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Geology of the Juazohn Quadrangle, Liberia

GEOLOGICAL SURVEY BULLETIN 1448

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-779-D

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GEOLOGY OF THE JUAZOHN QUADRANGLE, LIBERIA

By Russell G. Tysdal

ABSTRACT

The Juazohn quadrangle is underlain almost entirely by Precambrian crystalline rocks, both metamorphic and igneous. The predominant metamorphic rock is gneiss of quartz diorite composition, but granodiorite gneiss, amphibolite, quartzite, micaceous and pelitic schist, calc-silicate gneiss, and manganese-formation also are present. Iron-formation is present in narrow linear bands throughout the central part of the quadrangle. Most of the metamorphic rocks are probably of metasedimentary origin. The metamorphic grade is of the amphibolite facies.

Igneous bodies include diorite batholiths in the western part of the quadrangle and a few small granite and granodiorite intrusive bodies elsewhere. An ultramafic intrusive body of unknown age is present near Juazohn and is composed largely of serpentinized dunite. Associated rocks include syenitic and dioritic rocks. Diabase dikes of probable Jurassic age trend northwestward across the quadrangle.

Structural features include at least four major northeast-trending faults, three of which have wide zones of shearing along them. Northwest-trending faults in places offset the northeast faults, locally are associated with narrow shear zones, and many have been intruded by diabase. Isoclinal folds are common, but much of the itabirite-bearing central part of the province is characterized by broad open undulatory folds. Part of the north-central area of the quadrangle is marked by rocks having low dips that may be indicative of an unconformity.

Iron-formation of the Putu Range constitutes the major deposit of potential economic importance in the quadrangle. Small quantities of gold have been won locally.

INTRODUCTION

A cooperative program for reconnaissance study of the geology of Liberia was carried out jointly by the Liberian Geological Survey (LGS) and the U.S. Geological Survey (USGS) from June 1965 through 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 during the project, became available. The geologic map of the Juazohn quadrangle (Tysdal, 1977b) was compiled from data acquired by field mapping, largely done from December 1971 to April 1972; 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 Buchanan 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 Juazohn quadrangle is in the southeastern part of Liberia, West Africa (fig. 1), and its borders are at lat 5° and 6° N. and long 7°20′ and 9°00′ W. It encompasses about 18,540 km^2 (about 7,416 mi^2) and makes up about 19 percent of Liberia.

TOPOGRAPHY

Much of the eastern and western thirds of the Juazohn quadrangle is gently undulatory topography ranging from about 75 to 200 m (250 to 650 ft) above sea level. Local relief is as much as 25 m (82 ft), but is commonly less. The central part of the quadrangle is higher and hilly, culminating in Jide Mountain at more than 800 m (2,600 ft) above sea level. Local relief in the central area commonly reaches 100 m (300 ft) or more.

Details of topography and culture are shown on Miscellaneous Investigations Map I–779–A (U.S. Geological Survey-Liberian Geological Survey, 1973).

CLIMATE

The area receives more than 250 cm (100 in) of rainfall per year, chiefly from April to November, and the area is covered by dense rain forest. Streams and rivers are in flood stage during the rainy period, and the laterite-surfaced roads are at times nearly impassable. Fieldwork is limited mainly to the November-through-March dry period. Temperatures are commonly in the range of 80° to 85°F., though they may drop to the upper 70's

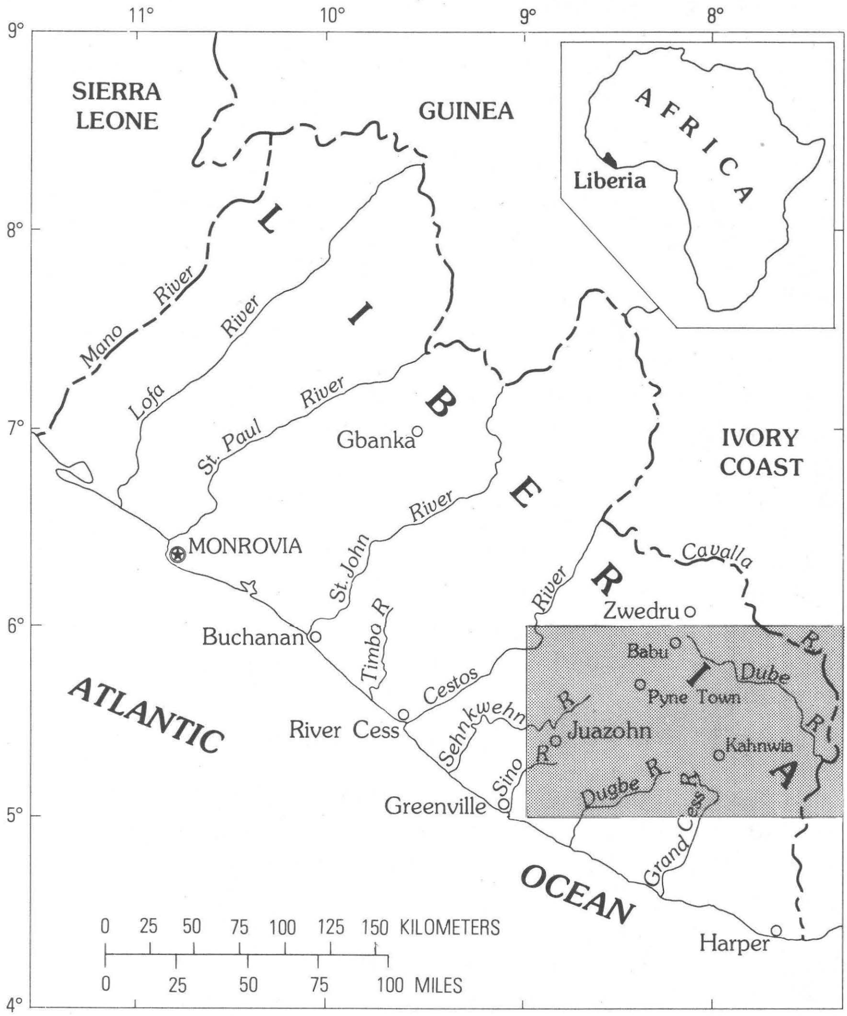

FIGURE 1.—Index map of Liberia showing the area of Juazohn quadrangle and location of principal towns and rivers.

during part of the rainy season and at night during the dry season.

ACCESS

Access by motor vehicle was generally limited to two main laterite-surfaced roads at the time the work was done. One, in the western part, extends southwesterly from Zwedru through Babu, Pyne Town, Juazohn, and on to Greenville at the coast in the adjacent Buchanan quadrangle (fig. 1). The other extends about south from Babu to Kahnwia, thence southeasterly to Watake, and into the Harper quadrangle, terminating at the coast in the city of Harper. Many short temporary logging roads locally branch from the main roads.

Rock outcrops are sparse along the roads owing to tropical weathering that has produced thick laterite and saprolite. Observations of saprolite in road cuts provided many structural data and limited petrographic data. Certain rock types, such as quartzite, schist, amphibolite, diabase, iron-formation, and pegmatite, can be identified from saprolite quite readily (White, 1971).

Extensive areas of the quadrangle were traversed along footpaths, particularly by geologists of the Müller Co., where sporadic outcrops are found. Thus a major effort of USGS–LGS geologists was to traverse the larger rivers where rocks are exposed best and weathered least. Traverses were made by rubber boats down parts of the Cavalla, Dube, Grand Cess, Dugbe, Sehnkwehn, and Sino Rivers (fig. 2).

Several airstrips in the western part of the quadrangle were used in gaining access to the interior. However, large parts of the Juazohn quadrangle are uninhabited and are thus not readily accessible.

MAPPING PROCEDURE

Complete aeromagnetic and aeroradiometric coverage of Liberia was flown by the Lockwood, Kessler, and Bartlett Co. under contract to the Liberian Government. Extensive use was made of the magnetic map of the Juazohn quadrangle (Wotorson and Behrendt, 1974) in compiling the geologic map of the quadrangle (Tysdal, 1977b). The radiometric map (Behrendt and Wotorson, 1974a) was not nearly as useful. Interpretations based on these data are indicated on the map (Tysdal, 1977b).

Aerial photographs (1:40,000 scale) for about the western third and the southern fourth of the quadrangle were taken between 1967 and 1969. Most of the remaining area is covered by photographs taken in the early 1950's, but many of these are practically unusable for photointerpretation because of cloud cover and poor quality. The newer photographs were used extensively to delineate structures; such delineations were appropriately indicated on the geologic map.

Field observations were plotted on "form line" base maps or aerial photographs at a scale of 1:40,000. These data were compiled on a base map at a scale of 1:125,000, together with photointerpretation data, geophysical interpretation data, and field data from other sources. The final geologic map was compiled at 1:125,000 scale from these data for publication at 1:250,000 scale (Tysdal, 1977b).

PREVIOUS WORK

Many workers have studied rocks in the Juazohn quadrangle and are noted in the text. The more comprehensive studies are mentioned here. Sherman[1] (1947) made the first compilations and descriptions of mining properties in eastern Liberia. Jan Offerberg (written commun., 1955), working for the Liberian-American Swedish Minerals Co. (LAMCO), produced the first detailed description of itabirite and iron silicate rocks in Jide Mountain of the Putu Range. The German-Liberian Mining Co. (DELIMCO)[2] made a detailed study of Jide Mountain, and on the basis of extensive drilling, tunneling, and geologic mapping, produced geologic maps and cross sections.

The Diamond Mining Corp. of Liberia (DMCL) made reconnaissance studies of heavy minerals of the area west of the Babu-Pyne Town-Juazohn motor road, an area drained mainly by tributaries of the Sehnkwehn River. Results of the DMCL heavy-mineral studies are documented only in part.[3,4]

The Müller Co. undertook extensive geologic traverses throughout the Juazohn quadrangle as part of a large mineral exploration program encompassing the eastern part of Liberia. This work resulted in 14 unpublished reports and many maps and is summarized in part in a very condensed report of Griethuysen (1971). The Müller data were used extensively in compilation of the geologic map of the Juazohn quadrangle (Tysdal, 1977b) and in this report. Preliminary interpretations of the aeromagnetic and aeroradiometric maps of the Juazohn quadrangle were made by Behrendt and Wotorson (1974a, b) and Wotorson and Behrendt (1974).

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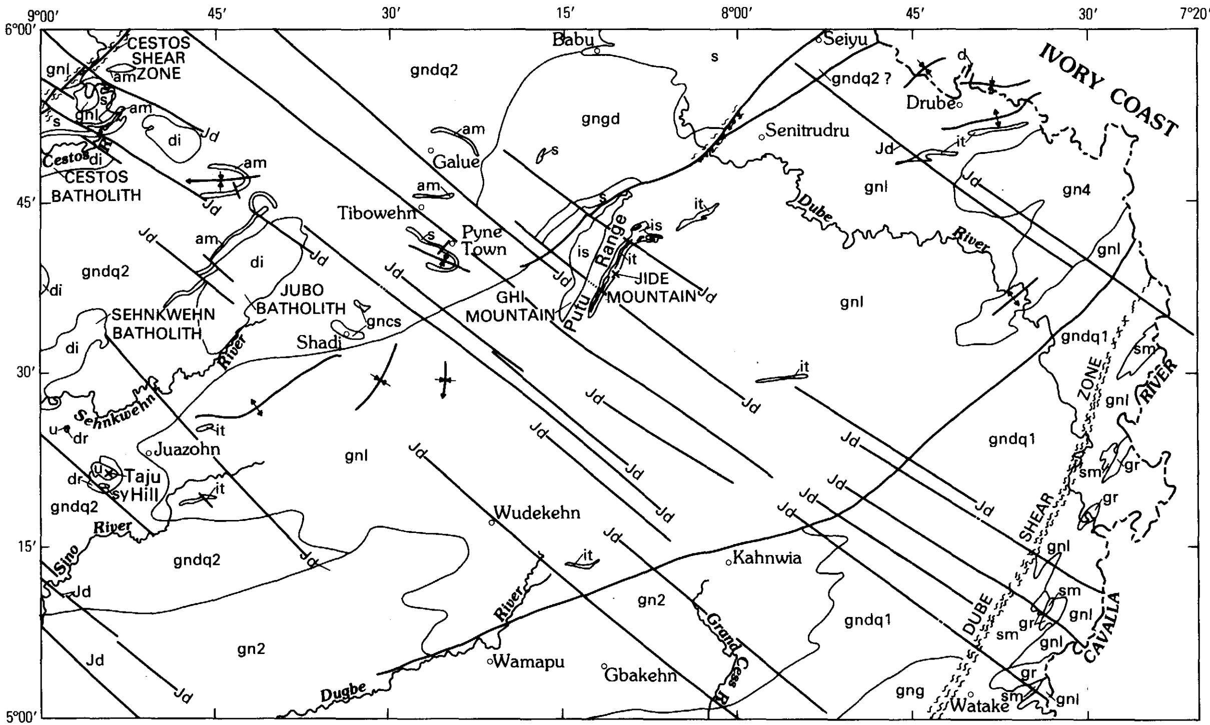
[1] Sherman, Arthur, 1941, Mining possibilities in eastern Liberia: Liberia Bur. Mines and Geology, unpub. rept. on file with the Liberian Geological Survey, Monrovia, Liberia.

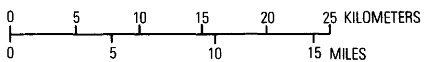
[2] German Liberian Mining Company (DELIMCO), 1971, Report of the research works, Putu Range: Monrovia, Liberia, unpub. rept., 10 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

[3] 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.

[4] 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.

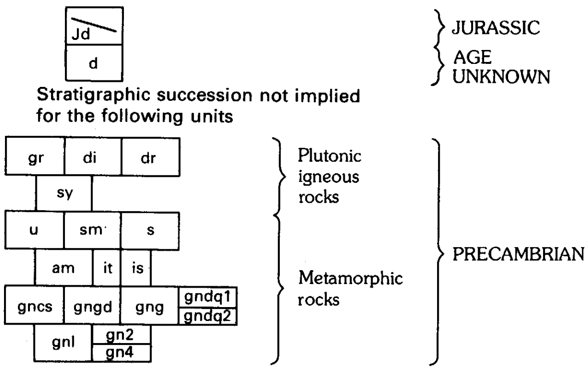


Planimetric base generalized from U.S. Geological Survey Juazohn Geographic map I–779–A



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

Jd	Jurassic dike
d	Diabase dike
sy	Syenite
di	Diorite
dr	Dioritic rocks
gr	Granitic rocks
u	Ultramafic rocks
is	Iron-formation, silicate facies
it	Iron-formation, oxide facies (itabirite)
am	Amphibolite
s	Schist
sm	Mica schist
gn2	Composite gneiss unit 2
gn4	Composite gneiss unit 4
gnl	Leucocratic gneiss
gncs	Calc-silicate gneiss
gndq1	Quartz diorite gneiss unit 1
gndq2	Quartz diorite gneiss unit 2
gng	Granitic gneiss
gngd	Granodiorite gneiss

Contact

Fault

Thrust fault, sawteeth on upper plate

Fault zone or shear zone

Antiform, showing trace of crestal plane

Synform, showing trace of trough plane and direction of plunge

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

ACKNOWLEDGMENTS

Many people have contributed to the compilation of the geologic map of the Juazohn quadrangle, and the areas each person traversed are shown on the responsibility diagram of the geologic map (Tysdal, 1977b). Fieldwork by personnel of the Liberian Geological Survey includes that of M. W. G. Baker, Geologist and Deputy Director of the Liberian Geological Survey; Jenkins Dunbar, Edward Philips, and Thomas Sherman, Geologists; and John Carr and Joseph Flomo, field assistants. Field traverses by U.S. Geological Survey personnel, in addition to those of the author, were made by George O. Bachman, Robert L. Earhart, Philip T. Hayes, Thomas D. Hessin, Joseph M. Hoare, George C. Simmons, and Richard W. White; Roberts M. Wallace made a preliminary interpretation of the Juazohn aerial photographs. Brian Micke, U.S. Peace Corps, also made several geologic traverses. Many observations along the north-trending part of the Cavalla River were made previously by geologists working for the Ivory Coast; they are credited in the text.

The hospitality of DELIMCO, National Christian Assemblies Missions, VANPLY Logging Co., Maryland Logging Co., East Asiatic Logging Co., a CARE project, and assistance of Peace Corps volunteers made logistics and fieldwork less difficult. Local officials and townspeople were very courteous and helpful in support of fieldwork in the rain forest of Liberia.

GEOLOGY

The Juazohn quadrangle forms part of the Guinean shield of West Africa and is made up largely of Precambrian igneous and metamorphic rocks. Exceptions are mainly diabase dikes of probable Jurassic age, laterite, canga, and young unconsolidated deposits. Most common are gneiss of quartz diorite composition with lesser granodiorite gneiss, schist, amphibolite, iron-formation, and dioritic to granitic rocks. Minor amounts of other rocks are also present.

The classification of igneous and metamorphic rocks used here is, as far as possible, based on 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	Granodiorite gneiss	$>10<50$	
Dioritic, undivided	Diorite gneiss	<10	>10
Quartz diorite	Quartz diorite gneiss	<10	>10
Diorite	Diorite gneiss	<10	<10

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

Rock samples were collected from more than 50 percent of the outcrops visited (about 1,300 stations) during field reconnaissance by members of the USGS–LGS group, and many of the samples were slabbed, etched with hydrofluoric acid, and stained with sodium cobaltinitrite for detection of potassium feldspar. Thus the percentage of potassium feldspar was determined fairly accurately. Thin sections from some samples were examined, but systematic detailed thin-section studies were not made.

Rocks that do not fit the above scheme are noted by specific compositional names (such as manganese formation, ultramafic rocks) 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.

Systematic classification according to the above scheme has presented difficulties because data came from many sources and were collected by many geologists among whom geologic concepts and technical terminology varied widely. Because the classification was deemed essential, considerable effort was expended to reconcile the difficulties.

METAMORPHIC ROCKS

Metamorphic rocks make up by far the bulk of the rocks in the Juazohn quadrangle. The stratigraphic order of the units is unknown, and they are discussed in this section according to rock type.

GRANODIORITE GNEISS

Medium-grained hypidiomorphic granodiorite gneiss, varying locally to quartz diorite in composition, distinguishes a unit north of the Putu Range. Foliation in the gneiss is commonly faint. It is defined by oriented biotite (3 to 10 percent) and locally tabular quartz grains and by dips at moderate angles. Minor mica schist and hornblende amphibolite are also present, and small granitic intrusive bodies as much as 1.5 km (1 mi) across are present in the western part of the unit. Near some of the granite bodies, the gneissic country rock shows a gradual change in composition, over tens of meters, from quartz diorite gneiss (or granodiorite gneiss having low potassium feldspar content) to complexly folded granodiorite having moderate to high potassium feldspar content, and locally containing pegmatite. The granite itself forms abrupt hills, is poorly exposed, and is mostly covered by a thick lateritic cap. At other places, country rock of gneiss, schist, and amphibolite is truncated abruptly by granite.

The southeastern and southwestern margins of the unit are marked by sharp magnetic contrasts (Wotorson and Behrendt, 1974), and both are believed to be fault controlled. At the southeastern margin, the generally diffuse, broad, flat magnetic pattern of the granodiorite gneiss is terminated abruptly along a northwest-trending linear magnetic break that is itself marked by magnetic and aerial photography patterns typical of diabase dikes. Hence, the linear element is probably a fault intruded by diabase. The position of the northwestern margin is in doubt, as diagnostic data are lacking.

The contact of the granodiorite gneiss with schist to the northeast is located only approximately. Possibly these are parts of one rock unit that has undergone different degrees of metamorphism. Specifically, the schist unit along strike in Ivory Coast (Papon, 1973, p. 67) is described as largely schistose, whereas the schist in Liberia seems to be transitional from schist to gneiss.

The magnetic pattern (Wotorson and Behrendt, 1974) in the northern part of the gneiss unit is characterized by linear highs and lows and is similar to that of schistose rocks to the northeast. Southwestward, however, the magnetic pattern becomes more diffuse, broad, and flat. It thus appears to be taking on the characteristics of a pattern more typical of igneous rocks, like those in the western part of the quadrangle. Perhaps the faintly foliated gneiss was formed by recrystallization during potassium metasomatism associated with formation of the granitic bodies.

GRANITIC GNEISS

Granitic gneiss in the southeastern part of the quadrangle underlies a small area terminated on the east by the Dube shear zone. The unit is considered to correlate with granitic gneiss (described by Brock, Chidester, and Baker, 1977) cropping out in the Harper quadrangle to the south. It is weakly foliated and is mainly of granodiorite composition but locally ranges from quartz diorite to granite in composition; intercalated amphibolite is present locally.

In the Harper quadrangle, the unit has a distinct magnetic pattern which is less distinct in the Juazohn quadrangle. This, coupled with limited field data for the unit in the Juazohn quadrangle, permits only approximate location of the boundaries. The unit does not have a distinctive radiometric pattern.

QUARTZ DIORITE GNEISS

Quartz diorite gneiss forms two mappable units in the Juazohn quadrangle; they are areally extensive, form few outcrops, and contain a variety of associated rocks, most of which are too small to map separately.

Quartz diorite gneiss unit 1 crops out west of the Dube shear zone in a hilly area of few exposures. Most of the rocks observed are hypidiomorphic granular quartz diorite gneiss in which foliation is defined by oriented biotite (and locally hornblende); migmatitic rocks are also common. Biotite-quartz schist and interbedded quartzite were noted at two localities, and small granitic to dioritic bodies are present locally.

The gneissic rocks in some areas have complex folds and segregations of quartz-rich pods and layers that weather differentially and give a ropy appearance to the outcrop. The mineral grains of these rocks are commonly fractured, and plagioclase porphyroblasts have distorted twin planes.

The migmatitic rocks are agmatite (Mehnert, 1968), with fragments of quartz diorite gneiss and locally dark amphibolite-biotite rock caught up in a swirly matrix of dark-grey medium- to coarse-grained gneiss of granodiorite composition. At a quarry 3 km (2 mi) northwest of the Maryland Logging Co. camp, the quartz diorite gneiss has coarse-grained granitic texture and composition, apparently because of impregnation with potassium. The coarse-grained rock probably represents a zone of melting, as xenoliths of amphibolite and the quartz diorite gneiss are present in it.

Quartz diorite gneiss unit 2 is present over much of the northwestern part of the quadrangle and along part of the Sino River. From the Sino River area to the Sehnkwehn River and northwest to the Cestos batholith, the unit is chiefly melanocratic and fine to medium grained. Biotite is present in some of the rocks, but hornblende is the common mafic mineral and typically makes up to 15 to 25 percent of the rock. Northwest of the southeast-flowing length of the Sehnkwehn River, hornblende commonly constitutes 20 to 35 percent of the rock. These rocks become coarse grained near the margins of large diorite plutons in the area.

Much of the unit is conspicuously banded because of concentration of mafic minerals in some layers. Thin layers of amphibolite or hornblende quartz diorite alternate with layers of leucocratic biotite quartz diorite. Leucocratic biotite quartz diorite gneiss to granodiorite gneiss in layers that are tens to hundreds of meters across is interstratified locally with the hornblendic rocks.

In the central part of the area underlain by quartz diorite gneiss unit 2, the abundance of hornblende decreases; in the northern part, biotite becomes the chief mafic mineral, commonly constituting 10 to 20 percent of the rock. The gneiss in the northern part is typically medium-grained, medium- to light-colored rock of quartz diorite to granodiorite composition. Banding is less common than to the south, and foliation is defined by oriented biotite. Schist is interbedded locally with the gneiss, but most of it was observed in saprolite, and its composition is uncertain. Garnet is common in much of the gneiss. Metasedimentary manganese-formation (described separately) and fine-grained quartzite are present in the central part of the unit, as are several small granitic intrusive bodies noted by the Müller Co.[5] Amphibolite units (described separately), many too thin to map separately, are common throughout the quartz diorite gneiss unit.

CALC-SILICATE GNEISS

Calc-silicate gneiss was noted in only one general area in the Juazohn quadrangle, along the main road about 20 km (12.5 mi) southwest of Pyne Town. It forms low rounded hills and, locally, resistant outcrops, but the best exposures are in a road-metal quarry about 1 km (0.6 mi) northwest of Shadi. The gneiss at the quarry is banded; layers a few meters thick have different concentrations of mafic minerals. The Müller Co.[6] has described the gneiss components as mainly hornblende and prehnite, and lesser altered pyroxene, calcite, quartz, epidote, micas, apatite, serpentine, and leucoxene. Pegmatite dikes cut the gneiss, and pegmatite is also present adjacent to the necked areas of boudins.

On the flank of a hill about 5 km (3 mi) north of Shadi, calc-silicate gneiss consists of alternating centimeter-thick bands of hornblende-poor and hornblende-rich calc-silicate rock. The hornblende content gradually increases up the ridge, and the rock is transitional into amphibolite. A granodiorite dike (dated as 2,140 m. y. old by Hurley and others, 1971) intrudes the gneiss unit.

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[5] Müller Company, 1969, Exploration Liberia, 7th progress report, March–May 1969: The Hague, Netherlands, Müller Co., unpub. rept., 11 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

[6] Müller Company, 1971, Exploration Liberia, final report, July 1967–July 1971: The Hague, Netherlands, Müller Co., unpub. rept., 8 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

LEUCOCRATIC GNEISS

The term leucocratic gneiss is used for light-colored rock for which only relatively few observations exist, or for rocks that were described previously in textural terms only (such as migmatite). In the Juazohn quadrangle, three areas of leucocratic gneiss were mapped: an area east of the Dube shear zone in the easternmost part of the quadrangle, an area along the Cestos River in the northwesternmost part of the quadrangle, and a large area in the central part of the quadrangle.

East of the Dube shear zone leucocratic gneiss and minor associated schist crop out. The gneiss is chiefly banded medium-grained rock of biotite quartz diorite composition. Less common leucocratic gneiss ranges from muscovite granodiorite to granite in composition and locally contains minor biotite. Quartz typically constitutes 20 to 30 percent of the gneiss but may reach 50 percent. Heavy minerals obtained from streams in the leucocratic gneiss area include mainly columbite-tantalite, rutile, and magnetite.[7]

Along the Cestos River, leucocratic gneiss ranges from granodiorite to granite in composition and contains both biotite and lesser muscovite. Pegmatites contain abundant muscovite. Many of these rocks are sheared.

The central part of the quadrangle contains the largest area of leucocratic gneiss (fig. 2). The unit is composed of a variety of rocks, but itabirite, described separately, is distributed abundantly throughout most of it so as to form a distinct itabirite province. In the northeastern part of the itabirite province, rocks observed along the Cavalla and Dube Rivers are mostly leucocratic, fine- and medium-grained biotite quartz diorite gneiss and biotite granodiorite gneiss containing less than about 20 percent potassium feldspar. Good foliation results from the parallel orientation of biotite. A few of these rocks are banded, as more biotite is present in some layers than in others. Biotite constitutes about 5 percent of most rocks and is more or less evenly distributed. Gneiss of granite composition is common near composite gneiss unit 4 in the northeasternmost part of the quadrangle, is medium grained, and contains biotite and locally muscovite. Some of it is weakly foliated, but much of it is massive and may represent small granite bodies. Pegmatite dikes were observed locally.

Granitic gneiss, granite, and pegmatite also crop out along the

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[7] Müller Company, 1968, Exploration Liberia, 3rd progress report, April–June 15, 1968: The Hague, Netherlands, Müller Co., unpub. rept., 8 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

Dube River close to the northwestern border of the map unit. In one particular area northeast of the river, an irregularly shaped radiometric anomaly appears to interrupt the pattern of the surrounding rocks and is possibly caused by moderately potassic granitic intrusive rocks. The Dube River, which elsewhere trends southeastward, flows northeastward along about an 8-km- (5-mi-) long quarter-circle section of arc skirting the southern margin of the anomaly before completing the semicircular diversion of its course. Strikes along the river commonly trend northeastward, but along the arcuate stretch of the river, the strike direction is north to about N. 20° W. Dips in this area are at low angles to the northeast—toward the anomaly. Thus the structure and drainage also are influenced by the rocks causing the radiometric anomaly.

Amphibolite forms tabular bodies at several places along the Dube River, and the Müller Co.[8] has noted them elsewhere in the northeastern half of the province. Some contain a few percent clinopyroxene, but most are hornblende-plagioclase-garnet rocks.

Rocks associated with itabirite in the Juazohn area are hornblende quartz diorite gneiss and leucocratic biotite quartz diorite to granodiorite gneiss. Much of the gneiss is banded, but in some, particularly the hornblende quartz diorite gneiss, foliation is faint. The hornblende content is commonly 20–30 percent, but reaches 40 percent in some rocks. Amphibolite is fairly common in the area.

In the south-central part of the itabirite province, the gneisses are largely banded and are of biotite quartz diorite composition. Granitic intrusive rocks form small hills about 30 to 100 m (100 to 300 ft) high along the main road north from Kahnwia for at least 20 km (12.5 mi). Data of the Müller Co.[9] (see footnote 5 on p. 12) indicate that similar rocks crop out for 15 km (9.5 mi) on both sides of the road. These leucocratic rocks are medium- to coarse-grained biotite-bearing granite and granodiorite bodies that, in some places, clearly crosscut the gneissic country rock. Xenoliths of gneiss are present in the granitic rocks, and agmatite is common near the margins of intrusive rocks. Medium-grained banded biotite quartz diorite gneiss is present along the margin of the granitic rocks. Irregular pods of quartz, a few centimeters

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[8] Müller Company, 1969, Exploration Liberia, 8th progress report, June–August 1969: The Hague, Netherlands, Müller Co., unpub. rept., 11 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

[9] 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.

(inches) across, were observed locally in the gneiss, and pyrite was observed frequently in association with the quartz.

In the hilly southwestern part of the itabirite province near Wudekehn, the rocks are noticeably different because of their coarse grain size. Even the iron silicate rocks are coarse grained. The gneiss is banded rock of quartz diorite to granodiorite composition containing biotite, and locally, garnet. Foliation in some of the leucocratic rocks is indistinct. Small granite and quartz diorite intrusive bodies were noted by the Müller Co.,[10] along with abundant migmatite. Also reported is a garnetiferous dioritic massif.

Many of the folds in the area, as viewed on aerial photographs, have a swirly pattern, as if the rocks were deformed plastically. The area also is in part characterized by random crosscutting radiometric anomalies, and the narrow negative aeromagnetic anomalies accompanying itabirite are generally short and discontinuous.

The central part of the itabirite province, south of the Putu Range, contains migmatite and anatectic granite striking N. 50° W. to N. 70° W.,[11] a trend that is normal to the regional pattern. No outcrops of itabirite were noted in the area, perhaps because of the limited traverses; however, itabirite may simply not be present. The near-surface aeromagnetic map (Wotorson and Behrendt, 1974) indicates that rocks in the central part of the province, south of the Putu Range, differ from those elsewhere in the province, but the area is included in the itabirite province because of a lack of diagnostic data.

COMPOSITE GNEISS

Two composite gneiss units are mapped in the Juazohn quadrangle. Composite gneiss units consist of rock types grouped together because each type is individually too small to show on the map, the exact location of only a few of the rock bodies is known, and the areal extent of the associated rocks is best illustrated by a single grouping.

COMPOSITE GNEISS UNIT 2

Composite gneiss unit 2 is an isoclinally folded sequence of rocks trending east to northeast in the southern part of the

[10] 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.

[11] Müller Company, 1969, Exploration Liberia, 6th progress report, December 1968–February 1969: The Hague, Netherlands, Müller Co., unpub. rept., 12 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

quadrangle. The unit is composed of graphite-bearing quartz diorite gneiss, magnetite-bearing gneiss, amphibolite, quartzite, manganese-formation, abundant pegmatite, garnet, pyrite, and some gold. Graphitic rocks are characteristic of the unit; hence it is called the graphite belt for ease of reference.

The most widely distributed rock in the graphite belt is fine- to coarse-grained biotite-quartz diorite gneiss. Locally the quartz content is as much as 60 percent. Banding is common; fine-grained biotite-rich layers alternate with coarse-grained quartz-feldspar layers. The fine- to medium-grained rocks contain plagioclase augen. Garnet and graphite are accessory minerals, and sillimanite is present in the southwesternmost part of the belt. Graphite flakes oriented parallel to the foliation commonly make up less than 5 percent of the rock, but in some layers constitute as much as 20 percent. Geologists of the Müller Co. (see footnote 5 on p. 12) noted a graphitic gneiss horizon near Gbakehn that is many hundreds of meters long, is 8 to 25 m (25 to 80 ft) thick, and contains 5 to 15 percent graphite. In the western part of the belt, they noted graphitic rocks in 10 long parallel bands. Some of these bands probably represent one unit repeated by isoclinal folding.

Magnetite-bearing biotite-quartz diorite gneiss in the graphite belt is not iron-formation of the itabirite-iron silicate-quartzite assemblage (described below). The rock causes some of the conspicuous linear magnetic anomalies on the aeromagnetic map (Wotorson and Behrendt, 1974), but others are caused by magnetite-bearing migmatite (Müller Co., see footnote 8 on page 14).

Banded hornblende-quartz diorite gneiss crops out in the southern part of the unit. Its alternating layers consist of hornblende-quartz diorite gneiss, mafic mineral-free quartz diorite gneiss, and hornblende amphibolite. Biotite, graphite, or garnet may be accessory minerals in any layer. Clinopyroxene-bearing hornblende-quartz diorite gneiss was observed locally along the Dugbe River.

Lenses and bands of metagabbro are locally concordant with gneiss of the graphite belt. Geologists of the Müller Co.[12] noted a gradation from metagabbroic gneiss into dioritic gneiss in one area. Sample assemblages of metagabbroic rocks include: diopside (30–35 percent), plagioclase (30 percent), hornblende (20 percent), and quartz (10–15 percent); augite (45 percent), plagio-

[12] Müller Company, 1970, Exploration Liberia, 11th progress report, April–July 1970: The Hague, Netherlands, Müller Co., unpub. rept., 10 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

clase (30 percent), magnetite (15 percent), hornblende (5 percent), and biotite (5 percent); diopside-hedenbergite (45 percent), hornblende (40 percent), and plagioclase (15 percent).

Quartzite beds were observed throughout the belt. Most of them have a fine- to medium-grained granoblastic texture and contain such accessory minerals as graphite, garnet, or hornblende. Manganese, in the form of spessartinite and gondite, is also present throughout the belt and is associated with beds of amphibolite and quartzite.

Metamorphic rocks of probable volcanic origin were noted locally by the Müller Co. (see footnotes 6, 9, and 10 on p. 12, 14, and 15) in the westernmost part of the graphite belt. They include a metatuff, a fine-grained siliceous rock in which spherulities are visible. Grains of quartz and albite are also present. Another rock type, apparently meta-andesite, has microlitic porphyroblastic texture and contains remnant phenocrysts of clinopyroxene and amphibole in a matrix of andesine and chloritized hornblende. The significance of these low-grade metamorphic rocks in an area where many of the rocks are of highest grade amphibolite facies is uncertain.

Near the eastern end of this gneiss unit of the belt, many poorly foliated to massive rocks crop out and have the same composition as the gneisses. Graphite is less common than farther to the west and is absent altogether in rocks east of the belt.

High-amplitude aeroradiometric anomalies in the southwestern part of the belt appear to crosscut the regional stratigraphic and structural patterns. Limited data suggest they are caused by small granitic intrusive bodies. Pegmatite veinlets and lenses are widely distributed. Some pegmatite consists largely of plagioclase; other pegmatite contains both plagioclase and potassium feldspar.

COMPOSITE GNEISS UNIT 4

Composite gneiss unit 4, in the northeasternmost part of the quadrangle, underlies an area characterized by low topographic relief and a broad flat magnetic pattern. The unit includes both gneissic and granitic rocks, but because most of the outcrops observed are gneiss or migmatitic gneiss, the name composite gneiss unit is used. Rocks along the Cavalla River are chiefly dioritic to granitic gneiss and abundant pegmatite dikes and sills. Similar rocks crop out along the Dube River where small granite bodies are present also. Between the rivers, P. van Roojen (oral commun., 1972) noted that outcrops are few and are dominated by homogeneous granitic rocks; both foliated and massive types being present. Large outcrops are generally migmatitic (agmatite).

Bos (1964) described similar metamorphic rocks and noted many small outcrops of massive granitic bodies in rocks having the same magnetic pattern along strike in Ivory Coast. He also noted a large granite body about 9 km (5.6 mi) northeast of the northeasternmost part of Liberia. Bos speculated that the granite bodies and associated pegmatite and migmatite of the area may reflect a granite massif that does not crop out. The broad, uniform magnetic pattern, upon which the limits of the map unit in the Juazohn quadrangle were based, is similar to those of the batholiths in the western part of the quadrangle and thus lends support to Bos' interpretation.

SCHIST

Isoclinally folded micaceous schist in large areas east of the Dube shear zone consists of fine-grained muscovite-plagioclase-quartz rock in which biotite is minor. Quartz commonly makes up 20 to 35 percent of the rock and locally exceeds 50 percent, whereas plagioclase commonly makes up 40 to 60 percent. Accessory minerals include garnet and tourmaline. Correlative schist in Ivory Coast is reported to be mainly mesocratic fine-grained rock dominated by equigranular quartz, and containing lesser plagioclase and biotite and accessory muscovite (Bos, 1964). Jeambrun (1965) noted a schist there in which muscovite and biotite make up more than 65 percent of the rock; the remainder being porphyroblasts of plagioclase and accessory tourmaline.

Fine-grained equigranular quartzite is commonly interbedded with the micaceous schist and may contain garnet, pyrite, or hornblende as accessory minerals. Beds of metasedimentary manganese-formation as much as 2 m (6 ft) thick are associated with quartzite; both spessartinite and gondite are present (Müller Co., see footnote 7 on p. 13). A few thin amphibolite bodies are also present. The Müller Co.[13] (see footnote 7 on p. 13) reported peridotite and hornblende in rocks on strike with the schist unit to the south in the Harper quadrangle.

Schist in the northernmost central part of the Juazohn quadrangle is characterized by few outcrops and low topographic relief. Outcrops along the Dube River are mainly leucocratic fine to very fine grained, gently dipping rocks of biotite-quartz

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[13] Müller Company, 1968, Exploration Liberia, 2nd progress report, January–March 1968: The Hague, Netherlands, Müller Co., unpub. rept., 7 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

diorite composition and are best termed schist-gneiss. Garnet is an accessory mineral locally, and muscovite is present in a few thin leucocratic granitic gneiss layers. A fine-grained finely laminated quartzite a few tens of meters thick crops out along the road north of Senitrudru, as do sillimanite schist and amphibolite. Heavy-mineral concentrates from streams in the area contain abundant kyanite. Similar schistose rocks crop out along strike to the northeast in Ivory Coast (Papon, 1973, p. 67). Isolated areas of schistose rocks southwest of the unit, and within the granodiorite gneiss and beyond, may be infolded remnants of this unit.

Schist along the Cestos River, in the northwestern corner of the quadrangle, is partly pelitic, containing sillimanite and muscovite. Other schist is rich in biotite or hornblende and has accessory garnet. Intercalated gneiss units were also noted. These schistose rocks trend northeastward and are along strike of similar schist in the adjacent Buchanan quadrangle (Tysdal, 1977a) and the adjacent Zwedru quadrangle (Force and Beikman, 1977; Griethuysen, 1971; Müller Co.[14]).

AMPHIBOLITE

The term amphibolite is applied to rocks that are of the amphibolite facies of metamorphism and contain about equal amounts of plagioclase and hornblende, plus minor amounts of other minerals. Garnet is a common accessory mineral, but in one place, north of Galue, it makes up about 40 percent of the rock. Clinopyroxene is an accessory mineral in some amphibolite bodies, and where it constitutes a few percent of the minerals, the Müller Co. (see footnotes 6 and 8 on p. 12 and 14) has termed this rock amphibole-pyroxenite.

Discontinuous tabular amphibolite bodies a few centimeters to a few meters thick are shown by a line on the map (Tysdal, 1977b); some units tens of meters thick are also shown on the map. Most amphibolite units are parallel to foliation in the country rock, but others crosscut it. The thicker resistant amphibolite units form narrow ridges that commonly reflect the local structure. Many of the amphibolite bodies are associated with negative magnetic anomalies that not only give a measure of the extent of a body, but also may reflect folding and direction of dip.

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[14] Müller Company, 1968, Exploration Liberia, 5th progress report, June 15–August 15, 1968: The Hague, Netherlands, Müller Co., unpub. rept., 10 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

Amphibolite is widely distributed in the Juazohn quadrangle (fig. 3). It appears to be most common in quartz diorite gneiss unit 2 and composite gneiss unit 2. No outcrops of it were noted in quartz diorite gneiss unit 1, although this may be in part due to fewer traverses across the unit. Amphibolite is present locally in the southwestern part of the leucocratic gneiss in the central part of the quadrangle (the itabirite-bearing rock unit), but a traverse across this unit along the main road from Babu to Kahnwia revealed no amphibolite bodies. Amphibolite is one of the more resistant rock types in Liberia and generally forms most of the outcrops along roads, even though it probably makes up only a small percentage of the total bedrock.

An amphibolite body forms the eastern and central part of the large hill north of Tibowehn, but it appears to grade westward into a pyroxenite body composed almost entirely of clinopyroxene. Anomalous amounts of chromium were noted in geochemical samples from near the pyroxenite (Müller Co., see footnote 11 on p. 15), but heavy-mineral samples collected by the writer from flanking streams did not contain chromite.

IRON-FORMATION

Iron-formation of probable metasedimentary origin is present mainly in the central part of the quadrangle where it forms linear bands, some of which can be traced for more than 30 km (19 mi) (fig. 3). Two facies of iron-formation are present: oxide (itabirite) and silicate. Each is described below, mainly on the basis of outcrops in the Putu Range where these rocks form steep-sided mountains and are best exposed.

The itabirite is finely laminated rock, commonly very fine to fine-grained, as in Jide Mountain (Putu Range), but is locally coarse grained and granoblastic, as near Juazohn. It is composed of quartz, iron-oxide, and minor iron-silicate minerals. Magnetite is the main iron-oxide mineral, but some hematite is generally present; locally, as in Jide Mountain, hematite is the main iron-oxide mineral (DELIMCO, see footnote 2 on p. 5). Chlorite is minor in the itabirite (DELIMCO, see footnote 2 on p. 5). Minor talc and manganese oxide (pyrolusite) were reported in drill cores examined by Jan Offerberg (written commun., 1955). The pyrolusite is a secondary weathering product, but some laminae of manganese silicate rock were noted.

Silicate facies iron-formation commonly flanks itabirite. Drill cores from Jide Mountain show that the iron silicate rock is a very fine to fine-grained quartz-chlorite schist (DELIMCO, see

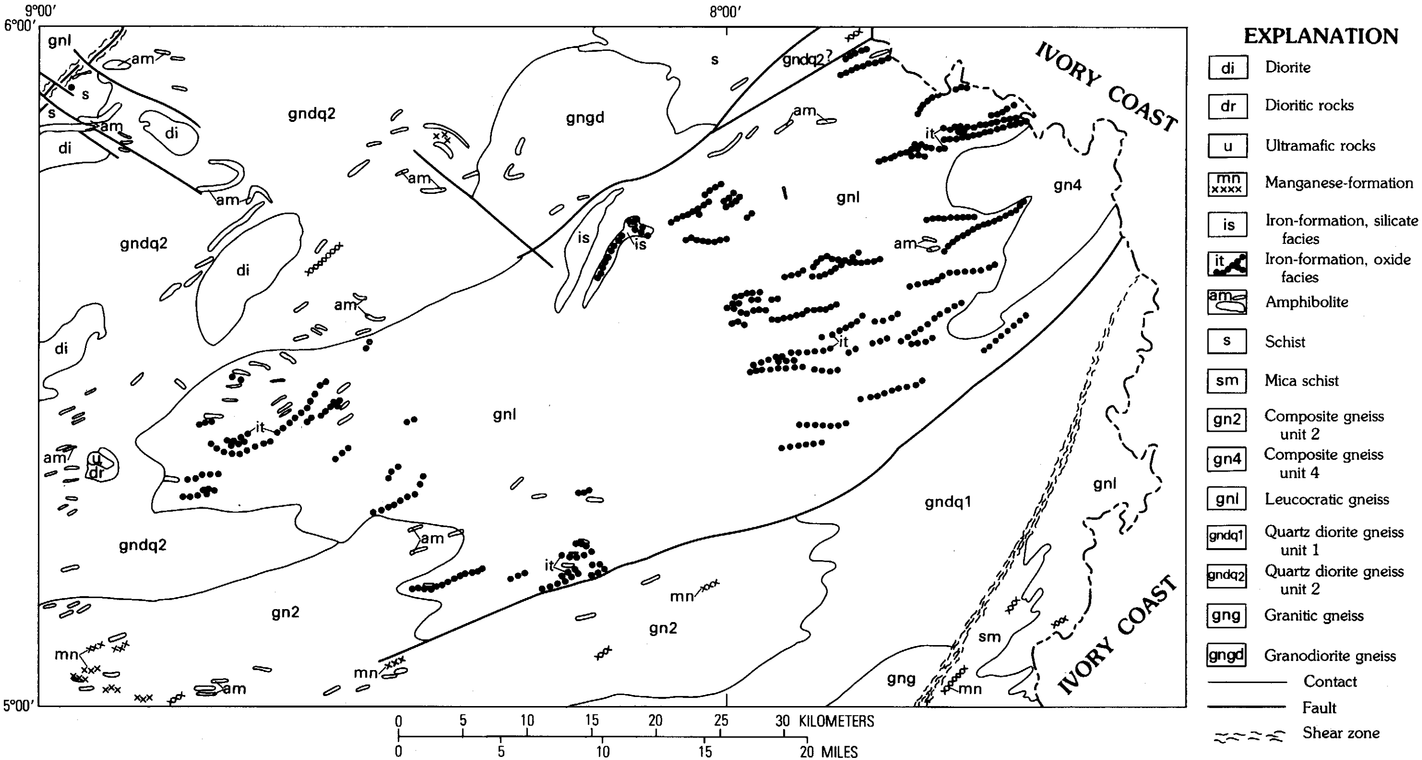

FIGURE 3.—Generalized geologic map showing distribution of amphibolite, iron-formation, and manganese-formation in the Juazohn quadrangle.

footnote 2 on p. 5). In Ghi Mountain (Putu Range), the iron-silicate is fine grained, finely laminated quartz-hornblende or actinolitic hornblende-plagioclase (oligoclase) -magnetite-biotite rock. Nearly pure quartzite beds are interstratified with the iron-silicate rocks. Magnetite forms laminae in some quartzite beds but constitutes a minor amount of the rock.

Rock adjacent to the iron-formation of Jide and Ghi Mountains is leucocratic medium- to coarse-grained gneiss of dioritic to granodiorite composition. T. P. Thayer (unpub. data, 1952) reported black amphibolite and banded green actinolite-talc schist near the crest of Jide Mountain about 3 km (1.8 mi) south of the highest peak.

A weathered zone as much as 50 m (165 ft) thick overlies unweathered itabirite in Jide Mountain and forms an enriched ore of hematite (see section on "Mineral Resources"). Blocks of this ore, in canga along the eastern slope of the mountain, form a dissected alluvial fan. An ironstone cap forms the crest of Ghi Mountain.

The thickness of itabirite deposits ranges from a few centimeters to more than 80 m (260 ft); the latter thickness being at Jide Mountain. In areas of steep dips, the thickness of some of the mapped itabirite units is probably exaggerated. But in general, dips are low in the area east and northeast of the Putu Range and northeast of Juazohn, and the itabirite units, though thin, may be more extensive than shown on the map.

Magnetic anomalies mark the location of most itabirite deposits. The largest anomaly, about 9,000 gammas (Wotorson and Behrendt, 1974), is at Jide Mountain and is caused by magnetite, which makes up about 40 percent of the itabirite. The other itabirite deposits in the quadrangle contain much less magnetite and have anomalies of only a few hundred gammas. Boundaries of many of the itabirite deposits shown on the geologic map (Tysdal, 1977b) are based on magnetic data; for some, however, the presence, as well as the mapped boundaries of the itabirite, are interpreted from magnetic data. However, some short, discontinuous itabirite units have no magnetic expression. The absence of a magnetic anomaly at Ghi Mountain indicates the paucity of magnetite in the iron-silicate sequence.

MANGANESE-FORMATION

Manganese-bearing rocks crop out in three main areas of the Juazohn quadrangle (fig. 3): in the schistose rocks east of the Dube shear zone, in the graphitic rocks of the southernmost part of the map area, and in quartz diorite gneiss unit 2 northwest of the itabirite-bearing map unit. Manganese-formation appears to be most common in composite gneiss unit 2, but this may be more apparent than real, owing to the high density of observations there.

Most of the manganese-formation is bedded metasedimentary manganese silicate, consisting of black fine-grained finely laminated rock containing much spessartite. Rock containing more than 80 percent spessartite is termed spessartinite; the term gondite is applied to rock containing about 60 to 80 percent spessartite and less than 20 percent mafic minerals, the remainder being largely quartz and minor goethite and hematite. The quartz is granoblastic and locally forms thin discontinuous laminations, veinlets, and irregular light-colored patches.

Manganese silicate rock is resistant to erosion and forms prominent steep-sided ridges. The ridges are discontinuous, range from about 30 to 100 m (100 to 300 ft) in height, are as much as to 2 km (1.2 mi) long, and contain abundant colluvial manganiferous debris on their flanks. Near Gbakehn, in the southernmost part of the quadrangle, spessartinite and gondite are present in layers 5 to 25 cm (2 to 10 in) thick and are interbedded with quartzite beds 0.5 to 1 m (1.6 to 3 ft) thick. Similar thicknesses of manganese formation were noted elsewhere (Müller Co., see footnotes 6 and 13 on p. 12 and 18), and the Müller Co. reported a layer 1 m (3 ft) thick near Watake in the southeasternmost part of the quadrangle. Amphibolite units are commonly associated with the manganese silicate rock.

Richards[15] noted manganese oxide (psilomelane and pyrolusite) at Mount Dorthrow 8 km (5 mi) east of Seiyu in the northernmost central part of the quadrangle. The Müller Co. concluded that the rocks observed were float blocks of (low-grade) manganese-formation enriched by weathering.

Sherman (see footnote 10 on p. 15) reported manganese a few kilometers southwest of Juazohn and at three localities a few kilometers west of Kahnwia. None of these localities were found by later workers, and it is not known if they are bedded manganese or simply weathering residuals; hence, they are not shown in figure 2 or 3. The three manganese deposits west of Kahnwia are the only ones reported from the itabirite province; they are close

[15] Richards, J. G., 1953, Report on tour in Eastern Province from Nyaake to Mt. Dorthrow, Dwarbo Town, Gbaldrue Clan, Knobo Chiefdom: Liberia Bur. Mines and Geology, unpub. rept., 6 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

to the manganese-bearing composite gneiss unit 2, in which their presence would be more likely.

IGNEOUS ROCKS

Igneous bodies crop out throughout the Juazohn quadrangle but make up only a small percentage of the rocks. Massive diorite (batholiths) is prominent in the western part of the quadrangle. Ultramafic rocks, altered largely to serpentinite, crop out in an intrusive complex near Juazohn and are associated with intrusive syenite and dioritic rocks. Diabase is the most widespread rock type, occurring in dikes that trend northwest across the quadrangle, forming prominent narrow linear ridges.

GRANITIC ROCKS

Granitic rocks ranging from granodiorite to granite are present in both the schist and gneiss units east of the Dube shear zone. Muscovite is the dominant mica, but sparse biotite is present. Some of the granitic rocks are rich in apatite, others are tourmaline-rich (Müller Co., see footnote 6 on p. 12). Some granitic rocks east of the Dube shear zone are too small to show at map scale.

Pegmatites are abundant and cut all the rock units east of the Dube shear zone. Most of the pegmatites are of granite composition; they contain abundant muscovite and lesser tourmaline and apatite. Coarse-grained hydrothermal veins that have graphic textures and booklets of muscovite are present also and are related to the granitic rocks (Müller Co., see footnote 6 on page 12).

DIORITE

Hornblende diorite underlies areas characterized by few outcrops and low-lying topography in the western part of the quadrangle, where it forms the Cestos and Sehnkwehn batholiths (Tysdal, 1977a and b, 1978) and the Jubo batholith (Tysdal 1977b). The rock is medium to coarse grained and consists of plagioclase (45–65 percent), hornblende (20–40 percent), quartz (2–12 percent), and potassium feldspar (0–10 percent). The texture is massive except where the rocks are foliated and grade into gneissic country rock.

The diorite was observed mainly in the riverbeds where it forms many rounded boulderlike outcrops, some measuring as much as tens of meters across. Along the Cestos River, the outcrops are locally unusual in that they extend for more than 2 km (1.2 mi) and are so abundant as to make river traversing a slow process. Elsewhere, outcrops are few and consist of isolated rounded boulders.

The known batholiths appear on the aeromagnetic map as broad uniform areas of low magnetic relief (Wotorson and Behrendt, 1974). An area of similar magnetic expression northeast of the Cestos batholith is assumed to represent diorite pluton.

DIORITIC ROCKS

Intrusive dioritic rocks north and south of the ultramafic rocks at Taju Hill form massive rounded outcrops. The rocks are mainly diorite but also included are quartz diorite, trondhjemite, dioritic migmatites, gabbroic diorite, and locally, on the north side of Taju Hill, gabbro. The intrusive dioritic rocks contain microscopic inclusions of the intrusive ultramafic rocks, and drill cores reveal small diorite veins in the ultramafic rocks. Thus the diorite is the younger of the two intrusives (Müller Co., see footnotes 6 and 12 on p. 12 and 16).

SYENITE AND TRACHYTE

Aegirine syenite forms a resistant knoll on the southern flank of Taju Hill, within dioritic rocks of the Juazohn ultramafic complex. The syenite grades locally into granodiorite, both within and marginal to the syenite body. The coarse-grained part of the aegirine syenite contains large booklets of biotite in addition to aegirine, orthoclase, and magnetite (5 percent). Secondary apatite (as much as 15 percent) was noted, and sulfide and copper mineralization are also present. X-ray diffraction determinations show spinel in weathered "concretions" taken from the outcrop surface (Müller Co.,[16] see footnote 6 on page 12).

Data from 80 to 100 m (260 to 330 ft) of drill cores of the Müller Co. show the aegirine syenite has been intruded by pegmatitic syenite that contains less than 2 percent dark minerals. The medium-grained equivalent of this latter rock type is common in the basal few meters of three drill cores and apparently indicates that a syenite intrusive body underlies the area (Müller Co.,[16] see footnote 6 on page 12).

Sodic trachyte dikes have been observed along only the Sehnkwehn and Sino Rivers within a 12- to 15-km (7.5- to 9.4-mi) radius of the Juazohn intrusive complex and are presumed to be related to the syenite of Taju Hill. The nearly vertical dikes are 1 to 5 m (3 to 16 ft) thick. The trachyte contains phenocrysts of hornblende.

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

ULTRAMAFIC ROCKS

Ultramafic and associated rocks form a complex that intrudes the country rock about 10 km (6 mi) southwest of Juazohn and also about 15 km (9.5 mi) west of Juazohn. The ultramafic body 10 km (6 mi) southwest forms the central part of Taju Hill, a ridge that measures about 5 km (3 mi) (east-west) by 1 km (0.6 mi) (north-south) and reaches a height of about 150 m (about 500 ft) above the surrounding terrane. Taju Hill is capped by a 10-m- (33-ft-) thick lateritic soil; thus outcrops are found only on steep slopes marginal to the body and in deeply incised valleys. The Müller Co. obtained eight drill cores from Taju Hill, and the following discussion is based on their data (see footnotes 6, 9, and 12 on p. 12, 14, and 16).

The ultramafic rocks include serpentinite; serpentinized dunite, composed of a honeycomb of antigorite enclosing grains of olivine, with accessory chromite; and pyroxenite, composed of augite or diopside (70–95 percent), and minor hornblende (0–5 percent), actinolite (0–5 percent), magnetite (0–20 percent), olivine (0–10 percent), or serpentine (0–5 percent). Contacts with the surrounding dioritic rocks dip southward at the two places where observed (Müller Co., see footnotes 6 and 12, p. 12 and 16).

The Juazohn intrusive complex is characterized by a gravity anomaly of +40 mGal (Behrendt and Wotorson, 1974b) and an aeromagnetic anomaly of –1,800 gammas (Wotorson and Behrendt, 1974; Behrendt and Wotorson, 1974b). The Müller Co. made a detailed ground-magnetometer survey and concluded that six separate anomalies exist, oriented northwest, parallel to the foliation in the Taju Hill area. Both of the ultramafic intrusives near Juazohn are about in line with the northwest trending deep-seated Geni fault in the Buchanan quadrangle (Tysdal, 1977a). The residual magnetic map (Behrendt and Wotorson, 1974b) shows a corresponding lineation in the Juazohn quadrangle. The regional magnetic map (Wotorson and Behrendt, 1974) does not show such a lineation.

DIABASE

A swarm of diabase dikes trends northwest across the central part of the quadrangle, and a few widely spaced dikes crop out northeast and southwest of the main grouping. The diabase is fine grained and ophitic and is composed of labradorite, lesser augite, and as much as 10 percent magnetite and ilmenite. Some wide dikes show coarse-grained (gabbroic) interiors and chilled aphanitic borders.

Diabase that has been weathered to saprolite is easy to recognize in road cuts because it generally retains its felted texture and is spotted with uniformly distributed tiny black grains of magnetite and ilmenite. At many places, the diabase weathers into rounded boulders.

Much of the diabase apparently was intruded along a system of faults, dips steeply to the south or is vertical, and forms narrow linear ridges owing to its resistance to weathering. The dikes are commonly less than 30 m (100 ft) thick and form ridges as much as 60 m (200 ft) high.

The diabase contains sufficient magnetite to produce a characteristic narrow linear negative magnetic anomaly (Wotorson and Behrendt, 1974; Behrendt and Wotorson, 1971, 1974b). A very few dikes, however, contain almost no magnetite. In areas where no outcrops are known, but where a characteristic long narrow magnetic anomaly exists *and* a coinciding characteristic long narrow ridge appears on the aerial photographs, a dike was mapped as an observed feature (Tysdal, 1977b). Many field checks of such features invariably corroborated the interpretation.

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 whole-rock and mineral separates from dikes that intrude Precambrian crystalline rocks give K-Ar ages of 193 m.y. to 1,213 m.y. However, 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 present in the dikes intruded into the crystalline rocks, and that all of the dikes are Early Jurassic in age. Grommé and Dalrymple stated that the mean paleomagnetic directions of six dikes intrusive into sedimentary rocks 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.

A single north-trending dike is present in the quadrangle near the Cavalla River north of Drube, close to the northern margin of the quadrangle. The dike, noted on a river traverse, had been mapped in Ivory Coast by Lemarchand (1965). Lemarchand described the diabase as a medium-grained rock composed of labradorite and pigeonite (locally bordered with hornblende) and minor magnetite. The dike is 10 to 15 m (33 to 50 ft) thick, strikes N. 15°–20° E., and dips 55° W.(?). The age of this dike is not known.

METAMORPHISM

Greenschist-facies metamorphic rocks are uncommon in the Juazohn quadrangle. The Müller Co. (see footnote 6 on p. 12) reported an isolated occurrence of albite-bearing metavolcanic rocks in the western part of composite gneiss unit 2, but its geologic relationship is unknown. The iron-formation of Jide Mountain may belong to the greenschist facies, but thin sections were not prepared for these rocks so plagioclase composition is not known. Chlorite, talc, and actinolite present in the rocks are indicative of the upper greenschist facies, or the lowermost amphibolite facies. The prehnite-bearing calc-silicate rocks southwest of Pyne Town are suggestive of contact metamorphism in the albite-epidote hornfels facies, the approximate equivalent of the greenschist facies.

Most of the metamorphic rocks in the Juazohn quadrangle are of the amphibolite facies. The upper part of this facies is reached in the southwesternmost part of the quadrangle where sillimanite gneiss and mafic gneiss having abundant clinopyroxene exist. A similar increase in metamorphic grade toward the same area was noted in the Harper quadrangle (Brock, Chidester, and Baker, 1977). Sillimanite-bearing schist is present in many areas of the quadrangle.

The presence of minor clinopyroxene in amphibolite is fairly common in the quadrangle, but the adjacent gneiss does not contain pyroxene minerals, even where the composition is appropriate. Thus, such amphibolite is believed to represent rock that contained less water than neighboring rocks and, while undergoing the same temperature and pressure conditions of metamorphism as neighboring rocks, formed higher rank index minerals.

The schist east of Babu is continuous with similar rocks in Ivory Coast which, according to Papon (1973), overlie a migmatite basement. Papon stated that the migmatite was metamorphosed retrogressively during metamorphism of the schist. Thus two (or more?) periods of metamorphism may have taken place in the Babu area.

STRUCTURE

The Juazohn quadrangle can be divided into three broad northeast-trending structural provinces. Rocks southeast, and locally south, of the itabirite province are characterized by steeply dipping, narrow isoclinal folds, a distinct magnetic pattern, and a locally distinct pattern on aerial photographs. The itabirite province itself more typically contains broad, open undulating folds, although isoclinal folds also are present. Aerial photographs show mainly broad open folds in the area northwest of the itabirite province, although isoclinal folds were reported by the Müller Co. (see footnote 6 on p. 12).

A subtle northwest-trending structural province extends from the northwest corner of the quadrangle across quartz diorite unit 2 and across the central part of the itabirite-bearing unit (gnl on fig. 2). The province is marked by the greatest density of diabase dikes; by structural features in the gndg 2 map unit (fig. 2) that trend both northeast and northwest; and by a notable absence of iron-formation in the central part of the itabirite province (fig. 3). The width of this province is uncertain, but along the Babu-Juazohn road, it must extend at least from about Pyne Town to about 20 km (12.5 mi) southwestward.

FOLIATION AND BEDDING

Foliation in most of the Juazohn quandrangle reflects compositional layering or schistosity, but whether these planar elements are actually bedding is not known. Locally, however, foliation is coincident with bedding, mainly in areas of iron-formation and quartzite beds. Foliations interpreted from aerial photographs are presumed parallel to compositional layering.

Foliations (and fold axes) trend northwest, swinging locally to more westerly trends in the western part of the quandrangle. Dips are steep in the isoclinally folded rocks, but moderate to low angles prevail elsewhere.

FOLDS

Large-scale isoclinal folds characterize the rock southeast and south of the itabirite province. East of the Dube shear zone isoclinal folds were seen only in hand specimens, whereas west of this zone isoclinal folds several kilometers in wavelength can be seen on aerial photographs and were observed during river and road traverses. Most of the fold limbs dip to the south or southeast, parallel to the foliation, but some are vertical, and a very few dip to the north.

In the itabirite province, river traverses along the Cavalla and Dube Rivers revealed broad undulating anticlines and synclines; the axes trend northeast, locally changing to east. Dips on the flanks of these folds are generally moderate, although steeply dipping synclinal limbs were also observed. Folds observed in outcrop were also gently undulating.

The itabirite lenses in the northeastern part of the quadrangle are present within both tight, steeply dipping synclinal limbs and more open folds. The itabirite in Jide Mountain of the Putu Range forms a tight isoclinal syncline (DELIMCO, see footnote 2 on p. 5), and isoclinal folds are visible in many outcrops. Farther to the northeast, itabirite crops out in a gently dipping syncline, giving way to gently dipping beds.

The distribution and trends of the itabirite lenses in the northeastern half of the itabirite province show that the itabirite lenses, in aggregate, curve to form a broad nose south and southeast of the Putu Range. The few scattered dips and strikes of other rocks, in general, reflect the nose, too. Perhaps the entire itabirite-bearing rock unit northeast of the nose area represents a very large fold.

Folds in the southwestern part of the itabirite province are commonly broad and open, although some of them, on the basis of aerial photo interpretation, are not so open and reveal a swirly pattern, as if the rocks were plastic during deformation. The contrast of short discontinuous lenses of itabirite in areas of swirly folds with long lenses of itabirite elsewhere exemplifies the two patterns. In general, these areas of swirly folds show prominent topographic relief and patterns of crosscutting radiometric highs. Because these areas of high radiation are irregular and cut across the regional foliation, they, and consequently the associated folds, are thought to have formed after the broad open folds.

Data on folding in the central part of the itabirite province are sparse. Distinctive fold patterns are absent from aerial photographs and the magnetic map. The few foliations measured in the area trend northwest, counter to the regional grain, and may indicate that folds also trend northwest.

The most revealing traverse in terms of folds was made along the Sino River in the southwesternmost part of the quadrangle. The rocks are deformed moderately to intensely along much of the river traversed. The most common folds are open, have near-vertical axial planes that strike about normal to the trend of foliation, and plunge parallel to the dip of the foliation. At several localities, these folds are transected by pegmatite dikes that appear to have been emplaced after folding. Younger folds, which plunge westerly and locally northeasterly, deform both the gneiss and the pegmatite dikes. These latter folds are tight and some are isoclinal.

Folds in the upper reaches of the Dugbe River, within the itabirite province, are broad open folds that have axes normal to the strike of the foliation and that plunge parallel to the dip of the foliation. As are those along the Sino River, these folds are older than the pegmatite dikes that transect them. Folded pegmatite dikes were not observed.

Major broad, open folds strike northwest to west in the subtle (northwest-trending) structural province northwest of the itabirite province. One of these folds immediately south of Pyne Town is unusual in that its northeastern limb contains an isoclinal recumbent fold, its axis striking about parallel to that of the major fold.

FAULTS

Two systems of faults are prominent in the Juazohn quadrangle. The older faults trend northeast and are commonly marked by a wide zone of strongly sheared rocks. The younger faults trend northwest; offset, at least locally, faults of the northeast trend; locally show a narrow zone of sheared rocks; and have diabase intrusion in many places.

NORTHEAST-TRENDING FAULTS

The Dube shear zone (Tysdal, 1977b) in the southeastern part of the quadrangle separates a unit dominated by schist on the southeast from gneiss, migmatite, and dioritic to granitic plutons on the northwest. It is named for the Dube River, the course of which it locally controls, where the intensely sheared rocks were first found. At the border with Ivory Coast, the shear zone connects with a major mylonite zone in the Taï 4a quadrangle of Ivory Coast, mapped by Bos (1964). Relationships of rocks on opposite sides of the shear zone imply a fault—contrasting rock type and different magnetic, radiometric, and gravity characteristics—but it was not possible to map an individual fault. The zone may actually consist of several closely spaced faults not discernible individually.

South of the Dube River, the Dube shear zone is marked by strong linear trends on the magnetic and radiometric maps. On the total magnetic component map (Behrendt and Wotorson, 1974b), the shear is associated with a conspicuous linear magnetic feature along its entire length, indicating that the structure is deep seated. Furthermore, the Bouguer gravity map (Behrendt and Wotorson, 1974b), though based on very few gravity measurements, shows a negative gravity anomaly for the rocks southeast of the shear zone and a positive anomaly for rocks to the northwest. This suggests a relative downdropping of the schistose sequence to the southeast. Brock, Chidester, and Baker (1977) found evidence of left-lateral strike-slip movement along the shear zone in the Harper quadrangle. All these data strongly indicate that the sheared rocks delineate a major fault or series of faults.

Most of the sheared rocks along the Dube fault are dark colored, fine to very fine grained, hard, dense, and resistant to erosion. Thin sections made from a few samples show the rock to be protomylonite and mylonite. Some of the protomylonite hand samples have a spotted appearance due to porphyroclasts of light-colored feldspar set in a darker matrix. Mylonites are not spotted but have greater development of tabular ribbons of quartz that are prominent in thin section and on the weathered rock surface.

Northwest of the Dube shear zone, a prominent magnetic lineation marks the southeastern boundary of the itabirite province, as previously noted by Wotorson and Behrendt (1974) and Behrendt and Wotorson (1971, 1974b). The lineation also marks a change in structure (fold style) and rock units and coincides with the southwestward continuation of a fault mapped by Bos (1964) in the Taï 4a and 4c quadrangles of Ivory Coast. In Liberia, sheared rocks were noted along the lineation only near its southwestern terminus, but a host of other data suggest the lineation represents a fault.

For more than half the distance from the Cavalla River to the Dube River, the lineation coincides with a markedly straight tributary of the Dube River. The drainage is similarly structurally controlled along the fault in Ivory Coast. From the Dube River to about 20 km (12.5 mi) to the southwest, the lineation closely parallels a prominent drainage divide. A topographic contrast exists across the lineation from the Dube River for about 40 km (25 mi) southwestward. Differential relief is considerably greater in the itabirite province than in the quartz diorite gneiss unit 1. Also, a slight difference in the direction of magnetic grain exists; the magnetic grain of the itabirite province trends generally east, whereas that of the quartz diorite gneiss trends northeast.

A search was made for sheared rocks along the road near Kahnwia, but no outcrops were found in the area where the magnetic lineation crosses the road. Outcrops to the north and south along the road are not sheared.

A narrow zone of sheared rocks was found along the Dugbe River, northeast of Wamapu, yet no trace of shearing was noted a few kilometers to the northeast where the Dugbe River crosses the linear trend in several places. Outcrops seem to be sufficiently abundant to permit detection of a zone of shearing if it exists particularly because sheared rocks in rivers are commonly the most resistant to erosion. Thus, if the lineation represents a fault, perhaps it is not accompanied by a shear zone.

Extension of the fault westward beyond the sheared rock near Wamapu is questionable. A magnetic contrast still exists but is less distinct, and a contrast in the style of folding exists; however, rocks on opposite sides of a westward extension of the fault are of the same type. Detailed study of the lineation should be undertaken along its full length.

Two branching faults are mapped (Tysdal, 1977b) in the north-central part of the quadrangle along the northwestern boundary of the itabirite province. The easternmost branch, immediately adjacent to the itabirite province, is mapped largely on the basis of magnetic evidence in the Juazohn quadrangle and is the continuation of a fault in the adjacent Taï 3d quadrangle of Ivory Coast (Lemarchand, 1965, map). Its inclination is not certain but may be at a moderate angle to the southeast. The rocks are not strongly sheared where the fault crosses the Cavalla River.

The other branch is a continuation of the Mount Troll fault of Ivory Coast, which Papon (1973, p. 68) shows as a reverse fault dipping steeply to the southeast. Where the fault crosses the upper reaches of the Dube River, however, the rocks are strongly sheared protomylonite and mylonite and define a thrust fault dipping about 40 degrees to the southeast. The southwest terminus of the fault is uncertain. No definite trace of it was noted along the Babu-Juazohn road, which, presumably, it should cross. Its projection southwestward would pass approximately through the Juazohn ultramafic complex. As mentioned earlier, this complex is also on line with the northwest-trending Geni fault of the Buchanan quadrangle (Tysdal, 1977b).

The Cestos shear zone (Tysdal, 1977a, 1978) crosses the northwesternmost corner of the quadrangle. It is a near-vertical structure that is marked by a wide zone of protomylonite and mylonite and by a distinct magnetic pattern in the Buchanan quadrangle. However, the pattern is not conspicuous in the Juazohn quadrangle.

NORTHWEST-TRENDING FAULTS

A system of northwest-trending faults, some intruded by diabase, transects the Juazohn quadrangle. Some of the gneiss adjacent to the diabase dikes is sheared, and the strike of foliation changes locally from the regional northeast trend to northwest adjacent to the dikes. In the northwesternmost part of the quadrangle and in the adjacent Buchanan quadrangle (Tysdal, 1977a, 1978) lateral offset is evident along some of the faults, on the basis of interpretation of aerial photographs and magnetic patterns.

In the northwestern part of the Juazohn quadrangle, some of the magnetic patterns, which commonly have a northeast grain, are truncated abruptly along a northwest-trending diabase dike. A different magnetic pattern, which also has a northeast grain, is present on the opposite side of the dike. The different magnetic patterns probably represent different rock units on two sides of a fault that has been intruded by diabase. The rock units are probably not in their original positions because other, different magnetic patterns show similar relationships along the same dike. Thus, the lines separating areas having different magnetic patterns are interpreted to represent faults that have both left-lateral and right-lateral offsets.

The pattern of contrasting magnetic properties on opposite sides of diabase dikes that have intruded faults is evident from the northwest corner of the quadrangle southeastward across quartz diorite gneiss unit 2 and across the leucocratic gneiss of the itabirite province. This pattern helps define the subtle northwest-trending structural province of the Juazohn quadrangle. The absence of iron-formation from the central part of the itabirite province, coupled with the change of the structural grain from northeast to northwest, further defines the northwest-trending structural province in the central part of the quadrangle.

UNCONFORMITIES

An unconformity may exist in the north-central part of the quadrangle. J. Stobernack (*in* White and Leo, 1969, p. 13) stated that itabirite of Jide Mountain unconformably overlies the gneisses beneath it. His map (DELIMCO, see footnote 2 on p. 5), on which the map pattern (fig. 2) of the Jide Mountain area is based, shows a tight isoclinal syncline along most of the backbone of the mountain and a shallow syncline at the northeastern end. Along this same trend, northeast of the mountain, itabirite dipping 15° S. crops out. This last outcrop area reflects the low-angle, and locally horizontal, dips of rocks over much of the area northeast of the Putu Range. All these shallow-dipping rocks, including the itabirite, probably are related; if the itabirite of Jide Mountain unconformably overlies older rocks, then it follows that the shallow-dipping rocks to the northeast may overlie older rocks unconformably.

If the itabirite and associated rocks overlie older rocks unconformably, then an explanation is needed for their preservation only in the itabirite province. Several possible explanations are discussed below:

(a) The province could represent a downdropped block. The movement direction on the fault along the southeastern margin is unknown, but the fault along the northwestern margin of the block is a thrust, and its movement appears to be opposite that necessary for a downfaulted itabirite province. One solution to the enigma is for the gneiss units to the northwest to be upthrown along a low-angle fault. Another solution is for the itabirite province to have been a downfaulted block originally, in which the itabirite rocks were protected while neighboring blocks underwent erosion. Then at a later time, the movement direction on the faults was reversed. Such reversal of direction of movement is not uncommon on ancient faults.

(b) Another possibility is that the itabirite sequence was originally a thicker deposit in the area of the province; thus the rocks would be last to be removed.

(c) The high-amplitude magnetic anomalies in composite gneiss unit 2 may represent iron-formation; thus the itabirite would not be restricted to the itabirite province nor bordered by faults. The objections to this idea are numerous. (1) Anomalies investigated in composite gneiss unit 2 were caused by magnetite in migmatitic rocks associated with plutonic rocks or by magnetite in biotite-quartz diorite gneiss; the itabirite-quartzite-iron silicate assemblage was not found. (2) The original depositional environments of the two units seem incompatible—a shelf origin is probable for itabirite rocks; a eugeosynclinal origin is probable for composite gneiss unit 2. Itabirite could have been incorporated into composite gneiss unit 2 during a thorough reworking, but it does not seem probable that the boundary between gneiss unit 2 and the leucocratic gneiss then would be the abrupt feature it is. More important, reworked itabirite would be expected also in quartz diorite gneiss unit 1, which is adjacent to the itabirite province and which has the same fold style as gneiss unit 2. Itabirite has not been found in quartzdiorite gneiss unit 1.

The problem of restriction of the iron-formation to the itabirite province is not resolved, but a study of the movement of faults, discussed in (a), might resolve the problem.

AGE PROVINCES

Hurley, White, and Fairbairn (1971) made whole-rock Rb-Sr age determinations on a few 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. Their interpretation shows three age provinces for Liberia: The Liberian age province (about 2,700 m.y. old), the Eburnean age province (about 2,000 m.y. old), and the Pan-African age province (about 550 m.y. old).

A 2,230-m.y. date was determined for gneiss on the western flank of Jide Mountain. A 2,070-m.y. date was obtained by Hurley and others (1971) from graphitic gneiss of composite unit 1 taken from a quarry near Greenville, about 1 km (0.6 mi) south of the quadrangle boundary.

A 2,130-m.y. date was yielded by a gneiss of granodiorite to quartz diorite composition from Pola in the Zwedru quadrangle, about 7 km (4.5 mi) northeast of Babu (Juazohn quadrangle). The gneiss, which is slightly sheared, dips westward at a low angle. It is in the area of the gently dipping schist east of Babu and, as speculated in the section on granodiorite gneiss, it may be part of the same sequence of rocks as the schist, but it has undergone different conditions of metamorphism. Schist in Ivory Coast, continuous with the schist east of Babu, overlies "migmatite" that has been metamorphosed retrogressively (Papon, 1973, p. 70). Papon stated that the metamorphism of the schist unit was accompanied by refolding in "migmatite" of the basement, causing the two units to appear concordant. Thus, the writer is not certain whether the gneiss at Pola represents underlying basement gneiss or rock metamorphosed beyond the schist stage that is equivalent to the schist east of Babu.

MINERAL RESOURCES

The itabirite of Jide Mountain, Putu Range, is the only iron-ore deposit likely to be of economic significance in the Juazohn quadrangle. It has been noted briefly or described by many workers, including the Holland Syndicate (H. Terpstra, unpub. data, 1935), Sherman (1947 and footnote 1 on p. 5), T. P. Thayer (unpub. data, 1952), Janelid,[17] Kun (1965, p. 230, 259), and the Müller Co. (see footnote 6 on p. 12). Evaluation of the deposit was undertaken first by LAMCO in the mid-1950's (Jan Offerberg, written commun., 1955). DELIMCO currently holds the exploration concession to the area. Schulze (1964) described the early iron industry of the Jide Mountain area, noting the

[17] Janelid, Ingvar, 1953, The iron-ore deposit at Putu Range, Sweden, Royal Inst. Tech., Div. Min. and Survey, unpub. rept., 6 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

manufacture of primitive implements, arrowheads, iron money, and other artifacts.

Four main types of iron ore are recognized by DELIMCO (see footnote 6 on p. 12). (1) Soft ore forms the weathered zone on top of the itabirite, and the chief mineral is hematite, formed by the martitization of magnetite. The soft ore is enriched, and mill-feed analysis shows that it contains an average of about 49.5 percent iron. Preliminary data indicate that the soft ore makes up about 9 percent of the known reserves of iron in the Jide Mountain deposit. (2) Itabirite of the transition zone is partially weathered hard ore between soft ore and unweathered itabirite. It is only partially martitized, contains an average of about 42.5 percent iron, and makes up about 4 percent of the known reserves. (3) Magnetite-itabirite containing more than 25 percent magnetite constitutes more than 75 percent of known reserves and contains an average of about 40 percent iron. (4) The remainder of the deposit is mainly hematite-itabirite that contains an average of about 44.5 percent iron and makes up about 11 percent of known reserves. This ore type is part of the unweathered material in which hematite is the chief mineral. The magnetite content is minor. Estimated reserves for the main ore body of Jide Mountain are about 450 million tons of crude ore (DELIMCO, see footnote 6 on p. 12).

Anomalous values for nickel and cobalt were detected in soils formed over ultramafic rocks at Taju Hill, but the underlying ultramafic rocks themselves did not yield high values for these elements. The high nickel (and cobalt) values decrease with depth in the soil, are greatest where the soil is thickest, and are considered residual elements of lateritic weathering processes in which mainly SiO_2 and MgO are removed from the soil. The anomalous values are apparently not related to sulfide mineralization, because nickel sulfides were not detected in the area, nor where high nickel values found in a distinct grouping. The nickel-rich soil covers about 1 km^2 (0.4 mi^2) to an average thickness of about 5 m (about 16 ft) and is too small a volume to mine profitably (Müller Co.,[18] and see footnotes 6, 8, 9, 10, 12, 16 on p. 12, 14, 15, 16, and 25; Griethuysen, 1971).

Chromium was detected in lateritic soil overlying a small area of ultramafic rocks containing chrome-diopside at Taju Hill. The concentration, apparently formed by lateritic-weathering proc-

[18] Müller Company, 1970, Exploration Liberia, 12th progress report, August–October 1970: The Hague, Netherlands, Müller Co., unpub. rept., 7 p., on file with the Liberian Geological Survey, Monrovia, Liberia.

esses, is far too small for mining (Müller Co., see footnotes 6 and 9 on p. 12 and 14).

Small gold placers are present throughout the quadrangle but are notably abundant in the graphite belt, which has yielded more gold than any other part of Liberia (Sherman, 1947, and see footnote 10 on p. 15). The east-northeast-trending rocks in the belt commonly dip south, but locally they dip north. These local areas of northern dips include the old gold workings and have yielded most of the geochemical anomalies, especially near Boken Jide where the gold originated in small quartz veins (Müller Co., see footnote 9 on p. 14). Only minor placer mining is being done at present (1973).

Molybdenum anomalies are related closely to the gold workings in the Boken Jide district (Müller Co., see footnotes 6 and 9 on p. 12 and 14; Griethuysen, 1971), which is located about 10 km (6 mi) southwest of Wamapu. Most of the high values are near contacts between north-dipping "metabasite" (probably metavolcanic rock) and typically south-dipping graphite gneiss. Assays showed that the molybdenum content is not economically exploitable. Most of the rocks give the impression of being enriched but are only weathered.

The Diamond Mining Corporation of Liberia (Leuria, see footnotes 3 and 4 on p. 5) explored for diamonds in the western part of the Juazohn quadrangle, mainly in the area drained by the Sehnkwehn River. Diamonds were not discovered, but minute amounts of scheelite, corundum, and pyrite were found in the area of the Jubo batholith. The reports (Leuria, see footnotes 3 and 4 on p. 5) list the heavy minerals from only a few sample sites.

One of the prime targets of the Müller Co. exploration in eastern Liberia was bauxite. No deposits of bauxite were found in the Juazohn quadrangle, although scattered pisolitic material was noted on a few hill crests (Müller Co., see footnote 5 on p. 12).

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