pinia[11]. Flowers with rudimentary styles never set fruit, because they are devoid of a normal style and stigma, however, the function of the ovules in this category is not known.

Caesalpinia produces energetically expensive flowers during early stages of inflorescence growth while less energetic and less expensive medium and short styled flowers at later stages might act as a reserve for the possible risk of floral predation[12,13]. This developmental plasticity of floral function mediated by energy constraints may also be adaptive in increasing pollination efficiency. Because flowers are retained on the inflorescence for more than two days after blooming, the display size of an inflorescence would increase substantially when terminal flowers in an inflorescence are in bloom. This would also increase pollinator visitation, hence the plant may gain more through pollen export in the later stages of inflorescence growth[14,15].

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Trondhjemite of the Alwar basin, Rajasthan: Implications of late Proterozoic rifting in the North Delhi Fold Belt

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Ajitgarh pluton, a minor granite–trondhjemite body, intrudes the Delhi metasediments of Alwar basin in the North Delhi Fold Belt (NDFB). The granite and trondhjemite, representing different pulses of anorogenic felsic magmatism, are distinct from the syntectonic granites of NDFB. The present work is also the first report of trondhjemite from Proterozoic environs of northwestern Indian peninsular region. Ajitgarh trondhjemite (AT) demonstrates trondhjemite mineralogy and chemical characters consistent with parameters prescribed for trondhjemite nomenclature. It is enriched in silica and depleted in CaO, MgO and FeO, as compared to the Archean TTG, and appears to be genetically related to the anorogenic magmatism of sodic affinity.

THE Trondhjemite–Tonalite–Granodiorite (TTG) association, a characteristic feature of the Archaean granite–greenstone terranes, is hitherto unreported from the Proterozoic Delhi Super-group rocks from northern fringe of Indian peninsular shield. We report here the trondhjemite occurrence from a trondhjemite–granite suite from Ajitgarh pluton (27°26'N: 75°50'E), a minor intrusive body in the North Delhi Fold Belt.

Ajitgarh pluton, a composite granite–trondhjemite body, intrudes the sericite quartzite of Delhi Supergroup. The geological set-up of the area is shown in the lithostratigraphic map (Figure 1). The contact between country rocks and the intrusive granitoids is obliterated by alluvial sand cover. Intrusive nature of the pluton is manifested by its emplacement discordant to the regional structural grain. Post-orogeny emplacement of granitoids is evident from absence of planar fabric, other textural characters and discordant nature of the pluton.

The generalized geological set-up of the area is summarized below:

Quartz–pegmatite veins
Granite
Trondhjemite
–Intrusive contact–
Sericite quartzite

The trondhjemite (AT), occupying the southeastern part of the pluton is in sharp contact with granite and

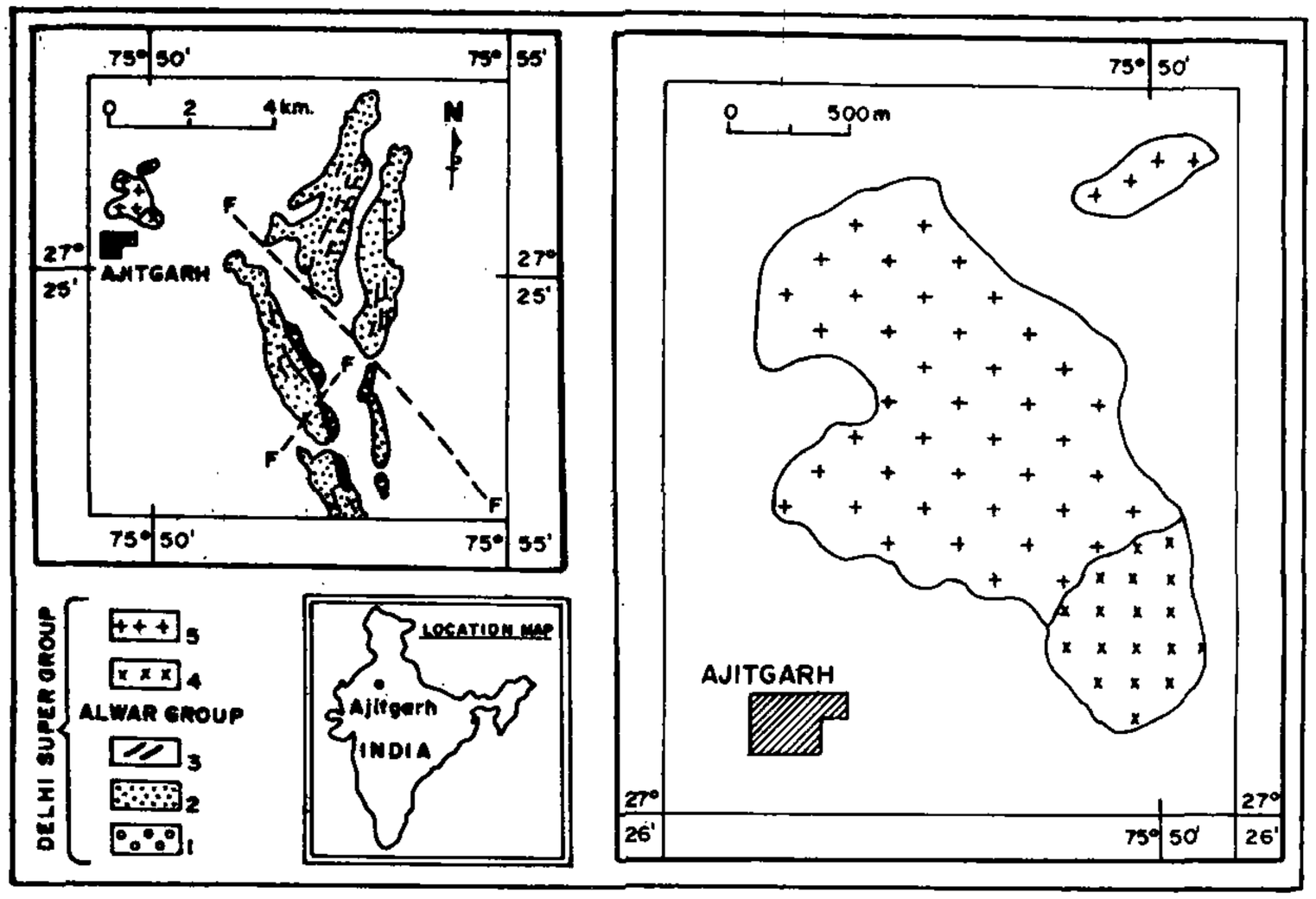


Figure 1. *a*, Map of Shahpura area showing regional lithological setting. *b*, Lithological map of Ajitgarh pluton showing distribution of trondhjemite and granite. Map of India showing location of Ajitgarh is also given in the inset. 1, Conglomerate; 2, Sericite quartzite; 3, Amphibolite; 4, Trondhjemite; 5, Granite.

Table 1. Modal composition of Ajitgarh trondhjemite

Sample no.	1	2	3	4	5	6	7	8	9	10
Quartz	39.5	38.0	43.0	45.5	47.0	44.5	40.0	47.5	44.5	45.5
Plagioclase	43.0	41.0	40.0	39.0	38.0	37.0	43.0	38.5	40.0	39.0
K-Felspar	12.0	9.5	11.0	10.0	10.0	11.5	10.5	8.5	12.0	11.0
Hb and Augite	3.5	8.5	4.5	1.0	2.5	3.5	2.5	3.0	2.0	1.5
Sphene	1.5	2.5	1.0	3.5	1.0	2.5	1.5	1.5	1.0	1.0
Opaque	0.2	–	0.5	0.5	2.0	0.5	2.0	1.5	0.5	1.5
Others	0.5	0.5	–	0.5	0.3	0.5	0.5	–	–	0.5

Hb, Horblende; Others: Allanite, Zircon, Epidote.

represents an earlier magmatic phase. Both trondhjemite and granite are dissected by younger tourmaline pegmatite veins.

Ajitgarh trondhjemite (AT) is a medium to coarse-grained holocrystalline, non-foliated, massive and compact, leucocratic rock with predominant hypidiomorphic granular texture. Major mineral phases are quartz and plagioclase (oligoclase) with minor alkali felspar, augite and hornblende. Sphene is the most abundant accessory mineral besides less significant zircon, epidote and allanite. Biotite is conspicuously absent.

Quartz, the most abundant mineral, is present as equant, anhedral grains. Plagioclase (oligoclase), ranging from An_{24} to An_{14} (determined by Michel–Levy method) shows limited compositional variation. The plagioclase laths show moderate sericitization and also demonstrate replacement relationship with quartz. Augite ($Z \wedge C = 24°$), occurring as anhedral grains, invariably shows replacive relationship with hornblende. Subhedral hornblende grains are characterized by strong pleochroism in shades of dark bluish green to pale green ($Z > Y > X$). In majority of cases, hornblende shows perfect reaction texture with augite where it is seen mantling the latter. K-felspar is mainly microcline microperthite with a few grains of orthoclase. Sphene is present both as rhombic crystals and as anhedral grains. In the hornblende free varieties, it is the only coloured mineral noticed. In majority of cases it appears to be a late crystallizing phase. Well developed zircon crystals are usually present as inclusions within larger plagioclase laths. Epidote, allanite and opaque are the other minerals noticed.

Table 2. Major element data for Ajitgarh trondhjemites and (CIPW) normative mineral composition

Sample no.	1	2	3	4	5	6	7	8	9	10
SiO_2	75.02	73.84	73.27	76.47	78.65	77.45	75.74	78.04	78.32	78.15
TiO_2	0.37	0.34	0.38	0.30	0.34	0.29	0.41	0.35	0.35	0.35
Al_2O_3	12.05	12.56	12.96	12.21	12.17	12.23	12.60	12.23	12.38	12.48
Fe_2O_3	0.46	0.59	0.85	0.43	0.13	0.26	0.47	0.36	0.24	0.39
FeO	1.15	1.43	1.97	1.04	0.31	0.66	1.66	0.88	0.57	0.99
MnO	0.04	0.04	0.05	0.03	0.02	0.03	0.03	0.04	0.03	0.02
MgO	0.54	0.53	0.34	0.20	0.32	0.24	0.25	0.10	0.09	0.08
CaO	1.51	1.36	1.36	0.53	0.62	0.72	0.92	0.59	0.58	0.55
Na_2O	4.80	4.40	3.96	4.11	4.24	4.01	4.60	4.08	4.42	4.63
K_2O	1.66	1.59	1.43	1.51	1.58	1.53	1.38	1.50	1.53	1.51
P_2O_5	–	–	–	–	–	–	–	–	–	–
	97.60	98.68	96.57	96.83	98.38	97.42	97.56	98.17	98.51	99.15
CIPW Norms										
Q	36.40	37.70	40.26	45.06	47.48	46.56	40.85	47.36	46.42	44.26
Or	9.81	9.40	8.45	8.92	9.34	9.04	8.16	8.86	9.04	8.95
Ab	40.62	37.23	33.51	34.78	35.88	33.93	38.92	34.52	37.40	39.18
An	6.95	6.75	6.75	2.13	0.38	2.53	4.56	1.93	0.30	2.23
C	0.41	1.13	2.43	3.03	3.45	3.05	1.89	3.19	3.31	2.23
Hy	2.54	2.97	3.23	1.61	0.26	1.17	1.74	0.81	0.35	0.36
Mt	0.67	0.86	1.23	0.62	0.10	0.38	0.68	0.52	0.35	0.28
Il	0.70	0.65	0.72	0.57	0.65	0.55	0.78	0.66	0.66	0.49

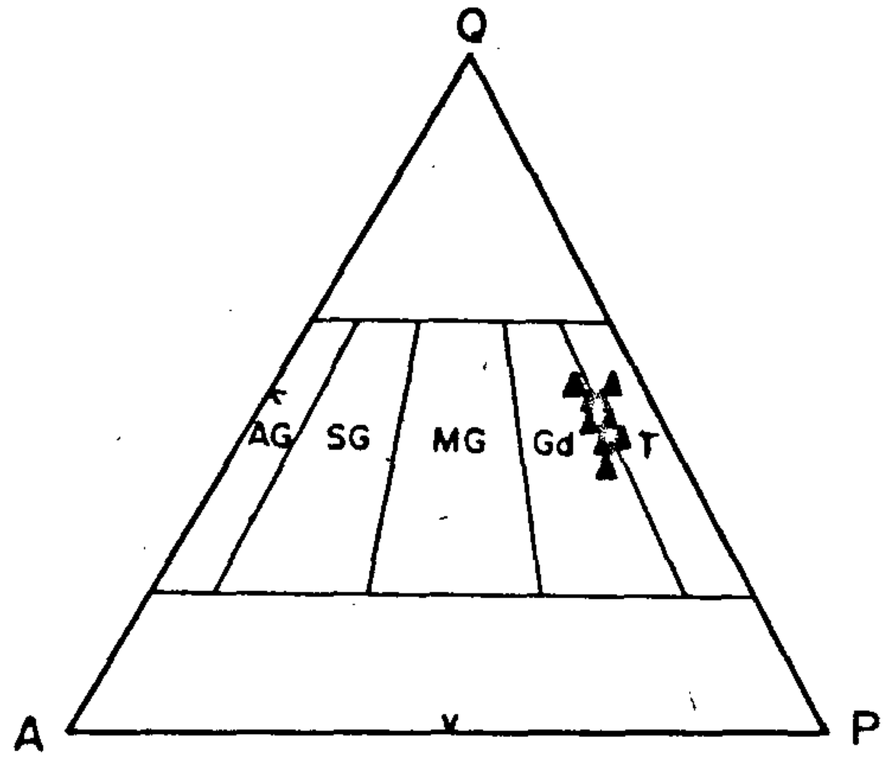


Figure 2. Modal QAP diagram of Ajitgarh trondhjemites. T, Tonalite; Gd, Granodiorite; MG, Monzogranite; SG, Syenogranite and AG, Alkali granite.

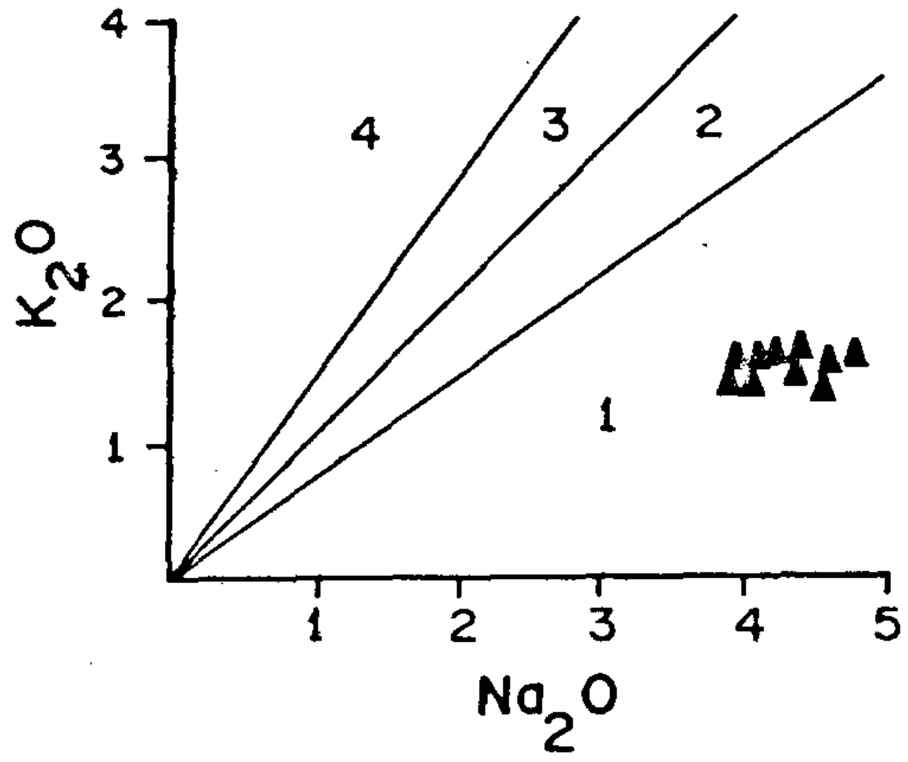


Figure 3. Na_2O–K_2O diagram showing tonalitic character o 1, Tonalite; 2, Granodiorite; 3, Adamellite; 4, Granite.

Table 3. Comparison of AT with trondhjemite values

	Trondhjemites[1]	Ajitgarh trondhjemite (Present data)
SiO_2	68–75%	73.27–78.65%
Al_2O_3	<14% at 75% SiO_2	12.07–12.96%
FeO(t) + MgO	<3.4	0.75–3.08
Na_2O	4–5.5%	3.96–4.80%
K_2O	<2%	1.38–1.66%
CaO	1.5–3%	0.53–1.51%

Paragenetic relationships indicate initial plagiocl pyroxene crystallization, followed by separatio quartz and hornblende. Sphene and epidote mark terminal phase of crystallization. The textural chara do not suggest any deformation as evident by eq nature of quartz grains, absence of preferred mi orientations and absence of recrystallization.

Modal mineralogical composition of AT shows dominance of quartz and plagioclase (together cons ing more than 80–85% of total rock volume) over

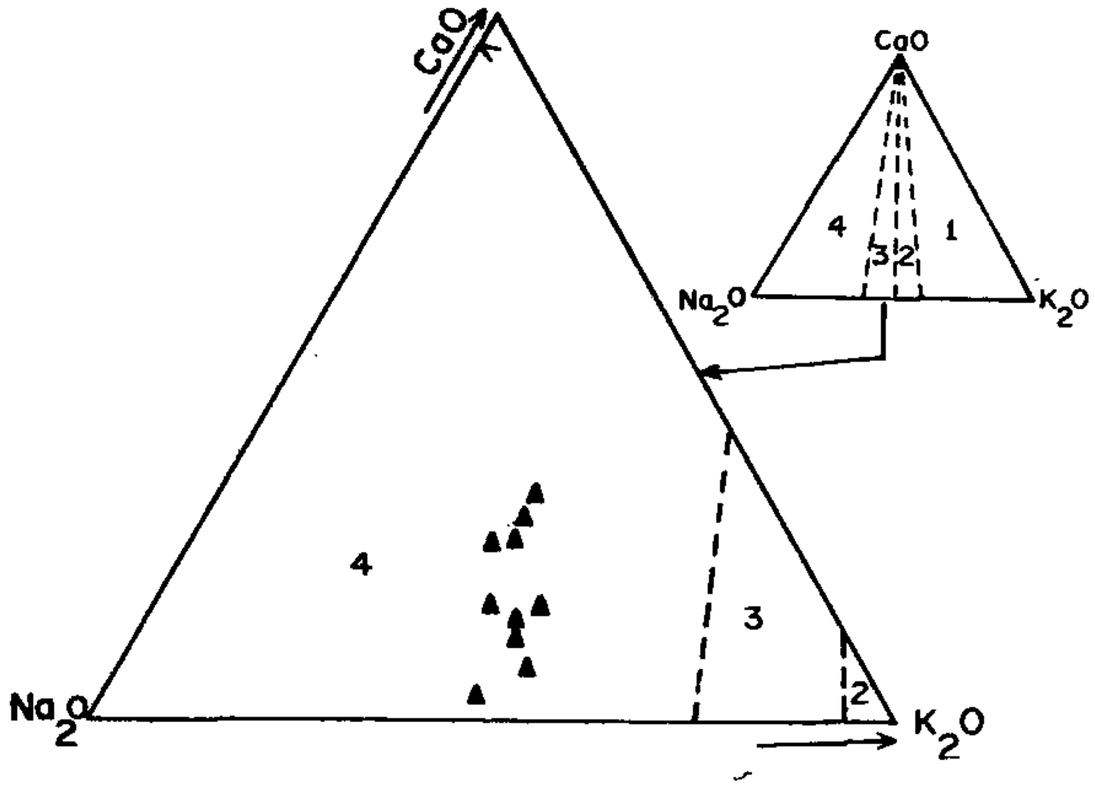


Figure 4. Na_2O–K_2O–CaO diagram showing tonalitic character of AT. 1, Granite; 2, Quartz monzonite; 3, Granodiorite; 4, Tonalite.

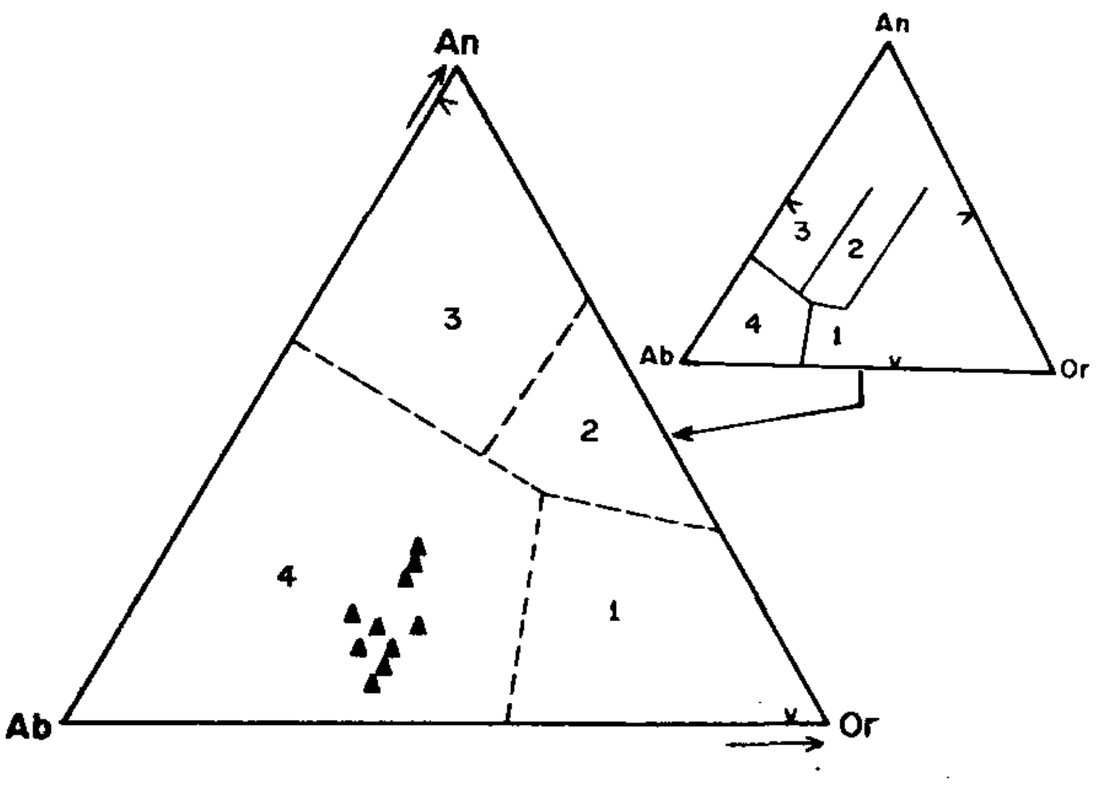
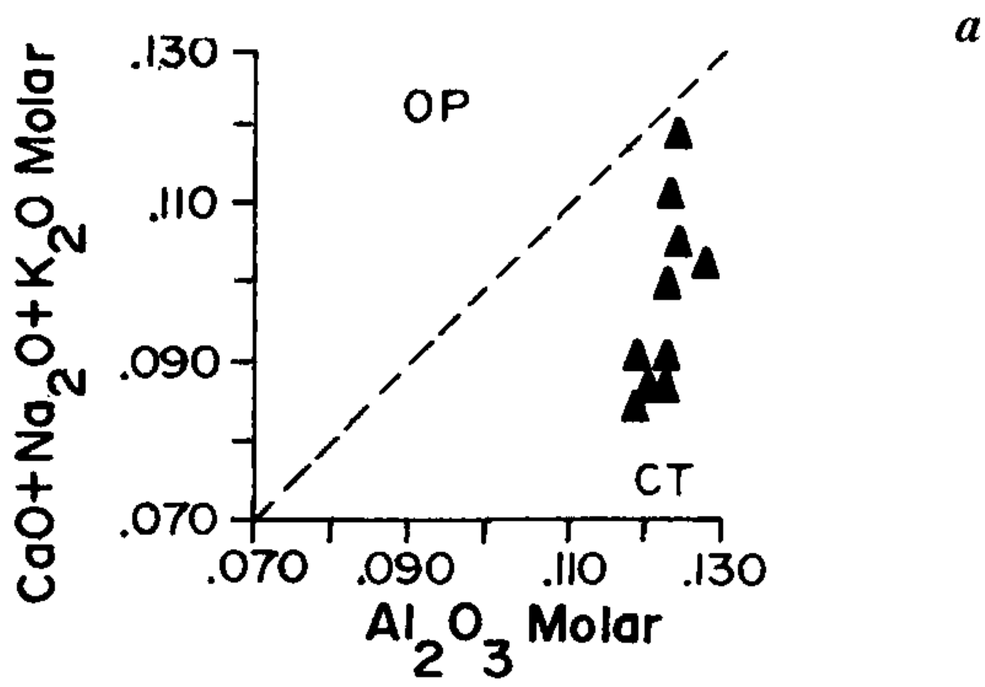
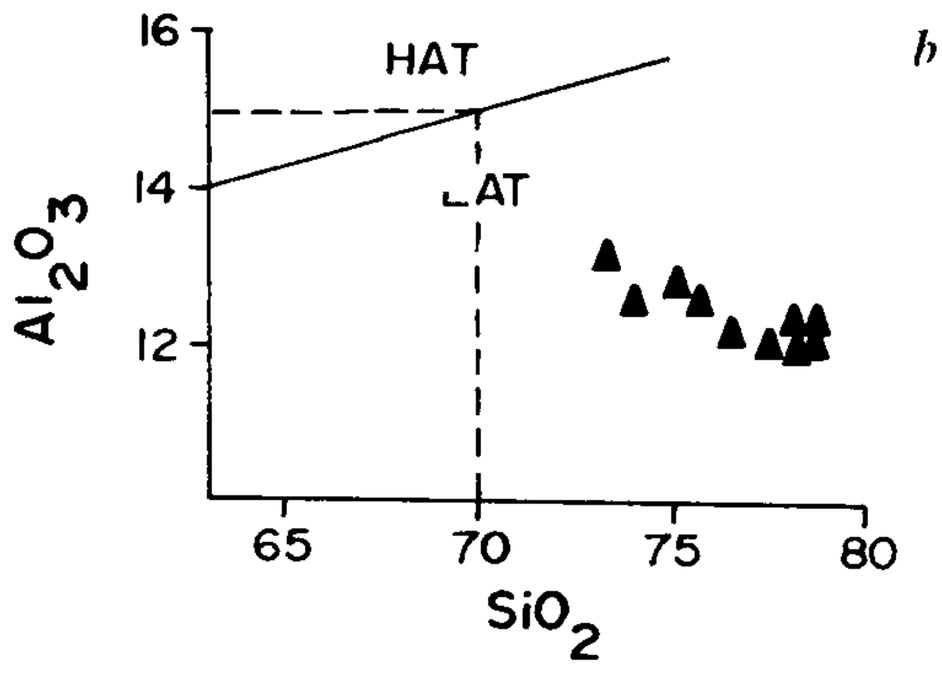


Figure 5. Normative Ab–An–Or diagram showing trondhjemitic nature of AT. 1, Granite; 2, Granodiorite; 3, Tonalite; 4, Trondhjemite.

minerals (Table 1). K-felspar concentration is about 10% whereas augite and hornblende, together show minor variation from 1 to 4.5% (with one sample having a high value of 8.5%). Sphene concentration is quite consistent, varying from 0.5 to 3%. In the modal Q–A–P diagram the AT plot in the tonalite–granodiorite fields (Figure 2).

The trondhjemitic character of AT is further substantiated by chemical parameters. The major element data on ten representative AT samples are given in Table 2. Chemical homogeneity indicates their cogenetic nature. High Na_2O/K_2O ratio (2.68 to 3.33) underlines sodic affinity. Appearance of normative corundum is attributed to low CaO and K_2O and does not indicate any alumina over saturation. Major element data for AT are within the prescribed ranges for trondhjemite and elemental abundances are coherent with typical trondhjemite values[1] (Table 3).





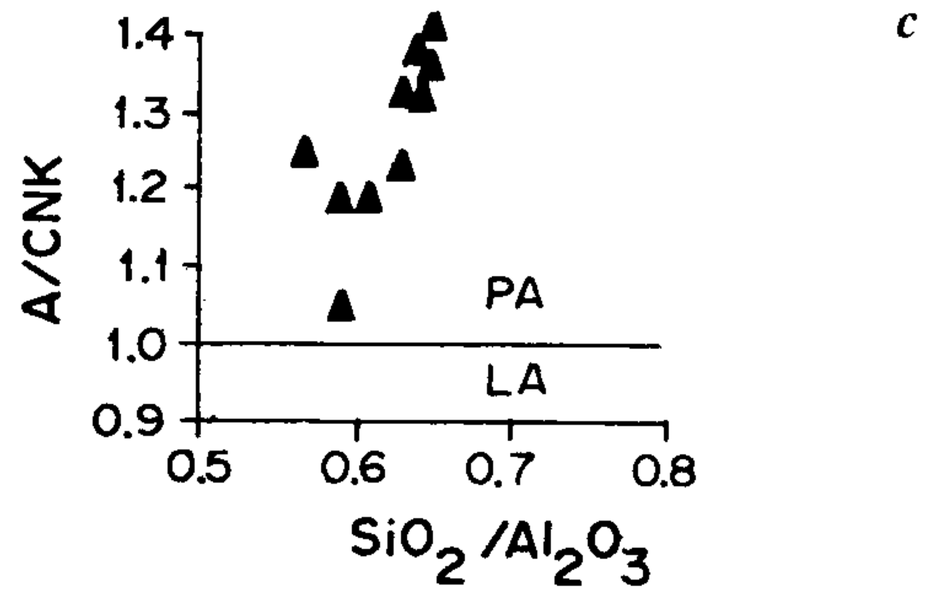


Figure 6 *a–c*. *a*, Molar A–CNK diagram showing continental trondjemitic affinity of AT. CT, Continental Trondjemite; OP, Oceanic Plagiogranites; *b*, SiO_2–Al_2O_3 diagram showing low alumina nature of AT. HAT, High Alumina Trondhjemite; LAT, Low Alumina Trondhjemite; *c*, A/CNK–SiO_2/Al_2O_3 diagram. PA, Peraluminous; LA, Low aluminous.

The AT shows slightly higher silica and lower CaO than prescribed for trondhjemitic rocks. The highest CaO value of 1.51 is at par with the lower limit for trondhjemite. An FeO/MgO ratio of 2 to 3 has been suggested for trondhjemite. In the present case the ratio varies from 1.33 to 12.73, with majority ranging from 2.54 to 5.06.

Alkali ratio has been a significant parameter in granitoid nomenclature and felsic rocks with sodic affinity

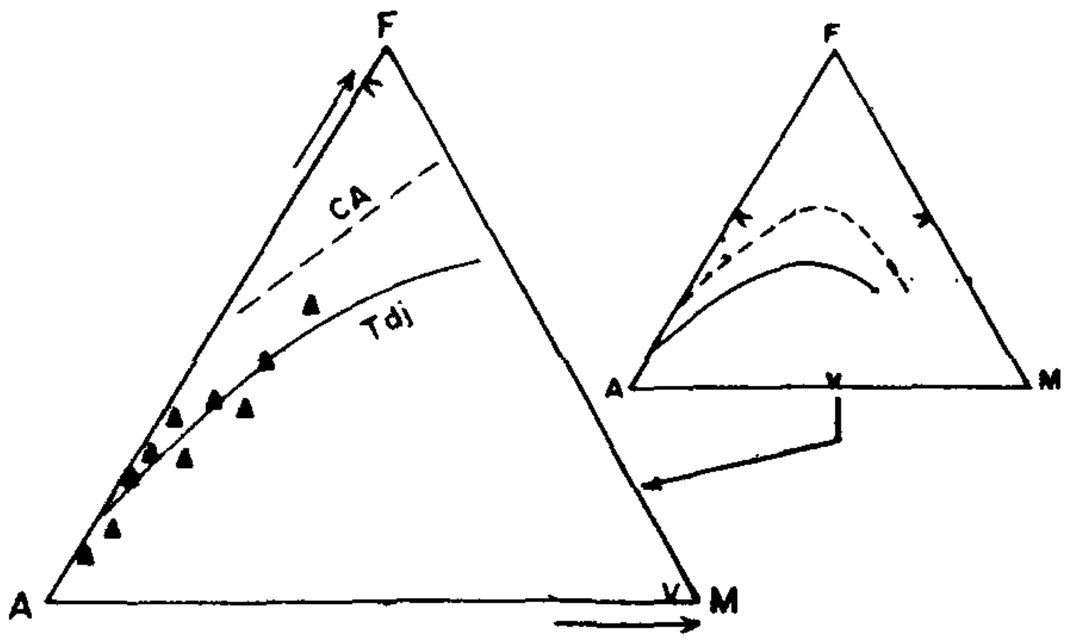


Figure 7. AFM diagram showing trondhjemitic trend.

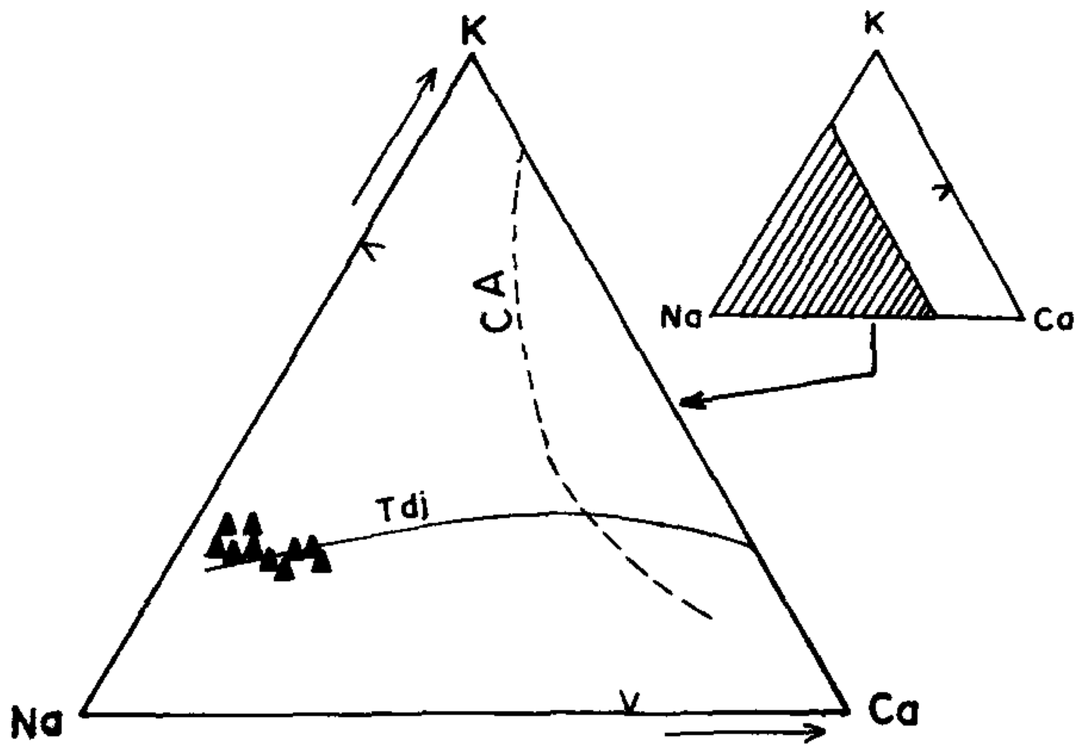


Figure 8. Na–K–Ca diagram showing trondhjemitic differentiation trend for AT. Tdj, Trondjemite; CA, Calc-alkaline.

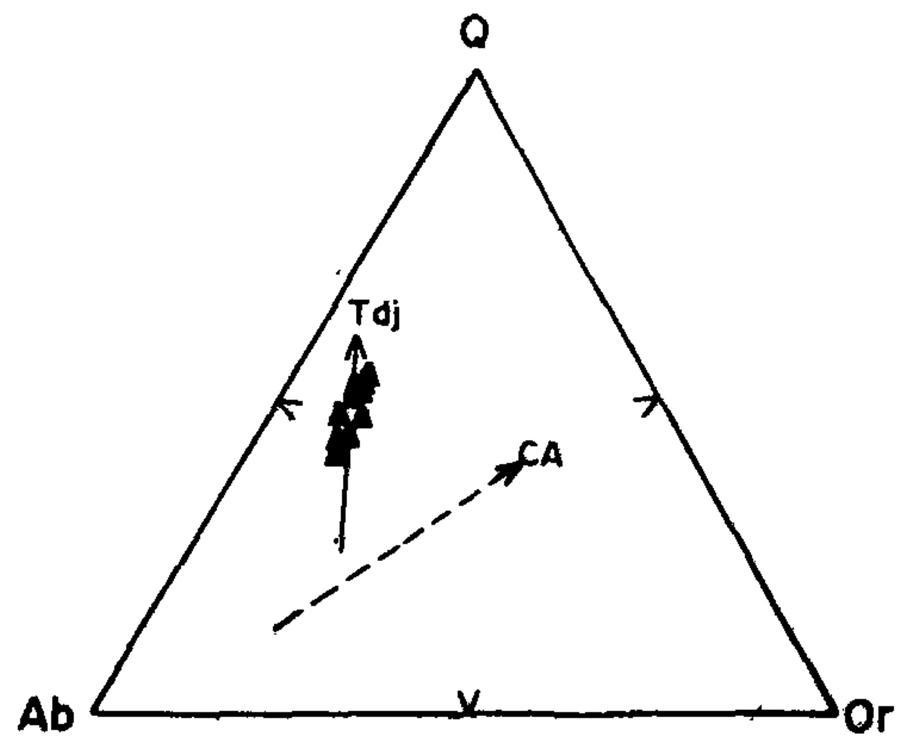


Figure 9. Normative Ab–Q–Or diagram showing trondjemitic trend for AT. Tdj, trondhjemite; CA, calc-alkaline.

($Na_2O/K_2O > 2$) have been named as tonalite[2]. In the Na_2O–K_2O and Na_2O–K_2O–CaO diagrams[3], AT plot in the tonalite field (Figures 3 and 4). In the normative Ab–Or–An diagram[1] also, the AT shows discrimination with tonalite and unambiguously plot in the trondhjemite field (Figure 5). Continental trondhjemitic affinity of AT is reflected in A/CNK ratio of > 1. In the molar A–CNK diagram (Figure 6), these plot in the continental trondhjemite field, quite distinct from oceanic plagiogranites[4]. In the A/CNK–SiO_2/Al_2O_3 diagram, these plot in the peraluminous field. In the Al_2O_3–SiO_2 diagram these plot in the Low Alumina Trondhjemite field. The fields, proposed for a silica range up to 70% have been extended to accommodate silica-rich AT (Figure 6).

Trondhjemitic fractionation trend of AT is faithfully reflected in various sensitive discrimination schemes. In the AFM diagram, the AT plot along trondhjemitic trend (Figure 7). The distinction between classical calc-alkaline and trondhjemitic trends is also seen in Na–K–Ca and normative Ab–Q–Or diagrams (Figures 8 and 9) wherein the AT defines trondhjemitic path of descent.

Thus the mineralogical composition and chemical signatures establish the AT to be continental trondhjemite, *sensu stricto*.

Trondhjemites are characterized by moderate CaO, MgO and FeO for a given value of silica. A comparison of AT with Archaean trondhjemites underlines broad chemical similarity although minor deviations are discernible. The AT are relatively enriched in silica and depleted in CaO, MgO and FeO, however, the alkali abundances are comparable. The average CaO abundance of 0.82% (range 0.53 to 1.51%) for AT is much below the usual values for Archaean TTG. However, a CaO value below 1% is not uncommon in Archaean TTG and CaO concentration as low as 0.29% has also been reported[5]. Relatively higher A/CNK for AT can be attributed to low CaO. The plagioclase in Archaean TTG is usually of oligoclase – andesine variety and in the present case the plagioclase (oligoclase) composition varies from An_{24} to An_{14}. Absence of biotite is a characteristic feature of AT. Minor biotite is usually present in Archaean TTG though pyroxene and amphiboles as the main mafic phases have also been reported.

Each felsic pluton has a distinct source and unique petrogenetic history, constraining any generalization. The difference between AT and Archaean TTG can be attributed to their distinct tectonic environments and evolutionary trends.

A 170 km long NNE–SSW trending lineament (extending between Khetri and Dudu), the 'albitite line' of Ray[6], represents a post orogeny rejuvenation of the rift system that controlled Delhi sedimentation. This intraplate magmatism has tentatively been correlated with 800 Ma anorogenic event[7]. Instead of a single 'albitite line' the intrusion seems to be along a number of subparallel fractures[8]. The lineament passes to the west of Ajitgarh pluton in close proximity. Post-orogenic emplacement of AT, its anorogenic tectonic

environment[9], sodic affinity and close proximity with intraplate sodic magmatism (albitite line) suggest a possible genetic link between two events. The relationship needs to be understood through detailed trace element and isotopic data.

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