# Contributions to the Petrology of the Goe Range Area Grand Bassa Co., Liberia

By

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ABSTRACT.—Two mutually conformable groups of Archaean rocks underlying the Goe Range Area are described. The first, consisting mainly of felsic syenite gneisses, with minor bands of amphibolites is termed Archaean undefined. The second, called the Goe Range Series, consists of metasedimentary rocks, in which argillaceous schists, quartzites, and iron formation are predominant. Petrographic and chemical evidence indicate that chemical precipitation and deposition of finely clastic rocks alternated during the period of sedimentation.

## Introduction

The Goe Range Area is named after its most prominent topographic feature: a low NW–SE trending range of hills. It is situated ca 60 km east of the Liberian capital city of Monrovia (Fig. 1). The area is within 15 km of the coast of the Gulf of Guinea. It is bounded to the west by the Farmington River which separates it from the Firestone Rubber Plantation, and to the south by the Government motor road connecting Firestone division 45 with the port city of Buchanan. Investigations have covered an area of 75 $km^2$.

Detailed investigations of the Mt. Goe Range are dealt with in unpublished reports of Berge (1958), and Offerberg (1958). More complete petrographic descriptions are found in Berge (1962). During the earliest investigations of the Mt. Goe Range (Nov. 1956–May 1958), the theodolite was used for surface mapping, and where outcrops were scarce, systematic pitting and trenching was done. The author completed mapping of the surrounding lowlands during April 1961 using pace and compass traverse.

A gently rolling plain with a mean altitude of 60 m. a. s. l. and maximum relief of 25 m comprises most of the area, and isolates the Goe range from other hill ranges in the coastal region of Grand Bassa County. The summit elevations of the Goe Range decrease from 275 m. a. s. l. on Mt. Goe I at the southeast end of the range to 175 m. a. s. l. on Mt. Hydro which forms the NW terminus.

The Goe Range area is underlain by rocks of the Pre-Cambrian Liberian-Guinean shield, which is generally assumed to comprise most of Liberia, Sierra Leone, the southeastern region of Guinea, and the northwestern part of the Ivory Coast. A comprehensive chronological division of rocks within the Liberian part of the shield is offered tentatively by Offerberg and Tre-

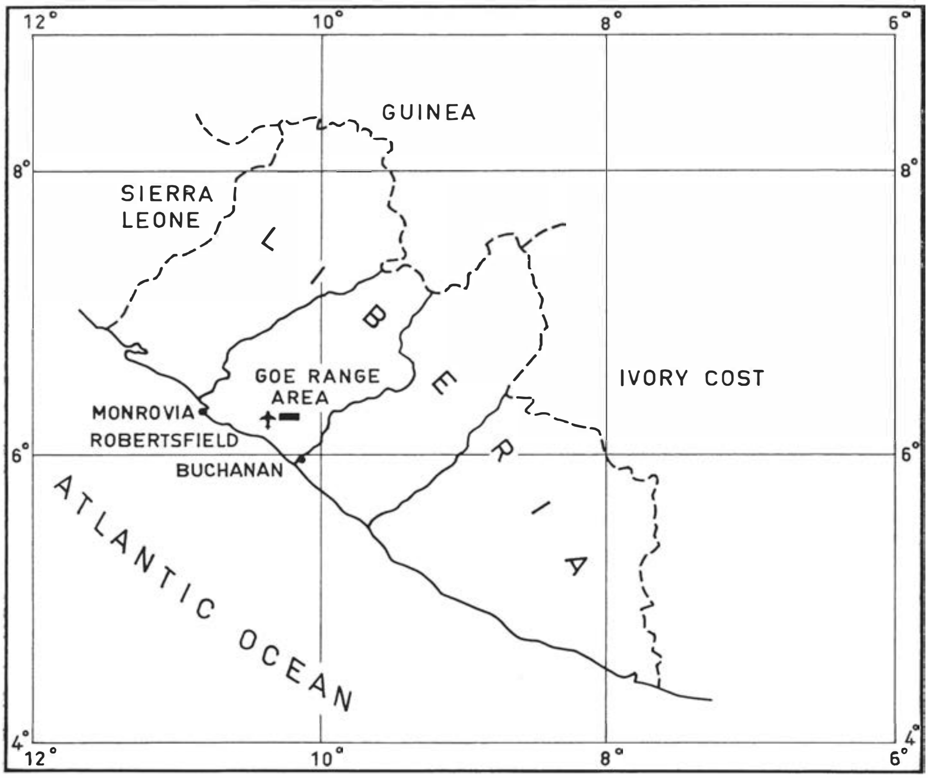


Fig. 1. Approximate position of the Goe Range Area.

maine (1961). The divisions have been related as much as is possible to periods of sedimentation and orogeny recognized in other parts of West Africa (Table 1, Pre-Cambrian only). The Goe Range Area is immediately adjacent to the large central region to which this classification has been applied.

Detailed investigations in Dahomey, Ghana, and the Ivory Coast have resulted in the definition of an older Dahomeyan, and a younger Birrimien series within the early Pre-Cambrian (Junner 1954). Although rocks of the Liberian-Guinean shield are generally unlike those of the Dahomeyan-Birrimien type sections, the former are frequently equated with the latter (Bolgarsky 1950, LeClerc *et al.* 1955, Obermuller 1941, Obermuller and Roques 1946, Roques 1948). Since there are no bases for correlation between the Goe Range Area, and the Dahomeyan-Birrimien type sections, the term Archaean will be used in any time evaluations in the present paper.

## Petrology of the Goe Range Area

The metamorphic rocks of the Goe Range area have been separated into two main divisions. The southwestern division is classified as "Archaean undefined" and consists mainly of felsic gneisses with some pegmatites and various

*Table 1.*

| Usual nomenclature | Offerberg and Tremaine (1961) | | Present paper |
|---|---|---|---|
| Akwapimien | | | |
| Falemien | | | |
| Tarkwaien | | | |
| Post-Birrimien | Post-Birrimien.—Charnockites, granites, and migmatites<br>Post-Birrimien?—Dike greenstone, orthogneisses of granodiorite and quartz diorite type | ARCHAEAN | Pegmatites<br>Metamorphism<br>Orthoamphibolites |
| Upper Birrimien | Basic metamorphic rocks of ultra-basic and gabbroic type | | |
| Lower Birrimien | Birrimien.—Iron formation, basic extrusives, quartzites, sandstones, conglomerates, phyllites, schists, and paragneisses | | Iron formation, quartz argillite schists, quartzites.<br>Paragneisses, para-amphibolites, and quartz epidosites |
| Dahomeyan | | | |

amphibolites. The central and northeastern division which consists of metasediments is called the Goe Range Series. Paragneisses, para-amphibolites, and quartz epidosites of this series predominate in the lowlands, while the hills of the Goe Range are formed by argillaceous schists, quartzites, and iron formation. Rocks of both divisions exhibit mutual parallelism as concerns schistosity, foliation, banding, and remnant bedding. All metamorphic rocks are irregularly intruded by post-Orodovician dolerites described elsewhere (Berge 1962, Offerberg and Tremaine 1961).

## Archaean undefined

*Felsic syenite gneisses*

Most of the southwestern division of the Goe Range area is comprised of a NW–SE trending band of acid gneisses of syenitic affinity, rich in acid plagioclase and potash feldspars. The width of this band varies between 2500 m, in the vicinity of Jablis, and 700 m, near the motor road junction in the southeast corner. Most of the narrow amphibolitic layers occur within this complex. The several textural varieties (after Sørensen 1960) are grey homogeneous gneisses, streaked gneisses, and veined gneisses. All gneisses have granoblastic texture.

Hastingsite is an iron rich variety, and most sphene occurs in close association with, or is included in the hastingsite. Plagioclase (An 13–22) seems to

*Table 2.*

| | Ba 95 b | Ba 12 | Ba 13 | Ba 102 | Ba 43 | Ba 90 | Ba 115 | Ba 101 | Ba 14 | Ba 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| Quartz | — | 0.4 | 0.4 | — | 10.1 | 0.6 | 1.0 | 25.9 | 10.5 | 15.5 |
| Microcline | 61.3 | 50.8 | 46.4 | 46.0 | 40.7 | 33.2 | 32.0 | 26.2 | 22.3 | |
| Plagioclase | 17.0 | 32.2 | 41.7 | 36.2 | 34.8 | 41.3 | 36.8 | 36.0 | 56.9 | 52.6 |
| Hastingsite | 9.2 | 7.2 | 10.3 | 12.0 | 7.8 | 10.0 | 21.0 | 3.2 | 5.0 | 7.7 |
| Biotite | 9.5 | 6.6 | 0.9 | 4.2 | 0.9 | 4.0 | 4.4 | — | — | 0.4 |
| Sphene | 1.4 | 1.9 | pr | 0.7 | pr | 0.3 | 1.7 | 0.2 | 0.9 | 0.9 |
| Ore | — | 0.9 | pr | — | 0.1 | 0.2 | 0.7 | 2.7 | 0.5 | 0.4 |
| Apatite | 0.2 | — | 0.2 | 0.5 | — | 0.2 | 0.3 | — | — | 0.1 |
| Garnet | 0.9 | — | — | — | 0.2 | 2.6 | — | — | — | — |
| Epidote | 0.1 | — | — | — | — | — | — | — | — | 0.1 |
| Orthite | — | — | pr | pr | — | — | pr | — | — | 0.1 |
| Muscovite | — | — | — | — | — | — | 0.3 | — | — | — |
| Calcite | — | — | — | — | — | — | — | — | — | — |
| | 100.1 | 100.0 | 99.9 | 99.7 | 100.0 | 99.9 | 99.4 | 100.0 | 100.0 | 100.1 |
| | An | An | An | An | An | An | An | An | An | An |
| Plagioclase | ca 22 | 13–16 | ca 20 | ca 19 | ca 15 | 13–18 | 15–21 | ca 15 | 18–20 | ca 20 |

replace hastingsite without displacing sphene inclusions. Plagioclase and dark brown biotite may form symplektites. All potash feldspar is microcline. The range in optic angles is extreme ($2Vx = 49–85°$), and is possibly the result of variations in the order/disorder relationships between Al and Si. Statistical measurements of 300 microcline grains show that there is no relationship between the development of perthite and quadrille structure (microcline grains frequently have blotchy or even extinction). Plagioclase is unzoned, but narrow, sharply defined albite rims have developed where plagioclase is in contact with microcline. The albite-plagioclase interface may parallel the albite microcline interface. There are occasional antiperthitic inclusions of microcline in plagioclase. The highest incidences of twinning in plagioclase, perthitic microcline, antiperthitic plagioclase, and "cracks" in plagioclase are coincidental.

The wide fluctuations of mineral proportions in various samples throughout the area is shown in Table 2 which is arranged in order of decreasing microcline content.

To the southwest of Jablis, an occurrence of garnet-porphyroblast gneisses coincides with the extensive development of ptygmatic folding of feldspar veins in the felsic syenite gneisses. Pegmatite pockets containing porphyroblasts of ilmenite are also common. Grey homogeneous gneiss, in which the principal feldspar is plagioclase (An 16–24), predominates. The core of the garnet porphyroblasts (ca. 1.5 mm diam.) consists of garnet (anal. Table 3) which is surrounded by a halo (1.5 mm radius) of microcline. Myrmekite is common in the vicinity of the porphyroblasts. The garnet is idioblastic, and contains inclusions of sphene, orthite, and less commonly apatite and quartz. Occasional

Fig. 2. Porphyroblastic gneiss in which the garnet-microcline porphyroblasts stand out in relief from the syenitic groundmass. Outcrop 50 m S of Jablis.

grains of hastingsite border on the garnet. Orthite and sphene are also inclusions in biotite and amphibole.

Columns A and C (Table 4) show the result of integration stage measurements of different segments of a single thin section. In the lower part of the table, the cation percentages of the principal elements have been calculated by reversing Barth's method (Barth 1959) of meso-normal calculations. The values although approximate are useful in comparing different segments of a sample or outcrop as the case may be. (Mg' stands for $Fe^{+2}$ + Mg.) In the lower part of column B, the cations of the garnet are recalculated to 100 %. In the fifth column, the cation calculations of porphyroblasts are made according to the proportions of garnet to microcline rim.

There is a distinct similarity between the calculated cation values of the garnet—microcline porphyroblasts (column 5, A plus B) and those of an adjacent homogeneous grey gneiss (Ba 95 b). The principal differences between the two are the higher Mg' and Ca, and much lower Na content in the porphyroblasts.

*Table 3.*

| | | | |
|---|---|---|---|
| CaO | 10.90 % | Almandine | 58.69 % |
| MgO | 0.91 | Pyrope | 3.80 |
| FeO | 25.34 | Spessartite | 5.05 |
| MnO | 2.15 | Grossularite | 27.20 |
| $Fe_2O_3$ | 1.68 | Andradite | 5.25 |
| Ca 0.974 | Mg 0.114 | $Fe^{+2}$ 1.760 | Mn 0.152 |
| $Fe^{+3}$ 0.105 | Al 1.894 | $Si_3 O_{12}$ | |
| $n_D$ 1.791 (obs.) | | $a_0$ 11.638 Å(obs.) | |
| 1.801 (calc.) | | 11.620 Å(calc.) | |

*Table 4.*

| Sample No. | Ba 96 A | Ba 96 B | Ba 96 C | Ba 96 D | Ba 96 A+B | Ba 95 b |
|---|---|---|---|---|---|---|
| Vol. of section | 19.5 | 6.5 | 74.0 | 100 % | 26.0 | |
| Quartz | | | 0.2 | 0.1 | | |
| Microcline | 80.5 | | 2.7 | 15.1 | | 61.8 |
| Plagioclase | 10.8 | | 82.9 | 64.2 | | 17.0 |
| Hastingsite | 2.7 | | 8.3 | 8.6 | | 9.2 |
| Biotite | 3.4 | | 2.0 | 2.4 | | 9.5 |
| Garnet | | 100 % | | 6.5 | | |
| Sphene | 1.9 | | 1.7 | 1.5 | | 1.4 |
| Orthite | 0.7 | | 2.3 | 1.7 | | |
| Apatite | 0.2 | | 0.0 | 0.0 | | 0.2 |
| Total | 100.2 | 100 | 100.1 | 100.1 | | 99.1 |
| Si | 57.28 | 42.86 | 53.09 | 53.24 | 54.06 | 54.05 |
| Al | 19.62 | 13.54 | 22.07 | 21.04 | 18.26 | 19.34 |
| $Fe^{+3}$ | | 0.75 | | | | |
| $Fe^{+2}$ | | 25.15 | | | | |
| Mg, Mg′ | 1.97 | 1.62 | 2.61 | 4.24 | 8.15 | 5.86 |
| Mn | | 2.17 | | | | |
| Ca | 1.57 | 13.91 | 4.83 | 4.78 | 4.33 | 2.39 |
| Na | 1.89 | | 13.73 | 10.53 | 1.47 | 3.29 |
| K | 16.23 | | 0.78 | 3.80 | 12.84 | 13.54 |
| Ti | 0.65 | | 0.55 | 0.53 | 0.49 | 0.45 |
| P | 0.09 | | 0.01 | 0.02 | 0.06 | 0.07 |
| | 99.60 | 100.00 | 97.67 | 98.20 | 99.66 | 99.89 |

A: 1.5 mm rim around garnet.
B: Garnet.
C: Exclusive of porphyroblasts.
D: Average over section.

## *Banded gneisses*

These gneisses have scattered occurrence throughout the Goe Range area. They may have close association with the syenite gneisses, or they may be interbanded with amphibolites and probably quartzites and schists of the Goe Range Series (northeast of Huisa). Although the appearance of the banded gneisses is similar to the paragneisses, a sedimentary origin is not conclusively indicated by field or laboratory investigation (although its probable association with quartzites and schists to the northeast of the Goe Range is suggestive). Banding may reflect primary sedimentary bedding, but metamorphic recrystallization has effectively obscured evidence of pre-metamorphic history. Quartz, plagioclase, and microcline comprise from 80 % to 90 % (by volume) of the banded gneisses. Biotite is the principal ferromagnesian mineral (1 to 10 % by volume). Hastingsitic amphibole is present in minute quantities in several of

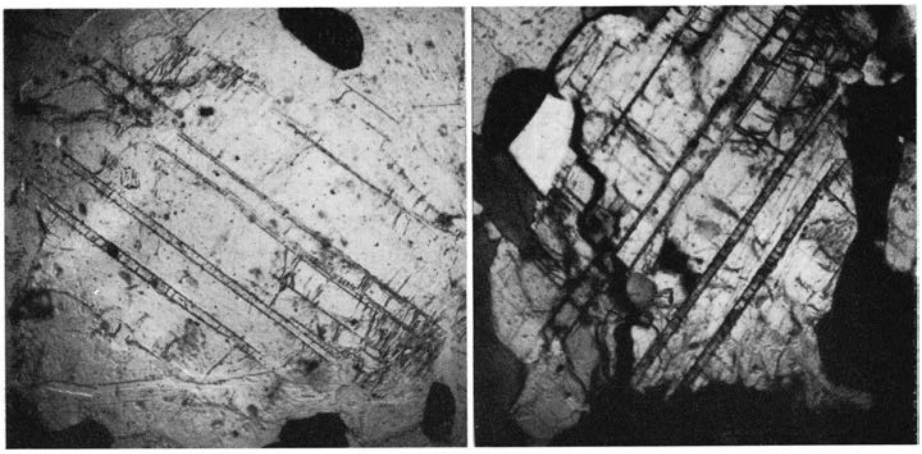

Fig. 3. Fig. 4.

Fig. 3. "Cracks" and parallel bands in plagioclase which are filled with isotropic material of low refringence; from banded gneiss at motor road bridge over Dor Creek, Ba 34, 1 nic., ×25, converg. light.

Fig. 4. Same as Fig. 3, 2 nic., ×25.

the gneisses. Except for the general lack of amphibole, the mineralogy of these gneisses is similar to the syenitic gneisses with the important qualification that there is much less quartz in the latter. Texture and grain size are similar in both gneisses, and it is this similarity that causes the tentative distinction between paragneisses and banded gneisses. It is not unlikely that banded gneisses may be transitional between paragneisses and syenite gneisses.

Special features which may be mentioned in regard to the banded gneisses are the frequency of biotite-plagioclase symplektites, the occurrences of finely antiperthitic plagioclase in the banded gneisses from the southeastern part of the area, and the similarly high incidence of "cracks" in the plagioclases which are described as follows:

With crossed nicols, the plagioclase grains appear to be crossed by networks of heavy black lines (Figs. 3 and 4). These lines are frequently straight, and parallel to a crystallographic direction of the plagioclase individual. It is not uncommon for a single grain to contain two sets of these lines. Such lines may continue across an entire grain, or they may fade or branch out. In grains with no twinning or cleavage the lines are more irregular and have no crystallographic orientation. These lines are apparently formed by parallel cracks which contain an isotropic substance which is at present unknown, but which may be opal. In some cases, the appearance is not unlike that of the feldspars in some of the amphibole gneisses with "straight narrow bands of low refringence (see p. 9). Some cracks are filled with a sub-microcrystalline material which forms finely radiating patterns within the cracks, and has low refringence. Some fractures are filled with a material of higher refringence which may be a clay mineral.

If such a phenomenon may be attributed to weathering, it is noted that, a) only the plagioclases have been attacked, and b) clay mineral formation has occurred to a limited extent, while the isotropic material appears more commonly. Similarly, the question is raised as to why, if weathering is accountable, do not the "cracked" feldspar grains have more widespread occurrence throughout the Goe Range area. On the other hand, there is a tendency towards a higher incidence of "cracks" in samples where antiperthites are also noted, and where circumstances are generally indicative of a higher metamorphic grade.

A banded gneiss-syenite gneiss hybrid occurring in the southeast corner of the area has clearly defined banding, but the mineralogy is more that of a syenite gneiss. This would seem to support the idea that the banded gneisses may grade into felsic syenite gneisses.

*Amphibolites*

Amphibolites of the Archaean undefined complex have general similarity as regards texture and mineralogy. They have features common to 'ortho-amphibolites' described from many Pre-Cambrian areas. Sphene-rich amphibolites are the most common within the Archaean undefined complex, and contain from 6 to 10 % sphene. They are strongly foliated granoblastic rocks. Iron-rich hornblende is the major mineral. Plagioclase (An 32–40), brown biotite, and sphene are subordinate, and quartz, apatite, ore, calcite, orthite, potash feldspar, and penninite are accessory. Plagioclase may be slightly zoned, and is frequently sericitized. Cracks filled by potash feldspar are observed to be crossing all major minerals in the assemblage, including sericitized plagioclase. Penninite has formed at the expense of hornblende, and less frequently biotite. The formation of penninite is associated with the infilling of cracks by potash feldspar. An ultramafic amphibolite with 86 % of ferromagnesian minerals comprises a wide band 200 m SSW of Wheazon. Iron-rich hornblende and hedenbergitic pyroxene are the principal ferromagnesian minerals. Plagioclase (An 30–35) and potash feldspar are the major felsic minerals. An oligoclase amphibolite occurs to the northeast of Cartown in sharp contact with a banded gneiss. It contains 30 % plagioclase (An 20–22), 60 % iron-rich hornblende, and 7 % hedenbergitic pyroxene.

In a lenticular band between Jablis and Negeewehn, an outwards gradation from the center beginning with dark greenish-black amphibolite, and progressing towards a grey streaked amphibole gneiss has been observed. The core amphibolite is banded (amphibole, feldspar, and sphene predominating alternately), and partly phacoidal, differing from the common sphene-rich amphibolites mainly by the absence of biotite. Instead, there is a considerable content of potash feldspar. The mineralogy of the "core" amphibolite and the grey streaked amphibole gneisses is the same, but as Table 5 shows (core amphibolite, followed by peripheral amphibole gneiss), there is a regular varia-

*Table 5.*

| | Ba 110 | Gl 57 | Ba 99 | Ba 97 | Ba 111 |
|---|---|---|---|---|---|
| Quartz | 1.3 | — | — | — | 0.2 |
| Fotash Feldspar | 7.0 | 4.7 | — | — | 0.7 |
| Plagioclase | 26.7 | 46.4 | 47.4 | 45.0 | 62.8 |
| Hornblende | 45.8 | 45.1 | 40.8 | 36.1 | 27.6 |
| Pyroxene | 4.9 | 0.1 | 9.5 | 9.1 | 6.9 |
| Biotite | — | 0.1 | 0.2 | 7.1 | — |
| Sphene | 11.6 | 2.7 | 0.1 | 0.8 | 1.1 |
| Apatite | 0.9 | 0.7 | 0.7 | 0.1 | 0.5 |
| Clinozoisite | 0.7 | — | — | 1.7 | — |
| Pistazite | — | — | 0.8 | — | 0.1 |
| Ore | 0.1 | — | — | — | 0.1 |
| Sericite | 1.0 | 0.3 | 0.3 | — | — |
| | 100.0 | 100.1 | 99.8 | 99.9 | 100.0 |
| Plagioclase An % | 50–54 | 46–50 | 38–40 | 44–48 | 42 |
| Amphibole Mg: Fe | 5 : 1 | 3 : 1 | 3 : 2 | 1 : 3 | 2 : 3 |
| Pyroxene type | Diopside | Diopside | | Ferrosalite | |

tion in the ratio of mafic: felsic minerals, the ratio of Mg:Fe (measured optically), and the anorthite content of the feldspar which may suggest differentiation occurring during the cooling of a gabbroic intrusion. All samples are a) granoblastic and medium grained, b) have a weak foliation with preferred orientation of hornblende and pyroxenes, and c) have equidimensional plagioclase grains which may or may not be twinned. An unique feature in several of the samples is the presence of clear grains of plagioclase which exhibit diffuse straight bands with slightly lower refringence. Each band contains two sets of mutually perpendicular mineralized fissures which are oblique to the direction of the band. The fissures may contain potash feldspar.

As mentioned previously, the contact between amphibolites and syenitic gneisses is gradational. Careful integration stage measurements have shown that in at least two cases, there are alternating bands of felsic and mafic enrichment on the amphibolite side of such contacts. However, the average composition of such banded zones is similar to the amphibolite. In addition, at the contact of an oligoclase amphibolite with a banded gneiss, amphiboles and plagioclase have been chloritized and epidotized, and microcline has been concentrated within 5 mm of the sharp contact in the amphibolite. In a felsic gneiss/sphene-rich amphibolite contact zone near the Farmington River, garnets containing large amounts of included material are present (anal. Table 6).

*Table 6.*

| | | | |
|---|---|---|---|
| CaO | 11.36 % | Almandine | 52.52 % |
| MgO | 0.77 | Pyrope | 5.17 |
| FeO | 23.16 | Spessartite | 9.32 |
| $Fe_2O_3$ | 2.60 | Grossularite | 25.03 |
| MnO | 4.06 | Andradite | 7.97 |
| $n_D$ | 1.793 (obs.) | $a_0$ | 11.613 (obs.) |
| | 1.797 (calc.) | | 11.631 (calc.) |

## The Goe Range series

*Paragneisses, para-amphibolites, and quartz epidosites*

The chief criterion for distinguishing the paragneisses from the banded gneisses is in their situation; that of being interbanded with the more obviously metasedimentary schists and quartzites. Otherwise, they resemble the banded gneisses. The paragneisses are typically fine to medium grained granoblastic assemblages of quartz, plagioclase (An 13–25), and microcline. Muscovite, biotite, and chlorite are subordinate. Accessory minerals are sericite, orthite, leucoxene, and apatite. Plagioclase grains frequently have albite rims when in contact with microcline. Biotite is dark brown. Quartz grains have undulose extinction.

Lime-rich para-amphibolites and quartz epidosites occur in narrow bands located from 400–800 m southeast of the Goe Range, and are concordant with surrounding paragneisses and schists. The lateral extent of any one band has not been ascertained, but such amphibolites have been found in widely scattered occurrences along the base of the range.

Lime-rich para-amphibolite comprising a narrow band 1100 m NNW of Wheazon has a pitted and scarred surface attributed to weathering. The fresh surface is greenish black with schlieren-like bands of lighter material. The greenish black areas of the rock consist almost entirely of magnesium-rich hornblende with small amounts of grammatite, and diopside. Narrow layers of clustered biotite enclosed in a matrix of plagioclase are observed in the dark bands. Light bands consist of a plagioclase-scapolite-calcite-quartz assemblage with accessory sphene, apatite, and epidote. Along the contact between the dark and light bands, amphibole contains inclusions of poikilitic or vermicular plagioclase and quartz, or is intergrown with calcite and scapolite. Plagioclase (An 22–45) may be zoned, but more frequently single grains contain sharp divisions of different composition. When growing together, calcite and scapolite form a regular mosaic. The interfaces between scapolite and plagioclase are more irregular. At a typical scapolite (Me 60)–plagioclase (An 34) interface, a narrow sharply defined, more calcic (An 45) rim is produced in the plagioclase which parallels the interface.

*Table 7.*

| | Ba 20 | Ba 82 |
|---|---|---|
| Quartz (obs.) | 49.7 | 16.0 |
| Quartz (calc.) | 41.2 | 15.3 |
| Plagioclase | — | 18.4 |
| Epidote | 36.2 | 14.1 |
| Amphibole | 8.0 | 45.9 |
| Biotite | 0.7 | 4.1 |
| Apatite | — | 0.1 |
| Sphene | — | 1.5 |
| Ore | 0.3 | — |
| Isotropic mineral | 5.2 | — |
| | 100.1 | 100.1 |

The quartz epidosites are banded assemblages of quartz, epidote, amphibole and/or plagioclase. All sample locations are close to the base of the Goe Range. Fresh surfaces are greenish grey.

Among the minerals listed in Table 7, epidote is pistacite, and amphibole is mostly iron-rich hornblende with extensive substitution of both ferric and ferrous iron probable (Berge 1962). Some grammatite is present. Plagioclase is andesine (An 31). Biotite is dark brown, and quartz grains have undulose extinction. An isotropic mineral may be opal.

*Quartzites, schists, and iron formation*

Quartzites, schists and iron formation occupy a broad band in the center part of the Goe Range area, and comprise the Goe Range. Surface width varies from 2.5 to 3.0 km. Across most of the area, the trend is NW–SE. Towards the east, there is a deviation in the trend towards the south. In the area of Huisa, there is an apparent division of this band, with branches trending to the ENE and SSE. Bedding, or banding and schistosity coincide with the general trend, and locally with the deviation.

In the central and western part of the area, the schists and quartzites become interbanded with previously described paragneisses and para-amphibolites which form the plain to the southwest of the range. Between Benewehn and Cartown no paragneisses have been observed in the lowland extension of the schists and quartzites. Detailed surface mapping which took place in 1957 has permitted an outlining of the stratigraphy of the schists and quartzites underlying the Goe Range. Because of deep weathering, few rocks are suitable for petrographic examination. Thus, the following description relies heavily on field observation made during the earlier survey. The various schists and quartzites are described in order of occurrence from northeast to southwest (across profiles A–A′ and B–B′), or in terms of apparent stratigraphy, from the lowest to the highest member. The implied structure in profile A–A′ is a southwest-dipping monocline, or an overturned isoclinal fold with the axial plane dip to the southwest. In contrast to this is the clearly determined gentle synclinal fold forming Mt. Goe I with the upper iron formation forming the synclinal core, and the lower iron formation on the northwest limb.

*Predominant rock type*

1. (Lower) Argillaceous schists
2. (Lower) Iron formation
3. Quartzites
4. Ferruginous-argillaceous schists
5. (Upper) Argillaceous schists
6. (Upper) Iron formation
7. Quartzites and kyanite quartzites

Detailed mapping of the lowland schist-quartzite stratigraphy has not been undertaken. Since the southwest limit of unit 7 is not determined, description of that unit is combined with random observations on other lowland schists and quartzites.

In the field, the schist and quartzite formations display both sedimentary and metamorphic characteristics. Remnants of bedding may appear as color banding and transverse mineralogical variations. There are frequent sedimentary facies changes along the strike, and there is the usual lateral thickening, thinning, and wedging out of individual units. The most striking of the sedimentary characteristics is the gradational nature of all contacts. Transition zones may be quite wide. Therefore, designation of formational boundaries is, at best, arbitrary and somewhat inaccurate. Hence, the names given to the units subsequently described define trends in the quantitative mineralogy rather than sharply bounded stratigraphic units.

1. (LOWER) ARGILLACEOUS SCHISTS.—The unit has a true thickness of from 150 to 250 m, and outcrops are weathered and soft. Schists are fine to medium grained, and may be interbanded with narrow quartzite layers. Individual layers may be as narrow as several mm. Banding is accentuated by brightly varied colors: red, orange, brown, black, and white. Quartz, muscovite, garnet, sericite, biotite, and kyanite have been identified in the field and through binocularscope examination. In the central part of the area, the argillaceous schists grade into the overlying lower iron formation through a thin bed of ferruginous quartzite. Towards the eastern part of the area, this quartzite becomes much thicker, and interfingers with the argillaceous schists.

2. (LOWER) IRON FORMATION.—The effects of lateritization have largely obscured the primary nature of this unit. Hence, in certain areas, it is easily identified by large outcropping masses of structureless vuggy goethite which contain occasional pockets of hematite. Subsurface exploration implies mainly that

the iron formation consists of ferruginous quartz-mica schists with minor intercalations of itabirite. Unaltered iron formation taken from a depth of 62 m below the surface on Mt. Goe III consists of narrow grey and brown bands of ca 1 cm thickness. Quartz, magnetite, and grunerite are the major minerals, and appear in both bands. Hematite and green siderophyllitic biotite are subordinate. The brown bands contain considerable amounts of a brownish sub-microcrystalline material which is a mixture of pyrophyllite and either vermiculite or a montmorillonite (X-ray photogram). The principal texture of the grey bands is a poorly defined mosaic, and quartz grains contain many fine inclusions of ore. Minerals are present in the following quantities:

| | Grey band | Brown band |
|---|---|---|
| Quartz | 59 % | 31 % |
| Ore | 29 % | 16 % |
| Amphibole | 10 % | 16 % |
| Biotite | 1.5 % | 0.8 % |
| Green-brown material | — | 37 % |
| Total | 99.5 % | 100.8 % |

Locally, iron formation may consist of quartzitic varieties containing garnet and micas as observed in less heavily weathered outcrops. Also occurring within the limits of this formation is a sub-microcrystalline banded "mudstone". Alternating bands in the mudstone are dark red to violet, and orange brown and vary from 1 mm to 1 cm in thickness. The red bands consist mainly of hematite with subordinate goethite, while in the brown bands, the reverse is true (X-ray photogram). The crystallinity of both minerals is good. A third component present in both bands is a kaolin-structure mineral.

The sole basis for the definition of this unit is a higher primary iron content than is found in the underlying argillaceous schists with the resulting 1–3 m thick lateritic capping which makes it an easily identifiable horizon.

3. Quartzites.—Large areas of the Goe Range are underlain by quartzite, most of which appears to be part of a single unit. Intercalations of the lower iron formation, and a ferruginous-argillaceous schist member occur within the quartzite. The latter of the two intercalations is most prominent in the western part of the Goe Range. The quartzite may locally reach true thicknesses of 200 m. In the western and central parts of the Goe Range, quartzites are typically grey to white in outcrop, and usually appear to be coarse grained. The apparently pure white color of the outcrop penetrates usually to a depth of several centimeters, and is caused by a surface removal of clay, mica, and "limonite", contained in the quartzite. Brown and red coarse grained quartzites are noted by Offerberg (1957) in the southeastern parts of the Goe Range. He mentions that they do not show characteristics of ordinary sedimentary quartzites and assumes that there has been some mobilization within the quartzite posterior to deposition. In addition to quartz, there are subordinate

quantities of pale brown biotite, muscovite, kyanite, chlorite, and garnet. Some of the ore may be attributed to post-metamorphic impregnation. Quartz grains are elongated in the plane of foliation (over 2.5 cm—the width of a thin section), but extinction is uniform. Irregular grain boundaries are very slightly sutured.

4. FERRUGINOUS-ARGILLACEOUS SCHISTS.—This unit attains prominence only within the western part of the area, where as an intercalation in the previously described quartzites, it has maximum thickness of 30 m. Principal minerals are kyanite, muscovite, biotite, and quartz. Iron bands result in the local development of hard goethite-rich outcroppings. Caves within such cliff outcrops exhibit weathered assemblages of quartz and mica with a red-yellow clay matrix.

5. UPPER ARGILLACEOUS SCHISTS.—Along almost the entire southwest margin of the main quartzite (unit 3), contact is made with an upper group of argillaceous schists. The unit rarely forms outcrops, but has been recognized mainly during trenching and drilling operations. The maximum thickness is 50 m along the central and western part of the range. Towards the southeast, the schist band widens, and appears to encompass the overlying upper iron formation. The unit as described here consists of a variety of schist and quartzitic members, but the principal minerals throughout are garnet, quartz, muscovite, biotite, and kyanite.

Quantitatively the most important are quartzose argillaceous schists. Graphite schists occur in narrow bands along the length of the range, and lenses of quartz-garnet rock are locally important along the southwestern part of the range.

The quartzose argillaceous schists may be brownish white, greenish grey, or, depending on the content of garnet, may have a violet tinge. At the surface, or in the vicinity of iron formation, they are frequently stained red. The rocks are medium to fine grained. Locally, up to 13 % of the schist consists of goethite which is present due to post-metamorphic impregnation. The schists consist of quartz, muscovite, biotite, garnet, kyanite, thuringite, and ore. The texture is generally lepidoblastic. In the medium grained schists, quartz grains are elongated within the foliation plane, and have slightly undulose extinction. Several sub-adjacent grains may have parallel optical orientation. In the finer grained schists, irregularly shaped equidimensional quartz grains comprise a poorly defined mosaic. The average grain diameter is 0.5 mm. The micas and kyanite are strongly oriented in the plane of foliation, and the micas are usually frayed. Kyanite is in elongate grains which have undulating extinction and are bent. Kyanite usually contains numerous inclusions of quartz. Garnets have an extremely varied appearance. In the medium grained schists, they vary as to size, but are generally idioblastic and often slightly elongated. They may contain inclusions of quartz. In fine grained schists the garnets ($a_0$ 11.50 Å)

Fig. 5. Elongate garnet relict in quartz argillite schist. Garnet replaced by Fe and Al hydroxides while linear trains of quartz inclusions remain in place. Ba 134, 2 nic., × 18.5.

are shapeless, elongated, and are extensively intergrown with, or are riddled with inclusions of quartz. The unit cell of these garnets is close to that analyzed from the quartz-garnet rocks, and is probably of approximately the same composition. Occasionally, garnets have been hydrolyzed, and replaced by goethite by such a process that linear trains of quartz inclusions have remained in position perpendicular to schistosity. From the appearance of the quartz grains, and the encompassing micas which are draped around the garnet relicts, it appears that the garnets have been slightly rotated (Fig. 5). Small amounts of a green chlorite mineral (thuringite?) are present. Biotite is reddish brown.

The schists are banded. Muscovite, kyanite, and quartz are rather ubiquitous, and show no apparent proportional variation. However, biotite and garnet occur within the same bands, and the chlorite may have a higher incidence in such bands. Integration stage measurements are given (Table 8) for the several samples. Crosscutting veins consist of coarse grains of quartz which are elongated perpendicular to the veins. Optic axes and elongation of the quartz grains are parallel. Extinction in vein quartz is uniform, contrary to the undulose extinction of the quartz grains in many of the schists. These quartz veins are of postdeformational origin.

*Table 8.*

| | Ba 132 | Ba 133 | Ba 134 | Ba 135 |
|---|---|---|---|---|
| Quartz | 42.3 | 53.2 | 38.8 | 48.2 |
| Muscovite | 24.5 | 29.5 | 0.2 | 39.2 |
| Biotite | 8.0 | 6.7 | 28.2 | 0.3 |
| Garnet | 0.8 | 5.4 | 18.9 | 5.0[a] |
| Kyanite | 10.8 | 1.6 | 9.7 | 1.6 |
| Chlorite | 0.4 | 0.2 | 0.4 | 0.7 |
| Ore | 12.5 | 3.4 | 4.0 | 5.0 |
| | 99.3 | 100.0 | 100.2 | 100.0 |

[a] Garnet relict.

Ba 132: From borehole, Mt. Goe I, 42 m below surface.
Ba 133: From borehole, Mt. Goe II, 45 m below surface.
Ba 134: From borehole, Mt. Goe II, 38 m below surface.
Ba 135: From borehole, Mt. Goe I, 89 m below surface.

The quartz garnet rocks may contain minor amounts of muscovite, biotite, chlorite, and ore. Narrow layers of this rock are usually separated from the quartzose argillaceous schist by pure quartzite. Quartz-garnet rocks are medium grained, and are red to violet depending on the amount of alteration of garnets and impregnation with ferruginous material. Concerning the texture and mineralogy, the quartz-garnet rocks fall into two categories. In the first, the garnets are mainly idioblastic, and contain few if any inclusions of quartz. There is usually some ore (goethite?) present, which is in some cases due to impregnation. Medium to fine grained quartz is packed in an irregular mosaic between the garnets. Quartz grains have undulose extinction. In a second type, the garnets are in irregular elongate, shapeless masses. They are riddled with inclusions of, or are extensively intergrown with quartz. Biotite, muscovite, and chlorite also occur within the general outlines of the garnet masses. Quartz grains are also elongated, and several adjacent grains may have parallel optical orientation. The effect is one of layering. In a sample from the first category, the boundary relations with the adjoining quartzite band shows a relative concentration of pyrite within the boundary zone. Powder diffraction photograms and $n_D$ determinations show that garnets from all three rocks are very similar, hence it seems reasonable to apply the chemical analysis of one to all. The integration stage measurements and the standard cell for the garnets are given in Table 9. The chemical analysis for the garnet is given in Table 10.

The graphite schists are soft, fine grained, and are easily powdered, and hence thin-sectioning is impossible. However, immersion studies of the powder, and powder diffraction photograms show that graphite is the major component. Quartz, muscovite, and chlorite are subordinate.

6. UPPER IRON FORMATION.—This unit extends the entire length of the Goe Range and has also been recognized to the west of the Farmington River

*Table 9.*

| | Ba 136 | Ba 137 | Ba 138 A | Ba 138 B | Ba 138 C |
|---|---|---|---|---|---|
| Quartz | 32.6 | 44.6 | 26.1 | 51.2 | 86.8 |
| Garnet | 67.4 | 52.5 | 64.8 | 33.3 | 2.8 |
| Ore | — | 1.4 | 7.9 | 10.2 | 9.4 |
| Pyrite | — | — | 1.0 | 4.7 | — |
| Muscovite | — | — | — | 0.3 | — |
| Biotite | — | 0.1 | 0.2 | 0.4 | 1.0 |
| Chlorite | — | 0.2 | — | — | — |
| | 100.0 | 98.8 | 100.0 | 100.1 | 100.0 |
| $a_0$ (obs.) | 11.528 | 11.540 | 11.535 | | |
| (calc.) | | | 11.507 | | |

Ba 138: A, Garnet-quartz band;
B, Boundary zone between garnet-quartz band and quartzite band;
C, Quartzite band.

in a rock quarry. Within this formation are local goethite-hematite concentrations capped by lateritic material. The primary iron formation varies between ferruginous schists, and compact itabirites. Within the western and central parts of the range, the uniformly dipping iron formation occupies a belt of from 12 to 50 m thickness. At maximum thickness, the formation consists of ferruginous schists. Towards the southeast, the iron formation occupies a trough with a maximum surface width of 300 m. Hard compact itabirite occurs on either side of the Farmington River. The quartz bands appear to be rather free of impurities. The ferruginous bands are composed chiefly of specularite or goethite. Itabirites observed elsewhere along the range appear to contain more goethite (however, there is good indication, e.g. the hydrolyzed garnets at some depth, that all examined samples are within a zone of surface alteration). Ferruginous schists appear similar to those of the lower iron formation. At the base of the trough shaped occurrence of iron formation towards the southeast, the ferruginous bands of an apparently itabiritic rock are occupied by ferromagnesian silicates.

Alternating quartz and ferromagnesian bands have maximum thickness of 1.5 cm. Quartz bands are grey. Ferromagnesian bands are brownish green, but may contain very narrow (2 mm wide) yellowish strips. Under the microscope, the quartzites take on a banded appearance due to change in grain size perpendicular to banding (Fig. 6). The texture is an irregular mosaic, and the grain boundaries are rather straight. In the coarse grained bands, quartz individuals may have elongation of up to 4 mm parallel to banding. In the finer grained bands, more equidimensional grains are 0.2 mm in diameter. The maximum width of different bands within the quartz members is 2.5 mm. Coarse quartz

*Table 10.*

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 67.3 | 60.25 | 58.94 | 36.75 | 23.81 | 58.4 | 88.3 |
| $Al_2O_3$ | 17.8 | 22.79 | 15.87 | 20.65 | 23.12 | 12.9 | 0.8 |
| $Fe_2O_3$ | — | 4.23 | 3.28 | 0.29 | 0.23 | 0.2 | pr |
| FeO | 10.6 | — | 3.69 | 38.37 | 39.45 | 27.6 | 9.9 |
| MgO | — | 0.87 | 3.33 | 1.74 | 2.72 | — | — |
| CaO | 0.1 | 0.73 | 3.19 | 1.29 | — | 0.8 | pr |
| $Na_2O$ | n. c.[b] | 0.35 | 2.05 | n. d.[a] | n. c.[b] | n. c.[b] | n. c.[b] |
| $K_2O$ | 3.6 | 2.47 | 3.95 | n. d.[a] | — | pr. | 0.1 |
| | 99.4 | 91.69 | 94.30 | 99.09 | 93.83 | 99.9 | 99.1 |

[a] Not determined. [b] Not calculated.

A: Calculated composition of three argillaceous schist samples, Mt. Goe I and II (Ba 132, 133, 134).
B: Average of 32 paleozoic coal measure shales from North America (Norin 1946).
C: Goldschmidt's average composition of 68 Quaternary clays from Southern Norway (Goldschmidt 1933).
D: Analysis of garnet from quartz rock, Mt. Goe I, Bassa. Al and Si are calculated and corrected to 100 %; Alm. 87 %. Py. 7 %, Spess. 2 %, Gross. 3.4 %, And. 0.4 %, $(Ca_{0.113}Mg_{0.212}Fe^{++}_{2.612}Mg_{0.063})(Al_{1.992}Fe^{++}_{0.008})Si_3O_{12}$ (anal. B. Almqvist).
E: Ferrous chamosite (Brindley and Youell 1953).
F: Calculated average composition of three quartz-garnet rocks, Mt. Goe I and II.
G: Calculated composition of quartzite adjoining quartz-garnet rock intercalation in argillaceous schists.

grains frequently contain fine inclusions of siderophyllite, clinozoisite, a chlorite, and some ore. The finer grained quartzites are riddled with inclusions of ore. Ferromagnesian bands may be 1–2 cm in width, and consist mainly of fibrous aggregates of vermiculite or a montmorillonite, hematite, garnet, and quartz. Fibrous masses with optical continuity are up to 1.2 mm in length with orientation perpendicular to the plane of banding. However, these minerals are mostly in very fine grained masses with wavy extinction, and probably radiating orientation. Garnet is in anhedral masses, and may contain much poikilitic quartz. The unit cell ($a_0$ 11, 540) is similar to the garnet of the quartz-garnet rock.

In a second sample, coarse grained quartz has formed in fissures created by minor faulting during deformation. These quartz veins are perpendicular to bedding, and are lined by narrow layers of acicular hematite and chalcedony. Quartz veins and iron formation are in turn cut by narrow veins of chalcedony. The chalcedony and acicular hematite have a post-deformational origin.

7. Quartzite and kyanite quartzite.—The southwestern-most unit encountered during detailed mapping is a quartzite which occasionally contains sufficient kyanite to take on a schistose appearance. Towards the Farmington River, the unit becomes more calcic, and a sample is described earlier as a quartz epidosite. Within the central part of the area, this quartzite is in appa-

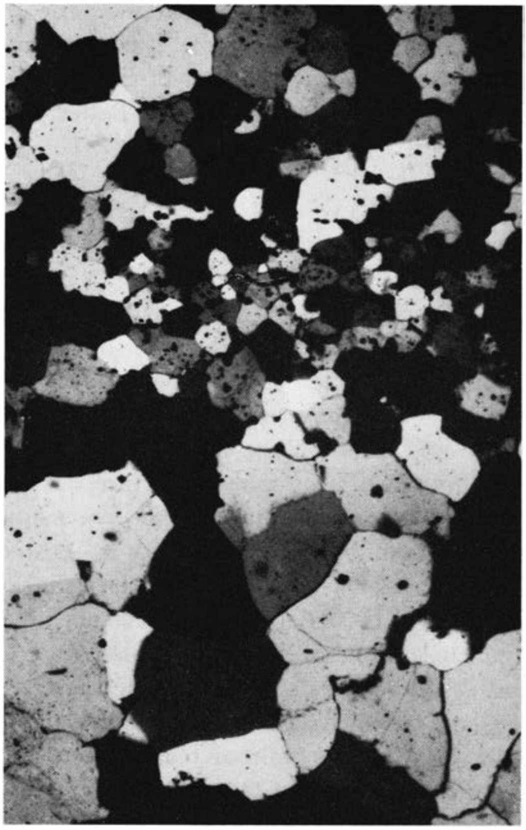

Fig. 6. Banding in quartz layers of iron formation shown as a variation in size of quartz grains. Note that the heaviest concentration of ore inclusions (black) is found in the fine grained layer, Ba 139, 2 nic., ×24.

rently overlying relationship to the upper iron formation, and carries accessorily kyanite, muscovite, and biotite.

To the southwest of the Goe Range, schists and quartzites similar to all of the units described above have been observed sporadically. However, the stratigraphic relationships cannot be given with any certainty. The most frequently observed rocks consist of quartz, muscovite, and sometimes biotite and kyanite. A quartzite sampled from 700 m northwest of Wheazon consists entirely of quartz with a few solitary minute idiomorphic crystals of magnesium-rich hornblende. Grains of the latter are 0.1–0.2 mm in diameter. Four hundred meters to the northeast of Pottertown is located an outcrop of a pink muscovite-rich schist which has been traced with some certainty as far as the base of Mt. Goe II. It may be a part of the kyanite-rich quartzites which occur near the base of Mt. Goe I. It consists mainly of quartz, biotite, and muscovite with minor staurolite, ore, and blue tourmaline.

Outcrops in the vicinity of Dodotown are predominantly of a compact, highly foliated, rather gneissic kyanite-rich quartzite. The quartzite is pinkish to white. Microscopic examination does not reveal the cause of the pinkish colors in some members. Elsewhere, a band of iron formation of unknown width has a general N–S trend from the vicinity of Pottertown to the southwest of Dodotown.

*Geologic structure*

Observations have been made mainly on foliation and schistosity attitudes, and occasionally on planes of bedding or banding. The emergent picture is one of regional concordance of these attitudes with the general trend of rock formations. Except in the Huisa area, the regional strike is to the northwest or north-northwest. With the exception of Mt. Goe I and the rocks of the Huisa area, the foliation and banding have dips which vary from 30° to 70° to the southwest. On Mt. Goe I, dips on the flanks of the mountain are inwards implying a synclinal trough. The implied structure has been borne out by subsurface exploration. This is in contrast to the prevailing apparent monoclinal attitude of rock formations. The possibility exists that the rocks of the Goe Range Series are part of a large overturned isoclinally folded syncline with the strike and dip of the axial plane to the northwest and southwest respectively. Any conclusion to this effect is speculative.

Detailed mapping in the region of Mts. Goe I and II has shown the probability of faults, the planes of which have sub-perpendicular strike to the regional foliation (Offerberg 1958). No signs of thrust faulting have been found, although normal faulting is indicated to some extent.

*Metamorphic facies*

The mineral assemblages of rocks in the Goe Range area suggest an amphibolite facies of metamorphism. However, key assemblages show that there is variation from the epidote-amphibolite/amphibolite boundary in the central and northeast parts of the area to the amphibolite/granulite boundary in the vicinity of Jablis.

Within the central part, the most definitive information is given by the quartz epidosite (Ba 82) sampled near Pottertown, in which plagioclase (An 31) is in equilibrium with epidote. The plagioclase/epidote curve in Ramberg (1949) shows that such an equilibrium exists at the epidote-amphibolite/amphibolite boundary. Within the immediate vicinity, muscovite-biotite, garnet, and kyanite assemblages are common. Such are recognized as being stable within the epidote-amphibolite facies by Ramberg (1952), and are assigned to the garnet-staurolite subfacies of the epidote amphibolite facies by Turner and Verhoogen (1961). The irregular occurrence of a chlorite mineral in such assemblages may preclude the possibility of the amphibolite facies. Within the same general area, the almandine garnet of the quartz-garnet rocks can give little information as to the facies of metamorphism. It is evident that all metallic cations have been used in the development of the garnet, and the ratios thereof simply reflect the pre-metamorphic chemical constitution of the rock.

In the southern and southwestern parts of the Goe Range area, biotite-garnet-potash feldspar assemblages are of great importance in determing the conditions of metamorphism. Near the amphibole gneiss/amphibolite contact in the outcrop at the Farmington River (Ba 6), the ratio of Fe + Mg/Mn in garnets coexisting with microcline and biotite is 86 : 14. This indicates conditions in the upper range of the amphibolite facies (Ramberg, 1949, chart p. 33). In the porphyroblastic gneiss south of Jablis the same ratio is 93 : 7 indicating a zone transitional between amphibolite and granulite facies. It may be noted, however, that within the porphyroblasts, biotite is virtually excluded. Also to be mentioned are the porphyroblasts of ilmenite which have regular occurrence in the alkaline gneisses of the Jablis area. The occurrence of these porphyroblastic gneisses suggest conditions approaching the granulite facies in which sphene and biotite are unstable.

Retrograde metamorphism has occurred to a limited extent and is responsible for the chloritization of amphibole and biotite, and occasional formations of epidote in amphibolites and at the contacts between the oligoclase amphibolite and banded gneiss to the northeast of the Goe Range.

## Discussion

Within the Archaean undefined complex, evidence for a plutonic igneous origin of the banded sphene-rich amphibolite gneiss group is given (pp. 8–9). Ideas concerning the origin of the syenitic gneiss are speculative, and can only reflect the present day controversy on such rocks, however, the transitional relationships between the syenite-, banded-, and paragneisses may be reiterated. It does seem probable that the banded gneisses are of sedimentary origin. The banding would then reflect sedimentary bedding. It may be of some interest to note the position of the chemically analyzed garnets from the syenite gneisses in the paragenetic classification recently proposed by Tröger (1962). The significant grossular content in the principally almandine garnets limits the choice to groups XXI (gneiss, mica schist, and calc silicate rock) and XVII (amphibolite) of Tröger's classification. Tröger notes that "these two groups are so similar that it is impossible to be able to decide whether a given garnet analysis should be placed in one group or another if the name of the parent rock has not been given". The porphyroblastic gneiss garnet (Ba 96) must therefore be placed in group XXI, while the garnet from the amphibolite/gneiss contact may belong in either of the groups.

The paragneisses are interbanded with para-amphibolites and quartz-epidosites which may have originated as calcareous shales or marls. The various associated schists and quartzites interbanded with paragneisses and amphibolites are similar to those underlying the Goe Range.

The three principal rock types constituting the Goe Range are the argillaceous schists, the quartzites, and the iron formation. The larger units of each type contain minor intercalations of other types, plus minor lenses of graphite schist and quartz-garnet rock. All units share certain chemical characteristics: a lack of lime and soda, and a predominance of silica, alumina, iron, and potassium (although in the quartzites, the last three are present in small amounts) (Table 10).

The general similarity between columns A and B, and the contrast between columns A and C is noted, particularly with regard to alkali-lime content. While Na is not calculated in column A, there are no minerals in the schists which would be likely to allow more than minute quantities of Na in substitution. There can be little doubt that the argillaceous schists described here result from the metamorphism of very mature clastic sediments.

The quartz-garnet rocks intercalated in the argillaceous schists are essentially bi-mineralic rocks in which metamorphism has caused the complete conversion of iron-aluminum silicates into garnet. Petrographic studies indicate that there has been no introduction or removal of material during metamorphism (e.g. the rather pure quartzite which envelopes the quartz garnet rock, column G). Thus the sedimentary composition is adequately reflected. The reason for postulating a pre-metamorphic iron aluminum silicate rather than independent oxides (or hydroxides) of iron and aluminum with quartz is that the apparently uniform composition of the garnet may reflect a pre-metamorphic silicate of a determinate composition. Otherwise, constant proportion of independent oxides of iron, alumina, and magnesium might be considered somewhat fortuitous. Thus it is tentatively proposed that these layers represent a metamorphosed sequence of interstratified layers of iron silicate and chert, or orthoquartzite (the garnet itself may be placed in Tröger's group XIX—mica schists). There is similarity between the garnet and certain chamosite analyses (D and E, Table 10) with the exception of silica. Sedimentary chamosite has been frequently encountered together with carbonate-bearing iron formation in other localities (e.g. Clinton iron ore beds), but also in association with orthoquartzites. Thus, S. Palmquist (1935) has discussed the occurrence of beds of chamosite (partly oolitic) in orthoquartzitic strata in the Lias of southern Sweden. Because of the present appearance of the quartz, it is unlikely that such was mechanically deposited (see below). Marmo (1956) has proposed that garnet (almandine) in narrow layers in a siliceous rock associated with iron formation in the Kangari hills of Sierra Leone is of mechanically deposited sedimentary origin. While the milieu of the garnet in Sierra Leone makes such deposition possible (generally immature clastic and volcanic sediments), it seems improbable that sedimentary garnets could be deposited in an environment which alternates between shale accumulation and chemical sedimentation: that of the Goe Range series.

There is no definite chemical criterion for favoring conditions of chemical as against mechanical deposition for the Goe Range quartzites. The uniform orientation of several quartz grains in the quartz-garnet rock and the very much elongated grains in the quartzite with little or no undulose extinction may suggest that the quartzites (as well as quartz in the quartz-garnet rocks) are, at least to a great extent, recrystallized bedded cherts.

Both the upper and lower iron formations may bear distinct resemblance in mineralogy and structure (the banding) to sedimentary iron formations in many other Pre-Cambrian areas. The general lack of minerals which might be attributed to clastic deposition makes it reasonable to suggest that conditions leading to chemical deposition prevailed at the time of iron formation accumulation.

The lack of structural evidence inhibits the construction of a detailed stratigraphic column. However, such a column may be divided into two distinct sequences; one in which quartzo-feldspathic and calcareous sediments alternate and predominate, the other in which argillaceous shales alternate with sediments of chemical deposition. The second group which underlie the largest part of the definitely established metasedimentary rock division are characteristic of conditions of low relief and deep weathering in the continental areas, and are in no way resembling the geosynclinal sediments as described within the Birrimien column from the Ivory Coast and Ghana.

The following table summarizes such chronologic information as may be drawn from this investigation.

| Period | Rock divisions and tectonics |
|---|---|
| Archaean | Post deformational metasomatism (?), and the formation of pegmatites. |
| | Metamorphism with amphibolite facies prevailing, and associated folding and possibly faulting. |
| | Intrusions of basic igneous rocks in pre- or paratectonic stages (sphene-rich amphibolite-amphibole gneiss group). |
| | Peneplanation and deep weathering leading to alternating chemical (iron formation and quartzites) and clastic (quartz argillite schists) sedimentation (marine). |
| | Quartzo-feldspathic and calcareous sediments. |

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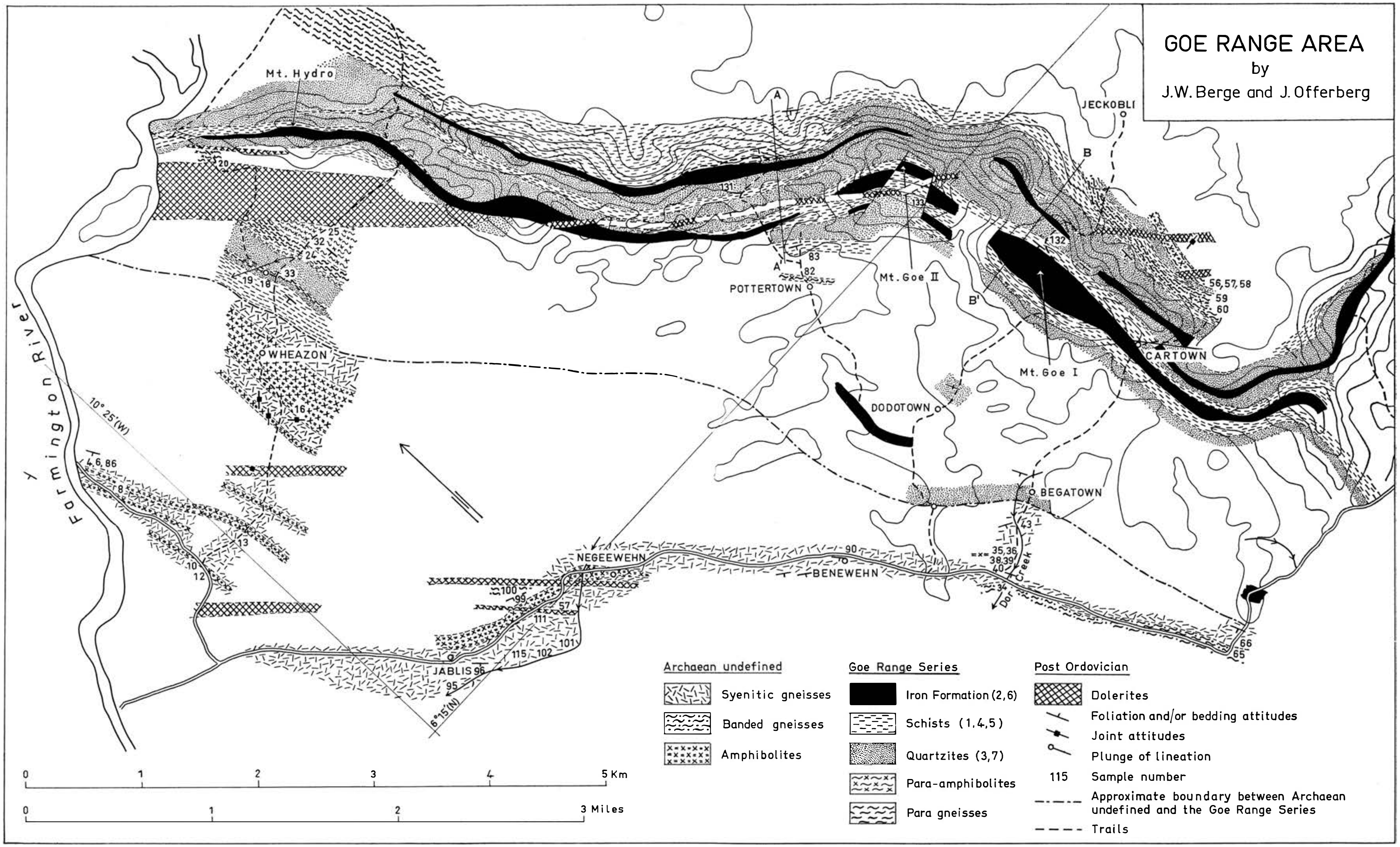
GOE RANGE AREA
by
J.W. Berge and J. Offerberg
Mt. Hydro
JECKOBLI
POTTERTOWN
Mt. Goe II
Mt. Goe I
CARTOWN
WHEAZON
DODOTOWN
BEGATOWN
NEGEEWEHN
BENEWEHN
JABLIS
Farmington River
Dor Creek
10° 25'(W)
6°15'(N)
Archaean undefined
Syenitic gneisses
Banded gneisses
Amphibolites
Goe Range Series
Iron Formation (2,6)
Schists (1,4,5)
Quartzites (3,7)
Para-amphibolites
Para gneisses
Post Ordovician
Dolerites
Foliation and/or bedding attitudes
Joint attitudes
Plunge of lineation
115 Sample number
Approximate boundary between Archaean undefined and the Goe Range Series
Trails
0 1 2 3 4 5 Km
0 1 2 3 Miles