ANTON DE KOM UNIVERSITEIT VAN SURINAME

FACULTEIT DER TECHNOLOGISCHE WETENSCHAPPEN

GEOWETENSCHAPPEN

The influence of Pleistocene climate change on the origin of the gold placers in Suriname

A thesis to complete the study of **Bachelor of Science** in Geosciences

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Approval

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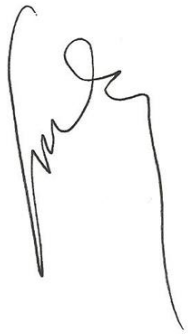

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Preface

To complete the bachelor's degree in Geosciences at the Anton de Kom University of Suriname, Faculty of Technological Sciences, scientific research must be carried out. In this context, the thesis entitled: The influence of Pleistocene climate change on the origin of gold placers in Suriname, is written.

A word of thanks goes out to everyone who in any way has given the necessary guidance and support to the realization of this graduation project. A special word of thanks goes out to my main supervisor Professor Kroonenberg, my co-supervisor Goenopawiro MSc, teacher R. Finkie MSc. I am also very grateful to my parents, relatives and friends for the necessary motivation and support during my study period.

Summary

Earlier publications done by De Haan, (1952); Grutterinck, (1952); Brinck, (1955); Krook, (1970); Aleva, (1979); Prance, (1979); Kroonenberg et al. (1983); Kieo-A-Sen et al. (2016), Kroonenberg et al. (2017), all indicate that the Guiana shield has undergone several climatic shifts which have altered the landscape and mineralization of the Guiana shield. At the end of this study the depositional climate and the origin of the gold placers on the hills and in creek-/riverbeds must be clarified. The depositional climate and the origin of the material atop of the gold placers will also be a focus of this study.

The Guiana shield has a stabilized tropical forest and humid climate, which complicates mineral exploration. To understand the surface dynamics of the Guiana Shield, the West African plateau with the Birimian greenstone belt is studied. West African shield and the Guiana shield are inextricably linked and share similarities in geology, geomorphology, and geochemistry. West African plateau, to be specific, Sub-Saharan West Africa has a semi-arid climate with scarce vegetation making mineral exploration and studying the surface dynamics of the plateau easier. Chardon et al. (2018) explains the formation of the pediments/glacis in West Africa and to compare the results from Chardon with pediments from Suriname, a field study is conducted. The area studied is Kriki Negie in Brokopondo, at the foot of the Brownsberg mountain and nearby the Koemboe creek. Exposed pediment surfaces known as kraskouw or mokololo are sampled and studied.

The results from the fieldwork and the literature available show correlation on pediment forming. The kraskouw layer which is, a colluvial weathered deposit, deposited by creep during a semi-arid period is what Chardon et al. (2016; 2018) describes as the lateritic pediments which lay atop the different pediments/glacis. At Kriki Negie this kraskouw layer overlies the gold bearing clay layer, and the kraskouw is also found in river terraces (Brinck, 1955). The kraskouw consist of chunks of laterite, clay and quartz cemented together. Kraskouw can also be found in river terraces (Brinck, 1955), but they do differ from them because of the rounded gravel found in the river terraces. The kraskouw is angular and a colluvial deposit, whilst the rounded gravel in the creeks is alluvially deposited by rivers or colluvially deposited on a riverbed but rounded by abrasion.

The kraskouw can contain gold, if the parent rock of the kraskouw contains gold mineralization. However, indication of gold in the kraskouw is no guarantee of gold occurrence in the layers below, as kraskouw is not an in-situ weathered material.

At Kriki Negie two kraskouw profiles, tailing material from a sluice box and gravel from an abandoned mine are sampled to determine the mercury levels. The mercury levels of the samples are erratic, caused by the composition of the samples. Higher concentration of quartz in a sample result in lower mercury levels than samples with higher concentration of laterite. The tailing from the sluice box, and the gravel of the abandoned mine do show elevated mercury levels, but the higher level of mercury does not directly indicate usage of mercury. The mercury values are influenced by the parent rock type and the weathering process. The mercury levels in the profiles cannot be used as background value to distinguish natural from polluted material as they have similar levels to tailings and sediments from small-scale gold mining areas (Kroonenberg et al., 2022).

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1 Introduction

Gold has been a major economic asset for Suriname for more than a century. The long history of gold mining, concentrated in large parts of a greenstone belt in the northeast of the country, began with small-scale artisanal extraction activities and has recently seen the development of major open-pit operations (Kioe-A-Sen et al., 2016)

Gold has a significant impact on the economy of Suriname since the early discovery of the metal in the 19th century. Most of the gold deposits are in the NW–SE-stretching Marowijne Greenstone Belt in the eastern part of Suriname. Gold found in Suriname formed during the Trans-Amazonian Orogeny, during 2.26 Ga and 1.98 Ga. The gold formed due to effects from seafloor spreading, subduction and continental collision between the Guiana shield and the West-African craton. The gold bearing NE Greenstone belt which then formed in Suriname, is found in the northeastern part of the ground mountain range, which also extends into French Guiana and northern Brazil. The map of the Guiana Shield shows that it also reappears in Western Suriname and then continues from there to Guyana and Northern Venezuela. It consists mainly of metamorphosed volcanic and sedimentary rocks, and furthermore of large intrusions of igneous rocks. The style of gold mineralization has been classified as syn- to late orogenic (Voicu et al., 2001; Daoust et al., 2011; Kioe-A-Sen et al., 2016).
Recent studies (Kioe-A-Sen et al., 2016) regarding gold exploration distinguishes two main areas with gold deposits. These are:

1. E-W direction, Rosebel, Nassau and Maripaston
2. NW- SE direction, Sara kreek, Lely Mountains and Benzdor

Currently, gold is being mined at various locations by small-scale operations as well as major companies. Large scale gold exploitation is done in mines with gold bearing quartz veins.
Small scale gold exploitation in Suriname is done in placers with dredging. The gravel in the river or creek beds bear gold. The gravel covering weathered material is not rounded, indicating that the material has not been transported over a long distance.

The focus of this research is to determine under which climatic conditions the gold placers formed in Suriname.

1.1 Problem Statement and Objectives

In Suriname gold placers are found in gravel deposits in the beddings of creeks or in sand/clay layers on slopes of a hill. The material laying directly above the gravel deposits is locally known as kraskouw or mokololo and are not rounded, indicating it to be close to the parent rock.

The gold bearing gravel deposits in the creeks are rounded, which indicates they have been transported over a certain distance. The gold placers on slopes are in clayish sand layers and are covered by colluvium locally also known as the kraskouw.

To understand the depositional environment we need to look at the different placer models, these are; washout, river, aeolian, beach, and continental shelf.

In Suriname we have cases of washout placers and river placers.

Washout placers (colluvial and alluvial) originate when weathering susceptible rock gets chemically and/or mechanically weathered and gets deposited on slopes or creek beddings due to erosion or debris flows. The river placer model indicates that sediments get deposited by different streams of a river or creek which sorts the transported sediment accordingly to size. A deep river with different streams can sort sediments to size as gravel, sand, and clay.

These models can explain the rounding of the gold bearing gravel deposits or the deposition on the slopes, however the current rivers and creeks do not possess such power to transport the heavy material, neither are erosion and debris flows a regular occurrence due to the current tropical climate with dense vegetation in Suriname.

<u>This study is focused on answering the following problem statement:</u>

To explain the difference between the current waterpower of the creeks compared to the heavy gravel-gold deposits in the creeks, the depositional climate for these sediments is required.

Main research questions:

1. What type of climate contributed to the transport and rounding of the gold bearing gravel deposits?
2. What is the origin of the gold bearing deposits?

Sub research questions:

1. Is the ‘kraskouw’ a gold bearing deposit?
2. What are the mercury levels of the colluvial material covering the gold bearing deposits?

The main objective of this study is:

To confirm what type of climate had a main role in weathering and transporting gold bearing gravel on slopes as in creek beddings and whether the kraskouw is gold bearing.

2. Geology of Suriname

2.1 Marowijne Greenstone Belt

Gold found in Suriname was formed during Trans-Amazonian Orogeny, between 2.26 Ga and 1.98 Ga, due to seafloor spreading, subduction and continental collision between the Guiana shield and the West African craton (Gibbs & Barron, 1993; Kroonenberg et al., 2016). Gold in Suriname occurs in the Greenstone belt which has an NW-SE direction.

The Marowijne Greenstone Belt in the northeast, is now considered to be the oldest rock unit of Suriname, with an age between 2.18-2.08 Ga (billion years) (Kroonenberg et al., 2016). It is also the main gold bearing area, as is evident from the map of the main gold concessions (figure 2.1 Gonini.org, 2020).

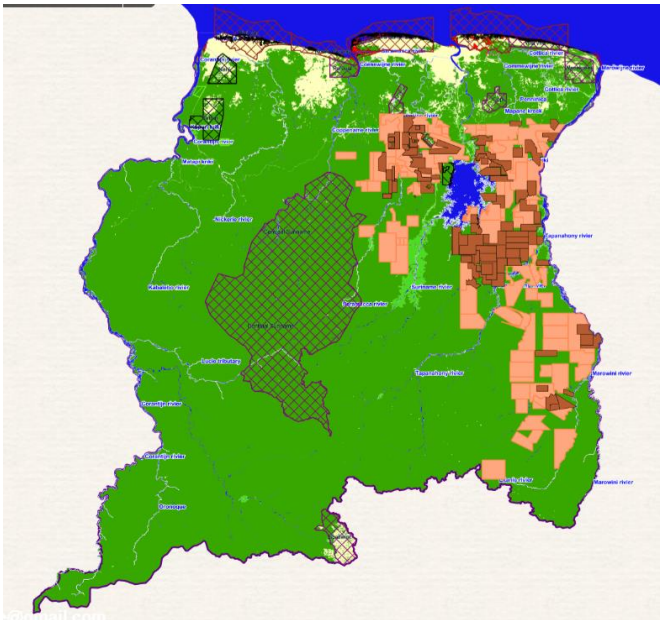

Figure 2.1 Location of gold exploration (orange) and exploitation (brown) concessions. Gonini.org.

Kroonenberg et al. (2016) described that the base of the Marowijne Greenstone Belt (figure 2.2) consists of three formations. These are the Paramaka formation at the base of the greenstone belt, the Armina formation deposited on the Paramaka formation and to the top of the greenstone belt is the Rosebel formation.

Kroonenberg et al. (2016) describes the three formations as following.

The Paramaka formation consists of a series of basaltic lavas, andesites, volcaniclastic and chemical sediments. It is intruded by ultramafic and tonalitic bodies.

The Armina formation consists of a series of turbiditic greywackes and phyllites, which in turn is intruded by a series of bi-mica and other granites, mainly in the extreme northeast.

The Rosebel formation is a sequence of sandstones and conglomerates deposited by rivers. All these rocks have been metamorphosed under greenstone or amphibolite facies conditions.

Even though such a sequence of greenstone rock would be characteristic for a gold-bearing belt, none of these formations are the primary source of gold. Mineralization is hosted in undeformed veins in which native gold mostly occurs as free grains. At first glance, the deposits of the Rosebel gold district appear to show many characteristics of orogenic gold systems (Kroonenberg et al., 2016).

Daoust et al. (2011) concluded that the characteristics of orogenic gold system such as having metamorphic grade volcanic sediments and gold mineralization in sulfide-bearing-quartz-carbonate veins are not limited to the Rosebel formation only, as these characteristics occur in deposits, such as Las Cristinas in Venezuela, Omai in Guyana (Voicu et al., 2001; Kroonenberg et al., 2016) and St-Elie in French Guiana. The structures most affected by the Trans Amazonian Orogeny is where the deposits as aforementioned can be found (Voicu et al., 2001).

Large scale gold mining in Suriname is done in quartz veins and shear zones which intersect these formations. As these are intrusions, they are younger than all the three formations of the Marowijne Greenstone Belt. Due to these gold bearing intrusions, the prospection for gold is not easy. The larger mines in Suriname are also the mines that were prospected in the 19th century.
A case can be made for Paramaka formation as the deep source of the gold, because if the Paramaka formation is absent, usually no gold is found (Kieo-A-Sen et al., 2016; Kroonenberg et al., 2016)
The erratic spatial distribution of gold mineralization means, that there is no straightforward relation to be expected between mercury content of the three main formations and gold mineralization. Where gold mineralization is present, there is indeed often also evidence of mercury, because both elements usually have been mobilized together by hydrothermal fluids in the mineralized veins and shear zone.
Another problem is that the weathered overburden that is usually prospected by artisanal gold miners is not necessarily the product of the weathering of the directly underlying solid rock. Often, they find gravel or quartz blocks in their profiles, indicating that their deposit has suffered colluvial slope movements such as creep, or even transport by creeks of rivers, in the case of rounded gravel (Brinck, 1955). Slope movements and river processes were probably much more active during semi-arid periods with savanna vegetation in the Pleistocene.

Formation	Rock type	Age (1 Ga=10^9y)
Gran Rio Granite	Biotite granite	2.09 Ga
Pikien Rio Pyroxene Granite	Pyroxene granite	2.10 Ga
Rosebel Formation	Qz sandstones, conglomerates	2.12 Ga
Patamacca Granite	Two-mica granite	2.12 Ga
Taffra Schist	Staurolite schists	
Armina Formation	Metagreywackes, phyllites	<2.16 Ga
Sara's Lust Gneiss	Migmatitic gneisses	2.15-2.08 Ga
Kabel Tonalite	TTG -Tonalite, trondhjemite, granodiorite	2.18-2.12 Ga
Paramaka Formation	Phyllite, metachert, gondite	
Paramaka Formation	Metaqzandesite etc	2.14-2.15 Ga
Bemau Ultramafitite	(Meta)gabbro, MetaUltramafite	2.14 Ga
Paramaka Formation	Metabasalt	
Paramaka Formation	Amphibolite	

Figure 2.2 A concise stratigraphy of the Marowijne Greenstone Belt (Kroonenberg et al., 2016)

According to previous exploration studies by Brinck (1955) three areas can be distinguished with gold occurrences, an E-W area from the Marowijne river to the Saramacca river (Nassau, Rosebel, Mindrinetti area), an NW-SE area with the Sara creek and Upper Gran creek and the Drietabbetjekreek and Oelemari area. Current gold exploitation shows two major areas with gold occurrences (figure 2.3), an E-W tendency (Rosebel, Nassau and Maripaston) and an NW-SE scope (Sara creek, Lely Mountains and Benzdorp) (Kioe-A-Sen et al., 2016).

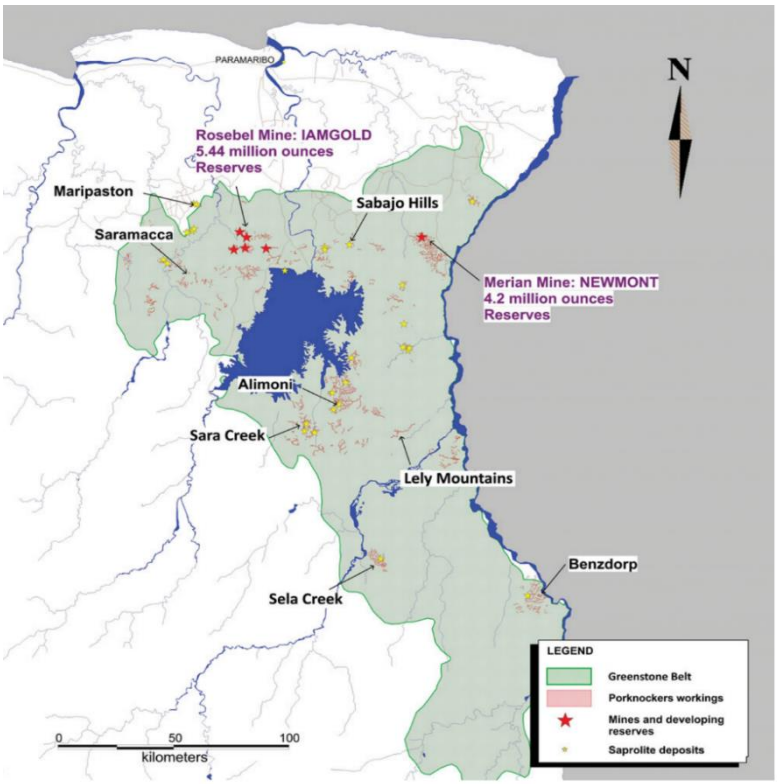

Figure 2.3 Main gold occurrences in the greenstone belt (Kioe-A-Sen et al, 2016)

2.2 Placer models

To understand the deposition of the gold placers, the model for the different placers is required. There are 6 different placer models in sedimentary deposits namely, washout, river, aeolian, beach, dune, and continental shelf (Stanaway, 2012).

Washout placers

Colluvial and eluvial placers

Stanaway (2012) concludes that these placers originate close to the locations of chemical and mechanical weathering, as well as the washout of weathering-resistant components of rock. The washout of minerals downslope happens in form of Clays, oxides, talus, and solutes. Resistant minerals congregate in the talus downslope or in lag deposits.

Colluvial placers occur on scoured and erosional slopes and can change into sheetwash and alluvial placers as they descend the slope as seen in figure 2.4.

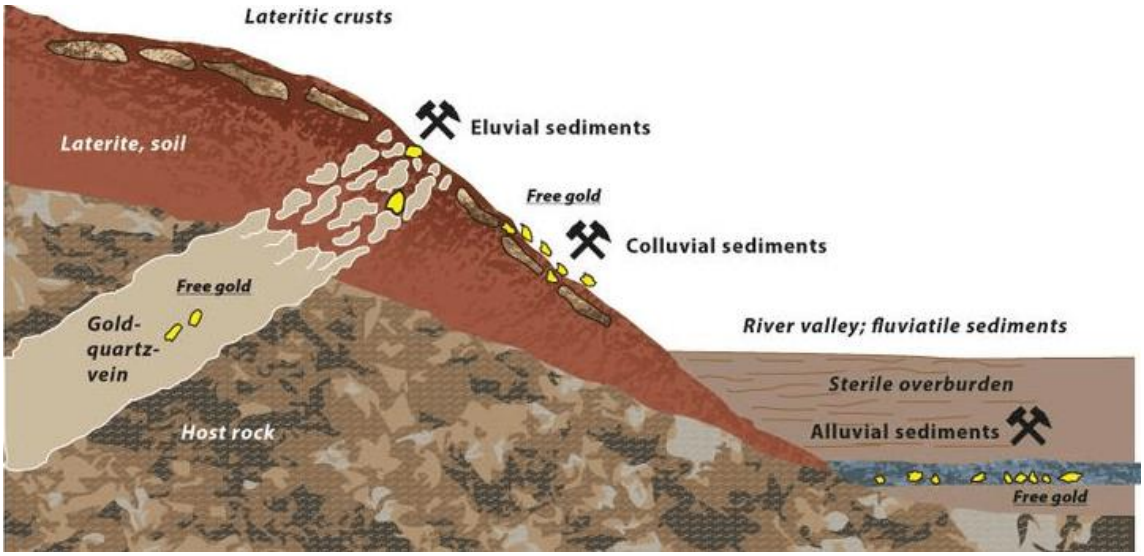

Figure 2.4 A representation of how different gold placers can originate from the same parent rock

Sheetwash and debris flow placers

Sheetwash placers are accumulations of sediment that obtain their valuable minerals from a weathered rock in the surrounding area. The combination of heavy precipitation and a lack of vegetation can lead to flash floods, debris, and mud flows, which deposit sediment that has not been properly sorted into drainage depressions. These processes can operate on either higher gradient alluvial fans or lower gradient peneplain surfaces, both of which have been subjected to extensive chemical weathering (Stanaway, 2012). Some of the contributing factors that lead to sheetwash placers are as follows:

- concentration of the mineral in a weathered rock
- liberation of certain mineral as result of weathering
- preferential entrainment of hydrolysate clays and silt fines in the suspended load of the stream flood or debris flow
- lag of larger clasts of weathered rocks

Regions where a constant shift of climate such as a semi-arid climate to a humid climate is where sheetwash and debris flow placer for. The chemical weathering occurs in a humid climate with stabilized tropical forest and the mechanical weathering, erosion, debris flows occur in a semi-arid period with scare vegetation. The flow initially deposits coarse clasts, then selectively transports sand along with the mud, deposits the sand and finally allowing the mud to flow away by itself (this all occurs as one operation) (Stanaway, 2012).

River placers

River denudation placers

Erosion of riverbeds and incision therefore form denudation placers. Minerals that cannot be transport by waterpower, or lack thereof, get deposited in these scour surfaces. Lag gravel, coarse sand and heavy minerals outline the scours. River denudation placers have two categories, the bottom placers, and the above-bottom placers. Bottom placers are denudation placers formed on

the bedrock and above-bottom placers are denudation placers that form in a scour surface already sedimented with alluvium form earlier deposits. Because the heaviest minerals get deposited first, the source of denudation placer is closer than of river accumulation placers (Stanaway, 2012).

River accumulation placers

Rivers with different flow regimes deposit different minerals at different times. As previously mentioned, heavy minerals deposit first followed by, gravel, sand, and clay. Density of the minerals and sediments has the most influence in river accumulation placers. The deposited sediments in an accumulation placer are not transported in later stages. These forms fining upwards sequences of sands downstream. Accumulation placers can be found on the inside bend of a river or creek (Stanaway, 2012).

Aeolian placers

Deflation placers

On beaches earlier flows by rivers deposit sediments. These beaches consisting of sand, pebbles and mineral deposits get eroded, not by waterflow but by strong winds. Sediments with lower specific gravity such as fine sand grains get transported away from the beach leaving only heavy and dense pebbles and gemstones. Due to the entrainment of finer sands by the wind, mineral rich placers can form on a beach (Stanaway, 2012).

Beach placer

Transgressional beach placers (denudational)

Beaches derive their deposits from shorefaces/cliffs or rivers. In a transgressional period, the erosion from the sea is land inwards on a beach. Tidal changes cause rework of the beach. Waves advancing towards land deposit heavy and lighter sediments whilst waves retreating from the beach entrain lighter sediments. The constant reworking of the beach results in only heavy minerals/sediments on the beach (Stanaway, 2012).

Regressional beach placers (accumulational)

Regressional beach placers form when the sea retreats and deltas form. The erosion of the beach is away from the land and reworking of these beach ridges are uncommon. Unlike transgressional beach placers which get their minerals from denudation, regressional beach placers get their minerals through accumulation. The economic grades of minerals of such placers are low and requires temporary marine transgression to get higher mineral grades (Stanaway, 2012).

Continental shelf placers

Transgressive lag placers

Transgressive lag placers are denudational, and form in easily eroded intra-cratonic basins and on continental passive margins with negligible new sediment supply. Higher sea-levels during a transgressional period entrain lighter sediments leaving only heavier sediments behind in the scour surfaces.

The lighter sediments go in three directions: towards land, along the coast and offshore. (Stanaway, 2012).

Subsiding shelf placers

Subsiding shelf placers occur in cratonic basins or passive continental margins and result from an abundant fine sediment supply via coastal and offshore marine erosion. Subsidizing shelf placers form at depths below fair-weather wave base and above storm wave base. Fairweather wave base refers to the depth beneath the average daily waves while storm wave base refers to the depth beneath storm driven waves and is often much deeper. During storms the waves going towards land are stronger than normal waves. The regression of the waves from the land entrain fine sand which can contain minerals. The cycle of storm induced waves and normal waves causes the deposition in the scour surfaces (Stanaway, 2012).

Dune placers

The sediments entrained by the wind and blown away from the beach create dune placers. The winds entrained sediments pile dunes against water or land barriers, such as lagoons, swamps, steep hillsides, or fault scarps. Dune placers form in the near vicinity of the beach placers. Tropical/humid vegetation can grow on these dunes and reworking of the dunes get halted. Strong winds entrained sediments can contain minerals of economic value if the beach where the sediments “originate” from are mineralized.

3. Methods, techniques, and analysis

3.1 Literature survey to compare Guiana Shield with African greenstone belts in dry climate

This study is literature focused and aims to understand the similarities between the Guiana shield and the West African plateau. The current gold colluvial and alluvial deposits are not possible under current climatic influences. Therefore, this study focuses on the West African shield, as it is geologically like the Guiana shield and the climatic conditions differ from the climate in the Guiana shield (dry climate vs humid climate). The area studied is Kriki Negie and the colluvium atop of the gold bearing clay layers is sampled for analysis.

Small-scale gold mining in Suriname is done in gold placers by dredging and hydraulicking.

The gold is found, among other things, in gravel layers that are covered with colluvium or alluvium material. These gold-bearing gravel layers in the creeks, rivers and river terraces are alluvially deposited (Brinck, 1955). The gold in these gravel layers is only partly alluvially deposited, for the most part it is colluvial, so the gold is not transported far from its parent rock in the quartz veins (Brinck, 1955). Gold exploitation is done in deposits on gentle slopes on either side of the creeks. These deposits occur explicitly at the foot of laterite plateaus. Local colluvial deposits on the slopes of the mountains are gold-bearing and possess concentration at a uniform level. In some places the colluvial deposits cover the terrace deposits (Brinck, 1955). One of the colluvial deposits is the "kraskouw". The kraskouw layer is above the gravel layer and is a product of lateritic weathering. The kraskouw is formed when iron particles in clay concentrate with the result that the clay hardens.

This Kraskouw layer occurs in colluvial and alluvial clays above the water table. Kraskouw does not occur in lateritic weathering profiles of consolidated rocks (Brinck, 1955). The Kraskouw can contain quartz particles with gold and the gravel layer under the Kraskouw usually has quartz blocks which can contain concentrated gold. The Kraskouw may be an indication of gold-bearing layers on the slopes.

3.2 Fieldwork, sampling, and analytical methods

Krikie Negie in Brokopondo is the area where fieldwork was carried out. This area lies as the foot of the Brownsberg mountain. The sampling was done on the regolith focusing on soft weathered colluvial deposits. Because of the strong tendency of Hg to form complexes with organic matter in the soil, it often concentrates in the upper soil horizons, especially in forest soils and peaty soils. The focus of the sampling is the colluvial material on slopes. Local goldminers have exposed pediments consisting of laterized colluvial deposits knows as kraskouw which lay atop the gold bearing clay layer. The sampling will be done on these recently excavated kraskouw deposits to determine the Hg levels. Method of sampling:

- Localizing freshly excavated kraskouw deposits
- Sampling the profiles from soil to bottom every 80-120 cm (5 samples)
- Sampling material from the tailing of a sluice box for reference

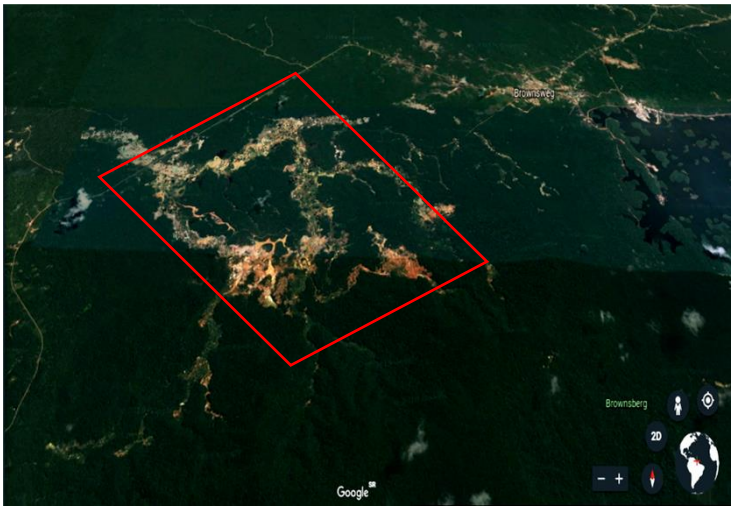

Figure 3.1 Satelite view of Krikie Negie.

Figure 3.2 Krikie Negie mining area

Figure 3.3 Field sampling on Kraskouw profile A & B

Figure 3.4 Material from the sluice box at kriki negie is sampled as well

3.3 Laboratory analysis

The samples are sent to FILAB in Suriname. FILAB in Suriname uses oxydative digestion + AAS cold vapor (FIMS 100) with a detection limit of 1 ppb. The samples are first crushed then dried to 40 degrees Celsius. Atomic Absorption Spectrometry (AAS) determines the quantities by “measuring the absorbed radiation by the chemical element of interest”. This is done by reading the spectra produced when the sample is excited by radiation. Cold Vapor AAS instruments have a peristaltic pump that transports sample and stannous chloride into a Gas Liquid Separator (GLS) where a stream of pure, dry gas (typically argon) is introduced to the liquid mixture to release mercury vapor. Gas carries the mercury in the vapor phase through a dryer and into an atomic absorption optical cell. Once in the absorption cell, the elemental mercury will absorb light at 253.7 nm in logarithmic proportion to its actual concentration in the sample. Using this principle, the detector, in combination with the software, can determine the quantity of mercury present in the samples (Teledyne leeman labs, 2016)

4 The impact of climate change on gold placers in Suriname

4.1. literature survey about climatic influences in comparison with Africa

The Guiana shield consists of lateritic and bauxitic surfaces which shape the landscape. These surfaces can contain mineralization of iron and aluminium. Theveniaut and Freyssinet (2002) suggest weathering episodes at 50–60 Ma (Bakhuis Mountains, Suriname; Kaw mountain, French Guiana) and around 10 Ma in the Guiana Shield (Moengo bauxite deposit, Suriname; Kaw mountain).

The distribution of data (Ansart et al., 2022), on the other hand, suggests that there were four major weathering episodes during the Cenozoic 1) a lateralization event at approximately 35 Ma; 2) a bauxitization episode older than 15 Ma but with no more precise constraints; 3) a lateralization event at approximately 15–20 Ma; and 4) a bauxitization event (6–2 Ma). A model for landscape evolution and relief inversion is seen in figure 4.1.

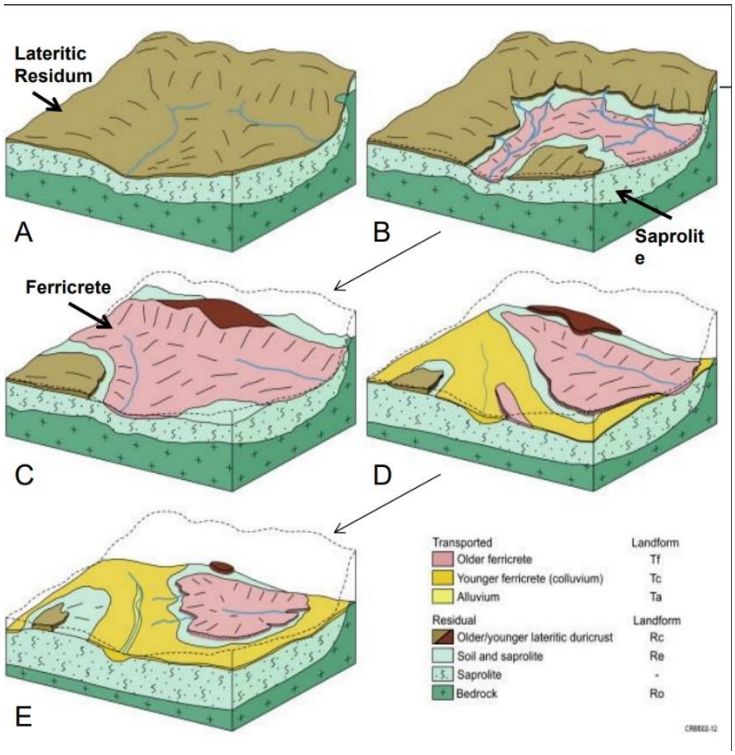

Figure 4.1. Model for landscape evolution and relief inversion. An initial, largely residual, lateritic -bauxitic surface in A is successively eroded and reweathered (B –E). The later, relatively lower surfaces are dominantly depositional, cemented by Fe oxides to form ferricrete (Butt & Bristow, 2012)

The Guiana shield is covered by a tropical forest which complicates the exploitation of minerals. The Guiana shield and the West African plateau lay together 2.00 Ga during the supercontinent Gondwana, and these two plateaus have similar greenstone belts composed of metamorphosed volcanic and sedimentary rocks. During the supercontinent Gondwana the greenstone belts stretched from northeastern South America to modern-day Mali and Nigeria. The exploration for minerals in Sub Saharan West Africa is easier than in the Guiana shield because the climate is dry. The Birimian greenstone belts of West Africa host large amount of gold. The Guiana shield shares

the large potential of gold mineralization, but the tropical forest serves as an obstacle for exploration. To grasp the surface dynamics a semi-arid period had on the Guiana shield, the West African plateau can be studied because the dry climate has exposed the surface dynamics in West Africa (Goldfarb et al., 2017).

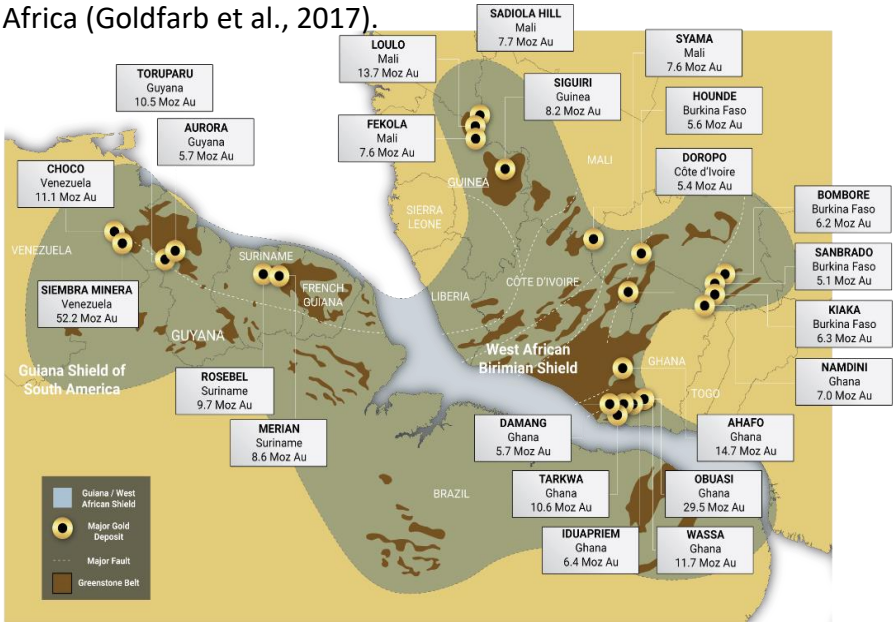

Figure 4.2 The major gold deposits in the greenstone belt of the Guiana Shield and West African Plateau (Goldfarb et al., 2017)

Regolith, which is a result of rock weathering, covers large portions of the West African and Guiana shield. The regolith which burdens fresh parent rock can act as a filter for concentration of metals such as Fe, Al, Ni, Cu, Au, or Mn. These mineralizations are characterized as lateritic ore deposits (Valeton, 1994; Freyssinet et al., 2005; Scott and Pain, 2008; Chardon et al., 2018).

The West African surface which is mostly consisting of a bauxite or laterite surface is formed due to long periods of intense chemical and mechanical weathering during climate shifts. In a humid period, deep chemical weathering is intense but due to dense vegetation the material cannot be displaced. In a semi-arid period, the vegetation is scarce and mechanical weathering is intense due to slope movements and heavy erosion. The shifts of climate in the Cenozoic period are what have shaped the West African surface. During a semi-arid climate, the bauxitic and lateritic surfaces got dissected and pediments/glacis with various levels were formed (King, 1948; ; Millot, 1970; Boulangé and Millot, 1988; Valeton, 1991; Colin & Vieillard, 1991; Chardon et al., 2006; Chardon et al., 2016; Chardon et al., 2018)

The pediments/glacis formed are considered as gently inclined slopes of transportation and/or erosion that cut bedrock and/or regolith and connect eroding slopes to areas of sediment deposition or alluvial transportation at lower levels (Oberlander, 1997; Chardon et al., 2018).
The physical and chemical processes that work together to form pediments are called pedimentation. The glacis which dissected the landscape transport sediments from the hills towards the rivers and creeks. The glacis play an important role in the sedimentation transport from erosional slope movements. Pediments can complicate mineral exploration because they also transport regolith which burden the earlier deposited sediments consisting of liberated minerals. At first glance the regolith looks as an in-situ weathered product but is a colluvial deposit (Payne, 1969; Pease, 2015; Chardon et al., 2018)
The pediments/glacis of West Africa (figure 4.3) can be grouped in three categories: The High, Middle and Low glacis. These pediments mark the last main dissection stages of the African Surface (Chardon et al., 2018). The landscape above the pediment/glacis but below the bauxitic surface is defined as an intermediate surface which is weathered bauxite or laterite and preserved on the parent rock by Valeton (1991) and Chardon, et al. (2018). Chardon et al. (2018) analyzing the pediments/glacis, concludes that each glacis level has undergone duricrusting and/or lateritic weathering after its formations. The successive shifts from pedimentation to duricrusting/lateritic weathering is an indication of climatic shifts from a semi-arid climate to a humid climate. The formation of a pediment took during a semi-arid period and the duricrusting of the pediment took place towards the end of a humid period (Beauvais and Chardon, 2013; Chardon et al., 2018).

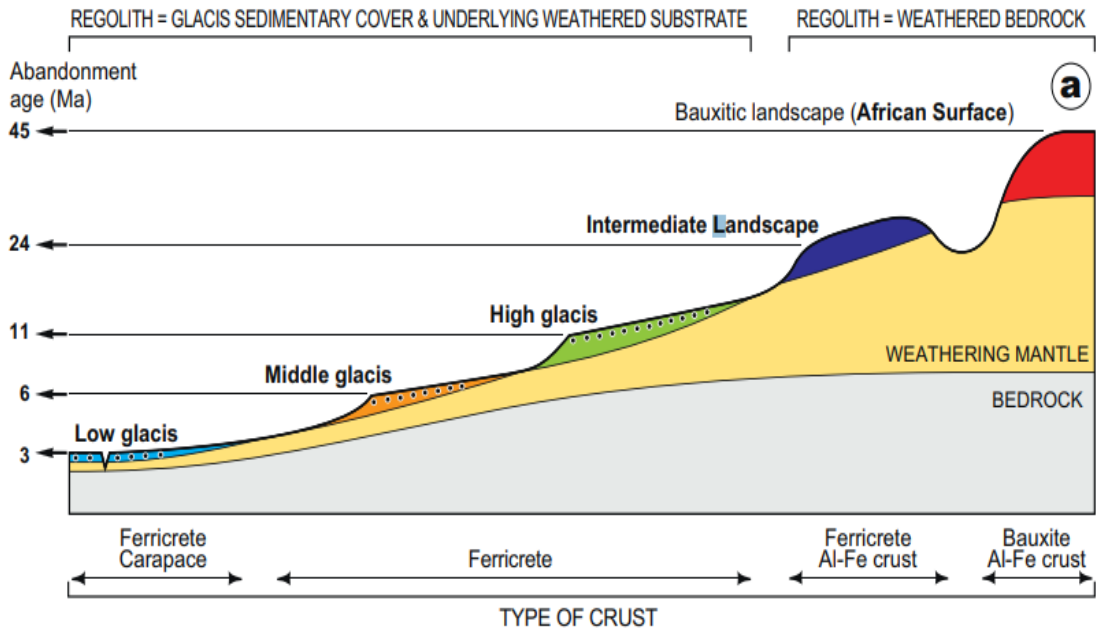

Figure 4.3 Synthetic representation of the West African landform-regolith sequence (Chardon et.al.,2018)

Chardon et al. (2018) explains that due to the duricrusting of the glacis towards the end of a humid climate, the duricrusted glacis did not completely get eroded downslope during the following semi-arid period to create a new glacis sytem. Pedimentation and duricrusting happened multiple times in the Cenozoic period and the stepwise glacis attest that (figure 4.3 and figure 4.3). Each glacis system/generation is influenced differently due to the amount of erosion and level of duricrusting of the previous glacis generation (Chardon et al., 2018)
The glacis in West-Africa are made of greenstone belt material and can contain gold mineralization.

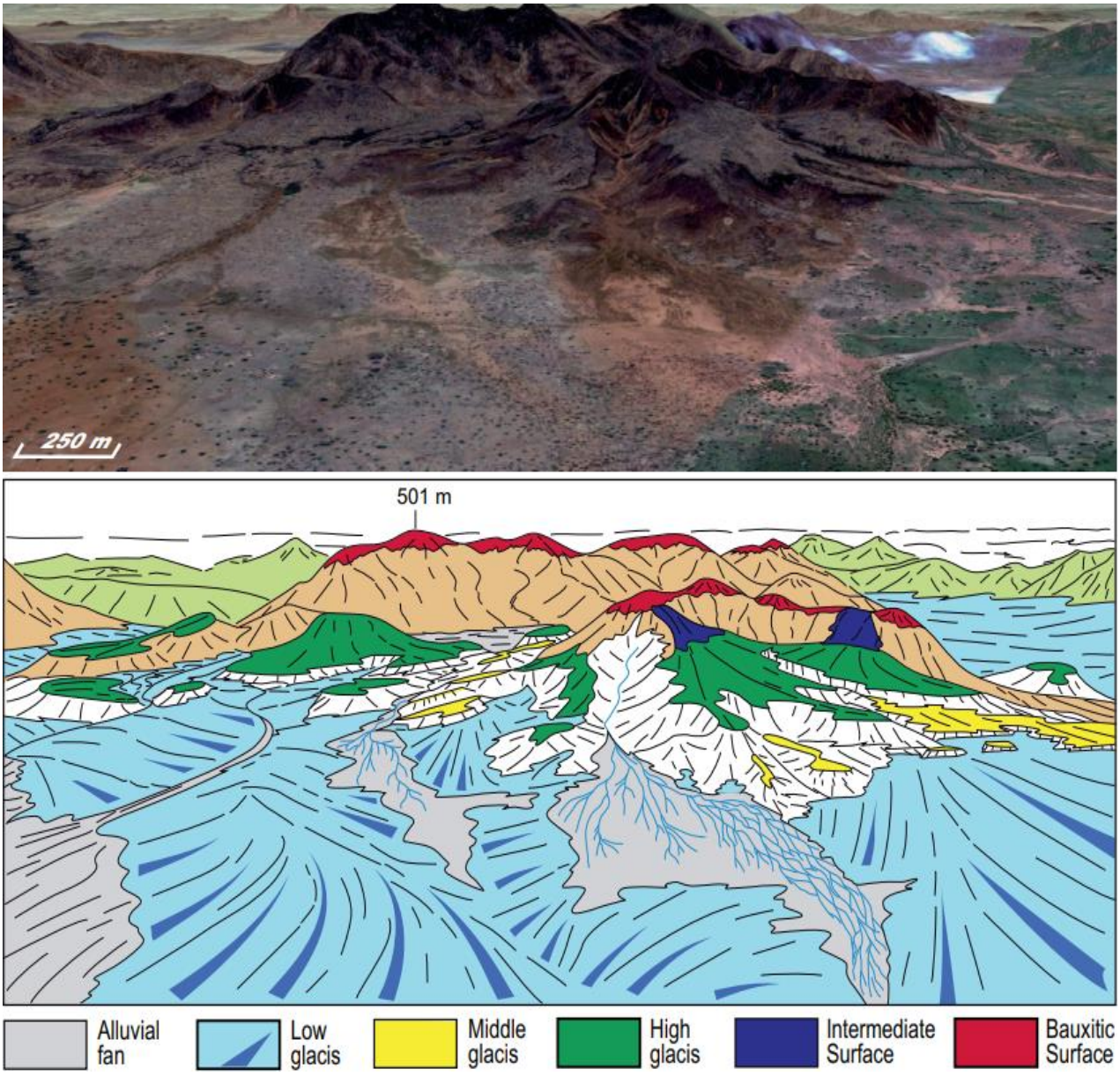

Fig 4.4 Remnants of the West African morphoclimatic sequence as exposed in the Goren greenstone belt near Kaya, Central Burkina Faso

In the north and east of Suriname, the highest points are plateaus topped with laterite or bauxite. These plateaus usually reach 500 to 650 m. Nassau Mountains (500–550 m), Lely Mountains (600–650 m), Browns Mountain (500 m), Brokolonko Mountains (500 m), and Bakhuis Mountains (400–450 m) are some of the most well-known (Aleva, 1979; Kroonenberg et al., 1983; Kroonenberg et al., 2017). The weathering periods after the formation of the planation surfaces (figure 4.5) did not add much to the thickness or composition of the duricrusts that were already there. During these periods, a lot of bauxitization probably only happened on the slopes of the Bakhuis Mountains plateau hills. The primary saprolitic weathering of the planation surfaces developed during the Late Tertiary I and II phases and the Plio-Pleistocene phase, show successively weaker profile developments, with only some weakly plinthitic soil development on the last or subrecent surface (Kroonenberg et al., 1983; Kroonenberg et al., 2017). The planation surfaces which Aleva (1979) refers to are the same as the bauxitic surface in figure 4.3 and figure 4.4.

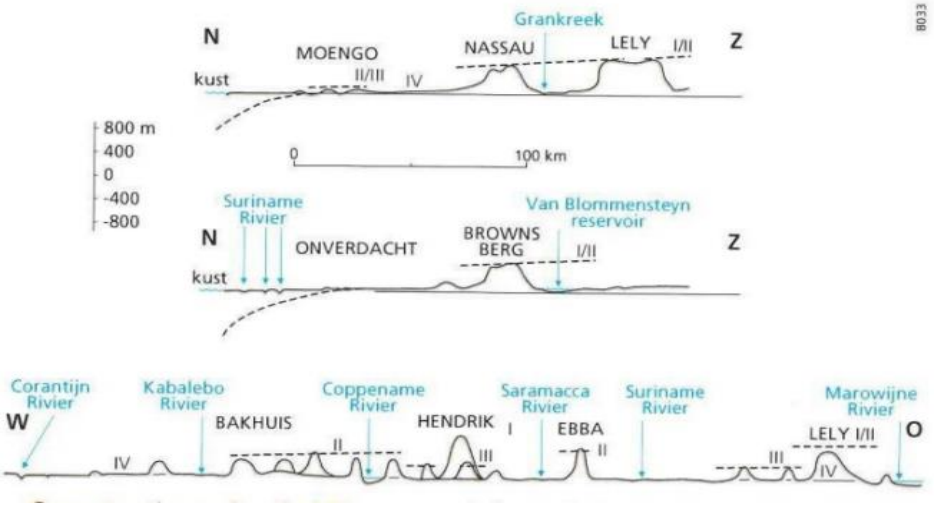

Fig 4.5 Illustration of the planation surfaces of Suriname

Kroonenberg et al. (1983; 2017), Krook (1970, 1979) advocated a similar model to Chardon (2018) in Suriname which is controlled by climatic change. A semi-arid period with scarce vegetation contributed to erosion, formation of pediments by sheetwash, formation of braided rivers and transport of coarse-grained sediments to the sea. Kroonenberg et al. (1983) and Krook (1970) refer to this as stripping of the saprolite. In a humid period, dense vegetation returns and deep weathering along with incision of riverbeds and planation levels take place. Leaching of minerals of the parent rock during a humid period created bauxitic or lateritic crust which protect the earlier deposited sediments. This cyclic nature of climate shift is what Kroonenberg et al. (1983) refers to as the reason different summit levels formed. Kroonenberg et al. (1983) continues by saying that the rise of the different summit levels is dependent on the resistance of the underlying rocks to deep weathering. This is known as the etching and stripping concept of Kroonenberg et al., (1983) which share a lot of similarities with Chardon et al. (2018)

4.2. Field and laboratory data

Krook (1970), Kroonenberg et al. (1983; 2017), Chardon et al. (2018) all address the cyclic nature of climate shifts the Guiana shield and West African shield have experienced. These climatic changes with their respective weathering periods have been vital to the current landscape we see in the Guiana shield and the west African plateau. The difference between these two plateaus is only the current weathering front, dense/scarce vegetation, and climate. The west African plateau of now is what the Guiana shield looked like in a semi-arid period, as the Pleistocene. The result of these climatic changes is the gold placer deposits on these two shields.

Between 1875 and 1940, Suriname produced 40-ton gold (Grutterinck, 1950) which was mostly found in washout placers and river placers. These placers in the valleys of rivers and creek beds were covered by gravel atop of a soft clayish layer. The gravel layer (figure 4.6) contained angular pieces of quartz and hardened clay what Brinck (1955) refers to as the Kraskouw or mokololo by the natives of the surrounding areas.

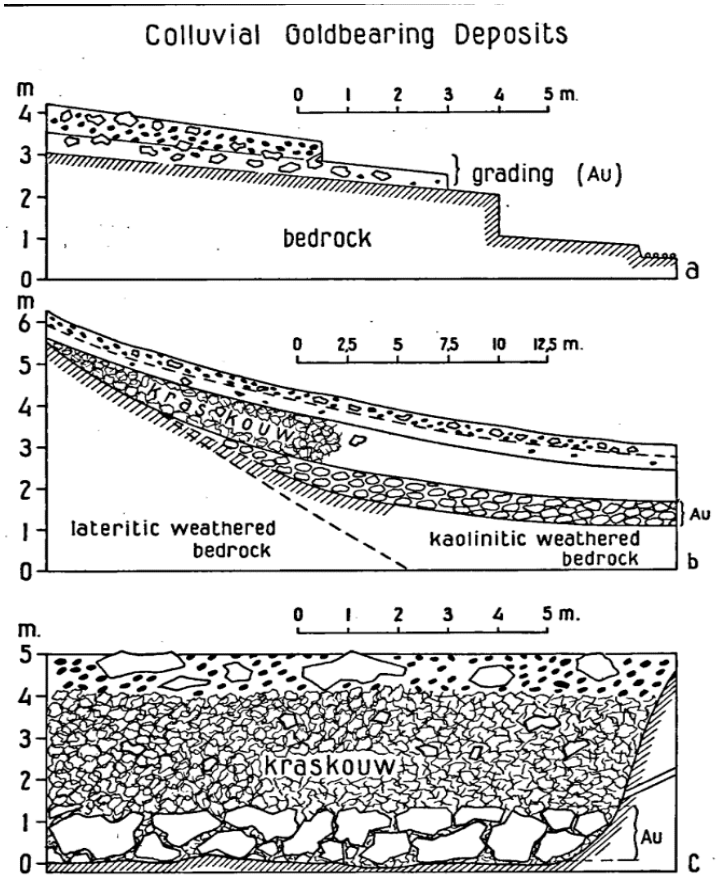

Figure 4.6 Brinck (1955) The formation of the kraskouw layer

In Suriname there are washout placers and river placers. Washout colluvial and alluvial placers form when weathering-resistant rocks undergo mechanical, chemical weathering, and erosion. These deposits occur in Suriname near river terraces and rivers. (Dahlberg, 1984; De Vletter & Hakstege, 1998). Sheetwash and debris flow placers are sediment deposits whose minerals come from a weathered rock. In dry climates with little vegetation, high precipitation can cause debris flows and mudslides. Areas that have a dry climate alternating with a tropical climate are favorable for sheetwash placers. These placer deposits depend on the amount of concentration of a mineral in a parent rock, the amount of weathering needed to release the mineral from the parent rock, the amount of clay and silt in the flow and the number of clasts in the flow.
Gold occurs alluvium or colluvium in the creeks and rivers, or as colluvium on slopes. These placer models are present in the current tropical climate, but the tropical climate is not the sole cause for the forming of these. In the current tropical climate weathering is possible, but its erosion to slopes and rivers is less common, because of the dense vegetation on the hills.
Grutterinck (1950) and De Haan (1952) discuss the possibility for the deposition of the colluvium material along the slopes. These are created by creep over long periods, under arid conditions. During the arid conditions the physical weathering of the rock material was more intense. Due to a savannah vegetation in the arid climate, eventual rain showers resulted in debris flow along the slopes of hills. The eroding material from the hills settled along the hills and in the creek beds. The source of the gold in colluvial as well as alluvial deposits can be traced back to weathered and transported rock that contained a quartz intrusion enriched with gold illustrated in figure 3.2.

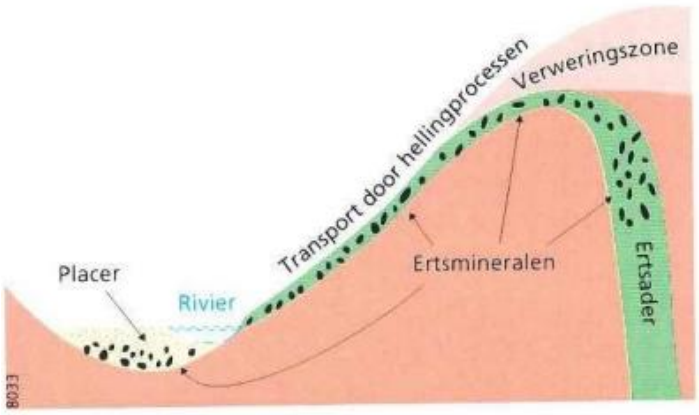

Figure 4.7 Formation of placer deposits

At Kriki Negie in district Brokopondo, the local population mines gold at the foot of the Brownsberg plateau. The mining is done in yellowish clay layers which have quartz veins (figure 4.8 and figure 4.9). This yellowish clay layer is overlain by a lateritic 'kraskouw' layer known as mokololo by the locals. The kraskouw consists of a mixture of quartz, laterite, and yellow clay, all cemented together. That is exactly the situation Chardon et al. (2018) describes in West Africa as duricrust pediments that consist of Iron oxy-hydroxide-cemented clastic sediments that were once transported in a dry climate along a gentle slope and later cemented together by lateritization. The locals admit to having found gold nuggets in the kraskouw layer. The gold nuggets indicated that there was gold in the area in and beneath the kraskouw layer as Grutterinck (1950) indicated.

Figure 4.8 Gold mining at Kriki Negie, Brokopondo. The gold mineralization is in the yellowish clay layer which is below the reddish brown kraskouw layer

The lateritic kraskouw layers is excavated to expose the gold bearing yellowish clay layer. The soft clayish slurry is thereafter sent through a sluice box to retain the gold. It is not uncommon to see the kraskouw layer undergoing hydraulicking and made a slurry to go through a sluice box. The kraskopuw layer does contain gold, but in very low amounts.

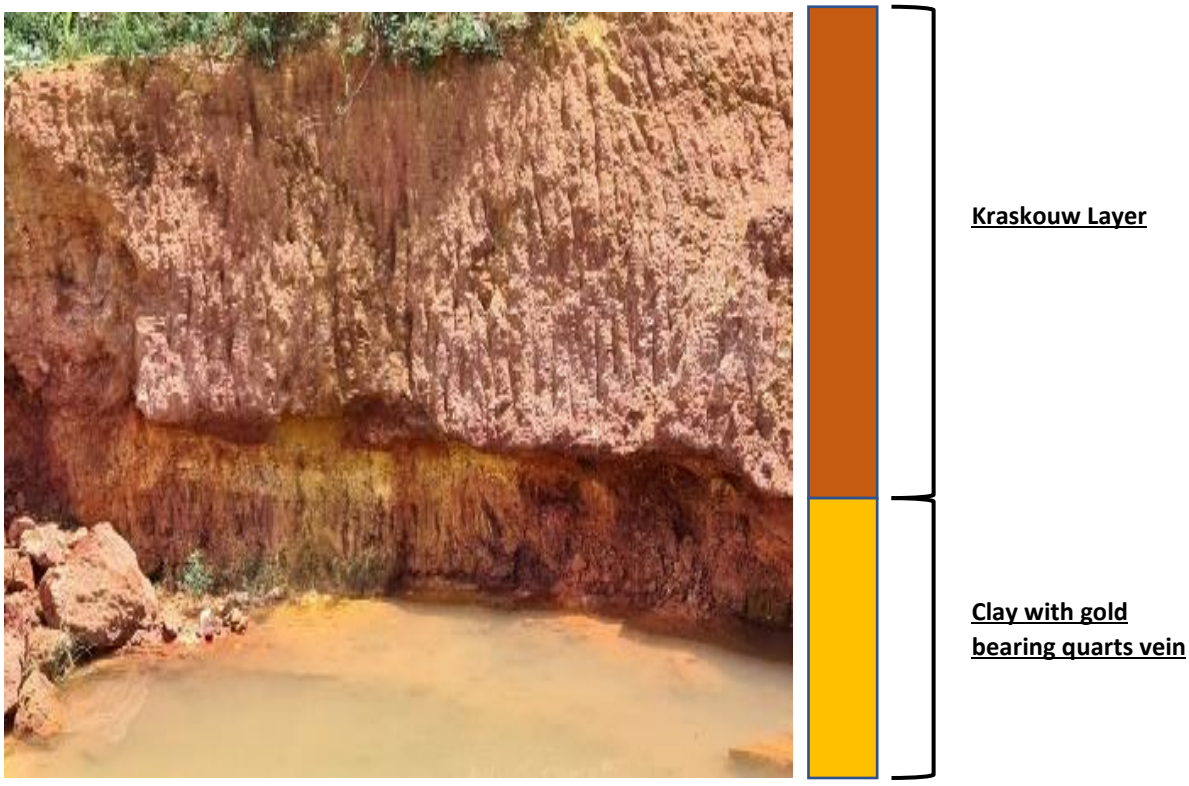

Figure 4.9 Profile with the kraskouw layer and yellowish clay layer

Figure 4.10 The clayish material mined beneath the kraskouw undergoes hydraulicking which directs the slurry through a sluice box which retains the gold

The lateritic kraskouw layer can be an indication of gold in the area, but the layers beneath the kraskouw may contain no gold mineralization (Arhin et al., 2009). This because the laterite/ kraskouw is transported over time and is not an in-situ weathering product.

Gold dredging is done in placers in the rivers, creeks, and hydropower lake of Suriname. These placers are washout alluvial- and river accumulation placers. River accumulation placers are formed by currents which selectively transport and deposit mineral grain. A deep river with different currents sorts by grain size such as gravel, sand, and clay. In river denudation placers, the deposits are closer to the parent rock compared to river accumulation placers, because the current does not have enough force to transport the material. The alluvial deposits certainly did not form in a humid tropical climate, because the current rivers do not contain the waterpower to transport the gravel parts. These deposits originated in a different climate with different surface dynamics. The Guiana shield has experienced many climatic shifts (Kroonenberg et.al, 1983, Kroonenberg et.al, 2017). These placer deposits formed in a semi-arid period in which heavy sedimentation of coarse sediment took place. The Pleistocene is such a semi-arid period and is most likely the period in which these placers originated.

Figure 4.11 Gold dredging is done on scalians in the Suriname hydropower lake, creeks, and rivers

On the foot of a hill a pediment can turn into a river terrace (figure 4.12) and can contain kraskouw. River terraces are old riverbeds, and they are parallel to the river but on a higher plane. River terraces such as the Marowijne terrace in figure 4.13 contain rounded gravel. Due to heavy erosion into the riverbeds, the rivers became braided. These braided rivers continuously transported sediment downstream and the sediment particles rounded the gravel due to abrasion.
The river terraces formed due to sedimentation into the riverbed in a semi-arid period and the incision of the riverbed in a humid period. The rounded gravel in the river terraces is not the same as the kraskouw. The kraskouw is angular and a colluvial deposit as seen in figure 4.14.

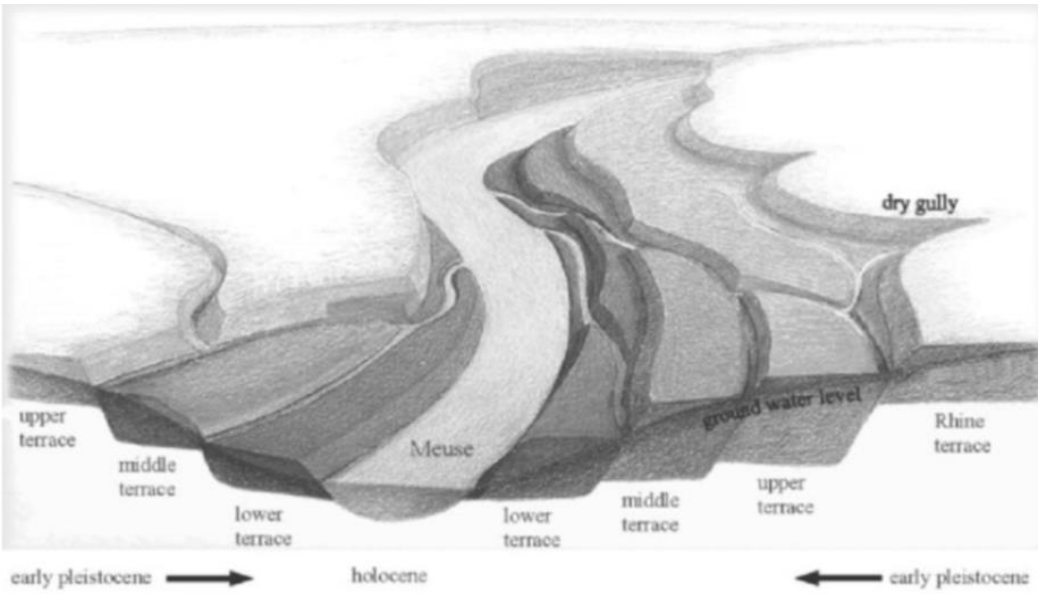

Fig 4.12 Formation of river terraces through time

Fig 4.13 Marowijne terrace at Nasseau mountain with rounded gravel

Figure 4.14 In situ kraskouw block at the Krikie Negie area

4.3. Mercury content soil Kriki Negie area

Gold mineralization and mercury are often found together because these elements can be mobilized in hydrothermal fluids and set in shearzones (Kioe-A-Sen et al., 2016). Gold mineralization is distributed erratically in Suriname and therefore no straightforward relation can be made of expected mercury levels of the gold mineralization (Kroonenberg et al., 2022). Due to colluvial deposits as the kraskouw, the mercury levels of exposed surfaces consisting of kraskouw are not an indication of the mercury levels of lower buried layers. So, the mercury content of a soil mantle is not necessarily correlated with the mercury content of the underlying hard rock (Kroonenberg et al., 2022)

Another aspect to consider about the mercury levels of Kriki Negie is the fact that Heap leaching is done in this area. Heap leaching uses mercury which enters the soil and can influence mercury levels. Heap Leaching is an industrial mining process that is applied to precious metals, such as extract gold, copper, uranium, and other elements from ore using a range of chemical reactions that absorb specific minerals and separate them again after their division from other materials. Heap leaching method differs from the other techniques in that it is used on construction foil, is placed, then chemicals are added to the ore and saturated solution pulls up to obtain the minerals. Most mining companies prefer the economic feasibility of heap leaching, as it is a better alternative for conventional processing methods such as buoyancy, agitation and leaching of barrels (Petersen, 2016).

Figure 4.15 Heap leaching is another method used in the kriki negie area to find gold. The pond seen in the picture is pond from which gold is recovered

Figure 4.16 Samples taken from profile 1. From left to right, 1-5

Figure 4.17 Samples taken from profile 2. From left to right, 1-5

Figure 4.18 Sample take from the tailing of the sluice box at Krikie Negie

The different samples taken from Kriki Negie were sent to Filab Suriname to measure the Hg levels. This analysis is a part of the NIMOS Hg project in Suriname. Filab uses oxydative digestion + AAS cold vapor (FIMS 100) with a detection limit of 1 ppb. The samples are first crushed then dried to 40 degrees Celsius. The samples referenced as profile 1 and profile 2 in table 4.1 are respectively profile A and profile B.

SAMPLE ID	SAMPLE REF.	Hg ug/kg
	Quant. Lim.	0.100
210719-001	PROFIEL 1-001	46.53
210719-002	PROFIEL 1-002	52.34
210719-003	PROFIEL 1-003	39.52
210719-004	PROFIEL 1-004	191.43
210719-005	PROFIEL 1-005	47.82
210719-006	PROFIEL 2-001	56.16
210719-007	PROFIEL 2-002	135.97
210719-008	PROFIEL 2-003	39.04
210719-009	PROFIEL 2-004	50.44
210719-010	PROFIEL 2-005	65.32
210719-011	Tailing Materiaal	139
210719-012	Grind verlaten mijn	137.63

Table 4.1 The results of the mercury levels from the different samples taken at Kriki Negie

5.1. Discussion

The exploration for minerals in the Guiana shield is complex due the humid climate with dense vegetation. The Guiana shield and the West African plateau were side by side 2.00 Ga ago during the supercontinent Gondwana and these two shields share similarities in geology, geomorphology, and geochemistry. The West African plateau, in this case the Sub-Saharan West-Africa offers an interesting view on how the surface dynamics were in the Guiana shield in a semi-arid period.
Brinck (1955) mentioned the kraskouw layer as a layer that burdens the gold bearing clay layer. This kraskouw layer deposited on hills, river terraces due to creep in a semi-arid period. The kraskouw layer mentioned by Brinck (1955) is the same as the duricrust pediments consisting of clay, quartz, and laterite on slopes of hills mentioned by Chardon et al. (2018).

This study has only taken samples from the kraskouw pediment. The mercury levels of the sampled rocks from Kriki Negie give various Hg levels, not corresponding to depth or location of sample. The variation in Hg levels of the two profiles can be accounted to the composition/fragments of the sampled rocks. Rocks with more quartz have lower mercury levels than rocks with laterite. In profile 1 the anomaly is the 4^{th} sampled rock and in profile 2 the anomaly is the 2^{nd} sample. The samples taken from profile A (1) and B (2) (figure 3.3) do show a reduction of quartz from top to bottom. The samples 3-5 from each profile are more clayish and brittle compared to the samples 1-2. As expected, the samples from the tailing of the sluice box are higher than the average mercury level of the samples, besides the anomalies. The gravel at the abandoned mine also showed high mercury levels. The higher level of mercury does not directly indicate usage of mercury. The mercury values are influenced by the parent rock type and the weathering process. The mercury levels in the profiles cannot be used as background value to distinguish natural from polluted material as they have similar levels to tailings and sediments from small-scale gold mining areas (Kroonenberg et al., 2022)

5.2 Conclusion

1. Substantial climate shifts in the late Cenozoic/Pleistocene led to an alternation of humid and semi-arid periods in the Amazonian region, during which tropical rainforest thrived and savanna vegetation predominated. The different periods with different weathering shaped the Guiana shield and west African plateau. The Guyana shield had a similar look to modern Sub-Saharan West-African plateau in the Pleistocene.
During a semi-arid period, the vegetation was scarce, and the ground was unstable on hills and plains therefore precipitation resulted in debris flows, heavy erosion, and slope movements. The transportation of material was a lot more intense and this how placers originated on slopes of hills and in creek-/riverbeds. The material which lays atop of the gold placers was also deposited in this window.

2. The origin of the gold bearing deposits are quartz enriched gold veins which have been weathered, eroded, transported to form gold placers on slopes of hills, river terraces and creek-/riverbeds. The shifting climatic conditions led to different rigid weathering episodes which loosened the gold enriched parent rock. Intense physical weathering in semi-arid periods such as the Pleistocene led to creep of rock on hills and sudden heavy rainfall during these periods led to debris flow and set in river terraces and creek-/riverbeds and. This explains the current heavy coarse material in the beds of creeks as these water bodies do not possess enough waterpower to transport the coarse/heavy material.

3. The kraskouw is a lateritic, quartz and clay cemented layer formed during a semi-arid climate due to intense weathering and erosion. The kraskouw layer lays on slopes of hills, and can contain gold, if the parent rock was intruded by a gold bearing quartz vein. At Kriki Negie in Suriname kraskouw is removed to get access to the gold bearing yellowish clay layer beneath it.

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