Cenozoic Landscape Evolution of the Southern Part of the Gran Sabana, Southeastern Venezuela—Implications for the Occurrence of Gold and Diamond Placers

By John C. Dohrenwend,[1] Galo Yánez P.,[2] *and* Glenda Lowry[3]

ABSTRACT

The Gran Sabana of southeastern Venezuela is a degradational landscape that is well adjusted to the lithologic and structural variations of the underlying Early to Middle Proterozoic Roraima Group (fig. 1). The Roraima Group consists of a sequence of flat-lying to gently folded, generally unmetamorphosed, terrigenous to shallow coastal marine strata that is 2,000–3,000+ m thick. Cuesta ridges and high mesalike tepuis (table mountains), having elevations as high as 2,800 m, are underlain by silica-cemented quartz sandstone. The larger valleys, at elevations of 800–900 m, are underlain by feldspathic sandstone, siltstone, claystone, and shale. Surficial deposits are generally limited to discontinuous colluvial-alluvial mantles, isolated colluvial aprons, thin (generally less than 2 m thick) fluvial terrace deposits, and somewhat thicker fluvial deposits within and adjacent to the channels of the largest rivers.

Within this degradational landscape, ferricrete-capped remnants of a middle (?) Tertiary geomorphic surface extend discontinuously from low strath terraces to high, structurally controlled ridges. The ferricrete remnants are particularly well developed on the finer grained and more feldspathic rocks that underlie the lower dip slopes, hills, and terraces within or adjacent to the larger valleys. These relict soils are characterized by a 1–3-m-thick, nodular to pisolitic ferricrete crust that contains abundant fragments of weathered bedrock and local concentrations of hematite and (or) gibbsite. This ferricrete crust is typically partly stripped and rubbled and is underlain by a deeply weathered, red- and yellow-mottled, clay-enriched horizon as thick as 15 m. In most respects, the middle Tertiary landscape defined by these ferricrete-capped remnants was as well adjusted to underlying lithology and structure as is the modern landscape and had an overall relief comparable to present-day relief. Thus, during middle and late Cenozoic time, landscape change in the Gran Sabana was limited to an undefined amount of upland dissection accompanied by less than 10 m of general lowering of the largest valleys. This scenario does not accord with previous geomorphic models, which emphasize cyclic planation as the principal mode of landscape evolution in northern South America.

Gold and diamond resources in the southern part of the Gran Sabana are primarily limited to areas underlain by or downstream from extensive exposures of the Uairén Formation, the oldest formation within the Roraima Group. Within these areas, geologic-geomorphic environments that host gold and diamonds include active channels and Holocene floodplains of the larger rivers, colluvial-alluvial placer deposits of small low-order drainage basins, and paleoplacer deposits associated with conglomeratic lenses and beds within the lower part (lower 500–600 m) of the Uairén Formation. Additional gold and diamond resources may lie within or immediately beneath ferricrete crusts developed on surfaces underlain by the Uairén Formation. For the most part, these placer resources are limited in both grade and extent.

RESUMEN

La Gran Sabana al sur de Venezuela es un paisaje degradacional que está bien ajustado a las variaciones litológicas y estructurales de Grupo Roraima el cual infrayace la región. El Grupo Roraima, de edad Proterozoico Temprano a Medio, consiste de una secuencia de 2,000 a 3,000 m de espesor compuesta por estratos continentales y costeros

[1]U.S.Geological Survey, 345 Middlefield Road, MS905, Menlo Park, California 94025.

[2]Corporación Venezolana de Guayana, Técnica Minera, C.A., Ciudad Bolívar, Venezuela.

[3]Corporación Venezolana de Guayana, Técnica Minera, C.A., Puerto Ordaz, Venezuela.

marinos someros. Los estratos están dispuestos horizontalmente o plegados suavemente. Areniscas cementadas con sílice forman las crestas de las cuestas e infrayacen las mesas (tepuis) los cuales alcanzan una elevación de 2,800 m. Los valles más extensos, a una elevación de 800–900 m, están formados sobre arenisca feldespática, limolita, arcillita, abanicos coluviales aislados, depósitos delgados (generalmente menos de 2 m de espesor) de terrazas fluviales y sobre depósitos fluviales algo más espesos dentro y adyacentes a los canales de los ríos de orden mayor.

Dentro de este paisaje degradacional, hay depósitos remanentes cubiertos por una laterita ferruginosa endurecida (ferricrete). Dichos remanentes son de una superficie geomórfica de edad Terciaria media (?). Estos se extienden discontinuamente desde las terrazas más antiguas localizadas en valles bajos hasta crestas controladas estructuramente.

Los remanentes ferruginosos están particularmente bien desarrollados sobre rocas feldespáticas de grano más fino las cuales infrayacen las partes bajas de las pendientes de buzamiento, colinas y terrazas dentro o adyacentes a los valles más grandes. Estos suelos relictos están caracterizados por una costra ferruginosa nodular a pisolítica la cual contiene abundantes fragmentos de roca infrayacente y concentraciones locales de hematita y/o gibbsita. Esta costra ferruginosa está típicamente desnuda y desmantelada, por debajo hay un horizonte enriquecido en arcilla, muy meteorizado, de color rojo moteado de amarillo, el cual puede alcanzar 15 m de espesor. En general, el paisaje durante el Terciario medio, definido por los remanentes con tope laterítico, estaba también ajustado a la litología infrayacente y a la estructura, generando una fisiografía comparable a la moderna. Así pues, durante el Cenozoico medio y tardío, el cambio del paisaje en la Gran Sabana estaba limitado por una cantidad no definida de disección en las áreas más altas acompañada por un rebajamiento general de 10 m en los valles más grandes. Este modelo no está de acuerdo con modelos geomórficos previos, los cuales enfatizan la planación cíclica como el modo principal de evolución del paisaje en la parte norte de América del Sur.

Los recursos de oro y diamantes en la parte sur de la Gran Sabana están primordialmente limitados a áreas que suprayacen la Formación Uairén o que están aguas abajo de dicha formación la cual es la más antigua del Grupo Roraima. Dentro de estas áreas se distinguen varios ambientes geológico-geomórficos que contienen oro y diamantes. Estos incluyen canales activos y planicies de inundación de ríos mayores de edad Holoceno, depósitos aluviales-coluviales de tipo placer en pequeñas cuencas de orden menor, y en depósitos de paleoplaceres asociados con lentes y capas conglomeráticas localizados en la base (500–600 m) de la Formación Uairén. Los recursos adicionales de oro y diamantes podrían estar presentes en o inmediatamente por debajo de las costras ferruginosas desarrolladas sobre superficies que a su vez suprayacen a la Formación Uairén. Los recursos de tipo placer, en su mayoría son limitados tanto en tenor como en extensión.

INTRODUCTION

The Gran Sabana of southeastern Venezuela is a degradational landscape that is well adjusted to the lithologic and structural variations of the underlying Early and Middle Proterozoic Roraima Group. This 2,000–3,000+-m-thick sequence of terrigenous to shallow coastal marine strata is flat lying to gently folded and generally unmetamorphosed. Cuesta ridges and high mesalike tepuis (table mountains), which are formed on silica-cemented quartz sandstone, have elevations of as much as 2,800 m. In contrast, the floors of the larger valleys, which are underlain by interbedded feldspathic sandstone, siltstone, claystone, and shale, are at elevations between 800 and 900 m. Benched hillsides and piedmonts are widespread, and numerous lithologically controlled waterfalls and rapids interrupt the otherwise gentle longitudinal profiles of most streams. Surficial deposits are mostly limited to discontinuous colluvial-alluvial mantles on hill slopes and piedmonts, isolated colluvial aprons preserved beneath residual gravel lags, 1–2-m-thick fluvial deposits overlying strath terraces in the larger valleys, and 5–10-m-thick channel deposits within the narrow late Quaternary floodplains of the largest rivers.

As many as six planar geomorphic surfaces, defined on the basis of regional correlations of similar elevations of summit levels and areas of low relief, have been recognized in the region of the Guayana Shield (James, 1959; McConnell, 1968; Zonneveld, 1985; Schubert and others, 1986; Briceño and Schubert, 1990). The formation of these surfaces is generally considered to be the result of alternating periods of tectonic uplift and stability, landscape dissection in response to the uplift, and parallel slope retreat during the succeeding interval of stability. The ages of these surfaces are generally thought to range from Mesozoic to Holocene; however, it has been pointed out that many of these surfaces coincide with lithologic units and that the steps which separate them commonly coincide with lithologic discontinuities (Kroonenberg and Melitz, 1983). Moreover, within the area of the southern part of the Gran Sabana, ferricrete-capped remnants of a middle (?) Tertiary geomorphic surface cut across several of these regional planation surface levels (extending almost continuously from dissected strath terraces lying less than 10 m above modern streams to high, structurally controlled ridges rising more than 200 m above the floors of the larger valleys). It is likely, therefore, that present-day relief within the Guayana Shield is mostly a function of lithologic resistance and that at least some of these so-called planation surfaces are primarily a manifestation of lithologic control in a relatively stable landscape that is developed on a thick sequence of very gently dipping to flat-lying sedimentary strata.

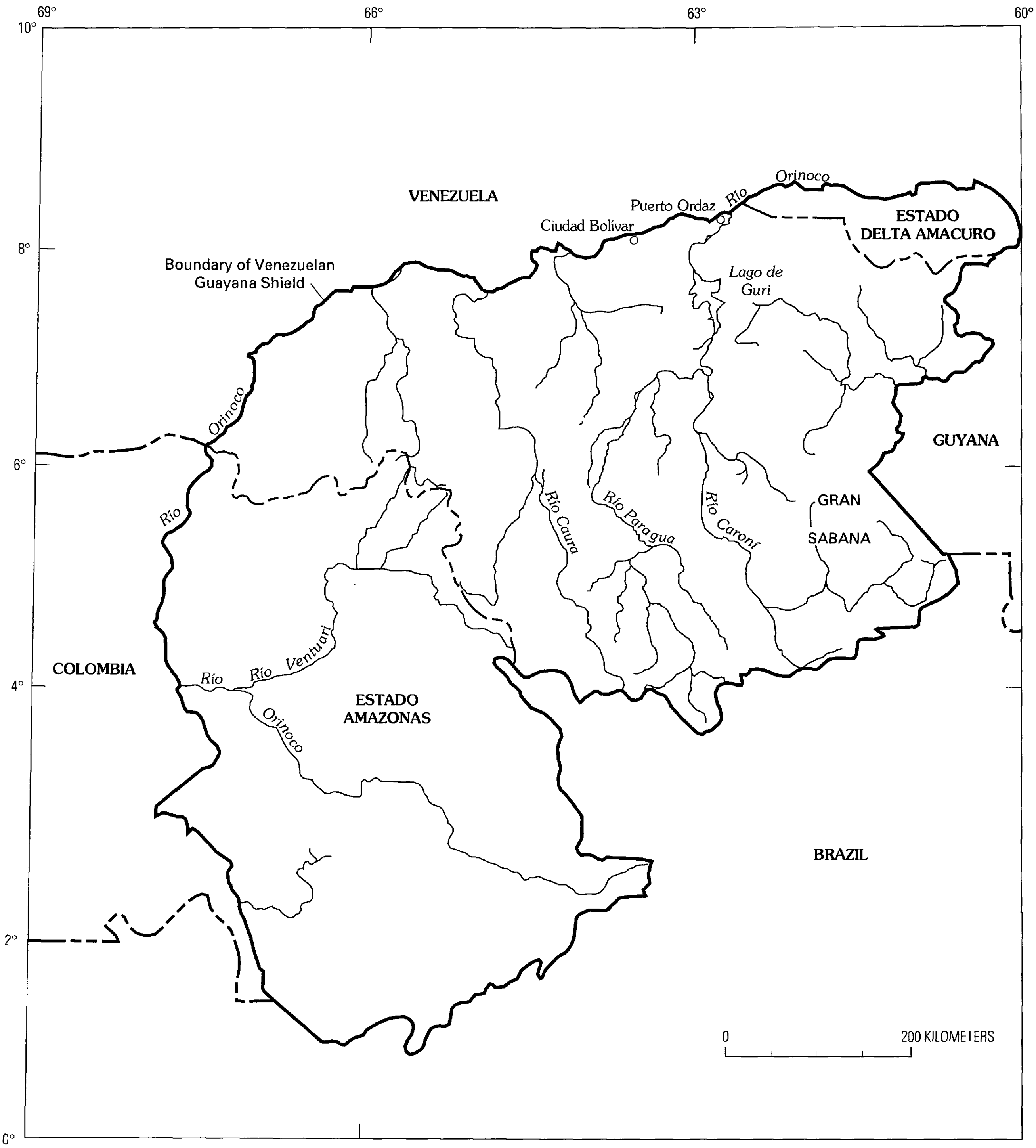

Figure 1. Location of the Gran Sabana, Estado Bolívar, Venezuela. Most of the geographic locations mentioned in the text are shown on plate 1 of Wynn, Sidder, and others (this volume).

LITHOLOGIC AND STRUCTURAL FRAMEWORK OF THE SOUTHERN PART OF THE GRAN SABANA

GENERAL STRATIGRAPHY OF THE RORAIMA GROUP

The Roraima Group is a laterally extensive sequence of Early and Middle Proterozoic, fluvial to shallow coastal marine strata that mantle a large part of the Guayana Shield and underlie most of the Gran Sabana (Reid, 1974; Yánez, 1984; Sidder and Mendoza, this volume). These strata unconformably overlie an igneous and metamorphic basement complex of Early Proterozoic age, and they are intruded by about 1.65-Ga diabase dikes and sills. The Roraima Group is dominated by quartzose sandstone but also contains significant amounts of conglomerate, conglomeratic sandstone, pebbly quartz sandstone, arkosic to feldspathic sandstone, siltstone, mudstone, shale, and tuff. Cross stratification is common to abundant throughout the sequence. Within the Gran Sabana, deformation is limited to broad open folds; dips are generally less than 7°, although dips of as much as 15° are present locally.

The stratigraphy and structure of the Roraima Group have been described in some detail by Reid (1974), Yánez (1984), and Ghosh (1985) and are summarized by Sidder and Mendoza (this volume). As defined by Reid (1974), the Roraima Group in the southern part of the Gran Sabana is divided into four units, the Uairén, Cuquenán, Uaimapué, and Mataui Formations.

The Uairén Formation can be usefully divided into upper and lower parts that are recognizable both geomorphically and lithologically throughout the southern part of the Gran Sabana. The lower part (Canaima Formation, Unit I of Yánez, 1984) is about 600 m thick and consists primarily of well-sorted, generally coarse to medium grained, moderately bedded to massive, cross-stratified quartzose sandstone and intercalated lenses and beds of polymictic and quartzose pebble conglomerate and minor thin beds and laminae of shaly siltstone. These rocks form the high cliffs and extensive dip slopes of Chiricayen, Cerro el Abismo, and other cuestas along the southern margin of the Gran Sabana. The upper part of the Uairén Formation (Canaima Formation, Unit II of Yánez, 1984) is 100–300 m thick and consists primarily of medium-grained sandstone with abundant trough cross-stratification and intercalated channel gravels. These rocks form benched scarp slopes and irregular ridges, particularly along the southern margin of the valley of the Río Cuquenán. A ferricrete-capped lateritic soil, interpreted by Reid (1974) as a Precambrian paleosol and used by him to define the top of the Uairén Formation, is in fact part of a deep weathering profile of middle (?) to late Tertiary age that mantles the middle part of the Roraima Group (from the upper part of the Uairén Formation to at least the middle of the Uaimapué Formation). This soil is highly significant to understanding the Cenozoic landscape evolution of the Gran Sabana and is described and discussed in some detail in a following section of this report.

The Uairén Formation is overlain by the Cuquenán Formation (Canaima Formation, Units III and IV of Yánez, 1984). Exposures of the Cuquenán Formation are limited, and it has not been comprehensively described. This unit underlies the valley of the Río Cuquenán from the vicinity of Moroc Meru to the confluence of the Río Cuquenán with the Río Aponguao. In this area, deeply weathered outcrops are present almost continuously along the Río Cuquenán wherever the modern channel is actively eroding the late Pleistocene strath surface, which underlies most of the valley floor. These outcrops reveal well-bedded to massive, fine- to medium-grained sandstone interbedded with medium- to thin-bedded and laminated siltstone, claystone, and shale.

The Uaimapué Formation, which overlies the Cuquenán Formation, can also be divided into two geomorphically distinct parts. The lower part (Canaima Formation, Unit V of Yánez, 1984) consists primarily of pervasively channelled and cross-stratified, fine- to coarse-grained sandstone and thin-bedded to laminated fine-grained sandstone, siltstone, and mudstone. The topography developed on these rocks is characterized by benched scarp slopes similar to the topography of the upper part of Uairén Formation. The upper part of the Uaimapué Formation (Guaiquinima Formation of Yánez, 1984) contains abundant beds and lenses of tuff and jasper that are interbedded with cross-stratified arkosic to quartzose sandstone. These resistant beds form conspicuous benches along hill slopes and numerous waterfalls and cascades along both major and tributary streams.

The Mataui Formation (Auyantepuy Formation of Yanez, 1984) consists primarily of pervasively cross stratified, fine- to medium-grained quartzarenite. This unit underlies the spectacular, vertical-walled high tepuis such as Cerro Roraima and Cuquenan Tepuy that dominate the landscape of the northern part of the Gran Sabana. It is not present within Gran Sabana Sur and therefore is not described in any detail in this report.

REGIONAL DEFORMATION OF THE RORAIMA GROUP

In the southern part of the Gran Sabana, the Roraima Group displays an apparent north-south deformational gradient ranging from relatively tight folds with conspicuous axial plane foliation in the south near the Brazilian border to very gently dipping to horizontal strata without foliation in the north in the vicinity of Chimata, Cuquenán, and Roraima tepuis. This deformational gradient is most conspicuous in the western part of the study area between the valley of the Río Icabarú and the Río Caroní, but it is also present in the

Figure 2. South-facing cuesta scarp developed on quartzose sandstone of the lower part of the Uairén Formation near the axis of a broad northwest-plunging anticline at Chiricayen, Venezuela (lat 4°50′ N., long 61°15′ W.). Aerial view looking west.

eastern part of the study area, east of Santa Elena de Uairén. In the Icabarú–El Paují area, the axial plane foliation is sufficiently well developed to impose a conspicuous geomorphic overprint on the ridge and valley topography. It is likely that this north-south deformational gradient has been a significant factor in the geomorphic evolution of the region, facilitating the deep dissection and general stripping of the Roraima Group south from the Pacaraima Mountains into Brazil and the northward encroachment into the Gran Sabana by the southward-flowing drainages of the northern Amazon basin.

GEOMORPHOLOGY OF THE SOUTHERN PART OF THE GRAN SABANA

The Gran Sabana is a degradational landscape that is mostly adjusted to the lithologic and structural variations of underlying bedrock (fig. 2). Indications of middle to late Cenozoic tectonism are not apparent within the region; however, it is unlikely that a broad regional upwarping of the present landscape would generate any readily recognizable geomorphic expression of tectonic activity. Indications of general landscape maturity are abundant.

1. General topographic features are well adjusted to lithology and structure. Relatively resistant rock types underlie high tepuis and cuestas, whereas relatively nonresistant rock types underlie the larger valleys and adjacent low, rounded hills. In areas of folded, gently to moderately dipping rocks, ridges and valleys outline principal structures. Major streams are present as subsequent streams that are deflected around the noses of plunging folds. In the western part of the region between the Río Icabarú and the Río Caroní, a classic ridge and valley topography has developed over the gently plunging, east-trending folds of the area.

2. Local geomorphic indicators of structural and lithologic control are common. Hillside and piedmont benching is widespread, particularly in areas underlain by either the Uairén or Uaimapué Formations. Lithologically controlled waterfalls and rapids are abundant along most lower order streams, and indeed such waterfalls are common

Figure 3. Detail of the pseudokarst labyrinth on the summit platform of Cerro Roraima, Venezuela. The pervasively cross-stratified quartzose of the Mataui Formation that forms the summit platform has been deeply etched by orographically intensified rainfall estimated at about 5 m per year. High-angle-oblique aerial view from a height of about 300 m.

even along some reaches of the principal drainages of the Río Cuquenán and Río Icabarú.

3. Paleosurface remnants are limited in abundance, extent, and state of preservation. In fact, the only indications of former geomorphic surfaces that remain in the present landscape are (1) possible paleosurface remnants defined by generally accordant ridge crests in broadly folded areas of ridge and valley topography; (2) laterite-capped hills, ridges, and low terraces that have survived only because of the põtection afforded by their resistant ferricrete caps; and (3) low, generally accordant, and completely rounded bedrock hills within the broad valleys of the principal streams at the general level of the laterite-capped terrace remnants.

CENOZOIC LANDSCAPE STRIPPING

Ubiquitous geomorphic evidence indicates pervasive late Tertiary and Quaternary stripping of this landscape. These geomorphic features include:

1. Deep etching and almost continuous bedrock exposure on most tepuis and higher cuestas cover (cover, fig. 3)

2. Conspicuous, widespread bedrock outcrops and benching on most cuesta scarp slopes and extensive bedrock outcrops on many cuesta dip slopes (fig. 4)

3. Almost continuous bedrock exposure and numerous waterfalls and rapids along the channels of most tributary streams (fig. 5)

4. Almost continuous exposures of deeply weathered bedrock along the channels of the major rivers wherever these channels impinge upon pre-Holocene valley surfaces (fig. 6)

5. Extensive and widespread occurrences of rubbled ferricrete, lateritic lag gravels, and truncated deep weathering profiles developed directly on bedrock

6. A general lack of continuous surficial deposits (>1–2 m thick) in all areas of the landscape except local colluvial wedges on hill slopes armored by lateritic and (or) conglomeratic rubble and thin fluvial channel and overbank deposits within the modern floodplains of the largest rivers

Figure 4. Prominent benches in almost flat lying strata of the Uairén Formation. Surficial deposits in this area are limited to discontinuous colluvial aprons along the base of the bench scarps. Aerial view north along the Brazilian frontier approximately 35 km northeast of Santa Elena de Uairén, Venezuela.

The principal reasons for this stripping are threefold:

1. The region is mostly underlain by weakly to moderately indurated, essentially unmetamorphosed, generally medium to very fine grained sedimentary rocks.

2. The humid-tropical conditions that likely dominated the middle to late Cenozoic climate of the region have deeply leached and weathered these rocks such that when eroded they rapidly disaggregate into their constituent mineral grains or decompose into finer grained weathering products.

3. The wet-dry seasonality of the present-day climate, and of probable late Cenozoic paleoclimates, facilitates seasonal flushing from the landscape of all available surficial materials.

LATE CENOZOIC DEGRADATIONAL PROCESSES

Middle to late Cenozoic degradation of the uplands of the Gran Sabana has been dominated by the following processes: (1) intense leaching and solutional etching of upland areas (particularly the tepuis and higher cuestas underlain by the quartzitic sandstone and conglomerate of the Matauí and lower part of the Uairén Formations); (2) solutional etching and rubbling of ferricrete crusts; (3) discontinuous slumping and sliding along laterite-capped hill slopes underlain by the upper part of the Uairén Formation and both laterite- and sandstone-capped scarp slopes underlain by the lower part of the Uaimapué Formation; and (4) basal sapping of hill slopes and cuesta dip slopes, particularly those underlain by interbedded sedimentary rocks of varying permeability and erosional resistance. The basal sapping is manifest on two distinct geomorphic scales: (1) conspicuous, locally intensive hillside and piedmont slope piping has formed narrow, almost vertical sided gullies and small box canyons as much as 30–40 m in width and 20 m in depth; and (2) more general large-scale basal sapping has cut large, steep-sided, generally U-shaped valleys into many of the larger cuestas and tepuis. These valleys and cuestas are strikingly similar, in both planimetric and cross-sectional form, to those canyons and escarpments

Figure 5. Detail of the flat, bedrock-floored channel of Quebrada de Jaspe cut into jasper beds of the upper part of the Uaimapué Formation.

of the Colorado Plateau region where sapping erosion has been a principal degradational process (Laity and Malin, 1985; Howard, 1988). Many of the large, U-shaped valleys in the Gran Sabana are now beheaded, indicating that a significant amount of slope retreat has likely occurred along at least some of the cuesta scarps of the region and that basal sapping has been a significant valley-forming process during most of Cenozoic time. The relatively minor (generally less than 5–10 m) general lowering of the larger valley floors has, most likely, been principally accomplished by high discharge stream flow during wet-season flooding.

SURFICIAL DEPOSITS

Surficial deposits of the Gran Sabana are mostly limited to a discontinuous veneer of colluvium and alluvium, generally less than 1–2 m thick, on most hillsides and piedmont slopes. Gray to dark-brown, weakly to moderately developed soils are on these deposits. In adjacent areas, ^{14}C age determinations made on similar surficial deposits indicate a Holocene age (Schubert and others, 1986). Locally, significant colluvial aprons have been preserved on hill slopes armored by pebble to cobble lags of weathered conglomerate or by cobble- to boulder-sized fragments derived from well-indurated sandstone or ferruginous lateritic crust; however, these occurrences are limited to a small proportion of all hill slopes. Alluvial fans are not present within the study area; instead, piedmont surfaces are erosional straths discontinuously veneered by thin alluvial and colluvial deposits. Significant fluvial and valley bottom deposits are limited to the valleys of the largest tributaries and principal rivers, and even in the broadest valleys these deposits are generally thin, except within the modern floodplains of the larger rivers where they may be 5–10 m thick. Aerial observations and analysis of large-scale aerial photographs show that most tributary channels are developed in bedrock and contain little fluvial sediment. Waterfalls and rapids also are abundant along many of these lesser streams. Within the valley of the Río Cuquenán, between Moroc Meru and the Río Yuruaní, bedrock exposure is almost continuous along the modern channel and only 1–3 m of fluvial deposits lie beneath the surface of this 3–8-km-wide fluvial valley.

Figure 6. Valley of the Río Cuquenán downstream from its confluence with the Río Yuruaní, Venezuela. This flat-floored strath valley, 7–8 km wide at this point, is the most extensive middle to late Cenozoic planation surface in the southern part of the Gran Sabana.

LATERITIC SOILS OF THE GRAN SABANA

Relict lateritic soils cap numerous cuesta dip slopes, ridges, piedmont slopes, and strath terrace remnants within and adjacent to the valleys of the Río Cuquenán, Río Aponguao, and Río Yuruaní (fig. 7). Laterite also is present as isolated remnants on cuesta dip slopes and other structurally controlled surfaces on high interfluve areas between the Río Cuquenán and the Río Yuruaní and on the high stripped structural surface west of the upper valley of the Río Yuruaní. In most areas the well-indurated ferricrete crust that characterizes these relict soils has been at least partly stripped and rubbled (fig. 8). These relations suggest periods of landscape stability and instability in the Gran Sabana.

The relict lateritic soils of the Gran Sabana are generally similar to lateritic soils described from other tropical and subtropical areas of the world (Nahon, 1986). In most areas of the southern part of the Gran Sabana, these soils are characterized by the following general profile from bedrock upward to the surface (layer designations from Nahon, 1986):

Layer I.—Weathered bedrock having preserved original structures

Layer II.—Highly irregular transitional zone between layer I and a pervasively mottled, clay-rich layer (layer III). This transitional zone may have as much as several meters of relief

Layer III.—Pervasively red and yellow mottled, clay-enriched zone wherein many preexisting rock structures have been destroyed. This layer locally is as thick 15 m or more (fig. 9)

Layer IV.—Transitional zone 0.5–2 m thick between the mottled layer (III) and the ferricrete crust (V)

Layer V.—Ferricrete layer having nodular and (or) pisolitic structure and containing numerous fragments of the underlying weathered bedrock. The upper part of this layer, commonly vesicular and weathered to dark brown or black, superficially resembles basic volcanic flow rocks. This layer is typically at least 1 m thick and locally may be as thick as

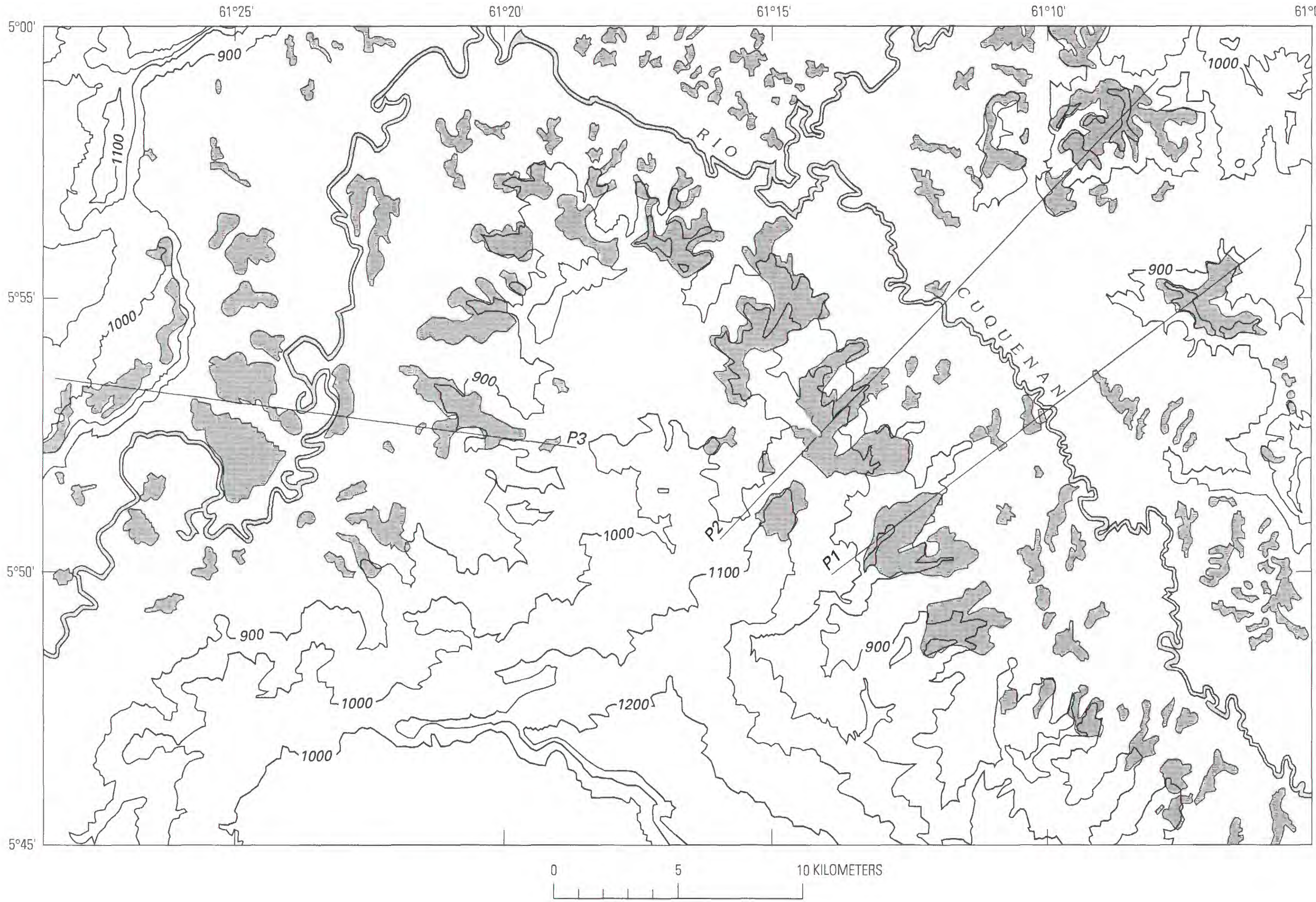

Figure 7. Map showing the distribution of laterite-capped paleosurface remnants (shaded) within and adjacent to the valley of the Río Cuquenán in the vicinity of Cerro Chiricayen, Venezuela. Topographic contour interval 100 m. Lines of topographic profiles (fig. 14) are also shown (labeled P1, P2, and P3 to refer to profiles 1, 2, and 3, respectively).

Figure 8. Surface of a relict laterite soil capping a cuesta ridge along the southwestern flank of the valley of the Río Cuquenán. These relict lateritic soils are typically degraded such that the upper part of the ferricrete crust is discontinuously exposed, etched, and partly rubbled to form a dark-red-brown to black, rough and irregular surface that is superficially reminiscent of the surface of a basaltic lava flow. View north toward Cerro Roraima (on skyline at center).

3 m. Locally, it contains conspicuous concentrations of hematite and gibbsite (figs. 10, 11)

Layer VI.—Thin (generally <10 cm thick) surface layer of ferruginous pebbles and other lateritic rubble generated by degradation of the underlying ferricrete crust

DISTRIBUTION AND SIGNIFICANCE OF RELICT LATERITIC SOILS

The present distribution of these relict ferricrete soils is apparently controlled by both stratigraphic (lithologic) and geomorphic factors. Lateritic soils are not present on the high cuestas and tepuis that are underlain by the deeply leached and pervasively etched quartzitic sandstone and conglomerate of the lower parts of the Uairén and Mataui Formations; however, they are particularly well developed in areas underlain by the finer grained and more feldspathic rocks of the upper part of the Uairén Formation, the Cuquenán Formation, and the lower part of the Uaimapué Formation. They are present, but are generally somewhat less well developed, on strata of the upper part of the Uaimapué Formation.

Within and adjacent to the valley of the Río Cuquenán, a relict lateritic soil having a strongly indurated, 1–3-m-thick ferricrete crust mantles (1) dissected and rounded remnants of strath terraces of the Río Cuquenán that are within 5–10 m of the level of the modern floodplain (fig. 12), (2) terrace remnants of tributary streams along the valley flanks and within some of the larger tributary valleys, and (3) dip slopes and cuesta ridges developed on the upper part of the Uairén Formation and on the lower part of the Uaimapué Formation (figs. 8, 13). Locally, these landscape relics range almost continuously over 200–300 m of elevation, from the level of the strath terraces along the Río Cuquenán to the crests of the cuesta ridges that form the valley sides (figs. 7, 14).

The paleolandscape defined by these surface remnants was similar to the modern landscape. All of the major

Figure 10. Typical lateritic soil roadcut exposure showing upper part of layer III (clay-enriched, red and yellow mottled zone), layer IV (ferricrete-mottled zone transition), and layer V (nodular ferricrete). Road cut is approximately 4 m high.

Figure 11. Upper part of a relict lateritic soil profile showing layer IV (ferricrete-mottled zone transition), layer V (nodular to pisolitic ferricrete crust; here about 2.5 m thick), and layer VI (disaggregated ferruginous pebble gravel lag). This relict soil profile is on the summit surface of Yuoromota tepuy at an elevation of about 1,000 m, approximately 180 m above the level of the modern floodplain of the Río Cuquenán.

landscape components (such as stream valleys and cuesta ridges) occupied essentially the same relative and absolute positions as they do within the present landscape. Local relief between valley bottoms and ridge crests was about the same as now, and regional base level was within 10 m of modern base level. Upland dissection may have been somewhat less extensive than at present; however, geomorphic evidence to support this possibility is not preserved within the present landscape.

The age of this relict lateritic soil, and of the paleolandscape whose remnants it mantles, is not well constrained. Theoretical calculations suggest that a period of at least 1 m.y. would be required (under climatic conditions suitable for lateritic soil formation) to form a lateritic soil similar to that mantling much of the landscape of the southern part of the Gran Sabana (Fritz, 1975). Field studies also suggest that development of ferricrete profiles requires a period of more than 1 m.y. of favorable climatic conditions (Nahon, 1986). For example, Nahon and Lappartient (1977) determined that formation of a ferricrete soil profile derived from basic volcanic rocks of the Senegalese-Mauritanian Basin occurred within 6 m.y.; however, ferricrete profile development on feldspathic to arkosic sedimentary rocks may take somewhat longer. Whatever the case, planation of the broad valley of the Río Cuquenán, development of a thick, strongly indurated ferricrete on that surface and on the surrounding hillsides and subsequent dissection of the valley sides and degradation of the ferricrete would probably require an

Figure 11. Detail of a strongly developed nodular ferricrete crust containing abundant rinds and nodules of hematite and lesser amounts of segregated gibbsite. Hammer is shown for scale.

aggregate period of several million years. Thus, the landscape remnants capped by this lateritic soil are likely to be at least as old as early Pliocene or late Miocene.

CENOZOIC EVOLUTION OF THE GRAN SABANA LANDSCAPE

As many as six planar geomorphic surfaces have been interpreted in the Guayana Shield (James, 1959; Short and Steenken, 1962; McConnell, 1968; Zonneveld, 1982; Schubert and others, 1986; Briceño and Schubert, 1990). These geomorphic surfaces have been defined on the basis of regional correlations of similar elevations of summit levels and areas of low relief. The surfaces are generally interpreted as remnants of a series of regional planation surfaces that have been uplifted in the main shield area and downwarped along the coast and continental shelf (with a hinge line along the north coastal plain of the continent). Formation of multiple erosion surfaces is generally considered to be the result of alternating periods of tectonic uplift and stability, landscape dissection in response to the uplift, and parallel slope retreat during the succeeding interval of stability. The surfaces are generally thought to range from Mesozoic to Holocene in age; however, it has been pointed out by Kroonenberg and Melitz (1983) that many of these surfaces coincide with lithologic units and that the steps which separate them commonly coincide with lithologic discontinuities. Therefore, it is likely that present relief within the Guayana Shield is mostly a function of lithologic resistance and that at least some of these geomorphic surfaces are primarily a manifestation of lithologic control in a relatively stable landscape that is developed on a thick sequence of very gently dipping to flat-lying sedimentary strata.

Within the southern part of the Gran Sabana, the existence of an extensive laterite-capped paleolandscape that has 200–300 m of local relief and cuts across several of the regional planation surface levels hypothesized by previous workers argues strongly for a middle to late Cenozoic history wherein (1) vertical dissection, controlled at least in part by variations in lithologic resistance to weathering and erosion, has been the dominant mode of landscape evolution and (2) lateral planation was limited to the formation of broad erosional floodplains along the major rivers. Indeed, landscape change in the Gran Sabana during middle and late Cenozoic time has been primarily, if not entirely, denudational. This denudational history has been marked by periods of general landscape dissection and stripping interrupted by intervals of relative landscape stability. The broad strath terraces that occupy the larger stream valleys most likely formed during the intervals of relative landscape stability. It is unlikely that any significant episodes of aggradation took place during most, if not all, of Cenozoic time.

In the mid-Tertiary, the landscape of the Gran Sabana was sufficiently stable to permit formation of broad strath floodplains, as wide as 7–8 km, along major drainages of the region and widespread development of deep weathering profiles capped by thick, well-developed ferricrete crusts. In most other respects, however, this mid-Tertiary landscape was much like the landscape of today. The position and general morphology of the major landscape elements (tepuis, ridges, and major valleys) were essentially as they are today, and the overall landscape was well adjusted to underlying lithology and structure. Overall relief between ridge crests and valley bottoms may have been somewhat greater, however, than present-day relief.

Following this mid-Tertiary period of relative landscape stability and lateritic soil development, a probable long-term climatic change destabilized the landscape. Upland areas were dissected perhaps as much as 100–150 m, and the lateritic soils were gradually stripped, etched, and rubbled; however, downwearing of the valley floors was

Figure 12. Surface of a relict ferricrete crust capping a series of low (5–10 m high) fluvial terrace remnants. This dissected broad valley surface can be traced almost continuously from this location, adjacent to the modern channel of the Río Cuquenán, to the crests of the low ridges along the valley margin on the left skyline (approximately 7–8 km distant and 200 m higher in elevation).

generally less than 5–10 m. During the waning stages of this period of landscape destabilization and dissection, probably in late Tertiary or earliest Quaternary time, a shorter interval of relative landscape stability permitted formation of a 2–3-km-wide strath floodplain that is inset 5–10 m below the general level of the middle (?) Tertiary broad valley surface. General upland degradation likely slowed during this time, but available stream power was sufficient to rapidly transport essentially all available detrital material out of the local landscape system. This interval of renewed lateral stream planation was followed by renewed incision of the valley floors and a probable acceleration of upland stripping that apparently began during the late Quaternary, probably in response to a late Pleistocene–early Holocene climate change when an increase in mean annual temperature of as much as 5°C–7°C and a substantial increase in mean annual precipitation likely occurred in northern South America (Hammen, 1972; Liu and Colinvaux, 1985; Schubert and others, 1986). The net result of this Cenozoic degradational history is an erosional landscape, well adjusted to underlying lithology and structure, that is discontinuously mantled by generally less than 2 m of late Quaternary colluvial, alluvial, and fluvial deposits.

OCCURRENCE OF PLACER DEPOSITS

The presence of numerous paleosurface remnants developed on bedrock and mantled by thick ferricrete crusts and the almost complete absence of Tertiary or Quaternary deposits of any significant thickness indicate a lack of significant periods of sedimentary accumulation in the region of the southern part of the Gran Sabana during middle and late Cenozoic time. Surficial deposits in the Gran Sabana are limited to (1) generally less than 1–2 m of discontinuous colluvial-alluvial mantles on hill slopes and piedmonts, although somewhat thicker colluvial aprons are preserved locally beneath pebble to cobble lag gravels weathered from conglomerate lenses and beds within the Roraima Group or beneath cobble- to small boulder-size rubble derived from degraded ferricrete crusts; (2) thin fluvial deposits in the

Figure 13. Laterite-capped cuesta ridge developed on gently dipping strata of the upper part of the Uairén Formation. A strongly developed ferrugenous crust, 2–4 m thick, caps the gently northeast sloping surface of this cuesta from the floor of the valley of the Río Cuquenán (out of view to the right) to the crest of the ridge. Local relief in this view, from the tree-covered floodplain of the small stream in the foreground to the cuesta summit, is about 160 m.

larger valleys that are generally 1–2 m thick over Pleistocene (?) strath surfaces and 5–10 m thick within the narrow modern floodplains of the largest rivers; and (3) numerous, widely scattered landslide deposits, particularly in areas underlain by the upper part of the Uairén and the lower part of the Uaimapué Formations. Tertiary deposits have not been identified in the southern part of the Gran Sabana.

Consequently, gold and diamond resources in the southern part of the Gran Sabana are primarily restricted to three general geologic-geomorphic environments:

1. Placer deposits within the active channels and Holocene floodplains of the larger rivers downstream from extensive exposures of the Uairén Formation

2. Colluvial-alluvial placer deposits of small low-order drainage basins within or adjacent to extensive exposures of the Uairén Formation. These placers typically are associated with pebble to cobble gravels lying on or within about 1 m of the basal colluvial-alluvial contact with the underlying bedrock

3. Paleoplacer deposits associated with conglomeratic lenses and beds within the lower 500–600 m of the Uairén Formation

These placer deposits have been mined in several locations where the conglomerates presently lie within a few meters of dip-slope surfaces. Additional gold and diamond resources might be present within or immediately beneath lateritic ferricrete crusts developed on surfaces underlain by the Uairén Formation. Gold concentrations beneath the iron crusts of lateritic soils have been reported from Western Australia (Mann, 1984), from the Mato Grosso area of Brazil (Michel, 1987), and from Dondo Mobi, Gabon (Colin and Viellard, 1991).

These gold and diamond resources are generally widely scattered and probably limited in both grade and tonnage, and economic exploitation of these resources is generally limited to surface mining techniques. Therefore, the resources are, for the most part, probably best suited for exploration and exploitation by small independent operators.

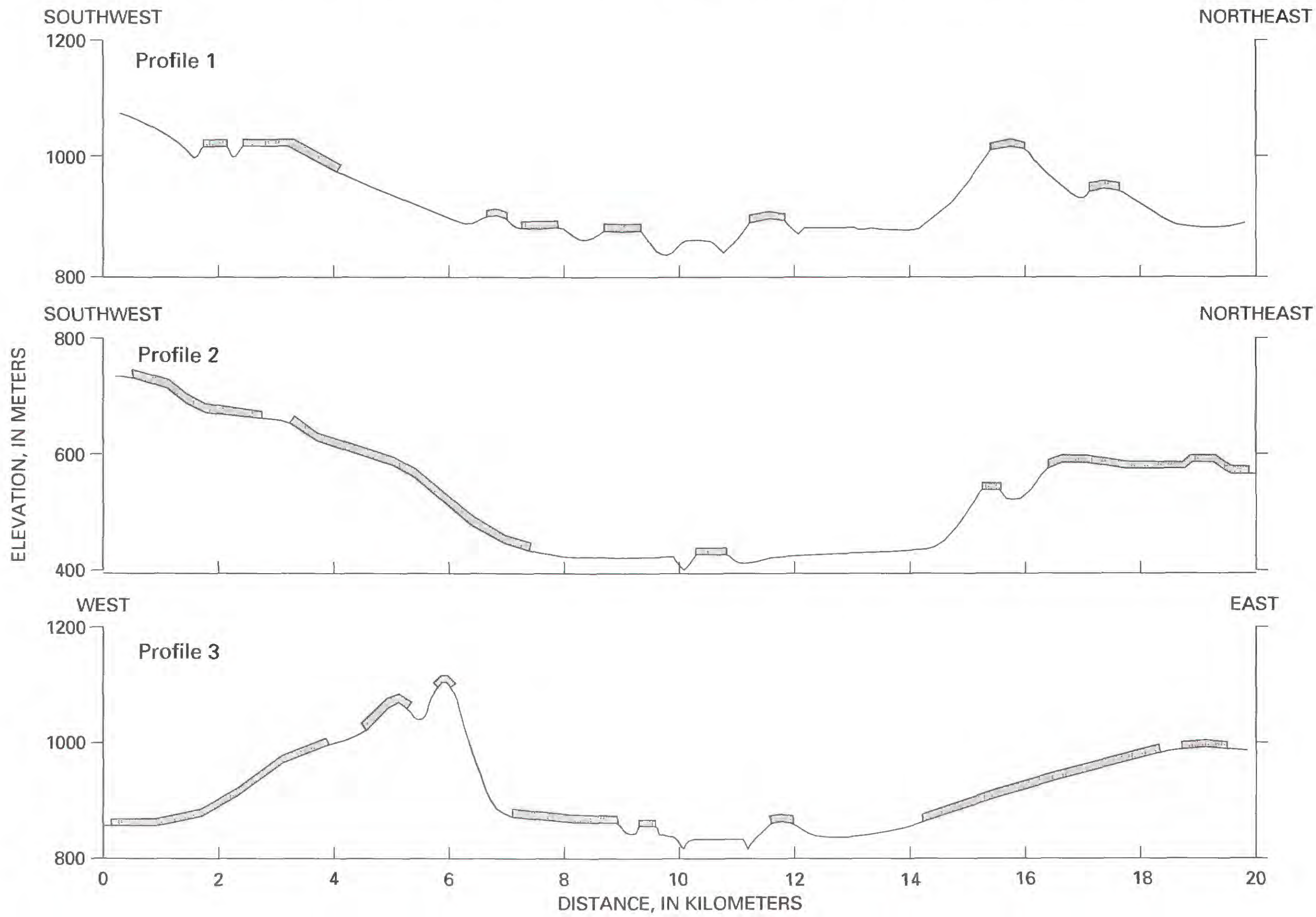

Figure 14. Topographic profiles across the valley of the Río Cuquenán showing the distribution of relict lateritic soils (shaded) capping the remnants of the middle Tertiary paleolandscape. Profile locations are shown in figure 7. Vertical exaggeration times 10.

PALEOPLACERS WITHIN THE LOWER PART OF THE RORAIMA GROUP

Gold and diamond paleoplacers are present at several different stratigraphic levels within the lower part of the Roraima Group. In northern Brazil, gold and diamonds are present within small conglomerate lenses approximately 160–210 m above the base of the local Roraima section near the summit of Serra Tepequem (approximately lat 3°47′ N., long 61°42′ W.) (Borges and D'Antona, 1988). In Venezuela, along the southern margin of the Gran Sabana, several mines are producing diamonds and (or) gold from conglomerate within the Uairén Formation. Four mines, apparently inactive at present, are between approximately 500 and 530 m elevation on the gentle dip slopes of low cuestas that rim the inner valley of the Río Icabarú in the vicinity of the town of Icabarú. Production from these mines was probably mainly from gravel lenses and beds that are within the same general stratigraphic horizon immediately beneath this dip-slope surface. Moreover, at least two gold and diamond prospects are in conglomerate and associated deeply leached sandstone near the axis and on the east-dipping flank of the Chiricayen anticline (near lat 4°50′ N., long 61°15′ W., and lat 4°42′ N., long 61°06′ W., respectively). At both prospects, the productive conglomeratic layers are at least 500–600 m above the base of the Uairén Formation.

PLACERS IN COLLUVIAL-ALLUVIAL DEPOSITS OF LOW-ORDER DRAINAGES

Six active gold and diamond placer mines are within headwater areas of tributary drainages of the Río Icabarú and the Río Cuquenán. Three of these mines are immediately south of the north-dipping cuesta ridge, underlain by lower Roraima Group rocks, that bounds the southern margin of the strike valley of the Río Icabarú (in the vicinity of lat 4°10′ N., long 61°12′ W.). The other three mines are in a similar geologic and geomorphic setting at the base of the scarp slope that defines the nose of the west-plunging syncline that underlies Paraitepuy (between lat 3°32′ and 3°39′ N. and long 61°25′ and 61°28′ W.). These mines are all underlain by lower Roraima rocks, and they are all within a few kilometers of the headwaters of low-order streams draining deeply dissected strata of the Uairén Formation. Production from these mines is derived from thin basal lenses of late Quaternary (Holocene?) pebble to cobble gravel that lie on or close to irregular bedrock surfaces. In addition, at least some production from two of these mines is derived from conglomerate lenses within the underlying, deeply weathered bedrock. Gold and diamond colluvial-alluvial prospects also occur near the axis of the north-northwest-plunging anticlinal nose of the Chiricayen anticline (within the drainage of Quebrada Nunque between lat 4°48′ and 4°52′ N. and long 61°15′ and 61°20′ W.). The gold and diamonds in these prospects are in basal colluvial-alluvial gravels of probable late Quaternary age that were likely derived from local conglomerates several hundred meters above the base of the Uairén Formation.

PLACERS IN MODERN CHANNELS OF THE LARGER STREAMS

Approximately 40 chupadoras (pontoon-mounted air-lift pumps) were present during 1989 on the Río Icabarú between Los Caribes and the confluence of the Río Icabarú and the Río Caroní, a distance along the river channel of about 140 km. These chupadoras are not uniformly distributed along the river channel; rather, they tend to be concentrated along limited reaches of the river. Most notably, about 60 percent were operating along a 30-km-long reach starting about 17 km downstream from Los Caribes and extending to the first major salto (waterfall), about 5.5 km downstream from the Río Hacha. About half of these were within 6 km of junctions with major tributaries. The reasons for this nonuniform distribution are not entirely clear. The distribution may indicate geologic and (or) fluvial geomorphic controls on the location of the richest channel placer or practical limitations of chupadora mining. It is probably significant, however, that almost all of these operations were within the region that is either underlain by or adjacent to uplands underlain by the lower part of the Roraima Group.

REFERENCES CITED

Borges, F.R., and D'Antona, R. de J.G., 1988, Geología e mineralizçoes da Serra Tepequém: Congreso Brasileiro de Geología, 35th, Belém, Pará, Brazil, Annals, v. 1, p. 155–163.

Briceño, H.O., and Schubert, Carlos, 1990, Geomorphology of the Gran Sabana, Guayana Shield, southeastern Venezuela: Geomorphology, v. 3, p. 125–141.

Colin, Fabrice, and Viellard, P., 1991, Behavior of gold in the lateritic equatorial environment—Weathering and surface dispersion of residual gold particles, at Dondo Mobi, Gabon: Applied Geochemistry, v. 6, p. 279–290.

Fritz, Bertrand, 1975, Etude thermodynamique et simulation des reactions entre mineraux et solutions, application a la geochimie des alterations et des eaux continentales: Universite de Strasbourg, Sciences Geologiques, Memoire, 41, 152 p.

Ghosh, S.K., 1985, Geology of the Roraima Group and its implications: Simposium Amazonico, 1st, Caracas, 1981, Publicación Especial 10, p. 31–50.

Hammen, Thomas van der, 1972, Changes in vegetation and climate in the Amazon Basin and surrounding areas during the Pleistocene: Geologie en Mijnbouw, v. 51, p. 641–643.

Howard, A.D., 1988, Introduction to cuesta landforms and sapping processes on the Colorado Plateau, *in* Howard, A.D., Kochel, R.C., and Holt, H.E., eds., Sapping features of the Colorado Plateau—A comparative planetary geology field guide: National Aeronautics and Space Administration Special Publication SP–491, p. 6–56.

James, P.E., 1959, The geomorphology of eastern Brazil as interpreted by Lester C. King: Geographical Reviews, v. 49, p. 240–246.

Kroonenberg, S.B., and Melitz, P.J., 1983, Summit levels, bedrock control, and the etchplain concept in the basement of Surinam: Geologie en Mijnbouw, v. 62, p. 389–399.

Laity, J.E., and Malin, M.C., 1985, Sapping processes and the development of theater-headed networks in the Colorado Plateau: Geological Society of America Bulletin, v. 96, p. 203–217.

Liu, Kam-biu, and Colinvaux, P.A., 1985, Forest changes in the Amazon Basin during the last glacial maximum: Nature, v. 318, p. 556–557.

Mann, A.W., 1984, Mobility of gold and silver in lateritic weathering profiles—Some observations from Western Australia: Economic Geology, v. 79, p. 38–49.

McConnell, R.B., 1968, Planation surfaces in Guyana: Geographical Journal, v. 134, p. 506–520.

Michel, D., 1987, Concentration of gold in in-situ laterites from Mato Grosso: Mineralium Deposita, v. 22, p. 185–189.

Nahon, D.B., 1986, Evolution of iron crusts in tropical landscapes, *in* Colman, S.M., and Dethier, D.P., eds., Rates of chemical weathering in rocks and minerals: Orlando, Florida, Academic Press, 603 p.

Nahon, D.B., and Lappartient, J.R., 1977, Time factor and geochemistry in iron crust genesis: Catena, v. 4, p. 249–254.

Reid, A.R., 1974, Stratigraphy of the type area of the Roraima Group, Venezuela: Conferencia Geológica Inter-Guayanas, 9th, Ciudad Guayana, Venezuela, 1972, Memoria, Publicación Especial 6, p. 343–353.

Schubert, Carlos, Briceño, H.O., and Fritz, Peter, 1986, Paleoenvironmental aspects of the Caroni-Paragua River basin (southeastern Venezuela): Interciencia, v. 11, no. 6, p. 278–289.

Short, K.C., and Steenken, W.F., 1962, A reconnaissance of the Guayana Shield from Guasipati to the Río Aro, Venezuela: Asociación Venezolana de Geología, Minería y Petroleo, Boletín Informativo, v. 5, no. 7, p. 189–221.

Yánez, Galo, 1984, Geology and geomorphology of the Roraima Group, southwestern Venezuela: West Lafayette, Indiana, Purdue University, Ph.D. dissertation, 145 p.

Zonneveld, J.I.S., 1982, Summit levels in Surinam: ITC Journal, 1982, p. 237–242.

———1985, Geomorphological notes on the continental border in the Guyanas (N. South America): Zeitshrift fur Geomorphologie, N.F., supplement band 54, p. 71–83.