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GEOLOGY OF THE MONROVIA QUADRANGLE, LIBERIA

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INTRODUCTION

As part of a program undertaken cooperatively by the Liberian Geological Survey and the U. S. Geological Survey, under the sponsorship of the Government of Liberia and the Agency for International Development, U. S. Department of State, Liberia was mapped by geologic and geophysical methods during the period 1965 to 1972. The resulting geologic and geophysical maps are published in ten folios, each covering one quadrangle (see index map). The Monrovia quadrangle was systematically mapped by the author from June 1971 to July 1972. Field data provided by private companies and other members of the LGS-USGS project were used in map compilation, and are hereby acknowledged. Interpretation of gravity data (Behrendt and Wotorson, 1974, c), and total-intensity aeromagnetic and total-count gamma radiation surveys (Behrendt and Wotorson, 1974, a, and b) were also used in the compilation, as were other unpublished geophysical data furnished by Behrendt and Wotorson (near-surface, regional magnetic component, and geologic correlations based on aeromagnetic and radiometric characteristics).

Most of the Monrovia quadrangle has a surface of low relief. A few mountainous areas rise abruptly above the rolling surface to about 400 m. The wet season (May-October) during which most of the annual 400-500 cm of rain falls, alternates with a dry season during November-April. Virgin rain forest is primarily in the mountainous areas; most of the rest of the area is occupied by small farms. Access, by means of many laterite roads, is better than in most of Liberia. Thick saprolite and laterite make fresh bedrock exposures very sparse along roads and trails. The best observations were made along the coast and along the rivers; river traverses were made by rubber boat and helicopter during the dry season.

ROCKS

The Monrovia quadrangle lies within the Guinean Shield of West Africa and includes parts of the Pan-African (550 m.y.) and Liberian (2700 m.y.) age provinces (Hurley and others, 1971). (See inset map). Rock units have been distinguished on the basis of available field, petrographic, and geophysical data; some are delineated solely on the basis of their radiometric and/or magnetic character. Metamorphic rocks show a range in grade from lower amphibolite to granulite facies and consist predominately of silicic gneisses; subordinate rocks are mafic gneiss, amphibolite, schist, quartzite and iron-formation. Jurassic dikes and sill-like bodies are widespread. Late Precambrian(?) to Cenozoic sedimentary rocks are present along the coast and offshore.

A simple classification of gneissic rocks based on plagioclase/potassium feldspar ratio has been used following broad igneous compositional parameters (see map explanation). No implication of igneous origin is intended. In those cases where gneisses do not fall readily into the above scheme, or where data are insufficient to allow proper classification, appropriate mineral modifiers (that is, garnet-zoisite-hypersthene gneiss) or suitable descriptive terms (for example, melanocratic gneiss) are used.

Metamorphic rocks

Most of the silicic gneisses are strongly foliated and layered, and their structural relation with intercalated, obviously surface-accumulated rocks such as iron-formation, quartzite, schist, and amphibolite suggest that the gneisses are metasedimentary. Considerable orthogneiss may be present. However, no attempt was made to distinguish orthogneiss from paragneiss.

Granitic gneiss

Granitic gneiss (gng) is characterized structurally by a consistent N. 70°E. to nearly east trend visible in the field and on radiometric and magnetic maps. These gneisses are banded and are predominately granodioritic but range from granite to granodiorite. Subunit gng_1 is characterized by diversely oriented large-scale folds and a general lack of structural continuity, and by lower-amplitude magnetic anomalies than adjacent units. The gng_1 gneisses differ from those of unit gng in that they range over short distances from banded to nonbanded, are almost massive rocks, and are commonly coarser grained.

Leucocratic gneiss (gnl)

Rocks mapped as leucocratic gneiss crop out widely in the Monrovia quadrangle. Unit gnl is defined on the basis of closely spaced moderate magnetic anomalies that have a consistent N. 65° E. trend. Subunit gnl_3 is concordant and interlayered with gnl but displays less consistent trends and lower amplitude and wider spaced magnetic anomalies. Both units consist of granodiorite gneiss with subordinate granite and quartz diorite and minor diorite gneiss. Amphibolite appears to be more common in gnl, which is consistent with the magnetic character of the unit.

Gneiss of subunit gnl_1 is similar to that of unit gnl, but appears to contain more amphibolite, much of which forms mappable units at 1:250,000 scale. Berge (1966) reported considerable syenitic gneiss on the southwest side of the Goe Range. Subunit gnl_1 has radiometric and magnetic characteristics similar to gnl_3 but trends about N. 45°W. and is south of the Todi shear zone. Subunit gnl_2 is a two-mica and kyanite gneiss within gnl_1. At Mt. Montro kyanite-quartz-biotite gneiss contains as much as 45 percent kyanite (Stanin and Cooper, 1968).

Melanocratic gneiss

Medium- to dark-colored granodioritic to gabbroic gneiss (gnm) with subordinate intercalated quartzose leucocratic gneiss and amphibolite occupies the coastal area. Many rocks contain hypersthene and diopside commonly in association with hornblende. Light-colored gneiss is generally distinctly layered whereas the dark rocks are not. Quartzite and garnetiferous leucocratic gneiss are locally abundant in the Lake Piso area.

Composite gneiss

The composite gneiss unit gn_1 consists primarily of layered biotite-rich gneiss that in many places encloses or is associated with itabirite, schist, quartzite, and amphibolite. The composite gneiss unit (gn_1) is characterized by generally higher magnetic anomalies than other gneiss units. Along the St. Paul River much of the rock is hornblende-bearing gneiss, in which feldspar is commonly altered to sericite. Amphibolite lenses are very common southeast of the Bong Range near the quadrangle border. Northeast of the Todi Shear zone the gneiss contains mineral assemblages of the amphibolite facies, and southwest of the fault zone it contains mineral assemblages of the granulite facies.

Subunit gn_2 consists of nearly equal amounts of biotite- and/or muscovite-bearing granitic gneiss and amphibolite. The high amphibolite content of the unit is not reflected in the magnetic map (Behrendt and Wotorson, 1974, a).

Schist and quartzite

A variety of pelitic schist(s) and quartzite (q) are associated with iron-formation in the Goe-Fantro Ranges and their northwesterly extension. They include kyanite-bearing quartz-muscovite schist and muscovite-kyanite quartzite, with all gradations from pure quartzite to muscovite schist; ferruginous-argillaceous schist intercalated with quartzite and itabirite; and subordinate graphite schist (Berge, 1966). At Bomi Hills a thin biotite schist is present but was not mapped separately.

A klippe at Gibi Mountain is made up of quartzite and minor amounts of itabirite. Small pods of graphitic schist crop out at and near the base of the klippe. The entire sequence, about 200 meters thick, is mylonitized and no relict textures were found.

Amphibolite

Amphibolite (am) layers range from a few decimeters to mappable units hundreds of meters thick. Most large units form ridges and are associated with negative magnetic anomalies of 150-300 gammas. Relict diabasic or gabbroic textures were noted locally. Several amphibolites in the melanocratic gneiss (gnm) and adjacent leucocratic gneiss (gnl_1) units contain as much as 10 percent sphene and 2 to 4 percent apatite, whereas amphibolite associated with other rocks typically has less than 2 percent sphene/apatite.

Itabirite

Hematite-magnetite itabirite (it) is the dominate type of iron-formation and forms the major deposits in the Bong Range, Bomi Hills, and Goe-Fantro Ranges. Itabirite is associated with quartzite, schist, and amphibolite and commonly grades laterally into nearly pure quartzite in the Bong and Goe-Fantro Ranges. It typically forms long narrow ridges and is marked by pronounced magnetic anomalies.

Composite unit

The Goe-Fantro Ranges, their northeastern extension, and the Bong Range are underlain by a variety of rock units which are individually too small to map separately, but are mapped collectively as composite unit z. The unit comprises schist, quartzite, amphibolite, banded leucocratic gneiss, and subordinate itabirite and in many places is associated with composite gneiss unit gn_1. At the west end of the Bong Range sillimanite-quartz-muscovite, quartz-biotite, and amphibole-biotite schists grade along strike into gneisses formed from the schists (Stobernack, 1968). The larger itabirite beds east of the Lofa River have been mapped separately.

A unit about 20 meters thick of sooty black manganese-rich quartz-garnet rock mapped as a marker bed (mn) within composite unit z crops out in the western part of the Firestone Plantation. Chemical analyses indicate as much as 14 percent manganese in the rock. Graphite is present in some of the rocks.

Igneous rocks

Pegmatite

Nearly all observed pegmatites in the Monrovia quadrangle are in the melanocratic gneiss and fall into two categories, granitic quartz-muscovite-microcline-plagioclase rock with minor hornblende or biotite, and massive bull quartz with minor amounts of feldspar and mafic minerals. Where relationships with the country rock can be observed, the granitic pegmatites strongly resemble the leucocratic part of the country rock in mineral composition. It is not feasible to show the pegmatites at the scale of the geologic map.

Norite

A norite body (gbn) near Cape Mount consists of "labradorite (An60-70), hypersthene, and augite, with well-developed coronas of actinolitic hornblende and garnet" (White and Leo, 1969, p. 12). Relations with the enclosing granulite-facies gneisses are not known.

Diabase and basalt

A dominant feature of Liberian geology is the northwest-trending tholeiitic diabase dike (Jd) system. The dikes form long continuous ridges and the larger dikes produce distinctive negative magnetic anomalies. Large sill-like bodies of diabase near the coast intrude the Paynesville Sandstone. Tholeiitic amygdaloidal basalt (Jb) appears to overlie the Paynesville at two localities along the coast (White, 1972). The diabase dikes are Early Jurassic in age, the ages ranging from 173 to 192 m.y. (Gromme and Dalrymple, 1972).

Sedimentary rocks

Sedimentary rocks are confined primarily to the coastal belt east of Monrovia in the Roberts and Bassa basins (White, 1972). Small patches of sedimentary rocks also crop out northwest of Lake Piso and at Gibi Mountain.

Rocks at Gibi Mountain

A sequence of sedimentary rocks has been found exposed in cliff faces and streambeds on Gibi Mountain in northern Montserrado County, Liberia. A basal conglomerate (0-100? m) is massive and consists of subrounded clasts of crystalline rocks, as much as 15 cm across, in a dirty arkosic matrix. A medial, generally massive sandstone member (150-200? m) consists of nearly equal amounts of medium- to coarse-grained, subangular to subrounded, fairly well sorted quartz and feldspar in a matrix of sericite and very fine grained quartz and subordinate chlorite. The upper shale and mudstone member (150+m) consists of sericite and very fine grained quartz and feldspar. Most of the rocks are tan to brown, but some finer-grained sandstone and shale beds are various shades of purple and drab green.

The basal conglomerate rests unconformably on granitic gneiss, and the upper member is overlain by a klippe of Precambrian mylonitic quartzite, itabirite, and graphitic schist. A pre-Jurassic age is indicated by the fact that Jurassic dikes intrude the sequence at Gibi Mountain. Similar rocks in Guinea and Sierra Leone are there thought to be late Precambrian or early Paleozoic (Allen, 1968), though no fossils have been recovered.

Paynesville Sandstone

The Paynesville Sandstone (White, 1972) typically forms low, rounded brownish knobs in broad savannahs underlain by white or brown unconsolidated sand deposits. The formation is non-conformable on gneiss. It is intruded by Jurassic diabase sills and dikes, and an amygdaloidal basalt flow appears to overlie it. Gravity and aeromagnetic data indicate a possible thickness of about 1,000 meters near Sugar Beach (Behrendt and Wotorson, 1974, a,c). The Paynesville is tentatively considered to be Devonian. It strongly resembles the spore-bearing Devonian crossbedded orthoquartzite that occurs stratigraphically below Cretaceous sedimentary rocks and Jurassic basalts in several offshore drill holes.

Farmington River Formation

The Farmington River Formation (White, 1972) consists of two interbedded facies, a "polymict conglomerate" (Kfc) that is most abundant near the base and to the northeast and becomes less abundant upward and seaward, and a "wacke" sandstone (Kf) that makes up the bulk of the formation and becomes finer grained upward with increase of the thin shale interbeds. The sandstone ranges from arkose to graywacke. A thickness of about 1.5 kilometers is estimated for the onshore part of the formation on the basis of gravity data (Behrendt and Wotorson, 1974, c). An Early Cretaceous age is based on pollen and spores from several localities. Correlative marine rocks have been found in several offshore drill holes.

Edina Sandstone

The Edina Sandstone (White, 1972) is typically a coarse- to medium-grained, gritty quartz sandstone that commonly contains lithic fragments near the base. The formation forms a thin veneer seldom exceeding a few meters in thickness. No datable fossils have been recovered from the formation. Similar deposits of late Tertiary to Quaternary age occur in Ivory Coast and Sierra Leone.

Lacustrine and beach deposits

Brownish silt (Qs) several meters thick containing small concretions of iron-stained clay occupies the former extension of Lake Piso. A series of raised beach ridges (Qb_1) usually less than 1.5 kilometers wide, and individual ridges as much as 10 meters high, extends along the coast. Small lagoons have formed locally between individual ridges. Behind the ridges are large savannahs, some extending as far inland as 15 km, underlain by white quartz sand (Qb_2) that averages one meter in thickness. Some white sand occurs between the raised beach ridges. The white sand deposits are potentially exploitable for silica sand (Rosenblum and Srivastava, 1970). Brown sand makes up the raised beach ridges and underlies the white sand deposits. These units are considered to be Pleistocene.

Fluvial and deltaic deposits

A thin veneer of brown fluvial silt and sand (Qf) covers an area of very flat topography southeast of Monrovia, some of which includes mangrove swamps. Bedrock is only locally exposed and the limits of the unit are based on interpretation of aerial photographs. Other more discontinuous deposits of brown sand and silt occur along the coast to the northwest and along the Mano River. All these deposits are considered to be Holocene.

Present-day lagoonal deposits and beach (Ql) form a narrow strip along the coast. Longshore bars are continually being built across streams and rivers, modifying their entrances. Lagoons form when small streams are intermittently blocked off, and the entrances to large rivers are continually changing.

STRUCTURE

Folds and lineations in metamorphic rocks

Large synforms and antiforms parallel the regional structural grain and are best seen on aerial photographs. Most of these folds are isoclinal, have steep axial planes, and plunge less than 30°. According to most workers, iron-formation in Liberia occurs primarily in troughs of tight isoclinal synclines. Excellent samples of these are to be seen in the Bong Mine.

In hand specimens and outcrops, shear and flexure folds with incipient axial plane schistosity are quite common; generally, the new schistosity is nearly parallel to banding in the rock. Cylindrical and flow folds are less common. Lineations due to preferred orientation of minerals, deformed grains, and intersecting planar surfaces are abundant in the Todi shear zone and in general rake 40° to the southwest or southeast.

Foliation and bedding in metamorphic rocks

Foliation concordant with large- and small-scale lithologic boundaries in itabirite, schist, and quartzite is believed to have developed parallel to primary stratification or as axial-plane foliation, the axial planes being nearly parallel to primary stratification. Foliation in many layered gneisses probably has a similar origin, though metamorphic differentiation has obviously played a more important role in these coarser grained rocks. Second- and third-order planar elements exist in practically all rock units, but are commonly only locally developed, except near the Todi shear zone where extensive shear foliation has obliterated the older fabric of the rocks.

Faults and shear zones

The northwest-trending Todi shear zone appears to separate the Liberian and Pan-African age provinces (Thorman, 1972). Faults, most of which are delineated largely on the basis of aeromagnetic data, are marked by mylonite that dips 50°-70° SW and has a distinctive slabby weathering character, especially along the St. Paul River where the zone was first recognized. Between faults, the trend of the rock fabric is intermediate between trends of the two provinces. Gravity (Behrendt and Wotorson, 1974, c) and field data indicate that the Todi shear zone dips southwest beneath the Pan-African age province. The zone narrows to the northwest and trends of rock fabric in the two provinces become nearly parallel to each other, but remain oblique to the shear zone. In the northwest, composite gneiss unit gn_1 can be traced across the zone with only a slight change in outcrop width, indicating that the Pan-African province is made up, at least in part, of older rocks belonging to the Liberian province.

The thrust at the base of the Gibi Mountain klippe appears to slope gently south, as mylonitic gneiss crops a few kilometers south of Gibi Mountain. Small-scale folds in the fault zone and in the allochthon trend northwest and some are overturned to the northeast, indicating relative northeast transport of the allochthon. Large-scale folds superimposed on all units at Gibi Mountain trend northeast, parallel to the mountain; their tectonic significance is not clear.

It is hypothesized that the Pan-African age rocks were thrust ortheastward over those of the Liberian province along the Todi hear zone. Quite possibly the klippe at Gibi Mountain, now 20 miles ortheast of the Todi shear zone, is an outlier of rocks of the Pan-frican province. Rocks exposed in the klippe are similar to ones n the Goe-Fantro ranges, which suggests that the upper plate of the odi shear zone was thrust to the northeast, the direction of movement hat is indicated by small-scale structures. If the klippe is a an-African outlier, the age of the thrusting could be as young as iddle or late Paleozoic, depending on the age of the sedimentary ocks underlying the thrust on Gibi Mountain; however, the thrust ust be older than the Jurassic dikes that cross the mountain.

Many of the larger diabase dikes appear to be intruded along major ertical faults, based on contrasting magnetic patterns and topography across the dikes. Several post-Cretaceous faults trend northwest and delineate the northeast sides of the Roberts and Bassa basins; related faults are offshore on the continental shelf, according to Behrendt and Wotorson (1970). Their gravity model for the Roberts basin shows about 2 km displacement.

METAMORPHISM AND AGE PROVINCES

Regional metamorphism

Regional metamorphism ranges from lower amphibolite facies (e.g., quartz-muscovite schists) to granulite facies (e.g., hypersthene-hornblende-plagioclase gneiss. In the Monrovia quadrangle, rocks metamorphosed to the amphibolite facies occur throughout the Liberian and part of the Pan-African age provinces, whereas granulite-facies rocks are restricted to the Pan-African age province. In the Firestone Plantation and near Mt. Montro the amphibolite facies are transitional southwestward into granulite facies. Berge (1966) noted a similar southwest transition in the Goe Range. The granulite isograd trends northwest and apparently terminates against one of the faults of the Todi shear zone near the St. Paul River, and it is not present on the other side of the shear zone within the Monrovia quadrangle. Hypersthene partly altered to hornblende is found within the northwest end of the shear zone, and may occur locally on the northeast side of the zone farther northwest in the Bopolu quadrangle (Wallace, 1974). Across the Mano River in Sierra Leone, granulite facies occur northeast of the projection of the Todi shear zone.

Dynamic metamorphism

Rocks in the Todi shear zone range from incipient protomylonite to ultramylonite, as described by Higgins (1971), and are derived almost entirely from felsic rocks. These cataclastic rocks have a distinctive slabby weathering character. Pronounced ribbon fabric is common in the more intensely deformed rocks owing to granulation of quartz and feldspar. The allochthonous mylonitic quartzite, itabirite, and graphite schist at Gibi Mountain contain no relict textures; quartz grains are elongated as much as 7:1.

Age provinces

The boundary between the Liberian (2700 m.y.) and Pan-African (550 m.y.) age provinces is practically indistinguishable in the northwest part of the quadrangle but is distinct in the southeast. Sharp discordance between structural and stratigraphic trends in the southeast give way to parallelism between these trends in the northwest where units can be traced across the Todi shear zone with virtually no offset. In the western part of the Pan-African province one rock has yielded an age of 2600 m.y. (Hurley and others, 1971). Thus it is apparent that at least some of the Pan-African rocks were once part of the Liberian province. The intensity of the Pan-African event appears to have been quite variable, and the ages determined for rocks affected by it may well represent a retrogressive phase of amphibolite-facies conditions superposed on an older amphibolite-to-granulite-facies terrain.

MINERAL RESOURCES

High-grade magnetite ore and itabirite are being mined (1972) at Bomi Hills by the Liberia Mining Company and itabirite in the Bong Range by the Bong Mining Company. Current reserves at Bomi Hills are expected to be exhausted in the near future. Iron-formation also occurs in the Goe-Fantro Ranges and their northwesterly extension. Deposits of kyanite have been found at Mt. Montro, and barite veins have been described near Gibi Mountain (Pomerene and Stewart, 1967). Possible commercial deposits of heavy minerals are found in beach sands near Robertsport, Monrovia, and Marshall. Diamonds are mined from placer deposits near Kakata and Bomi Hills and from gravels along the Lofa River.

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