Geology of the Buchanan Quadrangle, Liberia

GEOLOGICAL SURVEY BULLETIN 1449

Prepared in cooperation with the Liberian Geological Survey under the sponsorship of the Agency for International Development, U.S. Department of State

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By RUSSELL G. TYSDAL

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This report describes the geology shown on U.S. Geological Survey Miscellaneous Investigations Map I-778-D

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

W. A. Radlinski, *Acting Director*

Library of Congress Cataloging in Publication Data

Tysdal, Russell G
Geology of the Buchanan quadrangle, Liberia.

(Geological Survey bulletin; 1449)
Bibliography: p.
Supt. of Docs. no.: I 19.3:1449
1. Geology—Liberia—Buchanan region. I. Liberia. Geological Survey. II. Title. III. Series: United States. Geological Survey. Bulletin; 1449.
QE75.B9 no. 1449 [QE339.L5] 557.3'08s [556.66'2] 77-608145

For sale by Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 024-001-03064-1

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GEOLOGY OF THE BUCHANAN QUADRANGLE, LIBERIA

By RUSSELL G. TYSDAL

ABSTRACT

Crystalline rocks of Precambrian age underlie the Buchanan quadrangle and are capped by Cretaceous and younger sedimentary rocks in the coastal area. The crystalline rocks, largely of metamorphic origin, include mainly gneisses of quartz diorite to granodiorite composition. Less common rock types are amphibolite, schist, quartzite, charnockite, and iron-formation. Most of the metamorphic rocks are of the amphibolite facies, but some near the coast belong to the granulite facies. Igneous rocks are predominantly diorite of the Cestos and Sehnkwehn batholiths. Two belts of Jurassic diabase dikes form prominent ridges that trend northwest across the quadrangle. Sedimentary rocks are mainly quartz sandstones, unconsolidated beach sands, and lagoonal deposits.

The structure is dominated by northeast- and northwest-trending features. The northwest-trending Cestos shear zone is marked by a wide zone of mylonite that separates contrasting rock types. It is offset by northwest-trending faults that transect the quadrangle and are, at least locally, marked by narrow zones of shearing. The broad northwest-trending Todi shear zone near the coast separates granulite-facies metamorphic rock from amphibolite-facies rock to the northeast. Prominent folds in the quadrangle are broad and open; their wavelengths are measured in kilometers.

INTRODUCTION

A cooperative program of reconnaissance study of the geology of Liberia was undertaken jointly by the Liberian Geological Survey (LGS) and the U.S. Geological Survey (USGS) between June 1965 and June 1972. The project was sponsored by the Ministry of Lands and Mines of the Republic of Liberia and the Agency for International Development, U.S. Department of State.

Systematic quadrangle mapping of Liberia began in late 1970 when adequate base maps, prepared as part of the project, became available. The geologic map of the Buchanan quadrangle (Tysdal, 1977a) was compiled from data acquired by field mapping largely done during January–April 1971; from photointerpretation; from data supplied by colleagues in the cooperative program; from data supplied by private company geologists; and from interpretation of aeromagnetic, aeroradiometric, and gravity data obtained from geophysical surveys flown by Lockwood, Kessler, and Bartlett Co. under contract to the Government of Liberia. This bulletin, in conjunction with the bulletin on the adjoining Juazohn quadrangle (Tysdal, 1978), describes the geology of the structurally and metamorphically critical area that spans the boundaries of the Liberian, Eburnean, and Pan-African age provinces.

LOCATION

The Buchanan quadrangle is in the south-central part of Liberia, West Africa (fig. 1); its borders are at lat 5° and 6° N. and long 9°00′ and 10°15′ W. It is about 7,900 km^2 (about 3,100 mi^2) in land area and makes up about 8 percent of Liberia.

TOPOGRAHY

The southeastern half of the quadrangle is hilly, and local relief is about 25 m (82 ft) or less; the land surface slopes gently toward the ocean. The northwestern half of the quadrangle is more rugged, consisting of ridges and hills ranging from about 300 to 500 m (980 to 1,640 ft) above adjacent lowlands. Details of topography and culture are shown on Miscellaneous Investigations Map I–778–A (U.S. Geological Survey-Liberian Geological Survey, 1973).

CLIMATE

The area receives about 375 cm (150 in) of rainfall each year, generally from April through October or early November, and vegetation is thus a dense rain forest. Streams and rivers are in flood stage during the rainy period, and the laterite-surfaced roads are at times nearly impassable. The temperature is commonly about 80° to 85°F, though it may be in the upper 70's at night and during part of the rainy season. The field season is limited to the November-through-March dry period.

ACCESS

Access by motor vehicle, at the time work was done, was generally limited to laterite-surfaced roads at the eastern and western margins of the quadrangle. In the easternmost part, the main road extends north from Greenville for about 30 km (about 18 mi) in the quadrangle, and many short logging roads branch from

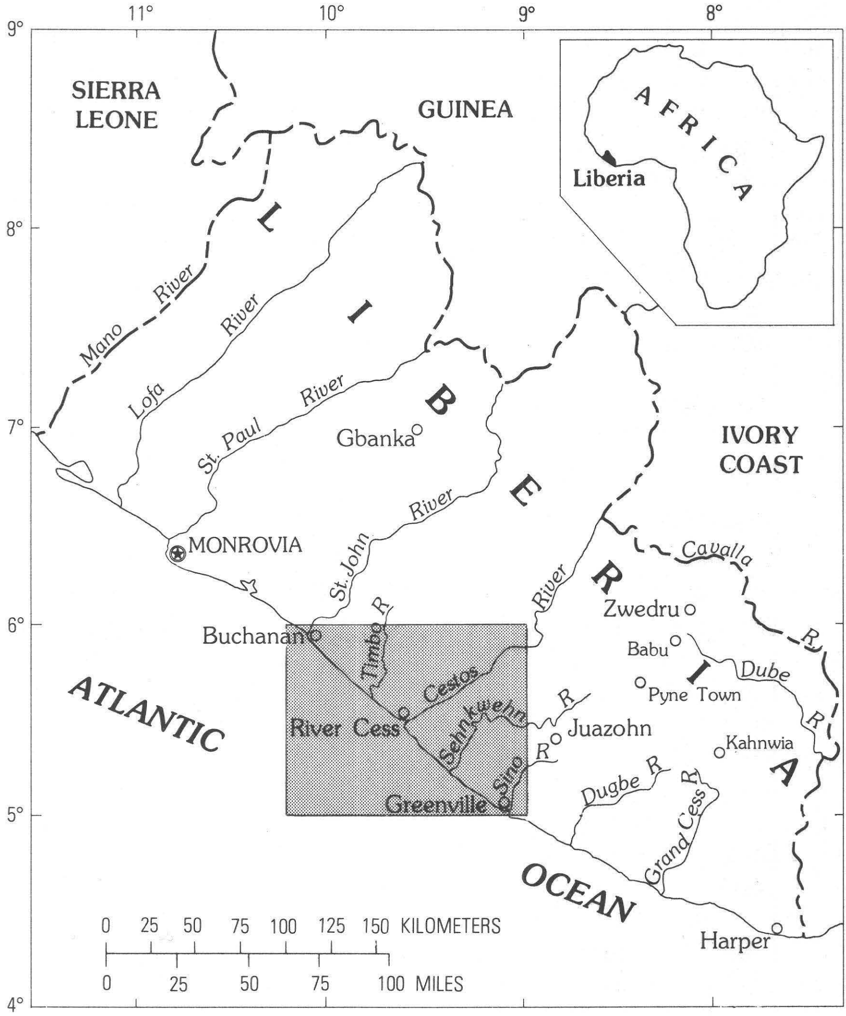

FIGURE 1.—Index map of Liberia showing the area of Buchanan quadrangle and location of principal towns and rivers.

it. In the western part of the quadrangle near Buchanan are several dirt roads and one paved road; the Liberian-American-Swedish Minerals Co. (LAMCO) railroad crosses the quadrangle northeastward from Buchanan.

Rock outcrops are sporadic along the roads because tropical weathering has produced thick laterite and saprolite. Many observations were made of saprolite in roadcuts, from which one can generally gain structural data and at least a general idea of rock composition and texture. Certain rock types, such as quartzite, schist, amphibolite, diabase, iron-formation, and pegmatite, can be identified from saprolites quite readily (White, 1971).

Some areas of the quadrangle were traversed along footpaths, particularly by geologists of the Müller Co. and LAMCO, but there, also, outcrops are only sporadic. Thus a major program was undertaken by the USGS–LGS group to traverse the larger rivers where rocks are best exposed and least weathered. Traverses were made by rubber boats along parts of the St. John, Timbo, Cestos, and Sehnkwehn Rivers.

A helicopter was used along segments of some rivers and along the coast. Several airstrips in the quadrangle were used in gaining access to the interior. However, parts of the quadrangle are uninhabited and are thus not readily accessible.

PROCEDURE

Complete aeromagnetic and aeroradiometric coverage exists for Liberia. Extensive use was made of the total-intensity magnetic map of the Buchanan quadrangle (Behrendt and Wotorson, 1974a) to compile figure 2. The radiometric map (Behrendt and Wotorson, 1974b) was not nearly as useful. Aerial photographs (scale 1:40,000), taken from 1967 to 1969, are available for most of the quadrangle and were used extensively to outline structural features.

Observations plotted in the field on base maps or photographs at a scale of 1:40,000 were transferred in the office to a base map at a scale of 1:125,000. All data acquired from photointerpretation, geophysical interpretation, and previous work were also plotted on this map. The final geologic map was compiled at the 1:125,000 scale from these data and was reduced to the 1:250,000 scale for publication (Tysdal 1977a).

PREVIOUS WORK

The Müller Co. made geologic traverses throughout the area east of the Cestos River as part of a large mineral exploration program encompassing the eastern part of Liberia. They recorded many observations from which 14 unpublished reports and many maps were compiled. This work is partly summarized in a report by Griethuysen (1971).

The Diamond Mining Corp. of Liberia (DMCL) made reconnaissance studies of heavy minerals of the area north of the Sehnkwehn River and east of the Cestos River; this area is drained mainly by tributaries of the Sehnkwehn River. Results of the DMCL heavy-mineral studies are documented only partly.[1,2]

In the western part of the quadrangle, LAMCO geologists made a reconnaissance study of the rocks in a wide expanse of territory along the railroad extending northeastward from Buchanan. The work is described by Offerberg and Tremaine (1961).

Sherman (1947) made the first compilations and descriptions of mining properties in eastern Liberia and noted several localities in the Buchanan quadrangle. Preliminary interpretations of the aeromagnetic and aeroradiometric maps of the Buchanan quadrangle were made by Behrendt and Wotorson (1974a, b).

ACKNOWLEDGMENTS

Many people have contributed to the compilation of the geologic map of the Buchanan quadrangle. Traverses by U.S. Geological Survey personnel, in addition to those of the author, were made by George O. Bachman, Lawrence V. Blade, Robert L. Earhart, Eric R. Force, Philip T. Hayes, Thomas D. Hessin, Sam Rosenblum, George C. Simmons, Charles T. Thorman, and Richard W. White; Roberts M. Wallace made a preliminary interpretation of a few of the Buchanan aerial photographs. Fieldwork by personnel of the Liberian Geological Survey includes that of John Carr, David Cooper, and Abraham Cassell, field assistants.

The hospitality of LAMCO, Tidewater Plantation, West African Corp., the Open Bible Standard Mission and National Christian Assemblies Missions, and VANPLY Logging Co. greatly facilitated logistics and fieldwork. Local officials and townspeople were uniformly courteous and helpful in all phases of fieldwork.

GEOLOGY

The Buchanan quadrangle forms part of the Guinean shield of West Africa and is made up largely of Precambrian igneous and metamorphic rocks (fig. 2). Exceptions include mainly diabase dikes of Jurassic age, Cretaceous and younger sedimentary rocks along the coast, laterite, canga, and young unconsolidated deposits. Most of the rocks are gneiss of quartz diorite composition, and lesser granodiorite gneiss, schist, amphibolite, iron-formation, and dioritic to granitic bodies. Minor amounts of other kinds of rocks are also present.

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[1] Leuria, Basil, 1966, Quarterly report, December 1, 1965–February 28, 1966: Diamond Mining Corp. of Liberia, unpub. rept., 9 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

[2] Leuria, Basil, 1966, Quarterly report, March 1–May 31, 1966: Diamond Mining Corp. of Liberia, unpub. rept., 6 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

The classification of igneous and metamorphic rocks is, as far as possible, based on general igneous composition as follows:

Igneous rock	Metamorphic rock	Percent potassium feldspar of total feldspar	Percent quartz in rock
Granitic, undivided	Granitic gneiss	>10	>10
Granite	Granite gneiss	>50	>10
Granodiorite	Grandiorite gneiss	>10<50	>10
Dioritic, undivided	Diorite gneiss	<10	
Quartz diorite	Quartz diorite gneiss	<10	>10
Diorite	Diorite gneiss	<10	<10

However, an igneous origin is not necessarily implied for the metamorphic rocks classified according to this scheme.

Rock samples were collected from about a third of the outcrops observed by the USGS–LGS group, and many of the samples were slabbed, etched with hydrofluoric acid, and then stained with sodium cobaltinitrite for detection of potassium feldspar. Thus the percentage of potassium feldspar was determined fairly accurately. Systematic detailed thin-section studies were not made, although thin sections from some samples were examined.

Rocks that did not fit the above scheme are noted by specific compositional names (such as manganese formation) or, where little information is available, by a general name (such as leucocratic gneiss). Composite units are designated for areas containing combinations of specific rock types that cannot be separated appropriately at map scale by use of the available data. The terms "leucocratic" and "melanocratic" are used to designate varied associations of rocks that are predominantly light colored or dark colored, or to designate rock units for which little information other than color index is available.

Because data came from many sources and were collected by many geologists among whom geologic concepts and technical terminology varied widely, systematic classification according to the above scheme has presented difficulties. Particularly difficult was the reclassification of rocks that were named wholly on a textural basis.

METAMORPHIC ROCKS

By far the bulk of the rocks in the Buchanan quadrangle are metamorphic (Tysdal, 1977a). The chronologic order of the rock units is unknown, and the units are discussed in this section according to rock type.

QUARTZ DIORITE GNEISS UNIT 2

A unit mapped as quartz diorite gneiss unit 2 is present in the eastern part of the quadrangle, east of the Cestos and Todi shear zones. The unit underlies an area of some of the lowest relief in the quadrangle and has very few outcrops.[3 4] It is mainly melanocratic medium- to coarse-grained rock composed of hornblende (20–35 percent), plagioclase (45–70 percent), quartz (8–20 percent), and locally garnet (0–15 percent). Along the coast, biotite-quartz diorite gneiss and granodiorite gneiss are common and are locally migmatitic. Thin tabular amphibolite bodies are interlayered with the gneiss in the coastal area. Quartzite beds were recorded northwest of New Town. Müller Co.[4] and Leuria (see footnote 1 on p. 5) noted kyanite in stream-sediment samples from near Kase Town.

LEUCOCRATIC GNEISS

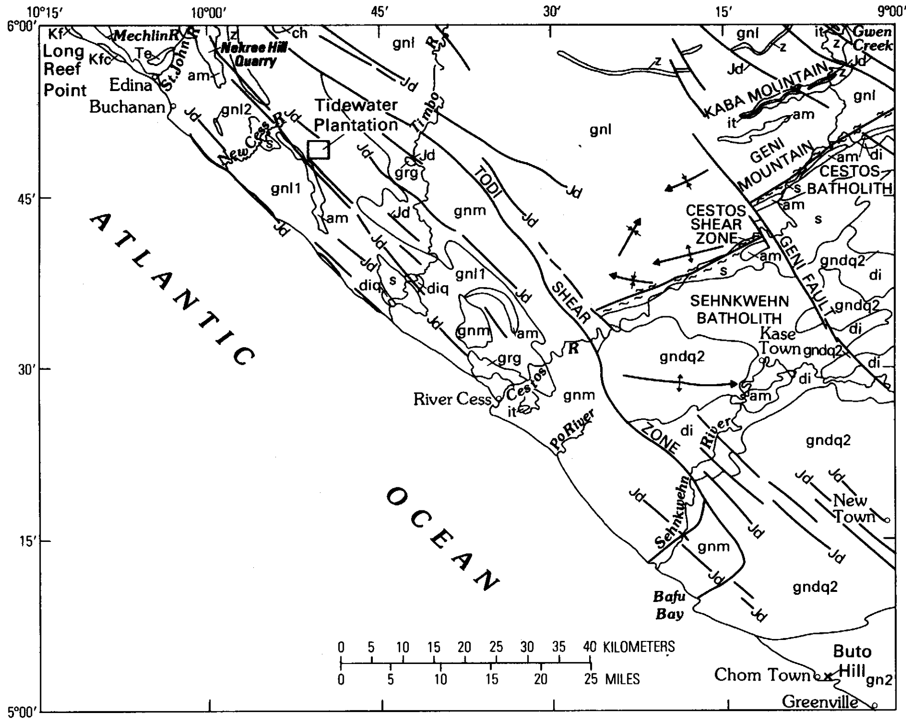
Leucocratic gneiss is separated into three units in the Buchanan quadrangle, mainly on the basis of the different components in each unit and on the density of observations for each unit. Each is described below.

Leucocratic gneiss unit, undivided.—Leucocratic gneiss northeast of the Todi shear zone (fig. 2) and northwest of the Cestos shear zone, as observed in marginal areas, is composed largely of gneisses of quartz diorite composition and lesser granodiorite gneiss. The gneisses are medium-to light-colored, medium- and coarse-grained rocks containing biotite (5–10 percent) and, locally, hornblende. Amphibolite, quartzite, itabirite, schist, and rocks of composite unit z (described below) have been mapped separately within the unit, and they are probably interlayered in this unit elsewhere in the quadrangle.

The central part of the unit, most of which is inaccessible, forms steep ridges that outline broad folds and is characterized by many narrow negative magnetic anomalies. The topographic pattern is suggestive of quartz-rich rocks, and the magnetic anomalies are suggestive of itabirite of low iron content, and lesser amphibolite. Aerial photographs show that a foliation is present in much of the terrane, and the aeroradiometric proper-

[3] Müller Company, 1970, Exploration Liberia, 9th progress report, September-December 1969: The Hague, Netherlands, Müller Co., unpub. rept., 12 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

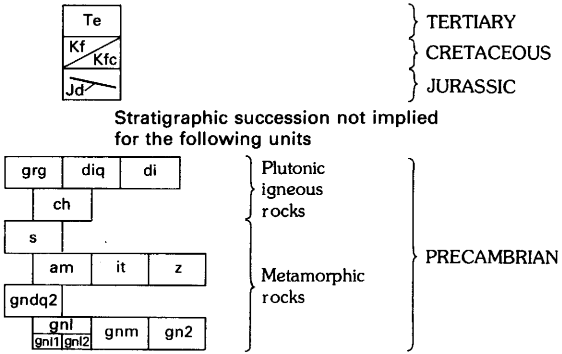
[4] Müller Company, 1970, Exploration Liberia, 10th progress report, January-March 1970: The Hague, Netherlands, Müller Co., unpub. rept., 10 p., on file with the Liberian Geological Survey, Monrovia, Liberia.



Planimetric base generalized from U.S. Geological Survey
Buchanan Geographic map I—778—A

EXPLANATION

CORRELATION OF MAP UNITS



PREPARED BY THE U.S. GEOLOGICAL SURVEY AND THE LIBERIAN GEOLOGICAL SURVEY UNDER THE JOINT SPONSORSHIP OF THE GOVERNMENT OF LIBERIA AND THE AGENCY FOR INTERNATIONAL DEVELOPMENT, U.S. DEPARTMENT OF STATE

DESCRIPTION OF MAP UNITS

- Te — Edina Sandstone
- Kf — Farmington River Formation
- Kfc — Farmington River Formation conglomerate
- Jd — Jurassic dike
- ch — Charnockite
- di — Diorite
- diq — Quartz diorite
- grg — Granite
- z — Composite unit z
- it — Iron-formation, oxide facies (itabirite)
- am — Amphibolite
- s — Schist
- gn2 — Composite gneiss unit 2
- gnm — Melanocratic gneiss
- gnl — Leucocratic gneiss
- gnl1 — Leucocratic gneiss unit 1
- gnl2 — Leucocratic gneiss unit 2
- gndq2 — Quartz diorite gneiss unit 2

- Contact
- Fault
- Fault zone or shear zone
- Antiform, showing trace of crestal plane and direction of plunge
- Synform, showing trace of trough plane and direction of plunge

FIGURE 2.—Generalized geologic map of the Buchanan quadrangle, Liberia.

ties are suggestive of low potassium content. Behrendt and Wotorson (1971) found that a general correlation exists between K_20 content of bedrock and total gamma radiation below 500 cps (counts per second). The leucocratic gneiss unit makes up part of one of the largest areas in Liberia of low to moderate radioactivity (100-250 cps) (Behrendt and Wotorson, 1974b), and thus probably contains relatively low concentrations of potassium.

Leucocratic gneiss unit 1.—Leucocratic gneiss unit 1 southwest of the Todi shear zone in the western part of the quadrangle contains gneisses that are mainly of quartz diorite and granodiorite composition and contains many interlayered amphibolite bodies. Quartzite, schist, and minor amounts of rocks associated with iron-formation are also present. The unit has been examined more extensively than the undivided leucocratic gneiss and differs from it in that it (1) contains larger amphibolite bodies and may contain more amphibolite per unit area; (2) contains much less iron-formation and associated rocks; (3) does not have the abundance of negative magnetic anomalies thought to indicate mainly low-grade itabirite deposits; (4) is characterized by a foliation that trends northwest instead of from northeast to east to northwest; and (5) is found southwest of the Todi shear zone.

Leucocratic gneiss unit 2.—Leucocratic gneiss unit 2 in the New Cess River area east of Buchanan is a sillimanite- and kyanite-bearing unit. The rock is deeply weathered and the mapped areal extent of the unit is based in part on the presence of these heavy minerals in saprolites. Sillimanite was observed locally as off-white fibrous needles in small knotlike mats or pods a few millimeters thick and as intergrown with biotite. The biotite gneiss also contains segregated lenticles and pods of quartz and feldspar.

The northernmost and largest area of leucocratic gneiss unit 2 is on strike with the kyanite-rich gneiss of possible economic value of the Mt. Montro area, in the Monrovia quadrangle about 15 km (9.3 mi) north of Buchanan (Offerberg and Tremaine, 1961; Stanin and Cooper, 1968; Thorman, 1977). Outcrops and saprolite between the two areas do not contain sillimanite or kyanite, however.

MELANOCRATIC GNEISS

Melanocratic gneiss crops out mainly southwest of the Todi shear zone, although two tiny outcrops were noted along the coast in the Bafu Bay area and near Chom Town. This unit is made up of a sequence of medium- to dark-colored rocks of gabbroic and locally dioritic composition; interlayered medium- to light-colored gneiss largely of quartz diorite composition but also of granodiorite composition; and lesser amphibolite that is mapped separately where practical. Quartz diorite to granodiorite gneiss makes up more than half the rocks in the northwestern part of the unit, but dark rocks predominate in the southeastern part.

The rocks of gabbroic and locally dioritic composition are composed of plagioclase (An_{35-50}, 45–65 percent), orthopyroxene (5–18 percent), clinopyroxene (5–20 percent), hornblende (2–12 percent), quartz (<1–20 percent; commonly about 1 percent), potassium feldspar (0–5 percent), and garnet (0–10 percent; commonly absent). They are medium- to coarse-grained rocks, a uniform yellowish green to dark green, and have a greasy luster. Locally, however, they are medium gray and spotted with dark clots of mafic minerals. These rocks, which are of the granulite facies of metamorphism, apparently form laterally discontinuous bodies in the northwestern part of the unit, but southeastward they are much more widespread and continuous. The foliation is generally faint but is more pronounced in the southeastern part of the unit. The origin of the granulite rocks is uncertain—they may be metasedimentary or metaigneous; detailed studies of them were not undertaken.

Medium- to light-colored quartz diorite to granodiorite rocks of the unit range from fine to coarse grained. They commonly contain a small percentage of biotite and locally contain hornblende or are free of mafic minerals.

COMPOSITE GNEISS UNIT 2

Composite gneisses are made up of rock types grouped together, because each is individually too small to show at map scale (Tysdal, 1977a). The exact location of only a few of the rock bodies is known, and the areal extent is best shown by a single grouping. Only one composite gneiss unit is mapped in the Buchanan quadrangle.

Composite gneiss unit 2 is in the southeasternmost part of the quadrangle and is a continuation of the graphite belt of the Juazohn quadrangle (Tysdal, 1977b). Medium- to dark-colored, fine- to coarse-grained biotite-graphite quartz diorite gneiss is the chief rock type; granodiorite gneiss is present locally. The graphite is less widely distributed and less abundant than in the

Juazohn quadrangle. Amphibolite, quartzite, and abundant pegmatite also characterize the unit, and sillimanite is present in the southeasternmost part. Fresh outcrops are sparse in the coastal area, except along the beach, but structural data were observed in saprolite in many rock cuts. The rocks are isoclinally folded, and the folding is reflected in the narrow, linear magnetic pattern of the unit.

MIGMATITE

The term "migmatite" is applied to rock consisting of a metamorphic (generally mafic) component that is disrupted by a less mafic igneous component of pegmatite, aplite, or granite. The term is used in areas containing outcrops in which the metamorphic country rock is fragmented and thus may appear to float in the younger rock. In the migmatite terminology of Mehnert (1968), the rock has agmatic (breccia) structure or schollen (raft) structure. In the Buchanan quadrangle, migmatite was mapped only in surf-cut outcrops along the coast in the River Cess area, mainly because outcrops elsewhere are too small to show the gross texture, or because the area of migmatite is too small to show at the map scale (Tysdal, 1977a).

Migmatite in the River Cess area contains gneissic country rock of quartz diorite to granodiorite composition with locally interlayered amphibolite. The granitic material has separated blocks of the country rock into isolated rafts, shows complex flow structures, and appears to have soaked into and replaced some of the gneiss. In an outcrop about 1.5 km (about 1 mi) south of River Cess, the migmatite is cut by several generations of dark-gray, fine- to medium-grained dioritic dikes. Several 0.25- to 1-m- (10- to 40-in-) wide granitic dikes, striking about N. 40° W., cut all the other dikes they cross. These grayish-orange fine-grained rocks are distinct because they are spotted with round black clots of biotite, feldspar, and quartz about 0.5 cm (0.2 in) in diameter.

SCHIST

Schistose rocks noted in the Buchanan quadrangle are mainly biotite-quartz-feldspar schist, mostly in outcrops too small to show at map scale (Tysdal, 1977a). The schist band near the mouth of the Timbo River is about 3 km (1.9 mi) thick, but it is probably folded isoclinally. The rock is fine to medium grained and forms poor outcrops except where it becomes coarse grained and grades into gneiss.

Biotite-quartz-feldspar schist is also present along the Cestos River where much of it is sheared and mylonitic. The mylonite precursor may or may not have been schist, but downstream from Geni Mountain, schist is present southeast of the mylonite, and the same relationship of mylonitic and unsheared (schistose) rock also exists in the northwestern corner of the adjacent Juazohn quadrangle (Tysdal, 1978). In addition, the fault shown along the Cestos River marks a prominent magnetic contrast, suggesting a probable change from schist to gneiss.

The staurolite schist that was noted along the Cestos River, southeast of Geni Mountain, is composed of quartz (30–40 percent), biotite (20–35 percent), plagioclase (15–30 percent, staurolite (3–10 percent), and garnet (1–2 percent). Tourmaline (<1 percent) was noted in one thin section, and chlorite (penninite) is a common alteration product of biotite. The staurolite is porphyroblastic, shows sieve structure, and locally shows helitic structure, as does garnet. In one thin section, a zoned relationship is evident; the garnet forming a core mineral followed successively outward by a thin rim of quartz and a thick rim of staurolite.

QUARTZITE

Quartzite, other than in rocks associated with iron-formation, is present in resistant isolated layers 1–2 m (3–6 ft) thick, flanked by saprolite or laterite. It is fine to medium grained and is poorly indurated in the outcrops observed; thus sedimentary structures were not noted. The quartzite is commonly light colored, fine to medium grained, and nearly pure quartz. Common accessory minerals are mica, magnetite, and locally in composite gneiss unit 2, graphite. A white feldspathic quartzite was noted in one place along the coast south of Buchanan.

AMPHIBOLITE

The term amphibolite is used for rocks that are of the amphibolite facies of metamorphism and contain about equal amounts of plagioclase and hornblende, plus minor amounts of other minerals such as quartz, sphene, biotite, garnet, magnetite, and clinopyroxene.

These rocks form layers a few centimeters thick, interbedded with gneiss; discontinuous tabular bodies a few meters to hundreds of meters thick; and irregularly shaped bodies, some of which are more than 1 km (0.6 mi) across. Most of the amphibolite bodies are parallel to the foliation of the country rock, but some trend at a high angle to it, as in the Tidewater Plantation area 20 km (12 mi) southeast of Buchanan.

Amphibolite is well exposed at the Nekree Hill quarry north of Buchanan, where it includes banded to spotted gneisses. White and Leo (1969) found the mafic part to be mainly green hornblende and andesine (An_{30-35}) with some layers rich in garnet and scapolite. Leucocratic layers consist of andesine and as much as 30 percent quartz. Local clinopyroxene porphyroblasts rimmed with hornblende, plus possible pyroxene pseudomorphs in the form of finely granoblastic hornblende clusters, suggest retrogression from granulite facies assemblages (White and Leo, 1969, p. 10). Cross-cutting dikelike zones of leucocratic material probably formed by sweating out from the adjacent rock (anatexis). Mafic minerals are concentrated at the margin of the leucocratic rock and are even more densely packed than in the amphibolitic gneiss country rock. In many places, the alinement of dark minerals in the gneiss continues faintly through the dikelike leucocratic zone to gneiss on the opposite side. These leucocratic zones commonly fade into the gneiss by gradual increase in mafic content.

A negative magnetic anomaly of 100–300 gammas characterizes most of the amphibolite bodies, but low-amplitude anomalies exist over two of the largest units near Buchanan.

Amphibolite is resistant to erosion, commonly forming ridges and outcrops, and is more prominent on the map (Tysdal, 1977a) than it would be if all rock types were equally well exposed. This latter point is well demonstrated in the western part of the Buchanan quadrangle in the Tidewater Plantation, which is laid out in a grid pattern by roads spaced at intervals of 1 km (0.6 mi) over an area measuring about 3 by 6 km (1.8 by 3.6 mi). More than about 80 percent of the relatively fresh rock exposed, other than diabase, is amphibolite. Saprolite exposed in roadcuts contains very little amphibolite; of the saprolite and the relatively fresh amphibolite combined, amphibolite is estimated to make up less than about 25 volume percent. If it can be assumed that much of the amphibolite present in the area is exposed, then the unexposed nonamphibolite rocks and saprolite probably make up about 80 to 95 percent of the rocks in the plantation area.

IRON-FORMATION

Two kinds of iron-formation are distinguished in the Buchanan quadrangle according to the composition of the dominant iron mineral—oxide or silicate. The oxide facies of iron-formation is discussed here; the silicate facies is discussed below wth composite unit z. Carbonate and sulfide facies iron-formation were not found in the quadrangle.

The oxide facies of iron-formation is mainly itabirite, a metamorphosed rock consisting of interlaminated bands of chert or granoblastic quartz and hematite or magnetite. Magnetite itabirites are the most common. The main occurrence of itabirite is in the northeasternmost part of the quadrangle in the Gwen Creek area, where it forms the backbone of the northeast-trending Kaba Mountain and the nearby northwest-trending mountain at the northern margin of the quadrangle. Enriched red hematite ore was collected atop Kaba Mountain. (Kaba means "red rock" in the Bassa dialect, the main language in the area.) Magnetic anomalies associated with the itabirite have amplitudes as large as 2,000 gammas.

Oxide facies iron-formation also crops out about 5 km (3 mi) east of River Cess in an isolated hill about 30 m (100 ft) high and about 1 km (0.6 mi) in diameter. This hill is the major topographic feature in the area. Only extensively weathered rock consisting of quartz, hematite, and minor magnetite is exposed on the hill. It is foliated and sheared, consisting of alternating layers (about 0.5 cm thick) of granoblastic quartz and hematite grains.

A magnetite anomaly of about 4,000 gammas amplitude is associated with this hill, but anomalies of much lower amplitude were recorded nearby (Behrendt and Wotorson, 1974a). A preliminary interpretation of the magnetic data, made by R. W. Bromery of the USGS (written commun., 1971), indicates that the magnetic mass is complex, and that the exposed magnetic rocks associated with the steep-gradient, high-amplitude anomaly may be part of an areally larger, buried magnetic mass that extends 3 to 5 km (2 to 3 mi) northwest, 1.5 to 2.5 km (0.9 to 1.6 mi) southeast, and about 2 km (1.25 mi) southwest. The top of the buried mass is estimated to be 200 to 300 m (650 to 1,000 ft) below the surface at its northwestern end and 100 to 150 m (325 to 490 ft) below the surface at the southeastern end.

COMPOSITE UNIT Z

Composite unit z is made up of rocks associated with itabirite; most of the rock bodies are individually too small to show at the map scale (Tysdal, 1977a). The unit is dominated by the iron silicate facies of iron-formation but also includes quartzite, amphibolite, and locally actinolite, pelitic schist, minor itabirite, and leucocratic gneiss.

In the Gwen Creek area, the silicate iron-formation includes grunerite-magnetite phyllite and grunerite-hornblende-garnet-quartz schist. Actinolite schist, associated with quartz-muscovite schist, is present in the northernmost part of the area, but hornblende amphibolite is present southward along the river and near Kaba Mountain.

Composite unit z, exposed along the road northeast of Buchanan, contains rocks made up of about equal parts quartz and garnet, in addition to quartz-grunerite rocks. The quartz is commonly granoblastic in platy or tabular discontinuous segregations parallel to foliation but locally forms crosscutting blebs. Grunerite locally forms porphyroblasts as much as 3 cm (1.2 in) across. These quartz-rich rocks are generally massive but have faint layering in some places. Quartzite, amphibolite, and associated rocks of probable metasedimentary origin are also present. The leucocratic gneiss of this unit, best exposed along the St. John River, is medium- to coarse-grained hornblende-bearing rock of quartz diorite to granodiorite composition.

IGNEOUS ROCKS

Igneous rocks of large areal extent are present in the eastern part of the quadrangle, forming dioritic batholiths. Small plutons of charnockite, quartz diorite, and granite have been mapped in the western part of the quadrangle, and two zones of diabase dikes cross the quadrangle.

GRANITE

Granite was mapped in two areas of the Buchanan quadrangle, near River Cess and along the Timbo River (Tysdal, 1977a). The granite body at the mouth of the Cestos River near River Cess is massive light-gray to pink, medium- to coarse-grained hypidiomorphic rock consisting of orthoclase (60–70 percent), plagioclase (15–25 percent), quartz (15–20 percent), and biotite (2–4 percent). Near the granite margins, biotite is faintly alined and defines a vague foliation. Contacts with adjacent rocks are sharp at the two places where observed, and the pluton interrupts the general trend of foliation of the country rock. The granite weathers spheroidally, producing rounded boulders as much as 3 m (10 ft) in diameter. The granite pluton along the Timbo River, at about lat 5°45′ N. and long 9°45′ W., is only about 200 m (650 ft) across. It consists of light-gray megacrysts of orthoclase as much as 2 cm (1 in) across in a fine-grained groundmass of plagioclase, quartz, biotite, and minor hornblende.

The granite is marked by a positive radiometric anomaly and appears to interrupt the trend of the surrounding gneiss.

DIORITE

Hornblende diorite makes up the Sehnkwehn and Cestos batholiths (Tysdal, 1977a, b) in the eastern part of the Buchanan quadrangle and is a gray-green, medium- to coarse-grained rock composed of hornblende (20–40 percent), plagioclase (45–65 percent), quartz (2–12 percent), and potassium feldspar (0–10 percent). The range in quartz content locally straddles the percentage limit (10 percent) separating diorite from quartz diorite, but the majority of rocks examined in thin section contain less than 8 percent quartz; hence the rocks are diorite.

Other phases of the batholithic rocks include the large amphibolite body near Kase Town (on the Sehnkwehn River) which appears to have a gradational contact with the batholith and which may be a roof pendant. A few aplitic zones were noted along the Sehnkwehn River, but these are narrow (a few meters wide) linear zones apparently caused by shearing. Neither pegmatites nor xenoliths were noted in the batholithic rocks. Topographically the batholiths form a nearly featureless surface of low relief. Outcrops are sparse; distances between outcrops along the rivers are commonly 0.5 to 1.5 km (0.3 to 1 mi) and locally as much as 4.5 km (2.8 mi). Rounded boulderlike outcrops are typical of these massive rocks.

The magnetic expression is a nearly uniform flat pattern on which the limits of the batholiths were largely drawn (Behrendt and Wotorson, 1974a). Locally, as along the eastern part of the Sehnkwehn River, the batholithic rocks are not characterized by this magnetic pattern but have a pattern like that of the nearby country rock.

QUARTZ DIORITE

Two small plutons, near the mouth of the Timbo River in the western part of the quadrangle, are the only quartz diorite intrusions known to exist in the map area. They are composed of biotite (2–3 percent), quartz (20–30 percent), and plagioclase (65–80 percent). The rock is brown, medium to coarse grained, forms abundant rounded outcrops, and is unfoliated except near shear zones. These plutons are not characterized by a distinctive magnetic or radiometric pattern.

CHARNOCKITE

Charnockite crops out only in the northwestern part of the quadrangle and is part of a larger mass present in the adjacent Gbanka quadrangle (Force and Dunbar, 1977). It is dark gray, medium- to coarse-grained rock that is commonly rich in large brownish-gray feldspar augens, which are locally stretched out to elongated lenses (Offerberg and Tremaine, 1961). Along its margins, however, the charnockite is fine grained and contains garnet (Force and Dunbar, 1977). The charnockite consists mainly of plagioclase (25–58 percent), potassium feldspar (10–48 percent), quartz (11–26 percent), hypersthene (0.3–4 percent), and hornblende (3–6 percent) (Sam Rosenblum, oral commun., 1973). Other minerals, present locally, include clinopyroxene, biotite, garnet, and chlorite. The rock thus ranges in composition from hypersthene-quartz diorite to hypersthene granite, but most outcrops are hypersthene-bearing granites; hence the name charnockite.

Boulders of spheroidally weathered massive rock form the typical outcrops. The charnockite is more resistant than the surrounding country rock and is marked by a slight but distinct topographic high on aerial photographs.

DIABASE

Diabase is found in two separate belts of northwest-trending dikes in the Buchanan quadrangle, one near the coast and the other in the northeastern part of the quadrangle. It is commonly fine grained and ophitic and is composed of labradorite, lesser augite, and locally orthopyroxene and minor magnetite and ilmenite. Along the coast immediately south of the harbor at Buchanan, however, the diabase is coarse grained (gabbroic). It consists of about 50 percent plagioclase and 25 to 30 percent augite; and quartz (<5 percent), magnetite (5 to 10 percent), and some hornblende that rims the augite. A similar gabbroic dike is present 3 to 7 km (1.9 to 4.4 mi) northwestward along the motor road from River Cess.

Diabase dikes form much of the coastline between Buchanan and River Cess; one of the better exposures being 18 km (11 mi) southeast of Buchanan in a surf-cut outcrop. The diabase is fine grained and is largely labradorite with minor augite and magnetite. Three dioritic dikelets, measuring 1 to 5 cm (0.4 to 2 in) thick, cut the main dike at about 90° to its long axis but do not cut the country rock. Thin sections show the dikelets to be altered, even though the dikelets appear fresh at the outcrop.

The dikelets probably represent a late stage of the magma that formed the diabase. The full width of the diabase dike is not exposed, but one contact of the dike with gneissic country rock is sharp. Xenoliths of gneiss as much as 1 m (3 ft) long are caught up in the diabase and are oriented with long axes nearly vertical.

The dikes are mainly vertical or dip steeply south; they range from a few meters to more than 50 m (164 ft) in thickness. Because they are resistant to weathering, the dikes commonly form prominent linear ridges easily seen on aerial photographs.

Magnetite in the diabase commonly causes a characteristic narrow linear negative anomaly on the aeromagnetic map of the quadrangle (Behrendt and Wotorson, 1974a). In areas that have not been traversed, but in which a characteristic long narrow magnetic anomaly coincides with a characteristic long narrow ridge on the aerial photographs, a dike is mapped (Tysdal, 1977a) as an observed feature. Field checks have shown this mapping technique to be valid.

Preliminary K-Ar dating of the northwest-trending diabase dikes of western Liberia yielded ages ranging from Jurassic to Devonian (White and Leo, 1969). Subsequent work by Grommé and Dalrymple (1972) has shown that dikes that intrude Precambrian crystalline rocks give K-Ar ages of 193 m.y. to 1,213 m.y. on whole-rock and mineral separates. But K-Ar ages of dikes intruding Mesozoic sedimentary rocks near the coast range from 173 m.y. to 192 m.y. Study of the K-Ar data shows that large and differing amounts of excess Ar^{40} are in the dikes intruded into the crystalline rocks and that all the dikes are Early Jurassic. Grommé and Dalrymple (1972) stated that the mean paleomagnetic directions of 6 dikes intrusive into sedimentary rock are very close to those of 19 dikes intrusive into Precambrian rocks, and that the poles of all 25 dikes are in agreement with other Mesozoic paleomagnetic poles from the African Continent.

SEDIMENTARY ROCKS

Sedimentary rocks on land are preserved only in the coastal area of the Buchanan quadrangle and (on land) form units that do not exceed a few meters in thickness. The rocks are mainly quartzose sandstone, unconsolidated beach sands, and lagoonal deposits.

FARMINGTON RIVER FORMATION

The Farmington River Formation crops out along the coast in the westernmost part of the quadrangle and is dominated by conglomeratic graywacke but also contains graywacke and a few thin shale interbeds. The conglomerate is most abundant in the basal part of the formation and becomes less abundant upward and toward the sea; the decrease in conglomerate is accompanied by a decrease in grain size of the graywacke and an increase of shale (White, 1972). The graywacke is poorly sorted and consists of coarse angular grains of quartz and feldspar and very fine grains of chlorite, sericite, calcite, and accessory grains of many different heavy minerals. Clasts of the conglomerate are cobble size, are well rounded, and according to a count of 100 clasts from near Long Reef Point (White, 1972), consist of granitic rock, gneiss, and "granulite" (28 percent), diabase (26 percent), amphibolite (20 percent), Paynesville Sandstone (19 percent—this unit of Paleozoic age does not crop out in the Buchanan quadrangle), and quartzite and vein quartz (7 percent). Fragments of gastropod and pelecypod shells and carbonatized plant detritus are present locally. Neither the top nor the base of the formation is exposed, and bedding was observed only locally.

In the Buchanan quadrangle, the Farmington River Formation is present in the Bassa basin (fig. 3), a structural depression that also extends onto the Continental Shelf (White, 1972; Behrendt and Wotorson, 1970). Northwest-trending high-angle dip-slip faults define the onshore margin of the basin. The thickness of the unit is unknown, but Behrendt and Wotorson (1970) believe their geophysical data indicate a maximum thickness of 3 to 4 km (1.9 to 2.5 mi) of Farmington River or younger rocks in the Bassa basin.

The formation is at least in part Cretaceous, as indicated by pollen and spores of probable Albian age obtained from it near Roberts International Airport (in Monrovia quadrangle about 30 km (20 mi) northwest along the coast) (White, 1972).

EDINA SANDSTONE

The name Edina Sandstone was applied by White (1972) to a few small outcrops of coarse-grained quartz sandstone on islands in the lower part of the St. John River near Edina. He described it as a locally crossbedded and commonly well sorted sandstone, containing well-rounded grains, although granules are present locally and grade into quartz-cobble conglomerate in places. Beds are typically cemented by clayey material. White measured a thickness of about 8 m (26 ft) of the unit near the Mechlin River 2.5 km (1.5 mi) upstream from Edina. Other remnants—some consisting of single outcrops—are thinner and are found in

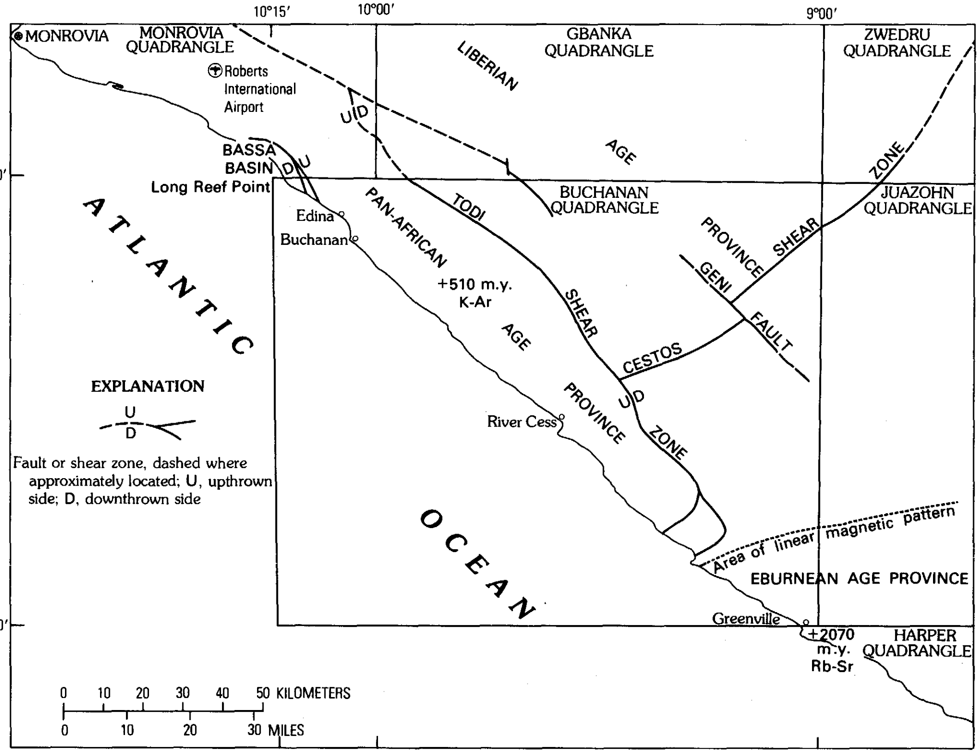


FIGURE 3.—Structure- and age-province map of Buchanan quadrangle, Liberia.

isolated patches along the coast near the mouths of the River Po and the Sehnkwehn River, and east of Bafu Bay (Tysdal, 1977a). The Edina unconformably overlies older formations, most of which are weathered, and is overlain by unconsolidated sediments.

The age of the Edina is uncertain, although it is younger than the Farmington River Formation in which Albian fossils have been found. By analogy with sandstone of similar distribution and character in Sierra Leone (Pollett, 1951; Reyre, 1966) and Ivory Coast (Spengler and Delteil, 1966, p. 108), White (1972) considered the Edina as Tertiary.

BEACH DEPOSITS

Unconsolidated quartz sand is present in savannah areas on a littoral terrace a few meters above sea level along the coast in the Buchanan quadrangle and is composed chiefly of nearly pure white quartz sand that overlies brown quartz sand (Tysdal, 1977a). The limits of most of the unconsolidated quartz sand deposits were mapped easily on aerial photographs as the white sand of the treeless savannah areas contrasts markedly with the adjacent dark vegetation of the rain forest, which is on older rocks. The white sand ranges from fine to coarse grained, is subangular to rounded, and forms a veneer as much as 2 m (6.5 ft) thick. Similar white sand deposits near Monrovia have been studied in some detail by Rosenblum and Srivastava (1971) and White (1972).

The brown quartzose sand is poorly sorted, fine to coarse grained, and forms beach ridges as well as flat-lying deposits. Beach ridges and intervening lagoonal deposits between River Cess and Greenville were examined by the Müller Co. (Griethuysen, 1971) in a search for heavy minerals of economic value. Auger drilling showed that the ridges average 5 to 8 m (16 to 26 ft) thick and are underlain by weathered crystalline rock, a sandy clay layer, or a dark organic clay layer;[5] bedding dips seaward at about 5°. Heavy minerals constitute about 2 percent of the sand in the ridges, are generally dispersed throughout the deposit, and are mainly ilmenite, rutile, zircon, monazite, and garnet. The heavy minerals are locally concentrated in lenses measuring 1 m (3 ft) thick, 15 m (50 ft) across, and 100 m or more (325 ft or more) long. Radiometric anomalies caused by

[5] Müller Company, 1971, Exploration Liberia, 13th progress report, November–December 1970—January–March 1971: The Hague, Netherlands, Müller Co., unpub. rept., 11 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

the zircon and monazite mark the position of many of the heavy-mineral concentrations (Behrendt and Wotorson, 1974b; Sam Rosenblum and S. P. Srivastava, written commun., *in* Behrendt and Wotorson, 1971).

The unconsolidated sand is believed to be of Holocene age. A probable minimum age is 1,440±250 m.y., the date yielded by a tree stump truncated at the base of the white sand (White, 1972). White believed that the bulk of the quartz sand is older, because soil similar to that in which the tree trunk was found overlies brown quartz sand in the Monrovia area.

LAGOONAL DEPOSITS

Lagoonal deposits consist mainly of Holocene sand, silt, and clay that are being deposited today or were deposited in the recent past (Tysdal, 1977a). The deposits are present near the mouths of rivers and streams, and because they are marked by the presence of mangrove trees, they are readily distinguished on aerial photographs. The deposits are probably formed of sediment derived from the sea by tides and trapped by mangrove roots. Some of the sediment, however, may be overbank deposits from floodwaters.

METAMORPHISM

Metamorphic rocks in the Buchanan quadrangle are of the amphibolite and pyroxene granulite facies. An exception may be the local presence of actinolite noted along Gwen Creek near the northern margin of the map (Tysdal, 1977a), in rocks shown as amphibolite. Amphibolite facies rocks are present throughout most of the quadrangle and range from lower grade amphibolite facies rocks (quartz-muscovite-biotite-staurolite schist) through upper grade rocks (sillimanite-kyanite-quartzofeldspathic gneiss). Additionally, some amphibolite bodies, such as those along the road trending north from Greenville, contain clinopyroxene, indicating the uppermost grade of the amphibolite facies.

Granulite facies rocks are present mainly southwest of the Todi shear zone and are truncated in and along the northwest-trending part of the shear zone. The southeasternmost margin of the melanocratic gneiss unit, which contains the granulite facies rocks, is interpreted to be truncated by the shear zone also. Hypersthene, diopside, and locally augite, all commonly associated with hornblende, are present in discontinuous outcrops in the melanocratic gneiss unit. These granulite-facies rocks are apparently gradational into rocks of the amphibolite facies. Some discontinuous bodies in the Buchanan quadrangle, however, may represent metamorphosed hypersthene-bearing igneous rocks and thus may have intrusive contacts now obscured by subsequent metamorphism.

Most of the rocks within the melanocratic gneiss unit were most likely subjected to the same temperature and pressure conditions as the pyroxenic rocks but may not have been of a composition suitable to form minerals indicative of the granulite facies. Possibly, the pyroxenic rocks simply lacked water to form amphibolite, so pyroxene formed instead.

STRUCTURE

Two large structural provinces are evident on the map of the Buchanan quadrangle and are separated by the Todi shear zone, a major structure (defined by Thorman, 1972) extending northwestward from near Greenville across Liberia and into Sierra Leone (fig. 3). A third, but much smaller and less prominent, structural province is present in the southeasternmost part of the quadrangle.

Rocks southwest of the Todi shear zone strike northwest; those northeast of it range from northeast in strike in the eastern part of the quadrangle, to east in the central part, to northwest in the westernmost part of the leuococratic gneiss unit. Folds observed on aerial photographs in these two structural provinces are commonly broad and open. The smaller structural province, in the southeasternmost part of the quadrangle, consists of east-trending isoclinally folded rocks that extend east into the Juazohn quadrangle (Tysdal, 1977a, b). This province (fig. 3) is delimited by a magnetic pattern consisting of alternating long linear magnetic highs and lows (Behrendt and Wotorson, 1974a). Rock units within this structural province consist of composite gneiss unit 2 and quartz diorite gneiss unit 2 (figs. 2 and 3; Tysdal, 1977a).

FOLIATION AND BEDDING

Foliations shown on the map reflect compositional layering or schistosity, but whether these planar elements are actually bedding is unknown. Foliations interpreted from aerial photographs are presumed to be parallel to compositional layering, an assumption proved generally valid when checked in the field.

FOLDS

Folds shown on the map of the Buchanan quadrangle (Tysdal, 1977a) are large-scale features mapped wholly or in part through the use of aerial photographs and the magnetic data. Folds thus mapped in the two major structural provinces of the quadrangle are broad, open structures that are many kilometers in wavelength. Folds in the southeasternmost part of the quadrangle are long, linear structures about 1–2 km (0.6–1.2 mi) in wavelength.

The best topographic expression of folds is in the leucocratic gneiss unit in the north-central to northwest part of the quadrangle. Steeply dipping northeast-trending itabirite and associated rocks of Kaba Mountain define the southeast flank of a syncline; the rocks turn north in the Gbanka quadrangle (Force and Dunbar, 1977) to define the northeast end of the syncline. The northwest flank is represented by a long narrow ridge. On the basis of the magnetic anomaly over the ridge, the topographic expression of the ridge, and the fact that the ridge is a continuation of rocks associated with iron-formation in the Gbanka quadrangle, the ridge is thought to contain itabirite and associated rocks.

On the basis of aerial photoevaluation, the topography in the south-central part of the leucocratic gneiss unit is interpreted to reflect a complex synclinal structure. The area is inaccessible and no ground data were obtained for it, but the topographic expression is thought to reflect iron-formation and associated quartz-rich rocks. This interpretation is based on comparison with areas of known iron-formation and associated rocks as observed on aerial photographs in the Buchanan, Juazohn, and Zwedru quadrangles. The magnetic pattern, which in general reflects a synclinal structure, indicates that the rocks do not contain a large concentration of magnetite.

The magnetic data show the long linear isoclinal folds in the southeastern part of the quadrangle to be 1–2 km (0.6–1.2 mi) wide. The contrast of intensity of magnetic highs and lows is less than in the Juazohn quadrangle (Behrendt and Wotorson, 1974a; Wotorson and Behrendt, 1974). This is probably caused by the lower angle of dip of the rocks in the Buchanan quadrangle and the absence of magnetite-bearing gneiss. Other magnetic rocks may be in part responsible for the low contrast of intensity, although exposures are too few in this coastal area to indicate definitely which rock types are present.

FAULTS

Faults of two prominent trends are widespread in the Buchanan quadrangle. Northeast-trending faults are older and are accompanied by a wide zone of shearing along the Cestos River. Northwest-trending faults commonly have a narrow zone of sheared rocks and have been intruded by diabase at many places. One series of northwest-trending faults, however, defines the Todi shear zone, a major structure in the coastal area of western Liberia.

NORTHEAST-TRENDING FAULTS

A major fault and associated wide zone of shearing, the Cestos shear zone, trends diagonally across the quadrangle and controls the course of the Cestos River, for which it is named (Tysdal, 1977a). It is a near-vertical structure that separates melanocratic quartz diorite gneiss and diorite on the east from leucocratic gneiss, iron-formation, and associated rocks on the west. The topography east of the fault has only minor relief, but the topography to the west is generally mountainous. Aerial photographs do not reveal folds east of the fault, but show many large folds to the west. Indeed, the shear zone truncates some of these folds. Magnetic linearity marks the shear zone, and contrasting magnetic patterns on opposite sides of the zone reflect the different rock types. Similarly, a radiometric contrast exists; the rocks east of the shear zone show less radioactivity.

All the rocks examined within the zone are sheared, although the intensity of shearing differs from place to place. Islands of unsheared rock within the zone were not observed, but they could possibly be present. To define individual faults within the zone on the basis of shearing is not feasible. The fault shown on the map (Tysdal, 1977a) is placed about midway within the Cestos shear zone; it corresponds to the locus of some of the most strongly deformed rocks and represents the line of greatest change in magnetic patterns. Most of the rocks in the zone dip steeply; vertical dips are common in the zone of most intense mylonitization.

NORTHWEST-TRENDING FAULTS

Two systems of faults have northwest trends: one system defines the Todi shear zone near the coast, and the other system is younger and is present throughout the quadrangle.

The Todi shear zone was mapped by Thorman (1972, 1977) in the Monrovia quadrangle as a northwest-trending zone of faults and sheared rocks separating granulite and amphibolite facies metamorphic rocks to the southwest from amphibolite facies rocks to the northeast. In the Buchanan quadrangle, long segments of individual faults within the shear zone are defined by

(1) an abrupt change in magnetic pattern, (2) a coincident change in radiometric intensity, (3) a strongly alined drainage pattern, (4) an abrupt change in strike of rocks, and (5) near the Cestos River, abrupt truncation of a prominent northeast-trending ridge. Most of the shear zone is marked by cataclastic rocks that range from protomylonite to ultramylonite. The mylonites commonly contain stretched quartz, and are hard, dense, and generally more resistant to erosion than unsheared rocks. Thus they commonly form outcrops in rivers. Dips of mylonitic rocks are commonly vertical or inclined steeply to the southwest. Near Bafu Bay, however, the sheared rocks strike northeast, and the dips range from 50° SE. to vertical.

The southeastern end of the Todi shear zone is not clearly understood; hence, neither is the junction of the melanocratic gneiss unit and the quartz diorite gneiss unit 2. Nevertheless, the short northeast-trending fault along the Sehnkwehn River, near the coast, seems to reflect strongly sheared rocks along the trend and to reflect the change in strike of the rocks from the general southeast trend to a northeast trend.

Photolineations in the melanocratic gneiss unit immediately west of the Sehnkwehn River, as observed independently by myself and the Müller Co. (see footnote 1 on p. 5), reflect the curving foliation trends produced by shearing in the rocks along the river. East of the river, a second set of photolineations, interpreted by the Müller Co., shows a similar curving trend. These lineations may reflect another fault that truncates the melanocratic gneiss unit.

Only two occurrences of melanocratic gneiss are known beyond the limit of this proposed fault. One is at the southern margin of Bafu Bay, where a sliver of melanocratic gneiss a few meters across and many meters long is caught up in a migmatite. The second is near Chom Town, where melanocratic gneiss crops out on Buto Hill.

A conspicuous positive Bouguer anomaly of 40–50 mGal parallels the coast of Liberia from Sierra Leone to Ivory Coast, according to Behrendt and Wotorson (1970, 1974c), who correlate it with the granulite and other rocks southwest of the Todi shear zone. Thorman (1972, 1977) concurs with the correlation for the Monrovia quadrangle, and field evidence indicates a similar correlation in the Buchanan quadrangle as far southeast as Bafu Bay. Beyond Bafu Bay, a crustal section fitted to the Bouguer anomaly data by Behrendt and Wotorson (1974c, p. 24) "suggests that the zone of uplifted granulite may exist offshore beneath the continental shelf in the Greenville area."

Other northwest-trending faults are present throughout much of the quadrangle. Many of these can be distinguished on aerial photographs by offset ridges and disrupted vegetation patterns. Offset magnetic patterns and abrupt truncation of magnetic patterns further delineate some faults and indicate others. Both left-lateral and right-lateral displacements (as much as 3 km (2 mi)) were noted, but the magitude of vertical displacements is unknown. Field traverses show that a narrow zone of shearing is common along many of the faults. Diabase dikes have intruded many of them, and most of the dikes in this region may have formed in this way.

The northwest-trending Geni fault offsets the Cestos shear zone and adjacent rock units and truncates Geni Mounain, for which it is named. On the basis of magnetic patterns, it offsets part of the Sehnkwehn batholith and quartz diorite gneiss unit 2. Aerial photographs and the magnetic pattern both suggest lateral displacement of rock bodies northwest of the Cestos shear zone.

RING STRUCTURE

A ring structure was noted in the northeasternmost part of the quadrangle, 2 km (1.25 mi) west of the eastern boundary of the quadrangle and 12 km (7.5 mi) south of the northern boundary. The structure, observed only on aerial photographs, has a diameter of about 1 km (0.6 mi). It has concentrically arranged ridges separated by streams in an annular pattern, but the ridges are also cut by gaps, probably reflecting a subdued radial drainage pattern. The cause of the ring structure and the nature of the rock are unknown.

AGE PROVINCES

Radiometric age determinations were made by Hurley and others (1971) on rocks from Liberia as part of a reconnaissance study to outline intracratonic age provinces in several of the more ancient regions of the continental crust. Samples from 23 localities in Liberia were dated, mostly by the whole-rock Rb-Sr method, but four analyses were done by the K-Ar method (White and Leo, 1971). Three age provinces were recognized: Liberian (about 2,700 m.y. old), Eburnean (about 2,000 m.y. old), and Pan-African (about 550 m.y. old). In addition, White and Leo (1971) showed an area in eastern Liberia that yielded dates transitional between those of the Eburnean and Liberian provinces.

The Pan-African province (fig. 3) is southwest of the Todi shear zone, which separates it from other provinces. The one rock dated from the Buchanan quadrangle (a leucocratic gneiss southeast of Buchanan) was obtained from this province. This gneiss yielded a K-Ar age of 510 m.y., obtained on hornblende concentrate. White and Leo (1971) noted that an Rb-Sr whole-rock date of 2,600 m.y. was obtained from an unsheared granulite in the Pan-African province in the Monrovia quadrangle (outside the area of fig. 3). This suggests that the granulite-facies rocks may be relics of the old crystalline basement, which had already been raised to the granulite facies during the Liberian thermotectonic event.

An Eburnean date of 2,070 m.y. was obtained on a rock collected near the Buchanan quadrangle border but in the Harper quadrangle (Brock, Chidester, and Baker, 1977) about 1 km (0.6 mi) south of Greenville. The date was obtained by the whole-rock Rb-Sr method on a gneiss from composite gneiss unit 2.

A Liberian age (2,700 m.y.) has been assumed for rocks in much of the quadrangle (White and Leo, 1971); however, on the basis of the projection of age dates southeast along strike from dated rocks in the Juazohn quadrangle, a large area of rocks east of the Cestos River may have ages transitional between Liberian and Eburnean ages. The boundary of Eburnean rocks must be in the southeastern part of the quadrangle.

MINERAL RESOURCES

Heavy minerals of possible economic value are present in beach sands along the coast between River Cess and Greenville. These deposits, described in the section titled "Beach Deposits," were investigated by the Müller Co. (Griethuysen, 1971) and were found to contain significant quantities of ilmenite, rutile, zircon, and monazite. Griethuysen (1971) reported that within a 0.4-km^2 (0.15-mi^2) area near Bafu Bay, 100,000 metric tons of heavy minerals were indicated in more than 2 million m^3 (2.6 million yd^3) of sand.

Itabirite of possible economic significance is present in the Kaba Mountain area (in the northeastern part of the quadrangle) and extends northward into the Gbanka quadrangle. The associated magnetic anomalies reach a maximum of about 2,000 gammas but are not nearly as large as those of deposits presently mined in Liberia.

Diamonds are reportedly being recovered in small quantity from a stream draining Buto Hill, near Chom Town, along the coast northwest of Greenville. The occurrence has not been investigated. The Diamond Mining Corp. of Liberia (Leuria, see footnotes 1 and 2 on p. 5) explored for diamonds in the area north of the Sehnkwehn River as far west as the Cestos River, but did not discover any diamonds.

Several isolated localities of gold in alluvial gravels were reported by Sherman (1947) and Offerberg and Tremaine (1961). Sherman (1947) also reported isolated occurrences of other minerals, but none of economic potential.

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