# A STUDY OF HEAVY MINERALS OF THE ARENACEOUS ROCK-UNITS OF NORTHERN KUMAON HIMALAYA, WITH SPECIAL REFERENCE TO STATISTICAL ANALYSIS OF TOURMALINE AND ZIRCON

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## ABSTRACT

The paper presents a study of heavy minerals from the arenaceous rock-units (Precambrian) of northern Kumaon Himalaya, belonging to the Berinag Group, Hatsila Formation (a part of the Calc Zone of Tejam) and Loharkhet Group. The Berinag Group includes magnetite, tourmaline, zircon, pyrite, hematite, ilmenite, leucoxene, sphene and zoisite. The Hatsila Formation includes magnetite, tourmaline, limonite, zircon and leucoxene. The Loharkhet Group contains magnetite, zircon, tourmaline, hematite, limonite, rutile, apatite and epidote. Of all the heavy minerals, only tourmaline and zircon have been studied in detail because of their highest mineralogical and chemical stability with regard to the rigour of the environment of deposition. Various types of plottings/parameters have been done/statistically calculated, to show the nature of variation of the grain size and shape data ; they include : Smithson's diagrams, Haggerman scatter diagrams, elongation quotient, length-frequency curves, breadth-frequency curves and lengtht/breadth-frequency curves. As a result, it has been concluded that : (i) statistically, the shape and size of the heavy minerals are different for different rock units, though petrographically as well as by visual look, the host arenites show much similarities, (ii) increase in the frequency of tourmaline towards stratigraphically younger horizons of the Berinag Group, may serve as a tool for stratigraphic subdivision and correlation of these strata in other parts of Himalayas, (iii) the rock-units show wide dispersal pattern of grain size, (iv) conditions of sedimentation were different for different rock-units, (v) energy of the environment was also different for these rock-units, (vi) there is no similarity or mathematical dependence of any set of data upon another set, and (vii) the provenance or source area for the Berinag Group was composed of acid igneous rocks, mostly granites and related rocks, as well as pegmatites; the provenance of the Hatsila Formation and the Loharkhet Group was more or less similar to that of the Berinag Group, but in the case of Hatsila Formation, it was situated at a relatively farther distance from the site of deposition.

## INTRODUCTION

The paper incorporates a study of the heavy minerals from the arenaceous rock-units of the northern Lesser Kumaon Himalaya. It has been found that the various rock types in these rock-units tend to show, in most of the cases, similarities in their gross lithologic and petrographic attributes. Thus, one of the major objectives of the present study is also to mark out the elements of similarities and dissimilarities among the various grain size data of the heavy minerals of the rock-units under investigation. Statistical analysis of tourmaline and zircon has been done and the quantitative data on their size and shape has been compared. Petrographic attributes of the heavy minerals have been studied. Based on data of various heavy minerals, the provenance as well as the environment of deposition of the rocks have been discussed.

## ROCK-UNITS STUDIED

The sector of the northern Kumaon Himalaya studied (Fig. 1), falls in the Sarju, Pungar and Ramganga river valley areas, approximately between latitudes 29° 50′: 30° 6′ and longitudes 79° 41′ : 80° 0′. The area exposes a very thick succession of sedimentary rocks south of the Central Crystalline Axis. A thick sequence of calc-


*Geophytology*, **8** (2): 176-188, June, 1979.

argillaceous rocks—the Tejam Group (Calc Zone of Tejam) is underlain in the south by a thick sequence of quartzites : the Berinag Group—and overlain in the north by another quartzite group of rocks—the Loharkhet Group (MISRA & BHATTACHARYA, 1972). The Tejam Group has been further subdivided into four formations : Calcareous Doya Dolomite, predominantly argillaceous Hatsila Formation, calc-argillaceous Kapkot Formation and argillaceous Saling Slate. Of all these rock units, the Berinag Group and the Loharkhet Group are arenaceous in nature. Though, the Hatsila Formation is predominantly argillaceous, it also includes many quartzite beds, which tend to show similarities in their petrographic and lithologic attributes, with those of the former two groups. Thus, the heavy minerals of the following three rock-units have been studied : Berinag Group, Hatsila Formation and Loharkhet Group.

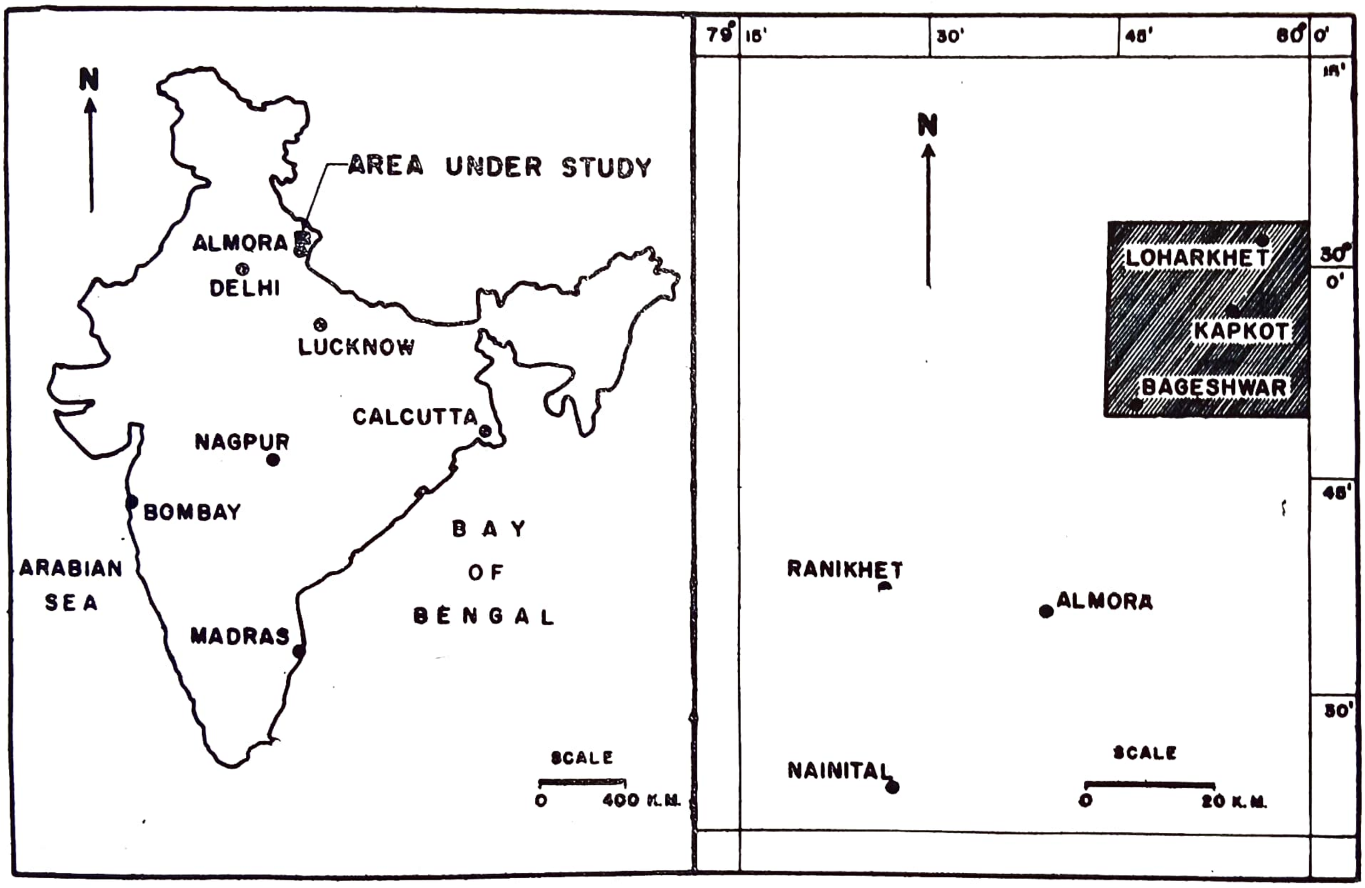


Fig. 1. Location in India and index map of the area showing the sedimentary belt under study.

The Berinag Group dominantly constitutes an arenaceous sequence consisting of orthoquartzites and a few argillaceous beds and basic rocks. High textural and mineralogical maturity is characteristic of the orthoquartzites of this group. The Hatsila Formation includes grey, green, olive, red, brown and black slates together with a few interstratified and lenticular beds of quartzitic sandstone and limestone. Textural-mineralogical maturity is relatively poor in Hatsila Formation. The Loharkhet Group is predominantly composed of orthoquartzites and a few interstratified beds of chlorite schists and amphibolites.Textural and mineralogical maturity of the arenaceous rocks of this group appears to be high. However, the degree of recrystallisation and the effect of metamorphism is relatively high in the orthoquartzites of this rock unit.

MISRA AND BHATTACHARYA (1972, 1973) worked out the geology, stratigarphy, structure and tectonics of this highly disturbed area. Later, they (MISRA & BHATTACHARYA, 1975) described the various primary sedimentary structures of the area and discussed their significance. BHATTACHARYA (1974) discussed the tectonic control of sedimentation in this part of Kumaon Himalaya. Earlier, broad outlines on the geology of the entire Kumaon Himalaya on a regional basis, have been given by HEIM AND GANSSER (1939 ) and GANSSER (1964).

HEAVY MINERALS

The heavy minerals of the arenaceous rock-units have been separated by the conventional bromoform method. For this purpose, the rock samples were ground down to the sieve size limit of —100 and +120 mesh, and the heavy minerals were separated by means of bromoform of specific gravity 2.89. The magnetic minerals were separated by Frantz Isodynamic separator.

The occurrence of the various heavy minerals, in order of their abundance, in various rock-units, is as follows :

Berinag Group : Magnetite, tourmaline, zircon, pyrite, hematite, ilmenite, leucoxene, sphene, zoisite
Hatsila Formation : Magnetite, tourmaline, limonite, zircon, leucoxene
Loharkhet Group : Magnetite, zircon, tourmaline, hematite, limonite, rutile, apatite, epidote

The distribution of the opaque minerals is as below ;

Berinag Group : Common—Magnetite, ilmenite (leucoxene), pyrite
Rare—Hematite
Hatsila Formation : Common—Magnetite, limonite
Rare—Hematite
Loharkhet Group : Common—Magnetite, hematite
Rare—Limonite

In general, tourmaline, zircon and iron ores are present in all the rock-units ; distribution of the others are, however, irregular. Some of the representative types have been sketched in Fig. 2. Brief notes on these are given below.

It may be mentioned here that under the microscope, the differences in the mineralogical properties of the heavy minerals in these three rock units are not always well-marked, unless pointed out in the description.

*Iron ores*—The iron ores include magnetite, hematite and limonite. Magnetite occurs as angular to well-rounded grains, and appears black to bluish black in reflected light. Hematite occurs as irregular or rounded grains with reddish brown colour in reflected light. Irregular grains of limonite show brown colour in reflected light. The distinction between hematite and limonite is not always marked.

*Tourmaline*—It occurs in various forms—prismatic with irregular terminations, rounded to well rounded, and irregularly fractured. It also shows various colours—indigo, dark brown, green yellowish brown. Combination of two or even more of these colours is also present. Strong pleochroism is a characteristic feature. Authigenic outgrowths and zoning are occasionally seen. Inclusions of opaque minerals and liquid infillings are common.

*Zircon*—It occurs in various forms—rounded to subrounded equant, prismatic and angular with euhedral margins. Colour ranges from pink or purple pink to almost colourless; the latter type is rare. The grains occur with, as well as without, inclusions. Zoning, rounded outlines, pitted surfaces and authigenic outgrowths are common. Degree of roundness is maximum in those which belong to the Loharkhet Group.

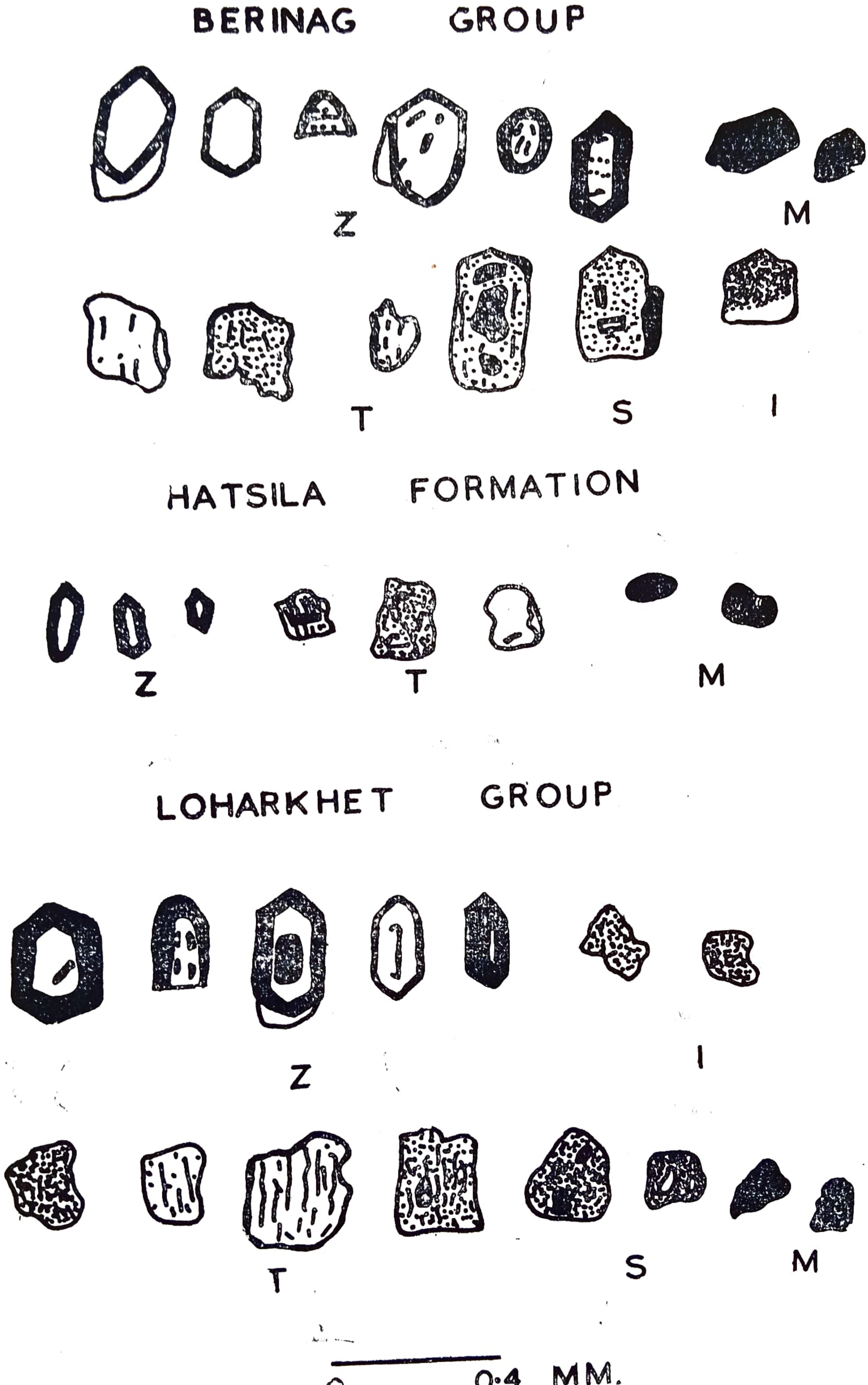


Fig. 2. Camera lucida sketches of the representative heavy minerals of the Berinag Group, Hatsila Formation and Loharkhet Group. T—tourmaline, Z—zircon, M—magnetite, I—ilmenite, S—sphene.

*Sphene*—It occurs as brown to light brown grains showing irregular to slightly rounded habit, showing faint pleochroism. Irregular fractures and dusty inclusions are sometimes present.

*Rutile*—The grains are of reddish brown colour, and are prismatic, pyramidal or irregular in habit. A few grains are authigenic.

*Ilmenite*—It shows brownish black colour in reflected light and commonly occurs as irregular to well-rounded grains. It usually shows complete or partial alteration to leucoxene.

*Pyrite*—It occurs as irregular aggregates or as well-developed euhedra. Metallic lustre and yellow colour in reflected light, are characteristic features.

*Zoisite*—It is commonly colourless ; rarely, with shades of green or red. Inclusions and faint pleochroism are common.

*Apatite*—Grains are colourless and usually show prismatic to rounded habits.

*Epidote*—The colour is greenish yellow. Grains are almost equant with subrounded outlines. Pleochroism is faint.

## STATISTICAL ANALYSIS OF TOURMALINE AND ZIRCON

In the present section, statistical analysis of the grain size data for tourmaline and zircon have been incorporated. The objective of such studies is mainly to ascertain the element of similarities or dissimilarities among the various rock-units, especially to note the differences in the various quartzites of the area. The significance of such studies rests on the fundamental principle that statistical properties of sediments are related to the environment of deposition.

Of all the heavy minerals, only tourmaline and zircon have been studied, because among the heavy minerals present in the quartzites, these two have the highest mineralogical and chemical stability with regard to the rigour of the environment. Moreover, they have also not been affected by metamorphism, which the sedimentaries of the present area have undergone.

Various types of representation of the heavy mineral data for the Berinag Group, Hatsila Formation and the Loharkhet Group, are given below. They mainly include : (A) Smithson's diagrams, (B) Elongation Quotients and (C) Frequency curves.

### (A) SMITHSON'S DIAGRAMS

The length (l) and breadth (b) of tourmaline and zircon grains have been counted by a micrometer eyepiece, and the length-breadth relationships (Smithson's diagrams) have been plotted on graphs (Fig. 3). It is seen that the shape and size of the catanae are different for different rock units.

The catanae for tourmaline for all the three rock units lie flatly on the 1 : 1 line, and are confined within the 1 : 5 line. However, the distribution pattern of points is different for different rock units. In the Loharkhet Group, there is a tendency for maximum concentration between the 1 : 1 and 1: 2 lines.

The catanae for zircon show marked differences in the distribution pattern of points. All the catanae lie flatly on the 1 : 1 line and touch the 1 : 5 line. In the Berinag and Loharkhet Groups, the points tend to show wide distribution between the 1 : 1 and 1 : 5 lines. In the Hatsila Formation, the maximum concentration is confined to the 1 : 2 and 1 : 5 lines.

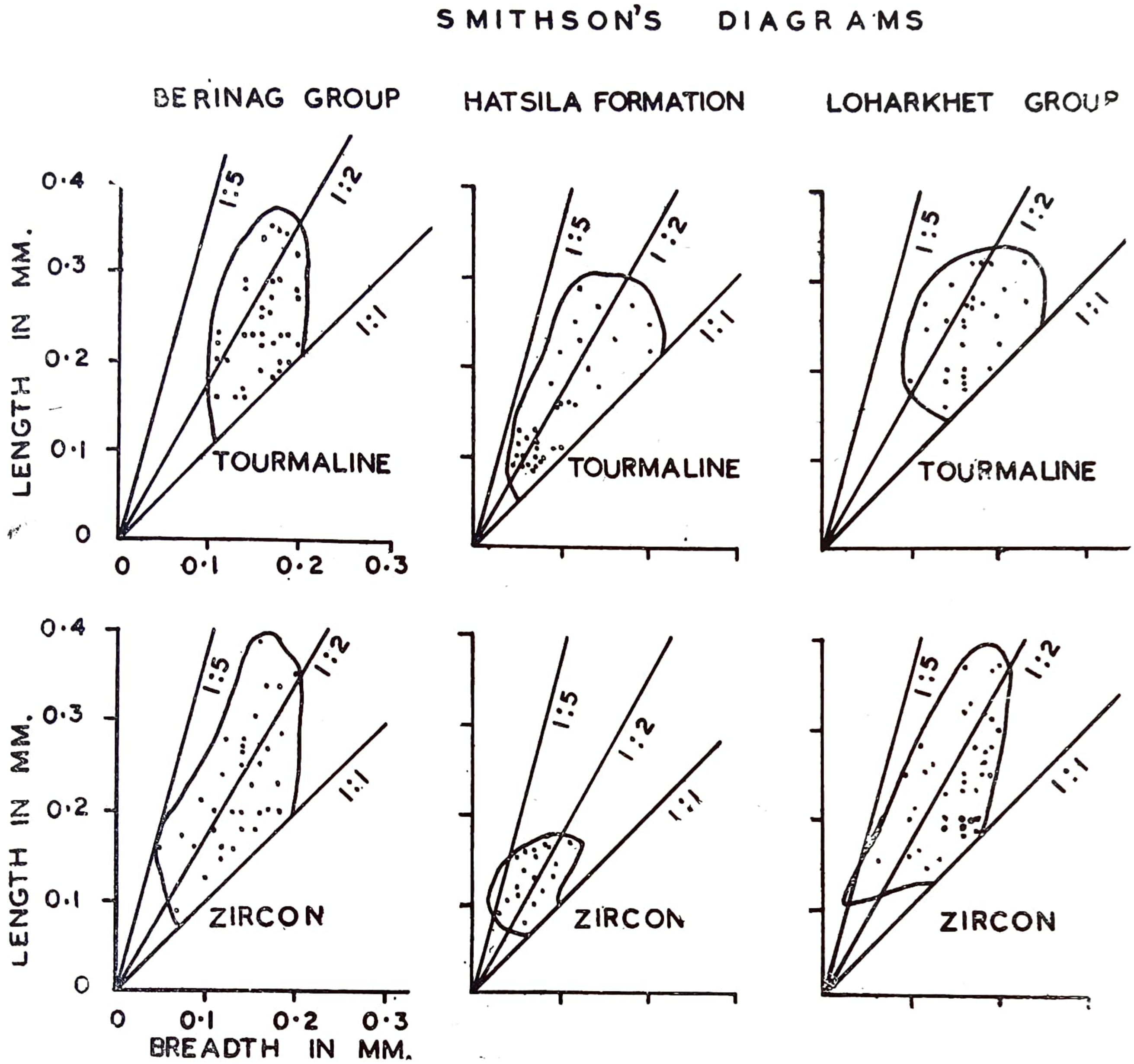


Fig. 3. Smithson's diagrams showing the length-breadth relationships existing in the tourmaline and zircon grains of the Berinag Group, Hatsila Formation and Loharkhet Group.

## (B) Elongation Quotient

Theoretically, the length (l) and breadth (b) of a detrital grain is governed by the energy of the environment of deposition. Thus, any value of the elongation quotient, i.e., the ratio of the length and breadth of the detrital grains, will correspond to a particular set of environmental conditions. For this purpose, elongation quotients of tourmaline and zircon grains of the Berinag Group, Hatsila Formation and the Loharkhet Group, have been calculated, and their distribution pattern has been shown in Fig. 4.

On the basis of the elongation quotient measurements, it may be concluded that the energy of the environment was different for these rock units.

## (C) Frequency Curves

The frquency percentages of length, breadth and length/breadth have been calculated for suitable ranges. Thus, three types of curves have been plotted.

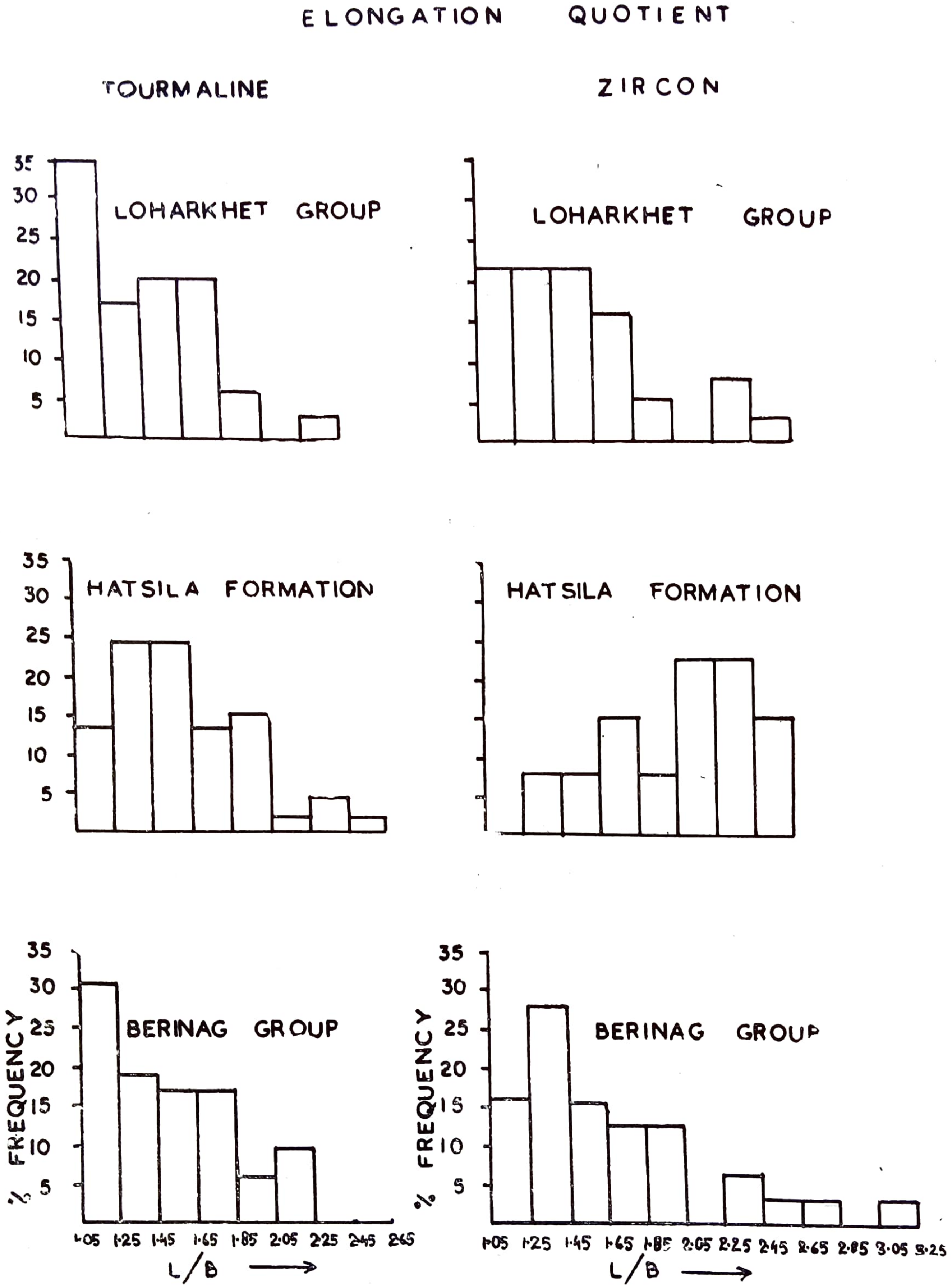


Fig. 4. Elongation quotients of tourmaline and zircon grains of the Berinag Group, Hatsila Formation and Loharkhet Group.

(i) *Length frequency curves*

The various curves drawn between length and frequency percentage of tourmaline and zircon for different rock-units have been shown in Fig. 5.

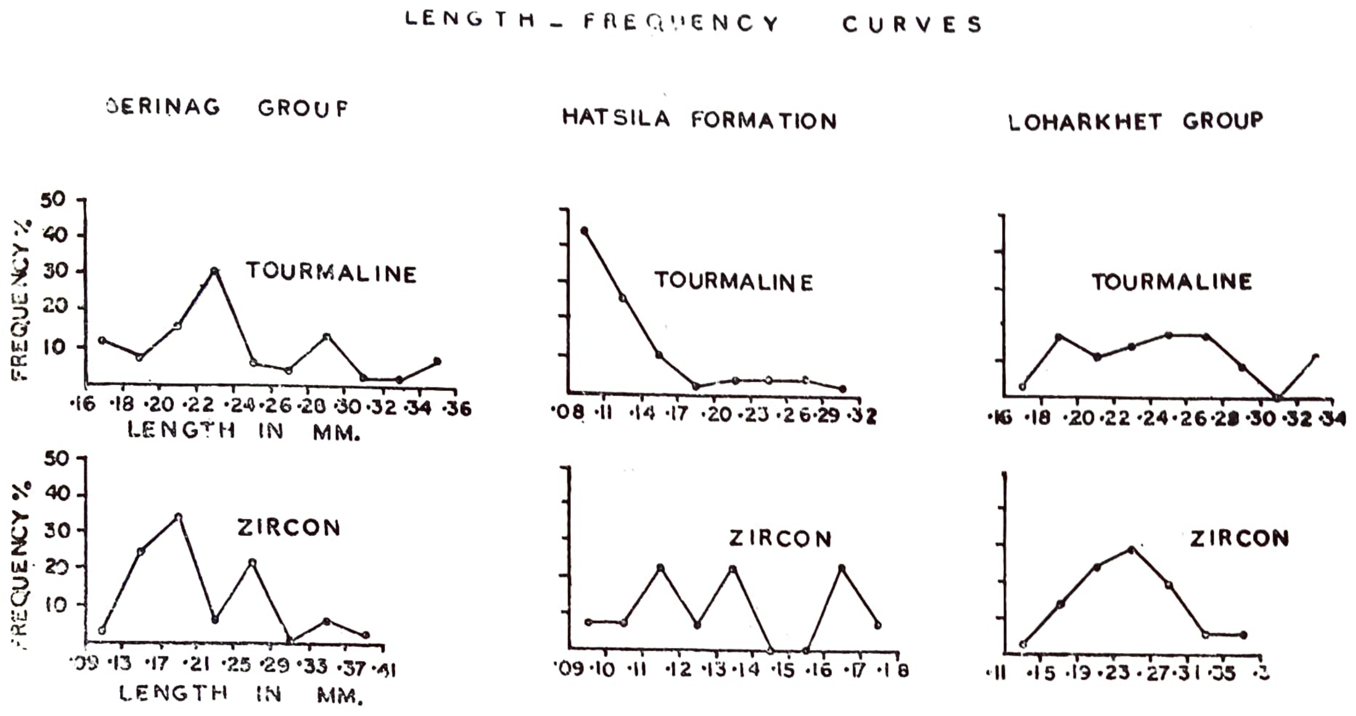


Fig. 5. Length—frequency curves for tourmaline and zircon grains of the Berinag Group, Hatsila Formation and Loharkhet Group. It can be seen that all the curves are dissimilar, as the maxima and minima of none of these curves coincide.

Tourmaline, in the Berinag Group, shows a peak at 30.8 per cent between 0.22 and 0.24 mm, and a frequency range of 1.9 to 30.8 per cent; in the Hatsila Formation, a peak at 44.4 per cent between 0.08 to 0.11 mm and a frequency range of 2.2 to 44.4 per cent ; in the Loharkhet Group, a more or less uniform frequency distribution pattern between 0 to 60 per cent with no prominent peak(s). All these three curves are different in their nature.

Zircon, in the Berinag Group, shows a peak at 34.75 per cent between 0.17 to 0.21 mm and a frequency range of 0 to 34.75 per cent; in the Hatsila Formation, three peaks each at 23.0 per cent at different values of length and a frequency variation of 0 to 23.0 per cent; in the Loharkhet Group, a peak at 29.7 per cent between 0.23 to 0.27 mm, and a frequency range of 2.7 to 29.7 per cent. All the three curves are of different nature.

All the length-frequency curves, as one can see from the diagrams, are dissimilar, because the maxima and minima of none of these curves coincide. Further, the peaks for both tourmaline and zircon fall under different class intervals.

(ii) *Breadth-frequency curves*

Curves obtained by plotting the breadth of tourmaline and zircon against their frequency percentages have been shown in Fig. 6.

Tourmaline, in the Berinag Group, shows a peak at 27 per cent between 0.13 to 0.15 mm and a frequency variation of 11.5 to 27.0 per cent in the Hatsila Formation, a peak at 60.0 per cent between 0.05 to 0.08 mm and a variation of 2.2 to 60 per cent ; in the Loharkhet Group, a peak at 60.0 per cent between 0.16 to 0.19 mm and a variation of 5.7 to 60.0 per cent. All the curves are different in shape.

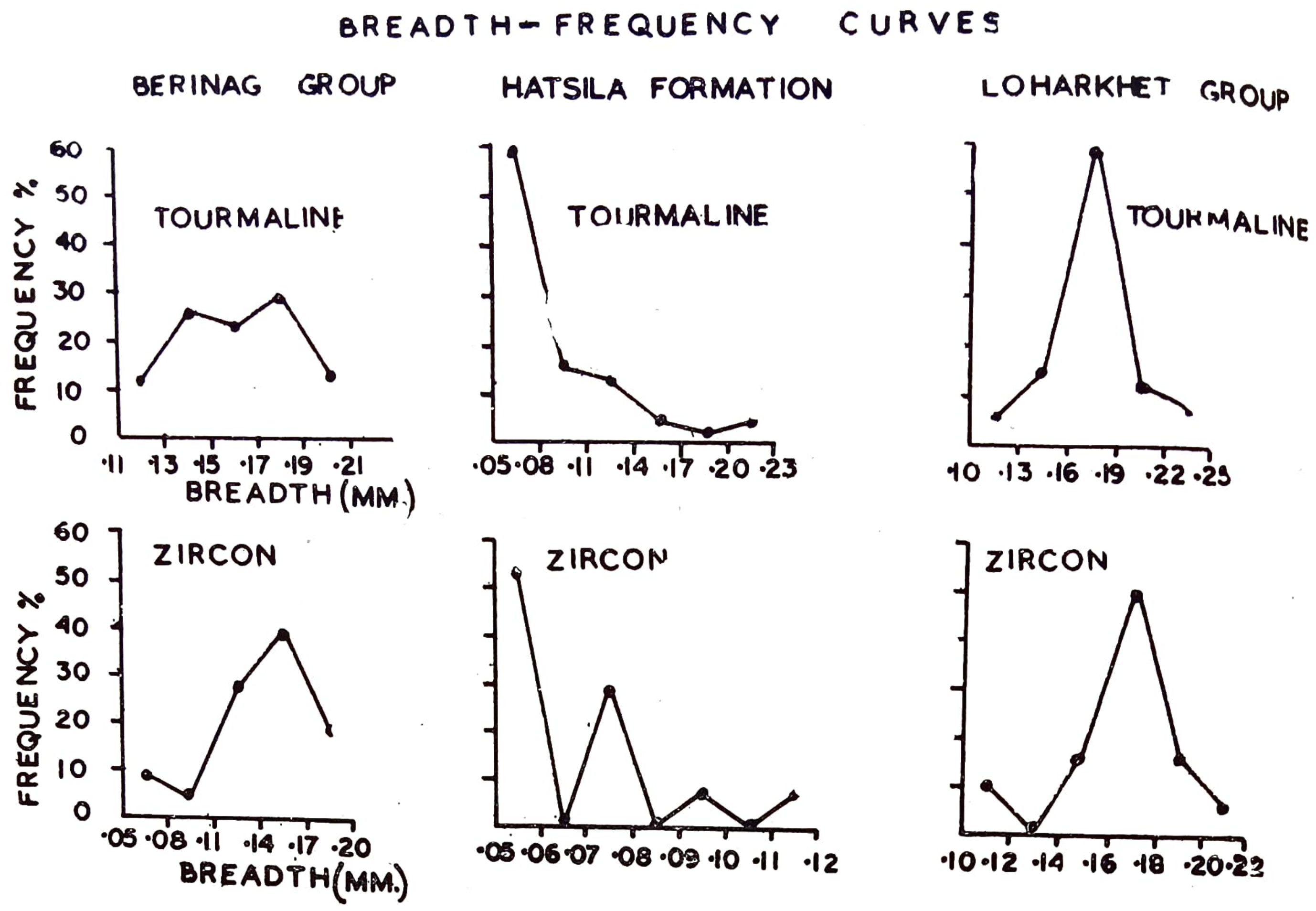


Fig. 6. Breadth—frequency curves for tourmaline and zircon for the three rock units studied. One can notice similarities for tourmaline and zircon for the respective rock units with minor variation trend in the Hatsila Formation. Further, the optimum values of breadth for Hatsila Formation are much smaller than both the Berinag and Loharkhet groups.

Zircon, in the Berinag Group, shows a peak at 40.6 per cent between 0.14 to 0.17 mm and a variation of 3.12 to 40.6 per cent ; in the Hatsila Formation, a peak at 53.8 per cent between 0.05 to 0.06 mm and a variation of 0 to 53.8 per cent ; in the Loharkhet Group, a peak at 51.4 per cent between 0.16 to 0.18 mm and a variation of 0 to 51.4 per cent.

In the above-mentioned curves, one can notice striking similarities for tourmaline and zircon for the respective rock units with minor variation trend in the Hatsila Formation. Further, one can also note that the optimum values of b for Hatsila Formation are much smaller than both the Berinag and Loharkhet Groups.

(iii) *Length/breadth-frequency curves*

Curves drawn between length/breadth and frequency percentage of tourmaline and zircon for different rock-units have been shown in Fig. 7.

Tourmaline, in the Berinag Group, shows a peak at 26.9 per cent between 1.05 to 1.25 mm and a range of 5.8 to 26.9 per cent ; in the Hatsila Formation, a peak at 35.5 per cent between 1.10 to 1.40 mm and a variation of 2.2 to 35.5 per cent ; in the Loharkhet Group, a peak at 34.2 per cent between 1.05 to 1.27 mm and a variation of 0 to 34.2 per cent.

Zircon, in the Berinag Group, shows a peak at 46.9 per cent between 1.11 to 1.50 mm and a variation range of 0 to 46.9 per cent ; in the Hatsila Formation, a peak at 38.5 per cent between 2.04 to 2.34 mm and a range of 0 to 38.5 per cent ; in the Loharkhet Group, a peak at 32.4 per cent between 1.35 to 1.58 mm and a variation of 0 to 32.4 per cent. The variation trends of the curves for the Berinag and Loharkhet groups tend to show some similarities between them, but one can see diversities in the case of the Hatsila Formation.

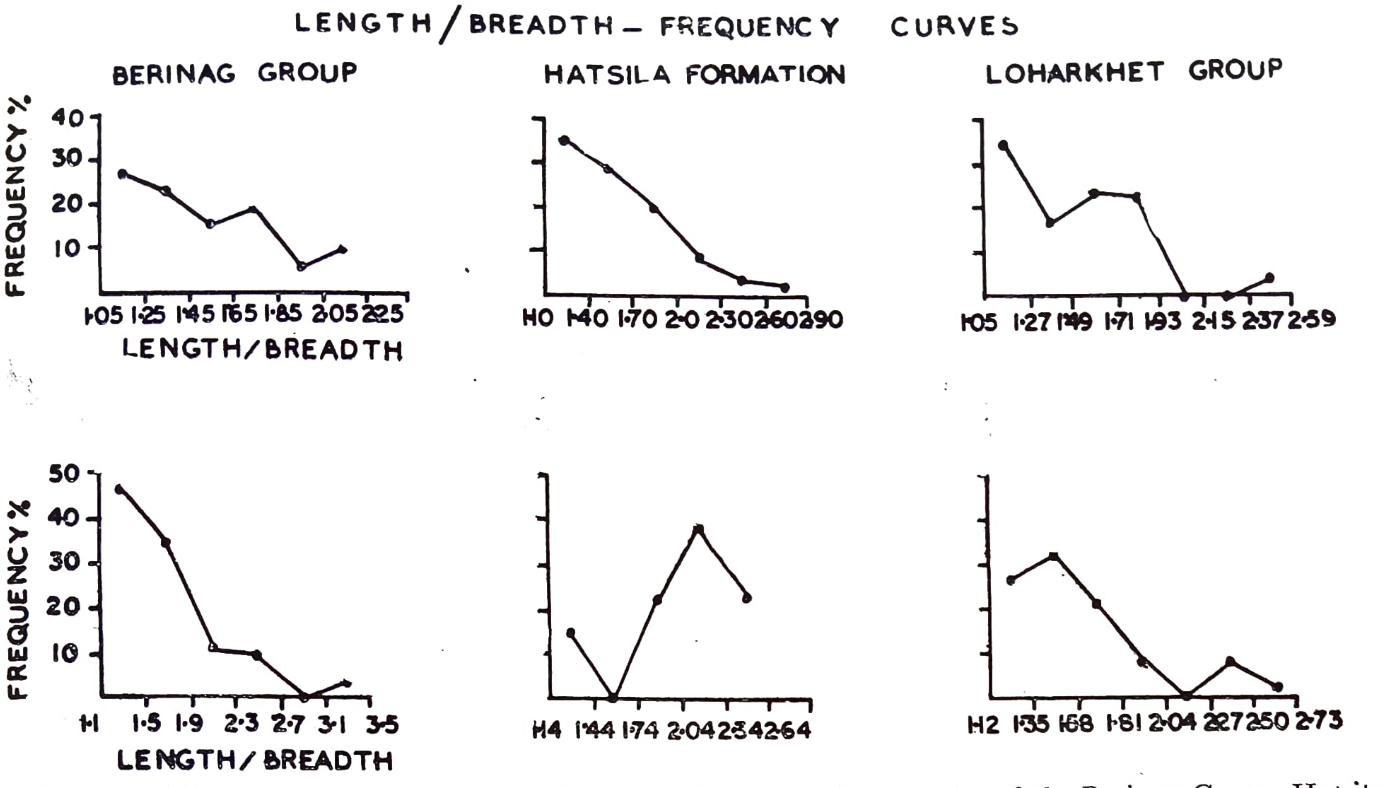


Fig. 7. Length/breadth—frequency curves for tourmaline and zircon grains of the Berinag Group, Hatsila Formation and Loharkhet Group. It can be seen that the variation trends of the curves for the Berinag and Loharkhet groups tend to show some similarities between them, but one can notice diversities in the case of the Hatsila Formation.

## PROVENANCE

The various types of assemblages of heavy (as well as light) minerals tend to present a complicated picture of the provenance or the source area of the sedimentary sequences of the area under study. This picture has further been complicated because of the fact that some of the minerals have also developed due to metamorphism. Varied nature of quartz (which forms the most dominating constituent) as well as some other minerals, indicates that the provenance was not composed of homogeneous lithology. Absence of feldspar from all the arenaceous groups is a noteworthy feature in this context.

On the basis of heavy mineral studies, the nature of provenance has been interpreted, which is given below.

### Berinag Group

(1) This group is characterised by the abundance of the heavy mineral suite tourmaline-zircon-magnetite. This indicates an igneous provenance of the acid type, constituted of granites and the related rocks.

(2) From the Smithson's diagrams, it can be seen that the catanae lie towards 1 : 5 line. This indicates that the source area was composed of magmatic rocks.

(3) Sphene, euhedral zircon, igneous quartz, magnetite and pink tourmaline indicate an acid igneous terrain, and the typical blue tourmaline (indicolite), possibly to the pegmatites.

(4) The relatively high euhedrality of zircon also possibly corresponds to an igneous source area.

### Hatsila Formation

(1) The provenance for the arenites of the Hatsila Formation, appears to bear similarities with that of the Berinag Group.

(2) Presence of a small number of heavy mineral species, coupled with a relatively finer texture of the constituents of these rocks, might indicate that the provenance was situated at a relatively farther distance from the area of deposition. This contention is further supported by the presence of the minerals of high mineralogical and textural stability like quartz, tourmaline and zircon.

(3) The remaining features of zircon and tourmaline are similar to those of the Berinag Group, thus, indicating an acid igneous provenance for the arenites of this formation.

### Loharkhet Group

(1) The arenites of the Loharkhet Group are also characterised by the abundance of the heavy mineral suite : tourmaline-zircon-magnetite, and their provenance also appears to be more or less similar to that of the Berinag Group.

(2) However, detailed studies have revealed the following characters:

(i) Zircon is marked by overgrowths.

(ii) The tourmalines, which are of various colours, also show marked inclusions.

(iii) Perfectly prismatic euhedral crystals are not common.

(iv) The highly terminated pyramids are rare in tourmaline and rounded edges are also commonly seen in tourmaline grains.

(v) Rutile is also sometimes present.

In all probability, the above-mentioned features indicate a provenance of granitic gneisses formed due to high grade of metamorphism and granitisation of sediments (Poldervaart, 1950, 1956 ; Wyatt, 1954 ; Ecleman & Kulp, 1956 ; Ecleman & Poldervaart, 1957).

### CONCLUSION

As a result of the above mentioned studies, the following conclusions have been arrived at :

(1) Tourmaline, zircon and iron ores are present in all the three rock units studied, viz., Berinag Group, Hatsila Formation and Loharkhet Group. Distribution of other heavy minerals are, however, irregular. For example, sphene and zoisite are found only in Berinag Group ; rutile, apatite and epidote are found in Loharkhet Gourp ; in the Hatsila Formation, the variety of species is very restricted.

(2) Though, petrographically as well as by visual look, the rocks of the rock-units studied bear similarities with each other but statistically, the shape and size of the heavy minerals are different for different rock-units.

(3) One important inference is that the frequency of occurrence of tourmaline in the Berinag Group, has been found to increase towards stratigraphically younger horizons of this Group. In the abesnce of any fossil record to act as a marker horizon, the above mentioned observation can be applied as a tool for stratigraphic subdivision and correlation of these strata.

(4) From the study of Smithson's diagrams, the following conclusions have been arrived at :

(i) That the catanae of zircon for the Berinag and Loharkhet Groups, tend to be elongate in the direction between 1 : 2 and 1 : 5 lines without touching the 1 : 1 line. This tendency of elongation clearly indicates magmatic origin of the rocks containing these zircon crystals (Poldervaart, 1956).

(ii) In the case of Hatsila Formation, the catanae of zircon lie flatly on 1 : 1 line and shows a tendency to extend towards the 1 : 5 line. This feature of the catanae indicates that the zircons have passed through a long process of erosion, transportation and deposition (LARSEN & POLDERVAART, 1957). This conclusion is also supported by the following observations from the present area :

(*a*) Only tourmaline and zircon are the main constituting heavy minerals, (*b*) Less stable species are absent, (*c*) Sizes of tourmaline and zircon are very small, and (*d*) Very high degree of roundness of tourmaline and zircon.

(iii) In the case of tourmaline of Berinag and Loharkhet groups, the convexity of the catanae is directed towards 1 : 5 line. This indicates a source area composed of magmatic rocks. However, in the case of tourmaline of the Hatsila Formation, the catanae show undulations, rather than convexity, towards 1 : 5 line, thus, indicating granitised or gneissic provenance.

(5) The haphazard pattern shown by the lateral and vertical spread of the histograms for the elongation quotient, indicates that the energy of the environment was different for the rock-units studied. However, one can see unimodal (rarely, slightly bimodal) pattern for the Berinag and Loharkhet groups, indicating that the energy of the environment was, to some extent, closely identical. On the other hand, there is a distinct polymodal pattern in the case of Hatsila Formation which indicates that random and well marked variations existed throughout the depositional history of this Formation.

(6) The provenance for the Berinag Group was composed of acid igneous rocks, mostly granites and related rocks, as well as pegmatites. The provenance of the Hatisla Formation and Loharkhet Group was more or less similar to that of the Berinag Group, but in the case of Hatsila Formation, it was situated at a relatively farther distance from the site of deposition.

(7) Presence of stable varieties of heavy minerals (mainly tourmaline and zircon) and absence or marked deficiency of relatively less stable species in all these rock-units, indicate prolonged weathering of a broad, low relief region in the source area under more or less stable tectonic conditions. This, coupled with the absence of angular grains, indicates long transportation before final deposition.

(8) For obvious reasons, the Central Crystalline Zone of the Higher Himalaya appears to be the source area for all these sedimentary rock formations. This Crystalline Zone consists of Archaean and Precambrian gneisses, migmatites, schists, quartzites and large intrusions of granites.

(9) The stable tectonic framework of the source and depositional areas as well as the long period of peneplantation and diastrophic quiscence accompanied by vigorous and prolonged chemical decay in the initial stages of basin development, ultimately resulted in the abundance of these ultra-stable heavy minerals.

## ACKNOWLEDGEMENTS

The author is grateful to Prof. S. N. Singh, Head of the Department of Geology, Lucknow University, for providing laboratory and library facilities, and to Prof. R. C. Misra for critically going through the manuscript. The work was started under financial assistance from the Wadia Institute of Himalayan Geology, Dehra Dun, in the form of a teacher-grantee, but could be completed only through the financial assistance from the

Indian National Science Academy, New Delhi. The author is thankful to both these agencies.

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