ANTON DE KOM UNIVERSITY OF SURINAME

FACULTY OF TECHNOLOGICAL SCIENCES

MINERAL RESOURCE MANAGEMENT

HEAVY MINERAL SURVEY TO DETERMINE POSSIBLE DIAMOND HOST ROCKS IN THE NASSAU MOUNTAIN AREA, SURINAME

A thesis submitted in partial fulfillment for the degree of
Bachelor of Science (BSc.)
in
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SUMMARY

Recent diamond finds by local gold miners in the Nassau Mountains area has led to renewed interest in these gems. These diamonds are mainly found in American Creek alluvial fan sediments deposited onto the dissected Marowijne River terrace. However, up till now, the occurrence of these diamonds has not been linked to diamond bearing host-rock or deposits. To identify the possible host-rocks, a heavy mineral study is done in order to establish the source of the creek sediments taken from the Paramakka and American creeks. These creek sediments contain diamond indicator minerals such as chromite and garnets. Besides these indicators other igneous and metamorphic minerals are found (pyroxenes, amphiboles, epidotes and others). From field data and creek sediments the host-rock may be the following: the Rosebel Formation, Plateau D and Plateau E (bauxite plateau; no geological data). This leads to possibility of the Upper-Paramakka Creek also being enriched with diamonds, besides the early mentioned locations. The primary host-rock may be kimberlite or lamproites intrusions in the nearby region or even possible unidentified kimberlite in Suriname.

PREFACE

In partial fulfillment of my Bachelor of Science degree, a Geoscience related topic should be researched within a thoroughly substantiated geological and intellectual framework in order to obtain a BSc degree. This research is about the diamond occurrences in Suriname with the focus on the diamond hotspot, the Nassau Mountain area. This thesis is a small part of the advanced and greater PhD research of R. Naipal, who is studying the diamond occurrences in the Marowijne Greenstone Belt.

With this thesis I want to promote and motivate students to also focus on retrieving data from chemical analytical methods and bring them into relation with geoscience related topics.

In this preface I want to thank my supervisors Prof. dr. S. B. Kroonenberg and R. Naipal, MSc for their guiding, assistance and motivation during the research. Secondly, I would like to thank F. Libby-Sastrohardjo, MSc, Miss N. Kioe-A-Sen, MSc, Ir. R. Cameron and K. Goenopawiro, MSc. for their guidance and advice during this research study. Also, I want to thank Saeed Khan, MSc. (PhD candidate – University of the West Indies) for his feedback on my thesis and Zeinab Abdoelbasier for assisting and helping me during my lab work. My thanks also go to DIXEN Minerals for their logistic support and Mr. Paansa & Mr. Pinas for their field guidance during the fieldwork.

The greatest thanks go to the “Bodemkundig Labratorium” for their support, cooperation and generosity for letting me do my laboratory work in their lab, even though they were sometimes pre-occupied with other analysis.

Last but not least, I also want to thank my loving parents (Anand and Anneke) and sister (Sharon) for their motivation and support during these past months, in order to realize one of my main goals.

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LIST OF ABBREVIATIONS

ml	milliliters
gr	grams

Mineral abbreviations

cpx	clinopyroxene
opx	orthopyroxene
zr	zircon
tour	tourmaline
ap	apatite
chl	chlorite
hbl	hornblende
st	staurolite
sp	spinel
fl	fluorite

CONTENTS

1. INTRODUCTION

1.1 Location study area

The Nassau Mountain in eastern-Suriname is a horseshoe-shaped mountain (Figure 1) which lies within the boundaries of 4° 44' – 4° 56' N and 54° 28' – 54° 40 W. It is geologically situated within the Paleoproterozoic Marowijne Greenstone belt in the northeastern part of Suriname. In the early 1900s some diamonds were found in the neighboring area of the Nassau Mountains (Headley, 1913). However, no further research was conducted after the first diamond find. Nowadays diamonds are mined by local small-scale gold miners in the Nassau Mountain area, but the ultimate provenance and Suriname host rock of these diamonds is still unknown. Diamonds are found at the confluence of the American Creek with the main Paramakka Creek. This study aims to find the possible provenances of these diamonds by heavy mineral analysis of creek sediments taken from the Paramakka - and American Creek. The heavy mineral analysis method focuses on the density separation of heavy mineral grains (minerals with a density greater than 2.85 kg/m^3) (Morton, 2006) with a Bromoform (heavy liquid with density of ~ 2.89 kg/m^3 at 25°). Diamond occurrences are often associated with diamond pathfinder minerals; which are the main components of the most known primary host rocks like kimberlite and lamproites. Dominant occurring pathfinder minerals are chromite (Cr-spinel), ilmenite, garnets, Cr-diopside, olivine (Castillo-Oliver, M et al., 2019). Up till now no kimberlites or other diamond host rocks have been identified in Suriname. Another possible source could be a secondary host rock containing fragments and possible diamonds of the former primary host) within close range of the Nassau Mountain area, such as an alluvial deposit.

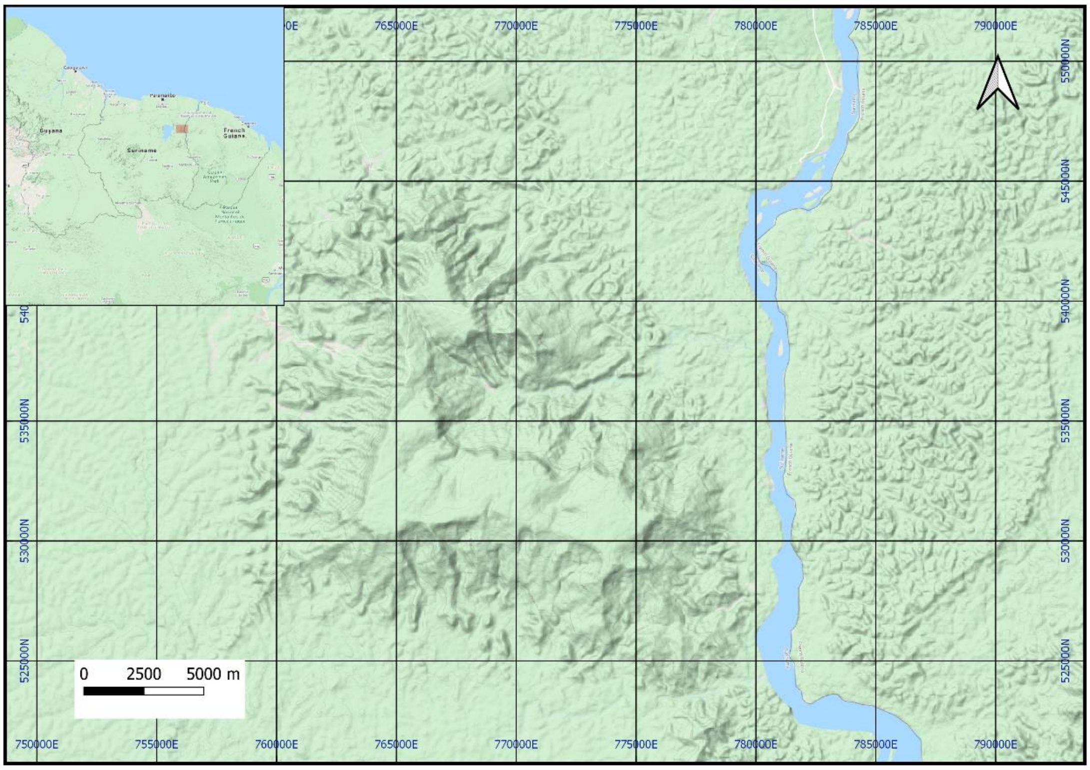

Figure 1. Displays the Nassau Mountain area (horseshoe mountain shape) and the setting within Suriname (in left map above in pink area overview). Map made with QGIS-software.

1.2 Problem Statement

The present meta-sedimentary and meta-volcanic base of the Nassau Mountain area is mainly overlain by bauxite-lateritic profiles. The Paramakka Creek and its tributaries transport the weathered and eroded sediments of these rock units and deposit these onto the terraces. Diamonds and other common heavy minerals are present in the sediments of the American Creek and in the confluence with the Paramakka Creek, based on information of local miners. The primary and secondary host-rock is still unknown. Therefore, this research aims to find the possible hosts via heavy mineral analysis, focusing on the diamond indicator minerals. The main research question: **"What are the possible diamond host rocks based on the American – and Paramakka heavy creek sediments from the Nassau Mountain area, Suriname?",** will be further discussed by answering the following sub-research questions:

1. Which indicator minerals are present in the creek samples and what is their abundance?
2. What kind of heavy minerals other than the indicator minerals are present in the creek samples?
3. What are the possible source and/ or host rocks of diamond based on the geology of the area and the identified heavy minerals?

1.3 Area limitations

The study area is limited to the upper- to mid-stream Paramakka Creek and the mid- and downstream of the American Creek in the Nassau Mountain area, Suriname

1.4 Objectives

The objectives of this project are as followed:

1. To determine the possible sources and host rocks for the diamond findings in the Nassau Mountain area based on present identified heavy minerals of creek sediment samples.
2. Understanding the geology of the Nassau Mountain area by the occurrence of the minerals present in the creeks.
3. Have a clear understanding of the lithology and geology of the Paramakka Creek drainage basins

1.5 Thesis outline

The thesis consists of five (5) chapters. The first chapter covers the introduction, research objectives and the problem statement/research questions. The second chapter includes the background information of the study area where the geology will be discussed. The third chapter covers the methods and techniques used during the research period, followed by the results and discussion in the fourth chapter. To finalize the thesis conclusions will be drawn in the last chapter.

2. LITERATURE REVIEW

2.1 Polymorphs of Carbon

Diamond is one of the world's most popular and valuable gems, composed of the element carbon (C). Carbon in the solid state exists in two polymorphs (i.e. both minerals have the same chemical composition, but a different crystal structure (Figure 2) diamond and graphite. Graphite, in comparison to diamond, is a lower pressure mineral with layered carbon atoms and interlayer bindings behavior resulting in a planar structure (Tappert & Tappert, 2011).

The crystal structure of diamond makes it the hardest mineral defined in the Mohs hardness scale (value of 10). Property characteristics of diamond includes: a density of 3.51 kg/m^3, a high refractive index of 2.4s, resistant to reaction with chemical agents (causing the diamonds to be chemically inactive), and having a high thermal conductivity.

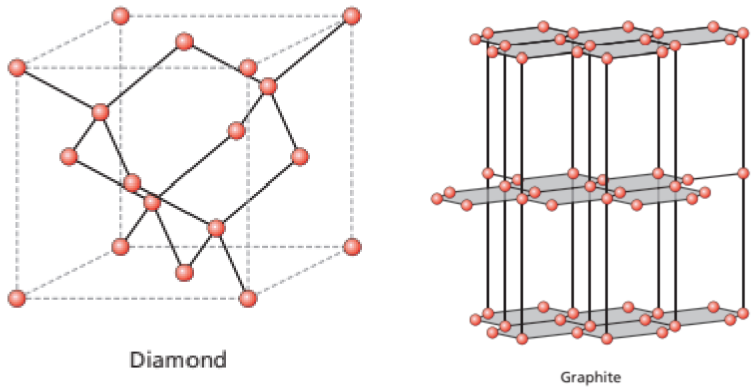

Figure 2. Displays the complex distribution of carbon (C) in diamond (left) and planar structured orientation in graphite (right)

2.1.1 Formation of diamonds

Diamonds are primarily formed deep in the Earth's crust at depths of 150-200 km, in the so-called 'diamond window' (Figure 3); this window is marked by a range of high temperature and pressures (pressure varies from 45-60 kilobars and temperatures between 900-1300° Celsius) (How diamonds are formed, n.d.). The conditions above create the lamproite and kimberlite composition magma as a result of melting of the Earth's upper mantle. The melting causes extension of the earth's crust which promotes magmatic intrusions forming dikes and sills (pathways of magma in the earth's crust formed under the least resistance behavior) in the upper part of the Earth's surface. The kimberlite and lamproite then samples the deep formed diamonds and concentrate them in the dikes; this makes the kimberlite or lamproite a primary host rock for the diamonds. These rocks eventually weather and erode; resulting in sediments containing diamonds, indicator minerals and others to be transported and deposited in creeks, rivers and their terraces.

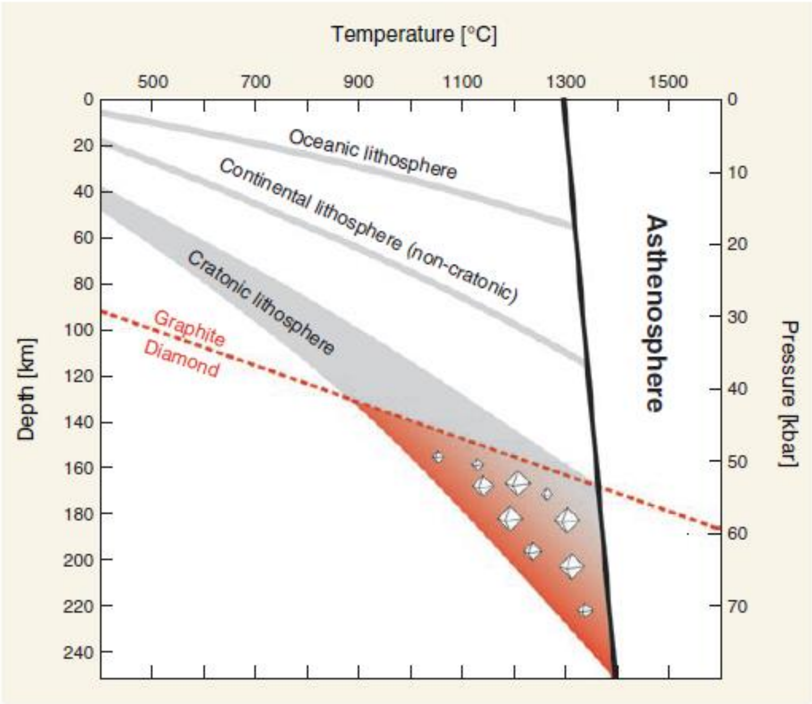

Figure 3. A pressure-temperature-depth diagram where the graphite and diamond conditions are given. The diamond window is ranged within a T of 900 – 1300 ° C under P greater than ~40 kbar which corresponds with depths of more than ~140 km (Tappert & Tappert, 2011)

2.1.2 Indicator Minerals

Indicator minerals are minerals present in a sediment load that indicate the composition of a lithology, rock types and metamorphism (McClenaghan, 2005). In the diamond exploration these indicator minerals help derive and classify the primary source rocks (lamproite or kimberlite) and the composition of the secondary host rocks such as the alluvial deposits. These indicator minerals in regard to diamonds are Cr-spinel (chromite), ilmenite, garnet, olivine and Cr-diopside (variety of clinopyroxene).

2.1.3 Kimberlite and diamonds

Kimberlite dikes are subsurface vertical structures that have cooled in the form of a coned-shaped pipe (see Figure 4). They are known as the rock types that usually contain diamonds that are formed deep in the Earth's crust. Lamproite differs in composition to kimberlite, because of the presence of certain minerals. Kimberlites are classified in (Roger Howard. Mitchell, 1995):

1. **Group 1 Kimberlites**

   Kimberlites enriched with CO_2 - ultramafic volcanic rocks consisting of a breccia matrix composed of the following essential minerals: carbonates, phlogopite (magnesium mica), olivine, pyroxene (Cr-diopside, clinopyroxene) and other common and major element minerals like: diamond, perovskite, pyrope and Mg-spinels (Smith et al., 2013).

2. **Group 2 Kimberlites (Olivine lamproites)**

Also called the Orangeite and differ in occurrence and petrology from to the kimberlite group 1. This group predominantly consists of ultrapotassic, peralkaline (oversaturated alkalies and undersaturated Al_2O_3 (Nelson, 2011) rocks that trap $H_2O(g)$. Here the phlogopite (magnesium mica) is the essential mineral besides the olivine. The composition is enriched with REE-rich perovskite, apatite, rutile and Mn-bearing ilmenites (Roger H. Mitchell & Bergman, 1991; Roger Howard. Mitchell, 1995)

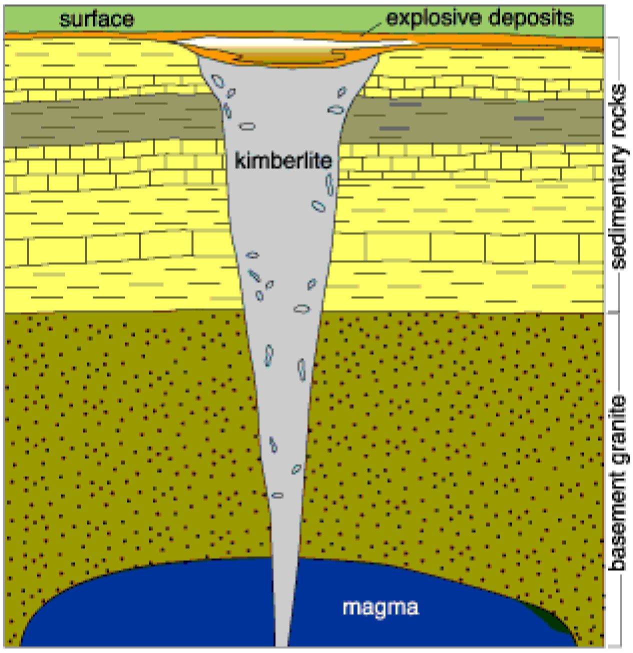

Figure 4. Displays the occurrence of the kimberlites within the earth's profile. The kimberlite is the diamond sampler and therefore is the host rock of diamonds. (KGS Pub. Inf. Circ. 16--Part 2 of 4, n.d.)

Diamonds come in different varieties of colors, caused by impurities (mostly by nitrogen atoms) replacing the carbon-atoms within the crystal structure; these contaminations or substitutes are labeled and grouped as followed (Breeding & Shigley, 2009) (Figure 5):

1. **1A diamonds**: these diamonds contain clusters of nitrogen atoms distributed over their crystal structure, causing them to be yellow of color. This group can be subdivided into the 1aA and 1aB group respectively containing nitrogen aggregates in pairs and the other containing four nitrogen atoms surrounding a vacancy.
2. **1B diamonds**: these 1B type diamonds, single nitrogen atoms are scattered over the internal structure, allowing light to pass through with the ultimate colors varying between yellow and brown. This type in comparison to the 1A is uncommon.
3. **2A diamonds**: these diamonds contain very little nitrogen to none and are formed under higher pressures than the other diamonds discussed in this section; these tend to have an

irregular shape. The colors here vary based on the angle of incoming light and the reflectance.

4. **2B diamonds:** these diamonds do not contain nitrogen impurities but contain the element boron. Boron colors the diamond to a bluish-gray tint and therefore makes this type highly valuable.

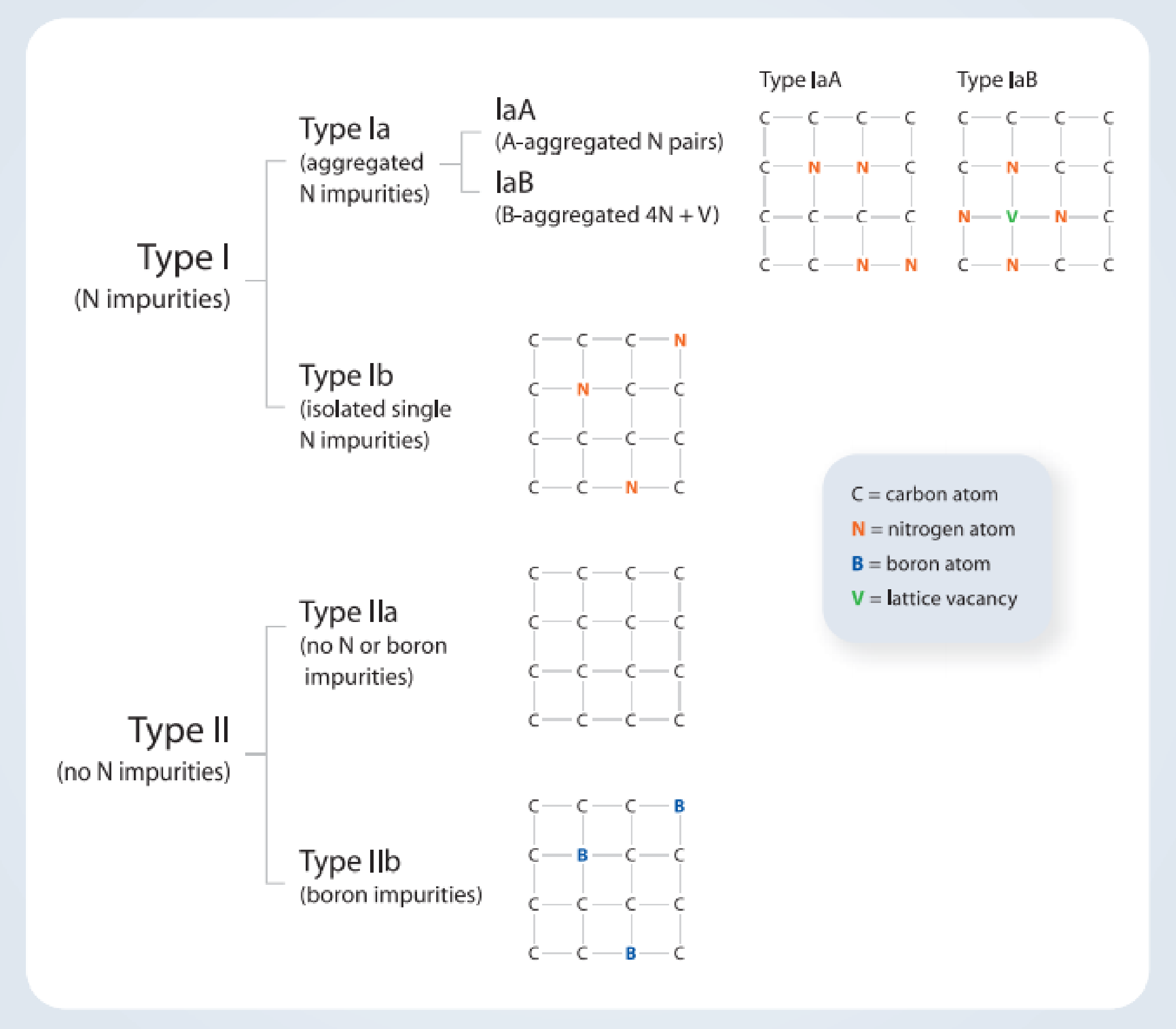

Figure 5. Displays the types of diamonds formed under the presence of a specific impurity of B or N. This figure also displays the N-sorting around a vacancy (V) (Breeding & Shigley, 2009)

2.2 Regional geology

Suriname is situated in the northeastern part of the Guiana Shield (Figure 6) within the Amazonian Craton (Kroonenberg et al., 2016). The Amazonian Craton is divided by the Amazon and Solimoes river-basin complex into the northern Guiana Shield and southern Brazilian Shield. The Guiana Shield has a total surface area around 900,000 km^2 (Kroonenberg et al., 2019).

Figure 6. Simplified overview of the Guiana Shield and Brazilian Shield separated by the river-basin complex (modified after (Cordani & Sato, 1999)). White outlined box displays location Suriname within the Guiana Shield on the overview map.

The Guiana Shield consists of high-grade metamorphic Archean terrains, formed before the Trans Amazonian Orogeny, and the Paleoproterozoic low-grade metamorphic greenstone terrains formed during the Trans-Amazonian orogeny in the Rhyacian period (± 2.26 – 2.09 Ga). These blocks were exposed to active tectonic changes like large-scale ductile shearing and faulting resulting in the deformation and reworking of the geology and metamorphism of rock units. Below in (Figure 7) a simplified sketch of the different rock units and their ages distributed over the domains of the Guiana Shield are displayed

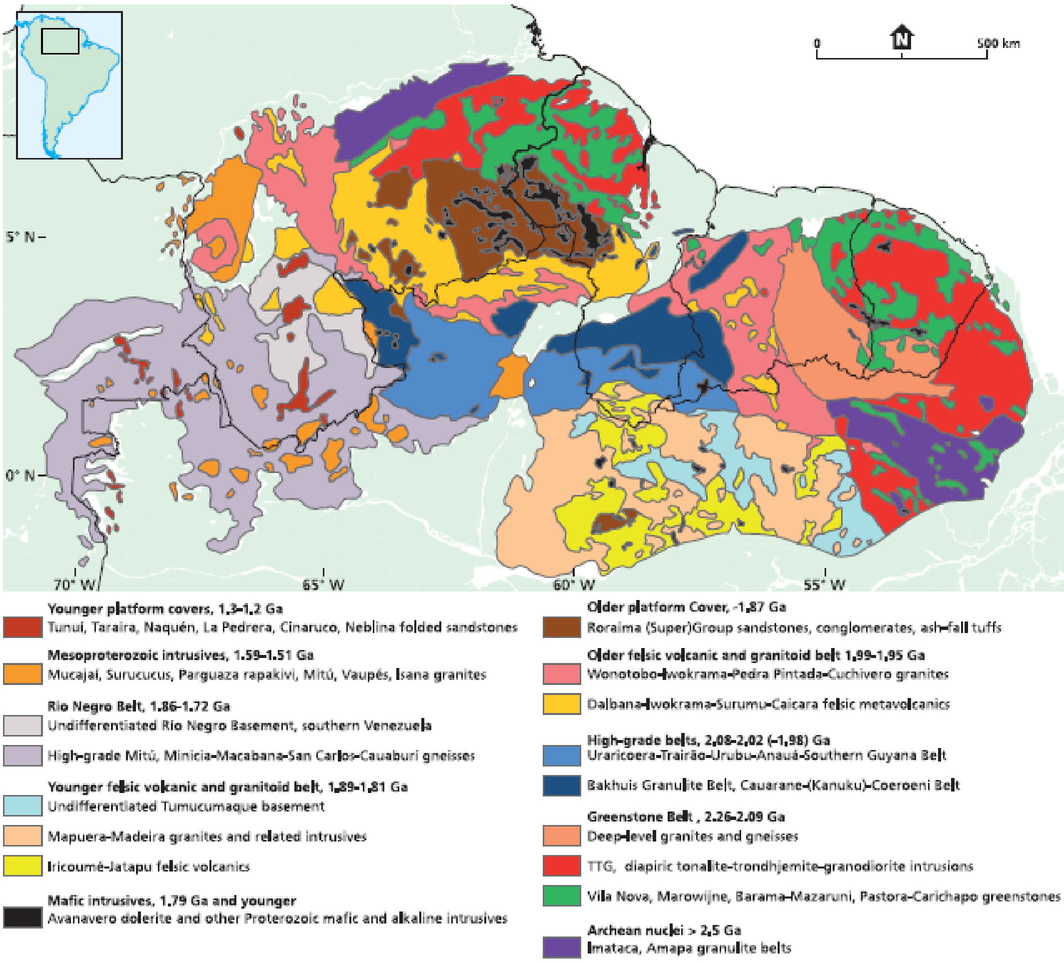

Figure 7. Simplified overview of the geology of the Guiana Shield (Kroonenberg et al., 2016).

Tectonostratigraphic and geological setting of these domains are:

1. **Archean high-grade belts:**

   The Guiana Shield consists of two Archean blocks situated in the Imataca Complex in northwestern Venezuela and Amapa granulite belt in the eastern part of the shield in Brazil (Kroonenberg et al., 2019). The Imataca complex has an ENE-trend, confined by faults with rocks from Greenstone Belt.

2. **Paleoproterozoic greenstone belts:**

   The Paleoproterozoic Greenstone belt is situated in the northern part of the Guiana Shield and bounded by the Archean two known nuclei with an overall WNW-ESE trend. The Greenstone belt consists mainly of low-grade greenschist facies rocks, diapiric TTG intrusions, shallow granitic intrusions (granitoid belts), deep-level granites and gneisses.

The formation of the Guiana Shield has taken place in four phases (Figure 8) of probable crustal thinning, reworking and metamorphosis resulting. These four phases are the:

1. Formation of Archean nuclei
2. The Main Trans-Amazonian Orogeny **(Phase D1 and D2a)**
3. The Late Trans-Amazonian Orogeny **(D2b)**
4. Subsequent Proterozoic & Paleozoic events

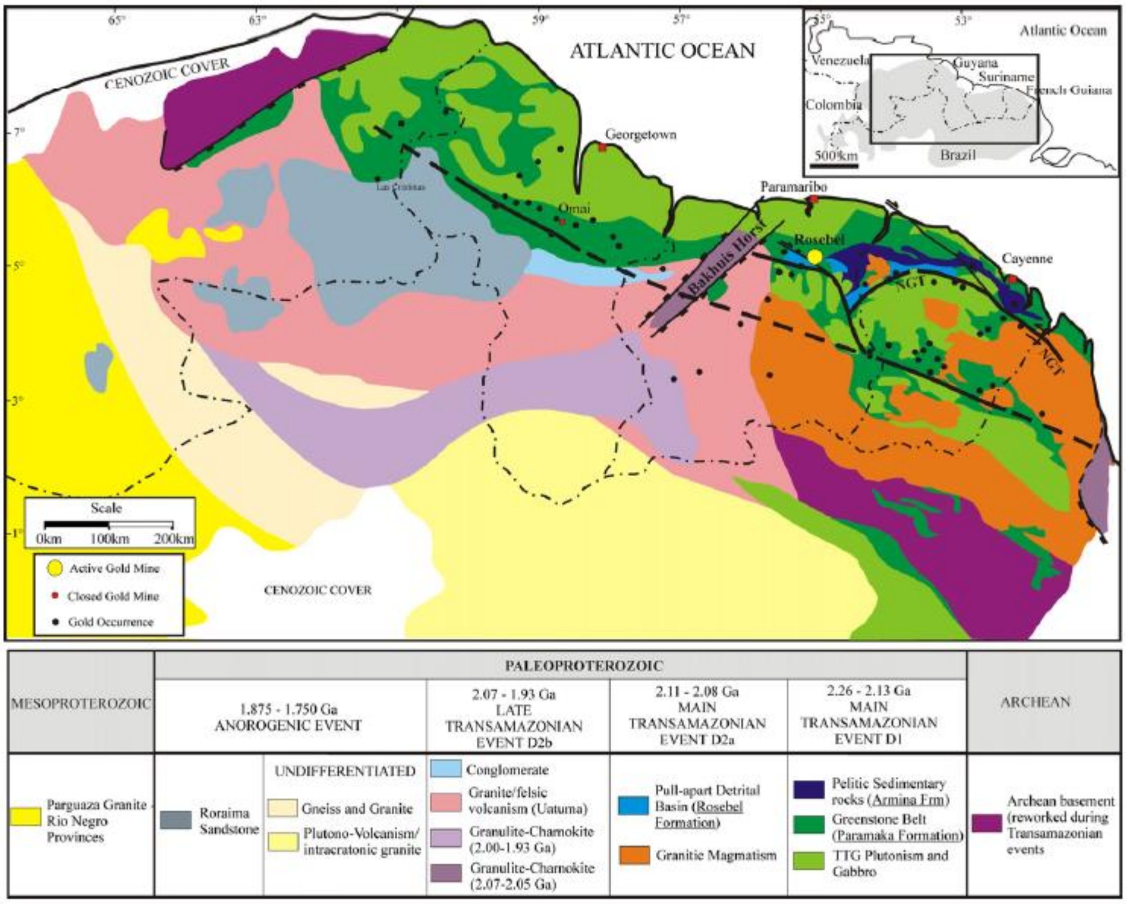

Figure 8. Simplified geological map of the Guiana Shield modified after Delor, Lahondère, et al., 2003 (Daoust et al., 2011); also displaying gold occurrences and simple overview of geological events in regard to the formation of the Guiana Shield

Ad 1. Formation of Archean Nuclei

The Archean nuclei were formed between 3.2 and 2.6 Ga and later submitted to reworking and deformation during the Trans-Amazonian events starting from approximately 2.26 Ga.

Ad 2. Main Trans-Amazonian Orogeny

The first event in the formation of the Paleoproterozoic Greenstone belt was an oceanic state of sea-floor spreading between the Archean cratons of Guiana and West-Africa and submarine extrusion of basalts. Subsequently the cratons started to converge, and andesitic volcanism, sedimentation, deformation started in what is called the Main Trans-Amazonian Orogeny, creating the greenstone-TTG belt and granitic intrusive episodes. The main phase is labeled with the **D1** and **D2a sub-phases** each associated with their own event and indicates stages of deformation.

The **D1 sub-phase** focusses on the formation of the greenstone-TTG belt (Figure 9b) as a result of North-South orientated convergence of the North-Amazonian and West-African cratons; causing the southern-border of the North-Amazonian domain to subject to subduction, thus creating the accommodation for the greenstone-TTG belt in the northern part of the Guiana Shield (Delor, Lahondere, et al., 2003; Vanderhaeghe et al., 1998).

The first deformation process is followed by a **D2 sub-phase**, causing gravity dominated deformation and the reworking with visible results of folding, low-grade metamorphism and lineation of minerals caused by normal fault movements (Delor, Lahondere, et al., 2003; Delor, Lahondère, et al., 2003) (Figure 9c). In the **D2a sub-phase** the North-South convergence switches to an NE-SW behavioral trend, causing a left-lateral strike slip movement (**D2a**) and allowing the syn-kinematical granites (in context to the orogeny these are also called the **D2a granites**) (Delor, Lahondere, et al., 2003; Vanderhaeghe et al., 1998). The left-lateral strike slip movement led to the formation of pull-apart basins; creating accommodation for coarse grained arenitic and conglomeratic material (synchronously filling of the basins during the strike-slip movement). These basins are unconformably overlying the greenstone-TTG belt and are subjected to deformation and metamorphic changes of Late-Trans-Amazonian events.

Ad 3. The Late Trans-Amazonian Orogeny

The Late Trans-Amazonian phase (**D2b**) is defined as a crustal thinning phase (Figure 9d) as a direct result in mantle upwelling, where rocks under the oceanic crust start melting and causing magma to reach the surface. This magma has formed the granulite grade metamorphic rocks and normal fault development has made the charnockitic magmatism unto the surface possible. The last phases are defined by the plutono-volcanism caused by magmatism of arc-subduction in a post-collisional setting (Reis et al., 2000).

Ad 4. Subsequent Proterozoic & Paleozoic events

The Proterozoic & Paleozoic events are associated with the post Trans-Amazonian phase; allowing the formation of anorogenic intra-cratonic granites with the time period of 1.83 – 1.79 Ga issued by (Costi et al., 2000; Lenharo, 1998), Roraima sandstones deposition in sedimentary basins around 1.875- 1.78 Ga Santos. Also, intrusions of Mesoproterozoic alkalines (1.7- 1.3 Ga) (Gibbs, A.; Barron, 1993), Neoproterozoic alkaline dikes and Mesozoic Apatoe dolerite dikes.

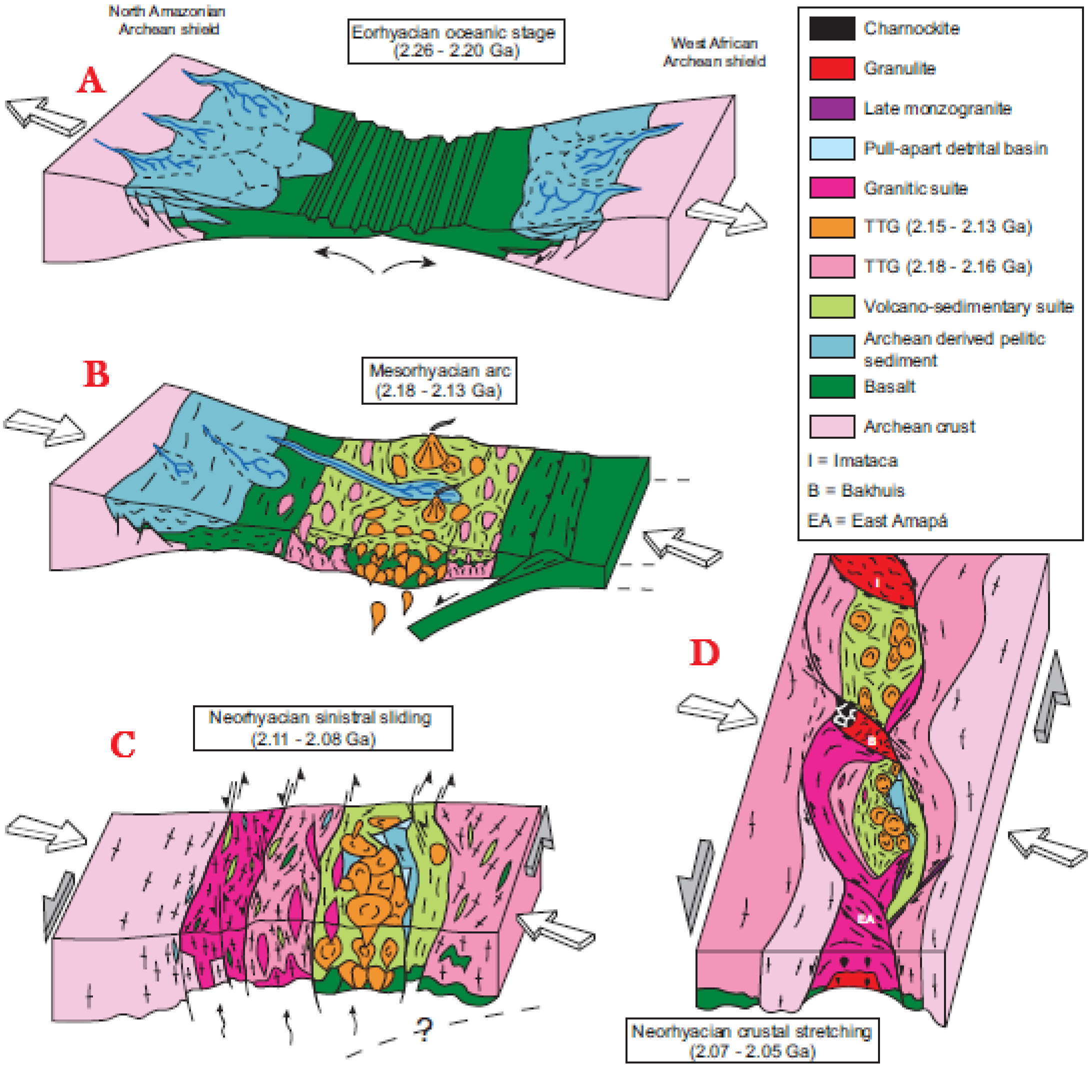

Figure 9. Displays a geodynamic evolution for the Guiana Shield Paleoproterozoic terrains (Delor, Lahondère, et al., 2003)

2.3 Regional geology - Suriname

Suriname is situated in the north-eastern part of the Guiana Shield in the Proterozoic basement, consisting of the greenstone-TTG rock complex in the north-east (Marowijne Greenstone Belt), high-grade metamorphic belts in the north-western part (Bakhuis Granulite Belt) and south-west the Coeroeni-Gneiss Belt and younger felsic volcanics and granitoids distributed over central-south Suriname.

The **Trans-Amazonian Orogeny in Suriname** context is divided in three phases. These phases are:

1. **The Main-Trans Amazonian Orogeny**: between the 2.18 – 2.09 Ga; the formation of the Marowijne greenstones, tonalite-trondhjemite-granodiorite (TTG) belt and deep-level granites and gneisses (Kroonenberg et al., 2016) like the Sara's Lust Gneiss, Pikien Rio Pyroxene Granite and Gran Rio Granite.
2. **The Second-Phase Trans Amazonian Orogeny**: between the 2.07 – 2.05 Ga); the formation of the high-grade belts (Bakhuis and Coeroeni belts) and basins that were filled up with sedimentary-volcanic material. These basins were formed by a rift-like setting and suffered subsequent metamorphism up till the amphibolite- granulite facies.
3. **The Third-phase Trans-Amazonian Orogeny:** between the 1.99- 1.95 Ga; throughout the whole country series of felsic volcanism, mafic to ultramafic intrusions and at greater depths below the existing high-grade belts the formation of charnockites and anorthosites causing a renewed high-grade metamorphism environment forcing the existing rocks to change under higher pressures.

The **Marowijne Greenstone belt** in regard to this study is roughly limited to the following rock formations, simply based on the rock occurrences identified within the surrounding area of the Nassau Mountain area. These rock formations with their rock types are from old to young (see Figure 10 for rock units):

1. **Paramaka Formation**: consisting mainly of mafic to felsic volcanics and volcaniclastic sediments, metamorphosed to the greenschist facies and, close to the TTG intrusions, to the amphibolite facies.
2. **Armina Formation**: consists of primarily coarse grained metagraywackes and fine-grained meta-siltstones/ phyllites, which are identified as metaturbidite deposits by (Bosma et al., 1983; Daoust et al., 2011; Naipal & Kroonenberg, 2016; Nathan & Scobell, 2012). All within the greenschist facies.
3. **Rosebel Formation**: metasedimentary rocks, consisting mainly of meta conglomerates and metasandstones; the meta conglomerates are polymictic (rock fragments are from different rock types), enriched with quartz and phyllite clasts possibly from underlying Armina formation.

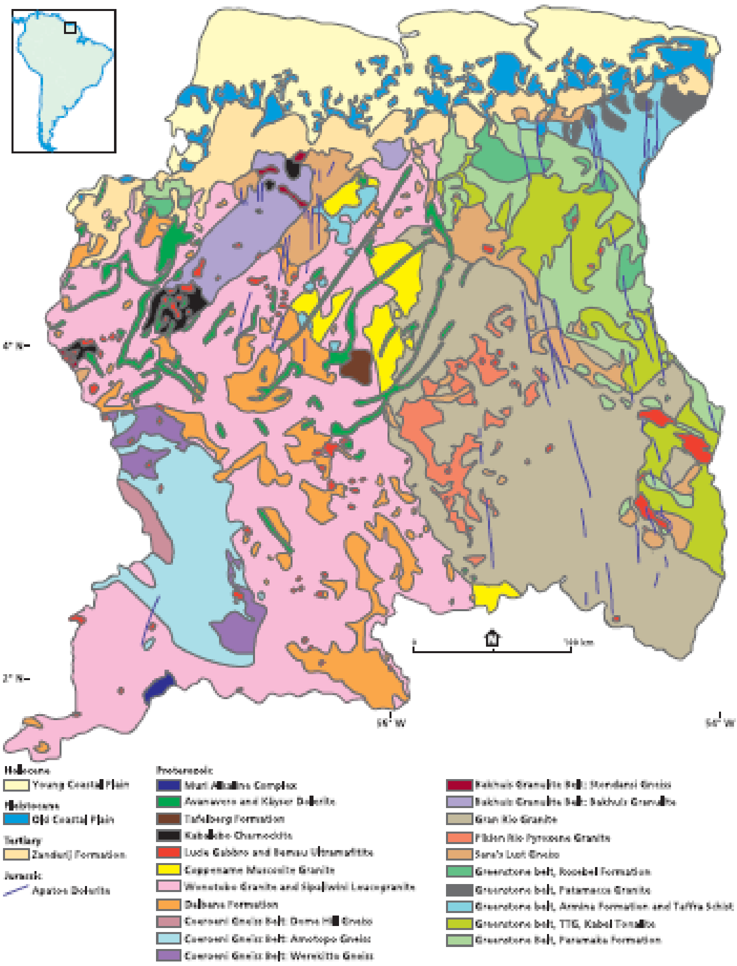

Figure 10. Simplified geological map of Suriname, according to modern data (Kroonenberg, et al., 2016)

2.4 Geology of the Nassau Mountain area

The Nassau Mountain is formed by four large plateaus; which were identified by De Munck (1954) as the A, B, C plateau situated from east to west and north of the C plateau D. There is another bauxite-lateritic plateau with limited information and in this research will be referred as “Plateau E”. Bauxite-lateritic profiles overlie the volcanic and sedimentary material throughout the mountain. These plateaus are drained by creeks that emerge from under the bauxite caps and undermine the plateau rims, thus causing slope retreat and gradual reduction of the plateau surface. The mountain has the highest top in the south-western part and the lowest in the northern part.

During the geological survey of the Nassau Mountain and surrounding area (defined in the report as ‘Kaartblad D8’ by (De Munck, 1954)), the identified rock units were classified according to an older system in comparison to the updated geologic rock formations by (Kroonenberg et al., 2016) and others. From young to old these formations are as follows:

1. **The Orapu Formation**
   a. **Rosebel serie:**
      Consisting mainly of well-rounded conglomerates, sandstones with clay-matrix (sub-greywackes containing feldspars fragments) and quartzites. The conglomerate deposits together with the sub-greywackes indicate local to possible regional folding (referred by (De Munck, 1954)) as possible folding on large scale). The Rosebel serie to the west has a more monomict composition that changes towards the east to a polymict composition (this is observable in the Sabajo Hills). The polymictic composition variation is caused by sediments from the Paramakka -, Bonidoro - and Rosebel serie (De Munck, 1954). The Rosebel serie has later (after 1954) been renamed as the Rosebel formation and identified as the meta-sedimentary formation of the Marowijne Greenstone Belt.
   b. **Bonnidoro Serie**
      Primarily observed are the dark grey-white phyllites and greywackes (De Munck, 1954). These rocks are more compact and massive clayish; whereas the Rosebel is more loosely grained and sandy. The greywackes and phyllites were later on identified as a sequence of different sediments deposited under environments and names as Armina formation turbidites, this is observable in the Marowijne river.
2. **The Balling Formation**
   a. **Paramakka serie**
      The Paramakka serie is build up out of different volcanics like lavas, tuffs, quartzites, breccias and pyroclastic agglomerates. The Paramakka serie has been later on defined as the Paramaka formation (where the Nassau serie is also included).
   b. **Nassau serie**
      This serie contains the metamorphosed sediments of different lavas tuffs, quartz gabbro's and agglomerates. The Nassau serie is covered by lateritic, ferrite-bauxite, weathered profiles with a base of mottled clay zones and kaolinic-bearing clays.
3. **Dolerite dikes**
   The dolerites are from possible Mesozoic age and are found in the upstream Paramakka area (based on fieldwork (Kroonenberg, S. B.; Naipal, R.; Paansa, B.; Sardjoe, 2019). These dolerites are possibly the Apatoe dolerites with an early- Jurassic age based on the geological map of Suriname (Kroonenberg et al., 2016).

2.4.1 Diamonds in Nassau Mountain

The first diamond occurrence was found by Messrs and later on by Fenley and Smith around the 1880s in the current Rosebel Goldmines concession (Headley, 1913). Later on, more diamonds were found, but no proper research was done on the occurrence in the nearby areas.

In 2016 the consultancy company HAZLO found four small diamonds (see Figure 11) in the tailing material of goldmining. The diamonds were researched for possible sources. Recently local people and small-scale goldminers have been mining for diamonds along with their main product: gold. It is known that diamonds are found in the downstream of the American and possibly the Chinese creek and their confluences with the Paramakka creek. The hotspot for diamonds at the current moment are the American Creek alluvial fan deposits on the Marowijne terrace. These diamonds are small and vary from subhedral to sub-rounded with identifiable crystal planes (Figure 11).

There is a possibility of indicator minerals being present, since it is known that diamonds are present and found. These minerals can indicate the possible host of these diamonds. The local geology of the Nassau Mountain does not give direct clues to diamond finds, due to the fact that most of the plateaus consist of the bauxite-lateritic caps that are overlying the underlying meta-volcanic rocks. A local gold miner indicated to have mined and found 50-80 carats in pits excavated in the alluvial fan of the American Creek near the adjacent Marowijne terrace. The terrace is much wider than the narrow terrace strips issued by (De Munck, 1954)). The in-situ material in the alluvial fan consists mainly of angular milky quartz cemented with a kaolin or iron-oxide matrix.

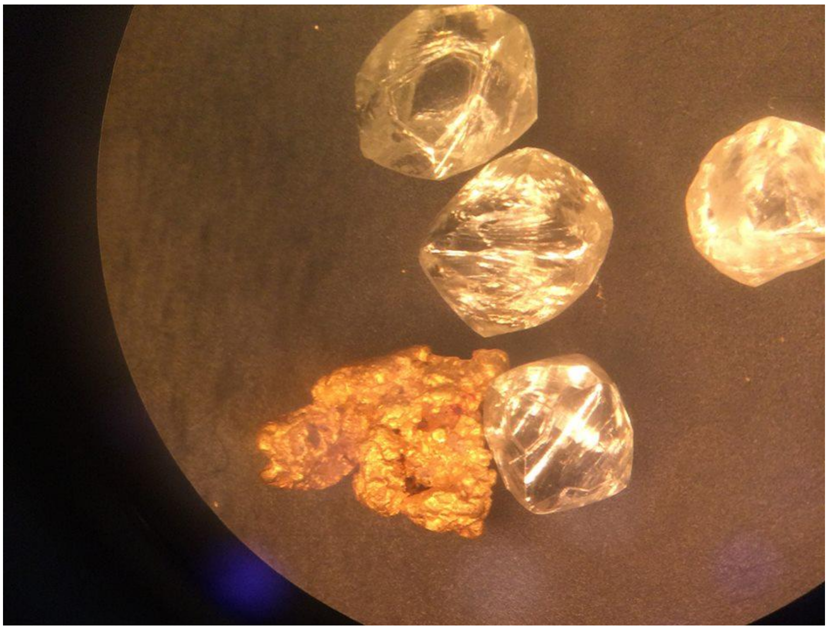

Figure 11. Diamonds and gold grains found in one of the tailings of the Nassau Mountain Area; grains presented during the SURIMEP Conference in 2017 by HAZLO. (Photo: Noël Sardjoe)

2.4.2 Diamonds in neighboring countries

Since the host rock of the diamonds in Suriname is unknown so far, a possible source is a kimberlite or lamproite intrusion near the Nassau. Therefore, we explore diamond occurrences in nearby countries like Venezuela, Guyana, French-Guiana, Brazil and West-Africa. Up till now Venezuela is the only country that has an identified kimberlite within the Guiana Shield (Simons, 2016). Diamonds are found mostly in alluvial depositions in West-Guyana, derived from the Roraima Supergroup sediments in West-Guyana or possibly from unidentified kimberlites (Tan, J.S.; Stachel, T.; Mortan, 2016). In Venezuela two diamond sources are known: those in the Roraima Supergroup deposits, of which the ultimate source is unknown, and those from the diamond bearing alluvial deposits in Guaniamo kimberlite West-Venezuela, (Meyer & McCallum, 1993). In Brazil most of the diamonds are found in the washings of alluvial deposits and it is believed that there are also kimberlites (Carolina kimberlite), that are diamondiferous (Hunt et al., 2009; Svisero, 1995).

3. RESEARCH METHODS

3.1 Fieldwork

In order to gather data fieldwork was done with the focus on the Paramakka and the American creeks. The Paramakka creek had the first focus with the aim to better understand the lithology of the drainage basins of the Paramakka creek, since it is the main driving force for material transport. Understanding the composition of rock units, could help identify possible diamond host rocks. Along this path, thirteen (13) creek sediment samples were taken figure below with the labels NRc1- NRc13 (see Figure 12).

On the second part of the fieldwork a visit to the spot where HAZLO found the first diamonds in 2016 (referred with DF in Figure 12 below); unfortunately, the spot was inaccessible due to pits that were completely filled with water, so that the tailing material could not be sampled for heavy minerals and possible diamonds. Based on the help and assistance of a local gold miner (referred in the Diamond in the Nassau Mountain section) the fieldwork focus came to the American creek, where diamond was still being found. Sediment samples were also taken along the American Creek and these are displayed by the labels of NRc9- NRc13. For this research Sample NRc4 and NRc8 were taken to represent the material in the Paramakka creek and the NRc10-NRc13 to identify the heavy minerals and indicators in the diamond area.

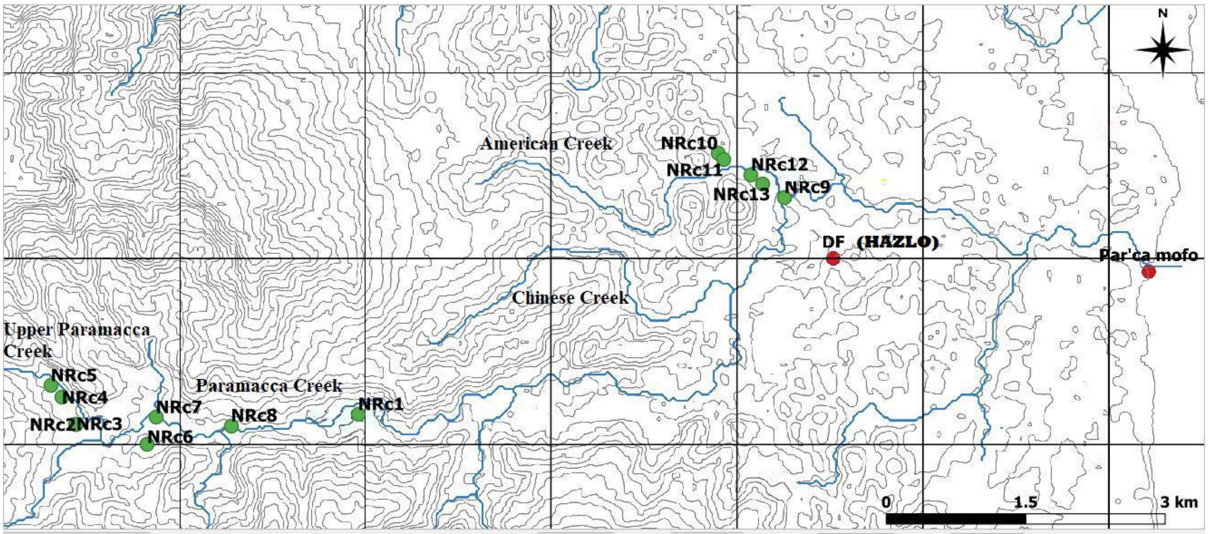

Figure 12. Topographic map showing the sampled locations *(Kroonenberg, Naipal, Paansa, & Sardjoe, 2019).* Map made by Ginny Bijnaar, MSc. Name description: DF (Diamond Find) by HAZLO and Par'ca Mofo (confluence Paramakka Creek with the Marowijne Creek).

Creek sampling was executed as followed:

1. Creek orientation on the map for finding passable paths to the creeks.
2. Finer grained sediments deposited between the bigger grain sizes like cobbles and boulders were sampled from the creeks. Each sampling spot is assigned a GPS-point.

3. Every sample was sieved to remove grains coarser than ± 1mm. They were mostly iron concretions and clayey aggregates.
4. The samples were panned, but not to the utmost concentration. Diamond indicators and other necessary minerals are lighter in comparison to the magnetite (± 5.14 kg/m^3) and gold particles (± 19.3 kg/m^3) that usually are present as dominant grains in panned concentration.

3.2 Labwork

3.2.1 Sieving

The hand the procedure differs from the mechanical sieving method and every sieve size is used individually.

ATTRIBUTES

a. Sieve trays with the sieve openings 500 µm, 250 µm, 125 µm.
b. Spray bottles
c. Trays for collecting the materials
d. Brush or pick – with soft hairs to clean out the sieve, to minimize material loss.

METHODS AND TECHNIQUES:

1. A suspension of sand and water was made, allowing the dust particles to settle.
2. The suspension was poured into the first sieve of 500 µm. The material of the sieve should be fully "drowned" in a bowl of water Figure 13).

Figure 13. A sieve with the wet material in a bowl of water

3. Remove the retained (i.e.= material that stays on the sieve) material from the sieve sets and thereafter dry and weigh Figure 14).

Figure 14. Retained material from the sieve (particles bigger than the sieve opening)

4. The sand particles smaller than the sieve (= material that has passed through the sieve) opening will be concentrated in the bowl Figure 15).

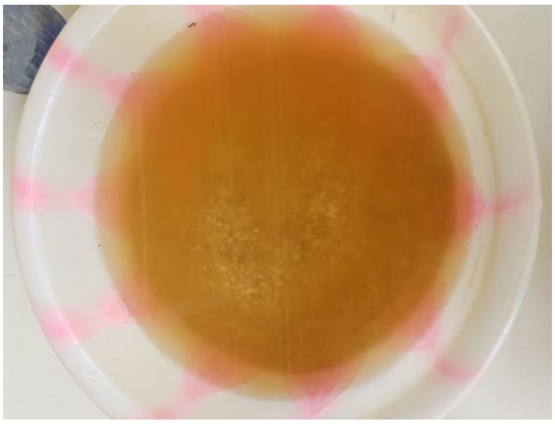

Figure 15. Material passed through the sieve (particles smaller than the sieve opening)

5. Every sample was then first put on the sieve set of 500 µm in order to categorize grains with a diameter > 500 µm.
6. Grains passed through the 500 µm are loaded unto the 250 µm sieve and so the grains passed through the 250 µm are then loaded unto the 125 µm.
7. The material passed through the 125 µm is the rest of the whole sample.
8. Every sieve set contains material bigger than the sieve openings; these remains are then carefully removed in order to sun-dry.
9. After being sun-dried these samples are then put back in sample bags with classification based on their grain size.

3.2.2 Preparing samples for density separation

1. For each sample used for density separation a weight of 40 grams was representative. This can be accurately done by the quartering method. Step by step guide in Figure 16.
2. The starting sample weight should be coned and should have the setting displayed in Figure 16a.

3. The top should be flattened out as evenly as possible, as in Figure 16b.
4. After the evenly flattening step; the sample was divided in two equal parts (this is called and further on referred as the first division), Figure 16c.
5. Followed by a second division (this is where the previously divided samples – reference to step 3- are once again divided; resulting is quarters, displayed in Figure 16d.
6. A representative sample was made by taking the opposite quarters for mixing, shown in Figure 16e.
7. The end sample that will be used for the density separation, must be weighted and should have the desired weight. If not quarter until the desired weight is achieved, according to Figure 16f.

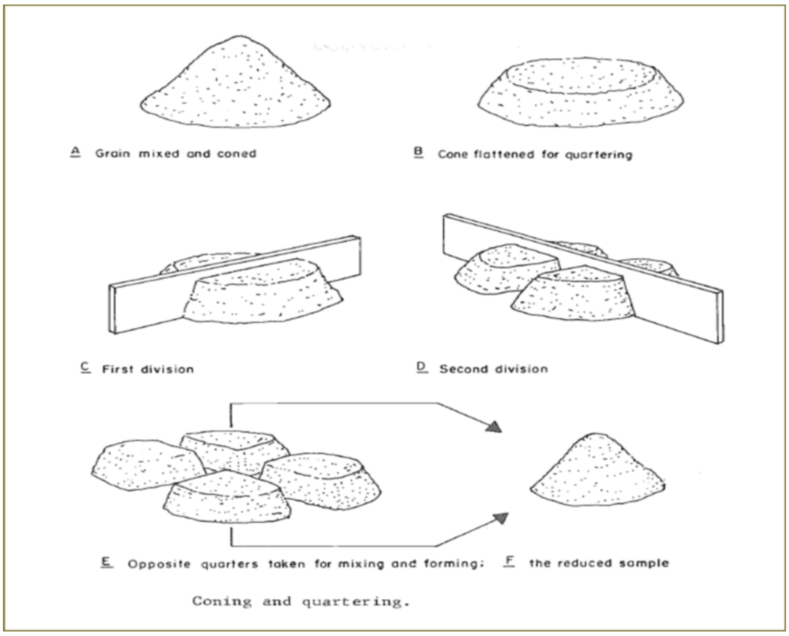

Figure 16. Coning and quartering: a step by step guide (Cachia, 2018)

3.2.3 Hematite and organic material leaching

Equipment and materials:

1. Beakers (300- 400 ml)
2. Hot plate with magnetic stirrer
3. 2M HCl
4. Flasks (2L) for fluid disposal
5. A lid – for covering the beaker

Methods and techniques:

1. The beaker was filled up to half of the beakers volume with 2M HCl and placed on a hot stove.
2. The liquid was warmed for five (5) minutes at 150° - 220° C
3. The sampled was cooked until the suspension started bubbling.
4. The acidic liquid is filtered into a disposal flask; the sediments concentrate in the filter paper.
5. Lastly wash sample thoroughly with tapped water
6. Let the sample dry

3.2.5 Density Separation

The density separation method below consists of a combination of different exercise manuals (Eby, n.d.; *Heavy Liquid Separation*, n.d.; *MINERAL SEPARATION AND PROVENANCE LAB EXERCISE*, n.d.) and papers (Brown, 1929; Mange & Maurer, 1992).

Equipment and materials:

1. Well ventilated fume hood
2. Heavy liquid- Bromoform ($CHBr_3$); around 100- 150 ml per 40-gram sample
3. Rubbing alcohol (70%)
4. Distilled water
5. Electric hot plate with magnetic stirrer (for removal of magnetic particles)
6. Filter paper (diameter 11mm)
7. Beakers (300 – 500 ml)
8. Separatory funnel (100 /500 ml) with pinch-cock
9. Glass funnels (40 – 50 mm)
10. Glass waste container
11. Squeeze bottles (containing alcohol and distilled water)
12. Glass stirring rod
13. Retort stand with clamps

Methods and Techniques:

1. Wash every glassware properly with tapped water, thereafter with distilled water and as last with the liquid the glassware will be used for. **Note**: the heavy liquid and alcohol go into a waste container.
2. Set-up the retort stand with the clamps and attach the separatory funnel and funnel with filter paper to the clamps; as displayed in the picture below. Lastly put an erlenmeyer flask (in this case substituted with a beaker).

3. Close the stopcock before adding the heavy liquid – bromoform- to the separatory funnels and fill the funnel to ½ of the funnel volume (Figure 17B-1).
4. Weigh every sample fraction- 40 gram is enough per sample fraction. In case a sample fraction does not add up to 40 grams, used the available weight and make a note regarding the weight.
5. Add the sample to the heavy liquid and stir the suspension in order to wet all particles and to remove air bubbles from suspension. **Note**: keep in mind the ratio of the material with the liquid with respect to the volume of the funnel (Figure 17B-1).
6. After the stirring; allow the sample to settle (this is where the separation starts). Stir occasionally to prevent particles sticking to the glassware. Close the separatory funnel with a glass/rubber stopper to reduce evaporation loss of the heavy liquid (Figure 17B-2).
7. When the heavy minerals have settled to the bottom of the separatory funnel (Figure 17B-3); open the pinchcock; allowing the heavy particles alone to drop onto the lower funnel with the filter paper. Close the pinchcock the moment all the heavy mineral particles have dropped, leaving enough liquid so the lighter particles can freely float within the separatory funnel (Figure 17B-4).
8. When all the heavy liquid as drained from the filter paper; remove filter paper carefully and turn upside down onto a watch-glass and wash down with alcohol, in order to remove all the particles from filter paper. Washing down the particles adhered to the filter paper will result in a solution (contaminated bromoform with alcohol), which can be re-used for washing down particles from filter paper. Afterwards this solution must be put into fluid waste container (containing liquids bromoform, alcohol, distilled water).
9. Dry heavy mineral fraction retrieved at step six (6). Afterwards weigh the samples and label for microscopic and composition analysis.
10. Using the same procedure for draining heavy minerals, drain the remaining liquid with lighter mineral fraction onto the funnel below (use other/non-used filter paper, not the same of heavy fraction in order to avoid contamination). It may be necessary to wash the adhere particles from the separatory funnel; first replace the funnel of undiluted/contaminated bromoform with the fluid waste container.
11. Do the same particle removal from filter paper steps mentioned in the steps 6 and 7, collect, dry, weigh and label for composition analysis.

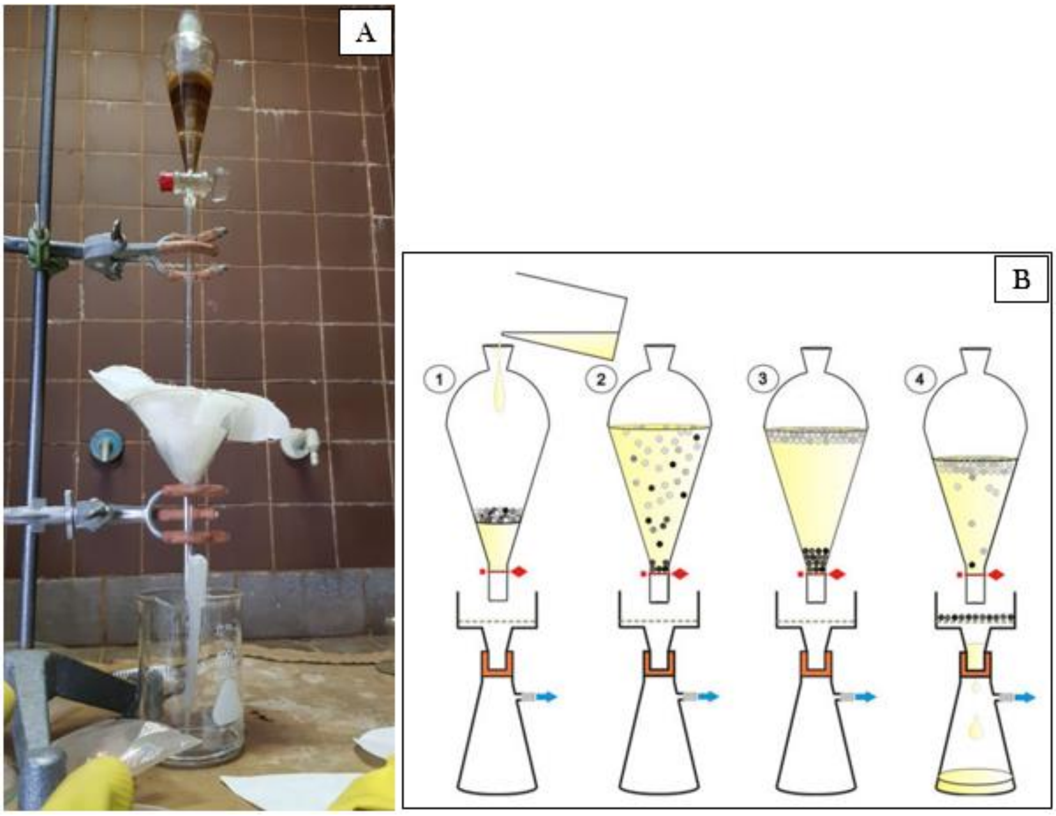

Figure 17. (a) Setup of glassware and example of density separation and (b) displaying the separation process (according to the above described procedure)

3.2.6 Preparation microscopic slides

Equipment and material needed:

1. Canada balsam
2. Microscope slides
3. Microscopic glasses for covering microscopic slides
4. Electric cooking plate
5. Pointed tweezers

Methods and techniques used:

1. Put the microscopic slide on an electric cooking plate and heat this to 50°C.
2. The microscopic slide should be slightly warm before adding the Canada balsam, this prevents the balsam to cool off and start sticking.
3. Distribute the balsam thoroughly onto the microscopic slide.

Figure 18. Displaying the distribution of the Canada balsam over the slide

4. Add the mineral grains bit by bit to prevent grains overlaying each other; use the tweezers to add the grains.

Figure 19. Figure Displaying the mineral grains distributed over the slide

5. Remove the slides from the electric cooking plate and put unto a relative cooler surface.
6. At last cover the slides with the microscopic glasses and press gently allowing the glass to stick to the grains.
7. Lastly let the microscopic slides dry and then view under a petrographic microscope.

3.3 Microscopic labwork

Microscopic analysis is conducted on the basis of optical properties pre-defined per mineral. These properties are visible with a petrographic microscope under the effect of direct light; these properties are (Einhardt et al., 2012):

1. **Plane Polarized Light (PPL)**
   a. **Form:** is the mineral form varying from euhedral (=original form), subhedral (=form borders are identifiable) and anhedral (=no identifiable form). This property can also be defined by an angular, sub angular/ rounded, well rounded character.
   b. **Relief:** is the intensity of the mineral border lining, which can vary from low (not clearly visible, medium and high (dark and accentuated border). The relief can have a positive

or negative character, based on the Line of Becke migration inwards or outwards; more information can be found on page 79 in (Einhardt et al., 2012).

c. **Pleochroism:** is characterized by a color change and are classified as weak pleochroism (low color change e.g. colorless to light yellow), medium (e.g. colorless to yellow) and strong (e.g. colorless to brown or blue).

d. **Cleavage and fractures:** these properties are mineral defined characteristics.

2. Crossed Polarized Light (XPL)

a. **Interference color:** the color change under crossed polarized light, where colors go colorless PPL color to first order grey or second order blue.

b. **Extinction:** is a mineral defined property and occurs when XPL light fractions dims, causing the mineral to go black in a specific orientation.

4. RESULTS AND DISCUSSION

RESULTS

4.1 Fieldwork

The first focus of the fieldtrip was the orientation and research focus to understand the lithology and the geology of the area in close range of the Paramakka creek (NRc1 – NRc8) with sample description in

Table 1) based on fresh unweathered rock samples. However, no other fresh rocks were observed than dolerites, meta-volcanics, pebbles and well-rounded grains, meta-basalts and meta-gabbro's. The material along the creek (in situ material) vary from angular to medium rounded consisting of a combination of clay, iron-oxide and quartz to quartzite coarser grains like pebbles. The other creek of interest, the American creek (NRc9 – NRc13 in (

Table 1) did not yield any rock samples, apart from weathered schists, but it is expected that more in situ rock samples should be present further upstream of the American creek. Along the terrace there is an abundance of angular milky quartz, which is distributed in an alluvial fan setting up to the confluence with the Paramakka Creek onto the Marowijne flat dissected terrace. These quartz fragments are angular in the American Creek area and are a bit sub-rounded in the Marowijne terrace strip; see Figure 20.

Figure 20. Rounded quartz pebbles in the Marowijne River terrace strip near Krikimofo (Source: Prof. S. Kroonenberg)

Table 1. Sample GPS-coordinates with sample description. Revised after (Kroonenberg, S. B.; Naipal, R.; Paansa, B.; Sardjoe, 2019)

Sample name	Easting	Northing	Sample description
NRc1	771921	536327	Baté concentrate contain gold and other heavy minerals (common magnetites)
NRc2	768884	536217	Baté concetrate containing material from the surrounding meta-basaltic lithology.
NRc3	768890	536225	
NRc4	768734	536510	
NRc5	768615	536637	
NRc6	769652	536002	
NRc7	769746	536295	
NRc8	770554	536205	
NRc9	776508	538662	Sieved sample of tailing (main mineral milky angular quartz)
NRc10	775792	539133	Baté sample quartz sand (milky, angular quartz 3-5 cm)
NRc11	775851	539068	Sieved sample of in-situ quartz sand
NRc12	776149	538903	Sieved sample of in-situ coarse grained quartz
NRc13	776277	538807	Sieved sample of in-situ red soil (quartz and iron-oxide)

4.2 Labwork results

4.2.1 Microscopic results

IDENTIFIED MINERALS WITH THEIR PROPERTIES

The following minerals grouped in this section are identified as the diamond indicator minerals:

1. **Clinopyroxene (cpx)**: occurs as subhedral with a low-medium positive relief. Clinopyroxene occurs with a yellow-greenish color (see Figure 21a) with no pleochroism. This grain shows a one-direction cleavage on the visible face. The interference color is not clearly visible but shows a light colorful range and has a 45° extinction.

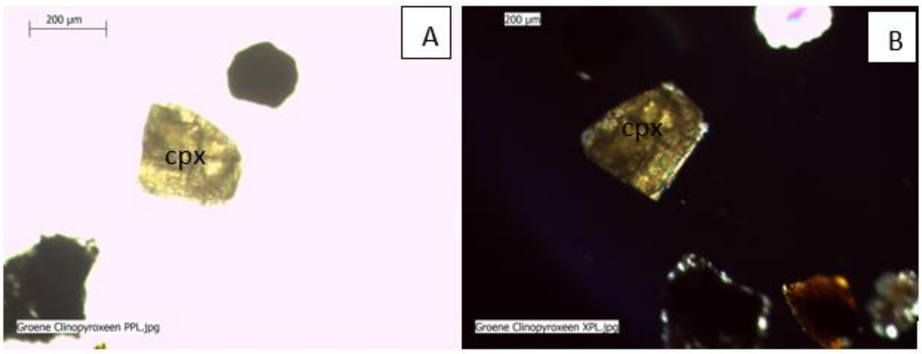

Figure 21. (a) Cpx under PPL with the yellow-greenish color and in (B) cpx under XPL with the colorful colors as interference color. American creek- NRc12 > 125 µm

2. **Garnet (gr):** occurs as a subhedral to anhedral mineral with a high relief (dark brown edges; (Figure 22) with positive character. The color of the garnet is colorless with light brown spots and shows no pleochroism. The garnet grain displays some light fractures. Garnet is an isotropic mineral and therefore under XPL the mineral turns completely black, displaying no optical properties.

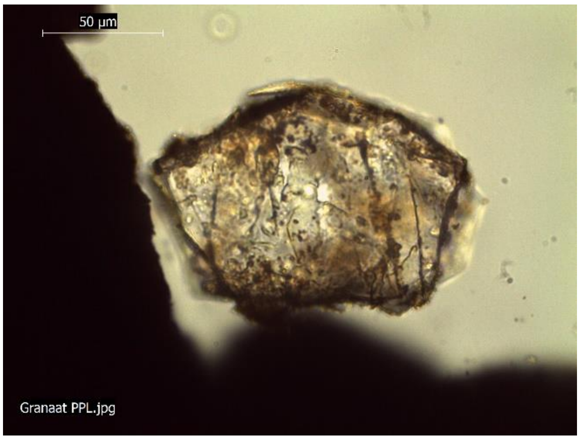

Figure 22. Garnet under PPL and in XPL this appears to be isotropic. American Creek- Sample NRc12 > 125 µm

3. **Cr-Spinel (chromite):** occurs as an anhedral mineral with medium-high positive relief. The color of chromite is light to dark red to red brown (Figure 23a) and shows no pleochroic behavior. Chromite and other spinels are isotropic minerals and show no interference color and is black under XPL. The chromite grains throughout the samples vary from color due to the uneven thickness of the grain.

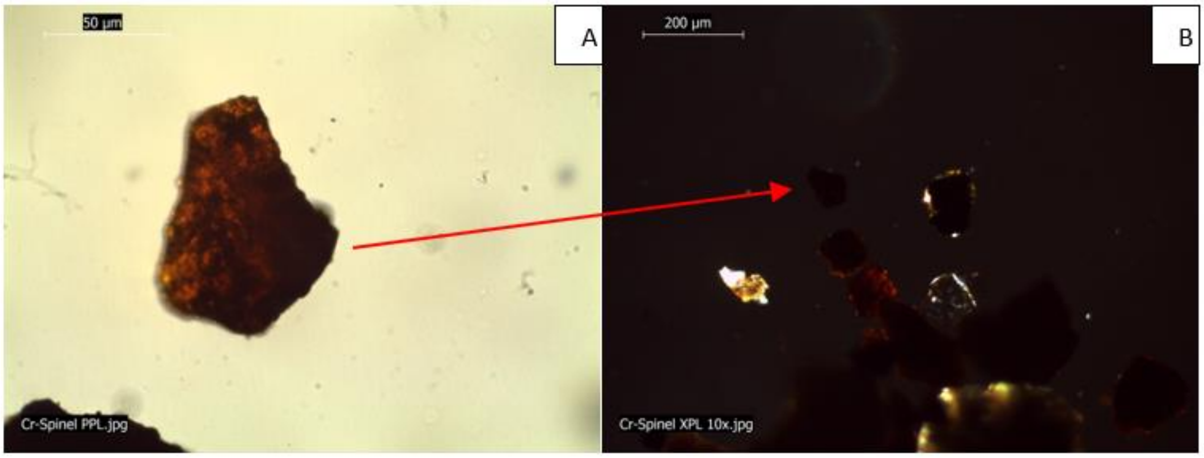

Figure 23. (a) Cr-Spinel in PPL under magnification of 50x, which is an important diamond indicator and (b) is the same spinel under XPL which appears to be isotropic (magnification 10x). Paramakka Creek- Sample NRc4 >125 µm

Other heavy minerals that are present are:

1. **Zircon (zr):** occurs predominantly in the samples NRc12 and NRc13 as a euhedral to anhedral mineral with a high relief (dark halo edges; Figure 24a) with a positive character. The

zircon grains are colorless, brown and pink and show no pleochroism. The interference color of the zircon is colorful and in metamorphosed zircon grains the color are visible in the zoning pattern. Zircon has a parallel extinction.

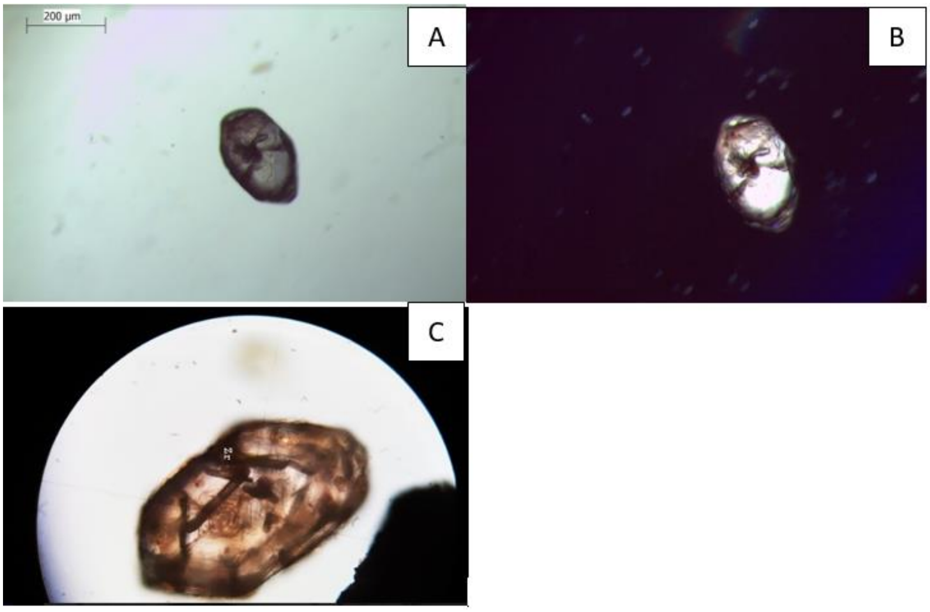

Figure 24. (a) High relief colorless zircon under PPL (b) Under XPL zircon shows a predominantly color zoning (c) shows a dark-brown zircon with internal zoning character under PPL. Paramakka Creek- Sample NRc4 > 125 µm

2. **Fluorite (fl):** occurs as a well-rounded (anhedral) mineral with a medium-high negative relief. The grain is colorless (Figure 25a) and shows no pleochroism. Fluorite shows an isotropic behavior. The grainsize of fluorite is around 63 µm.

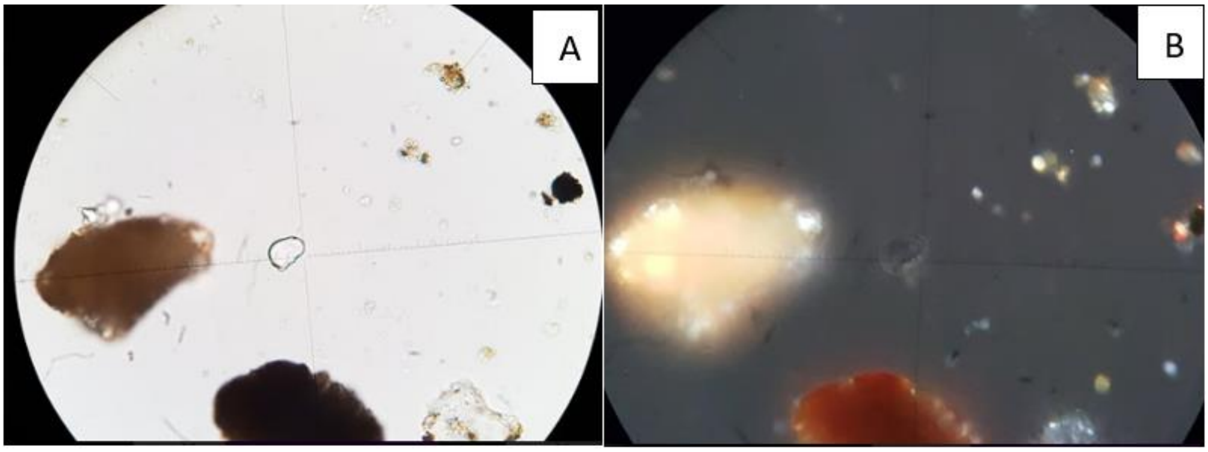

Figure 25. (a) Shows a micro-diamond (colorless grain with a light dark edge) and the same grain in (b) displaying isotropic behavior. American Creek- NRc11 <125 µm

3. **Orthopyroxene (opx):** occurs as sub-rounded with a medium- to high positive relief. Orthopyroxene has a light green-yellowish color with a weak pleochroism. Interference color

is intensified green and a parallel extinction. This grain shows a shard like texture, visible in Figure 26a below.

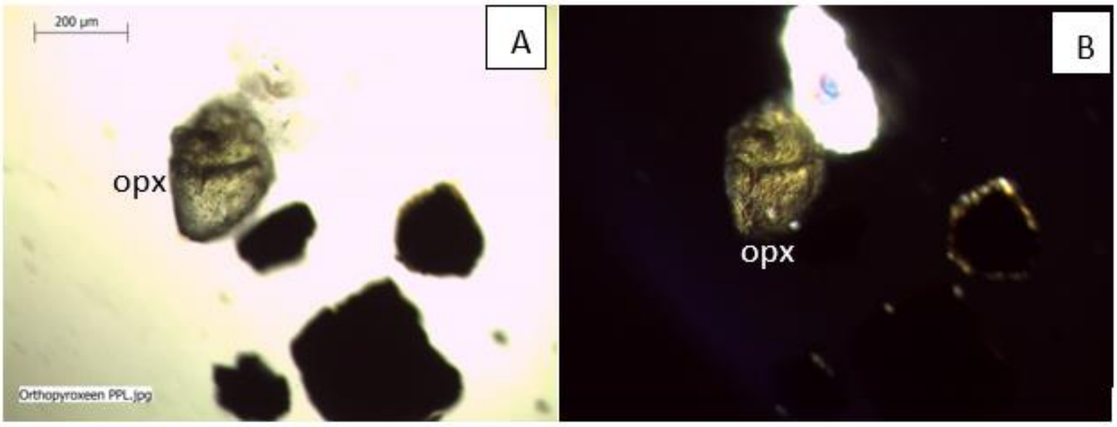

Figure 26. An orthopyroxene mineral under PPL (A) and XPL (B) found in the sample. American Creek- NRc12 > 125 µm fraction.

4. **Tourmaline (tour):** occurs predominantly as euhedral- subhedral (Figure 27a), elongated with a medium- to minimal high positive relief. Tourmaline has a characteristic property, the striations, these striations are parallel lines on the cleavage face. It occurs as a colorless-yellow, light-brown and a strong pleochroism of colorless to brown or greenish blue (this is more common in the samples. The interference color of tour is in the light colorful range and has a parallel extinction.

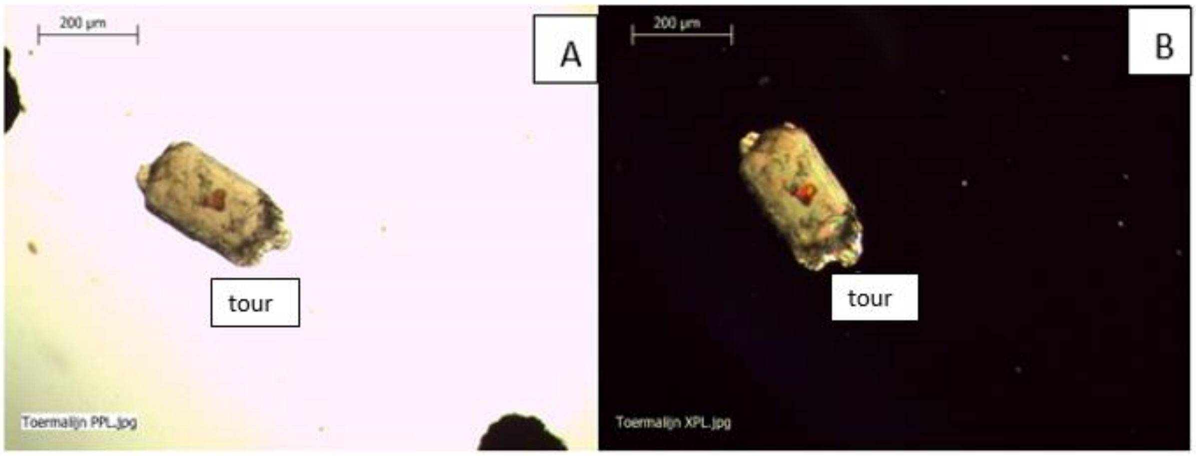

Figure 27. (a) Displays a yellow elongated tourmaline under PPL and (b) a colorful color range along the striations under XPL. Paramakka Creek- Sample NRc8 > 125 µm

5. **Apatite (ap):** is a trace mineral that occurs with a high relief and positive character. Apatite is commonly colorless (Figure 28a) and has no pleochroism. Under XPL the apatite has an interference color of light yellowish-grey (Figure 28b). The apatite extinction in the literature is parallel, however it was not clearly visible in the sample. Also, apatite grains tend to be fluorescent; under blue ultraviolet light the apatite-grains turn orange-yellowish.

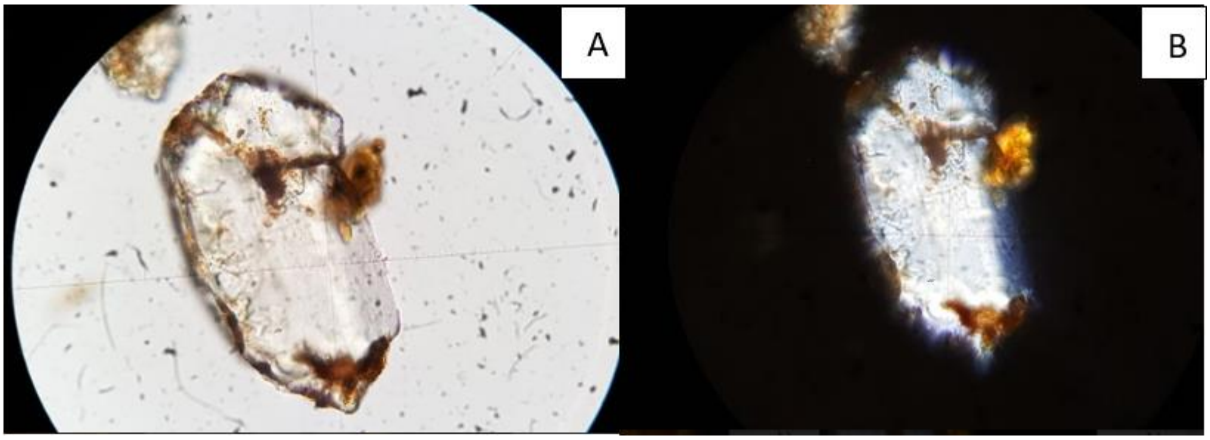

Figure 28. (a) Displays an apatite grain with high relief under PPL and (b) shows the apatite under XPL mode displaying a grey interference color. Paramakka Creek- Sample NRc4 >125 μm

6. **Chlorite (chl):** occurs as an aggregate-like texture of fibers and a low relief. Under PPL the mineral shows a dark green to greyish color (Figure 29a) with a light pleochroism. The interference color of this grain displays a black to blue like color (Figure 29b), which is caused by contamination of the grain. The extinction of the chlorite was not clear, but literature indicates an inclined extinction varying between the 0 – 10° degrees.

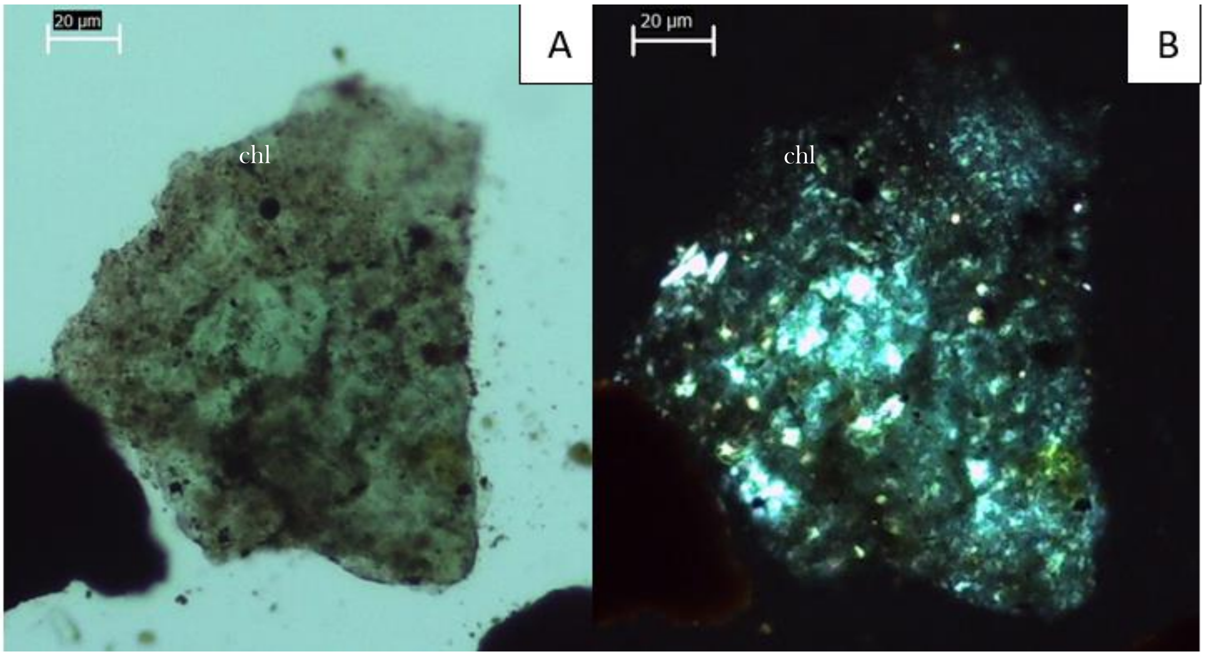

Figure 29. (a) Chlorite (grey-ish) under PPL -right above- and (b) Chlorite under XPL. Paramakka Creek- Sample NRc12 > 125 μm

7. **Staurolite (st):** occurs as an anhedral mineral with medium positive relief. St occurs as a golden yellow colored mineral under PPL (Figure 30a) with a pleochroism from golden yellow to yellowish brown. The interference color yellow golden and a bit of green (Figure 30b) and an undetermined extinction in the sample.

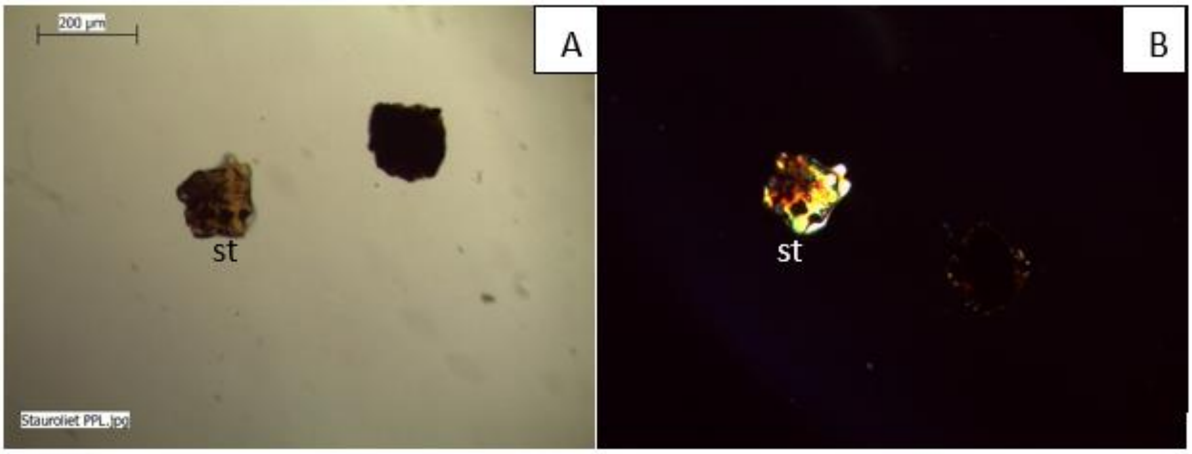

Figure 30. (a) Displays a staurolite grain with an unidentified opaque (black) mineral and in (b) staurolite shows the yellow to orange colors under XPL. American Creek- Sample NRc12 <125 µm

8. **Spinel (sp):** is an anhedral mineral with medium to high positive relief. The color of spinel is light-dark turquoise (blue green blend; Figure 31a) and shows no pleochroism. Spinel is an isotropic mineral (Figure 31b) and therefore shows no interference color. Spinels do not display extinction.

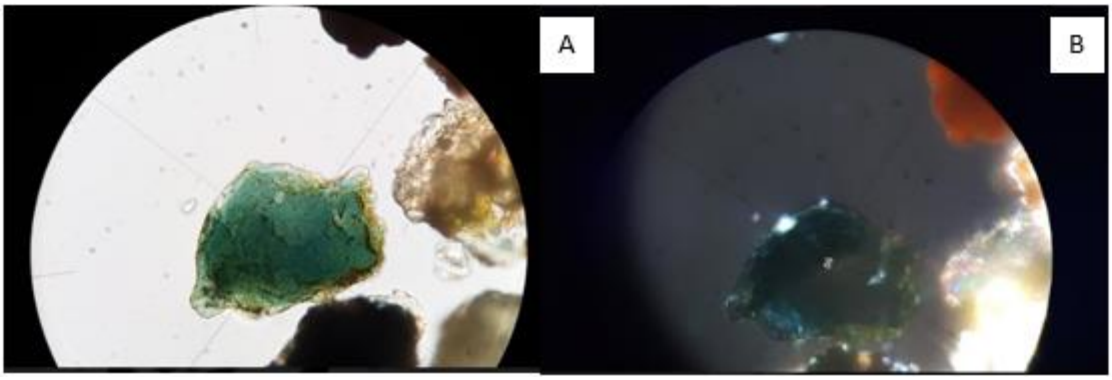

Figure 31. (a) Displays a spinel grain under PPL an (b) the isotropic spinel behavior under XPL. Paramakka Creek- NRc8 < 125 µm

9. **Hornblende (hbl):** is a light green mineral with a strong pleochroism from green to dark blue and has low to medium relief with a positive character under PPL. In the XPL mode the color of the hbl is blue and the extinction of the mineral is around the 12° - 34°.hbl has a positive elongation and a two-way cleavage in some grains.

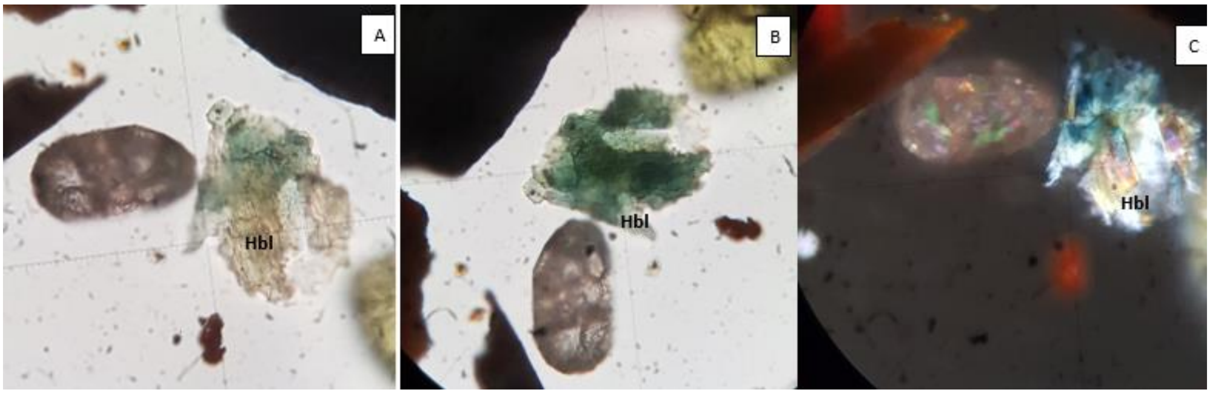

Figure 32. (a) Shows a light green-blueish hbl grain (b) the same hbl grain but displaying the strong pleochroic character and (c) the blue color under XPL mode.

10. **Epidote (ep):** is an easy identifiable mineral with a medium positive relief. Epidote is yellow-greenish (Figure 33a) and has a pleochroism of yellow to greenish. Epidote has bright colors (Figure 33b) as interference color and shows a parallel extinction.

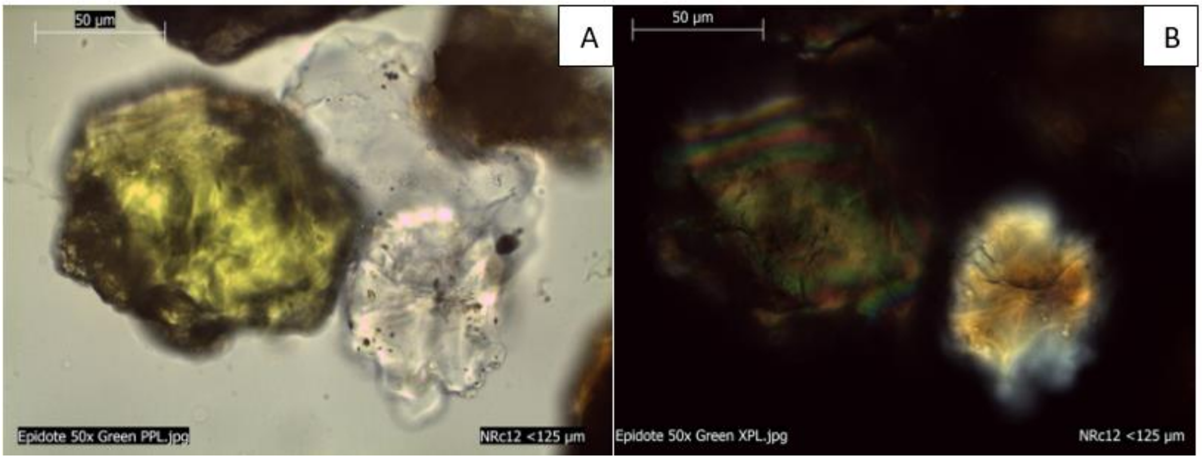

Figure 33. (a) Displays a yellow green epidote under PPL and (b) the interference color (rainbow like color range) under XPL. American Cree, NRc

12 < 125 µm

11. **Rutile (Rt):** occurs as a subhedral to anhedral mineral with high positive relief. The color under PPL is brown-reddish (Figure 34a) and shows a weak pleochroism from red to brown. The interference color is not clearly visible in this grain and shows a twinning (around the 60°; elbow twinning) (Figure 34b). Rutile has a parallel extinction.

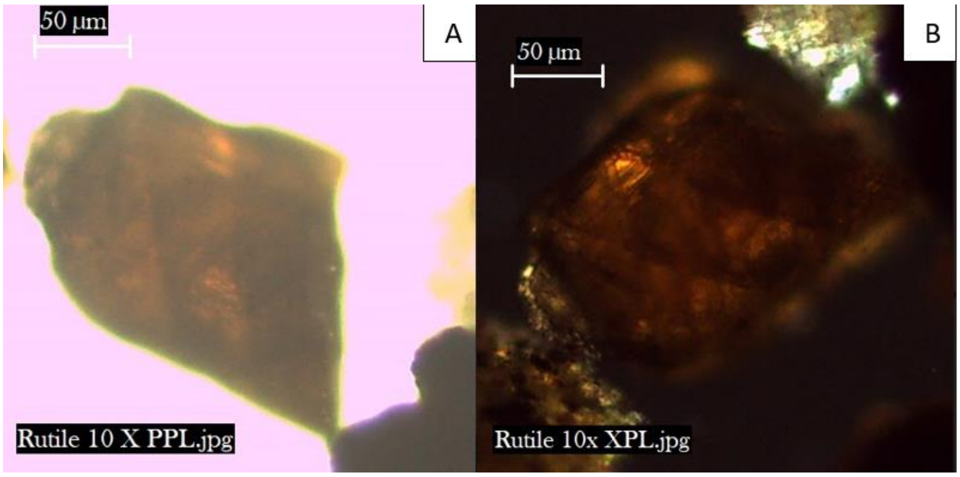

Figure 34. (a) Displays the rutile under PPL (red-brown color) and the twinning pattern (b) displays the same grain under XPL. American Creek- Sample NRc10 <125 µm

12. Opaque: this is a cubic shaped mineral (Figure 35) which is opaque and not displaying optical properties. This mineral can be a magnetite, ilmenite or pyrite simply based on the shape.

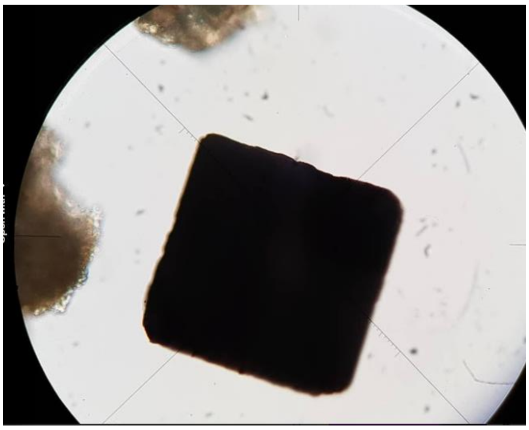

Figure 35. Displays a cubic opaque mineral

4.2.2 Mineral abundance charts

The mineral abundance per sample is given below in charts with the abundance level on the vertical axis and the sieve opening on the horizontal axis.

Note: the opaque mineral bar is the **only** bar in all the charts that has the same color (black) and has values between 0 – 10. The 0 - 10 values correspond with 0% -100% opaque abundance in a microscopic slide. Every other mineral besides the opaques are limited to the following classification (Revised after (Schönberger, 1975)):

1) 1 = rare mineral (1-3 grains)
2) 2 = common mineral (3-6 grains)
3) 3 = abundant (6+ grains)

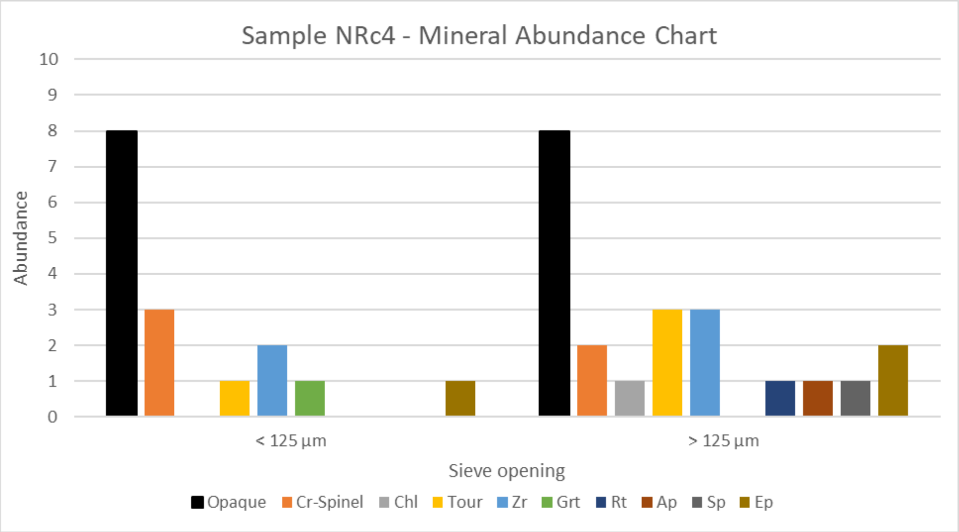

Chart 1. Displays the heavy minerals present in sample NRc4 from the Upstream Paramakka separated in two fractions < 125 µm and > 125 µm. This sample has common to abundant Cr-spinel (chromite – diamond indicator), 1-2 grains of Rt (rutile), Ap (apatite) and 1 grain of blue Sp (spinel) and common minerals like Tour (tourmaline) and Ep (epidote). Opaque minerals are abundant.

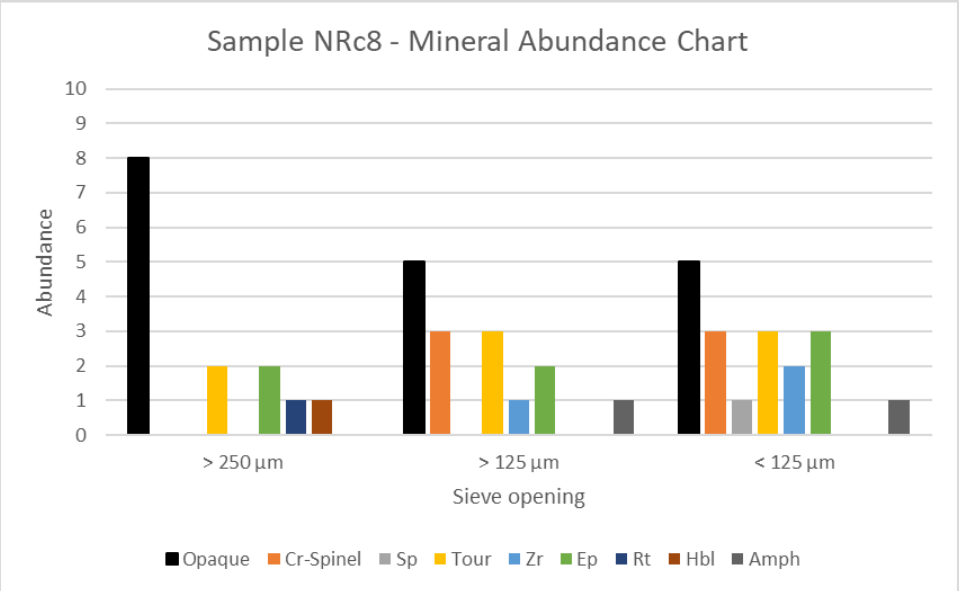

Chart 2. Sample NRc8 of the mid-Paramakka Creek shows an overall abundance of Cr-spinel, tour, ep and zr. Rear minerals are rt, hbl and types of dark amphiboles. Opaque minerals are overall high in occurrence.

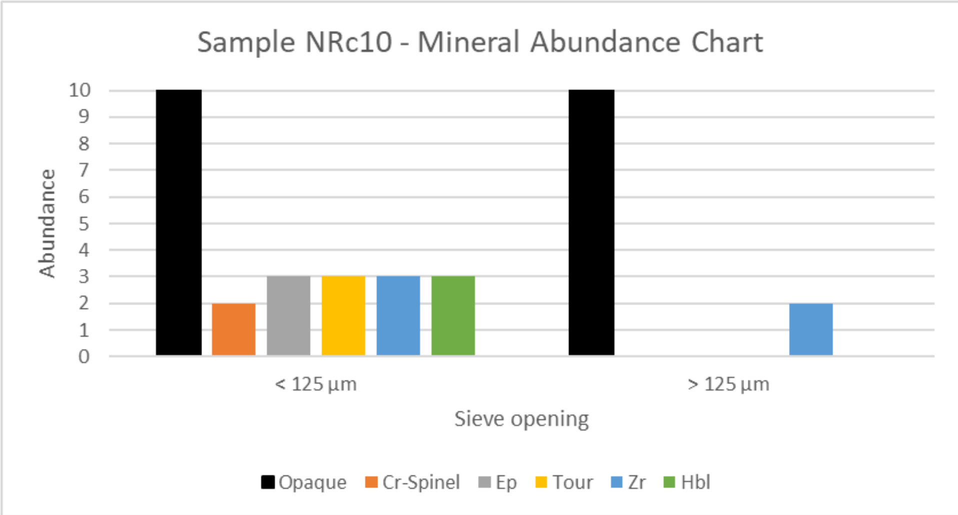

Chart 3. Sample NRc10 is from the American Creek and shows an abundance of opaques and more common minerals like tour, hbl, ep and zr in the smaller fractions.

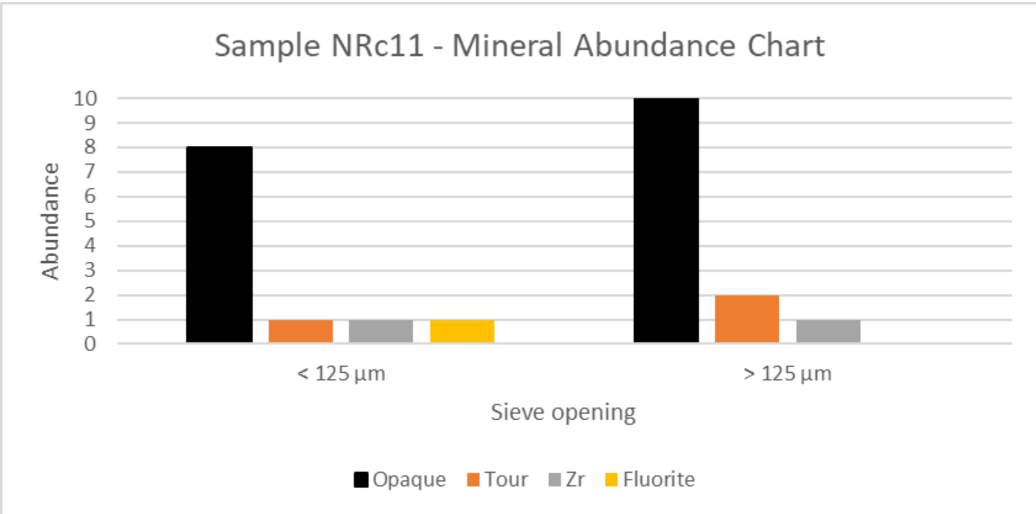

Chart 4. Sample 11 is from the American Creek and is situated in the area of diamond findings. The microscopic slide with the grains > 125 µm has shown one (1) microdiamond (see diamond microscopic description on page 32). Other heavy minerals are tourmaline as common to abundant and zircon, however no diamond indicators except diamond itself was present.

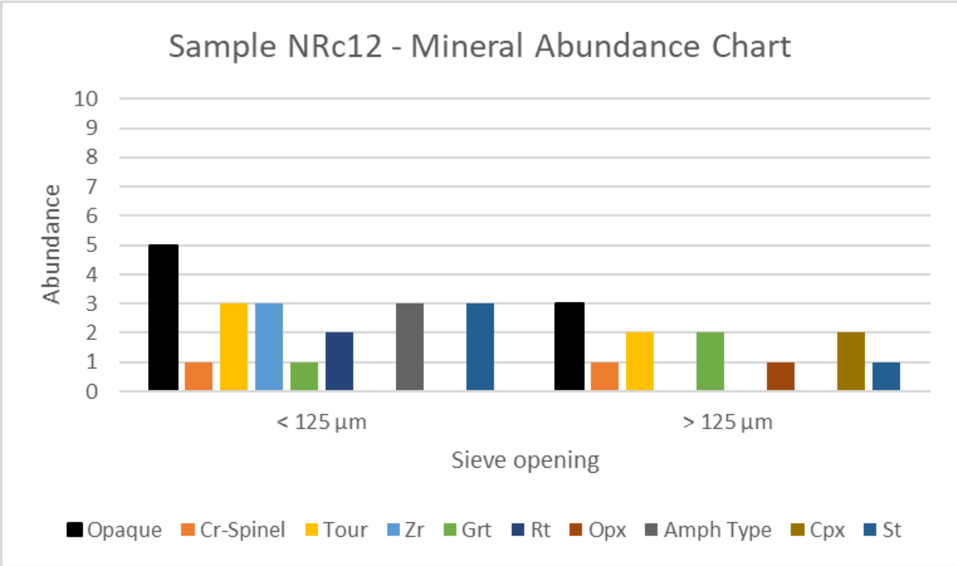

Chart 5. Sample NRc12 is also from the American Creek and has shown to contain more metamorphic minerals with small (rear) occurrences of Cr-spinel and St (staurolite). This sample contains two varieties of pyroxenes, these are clinopyroxene (cpx - possible diamond indicator if it is the Cr-diopside variety) and orthopyroxene (opx).

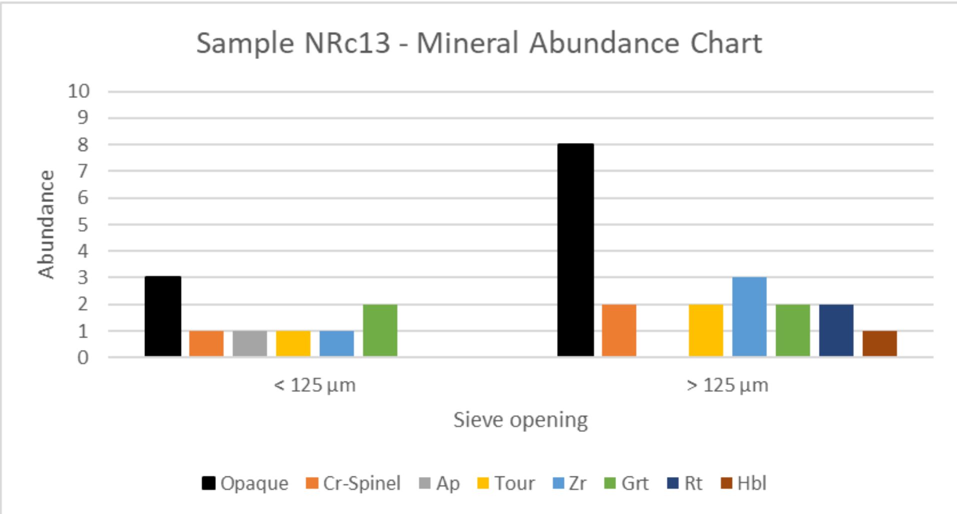

Chart 6. This sample NRc13 is from the American Creek; most of the diamonds are found in and nearby area. This sample indicates an overall abundance of Cr-spinel and garnet in the > 125 µm.

DISCUSSION

Field data from the American and Paramakka creeks indicated a coarser grained sediment load, which indicates a nearby accumulation of provenance which can be igneous and or metamorphic sediments. The American Creek alluvial fan consists of white very coarse angular quartz grains in the uphill mid-stream segment in comparison to the down-stream (terrace plain) where the grains are smaller. This has indicated an idea of alluvial fan concept, which is substantiated by the drainage pathways based on the contour interval. These alluvial fans have distributed their sediment load onto the dissected 50m Marowijne terrace strip, displayed in

Figure 36.. The Paramakka Creek sediments show primarily opaque and metamorphic heavy mineral, therefore indicates a metamorphic provenance, which is also reported by (De Munck, 1954)). However, the whole area of research contains metamorphic sediments also derived from heavy mineral charts and field data.

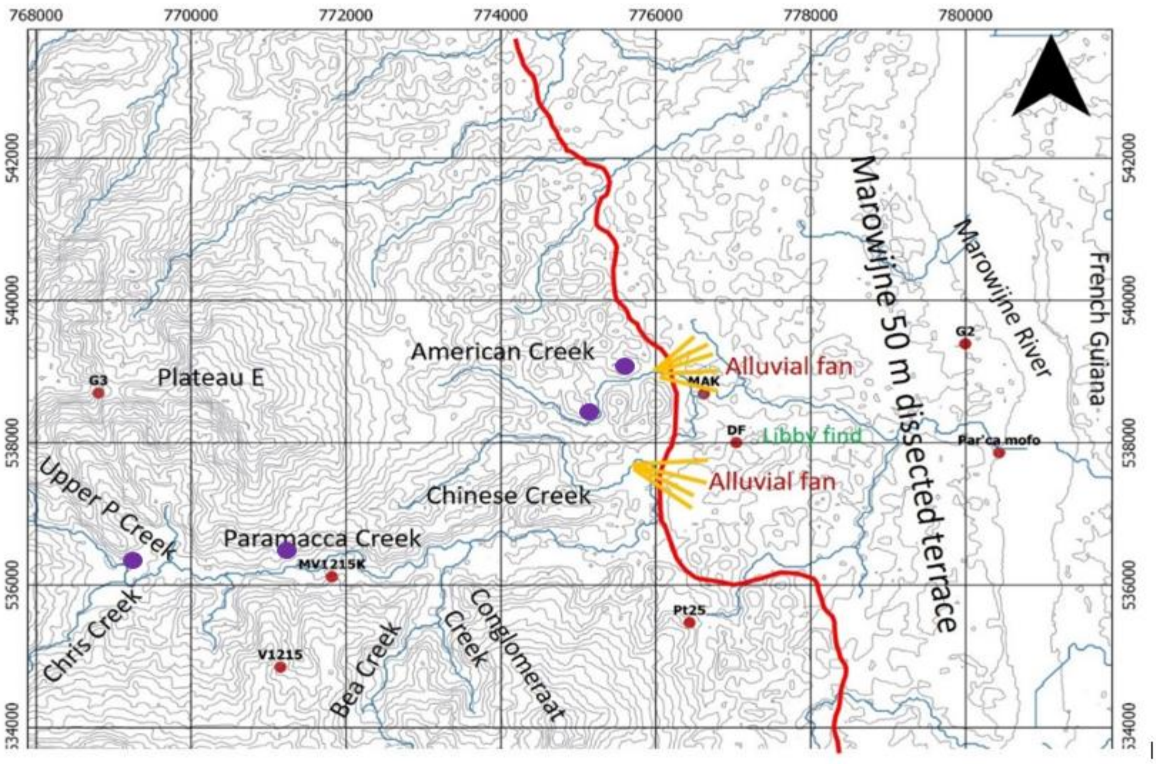

Figure 36. Field data results with the presence of alluvial fans found in the American creek containing angular quartz, the unidentified (= meaning no geological data) Plateau E and other like DF (diamond find by HAZLO) and the Marowijne river terrace (Kroonenberg, S. B.; Naipal, R.; Paansa, B.; Sardjoe, 2019). The purple dots indicate the presence of chromite grains.

The Nassau Mountain shows the presence of igneous, sedimentary (conglomerates) and metamorphic rocks. The heavy minerals in the creek sediments can be labeled as opaque and non-opaque minerals. The opaque minerals are not identified and therefore grouped under one term and are possibly hematite, ilmenite (which, if magnesian, is also an important diamond indicator) chromite and magnetite. The non-opaque minerals present in the samples were: tourmaline (greenish, brown and pink), rutile, chlorite, staurolite, epidote, zircon, hornblende, pyroxene, spinel and apatite. Also present primarily in the samples NRc10 – NRc13 are possible diamond indicator minerals like: green clinopyroxene (not identified to be the Cr-diopside), Cr-spinel (chromite), garnet. The abundance and presence of these minerals are displayed in the charts in section

4.2.1 Microscopic results.

Minerals like clinopyroxene and orthopyroxene indicate towards a more igneous (mafic to ultramafic) provenance and garnets point towards a metamorphic setting. Present diamond indicates a more common in an igneous rock setting, like a kimberlite or lamproite. Cr-spinel (chromite) are dominantly occurring in igneous – ultramafic rocks. Zircons are commonly formed in igneous rocks, but the mineral form of the zircon indicates another possible rock provenance. Euhedral zircon indicates an igneous provenance, rounded (sub-angular and more rounded) zircon gives a possible reworked sedimentary provenance and internal zoned zircon (forms differs) indicates a metamorphic provenance. Tourmaline, epidote, staurolite, spinels have a more metamorphic provenance, however tourmaline also commonly occurs in pegmatites (indicating an igneous setting). Minerals like rutile and apatite can be found in all three rock types. Sample NRc4 (see Chart 1) and NRc8 (see Chart 2) both indicate a dominant metamorphic environment; noticeable is the abundance of chrome spinel that indicate possible diamondiferous occurrences; more about this possibility later on. The metamorphic dominant character is also visible from fieldwork results, which did not yield fresh rocks but weathered rocks. Sample NRc11, NRc12 and NRc13 indicate an overall abundant garnets and common chrome spinel and a single to two clinopyroxene as possible diamond indicator. Other diamond indicators like ilmenite and identified Cr-diopside can be present. The provenance of these sediments can also give an indication about the distance of transportation or weathering; based on the charts of sample NRc10 – NRc13 indicate the grain size to be smaller than < 125 μm. The size is possible due to alluvial transportation and friction of grains with each other or surfaces and by weathering the grains weaken and tend to break.

Based on the information gathered from heavy mineral analysis, field results and the geological map of the Nassau Mountain by (De Munck, 1954)), the possible source- and host rocks can be derived: [1]

1. **Plateau D or Plateau E**

   These two plateaus are in close range of each other according to the geological map of (De Munck, 1954) in [Cross-reference the picture]. Plateau D consists mainly of Rosebel serie material (conglomerates and sandstones) and Paramakka serie (volcanics and possible ultra-mafic rocks) and the Nassau serie bauxite-lateritic caps material. Plateau E has no proper identified data except being bauxite-lateritic covered and in the area of the Bonidoro serie which contains phyllites. The Plateau E may contain remnants of the Rosebel serie and the Paramakka serie, because of the close range to Plateau D; it also is

[1] **Note:** The old geological rock unit classification used in the report of (De Munck, 1954) is used for easier referencing

situated in the extension plane of plateau D. Plateau D and E are represented by the NRc4 sample, which represents these two plateaus' sediments. Forthcoming out of this theory these two scenarios are probable:

- → **Plateau D** has enriched the upper Paramakka Creek with chromite, resulting in abundant (6+ grains) behavior; the Paramakka Creek may have deposited these diamonds onto the dissected Marowijne terrace, nearby the American and Chinese creeks confluence and where HAZLO found the diamonds in the tailings (Diamond find (DF) in
- → Figure *36.*). Note that the abundance of chromite does not necessarily mean that the Paramakka Creek is diamondiferous.
- → **Plateau E** in (
- → Figure 36. is in an uphill area based on the close contour intervals (also visible in same figure). This indicates a steep plane in comparison to a wider contour interval around the American and Paramakka creek, which indicates a flatter plane, which can function as an accommodation plane for these diamonds. These diamonds and their indicator minerals are deposited onto these terraces, where the alluvial fan material also occurs; creating an alluvially deposited environment, as can be seen from field data.

2. **Rosebel serie above Plateau D**

   In the map of (De Munck, 1954) a large Rosebel serie sedimentary body (deposit) is present in the north-western point of Plateau D. Known from previous research that the Rosebel formation can be diamondiferous, based on the diamond finding in the Rosebel Gold Mines gold concession. This may have enriched the possible Plateau D, because of the close range. Well-rounded pebbles of clay, iron-oxides and quartz indicate the presence of possible conglomeratic (sedimentary) provenance.

3. **Possible kimberlite/ lamproite**

   This is a possibility that in the nearby area or in Suriname there may be an ultramafic intrusion which has sampled the diamonds during the formation and therefore has enriched the Rosebel serie (based on diamond findings in the Rosebel formation (according to new geological formation description)) and are deposited with the conglomerates and sandstones.

The occurrence of these diamonds in the Nassau Mountain area have indicated that the host is in the nearby area; however, the ultimate source (kimberlite or lamproite) is not known, for there is not enough data to correlate this to the possible findings. Transportation of these paths based on research data and regional diamond occurrences, it is possible that these diamonds where sampled by the kimberlites or lamproites as primary source rock. These ultramafic rocks have then weathered and eroded their diamonds and associated minerals through drainage basins and alluvial deposits. In the context of Venezuela and Guyana it is the Remnant of the Roraima

Supergroup that has concentrated these diamonds and transported these through placer deposits. The same may have happened and were transported to the nearby laying countries.

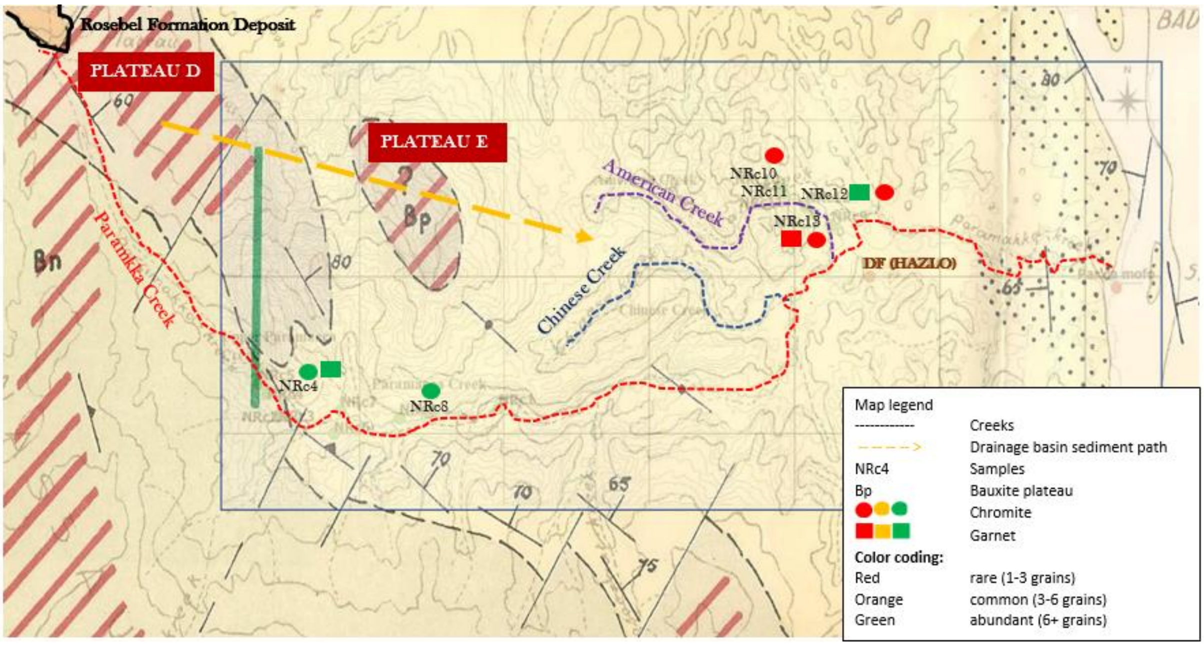

Figure 37. Geological map of the Nassau Mountain (De Munck, 1954) projected over the topographic map from (Kroonenberg, S. B.; Naipal, R.; Paansa, B.; Sardjoe, 2019). The orange thick dashed line indicates the path which sediments follow according to a drainage basin system. Sample NRc4 and NRc8 have plotted abundant presence of chromite and garnet grains (respectively green circles and green squares). Sample NRc4 indicates Upper-Paramakka Creek enrichment of chromite and NRc8 the mid-Paramakka Creek.

5. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

In the American Creek of the Nassau Mountain, diamonds are found and searched for as an accessory mineral besides gold. These diamonds are mainly found in the confluence of the American Creek with the primary Paramakka Creek and the alluvial fan deposits on the 50m Marowijne dissected terrace. The possible host-rocks for these diamonds can be the Plateau D and Plateau E (mainly consisting of Rosebel-, Paramakka- and Nassau sediments), which may have enriched the upper to mid Paramakka Creek and alluvial fan American Creek with these diamonds and their indicator minerals, through drainage basin systems. Also, the possible source can be the Rosebel serie based on the diamond findings in the RGM-concession and probable unidentified kimberlite/ lamproite bodies. The indicator minerals for diamond throughout the area are chromite, clinopyroxene (if chromian-diopside) and garnet; dominantly occurring in the mineral sizes smaller and coarser than the 125 μm fraction. The other heavy minerals present are: tourmaline, rutile, chlorite, staurolite, epidote, zircon, hornblende, pyroxene, spinel, fluorite and apatite; which indicates an overall metamorphic provenance distributed over the fractions smaller and coarser than 125 μm.

RECOMMENDATIONS

- Research must be done on the Nassau Mountain area in order to date up the geological information, especially the geology of the “Plateau E”, in order to better understand the northern part of the Mountain.
- Exploration for diamonds in the upper Paramakka Creek area close to the Plateau D and the presence of the Rosebel Formation deposition, according to the geological map of de Munck from 1954.
- Create thin sections (polished microscopic slides) for geochemical analysis and a proper optical mineral identification.

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APPENDIX

Appendix 1 Schematic overview of sample and sediment abundance

Table 2. Is a schematic overview of all the samples with their mineral abundance. Color definition: red: rare (1-3 grains); orange: common (3-6 grains); green: abundant (6+ grains). Revised after (Schönberger, 1975).

SAMPLE NUMBER	FRACTION (µm)	OPAQUE: Opaque distribution in %	TRANSPARENT: Cr-Spinel (chromite)	Chlorite (chl)	Tourmaline (tour)	Zircon (zr)	Garnet (grt)	Rutile (rt)	Apatite (ap)	Spinel (sp)	Epidote (ep)	Hornblende (hbl)	Amphibole (amph)	Fluorite (fl)	Pyroxene (px)	Clinopyroxene (cpx)	Orthopyroxene (opx)	Staurolite (st)
NRc4	< 125 µm	80	3		1	2	1				1							
	> 125 µm	80	2	1	3	3		1	1	1	2							
NRc8	< 125 µm	50	3		3	2				1	3		1					
	> 125 µm	50	3		3	1					2		1					
	> 250 µm	80			2			1			2	1						
NRc10	< 125 µm	50	2		3	3					3	3						
	> 125 µm	50				2												
NRc11	< 125 µm	80				1								3				
	> 125 µm	50			1	2												
NRc12	< 125 µm	50	1		3	3	1	2					3		1			3
	> 125 µm	30	1		2		2									2	1	1
NRc13	< 125 µm	30	1		1	1	2		1									
	> 125 µm	80	2		2	3	2	2				1						