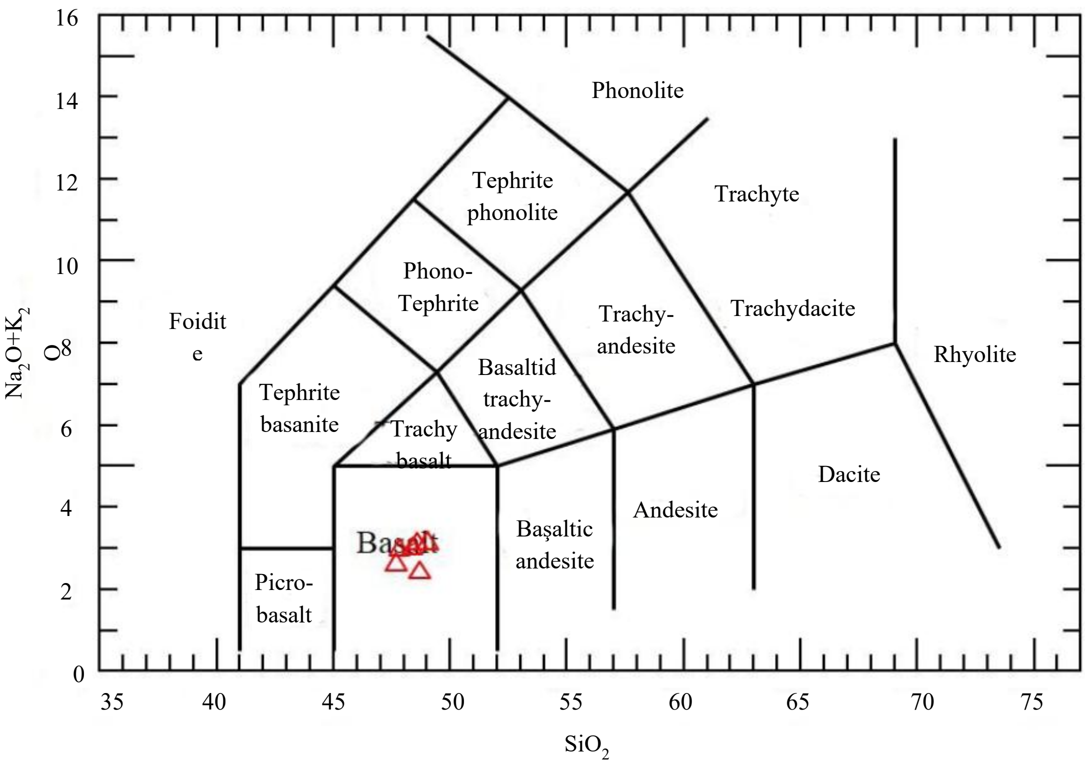

Figure-7. Total Alkali–Silica (TAS) classification diagram showing the basaltic composition of the Belagavi Deccan basalts (after Le Bas et al., 1986).

The relatively higher TiO_2 values (3.13–3.78 wt%) observed in some samples further indicate enrichment in iron and titanium, a characteristic feature of Deccan Trap basalts. Such enrichment is commonly associated with fractional crystallisation and magma evolution processes [22,23]. In addition, the comparatively low MgO values suggest that these basalts represent an evolved stage of tholeiitic magma differentiation, reflecting progressive magmatic evolution during emplacement of the lava flows.

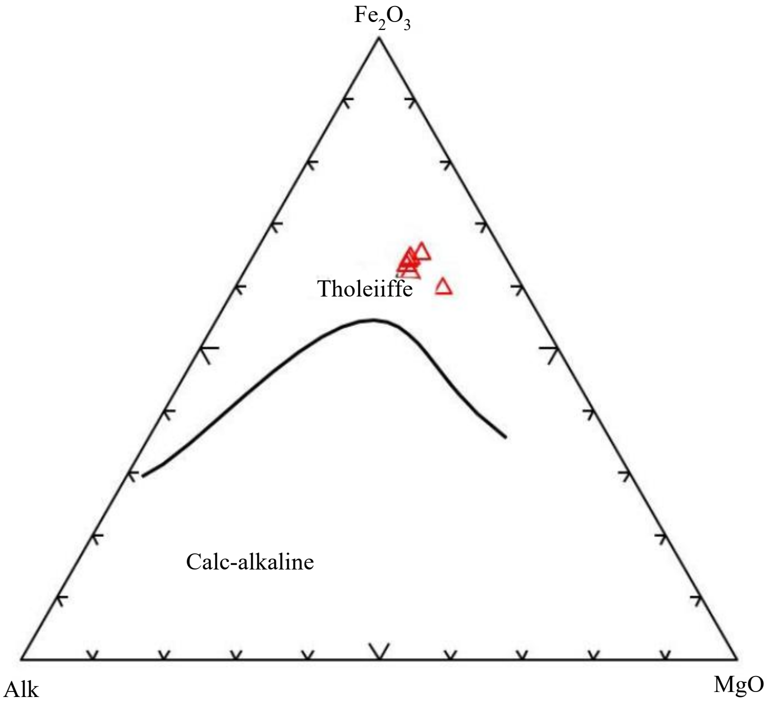

Figure 8. AFM (Fe_2O_3–Na_2O+K_2O–MgO) triangular diagram illustrating the tholeiitic affinity of the Belagavi basalt samples (after Irving and Baragar, 1971).

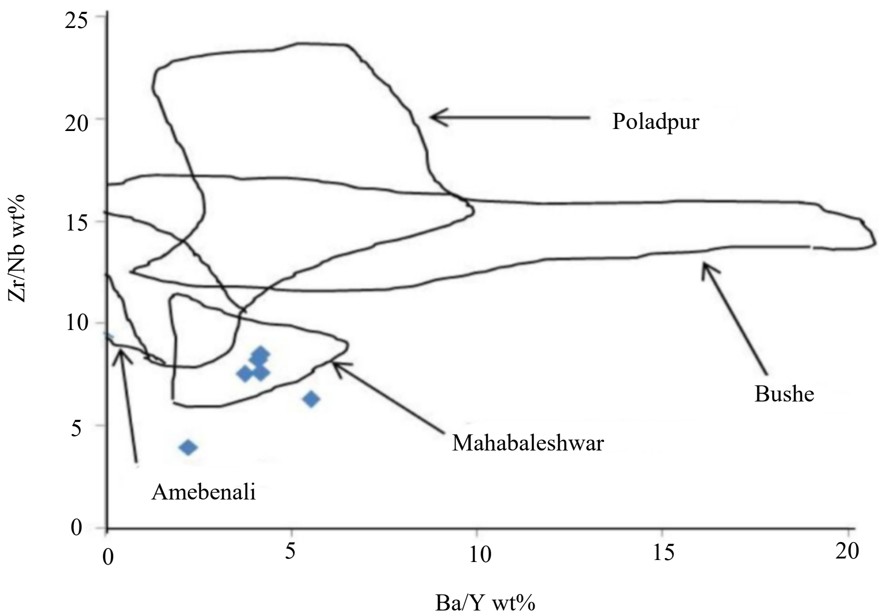

Figure 9. Ba/Y vs Zr/Nb plot comparing Belagavi basalts with major Deccan lava formations (after Mahoney, 1988).

CONCLUSIONS

The present study provides a comprehensive investigation of the petrography and geochemistry of the Deccan basalts exposed in the Belagavi region of northern Karnataka. The combined field observations, petrographic analysis, and geochemical data help to understand the mineralogical composition, textural characteristics, and magmatic evolution of these basaltic lava flows within the Deccan Trap volcanic province.

Petrographic studies of thin sections reveal that the basalts are predominantly composed of plagioclase feldspar and clinopyroxene (augite), with minor amounts of opaque minerals such as magnetite or titanomagnetite. The mineral assemblage and textural relationships observed in the thin sections indicate that the rocks belong to the tholeiitic basalt series, which is typical of the Deccan volcanic province. Several characteristic igneous textures were identified during petrographic analysis. These include sub-ophitic texture where plagioclase laths are partially enclosed within augite as shown in Figure 2, ophitic texture where plagioclase laths are completely enclosed by augite phenocrysts as shown in Figures 3 and 4, and glomeroporphyritic texture characterized by clusters of plagioclase crystals as shown in Figure 5. The presence of abundant opaque iron oxide minerals within the groundmass as shown in Figure 4 further reflects the iron-rich nature of the basaltic magma. These textural features collectively indicate multiple stages of crystallization and cooling of the basaltic magma, with early crystallization of plagioclase followed by the growth of pyroxene and opaque minerals during later stages of magma evolution.

The geochemical data obtained through X-ray fluorescence spectrometry (XRF) analysis provide further insight into the chemical characteristics of the basaltic rocks. The major and trace element compositions presented in Table 1 indicate that the analyzed samples have SiO_2 contents ranging from 47.70 to 49.03 wt%, confirming the basic nature of the rocks. The total alkali content ($Na_2O + K_2O$) is relatively low, while the Na_2O/K_2O ratios are comparatively high, indicating the sodic nature of the magma. Variations in the concentrations of Al_2O_3, MgO, CaO, and TiO_2 suggest differences in the degree of magmatic differentiation. The relatively higher TiO_2 contents observed in some samples reflect enrichment in iron and titanium, which is a common feature of Deccan Trap basalts.

The geochemical classification diagrams further support the basaltic and tholeiitic nature of the rocks. In the Total Alkali–Silica (TAS) diagram as shown in Figure 7 proposed by Le Bas et al. (1986), all analyzed samples plot within the basalt field, confirming their basaltic composition. Similarly, the AFM triangular diagram as shown in Figure 8 shows that the samples fall within the tholeiitic field, indicating an iron-enrichment trend typical of tholeiitic magmas (Irving and Baragar, 1971). These results clearly demonstrate that the basalts of the study area belong to the tholeiitic magma series, which is consistent with the geochemical characteristics of the Deccan Trap volcanic province.

Trace element ratios provide additional information regarding the petrogenetic relationships of the Belagavi basalts. The Ba/Y versus Zr/Nb plot as shown in Figure 9 indicates that the basalt samples from the study area show close geochemical affinity with the Mahabaleshwar lava formation of the Deccan Traps. The distribution of the samples within or near the Mahabaleshwar field suggests that the Belagavi basalts may have originated from similar mantle-derived magma sources and experienced comparable magmatic differentiation processes. The relatively low MgO values further indicate that these basalts represent an evolved stage of basaltic magma differentiation.

Overall, the integrated petrographic and geochemical evidence indicates that the basalts of the Belagavi region are tholeiitic basalts derived from mantle-derived magma, which underwent fractional crystallization and magmatic differentiation during emplacement. The mineralogical composition, textural characteristics, and geochemical signatures observed in this study are consistent with those reported for Deccan Trap basalts elsewhere in western and central India. The results, therefore, contribute to a better understanding of the petrogenesis and regional correlation of Deccan volcanic rocks, particularly in the northern Karnataka region.

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