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# Garnets from the Upper Swat Hornblendic Group, Swat District, Pakistan. Part I: Garnets from gneisses and pegmatites

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SUMMARY. Chemical analyses of eleven garnets from orthogneisses and related pegmatites, belonging to the Upper Swat Hornblendic Group, Pakistan, are presented along with the petrographic descriptions of the host rocks. The garnets show dominant almandine content, followed by grossular pyrope, spessartine, and andradite, in order of relative abundance. One garnet sample is different from the rest in having higher andradite and spessartine contents and higher refractive index, and is also different in habit. This is the first detailed study of garnets from Pakistan.

THE so-called Upper Swat Hornblendic Group of Martin *et al.* (1962) outcrops over large areas in Swat District, Pakistan, and extends to the north-east as well as south-west, forming a belt more than 200 km in length. It is considered to be of probable Precambrian age, although Jan *et al.* (1973) assigned to it a Late Cretaceous age. The rock types reported from this complex are mainly diorites and norites, with minor intrusions of ultramafic as well as acidic compositions. The rocks are metamorphosed to amphibolites and gneisses in their southern exposures. Certain lithotypes belonging to this group show conspicuous sporadic development of reddish brown to pinkish brown crystals of garnet. The garnets included in the present study were collected from eleven locations within the southern part of the Upper Swat Hornblendic Group (fig. 1).

## *Petrography of the garnetiferous rocks*

The modal compositions of the garnetiferous rocks from eleven localities (fig. 1) are reported in Table I. Gneisses and pegmatites are the major lithotypes hosting garnets of this area. The gneisses contain abundant epidote and only a little feldspar. These rocks are subdivided on a textural basis into:

*Homogeneous crystalloblastic gneisses* (sample nos. 16016 to 16019). These are typical gneisses of the area, and differ from others only in being homogeneous texturally. The rock is composed of abundant epidote (both clinozoisite and pistacite), bluish-green hornblende, partly to fully twinned plagioclase, alkali feldspar, quartz, and minor amounts of sphene, magnetite, and rare tourmaline (16017). Garnet crystals are idioblastic and relatively bigger garnet grains have quartz-rich envelopes.

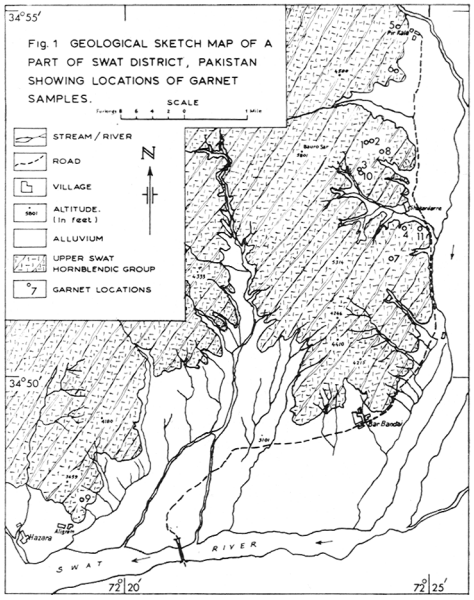


FIG. 1.

TABLE I. *Modal composition of garnetiferous rocks (vol. %)*

| Rock | Homogeneous crystalloblastic gneisses | | | | Xeno-blastic granular gneiss | Grano-blastic band | | Porphyroblastic gneisses | | Pegmatites | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specimen no. | 16016 | 16017 | 16018 | 16019 | 16020 | 16021 | | 16022 | 16023 | 16024 | 16025 | 16026 |
| Locality on fig. 1 | *1* | *2* | *3* | *4* | *5* | *6* | | *7* | *8* | *9* | *10* | *11* |
| Garnet | 5·2 | 9·7 | 4·1 | 4·8 | 5·9 | 6·6 | 3·3 | 11·4 | 6·8 | 7·1 | 3·9 | 28·8 |
| Epidote | 42·1 | 48·5 | 34·6 | 10·5 | 28·1 | 9·2 | 30·7 | 15·1 | 25·4 | 0·8 | 5·7 | 3·7 |
| Hornblende | 29·5 | 17·8 | 37·2 | 12·7 | 48·6 | 3·7 | 18·8 | 39·5 | 25·3 | — | — | — |
| Quartz | 4·5 | 5·3 | 13·1 | 35·5 | 5·0 | 45·5 | 26·1 | 18·9 | 24·0 | 40·2 | 35·4 | 41·5 |
| Alkali feldspar | 3·9 | 5·1 | 3·6 | 19·3 | 4·0 | 32·3 | 11·3 | — | 9·3 | — | 51·3 | 21·7 |
| Plagioclase | 1·8 | 2·3 | 2·7 | 10·6 | — | | 3·0 | 1·2 | 0·5 | | | |
| Muscovite | 7·9 | 6·0 | 3·1 | 3·8 | 2·5 | 1·0 | 3·9 | 0·9 | | — | — | tr |
| Biotite | 2·2 | tr | 0·5 | 0·6 | — | 0·3 | 1·0 | 2·1 | 7·2 | — | — | 2·8 |
| Chlorite | 0·9 | tr | tr | 1·2 | 3·0 | 0·2 | 1·0 | — | | — | 2·1 | 0·80 |
| Sphene | 1·3 | 2·0 | 0·8 | 0·9 | 2·2 | 1·2 | 0·9 | 0·3 | 0·4 | 0·4 | 1·6 | — |
| Magnetite | 0·7 | 0·5 | 0·5 | tr | 0·6 | — | tr | 0·6 | 0·6 | 0·5 | — | 1·0 |
| Limonite | tr | tr | tr | — | tr | — | — | tr | tr | tr | — | — |
| Tourmaline | — | 2·6 | — | — | — | — | — | 10·0 | — | — | — | — |
| Anorthite % in plagioclase | 30 | 36 | 32 | 43 | n.d. | 40 | 37 | 38 | n.d. | 36 | 31 | 28 |
| $\gamma$:[001] in hornblende | 14° | 20 | 21·5 | 22 | 27 | 22 | | 21 | 27 | — | — | — |
| Max. diam. of garnets (mm) | 1·8 | 3·36 | 1·4 | 0·08 | 2·70 | 1·25 | | 2·03 | 1·07 | 1·84 | 2·95 | 4·05 |

*Xenoblastic granular gneisses* (sample no. 16020). In addition to textural differences, these gneisses contain more hornblende and less epidote than the homogeneous gneisses described above. Pistacite is found as zoned crystals and alkali feldspars as patchily saussuritized grains. There is little plagioclase and chlorite is of two generations. Garnet is the only idioblastic mineral of these gneisses.

*Porphyroblastic gneisses* (sample nos. 16021 to 16023). These gneisses are characterized by the porphyroblasts of hornblende, epidote (more than hornblende), garnet, and rarely of plagioclase ($An_{37}$ to $An_{38}$) set in a matrix composed of hornblende, quartz, and andesine. Minor amounts of sphene, magnetite, biotite, and muscovite are ubiquitous, while green tourmaline may be developed locally. Porphyroblasts of epidote and hornblende may show a sieve texture, enclosing abundant subhedral quartz. Sometimes these gneisses have thin veins and streaks of granoblastic texture running through them (16021). In some others (16022) epidote porphyroblasts are of smaller size than those of hornblende.

Garnet in these gneisses shows an imperfectly developed atoll structure, having poikiloblastic central parts and compact outer zones. Garnet in few cases may also appear as much smaller euhedral crystals with or without zonally arranged minute inclusions.

*Pegmatites* (sample nos. 16024 to 16026). Coarse-grained quartzo-feldspathic pegmatites occur both as concordant layers and as discordant veins cutting all other rock-types of the area. Pegmatite bodies range in thickness from a few inches to several feet. Their quartz is xenoblastic but plagioclase ($An_{28}$ to $An_{36}$) forms coarse grains that may be unaltered (16026) or may show patchy saussuritization. Greenish brown sphene is sometimes present. They contain hornblende very rarely (none in the samples studied), although a little epidote is usually present.

Garnet appears colourless in thin sections, and is traversed by numerous fractures that may be straight linear or curvilinear. Minute flakes of reddish brown biotite lie inside, and parallel to, fractures of garnet grains, or sometimes they are found sticking tangential to garnet grain-boundaries. Some light-green chlorite is also associated with biotite.

The garnet crystals from one pegmatite (16026) display faint chocolate colour and corroded outlines (fig. 2), which contrast with idioblastic outlines of all other garnet samples. The garnet of this locality occurs accumulated in definite bands inside the pegmatite body.

### *Chemistry of the garnets*

The chemical analyses of eleven garnet samples are reported in Table II, along with recalculated values in terms of five end-member 'molecules'. All the garnet samples are pyralspites ranging in grandite content from 13·91 to 26·20 %. They contain a dominant almandine 'molecule', followed by grossular, pyrope, spessartine, and andradite. The garnet analyses reported in the present study show that in ten garnet specimens (16016–25), the MnO content ranges from 1·15 % to 2·90 % by weight, while in only

one specimen (16026) the MnO percentage becomes 4·85. In addition to having a higher manganese content, this specimen also possesses higher CaO and $Fe_2O_3$ percentages, and lower FeO and MgO percentages than all other analysed samples. Compared to the garnets from striped amphibolites of Connemara, Western Ireland (Leake, 1972), these garnets show a lower $TiO_2$ content.

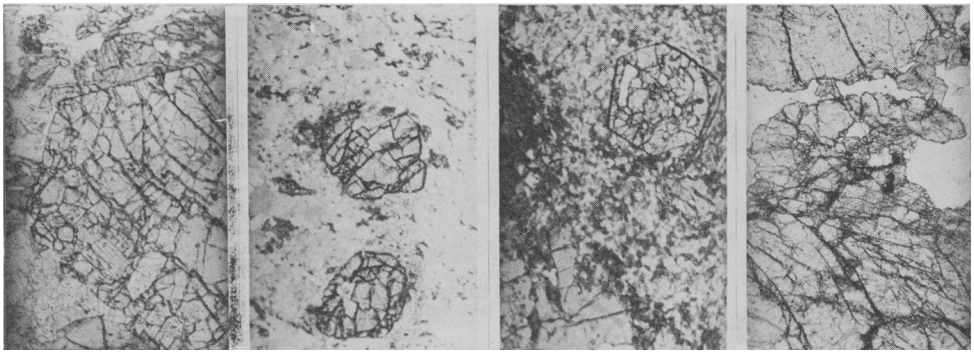

FIG. 2. Photomicrographs from the garnetiferous rocks. Height of each photograph is 1·95 mm. From left to right: *a*—garnet in homogeneous crystalloblastic gneiss. Quartz and epidote are seen as inclusions in garnet crystals, whereas the darker mineral outside garnet is hornblende. Plane polarized light. *b*—two garnet grains from a granoblastic felsic band in a porphyroblastic gneiss, showing quartz inclusions, many fractures, little alteration. Plane polarized light. *c*—idioblastic garnet showing atoll structure seen in porphyroblastic gneiss (16023). The xenoblastic porphyroblasts of hornblende and epidote are also partly visible. Plane polarized light. *d*—coarsely crystalline, corroded garnet grains lacking idioblastic outlines from sample No. 16026 showing abnormal (Chinner, 1960) contrast with habit of less manganiferous garnets shown in *a–c*. The opaque ore is a single phase magnetite (without ilmenite). Plane polarized light.

Refractive index (*n*) determinations for all the eleven garnet samples (Table II) show a very small variation, except for a slightly higher value for the Mn-rich specimen (16026). The higher refractive index of this garnet is related directly to its higher spessartine and andradite contents.

## *Discussion and conclusions*

The pinkish brown garnet crystals found sporadically distributed in certain rock units of the Upper Swat Hornblendic Group, as exposed north of Mingora, Swat District, Pakistan, seem to have been produced by regional metamorphism of the enclosing rocks. The garnetiferous rocks are mainly the epidote–hornblende–quartz gneisses and related pegmatites, and can be further subdivided on textural and structural grounds, as has been described earlier in this paper. Almost complete epidotization of the plagioclases in gneisses shows that these rocks are metamorphosed to the epidote–hornblende subfacies. Textural evidence shows that the garnets appear to have grown utilizing quartz, epidote, and hornblende; all three occur as inclusions in garnet crystals.

Since all the mineralogically and texturally different lithotypes described in this paper contain garnets of broadly similar compositions, it is inferred that the rocks

have reached the stage of metamorphic equilibrium. All the garnets are pyralspites with subordinate grandite content. Ubiquitous presence of sphene and absence of ilmenite in these rocks show that sufficient lime was available. The plagioclases are also moderately rich in calcium, anorthite content from 28 to 43 %.

TABLE II. *Chemical analyses of garnets from Swat District, Pakistan*

| | 16016 | 16017 | 16018 | 16019 | 16020 | 16021 | 16022 | 16023 | 16024 | 16025 | 16026 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 37·92 | 38·36 | 36·97 | 37·40 | 37·30 | 37·47 | 36·84 | 37·90 | 38·24 | 37·27 | 36·78 |
| $TiO_2$ | 0·15 | 0·13 | 0·12 | 0·21 | 0·13 | 0·08 | 0·22 | 0·08 | 0·08 | 0·06 | 0·05 |
| $Al_2O_3$ | 20·90 | 20·98 | 22·30 | 20·02 | 20·75 | 20·22 | 20·48 | 22·48 | 22·00 | 19·92 | 18·90 |
| $Fe_2O_3$ | 1·20 | 0·41 | 0·32 | 2·13 | 1·39 | 2·63 | 2·25 | 0·20 | 0·23 | 3·11 | 4·43 |
| FeO | 26·02 | 26·80 | 27·60 | 27·42 | 27·08 | 24·74 | 28·98 | 26·04 | 25·24 | 24·32 | 23·05 |
| MnO | 1·58 | 1·50 | 2·81 | 1·15 | 2·22 | 2·75 | 1·82 | 1·62 | 2·90 | 2·62 | 4·85 |
| MgO | 5·25 | 4·80 | 2·62 | 3·24 | 2·72 | 4·05 | 3·22 | 6·50 | 5·74 | 3·83 | 2·34 |
| CaO | 6·80 | 6·60 | 7·17 | 8·30 | 8·52 | 8·02 | 5·94 | 5·10 | 5·52 | 8·81 | 9·46 |
| $H_2O^+$ | 0·08 | — | — | — | — | 0·05 | 0·08 | — | — | — | — |
| $H_2O^-$ | 0·02 | — | — | 0·02 | 0·06 | 0·02 | 0·05 | — | — | — | — |
| Total | 99·92 | 99·98 | 99·91 | 99·89 | 100·17 | 100·03 | 99·88 | 99·92 | 99·95 | 99·94 | 99·86 |
| *Atomic ratios to 24 oxygen*: | | | | | | | | | | | |
| Si | 5·97 | 6·01 | 5·88 | 5·97 | 5·96 | 5·95 | 5·92 | 5·91 | 5·97 | 5·97 | 5·92 |
| $Al^{iv}$ | 0·03 | — | 0·12 | 0·03 | 0·04 | 0·05 | 0·08 | 0·09 | 0·03 | 0·03 | 0·08 |
| $Al^{vi}$ | 3·82 | 3·91 | 4·12 | 3·73 | 3·86 | 3·72 | 3·77 | 4·01 | 4·01 | 3·57 | 3·49 |
| Ti | 0·02 | 0·01 | 0·02 | 0·03 | 0·02 | 0·01 | 0·03 | 0·01 | 0·01 | 0·01 | 0·01 |
| $Fe^{3+}$ | 0·12 | 0·05 | 0·04 | 0·24 | 0·17 | 0·30 | 0·26 | 0·02 | 0·02 | 0·36 | 0·54 |
| $\Sigma$ | 3·96 | 3·97 | 4·18 | 4·00 | 4·05 | 4·03 | 4·06 | 4·04 | 4·04 | 3·94 | 4·04 |
| Mg | 1·23 | 1·10 | 0·62 | 0·77 | 0·53 | 0·96 | 0·77 | 1·51 | 1·34 | 0·90 | 0·56 |
| $Fe^{2+}$ | 3·41 | 3·50 | 3·65 | 3·64 | 3·61 | 3·27 | 3·87 | 3·38 | 3·28 | 3·20 | 3·09 |
| Mn | 0·21 | 0·25 | 0·38 | 0·15 | 0·34 | 0·36 | 0·24 | 0·20 | 0·38 | 0·35 | 0·65 |
| Ca | 1·14 | 1·11 | 1·22 | 1·40 | 1·40 | 1·36 | 1·02 | 0·85 | 0·91 | 1·48 | 1·63 |
| $\Sigma$ | 5·99 | 5·96 | 5·87 | 5·96 | 5·94 | 5·95 | 5·90 | 5·94 | 5·91 | 5·93 | 5·93 |
| *End-member molecules*, %: | | | | | | | | | | | |
| Alm. | 59·99 | 61·63 | 64·52 | 63·52 | 62·87 | 57·49 | 67·70 | 60·41 | 58·74 | 56·55 | 54·26 |
| And. | 3·56 | 1·53 | 1·02 | 6·61 | 4·57 | 8·13 | 7·32 | 0·51 | 0·51 | 9·66 | 14·23 |
| Gross. | 15·12 | 16·30 | 18·79 | 16·24 | 18·94 | 14·43 | 9·79 | 13·40 | 14·63 | 15·10 | 11·97 |
| Spess. | 3·65 | 4·46 | 6·69 | 2·72 | 6·14 | 6·30 | 4·21 | 3·81 | 6·83 | 6·09 | 11·58 |
| Pyrope | 17·68 | 16·08 | 8·98 | 10·91 | 7·48 | 13·65 | 10·98 | 21·87 | 19·29 | 12·60 | 7·96 |
| *Refractive index* (±0·002): | | | | | | | | | | | |
| *n* | 1·788 | 1·788 | 1·791 | 1·786 | 1·783 | 1·785 | 1·786 | 1·789 | 1·785 | 1·785 | 1·805 |

Out of the eleven garnet samples included in this study, only one (16026) shows slight chemical and mineralogical deviation, as already commented. In the case of pelitic gneisses from Scotland (Chinner, 1960), spessartine-rich garnets form fine-grained evenly distributed granules, and spessartine-poor garnets form coarsely crystalline porphyroblasts: the garnets from orthogneisses and related pegmatites included in the present study, however, show smaller-sized idioblasts of less manganiferous garnets and coarser anhedra of the single Mn-rich garnet (fig. 2).

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