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GEOLOGY OF THE BOPOLU QUADRANGLE, LIBERIA

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INTRODUCTION

As part of a program undertaken cooperatively by the Liberian Geological Survey (LGS) and the U. S. Geological Survey (USGS), 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 Bopolu quadrangle was systematically mapped by the author in late 1970. Field data provided by private companies and other members of the LGS-USGS project were used in map compilation, and are hereby acknowledged. Limited gravity data (Behrendt and Wotorson, in press), and total-intensity aeromagnetic and total-count gamma radiation surveys (Behrendt and Wotorson, 1974, a and b) were also used in compilation, as were other unpublished geophysical data (near-surface, regional magnetic component, and geologic correlations based on aeromagnetic and radiometric characteristics) furnished by Behrendt and Wotorson.

Northeast-trending hills and ridges as much as 1,000 m high and several tens of kilometers long dominate the topography, and thick rain forest covers much of the quadrangle. Population is largely in three small towns: Bopolu, Bendaja, and Bella Yella. Small villages and subsistence farms are scattered through the region, but large areas within the Kapelle National Forest are devoid of trails or inhabitants. Away from the jeep roads, except for a few landing strips for light aircraft, access is limited to foot trails or river travel. The principal rivers provide access by small rubber boat to many areas of good rock exposure, but numerous falls and rapids limit traverses to the early and middle parts of the dry season.

ROCKS

Bedrock in the Bopolu quadrangle, which is entirely within the Liberian age province of Hurley and others (1971), lies within the Guinean shield and consists predominantly of Precambrian crystalline rocks, diabase dikes of Jurassic age, and kimberlite dikes of Cretaceous(?) age. River deposits of Quaternary age are distinguished on the map only along the Mano River where they have appreciable continuous extent.

In general, rock units are distinguished primarily on the basis of field observations, but magnetic and radiometric properties have been used extensively in their delineation. Narrow river deposits, and laterite and saprolite, which obscure much of the underlying bedrock, are not distinguished on the map, except as noted above.

The classification of gneissic rocks used here follows broad igneous compositional parameters (see map explanation), and is based on plagioclase/potassium feldspar ratios. 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 for classification, suitable descriptive terms (e.g., melanocratic gneiss) are used.

Metamorphic rocks

The order of discussion of rock units has no implication as to genesis or stratigraphic order. Most of the felsic gneisses are strongly foliated and layered, and their structural relationship with intercalated, obviously surface-accumulated rocks such as iron-formation, quartzite, schist and amphibolite is highly suggestive that the gneisses are metasedimentary. Considerable orthogneiss may be present. However, no attempt was made to distinguish orthogneiss from paragneiss.

Granite gneiss

A unit designated as granite gneiss (gngg) in the northwestern part of the Bopolu quadrangle is closely associated with granite. It is distinguished from granite primarily by linear trends that are imparted by foliation observable in hand specimen and which are characteristic of the unit as seen on aerial photographs.

Granodiorite gneiss

Large bodies of granodiorite gneiss (gngd) are found predominantly in the central western margin of the quadrangle, and may include small bodies of granite. The foliation is generally weak, and is imparted chiefly by the subparallel orientation of biotite. The granodiorite gneiss has a predominant northeast trend.

Granitic gneiss

Granitic gneiss (gng) is the predominant rock unit in the Bopolu quadrangle and is characterized structurally by a consistent N. 40° E.

trend visible in the field, and reflected on radiometric and magnetic maps (Behrendt and Wotorson, 1974, a, b). The gneisses are layered and are predominantly granodioritic but range from granite to granodiorite in composition, and also include minor amounts of quartz diorite and intercalated amphibolite. The gneiss unit is characterized by magnetic variations of low amplitude and by moderately high aeroradiometric counts.

Quartz diorite gneiss

Two lenticular bodies of quartz diorite gneiss (gndq) are found in the southern half of the Bopolu quadrangle. They trend from N. 70° E. to N. 45° E. Pronounced layering parallels the foliation and reflects alternation in the relative proportions of light and dark minerals. Associated with this unit are appreciable but minor ultramafic intrusions and lesser amounts of interlayered amphibolite, quartzite, and muscovite schist, and a small amount of itabirite.

Leucocratic gneiss

This map unit (gnl) is so designated because field data are sparse and the available data are insufficient to permit a more definite classification. The observed outcrops are predominantly light-colored gneiss, generally of granitic to quartz dioritic composition. A characteristic linear pattern as seen on aerial photographs, and a flat, low-intensity pattern of magnetic data have been relied on extensively to extrapolate the sparse field data throughout the unit as delineated.

Melanocratic gneiss

The unit designated as "Melanocratic gneiss" (gnm) in the extreme southwest corner of the Bopolu quadrangle is a part of a larger body in the Monrovia quadrangle to the south (Thorman, 1974); it consists primarily of medium- to dark-colored granodioritic to gabbroic gneiss with subordinate intercalated quartzose leucocratic gneiss and amphibolite. Hypersthene and diopside are present in many rocks, often in association with hornblende.

Schist

Several large lenses of garnet- and staurolite-quartz-mica schist (s) occur within the granitic gneiss layers or near the boundaries of the gneiss. As the schist is poorly exposed and deeply weathered, observation of fresh outcrop is rare, but terranes underlain by micaceous schist are generally distinguished by abundant float of coarse muscovite on the ground surface, and by the distinctive texture and appearance of the saprolite. Included with areas designated as schist are minor, though locally abundant, interstratified amphibolite, quartz, and quartz-dioritic and granitic gneisses. Small dikes and lenses of pegmatite are common in some places.

Amphibolite

Amphibolite (am) layers range from a few decimeters in thickness, too thin to show at the map scale, to units hundreds of meters thick. Most large units form ridges and are associated with negative magnetic anomalies. The amphibolite is medium to coarse grained, and consists of roughly equal proportions of hornblende and plagioclase, and common accessory sphene. Variations in the relative proportions of hornblende and plagioclase produce varied, intergradational, and distinctive mafic to felsic interlayers on a scale ranging from a few millimeters to as much as several tens of centimeters. Pronounced though imperfect foliation is nearly everywhere parallel to the layering. Commonly, felsic veins associated with felsic layers impart a migmatitic aspect to the rock.

Itabirite

Hematite-magnetite itabirite (it) is the dominant type of iron-formation and forms the major iron ore of the Mano River Mine and the protores of the Bea, Tokani, and Kpo Mountain ranges within the Bopolu quadrangle. Itabirite is associated with quartzite, schist, and amphibolite and commonly grades laterally into these rock types in the protore deposits and elsewhere. It typically forms long narrow ridges and is marked by pronounced magnetic anomalies.

Composite unit

The Mano River Mine area and the Bea, Tokani, and Kpo Mountain ranges are underlain by a composite (z) of rock units which are individually too small to show at the map scale. The unit comprises schist, quartzite, amphibolite, layered leucocratic gneiss and subordinate iron-formation. Iron silicate facies is present in the Bea Mountains (Rehfeldt, 1967) as amphibole schist, the most common silicates being cummingtonite-grunerite, with or without hornblende, and minor garnet, biotite, and pyroxene.

Igneous rocks

Ultramafic rocks

Ultramafic rocks (u) form dikes, plugs, and sills in both the crystalline basement and the metasedimentary complexes. A meta-peridotite plug is located at the confluence of the Yambesi and Lofa Rivers; its margins are serpentinized and slightly foliated in harmony with the foliation of the bordering gneiss. This plug consists mainly of olivine, clinopyroxene, tremolite, and anthophyllite. Other moder-ately large ultramafic intrusions, south of the Mano River Iron mine area, are completely altered to talc and soapstone.

Granitic rocks

A large part of the northern half of the quadrangle is underlain by unfoliated or slightly foliated granitic rocks (gr). The rocks are quartz-rich, and range in composition from granite to trondjemite; they are commonly medium grained, relatively massive, and form bare domes that very rarely exhibit a faint northeast-trending foliation. Small pegmatite dikes, and dikes or small plugs(?) of aplite are randomly distributed and not uncommon in some outcrops.

Syenite

One intrusive mass of syenite (sy) about 300 m long and 200 m wide has been observed in an area immediately north of the Mano River Iron mine at about the junction of the Mano and Morro Rivers. No other syenite was observed in the Bopolu quadrangle.

Pegmatite

Pegmatites (pg) are not commonly of mappable size within the quadrangle and most frequently are found within and near the granite bodies. However, three mappable pegmatites were observed within gneissic rocks. All specimens collected are granitic and all pegmatites observed in the field are deeply weathered.

Diabase

East-trending diabase dikes (d) are prominent in the Zwedru quadrangle (Force and Beikman, 1974) to the east, are nonmagnetic, and are present in the extreme northeast corner of the Bopolu quadrangle. The diabase dikes have been dated as about 2.8 billion years old and are in the meta-granulite facies of metamorphism.

Swarms of tholeiitic diabase (Jd) dikes of Jurassic age cross the Bopolu quadrangle from northwest to southeast. They range from a few meters to more than 30 m in width and from a few kilometers to more than 200 km in length. They form high, straight, and narrow ridges, easily detectable on aerial photographs, and are associated with elongate northwest-trending negative magnetic anomalies on aeromagnetic maps (see Behrendt and Wotorson, 1974, a). The rock is generally composed of labradorite and titaniferous augite, with ubiquitous accessory magnetite and ilmenite. Ophitic texture is common and is prominent in specimens that are glomeroporphyritic.

Kimberlite

Outcrops of kimberlite (KJk) of Cretaceous or Jurassic age in the Bopolu quadrangle are extremely rare and nearly all the localities shown on the map have been discovered by drilling or excavation. The kimberlite bodies were located by heavy-mineral studies (Leuria, 1966, p. 30) of stream samples and soil samples, using such indicator minerals as picroilmenite, pyrope garnet, and chrome diopside as guides. A fairly fresh kimberlite crops out as several resistant layers in a creek about 35 km northeast of the confluence of the Mano and Morro Rivers. The rock is fine grained, has the appearance of diabase, and contains large ilmenite(?) crystals imbedded in the matrix, plus grains of garnet, olivine, mica, and augite.

Surficial deposits

Fluvial deposits

Mappable fluvial deposits (Qf) of probable Quaternary age occur along the Mano River in the southwest corner of the Bopolu quadrangle. These deposits range in thickness from about 3 m to more than 12 m and consist of layers of silty sand underlain by layers of medium- to fine-grained sand. No other fluvial deposits were mapped in the Bopolu quadrangle.

STRATIGRAPHY AND STRUCTURE

Schist and some amphibolite and quartzite in the western part of the Bopolu quadrangle are inferred to be metasedimentary, but the nature of the parent rock of much of the gneissic terrane to the north, east, and south is uncertain and both orthogneiss and paragneiss are probably present. Consequently, no systematic stratigraphic relations can be demonstrated beyond the approximate contemporaneity of interstratified metasedimentary and metavolcanic rocks within limited areas. Separated areas of such rocks as schist, composite rock units, or iron formation, may be generally equivalent to each other, as suggested by similarities in lithology and associated units; equivalence of such units is compatible with available structural information; however, such correlations are only tentative at best.

The regional stratigraphic pattern reflects the dominant northeast-trending grain of the Precambrian rocks, which swings to the west along the southwestern border of the quadrangle. Several linear features trend east-northeast, oblique to the predominant structural trend, and mark major faults. The Jurassic diabase dikes form northwest-trending swarms.

Folds

Folds range in size from small crenulations to broad antiforms and synforms, and are commonly isoclinal with axes predominantly steep but ranging from vertical to horizontal. Iron-formation commonly occurs in synclinal troughs.

Faults and shear zones

Most of the major faults in the Bopolu quadrangle are sub-parallel to regional stratigraphic trends and have probably had a major influence on the topography. The long, nearly straight, southwest-flowing major streams lie in valleys controlled by major faults that appear to have a predominant strike-slip component.

Some faults are complex and are marked by large mylonitic zones.

One such zone observed by C. H. Thorman (1974) in the Monrovia quadrangle was traced into the southwest corner of the Bopolu quadrangle on the basis of intermittent mylonitic zones, some of which are more than a kilometer in width.

High-angle, east-trending faults are oblique to the regional stratigraphic and physiographic trends and appear to be younger than the strike-slip faults. Many minor faults are exposed in the Bea and Kpo Mountain ranges and are believed to be the youngest faults.

METAMORPHISM

Regional metamorphism.--Throughout most of the mapped area the rocks are of amphibolite facies metamorphic grade. In the southwest corner of the quadrangle hypersthene-bearing rocks mark a transition into the pyroxene-hornblende granulite facies of transitional granulite facies. The distribution of hypersthene indicates that the isograd trends northwest, passing to the west of the Bea Mountains, a trend well established in the Monrovia quadrangle (Thorman, 1974). Hypersthene is reported in itabirite at the Mano River mine and hypersthene also occurs just north of the Bea Mountains. Thus the granulite-amphibolite facies isograd may be very irregular.

Dynamic metamorphism.--Cataclastic rocks have been collected from many of the major fault zones, some of which are as much as a kilometer wide. Only a few blastomylonites were observed. Most of the rocks are mylonite and protomylonite derived from felsic gneisses, indicating that deformation postdated the regional metamorphism.

MINERAL RESOURCES

Iron

Iron ore is mined in the Bopolu quadrangle at the Mano River Mine (National Ore Company, Limited), located in the southwestern part of the quadrangle. Production is chiefly from enriched itabirite, but minor amounts of ore are extracted from canga (an iron-rich conglomerate) and from enriched laterite and iron-silicate formations. Numerous occurrences of itabirite, the dominant iron-formation, and extensive tracts of metamorphosed sedimentary and volcanic rocks with which iron-formation is commonly associated, are in the Bea and Tokani Mountains and throughout the Kpo Range; they represent potentially large iron ore reserves.

Diamonds

Diamonds have been found in placer deposits along the Mano-Gbeya River system and in the Zoi-Bonbahun area. All the placers contain minerals (picro-ilmenite, pyrope-garnet, and chrome-diopside) characteristic of kimberlite, but no kimberlite has been located in this area. The placer diamond deposits north of the Bea Mountains and along the Lofa River have probably been derived from kimberlite deposits to the north.

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