CONTROLS OF HIGH-GRADE MINERALISATION IN ATLANTIC 1 MINING LICENCE, OFFSHORE NAMIBIA

A RESEARCH THESIS SUBMITTED TO THE FACULTY OF SCIENCE, UNIVERSITY OF THE WITWATERSRAND, IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS IN ECONOMIC GEOLOGY.

By

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05 September 2018

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DECLARATION

I, Elina Maria Amutenya hereby declare that the work contained in this thesis is my own original work and that I have not previously in it's entirely or in part submitted it at any other university for a degree.

Signature 

Date:………………05 September 2018

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Letter of consent

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Abstract

The placer deposit of the west coast of southern Africa is the world's largest secondary diamond deposit. Geophysical, sampling and mining production data collected and analysed within Atlantic 1 has revealed that mineralisation across Atlantic 1 is not homogeneously distributed and not all of the licence area is equally prospective. Therefore, for the purpose of economic sustainability of the mine, it is important that areas of high-grade diamond mineralisation are identified and the geological and structural controls on the diamond concentration and distribution are well understood. The geological and geophysical data were analysed through GIS (ArcMap) to visualise the sea floor, delineate and interpret the features, patterns and trends that are associated with high-grade mineralisation. The analysis of geographical and geophysical data of the Atlantic 1 marine deposits has revealed that there are specific localities where marine diamonds are best concentrated resulting in high-grade diamond mineralisation. Such localities are associated with the nature of the surface terrain and favourable depositional environments, which are of great significance to the prospecting for, and the mining of diamonds. High-grade diamond mineralisation is best concentrated in the depressions, gullies, gravel beach berms, potholes, scarp slopes and near the outcrops and platforms where turbulence is fixed and where gravel accumulations are stable enough to retain high-grade diamonds. The highest grades in the Atlantic 1 mining licence are located in Region V, within the Pre-proto gravel suites. The Pre-proto gravel suites forms part of a large platform feature that extends through Regions O and V, characterised by north-south striking paleo-placer lineaments. The Pre-proto gravel deposit in Regions O, V and inshore of W is characterised by an irregular surface terrain, and the highest grades are located in the depressions or against the platform within the Pre-proto gravel suites.

Acknowledgement

I would like to thank God the almighty for the strength and blessings bestowed upon me throughout this research. I would also like to thank a number of individuals and institutions, who generously contributed to its success. I would like to express my gratitude to the NASFAF for the financial support that enabled me to carry out my studies. Furthermore, I would like to thank the University of Witwatersrand in general, and the School of Geosciences in particular for the opportunity offered to me to study at this university, as well as the necessary tools, equipment and facilities used.

I am deeply indebted to my supervisors, Professors Judith Kinnaird and Paul Nex who supported and guided me from the initial stages of my research, to the point that I am today able to produce this report. I will be amiss if I do not acknowledge the assistance from Debmarine Namibia for the provision of data. Lastly, I offer my regards and blessings to my lovely husband Gabes Amutenya, my three children Jonita, Dorlia and Nabby, my entire family for their unconditional love and support, motivation, understanding, consideration and encouragement in every way possible throughout the process of this report and beyond.

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Definitions and acronyms used in the text:

Acronym / Abbreviation	Explanation	Acronym / Abbreviation	Explanation
CS	Coral Sea	REEs	Rare Earth Elements
DA	Debmar Atlantic	Ga	Billion years
DBMN	DEDMARINE NAMIBIA	Ma	Million years
DP	Debmar Pacific	MA-1	Mining Area 1
LGM	Louis G Murray	g/cm^3	Grams per meter cube
ML-47	Mining Licence – 47	SSS	Side Scan Sonar
GP	!Gariep	AUV	Autonomous Underwater Vehicle
$Crts/m^2$	Carats per meter square	SBP	Sub-Bottom Profiling
GRM	Global Resource Model	M	Melilititic
GIS	Geographic Information System	CO_2	Carbon dioxide
LAB	Lithosphere-Asthenosphere Boundary	CO_2-	Reduced Carbon dioxide
°C	Degree Celsius	H_2O	Water
Km	Kilometer	G1K	Group 1 Kimberlites
MFT	Mafuta	G2K	Group 2 Kimberlites
Kbar	Kilobars	NAMDEB	NAMDEB Diamond Corporation

Definitions

Autonomous Underwater Vehicle - is a robotic submarine equipped with high resolution sensors.

Bar: These are asymmetric coast-parallel features of mostly sand and pebble-sized material. These features are linear.

Bathymetry: Is the study of underwater depth of ocean floors or lakes and it usually displays the topography or sea floor relief and contours and is expressed as meters below water level

Beach Berm: A beach is the site of accumulation of sediment deposited by waves and currents around the sea margin. A beach berm is essentially a thick accumulation of gravel which strikes N-S and forms a ridge along the beach. The offshore face is steeper than the inshore back beach face and often contains well developed beach cusps. The gravel can reach up to 5m thick.

Berm Zone: These are zones of palaeo-beach berms which are approximately 1m high and 150m in width with a N-S strike.

Blocked Resource: Groups of 100x100m resource blocks at High Inferred and Low Indicated level of confidence.

Chronostratigraphy: Is the branch of stratigraphy that studies the age of rock strata in relation to time.

Deposit: A concentration [or occurrence] of material of possible economic interest in or on the earth's crust, that may include mineralized material that cannot be estimated with sufficient confidence to be classified in the Inferred category.

Depression: A depression is a low or depressed/hollow part of a surface. In Atlantic 1 these can be shallow, deep, large-scale (km-scale or Regional) or small-scale.

Erosion vs. Weathering: *Erosion* is the process whereby particles are detached from a rock and transported away. *Weathering* is the disintegration and decomposition of rock and sediment by near-surface mechanical and chemical processes. Weathering usually occurs in situ, while erosion implies the removal of material.

Footwall: Sedimentary sequence underlying the diamondiferous gravel ore body.

Geological continuity: The geometric continuity of the geological structure(s) hosting mineralization (e.g., vein thickness and up-/down-dip continuation).

Geological zones: Geological features that are formed in the same environment hence have similar geological characteristics.

Geomorphology: Geomorphology is the scientific study of the origin and evolution of topographic and bathymetric features created by physical or chemical processes operating at or near the earth's surface.

Grade continuity: The continuity of grade within the vein that exists within a zone of geological characteristics and/or grade cut-off.

Gullies: These are palaeo-channels that have been eroded into steep-sided ~linear features that are often perpendicular to the coast-line.

Homogeneity: The state of being homogenous.

Homogeneous: Uniform in composition or character

Jago: Submersible tool used for deep water exploration and marine science observations.

Lithostratigraphy: Is defined as a sub-discipline of stratigraphy associated with the study of the lithology of strata or rock layers.

Mineralisation zones: Geological zones or features that have similar mineralization controls.

NAMDEB: A 50:50 partnership company which was created in 1994 between De Beers and the government of Namibia.

Outcrop: This is defined as the total area over which a particular rock unit occurs at the surface. In Atlantic 1 these features are often isolated and small.

Outlier: An area of younger rocks surrounded by older rocks. In Atlantic 1 these are often resistant features.

Oversize: Refers to very coarse particles ranging in size from pebbles (19-64mm), cobbles (64-256mm) to boulders (>256mm).

Panel: A vessel anchored by two or more mooring anchors is said to be 'on a Panel'. The "Panel" refers to the rectangular area in which the moored vessel can operate.

Pavement: This is defined as a floor-like area of exposed rock which resembles a paved road.

Placer deposit: Is an accumulation of valuable minerals (e.g. diamonds, gold) formed by deposition of dense mineral phases in a trap site.

Plant feed: Refers to coarse sediments ranging in size from granule (2-4mm) to pebble (4-19mm) sized particles.

Platform: These are defined as laterally persistent high-lying areas of substrate. These surfaces are usually cemented or hard, but may also be weathered or eroded. These features generally have a shallow offshore dip.

Pothole: Deep, circular holes in a riverbed caused by erosion. In Atlantic 1 these are common features of the O-ridge.

Reflector/Capped Reflector: This term is used in Atlantic 1 to refer to gently dipping (~2°) Cretaceous sandstone units in Cretaceous clay. These units are visible seismically, which is why the term 'reflector' is used. If the outcropping surface of the reflector is very hard then the term 'capped' is used.

Remnant: This is defined as the part that remains after something has been removed. These are often similar to outliers, and are strictly speaking outliers themselves; however, the term refers to outliers who show evidence of extensive weathering and/or erosion.

Resource: Is a concentration or occurrence of material of economic interest in or on the earth's crust in such form, quality and quantity that there are reasonable and realistic prospects for eventual economic extraction. The location, quantity, grade, continuity and other geological characteristics of a Mineral Resource are known, or estimated from specific geological evidence, sampling and knowledge interpreted from an appropriately constrained and portrayed geological model.

Ridge: These features are the outcropping extensions of sandstone reflectors. These features are N-S striking and generally strike over large distances. There is often associated faulting and rough topography in the form of troughs and ridges and these areas often contain numerous loose sandstone slabs.

Scarp slope: In Atlantic 1 this term defines the area between the platform/ridge (high-lying) and the low-lying surrounds. These slopes can be gentle, steep, major or minor.

Scour: In Atlantic 1 a scour is somewhere between a depression, a gully and a pothole. A scour may not have the necessary circular shape to be defined as a pothole, nor the sub-linear shape of a gully, but should show the necessary amount of erosive effect over a given area to be defined a scour.

Slabs: In Atlantic 1 a slab refers to a large flat piece of rock usually made of sandstone which may or may not be cemented. Slabs are common on ridges where in situ weathering has broken up but not removed the main substrate. Slabs may also be present on platforms or other raised areas, and are not uncommon on the slopes of such features.

Stone: Diamond

Strata: A group of sedimentary rocks having approximately the same composition throughout. Note that the term refers to the plural of *stratum*.

Tombolo: This is a type of depositional feature composed of sand and/or gravel that connects an island to another island, or an island to the mainland. These are usually thick gravel features on the inshore of large outcrops/outliers.

Window Depression: This is a depression that exposes the underlying older strata. These depressions often have steeper offshore slopes and terminate against the offshore outcrop which modified wave energy to create the depression.

CHAPTER 1

INTRODUCTION AND RESEARCH DETAILS

1.1. General introduction

The Debmarine Namibia (DBMN) is a joint venture company owned by De Beers Group of Companies (50%) and the Government of the Republic of Namibia (50%). The company operates in the Mining Licence (ML) Area 47, commonly referred to as Atlantic 1. Atlantic 1 is a marine open pit alluvial diamond mining operation located about 8 km offshore, occupying a portion of the middle shelf of the South Atlantic Ocean and stretches from Oranjemund in the south to Chameis Bay in the north. Atlantic 1 is approximately 5 987 km^2 in extent, and the geographic location of the project area is shown in Figure 1.1. Namdeb Holdings (Pty) Ltd. holds the licences for both land and sea operations, and also owns 100% of the operating companies, these being Namdeb Diamond Corporation (Pty) Ltd. and De Beers Marine Namibia (Pty) Ltd. Mining in Atlantic 1 officially started in 1990 with the mining vessel called Louis G Murray (LGM) using a crawler mining system.

The Atlantic 1 marine mining operation is conducted utilising two different methods based on the direction that the orebody is intersected; either by vertical (top-down) or horizontal (parallel to the seafloor). Figure 1.2 shows the two mining models being utilised in the DBMN fleet. The Coral Seas (CS), Grand Banks (GB), Debmar Atlantic (DA), Debmar Pacific (DP), Gariep (GP) and Sam Shafiishuna Nujoma (SSN) are all vertical miners (drill ships) with a rotating wirth drill connected to the vessel with a rigid steel pipe (Figure 1.2A). Horizontal mining is done by utilising a crawler on the seafloor connected to the vessel via an umbilical, lifting wire and flexible riser pipes. The (Mafuta) MFT is currently the only crawler vessel in the DBMN fleet (Figure 1.2B).

The Atlantic 1 mining licence area has been divided into areas of known geological homogeneity. These divisions are represented spatially by an ArcGIS shapefile known as the Geozones Model (the Geozones) (Figure 1.3). Each geozone represents an area of homogenous geological conditions in terms of footwall type and age, morphology and texture, and trap-site potential (Gray, 2011a). The Global Resource Model (GRM) is a mineralisation model which attempts to group the Geozones on the basis of homogenous mineralisation style. Shaw et al., (2005) define the GRM zone as an area of sea-floor that can be defined and delineated on the basis of gravel orebody type alone or a combination of common underlying footwall age and/or lithology and/or topography variation style. For ease of reference the Atlantic 1 mining licence area is divided into Regions. There are a total of 60 Regions covering the extent of the resource area.

Geophysical, geological, sampling and mining data within Atlantic 1 has revealed that mineralisation across Atlantic 1 is not homogeneously distributed and not all of the licence area is equally prospective. Therefore, for purposes of economic sustainability of the mine it is important that areas of high-grade diamond mineralisation are identified and geological controls on the diamond concentration and distribution are well understood. This research will therefore focus on understanding the controls of high-grade mineralisation in the Atlantic 1 mining licence. The Atlantic 1 resource is broken down into 100 x 100 m blocks in which the resource grade is classified, and the resource grade is expressed in terms of number of carats per meter square (cts/m^2). The high-grade considered in the study would be the grade of 4.83 cts/m^2 and higher as it is indicated Figure 1.4A and B. As stated in the letter of consent, all the actual data used in this report are factored due to confidentiality.

1.2. Problem statement of the research

Since 2001 various studies have been undertaken to further unravel the complex nature of the Atlantic West Coast geology. These include several updates on the Atlantic 1 geological model (Pegler, 1997; Foster, 2001; Gray, 2010), Atlantic 1 mineralisation model (Gray, 2011b), Global resource model update (Gray, 2011a) and Geozone legend (Mubita, 2015). However, with all the above mentioned models and studies that have taken place, there has been no study focusing on identifying areas of high-grade mineralisation, understanding the diamond distribution controls and what should guide the exploration and mining in search for high-grade mineralisation within Atlantic 1. Therefore, the focus of this study is to apply Geographic Information System (GIS) and geophysical techniques, analyse the sampling and mining data, and geological observations from Jago footage to gain an appreciation of the spatial distribution and controls of the high-grade diamond mineralisation within the Atlantic 1 mining area.

1.3. Research aim

The aim of the study is to gain an understanding of the spatial diamond distribution and major controls of high-grade areas within the area of Atlantic 1.

1.4. Research objectives

The objectives of the study is to identify the geological and structural controls of high-grade diamond mineralisation within the Atlantic 1 mining licence.

The main questions of the study are as follows:

- What are the controls/factors which may have affected the diamond spatial distribution?
- Identify geomorphological bedrock features: gullies, potholes, riffles; or events such as changes in the river course (palaeo-fluvial conduits) which are associated with the high-grade mineralisation.
- How did the sea-level fluctuations and climate changes influence diamond concentration?

1.5 Research hypotheses

The occurrence of diamondiferous deposits off the Namibian west coast is generally associated with high energy, shallow marine depositional environments. The concentration of diamonds and consequent mineral enrichment of these deposits are as a result of the continual reworking of older mineralised deposits, and subsequent redeposition of diamonds in preferred trapsites. Reworking was mainly through the agencies of wave-induced bottom currents with sea-level changes, as well as fluvial and Aeolian erosional processes on emerged marine deposits.

1.6 Research significance

This study will contribute to an understanding of how the mineralisation occurs in Atlantic 1. It will assist in identifying features or geozones that are associated with high-grade mineralisation and what to look for in order to target the “hot spots”/ high-grade areas during exploration and mining. The importance of mining high-grade mineralisation is primarily to maximise the Net Present Value of the company.

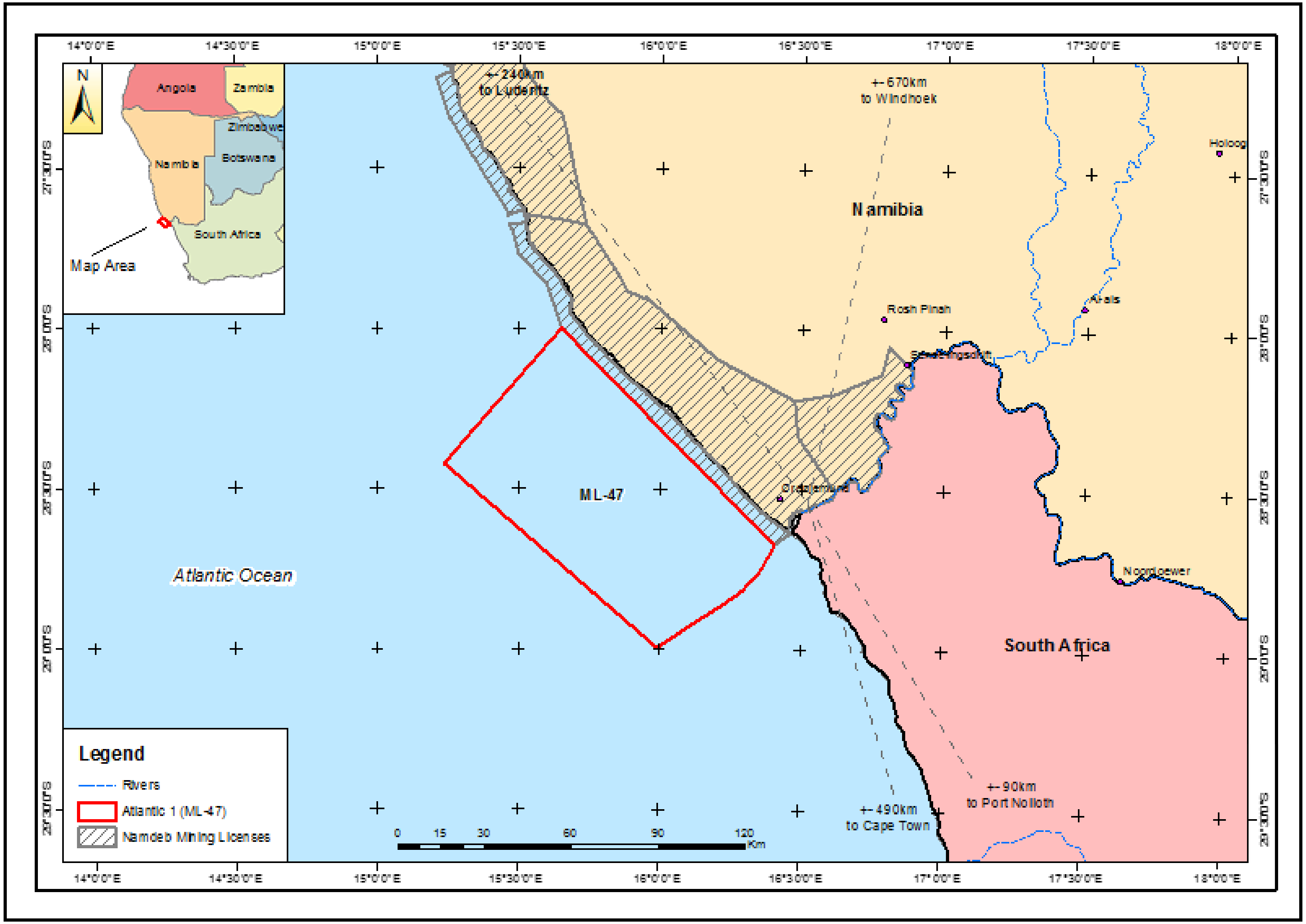


Figure 1.1: *Map of the southern coast of Namibia, showing the mine location and licence outline (ML-47), locally known as Atlantic 1.*

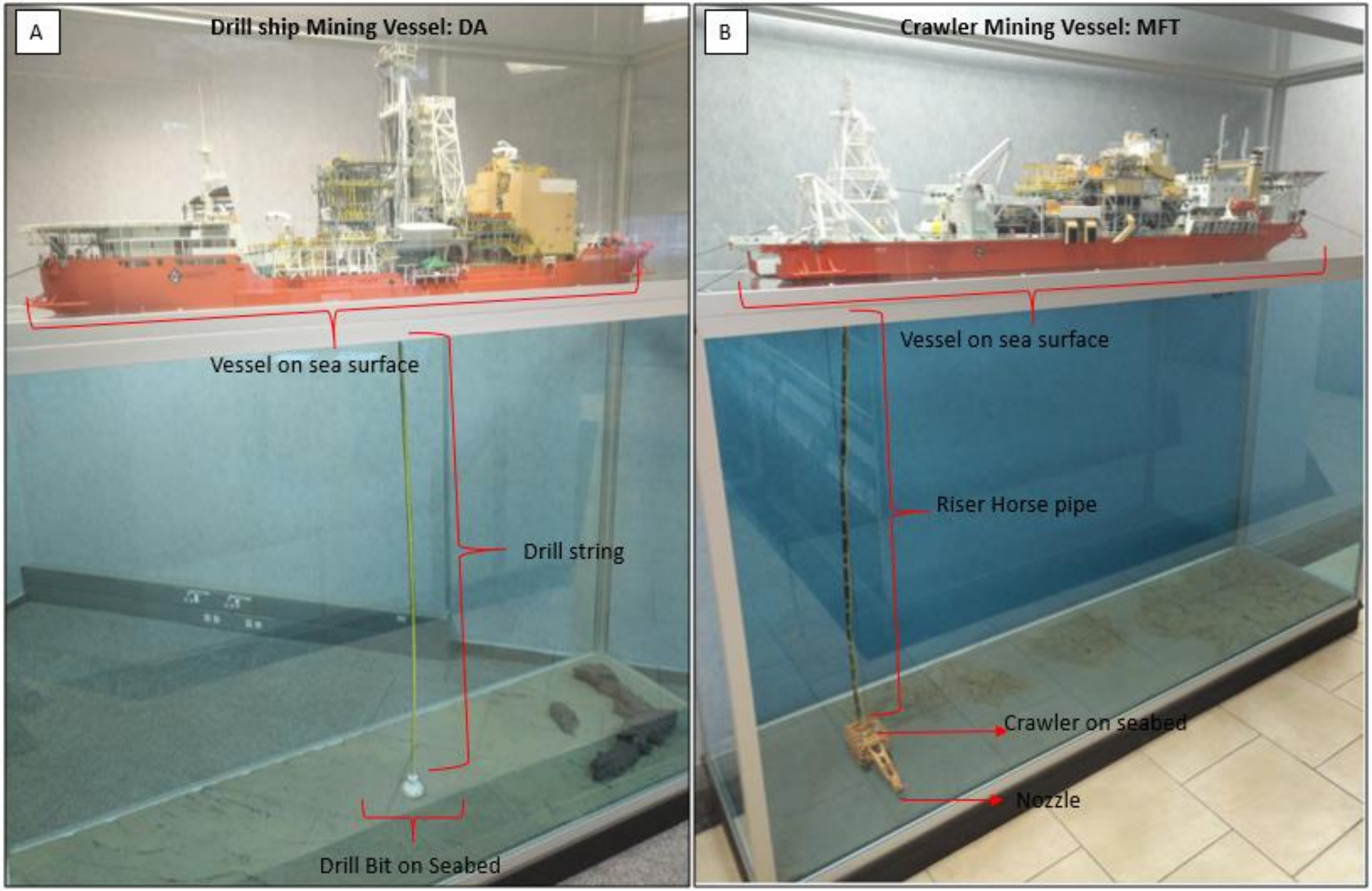


Figure 1.2: *The Atlantic 1 marine mining operation. A: Vertical model (drill ships) with a rotating wirth drill bit. B: Horizontal mining using a crawler mining tool. These are vessel models displayed in the Namdeb building, 8th floor, Windhoek, where Debmarine Namibia (Pty) operates from. Pictures of the models were taken on the 1st Feb 2018.*

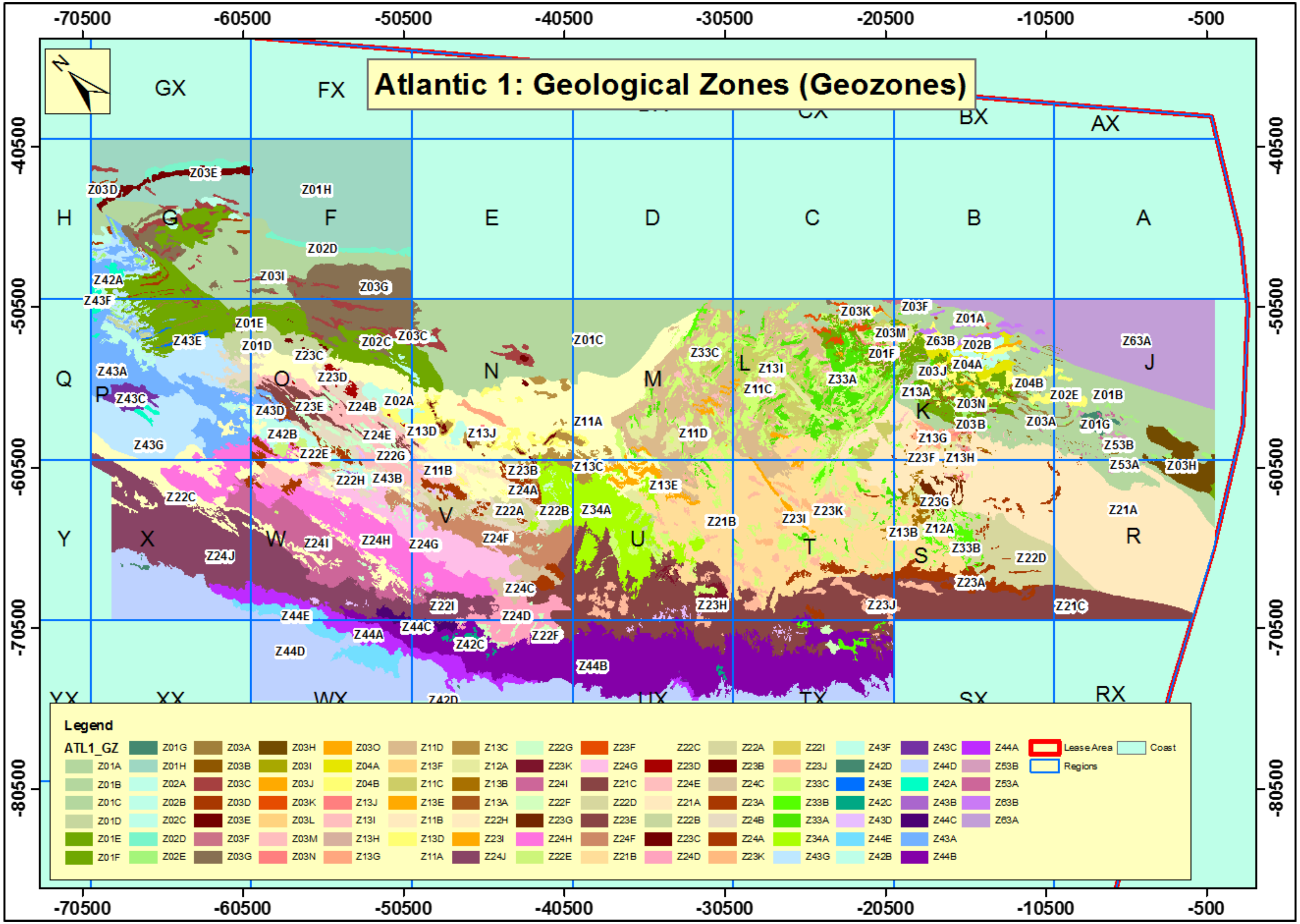


Figure 1.3: *Map showing the Atlantic 1 geological zones (the geozones), representing the areas of known geological homogeneity. The geological description of each geozone are specified in the appendices.*

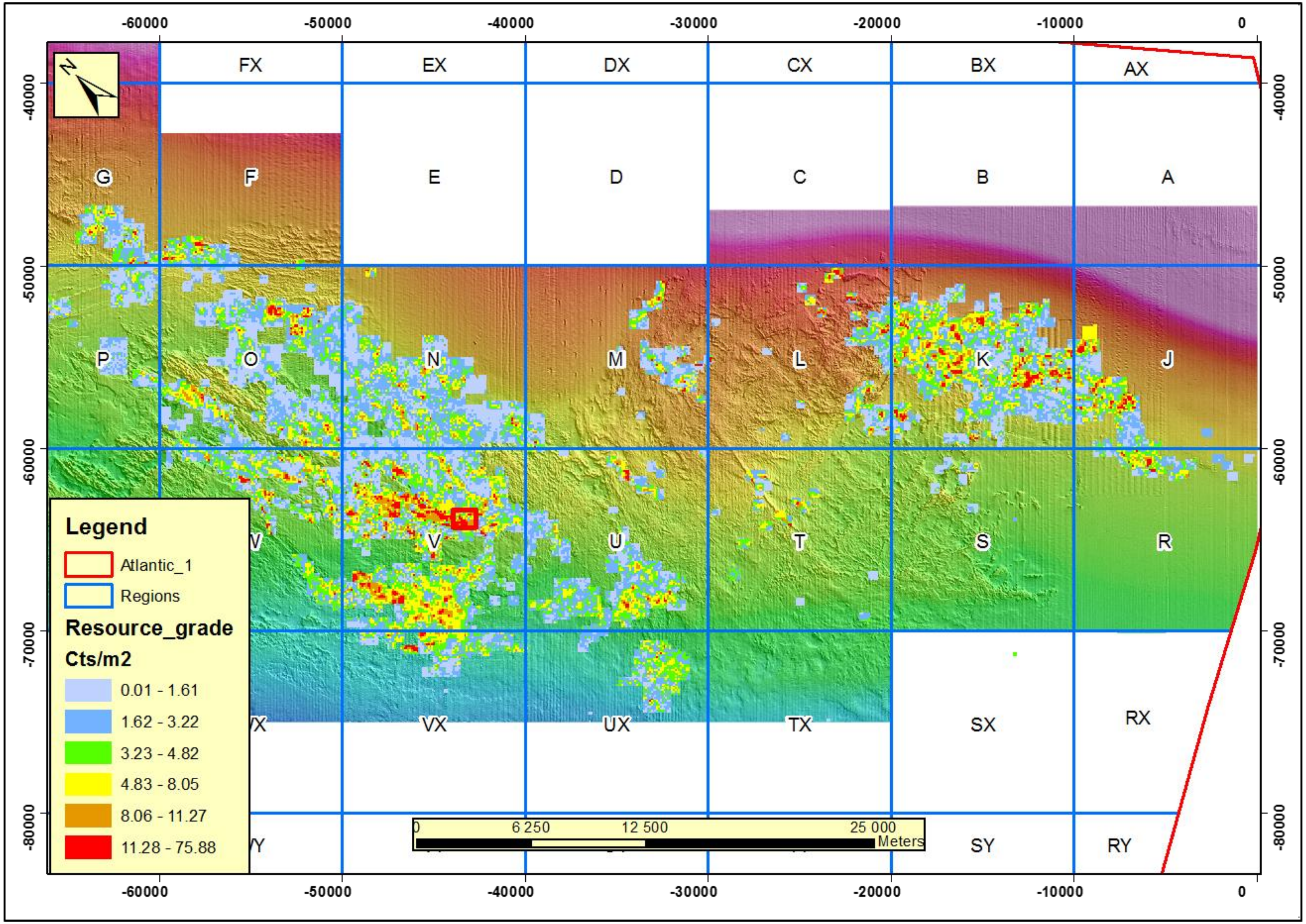


Figure 1.4A: *Map showing the Atlantic 1 resource grade distribution, presenting the estimated resource grade per 100m x 100m for the entire licence area. The legend shows grade in carats per square meter. The red rectangle block represent some of the high-grade areas within the Pre-proto source area.*

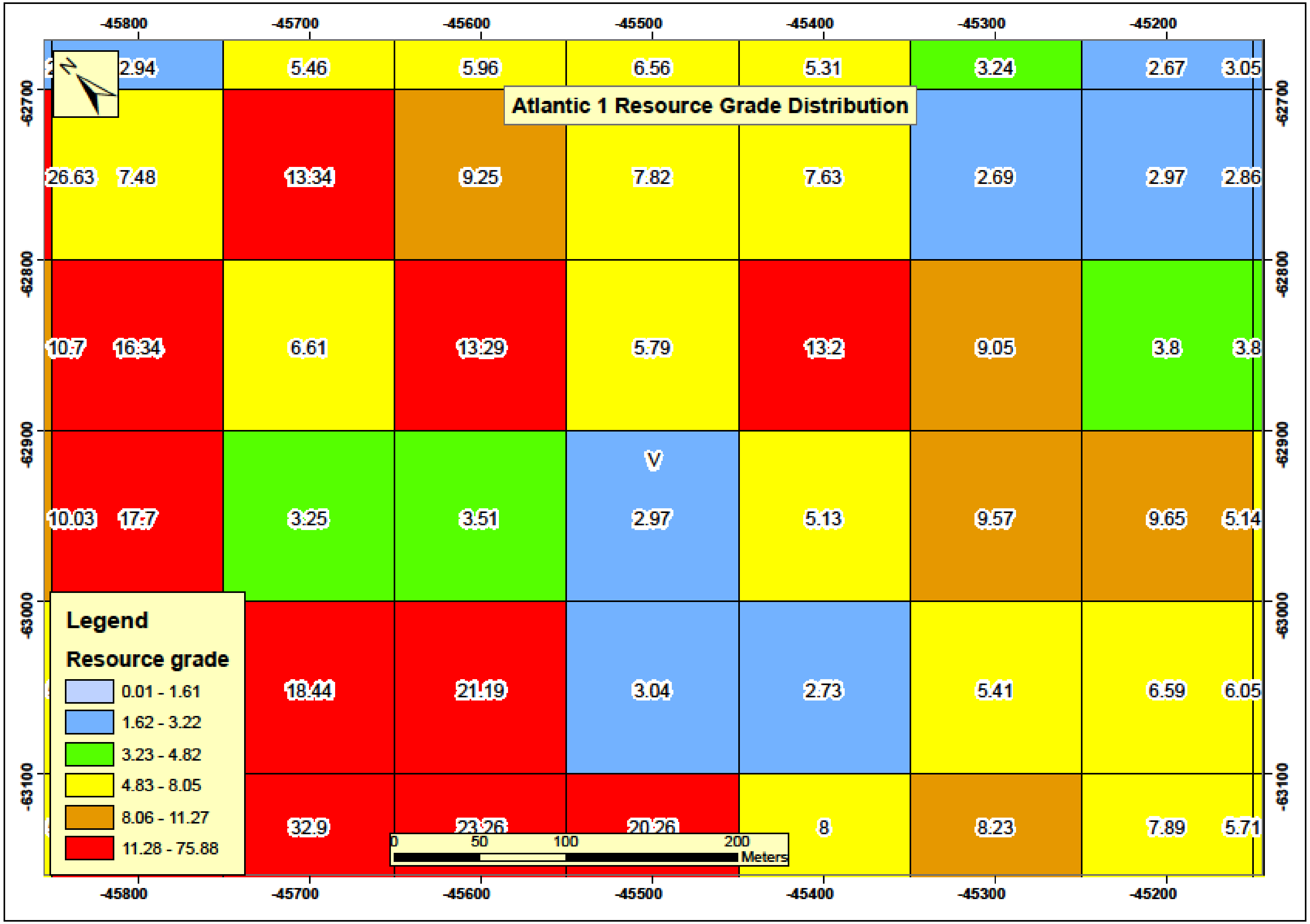


Figure 1.4B: *Map showing the Atlantic 1 resource grade distribution, displaying the estimated resource grade per 100m x 100m block focusing in Region V (the area indicated in figure 1.4A)*

CHAPTER 2

2. 1 PRIMARY SOURCE OF DIAMONDS

2.1.1 Origin and Age of Diamonds

Diamonds have formed over a significant period of the Earth's history. Diamonds have existed for approximately 2,300 Ma, which is about half the time Earth has been known to exist. However, there is a possibility for inclusions in diamonds to be found that may prove that diamonds have existed beyond this period. Known diamondiferous placer deposits range in age from the Recent (Hall et al., 1985; Shmakov, 2008) to the Proterozoic (Teeuw, 2002), with diamonds also present in the 2.89 Ga gold-bearing paleo-placers of the Witwatersrand Supergroup. According to Kirkley et al., (1991), the recent geochronological studies have shown that most diamonds: (a) are much older than their original hosts which are the volcanic rocks (kimberlite and lamproite) that carried them to the surface; (b) they are not genetically allied to these volcanic rocks, meaning that they are not crystallised from a kimberlite or lamproite magma, rather these are the only magmas that reach the surface from sufficient depths to bring up diamonds; and (c) have crystallised, possibly episodically, during a large part of earth's history.

Diamonds form under high pressure 50-60 kbar (150-250 km) and temperatures (900-1400 °C). As shown in Figure 2.1, these pressure-temperature conditions characterise the upper mantle layer and are within the diamond formation stability field. Furthermore, Figure 2.2 illustrates the hypothetical cross-section of an Archean craton and adjacent cratonised mobile belt, which shows the location of the lithosphere-asthenosphere boundary (LAB) in relation to the stability fields of diamond and graphite. The principal feature of this model relevant to the origin of diamonds is the existence of a keel of inflexible lithospheric mantle beneath the craton. The lithosphere and asthenosphere are separated by a major discontinuity boundary to distinguish their chemical and mechanical properties. The depth of the boundary which may lie at 200-250 km or as deep as 400-600 km acts as a central point for diverse reactions involving ascending magmas or fluids, and as a potential site for the underplating of subducted material (Mitchell, 1991). In other word, at the pressure needed to create diamonds, the temperature needs to be lower than the geotherm, and thus it is only in the keel of old continents that diamonds are form.

According to Mitchell (1991) and Kjarsgaard (1996), the lithospheric mantle is depleted in basaltic components and is believed to consist of spinel and garnet Iherzolite, harzburgite and dunite, while the asthenospheric mantle is believed to be relatively homogeneous and to consist of convecting mantle material, which can generate mid-oceanic ridge type basalts. The rocks from the asthenospheric mantle are considered to be "fertile" unlike the "barren" lithospheric mantle. Partial melting by rising plumes or diapirs may cause the rise of voluminous melts which may pool at the Iithosphere-asthenosphere boundary or erupt as continental flood basalts.

In addition, Figure 2.2 is a schematic model demonstrating magma source regions and the association between the diamond source rocks and the ascent of these magmas in the Archean craton and adjacent Proterozoic mobile belt. In the diagram, the location of the lithosphere-asthenosphere boundary (LAB) is shown in relation to the stability fields of diamond and graphite. Figure 2.2 illustrates that different group 1 kimberlites (G1K) of asthenosphere source will differ with respect to sources of xenocrystic diamonds depending on the nature of the mantle they ascend through. Kimberlite number 1 (K_1) may contain lithospheric and asthenospheric garnet lherzolite diamonds together with garnet harzburgite-derived diamonds. Kimberlite number 2 (K_2), contains lithospheric and asthenospheric diamonds from the garnet lherzolite diamonds together with garnet harzburgite-derived diamonds sources plus diamonds derived from lithospheric eclogites and subducted eclogites. Kimberlite number 3 (K_3), contains only lithospheric and asthenospheric garnet Iherzolite diamonds. Kimberlite number 4 (K_4), does not intersect any diamond-bearing Regions and is barren of diamonds. Group 2 kimberlites (G2K) originate at the Iithosphere-asthenosphere boundary and contain diamonds derived from garnet harzburgites and subducted eclogitic sources. An asthenospheric component may be involved in their origin, since they are more in the asthenosphere layer. Lamproite (L) contains diamonds derived from subducted eclogite and lithospheric garnet lherzolite sources. Melilititic (M) magmas are shown to be derived from above the diamond stability field and therefore they are barren of diamonds.

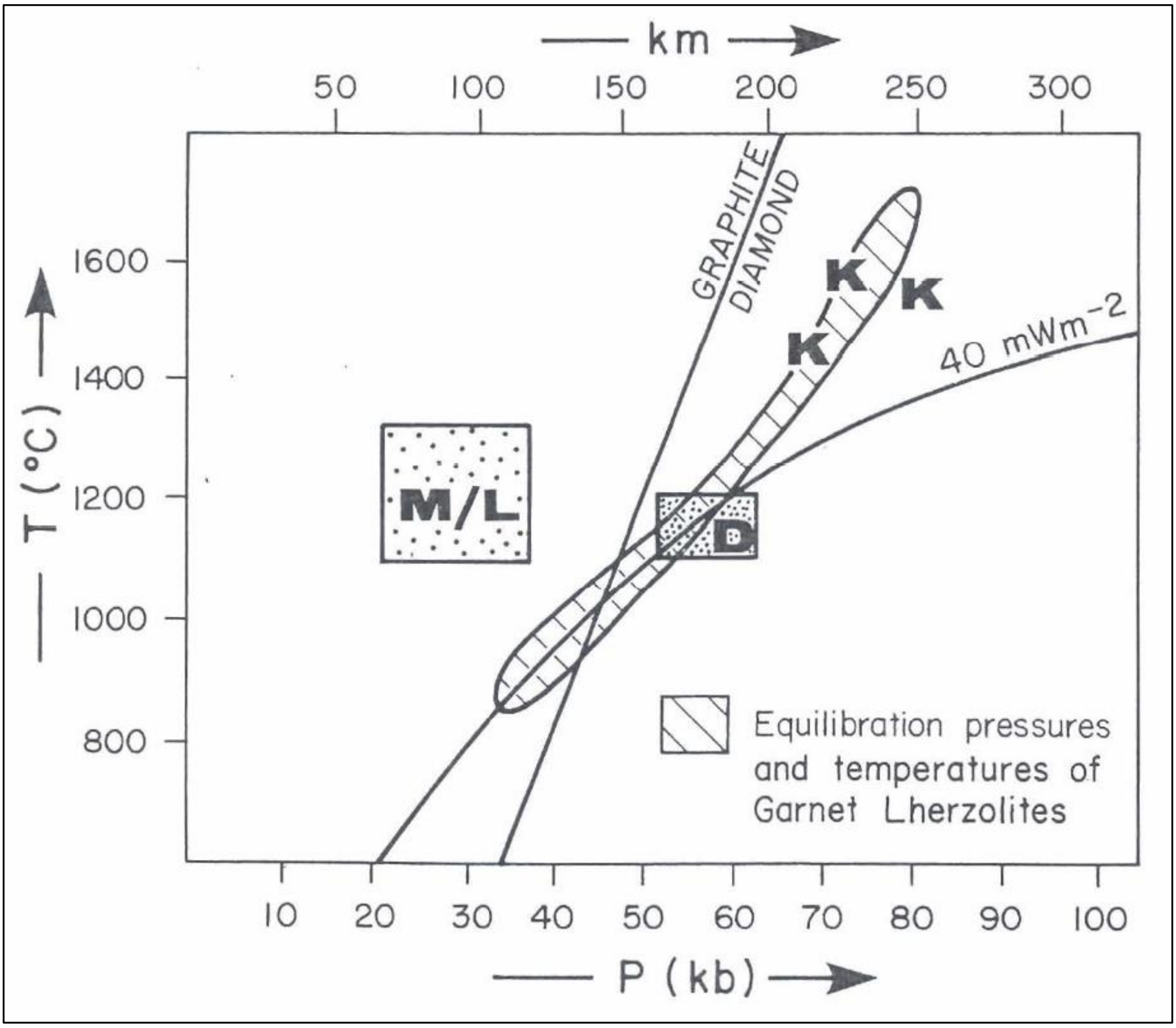


Figure 2.1: *A graph showing the stability pressure (depths) and temperatures of diamond-free and diamond-bearing (field D) as well as garnet iherzolite xenoliths. Kimberlites (K) are derived from within the diamond stability field while Melilitites (M) and ultrabasic lamprohyres (L) forms at much shallower depths within the graphite stability field (source: Mitchell, 1991).*

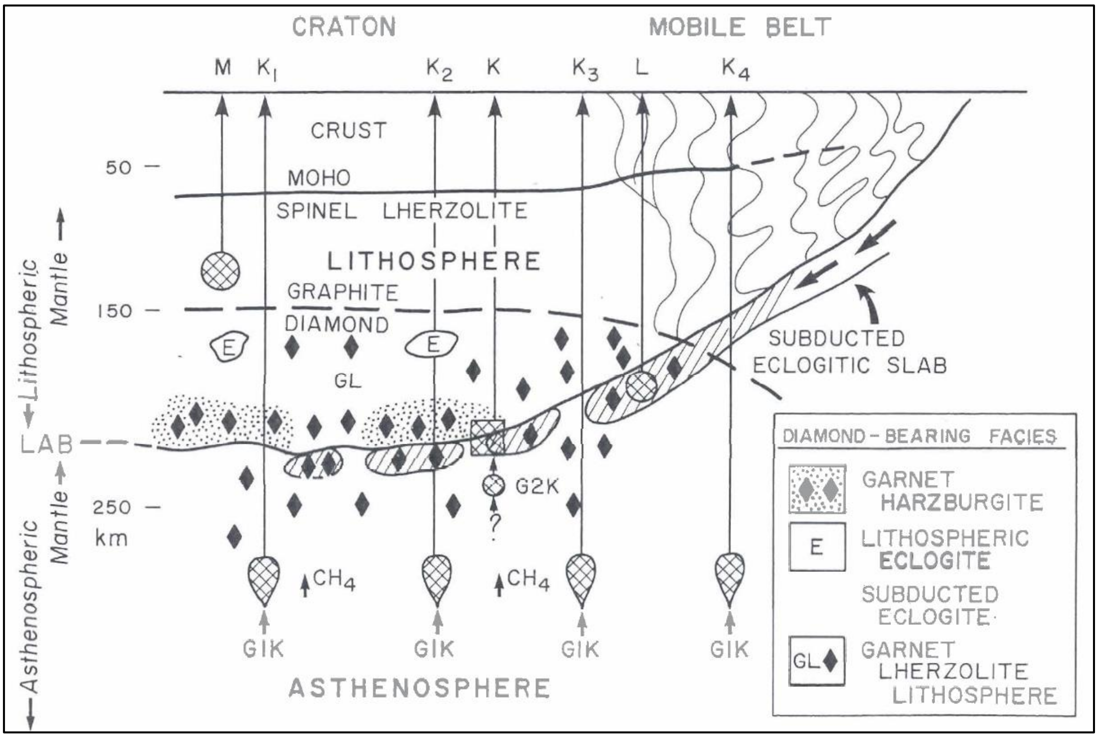


Figure 2.2: *Schematic model illustrating magma source regions and the relationship between the ascent of these magmas and diamond source rocks in the Archean craton and adjacent Proterozoic mobile belt (After Mitchell, 1991).*

2.1.2 Emplacement of Diamonds

Kimberlites remain the main source of primary diamonds although high-grade deposits in lamproites have been discovered. Kimberlites and lamproites are purely a mode of transportation of diamonds from the upper mantle to the crust. In this research, the focus will be on the kimberlites as a source of the West coast diamond deposits. Therefore, discussions on the lamproites are beyond the scope of this work. Clement et al. (1984) and Mitchell (1986) defined kimberlites as CO_2^- and H_2O rich ultrabasic rocks that have a distinctive inequigranular texture due to the presence of large, rounded anhedral macrocrysts (i.e megacrysts and xenocrysts) plus euhedral to subhedral phenocrysts set in finer grained groundmass. Kimberlites are alkaline, volatile-rich potassic, low density ultrabasic rocks that have an enriched incompatible (Sr, Zr, Hf, Nb, REEs) and compatible (Ni, Cr, Co) elements signature similar to, but distinct from lamproites (Kjarsgaard, 1996).

Kinnaird (2016) highlighted that kimberlites formed from small degree partial melts of carbonate-bearing and hydrous mantle peridotite to larger degrees of partial melting that would result in a basaltic magma. They occur as diatremes, pipes, dykes and sills, less commonly as volcanic tuffs. Diatremes form to about 1 km depth as the hot kimberlite magma >900°C heated near surface groundwaters and water flashed to steam resulting in explosive activity. Kimberlites occur in a circumscribed tectonic setting and are found only in prehistoric continental shield Regions older than 1.5 Ga according to Clifford (1966), quoted by Kjarsgaard, (1996). The characteristics for a preferred tectonic environment for Type 1 kimberlite pipes are: thick, old craton with low heat flow values, and the economic kimberlites are restricted to Archean cratons older than 2.5 Ga. Figure 2.3 shows the distribution of kimberlites worldwide in relation to Archean cratons.

In kimberlite-hosted deposits, diamonds occur as widely spread out, mantle-derived xenocrysts and diamondiferous mantle xenoliths in the kimberlite matrix. Figure 2.4 shows typical major components of kimberlite magmatic system, where the economic quantities of diamonds are mainly found in kimberlite diatremes and root zone.

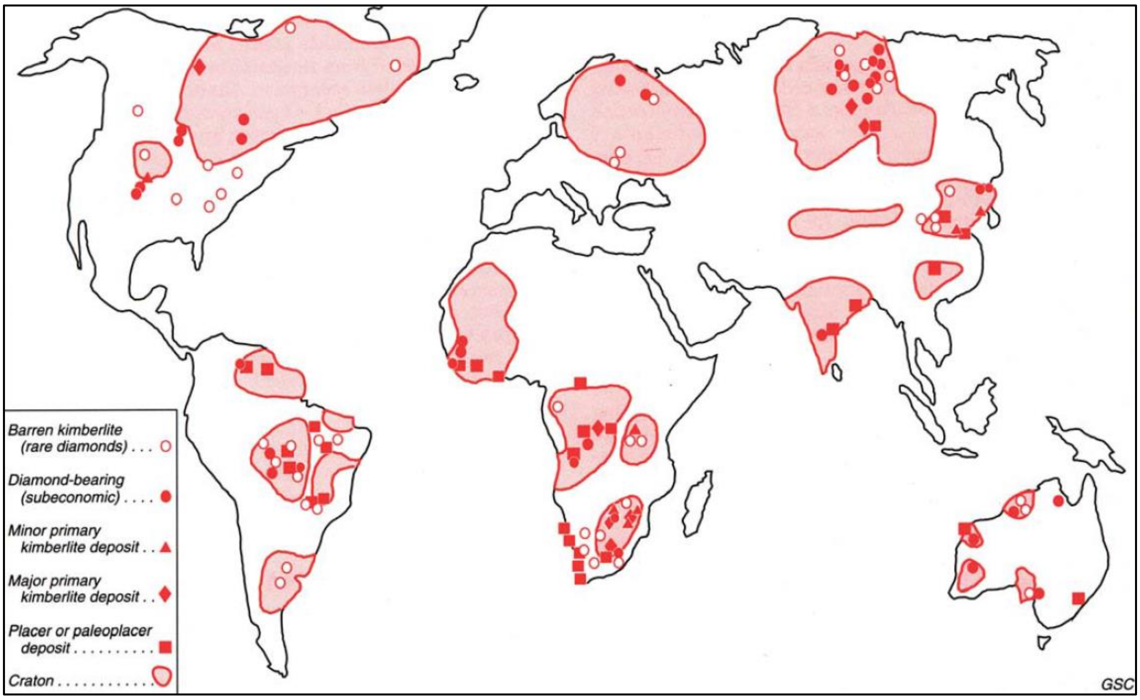


Figure 2.3: *The distribution of kimberlites worldwide in relationship to Archean cratons. (Source: Kjarsgaard, 1996).*

2.1.3 Tectonic setting of Kimberlites

Eggler (1989) believed that kimberlite magmas are formed by the partial melting of carbonated peridotite source regions. Kirkley (1991) added that this happens when a peridotite comprises of a small amount of a carbonate mineral such as dolomite (source of CO_2,) as well as phlogopite (source of potassium) becomes hotter, and a small portion (less than 10%) of the rocks start to melt initially. The resultant from this partial melting will have the chemical characteristics of kimberlites as mentioned above (volatile-rich, potassic, ultramafic). This process takes place at pressures of 50-65 kbar and temperatures of about 1200 -1500 °C (Kirkley, 1991).

Ringwood et al., (1993) on the other hand proposed an alternative model in which kimberlite magma is formed by partial melting in the transition zone (400-650 km depth). This model was proven by the presence of ultra-high pressure majorite garnets that occur as inclusions in the diamonds and in mantle xenoliths, which are normally consistent with kimberlite magma formation at depths of at least 300 km (Kjarsgaard, 1996).

Kimberlites ascend through the mantle at considerably high velocities (10-30 km/hr) by crack propagation processes. However, near the surface vent velocity increases to several hundred km/hr due to rapid CO_2 emitted from the magma. Highly gas-charged magma breaks through explosively to surface at points of weakness to form kimberlite diatremes and craters filled with fragmented rocks (kimberlite, lamprolite, country rocks (angular crustal material)). Mitchell (1991) emphasised that there are quite a few conflicting theories about tectonic settings of the kimberlites. Typically, each hypothesis only explains the distribution of kimberlites within a given province which is not certainly applicable to other provinces. However, the common hypothesis is that kimberlite fields are believed to be situated upon linear or arcuate trends related to the presence of major crustal fracture zones termed lineaments or disjunctive zones.

Mitchell (1991) added that models of the tectonic control of kimberlite emplacement vary based on the instigation of partial melting in the mantle and the mounting of magmas along the fracture zones. These include epeirogenic uplift, transform fault extension, and hot spot and subduction-related magmatism.

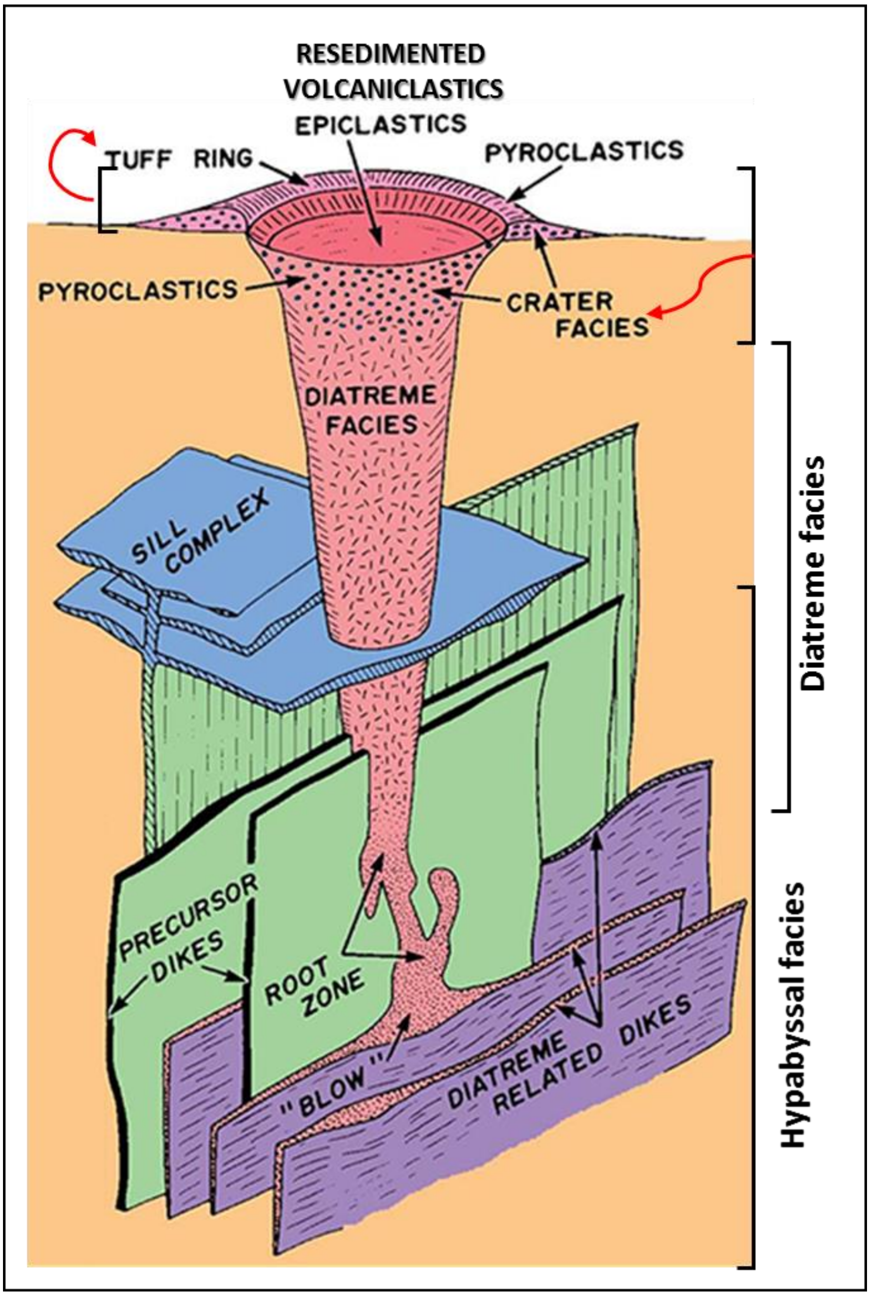


Figure 2.4: *Model of kimberlite magmatic system, showing crater, diatreme, and hypabyssal facies rocks consist dominantly of tuffsitic breccias, hypabyssal facies rocks are found in the root zone of the diatreme and consist of dykes, blows and sills. (Modified after Mitchell, 1986).*

2.2 SECONDARY (PLACER) DIAMOND DEPOSITS: WEST COAST DIAMONDS

2.2.1 West coast diamond source and transport

Over the past 90 million years most of the drainage basins covering the Kaapvaal craton have flowed from east to west and emptied into the Atlantic Ocean. The mid to late Cretaceous Palaeo-Olifants River, also termed the Karoo River, and the Kalahari River (Palaeo-Orange River) are the favoured mechanisms for bringing terrigenous material to the coast (De Wit, 1993; Pegler, 1997; Bosma, 2001; Moore & Moore, 2004 and Jacob, 2005). During the late Cretaceous / early Cenozoic periods, the lower Kalahari had captured the upper part of the Karoo River establishing the broad Orange River network observed today. After ~103 Ma it is thought that the Karoo River's contribution to the Basin declined and the Kalahari River became the dominant contributor to the Basin (Jacobs, 2005). The Palaeo-Orange (Kalahari) River is thought to have included the drainages of the lower Orange, Molopo and Fish Rivers (De Wit et al., 2000: reported in Moore & Moore, 2004). Eventually, the Orange River became the main channel bringing diamonds from hinterland sources to the Namibian coast (Spaggiari et al., 2006 and Jacobs, 2005) (Figure 2.5).

The most believed source of the west coast diamonds are the Cretaceous kimberlites, although it has been suggested that Dwyka glaciation may also have contributed to the diamond population through the erosion of pre-Karoo kimberlites and their incorporation into Dwyka sediments. As stated by Moore and Moore (2004), "if it is proposed that such a large diamond resource was transported to the west coast during the post-Gondwana erosion cycles, there is no reason to suppose that earlier cycles, such as the Dwyka glaciation, could not do the same, given a similar supply."

This becomes particularly relevant when considering that the drainage of the Palaeo-Orange (Kalahari) River tapped the Karoo Basin, and that diamonds have been found in the Karoo sediments. However, there is no shortage of kimberlites in the interior which could have been drained by the Orange system. South Africa is known to contain over 3000 kimberlites, although not all of these would have fallen directly within the drainage systems of the Palaeo-Orange River, and a large number of these kimberlites are not diamondiferous (Kirkley et al., 1991). The first kimberlite pipe was discovered on the Kaapvaal Archean-aged craton near the town of Kimberly, South Africa, hence the name. Kimberlite intrusions are dated from as early as 1.6 Ga in Kuruman, Northern Cape in South Africa to as recent as the Eocene in Namibia with the majority intruded over the last 200 Ma (Kirkley et al., 1991). The most obvious scenario is the erosion of kimberlites to release their diamond content, and subsequent transportation to the coast with or without a period of suspension in Karoo sediments. What then becomes important is the concentration of these diamondiferous sediments into a viable deposit (Figure 2.5).

Figure 2.5 shows that the marine diamonds originated from Cretaceous-age kimberlites intruded into the interior of South Africa, generally between 120 and 80 million years ago (De Decker and Woodborne, 1996). Erosion followed continental uplift since the late Cretaceous and removed approximately 1400 m of the kimberlite pipes and the surrounding country rocks. Roberts and White (2010) have confirmed that over the last 30-40 Ma, the African landscape has been sculpted by phases of both regional and continental wide uplift, which are controlled by the changing pattern of convective circulation beneath the lithospheric plate. During their work of estimating the uplift rate histories from river profiles, the interpretation of apatite fission track data across Namibia suggested increased denudation from 70 Ma up to the present. They further admitted that an increase in denudation from ~50 Ma to the present is not obviously reflected in offshore sedimentary flux, nevertheless, offshore basins do have Cenozoic sedimentary sequences which are up to 1 km thick, suggesting that the lack of proximal accommodation space has triggered deposition of Cenozoic sediments in deeper basinal areas.

Figure 2.5: *The source, transport, deposition and concentration of the mega-placer deposit on the Namibia west coast in the Orange Basin. The picture shows the journey of the west coast diamonds as originated from Kimberly area, and they were transported to the Atlantic coast via the Orange and Vaal River. They were then deposited and concentrated into viable deposits (After Gray, 2010).*

In terms of the geology and bathymetry of the continental margin, the “Great Escarpment” backs the west coast, rising to about 700 m and separating the inland plateau from the coastal lowlands. The coastal lowlands and escarpment are cut by numerous river channels with a drainage restricted to the western side of the escarpments. Most of these rivers are currently inactive however, the deeply incised courses reflect that there were periods when runoff from the escarpment must have been very pronounced. The Orange River presently accounts for more than 90% of the sediments discharged onto the western continental shelf according to De Decker and Woodborne, (1996).

2.2.2 West coast placer deposits

Placer deposits or placers is an accumulation of valuable minerals (e.g. diamonds, gold) formed by deposition of dense mineral phases in a trap site. The name is from the Spanish word placer, which mean "alluvial sand". Placer deposits are generally heavier and more durable than average minerals, and they have been eroded out of the original rocks in which they formed, transported and mechanically concentrated by water in streams. Examples of these minerals are diamonds, gold, tourmaline, beryl, and many other minerals (Kamona, 2014). Marshall and Baxter-Brown (1995) highlighted five different categories of placer deposits which are fluvial, marine, wind deflation (aeolian), lacustrine and glacial. The west coast diamonds occur in four main deposit types which are fluvial, beach, marine and wind deflation (aeolian) as shown in Figure 2.6. The degree of diamond concentration varies considerably in different deposits of any one of the categories, however, the most economically significant deposit type is the marine, followed by the fluvial. The only important example of an economic wind-concentrated diamond deposit is the Elizabeth Bay deposit in Lüderitz, Namibia. Brief descriptions of each of the placer deposits in west coast are listed below. However, this research will focus on the marine placer deposit which is being mined by Debmarine Namibia.

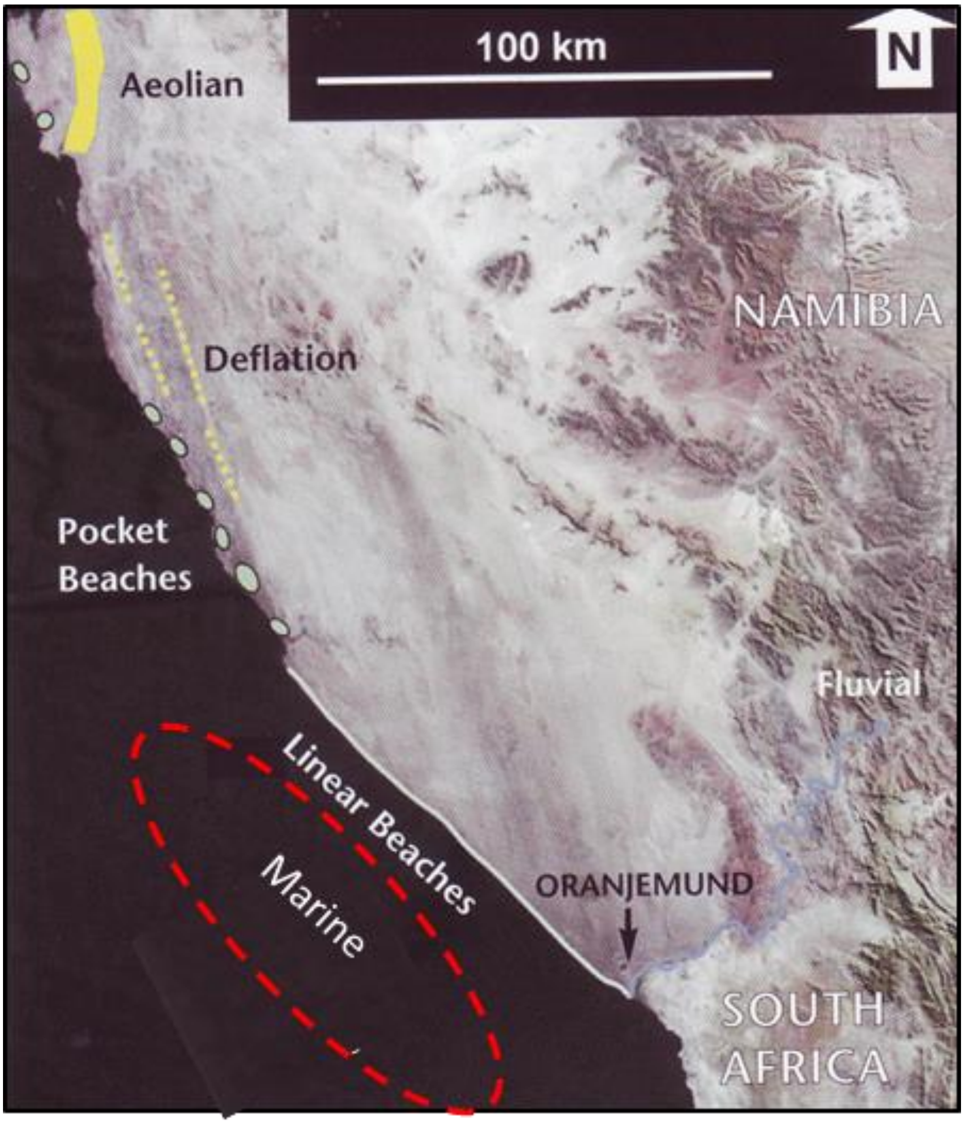


Figure 2.6: *The Landsat image of the west coast diamond placer deposits, Namibia: Fluvial, beach, deflation (aeolian) and marine diamond placer deposits (Modified after, Corbett, 2002).*

Fluvial deposits: Fluvial deposits are formed in river or stream sediments. The fluvial placers along the Orange River formed in high turbulence braided stream systems with eddies caused by large values for bed roughness. Under these conditions the heavy minerals, including diamonds, were preferentially deposited in the large pore spaces created by the coarse-grained basal deposits (Jacob et al. 1999).

Most fluvial diamond placers occur in non-aggrading braided systems where the diamonds are preferentially trapped by very rough substrates, including fluvial conglomerates deposited by a mixture of traction current and mass-flow processes (Figure 2.7).

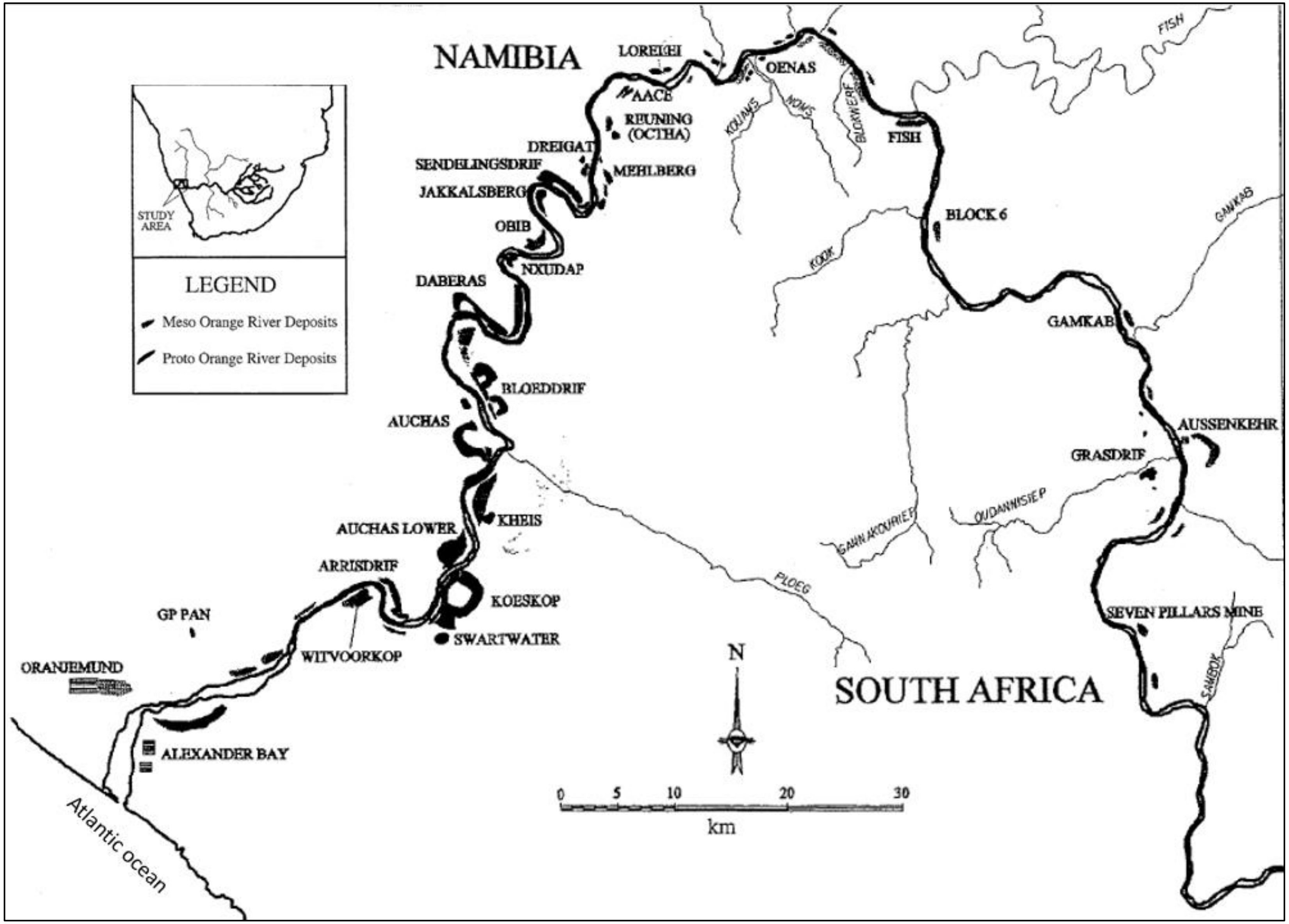


Figure 2.7: *A map of the lower Orange River showing the distribution of the main Proto and Meso Orange terraces (Jacob et al., 1999).*

- **Beach placers**: Beach deposits are formed by wave action on the seashore, for example black sands (magnetite) of California and New Zealand and the diamond gravels of southern Africa. Figure 2.8 shows the beach placer deposit of the Oranjemund mining area, locally known as MA-1.

Figure 2.8: *Beach placer deposits of the Oranjemund mining area, Namibia as seen from the air in Sept 2016.*

- **Marine placer deposits**: Marine deposits occurs both onshore and offshore as ancient strandlines that mark both eustatic and isostatic fluctuations. In broad terms, economic deposits of marine alluvial result from transgressive seas (Marshall and Baxter-Brown, 1995). The Namibian Plio-Pleistocene marine placers formed in a thick succession of cobble- to pebble-sized shoreface gravels.

- **Aeolian (Deflation) placer deposits**: Aeolian deposits are formed by wind action in arid areas. Strong wind currents, originating from the south, played a role in redistributing diamonds in the beach terraces. Small diamonds, in particular, are affected by aeolian or wind erosion as they were swept up distinct channels inshore of the Namibian coast.

2.2.3 Marine diamond concentration mechanism and placer formation

The continental shelf extends as much as 250 km offshore and reaches a water depth of up to 500 m (De Decker and Woodborne, 1996). There are three morphological regions that are distinguished on the continental shelf: an inner shelf, a middle shelf and an outer shelf. The inner shelf is the area where most of the diamond exploration and prospecting has taken place to date. Debmarine Namibia is mainly operating in the middle shelf which is characterised by bedrock subcrops of late Cretaceous and Cenozoic age, and has very low seafloor gradient and relief. The depth varies between 100 and 250 m.

The Benguela current that occurs off the southern African west coast moves rather slowly equatorward as a compensation current at an average of 117 cm/s and therefore lacking the capacity to affect the redistribution of diamonds on the continental shelf. The southern west coast is a wave-dominated micro tidal region. According to De Decker and Woodborne (1996), sediment movements along the coast on the inner shelf are by means of strong northward directed littoral currents which are generated by high energy south-westerly swells that are incompletely refracted by the general north-south orientation of the coastline.

On the arrival of diamond-bearing terrigenous sediments to the continental shelf it is thought that marine processes would have dominated. Ward and Bluck (1997) have been able to show that the palaeo-wave direction of the past favoured a north-easterly direction similar to the present (Figure 2.9 A). Ward and Bluck, (1997) assert that, “this high energy, long-shore drift system is over 40 million years old.” The offshore regime is thought to have been equally energetic in the past, if not more so, which would have been integral in forming the economic concentrations of heavy minerals (Terhorst and Hockney, 1991).

Diamondiferous deposits occur mainly in high energy environments along palaeo-strandlines. Therefore, sea-level transgressions and regressions, but specifically still-stands since the late Cretaceous, are of fundamental importance to understand the distribution and occurrence of diamondiferous sediments on the continents. There were several phases of sea-level fluctuations which became significant from the middle of the Eocene when the sea-level was about 180 m above the present level (Spaggiari et al., 2006; De Decker and Woodborne, 1996). This was followed by the Oligocene sea-level regressions which reached a maximum of approximately -500 m about 25 million years ago and resulted in diamonds being brought to the present-day shelf break. Extensive erosion of the coastal lowlands brought diamonds from high-lying, older marine deposits and redistributed them along lower strandlines. The Miocene transgression (about 20 million years ago) produced diamondiferous deposits on wave-cut terraces at elevations of +90 m above sea-level.

Several sea-level changes in the Quaternary (the last 2 million years) varied between +30 m and -200 m, with the transgressions rarely exceeding the present sea-level. These numerous changes in sea-level served to concentrate the diamonds onto the various wave-cut terraces, systematically improving the grade. Wave-induced coastal currents transported the sediments and diamonds northwards, continuously stretching further north from the primary source points at the Olifants and Orange River mouths and from the smaller rivers with catchments west of the Great Escarpment (De Decker and Woodborne, 1996). Constant reworking through sea-level changes trapped the diamonds within gravel-lag that was deposited in the gullies, potholes and the fluvial channels eroded into the wave-cut terraces.

The result of these fluctuations, particularly after the late Cretaceous interior uplift and subsequent river incisions, was to disperse and accrete littoral sediments over a substantial width of the continental shelf (Spaggiari et al., 2006). De Decker and Woodborne, (1996) summarise the occurrence of diamondiferous deposits off the Namibian west coast as, "generally associated with high energy, shallow marine depositional environments". Figure 2.9 shows the concentration of diamonds and consequent mineral enrichment of these deposits are as a result of the continual reworking of older mineralised deposits, and subsequent redeposition of diamonds in preferred trapsites. Reworking was mainly through the agencies of wave-induced bottom currents with sea-level changes, as well as fluvial and aeolian erosional processes on emerged marine deposits (Figure 2.9B). Work by De Wit, (1993) suggests that diamondiferous gravels were carried to the Atlantic margin from as early as the Cretaceous, through the Miocene, Pliocene and Pleistocene.

In terms of the size and quantity of wave-transported diamonds on emerged marine terraces and in the surf zone along the west coast the size and abundance decreases away from palaeo-River mouths which are "point sources" for the gems. The comparative difference between the specific gravity of quartz (2.5 g/cm^3) and diamonds (3.5 g/cm^3) means that diamonds are much more mobile than other heavy minerals. Because of their exceptional hardness, diamonds are more prone to rebounding during transport, thereby remaining as part of the sediments being transported. Eventually, the diamonds become entrapped, whereby the larger diamonds are more easily trapped since they only move under extreme conditions. The smaller diamonds move inexorably farther northward with time (De Decker and Woodborne, 1996). With regards to the depositional time, according to Jacob et al., (1999) and Bluck et al., (2005), the minimum diamond sizes and grades are recorded from the oldest deposits, with Oligocene-Miocene terraces hosting the largest diamonds and the highest grades. These observations are taken as evidence that most diamond transportation to the west coast initiated during the Eocene and peaked in the late Oligocene, before declining thereafter (Bluck et al., 2005).

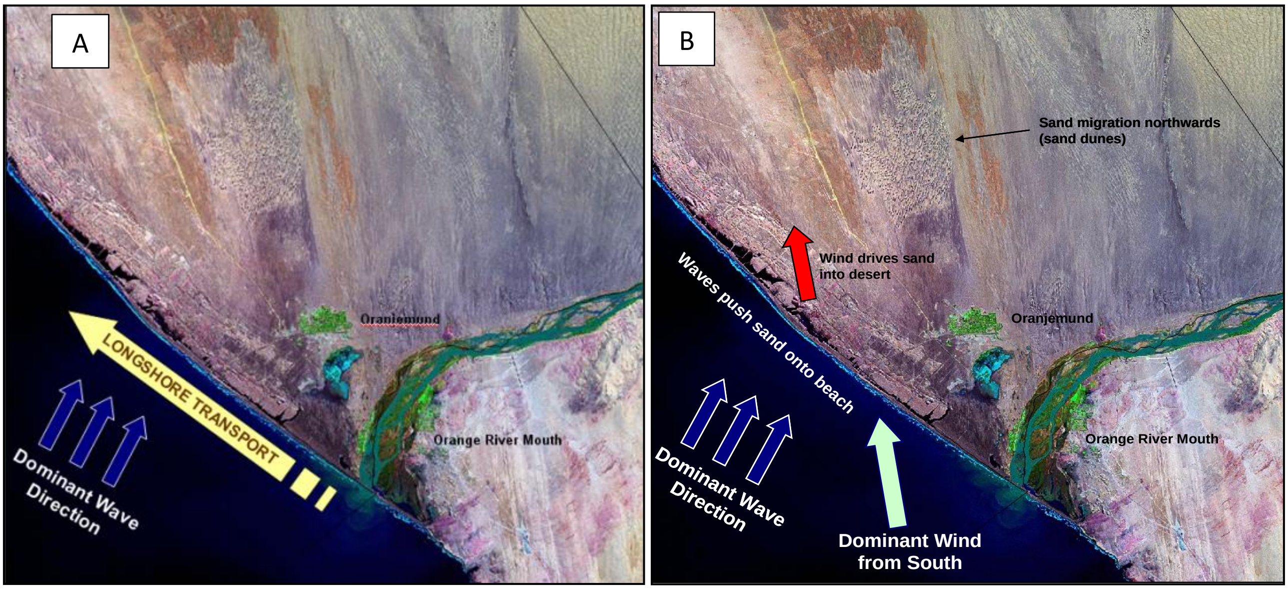


Figure 2.9: *The concentration of diamonds and consequent mineral enrichment of these deposits are as a result of the continual reworking of older mineralised deposits. A: The aggressive oceanic regime driven by longshore drift which is one of the most effective concentrating mechanisms on the Namibian west coast. B: Marine/fluvial deposits exposed to surface and subjected to reworking by aeolian process. (Gray, 2010).*

CHAPTER 3

RESEARCH METHODOLOGY

This research was accomplished through the following components which were used to identify high-grade areas and helped in understanding the geological controls of high-grade mineralisation. The listed components below are explained further in detail in this section on how they were used to identify high-grade areas:

- 3.1 GIS
- 3.2 Geophysical data
- 3.3 Field work
    - 3.3.1 Vessel trips
    - 3.3.2 Jago footage observations
- 3.4 Analysis of production and sampling data

3.1 Geographic Information System (GIS)

GIS software, specifically ArcMap, was used to visualise, analyse and interpret data to understand relationships, patterns, and trends that are associated with high-grade mineralisation. Both geographical and geophysical data of the Atlantic 1 deposit were analysed through ArcMap. Among the data that was captured are the visuals or images of surface terrains which distinguish elevation differences, depositional facies and structural features. This data was collected as maps of different geological and structural features that were generated using ArcMap.

3.2 Geophysical data

Since 2001, Atlantic 1 has been surveyed with an Autonomous Underwater Vehicle (AUV) which allows a significantly higher resolution of side scan sonar (SSS), swathe bathymetry and seismic data to be collected on a “stable” platform. Geophysical data using AUV provided the side scan sonar of the sea-floor, seismic reflection profiles of the underlying geology and bathymetry grids which were used in delineating geological features and analysing them in relation to high-grade mineralisation. All this data was collected as maps that were later analysed and interpreted.

3.2.1 Side Scan Sonar (SSS)

In order to gain insight into the textural characteristics of the sea floor, side scan sonar technology was used. The side scan sonar effectively takes pictures of the sea floor whose contrast can be analysed to determine the ‘roughness’ of the terrain (Figure 3.1). Textural features defined in this way can be truthed by both sampling and mining activities. Outcrops or elevated features were also traced this way, as well as the depressions.

3.2.2 Bathymetry

A bathymetry image (Figure 3.2A) depicts the morphology of the prominent or resistant features such as sandstone outcrops. Identified features were then mapped based solely on their surface expressions. To delineate the geometry of a feature requires an analysis of the sub-surface and this was done using seismic sections (Figure 3.2B). An analysis of the bathymetry is therefore usually done in conjunction with seismic interpretations.

3.2.3 Chirp Seismics

Chirp sub-bottom profiling (SBP) has been used extensively to delineate sub-surface geological features such as faults, ridges and unconformity surfaces. Geo-acoustic profiling was used to determine the textural, morphological and geometric characteristics of the gravel. Figure 3.3A shows the global airgun seismic lines, indicating the 6 lines (numbered and highlighted with red colour) that were picked for interpretations for this research, while Figure 3.3B shows the un-interpreted seismic profile generated and displayed from one of the airgun seismic lines shown in Figure 3.3A.

3.3 Field work

3.3.1 Vessel trips

Debmarine Namibia fleet consist of 7 (seven) vessels in total, of which 5 are mining vessels and 2 are sampling vessels. Among the mining vessels are the Debmar Atlantic (DA), Debmar Pacific (DP), Gariep (GP) and Grand Banks (GB), which vertical miners (drill ships) with a rotating wirth drill connected to the vessel with a rigid steel pipe (Figure 1.2A), and the Mafuta (MFT) which is currently the only crawler mining vessel in the DBMN fleet (Figure 1.2B). Horizontal mining is done by utilising a crawler on the seafloor connected to the vessel via an umbilical, lifting wire and flexible riser pipes. The Coral Sea (CS) and the Sam Shafiishuna Nujoma (SSN) are the sampling vessels doing exploration and sampling for Debmarine Namibia.

There were several field trips to the sampling and mining vessels at sea during the duration of the research. Vessel visits were done at the time the mining took place in the high-grade areas. The aims of the field trips were mainly to observe, record and interpret data from offshore marine deposits, to provide information for geological mapping and to evaluate the ore deposit. Data collected during field trips (vessel visits) was mainly gravel pictures observed from the screens during mining. Pictures taken during mining were then analysed and interpreted together with Jago footage and sampling data. Structures observed from rock samples collected where noted and interpreted (Figure 21). Figure 3.4 shows one the mining vessels (Debmar Atlantic) visited for data collection during the study.

3.3.2 Jago footage observations

The Jago is a small two-man submersible underwater vehicle that is used in sea floor exploration and marine sciences researches. It dives to a depth of 400 metres carrying a pilot and an observer. It can be transported in a standard 6 metre container and can be launched off the deck of any vessel offering sufficient stability and crane capacity. Figure 3.5 presents the Jago diving tool operation. Figure 3.5A shows when the Jago is on the vessel deck and Figure 3.5B shows when it is clearing the deck as it is about to be launched.

This submersible is charted by Debmarine Namibia every 2 years and it provides valuable information of an otherwise inaccessible/ remote terrain of the sea-bed in Atlantic 1. The first project of this type was carried out in 1996. Over the years the Jago has been effectively used to ground-truth the findings/observations of geophysical interpretations, sampling and mining information. The Jago dives allow for visual observations of the sea-bed and therefore is a valuable component which helps in understanding the geology and mineralisation controls in Atlantic 1 (Figure 3.6). During the Jago dives, data collected was mainly pictures of the sea-bed that were captured while the Jago tool was traversing at the sea floor. Figure 3.6A shows the footage observation picture taken during a Jago diving operation, showing sea-bed surface and type of gravel clasts in Region U. Figure 3.6B shows the interior of the Jago diving tool with the geologist observing the geology.

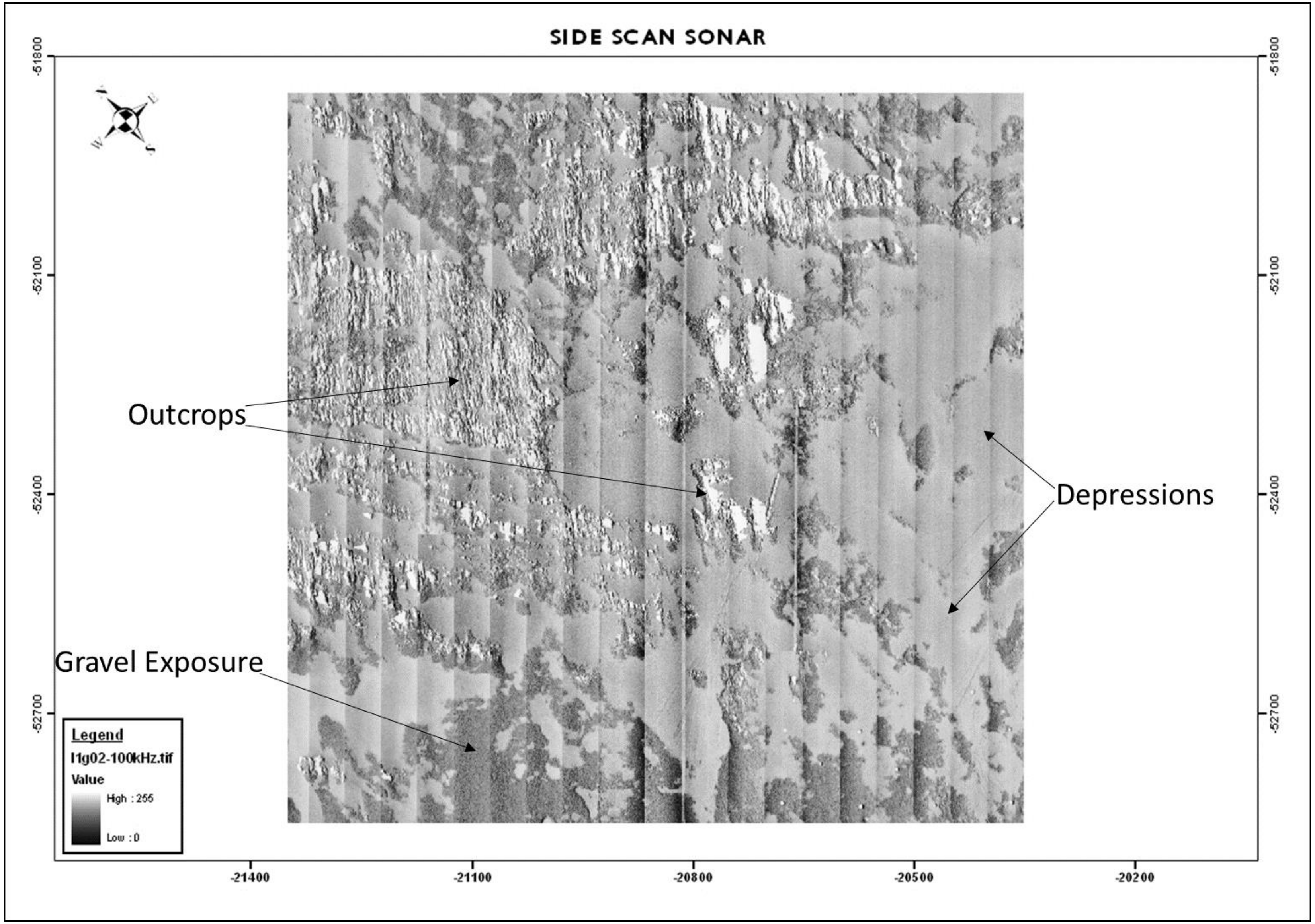


Figure 3.1: *Example of a side scan sonar image taken from Atlantic 1, showing the exposed gravel texture (Dark patches) and the depressions (light areas) covered by silt overburden.*

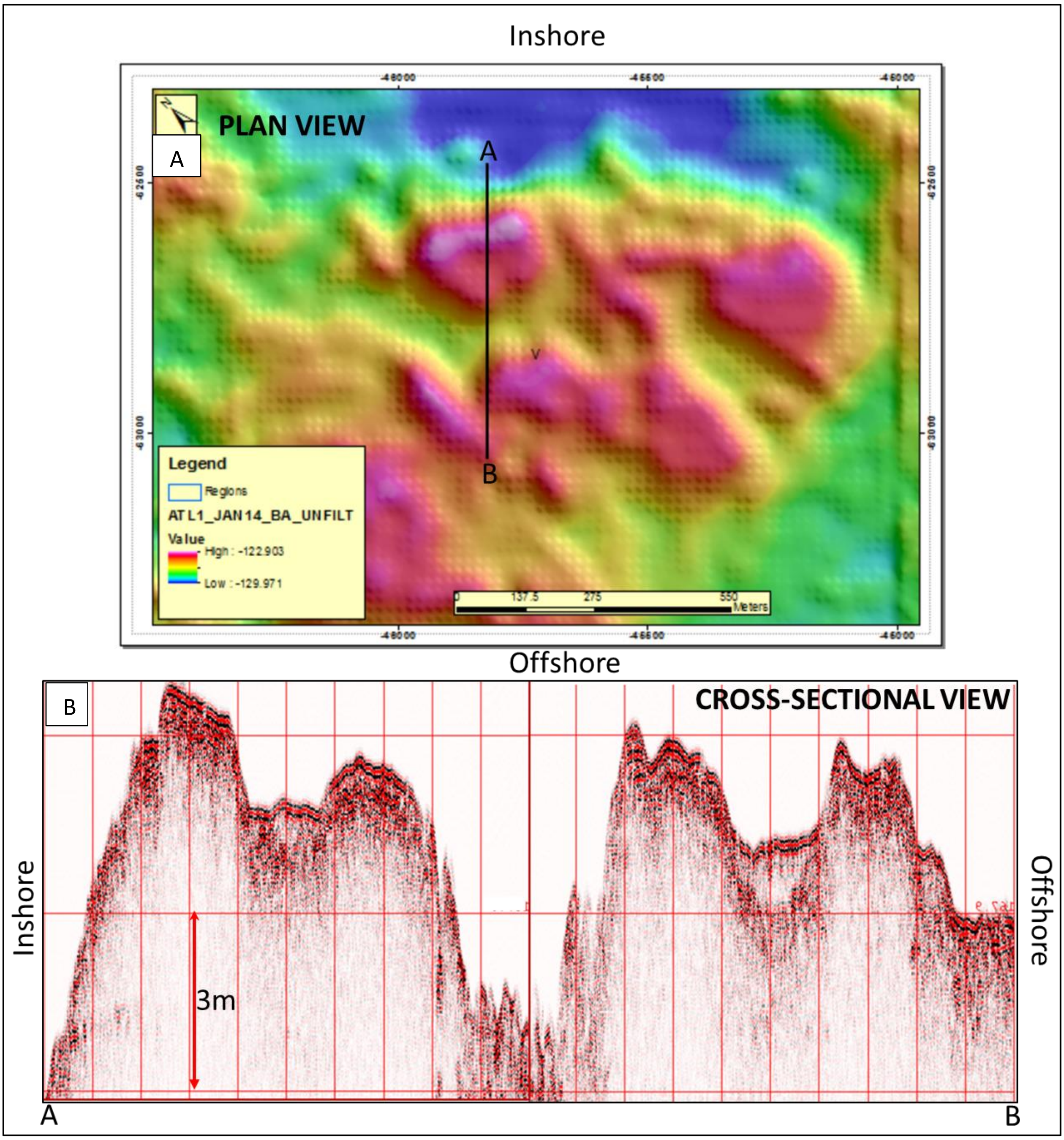


Figure 3.2: *The delineation of depressions and elevated features requires both mapping the bathymetry (A) and the subsurface extent of the feature using seismic acoustic profiling (B). The bathymetry map was drawn using ArcGIS, while the seismic cross section was drawn using SeisAVS software.*

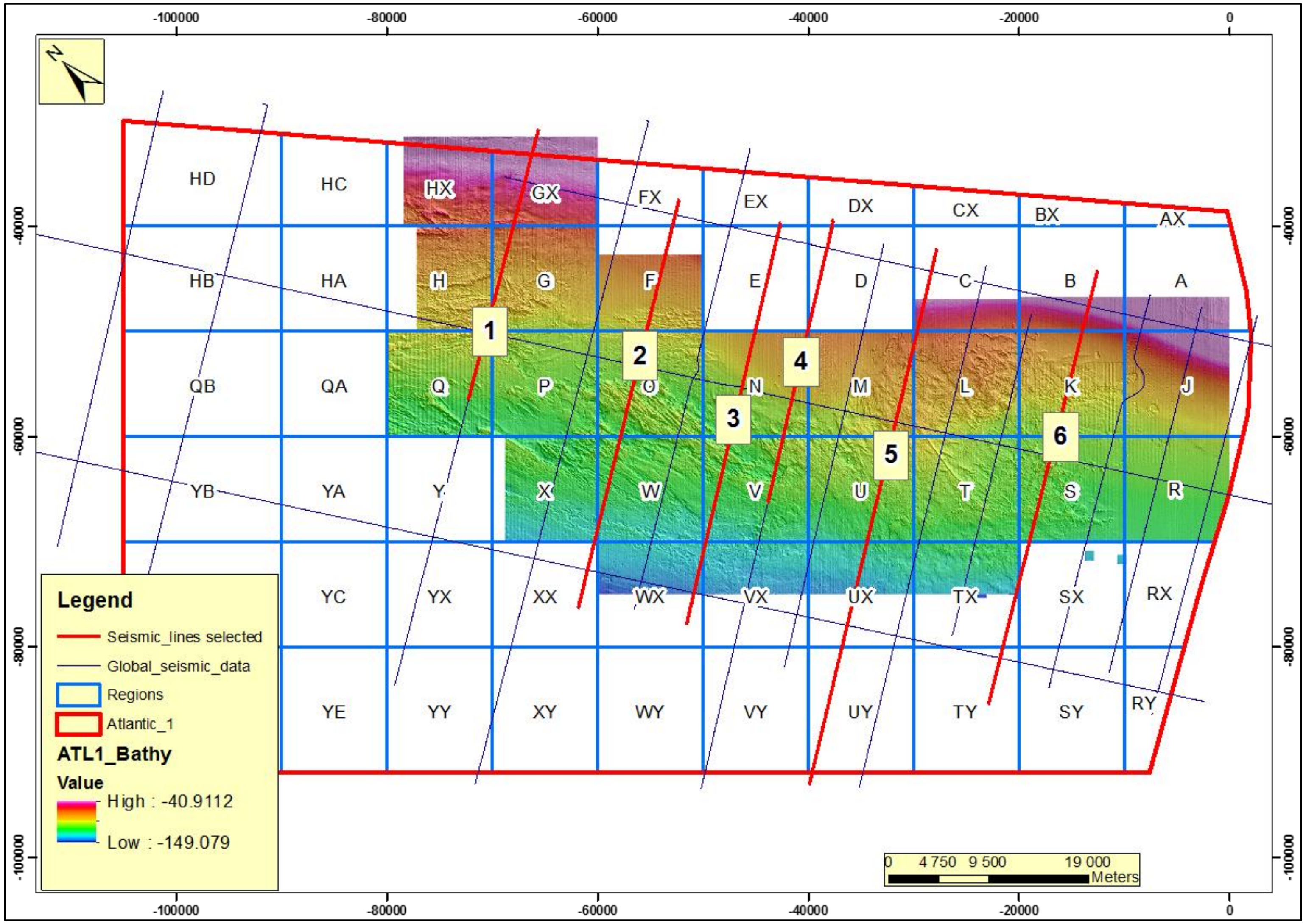


Figure 3.3A: *Map showing all the available global airgun seismic data presenting 6 lines (highlighted in red colour) that were used to generate seismic profiles and interpreted for the study.*

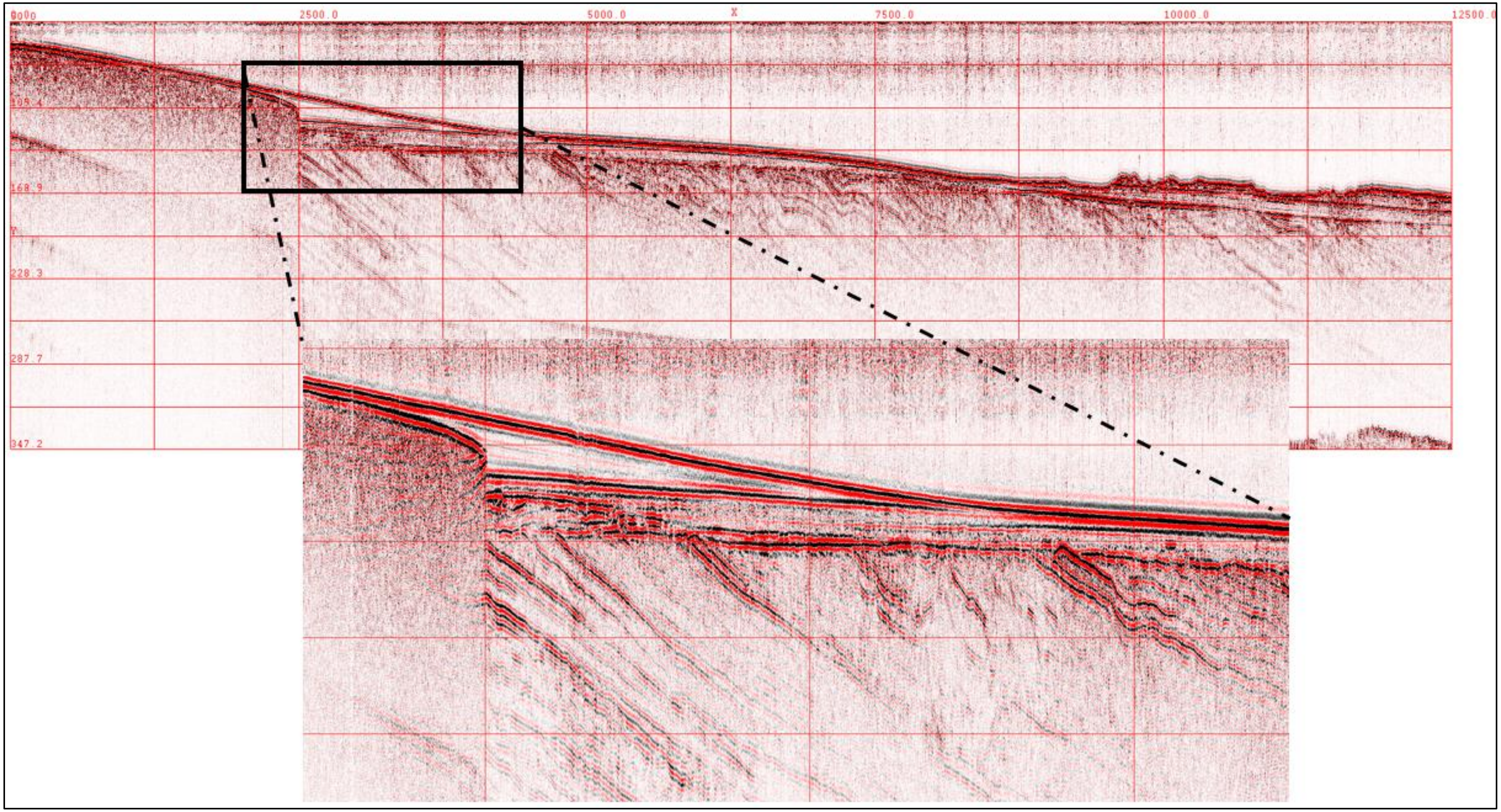


Figure 3.3B: *Un-interpreted seismic profile generated and displayed from line 4 in figure 3.3A.*

Figure 3.4: *The mining vessel (Debmar Atlantic) visited for data collection during the study.*

Figure 3.5: *The Jago diving tool. A: Jago diving vehicle on the deck of the S.A. Agulhas II research vessel. B: Jago diving vehicle clearing the deck as it is about to be launched.*

3.4 Sampling and Production mining data

The geological information and resource reconciliation data captured during the sampling campaigns and mining were critically examined in terms of the geological model, geological zones and mineralisation potential. Areas of high-grade mineralisation were identified and examined in relation to the geology. This helped in understanding the geological controls on high-grade mineralisation. Data collected included the maps showing number of stones per hole recovered during sampling (Figure 3.7A & B), and maps of recovered grade from mining in different geology (Figure 3.8).

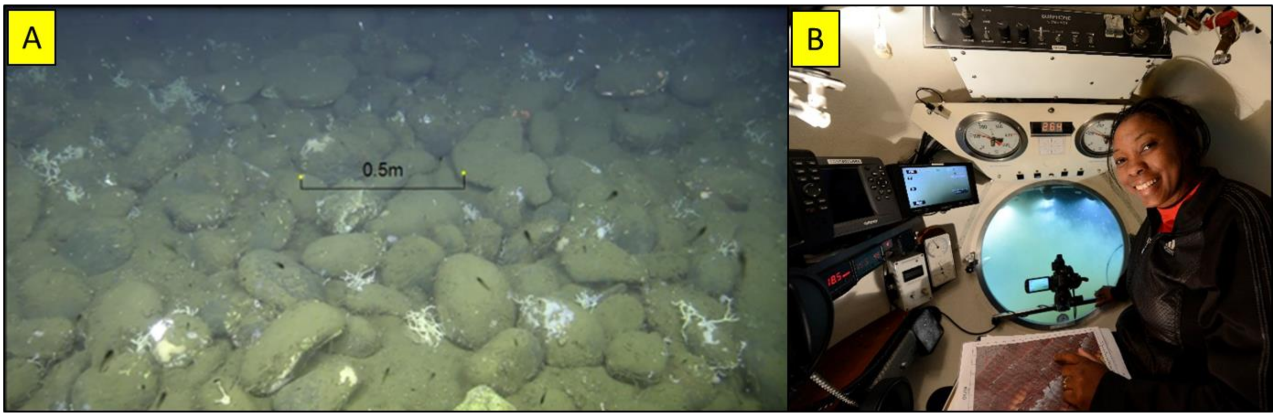


Figure 3.6: *The Jago footage observations. A: high gravel volumes composed of pebbles, cobbles and boulder size, typical of Region U material. B: A geologist (Elina Amutenya) inside the Jago observing sea-bed mining conditions and geology.*

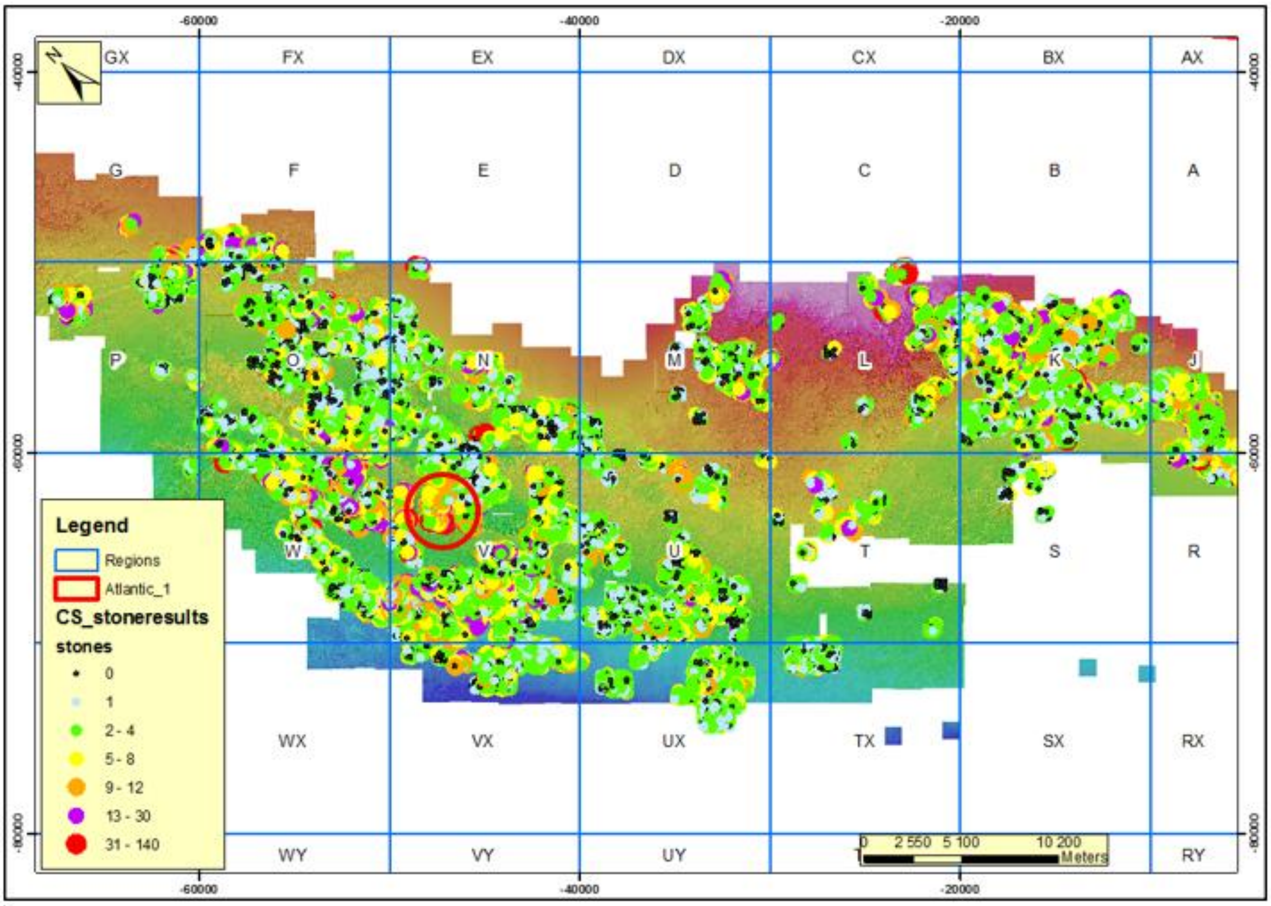


Figure 3.7A: *Maps showing number of stones per hole recovered during sampling.*

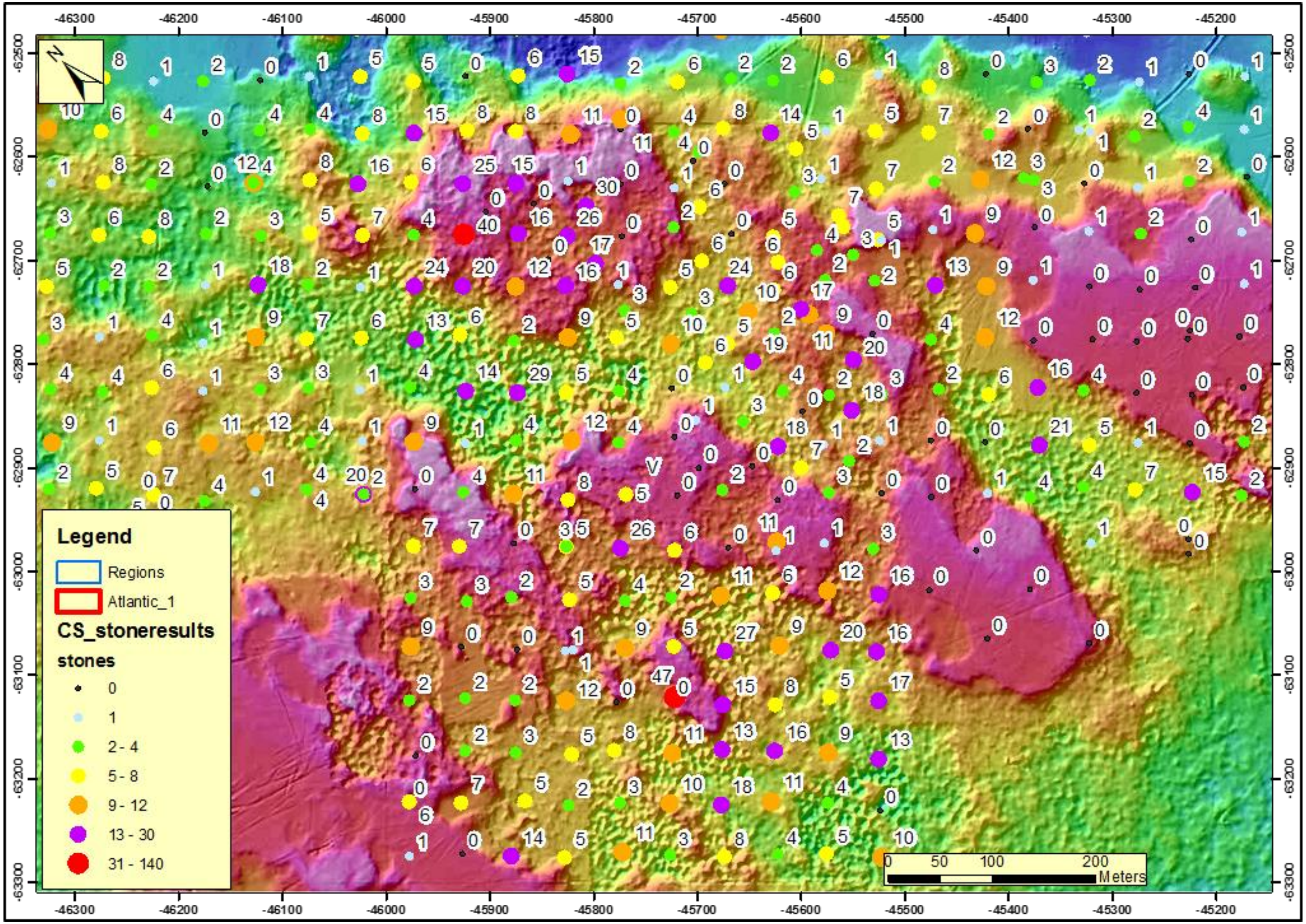


Figure 3.7B: *Map showing part of Region V (circled in Figure 3.7.) sampling stones recovery per hole.*

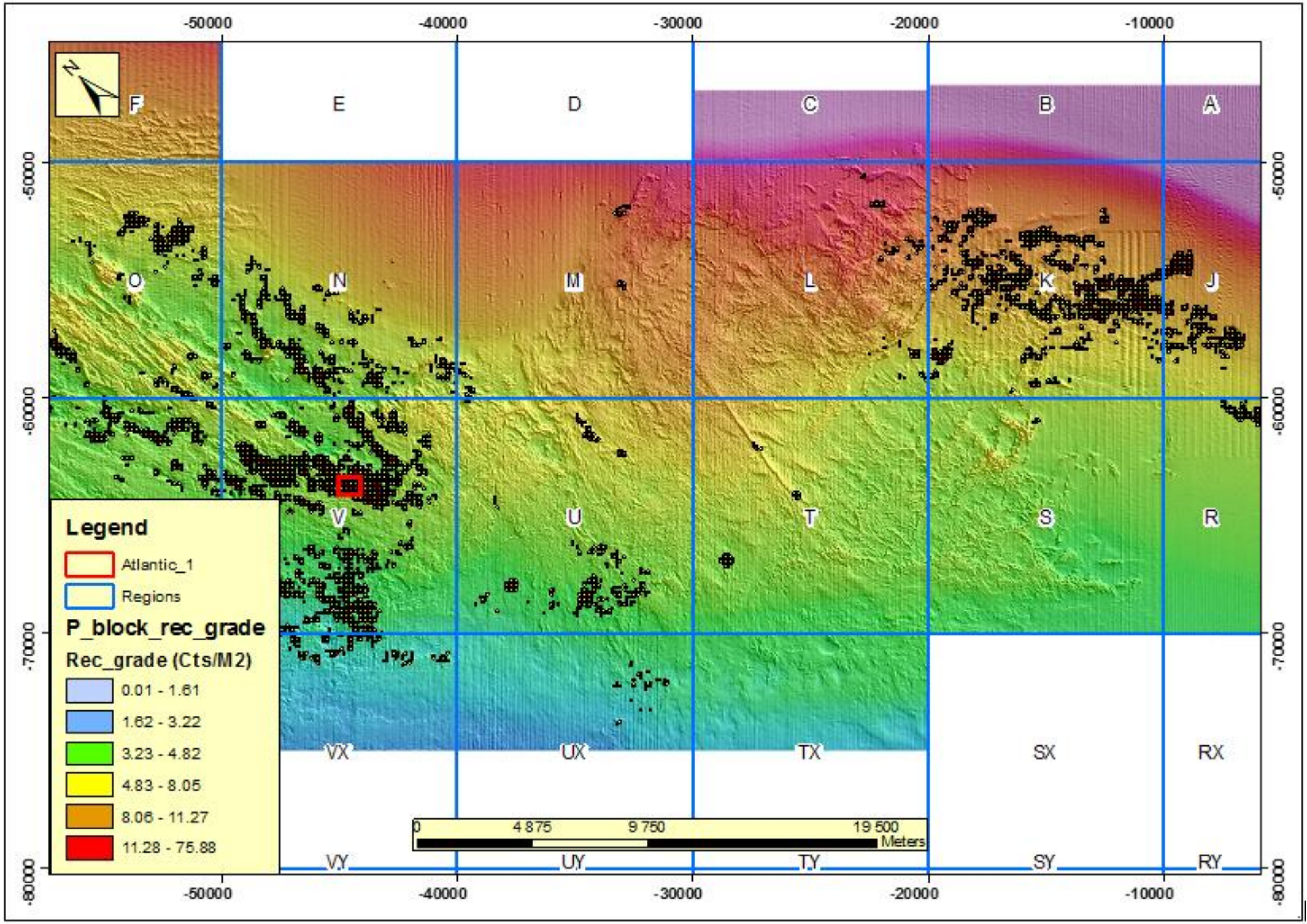


Figure 3.8: *Map showing the Atlantic 1 recovered grade, displaying high-grade recoveries in the depressions in Region V (area highlighted in red).*

CHAPTER 4

RESEARCH RESULTS

The geographical and geophysical data of the Atlantic 1 deposit that was analysed using ArcMap has revealed that there are specific localities where marine deposits have a higher probability of containing high-grade diamond mineralisation. Such localities are associated with the nature of the surface terrain and favourable depositional environments.

For all the areas in Atlantic 1 with resource blocks, the high-grade resource blocks were selected based on the sampling (estimated grade) and mining recovered grades. The high-grade considered in the study is the grade of 4.83 cts/m^2 and higher. Figure 4.1 presents the existing high-grade resource blocks in Atlantic 1 mining licence as updated at the end 2nd quarter 2017.

After the existing high-grade areas were located, the next task was to analyse in detail the underlying geology using geological (depositional facies) and geophysical (bathymetry, seismic and side scan sonar) images in order to identify the geological and/or structural controls in those areas. Using the GIS software, specifically ArcMap, patterns and trends were identified from side scan sonar and bathymetry images. Chirp seismic sections were generated and used to delineate sub-surface geological features. Geological observations including observed gravel pictures and images collected during Jago dives were also analysed and presented.

Areas of interest where most of the results were collected were mainly areas of high mineralisation trapsite potential which comprises the geological zones that have the ability to trap mineralised gravel. This is mainly a function of the geomorphology of the geozone footwall surface. For instance, the areas with rougher footwall topography will have a high trapsite potential relative to smoother footwall areas provided there is a supply of mineralised gravel.

Eventually, through a detailed analysis of the high-grade resource localities, geological and structural conditions were identified as favourable depositional environments or controls for high-grade mineralisation in Atlantic 1. Some favourable depositional environments identified included outcrops, depressions, gravel beach berms, potholes, gullies and scarp slopes that act as trapsites.

4.1 Geological and Geophysical data

Favourable depositional environments/ controls for high-grade mineralisation

Using ArcMap software, all the high-grade blocks in Atlantic 1 were identified as shown in Figure 4.1. The cluster of the highest grade blocks of 11.6 cts/m2 and higher in order of their dominance where found in Pre-proto source area which covers Regions V, O, W and inshore N. This were followed by the Proto and Meso source areas, which mainly cover Regions M-U-L-T and K-J, respectively. Other high grades were observed further to the northern part of the study area in Regions F and G (Figure 4.2).

4.1.1 Depressions and Eroded Platforms in Pre-proto source area:

High-grade blocks on the Pre-proto source area which covers Regions V, W, O, N where located in the depressions and eroded platforms. These features were identified as low or depressed part of the surface (Figure 4.3). Figure 4.4 show the associated grade on the mentioned features. The insight into textural characteristic of the sea floor was acquired using the side scan sonar (SSS) image, which were mainly analysed to determine the roughness of the terrain, which plays a big role in terms of trapping and retaining the diamonds. Figure 4.5 present the side scan sonar of the same high-grade area in Region V.

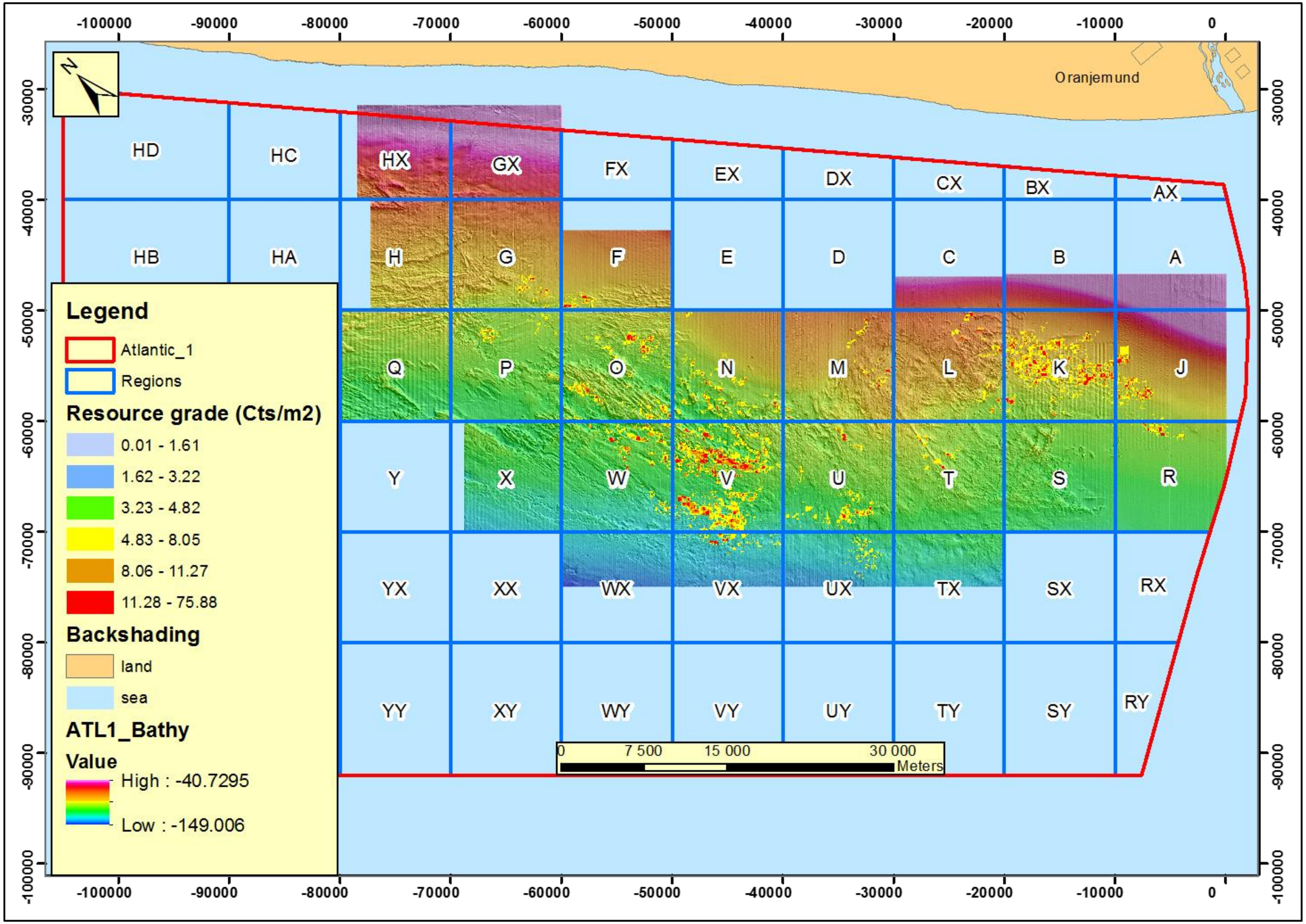


Figure 4.1: *Map showing the existing high-grade resource blocks in Atlantic 1.*

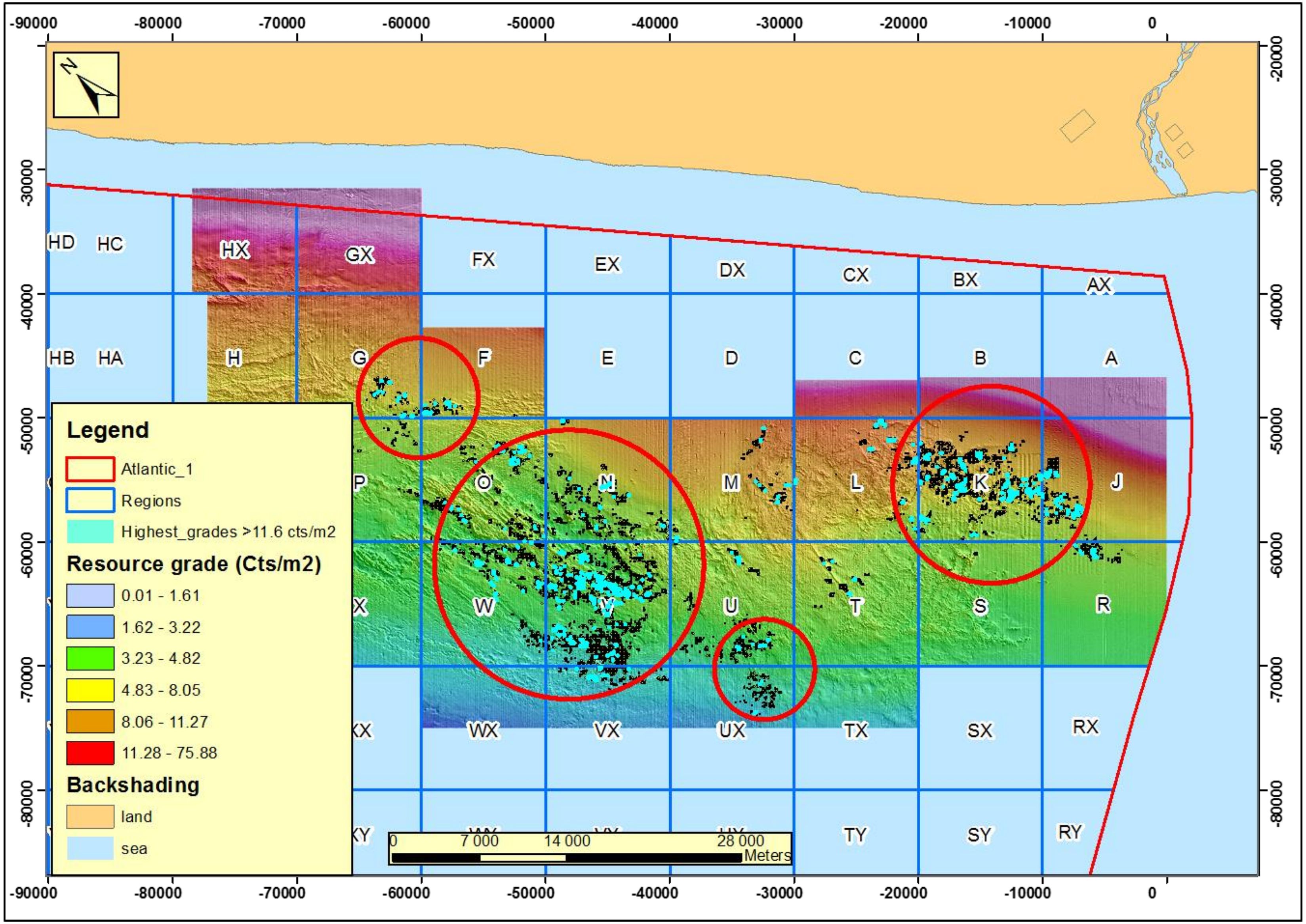


Figure 4.2: *The map presenting the existing high-grade resource blocks in Atlantic 1, with the cluster of the highest grade blocks (highlighted in blue) ranging from 11.6 to 75.88 cts/m*^{2} ***being outlined with red circles.***

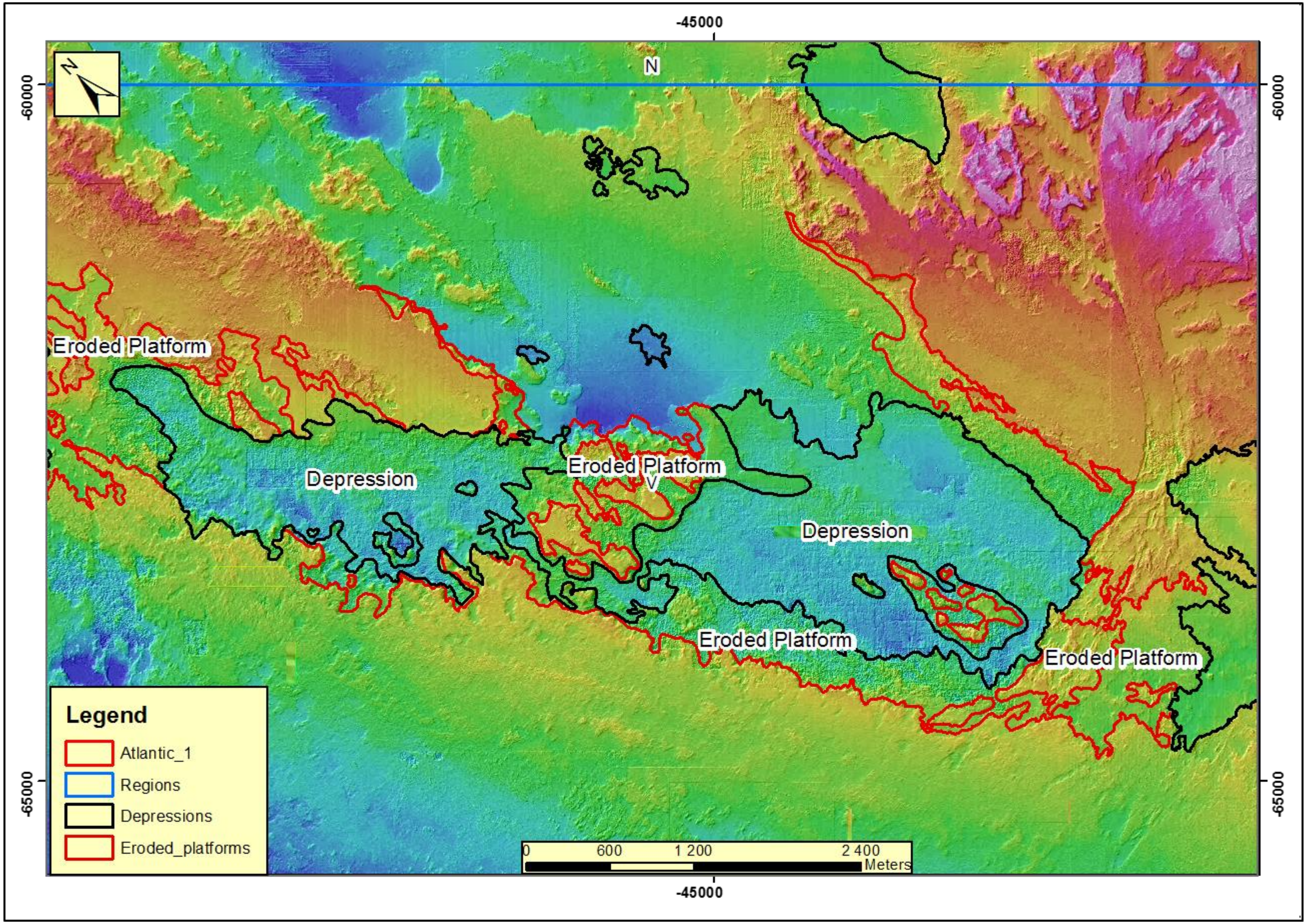


Figure 4.3: *Map showing the bathymetry surface terrain revealing depressions and eroded platforms in Region V, which are associated with high-grade mineralisation.*

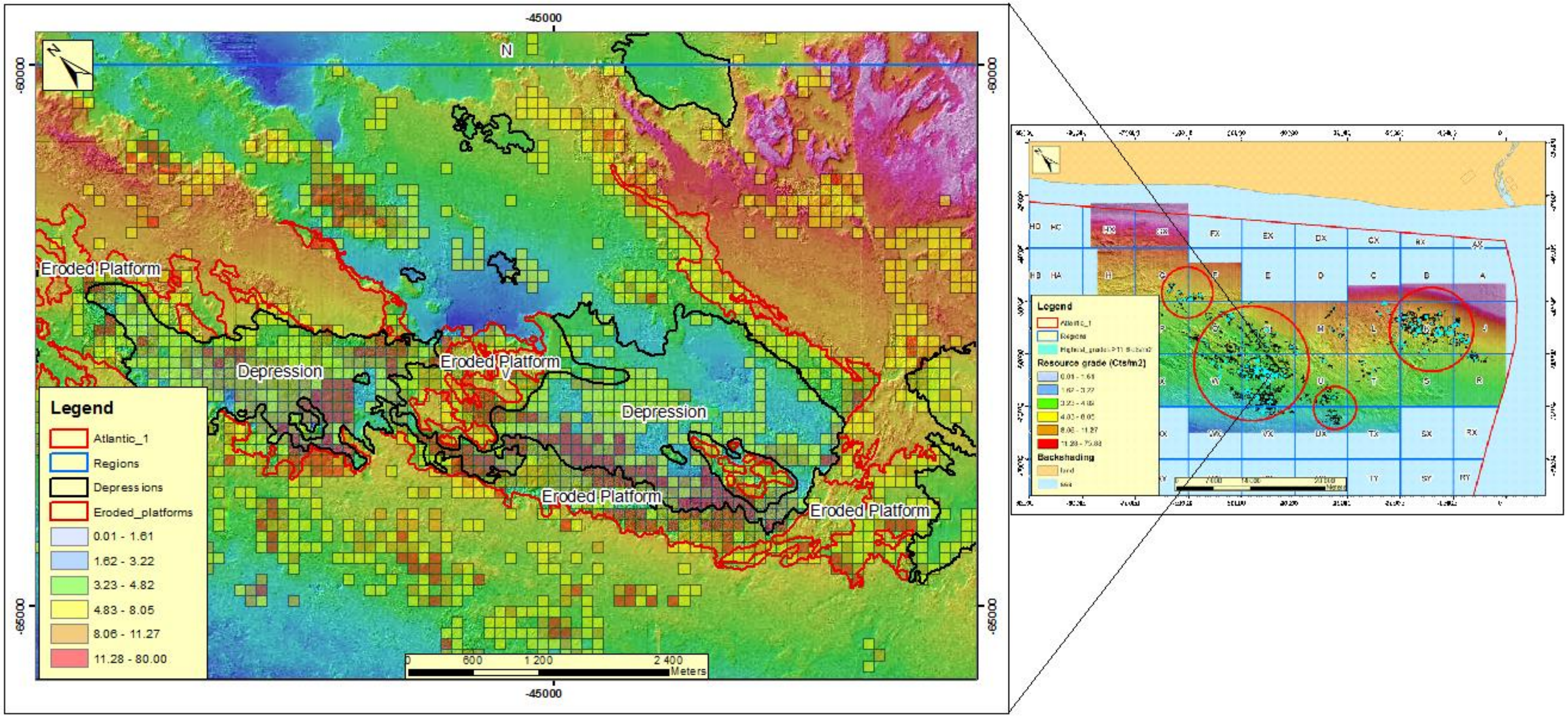


Figure 4.4: *Map showing the areas of high-grade mineralisation in Region V which is characterised by depressions and eroded platforms. The map presents the grade range associated with these features.*

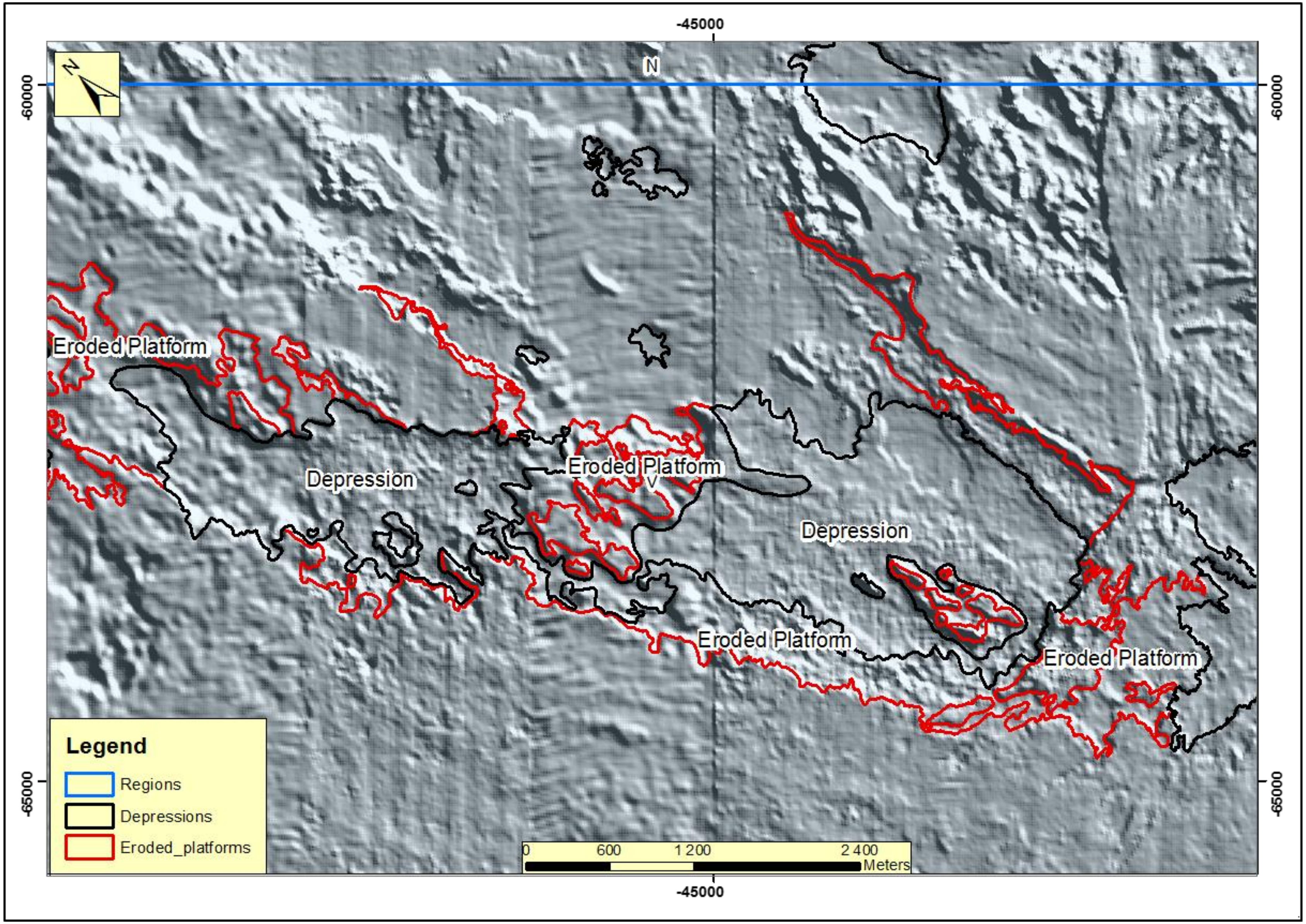


Figure 4.5: *Map showing the side scan sonar in Region V revealing the depressions and eroded platforms, and rough surface texture especially on the eroded platforms.*

The morphology of the prominent or resistant features such as outcrops are depicted from the bathymetry image (Figure 4.3). To delineate the geometry of the features requires the analysis of the subsurface, which is done using the seismic sections. Both the bathymetry and seismic cross section of the high-grade areas in Region V is presented in Figure 4.6. Furthermore, the interpreted seismic profiles which were generated from seismic lines (Figure 4.7) using siesAVS software were displayed and all the structures and different gravel layers observed were highlighted (Figure 4.8). The six seismic lines presented in Figure 4.7-displayed similar trend and structures, which were interpreted on a regional scale (Figure 4.8).

4.1.2 Beach berms:
Following the high-grade mineralisation in the Pre-proto source areas that cover mainly Regions V, O, W, and N, the second cluster of high-grade mineralisation were observed in the southern areas of the Atlantic 1, mainly in Regions K and L. These high grades were found in the beach berm geozones, which are characterised by thick gravel accumulation. Figure 4.9 shows the spatial localities of the beach berm zones that are mainly located in the southern inshore Regions (L & K) of the Atlantic 1 licence area and the sizes of the beaches decrease offshore. Figure 4.10 shows the seismic profile through a beach berm geozone.

4.1.3 Gravel Platforms:
Gravel platforms are referred to as high-lying gravel accumulations which generally have a shallow offshore dip. The gravel platforms are common in Region K in the southern regions of Atlantic 1 (Figure 4.11). Region K is characterised by large fairly extensive wave-cut gravel platforms, particularly on the inshore side. These are occasionally interrupted by thick recent gravel bars. Gravel platforms are fairly extensive planed Cretaceous surfaces associated with coarse to very coarse high gravel volumes, dominated by quartzite and well-rounded sandstone with a high percentage of exotics. The gravel volumes and coarseness generally increase from the offshore end of the platforms to the inshore.

4.1.4 Outcrops:
The outcrops were also found to be associated with high-grade mineralisation. Outcrops are total areas over which a particular rock unit occurs at the surface. In Atlantic 1 these features are often isolated and small. Figure 4.12 shows all the outcrop zones mapped from the Atlantic 1 licence area, while Figure 4.13 shows the seismic profile through the outcrop.

4.1.6 Depressions:
Depressions were observed as low or depressed/hollow parts of the surface. In Atlantic 1 these can be shallow, deep, large-scale (km-scale or regional) or small-scale. Figure 4.14 shows the different depression types mapped in Atlantic 1.

4.1.6 Gravel ridges and reflectors:
Gravel ridges and reflectors are rough topographic features consisting of ridges and small troughs/valleys. Ridges are defined by Kearey, (1996) cited in Mubita (2015) as the outcropping extensions of sandstone reflectors. Figure 4.15 shows all the Ridge zones in Atlantic 1. Figure 4.16 shows the seismic profile through the O-ridge area.

4.1.7 Flat surfaces with minor outcrops:
The majority of the Atlantic 1 area is made up of a large flat area consisting of gravel accumulations, outcrops and reflectors. These areas are also interrupted by scours, shallow depressions and raised platforms. Figure 17 shows the flat surface related areas across Atlantic 1.

4.1.8 Weathered and Cemented Platforms:
Platforms are defined as laterally persistent high-lying areas of substrate, which are usually cemented or hard, but may also be weathered or eroded (Kearey, 1996). The weathered cemented platforms are mainly located in the northern Regions (OWV and inshore U) and are associated with high-grade mineralisation (Figure 4.18).

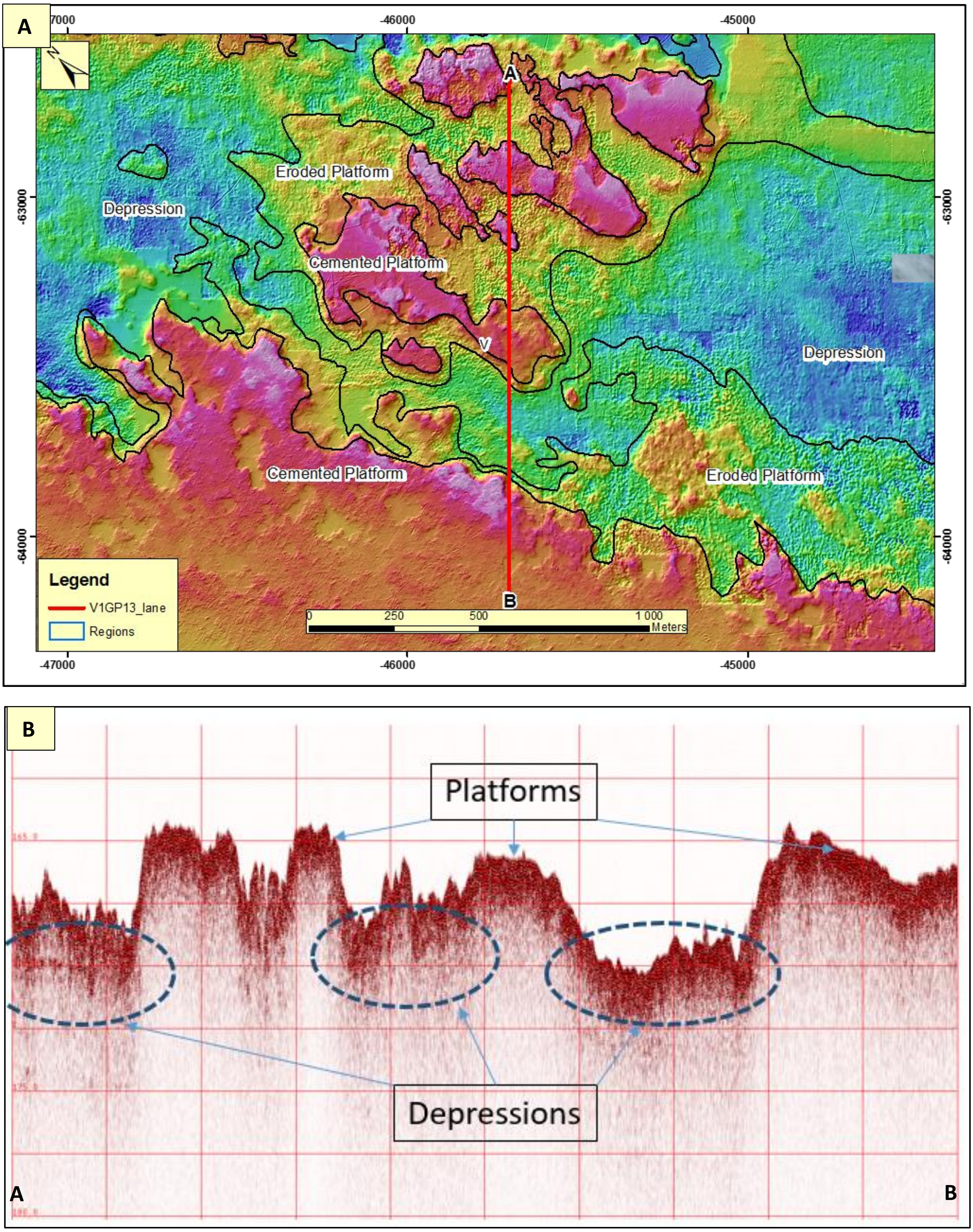


Figure 4.6: *The morphology and geometry of the prominent features that are associated with high-grade mineralisation in Region V. A: The bathymetry map revealing the prominent features and the depressions. B: Seismic section across the A-B line indicated in the bathymetry map.*

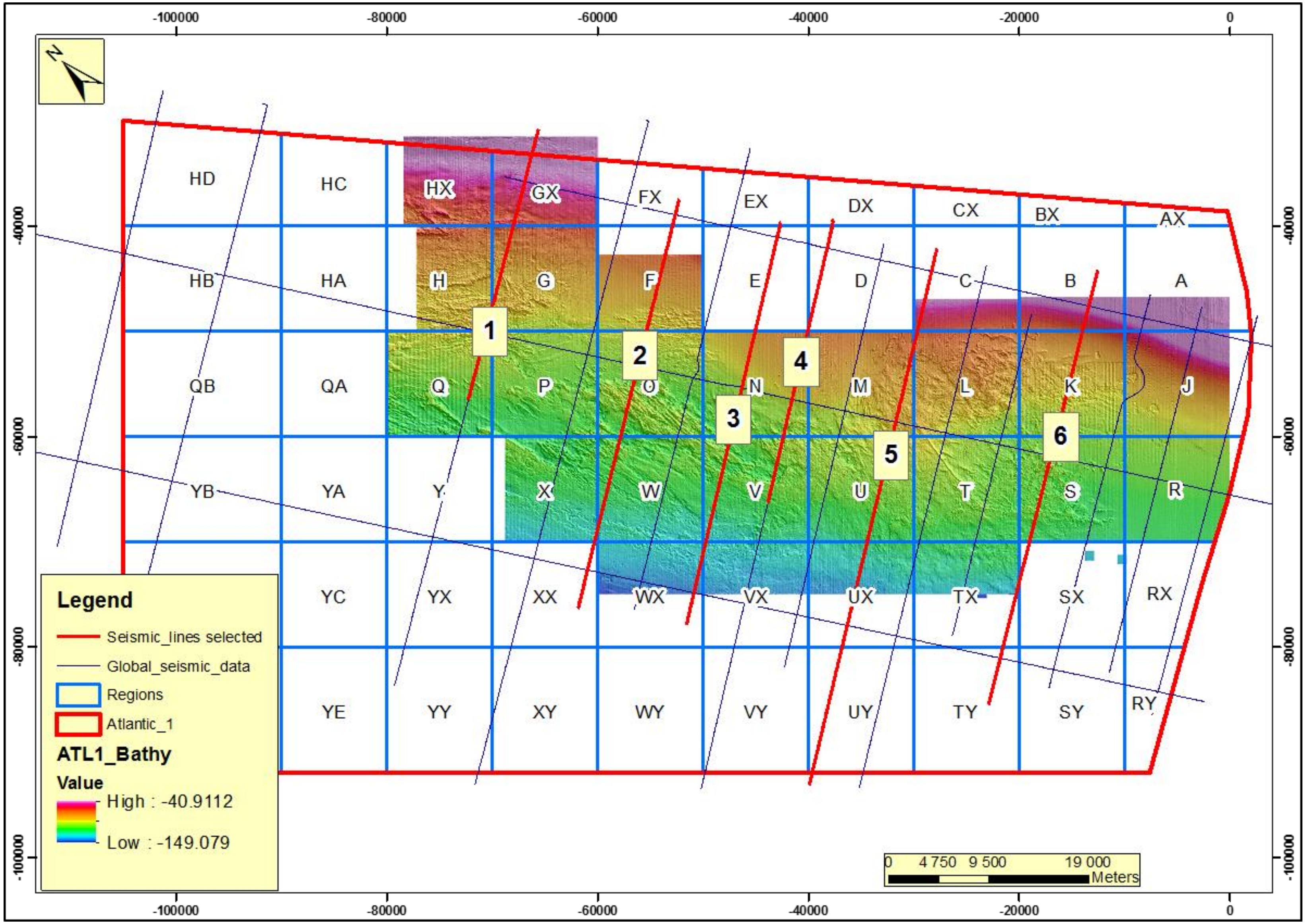


Figure 4.7: *Map showing all the available global airgun seismic data presenting the 6 lines (highlighted in red colour) that were selected to generate seismic profiles and interpretation for the study.*

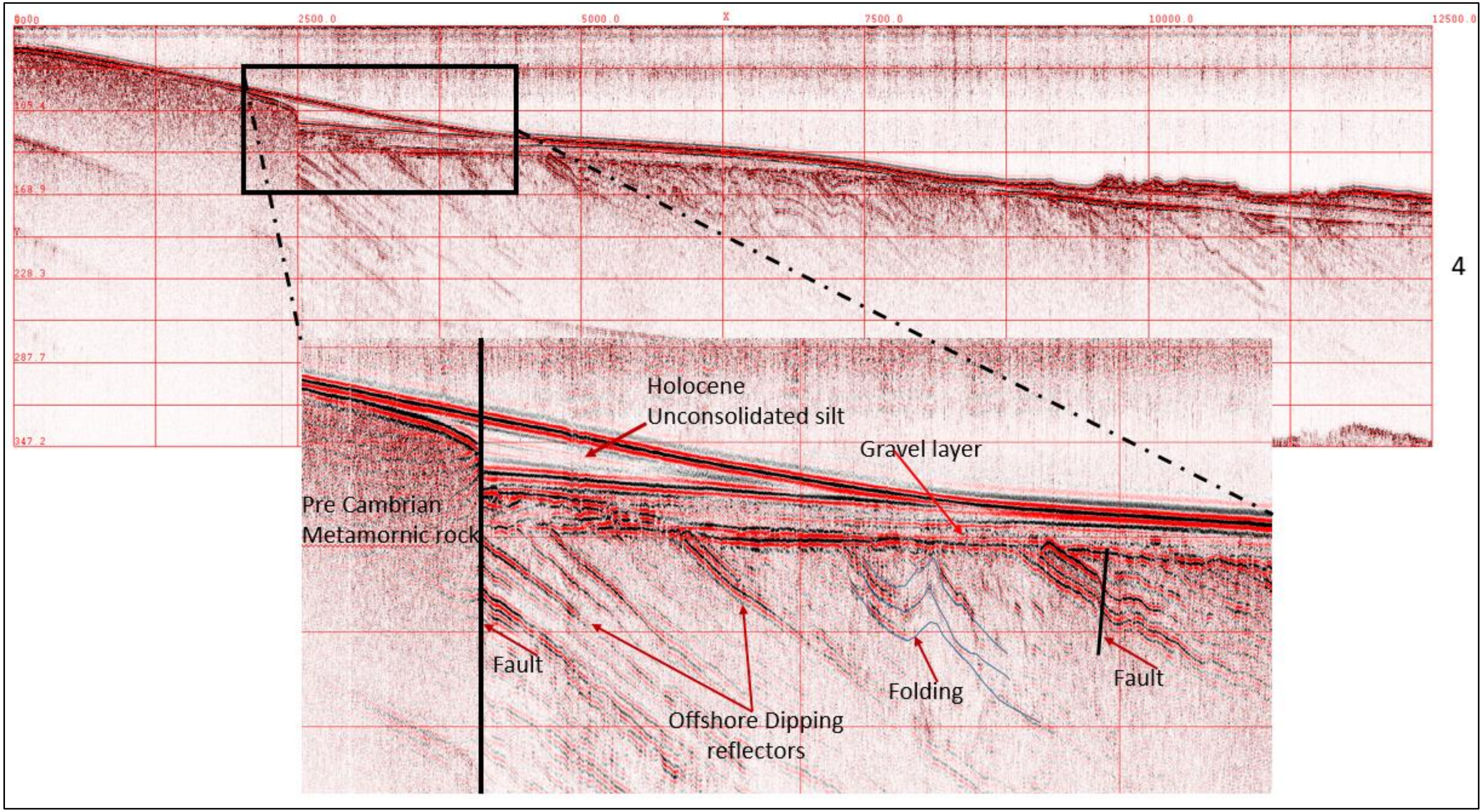


Figure 4.8: *Interpreted Seismic profile of line 4 in figure 3.7.*

The cemented platforms are located in Pre-proto source areas, and are characterised by north-south striking trending features especially in Regions O and V. From the sampling and mining data, the platforms have indicated a clay footwall overlaid by either sand, sandstone or conglomerate.

4.1.9 V-scarp mineralisation:

The scarp in Region V locally known as V-scarp is one of the high-grade mineralisation areas. It comprises of scarp slopes which can be defined as areas between the platform/ridge (high-lying) and low-lying surround. The area is mainly characterised by a highly undulating terrain and hard footwall substrates, namely, sandstone, minor conglomerate, minor siltstone and unclassified. The terrain appears to be characterised by small potholes and gullies which are highly mineralised. The extend shapefile of the V-scarp is presented in Figure 4.19. Sampling results in the area revealed that the deep and shallow depressions together with scarp slope and weathered sandstone yielded high stone hits which translate into high-grade mineralisation potential while the sandstone prominence yielded low-grade mineralisation potential (Figure 4.20).

4.2 Field work

4.2.1 Visits to the sampling and production vessels

During the duration of the research, there were several field trips to the sampling and mining vessels at sea. The main objectives of the field trips were mainly to observe, record and interpret data from offshore marine deposits, to provide information for geological mapping and to evaluate the ore deposit. Vessel visits were done at the time the mining was taking place in the high-grade areas. Targeted areas were mainly those with mineralisation trapsite potential, whereby the main aim was to observe the quality of the gravel associated with high-grade mineralisation. Data collected during field trips (vessel visits) were mainly gravel pictures observed from the screens during mining. Pictures taken during mining were then analysed and interpreted in terms of lithology, sedimentology, structural, and grade. Interpretation was done in conjunction with recoveries, sampling information and Jago footages from those areas. The images taken during field trips are presented in Figure 3.21, which mainly show volumes, compositions, sedimentology and structures. Figure 3.22 show the concentration of the exotics mainly observed in Regions K and U.

4.2.2 Jago footage observations

The south-west coast seafloor of Namibia represents one of the most diverse and resource rich areas in Namibia. Due to the complex nature of the resource, Debmarine Namibia uses various tools to explore and understand the various challenges associated with this deposit. The two-men submersible underwater vehicle (Jago), has been one of the effective tools that has been used over the years to ground-truth the analysis of geophysical interpretations, sampling and mining information. All the areas in Atlantic 1 where Jago dives have occurred are represented with shapefiles called the Jago dive tracks, and can be spatially viewed in ArcMap.

In this report, a few Jago tracks mainly in high-grade mineralisation areas were selected and sea-floor footage was analysed in association with sampling and production data. The main aim was to ground-truth the geological and geophysical interpretation hypotheses. During the Jago dives conducted for this study, the focus areas were to observe the lithologies and nature of the terrain, and to understand the factors that control mineralisation. The findings of the Jago dives that were carried out are explained below.

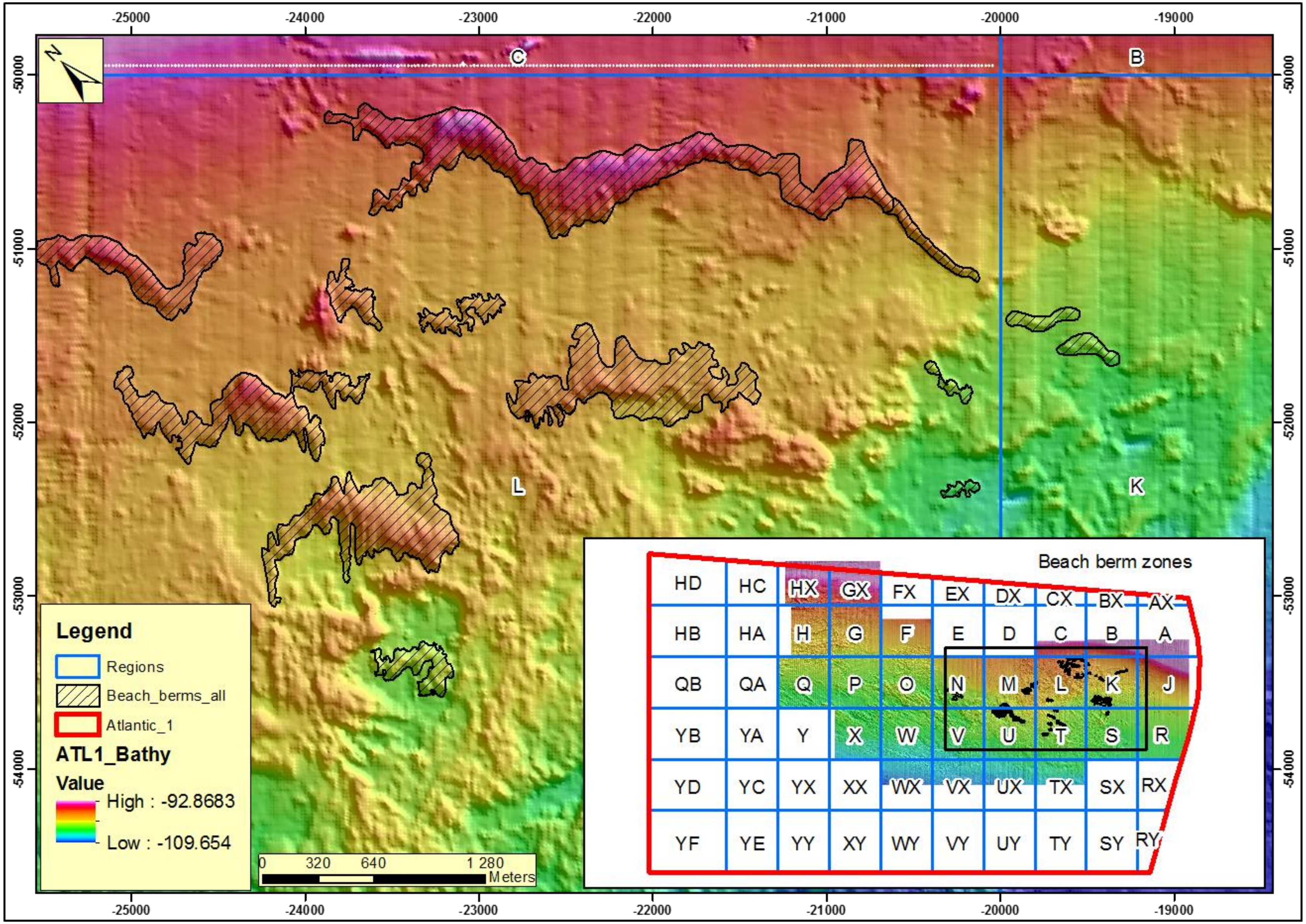


Figure 4.9: *Map showing the beach berm geozones mainly concentrated in the southern regions of the Atlantic 1.*

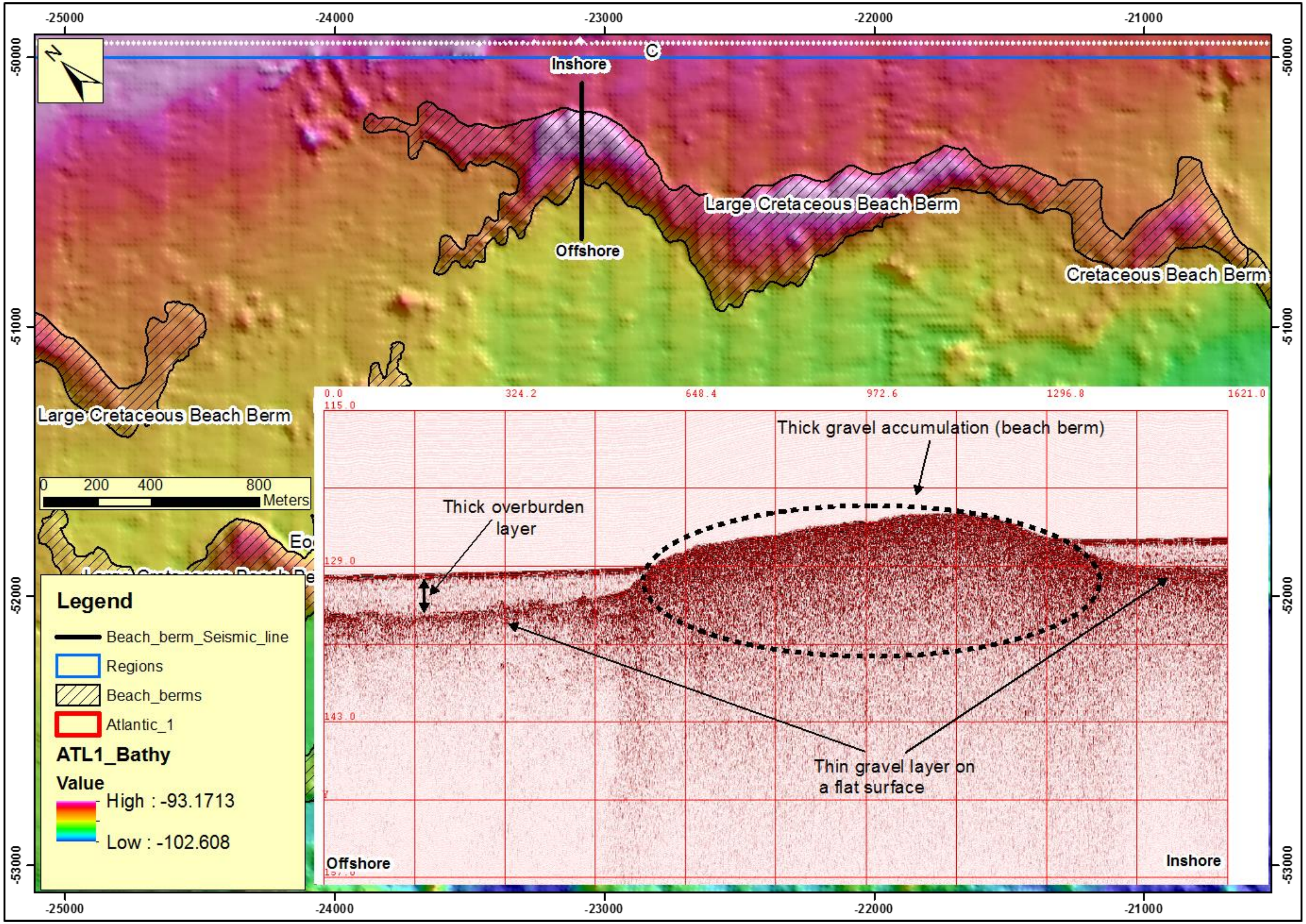


Figure 4.10: *Seismic section cross cutting through a beach berm geozone, revealing a thick gravel package.*

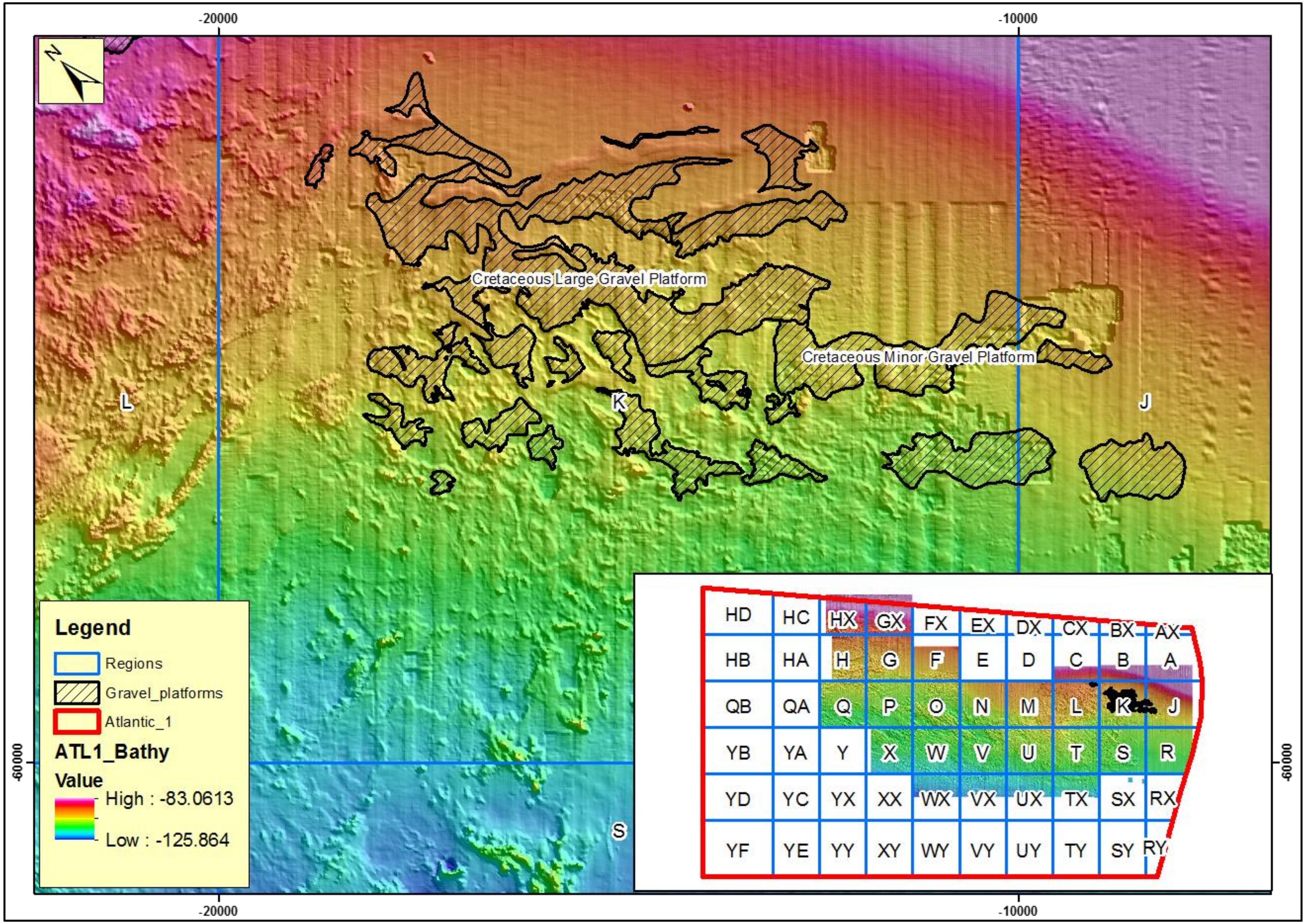


Figure 4.11: *Map showing the gravel platform zones located in Region K.*

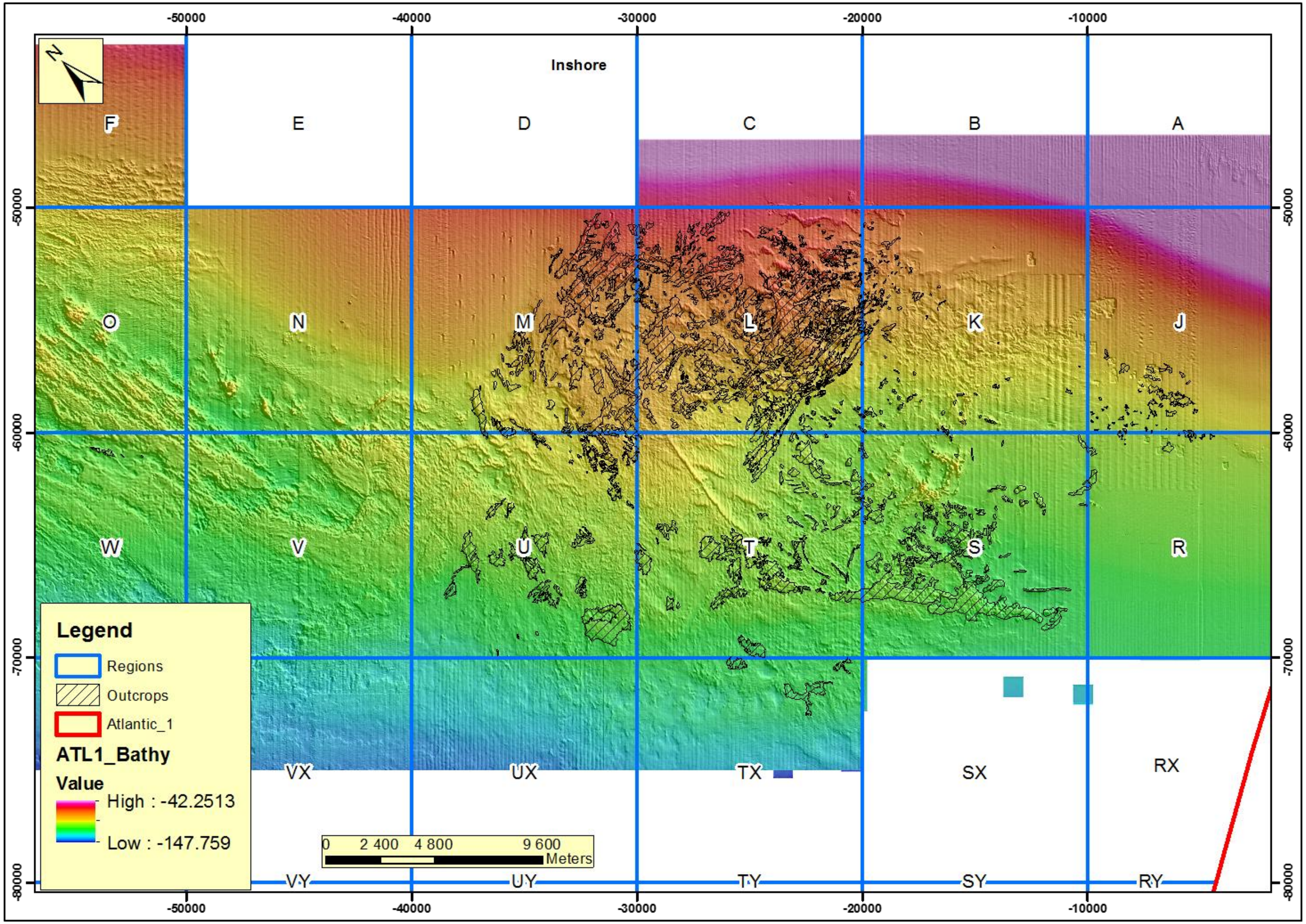


Figure 4.12: *Map showing the Atlantic 1 outcrop areas, mainly located in the central and southern regions.*

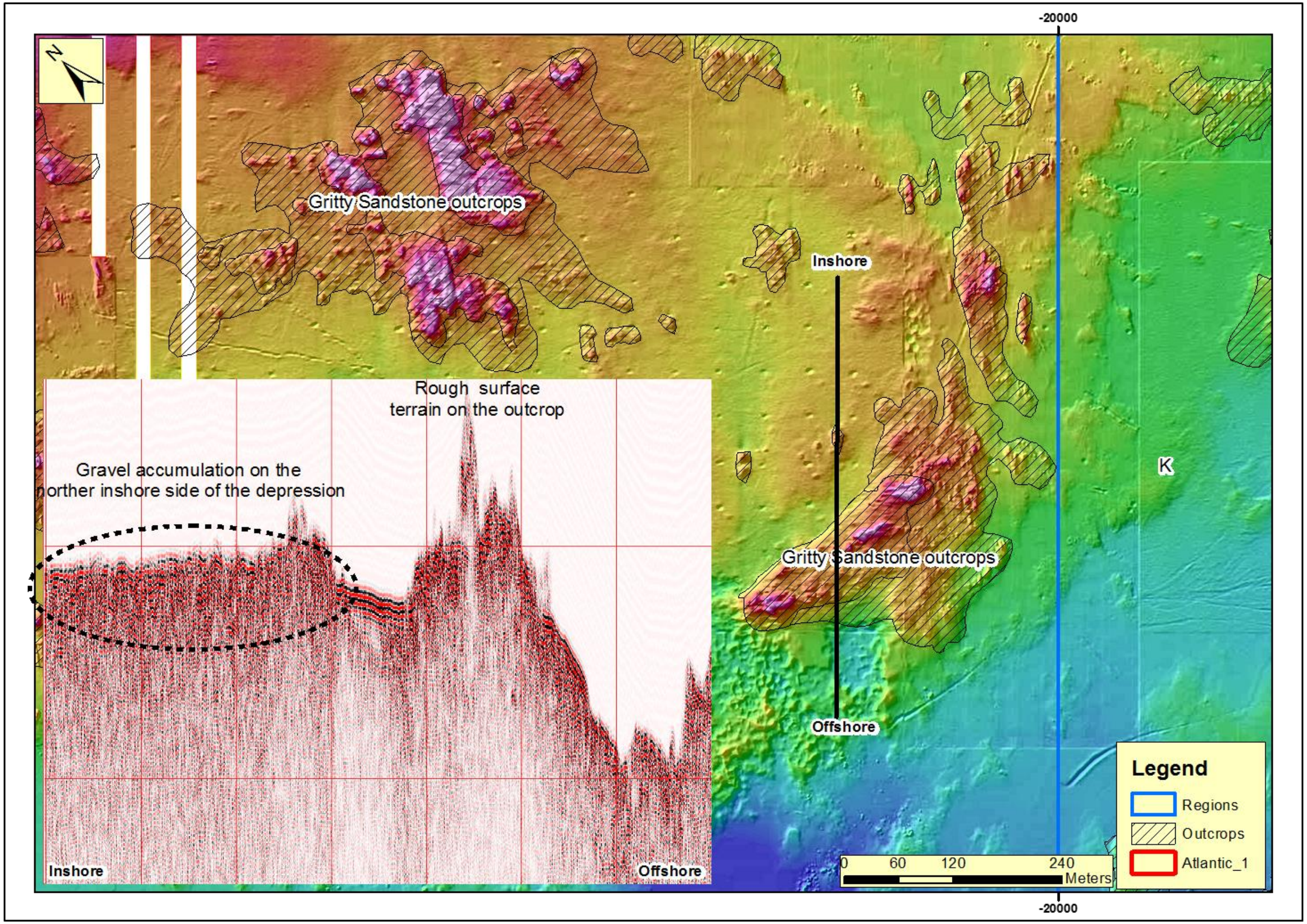


Figure 4:13: *Seismic section revealing the rough surface terrain on the outcrop areas.*

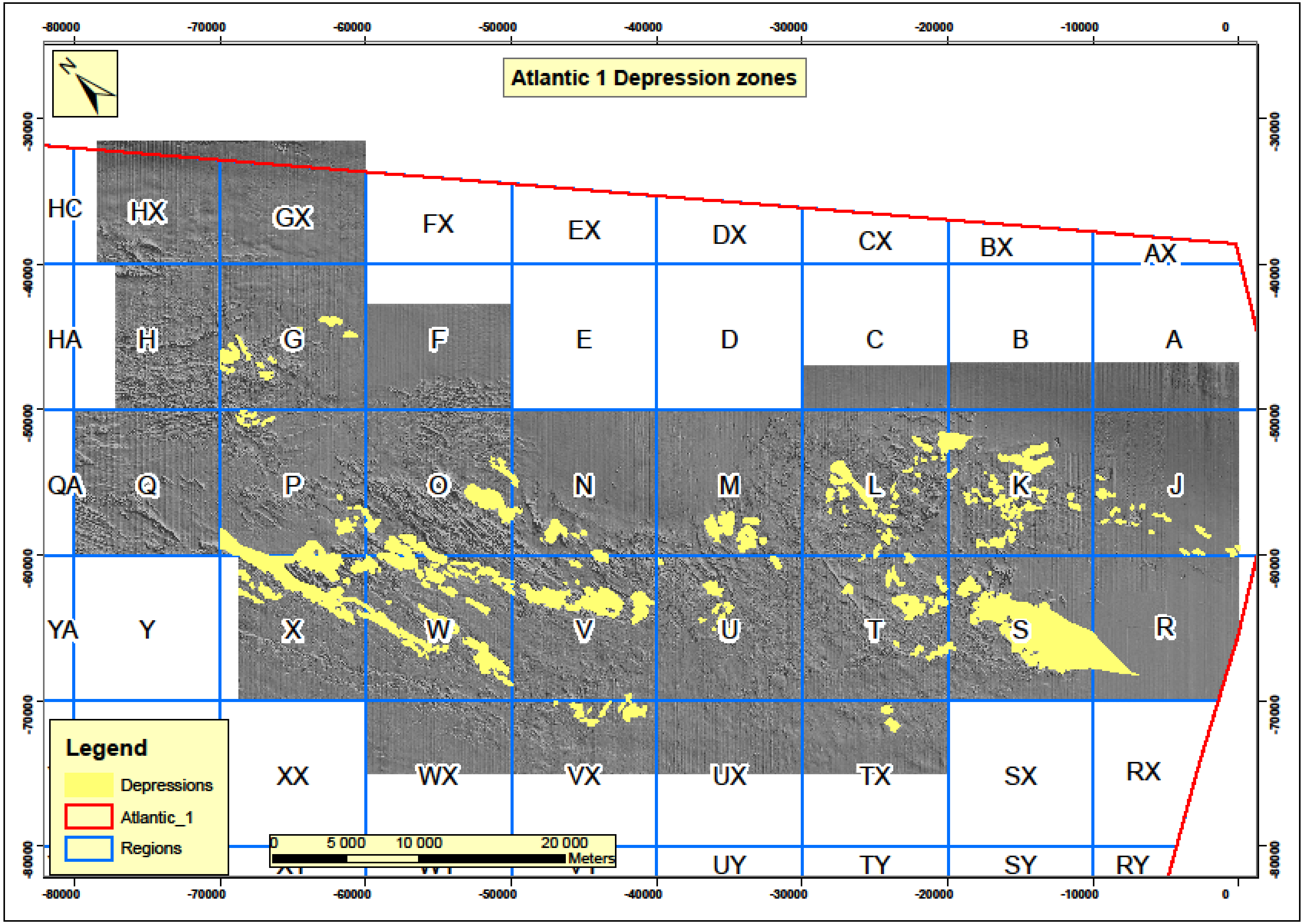


Figure 4.14: *Map showing the Atlantic 1 depression areas.*

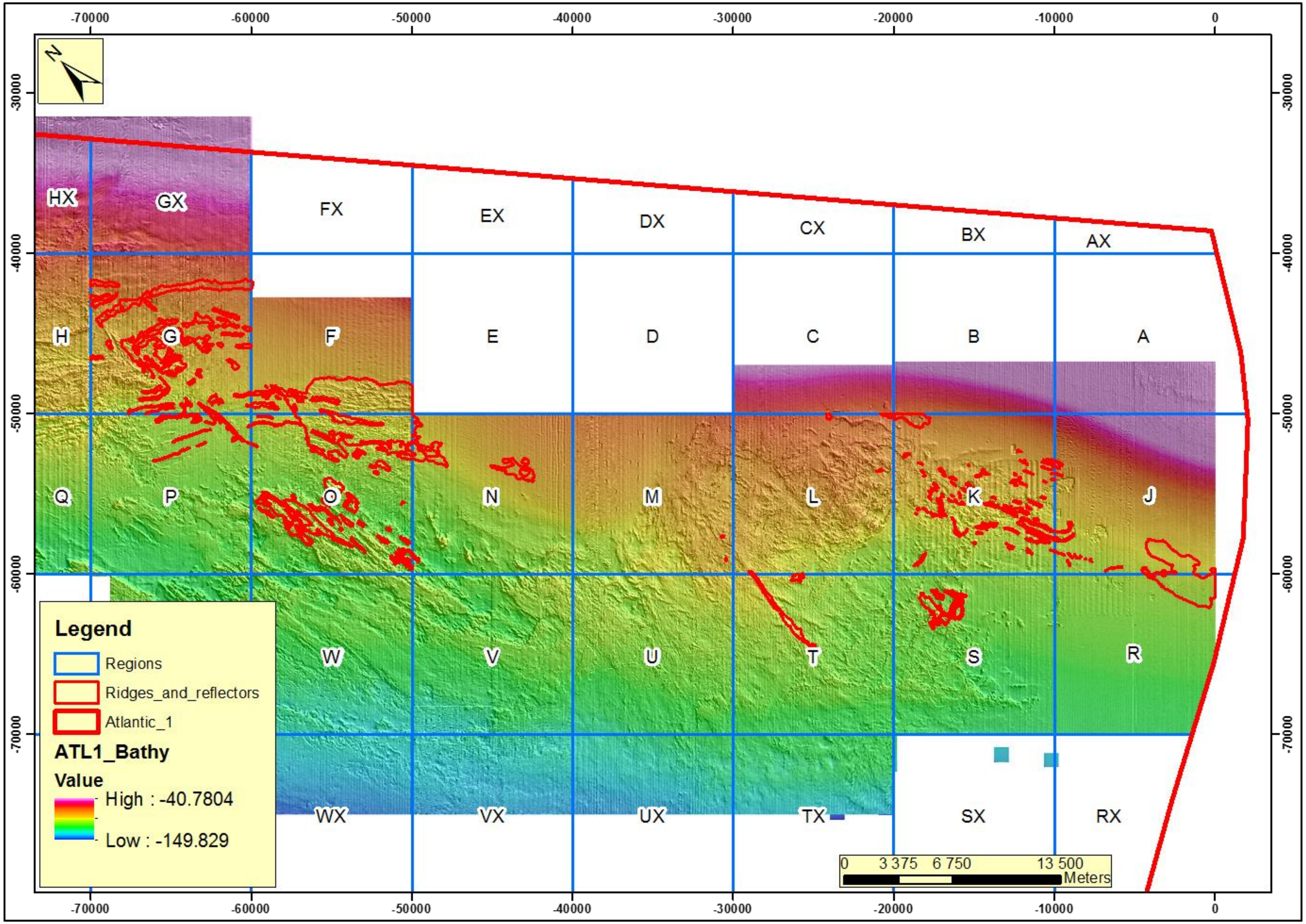


Figure 4.15: *Map showing the ridge and reflector zones in Atlantic 1, where north-south striking features (paleo-placer lineaments) are clearly visible in Region O and inshore of Region V.*

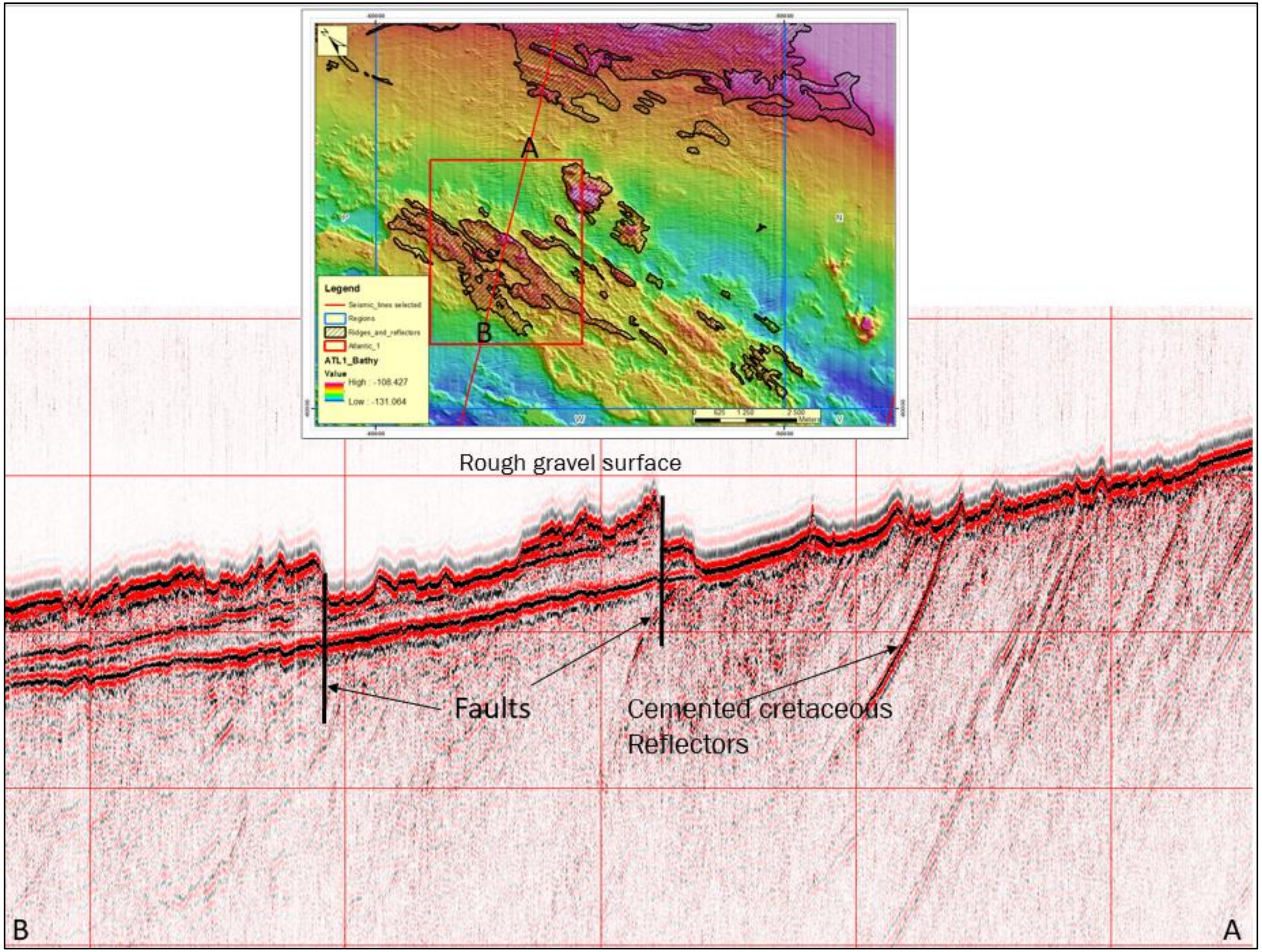


Figure 4.16: *Seismic profile showing the ridge and reflectors zones in Region O, revealing the exposed rough terrain and offshore dipping reflectors.*

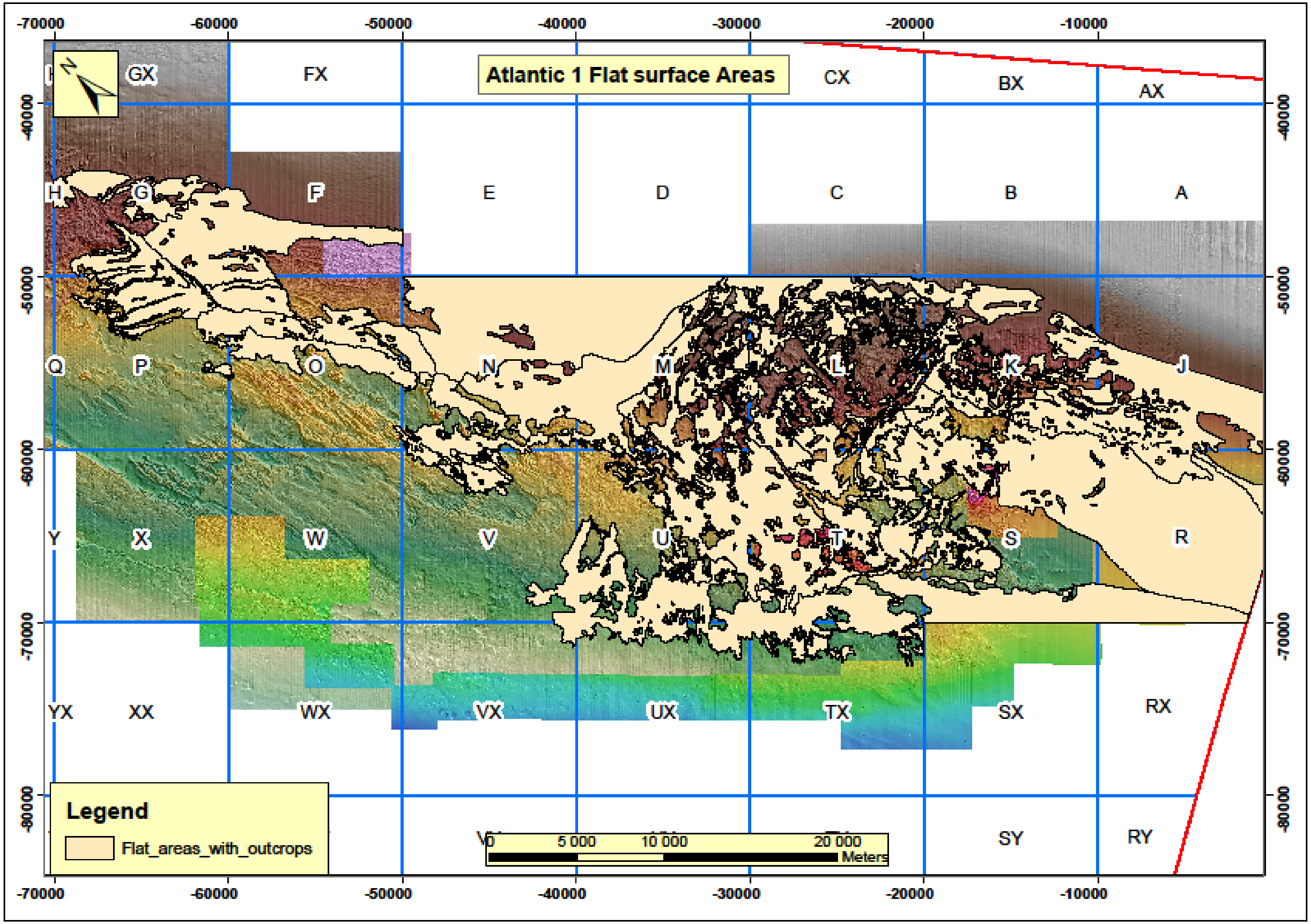


Figure 4.17: *Map showing the Atlantic 1 flat surface areas with outcrops, depressions and platforms.*

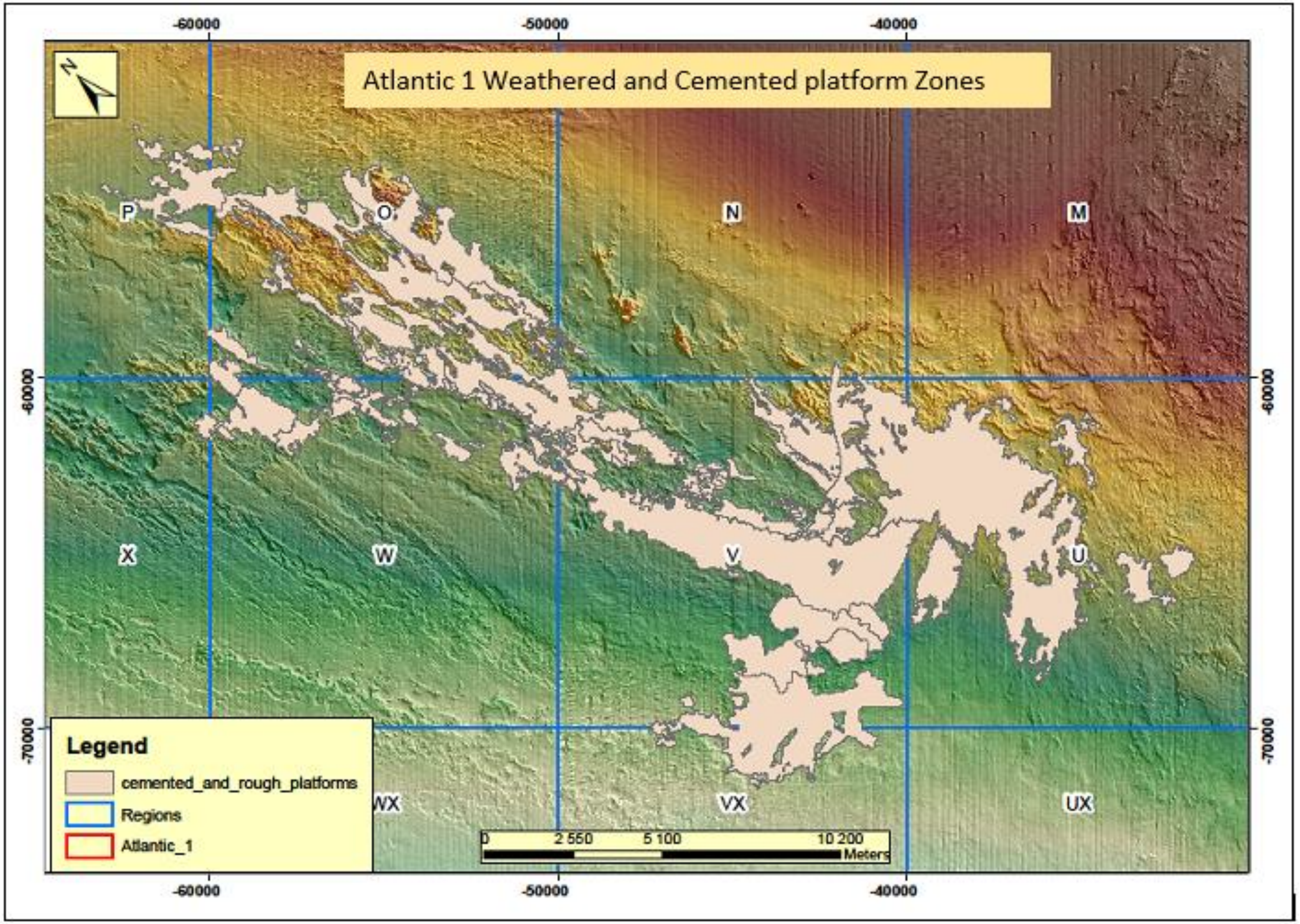


Figure 4.18: *Map showing the cemented and rough platform zones in Atlantic 1.*

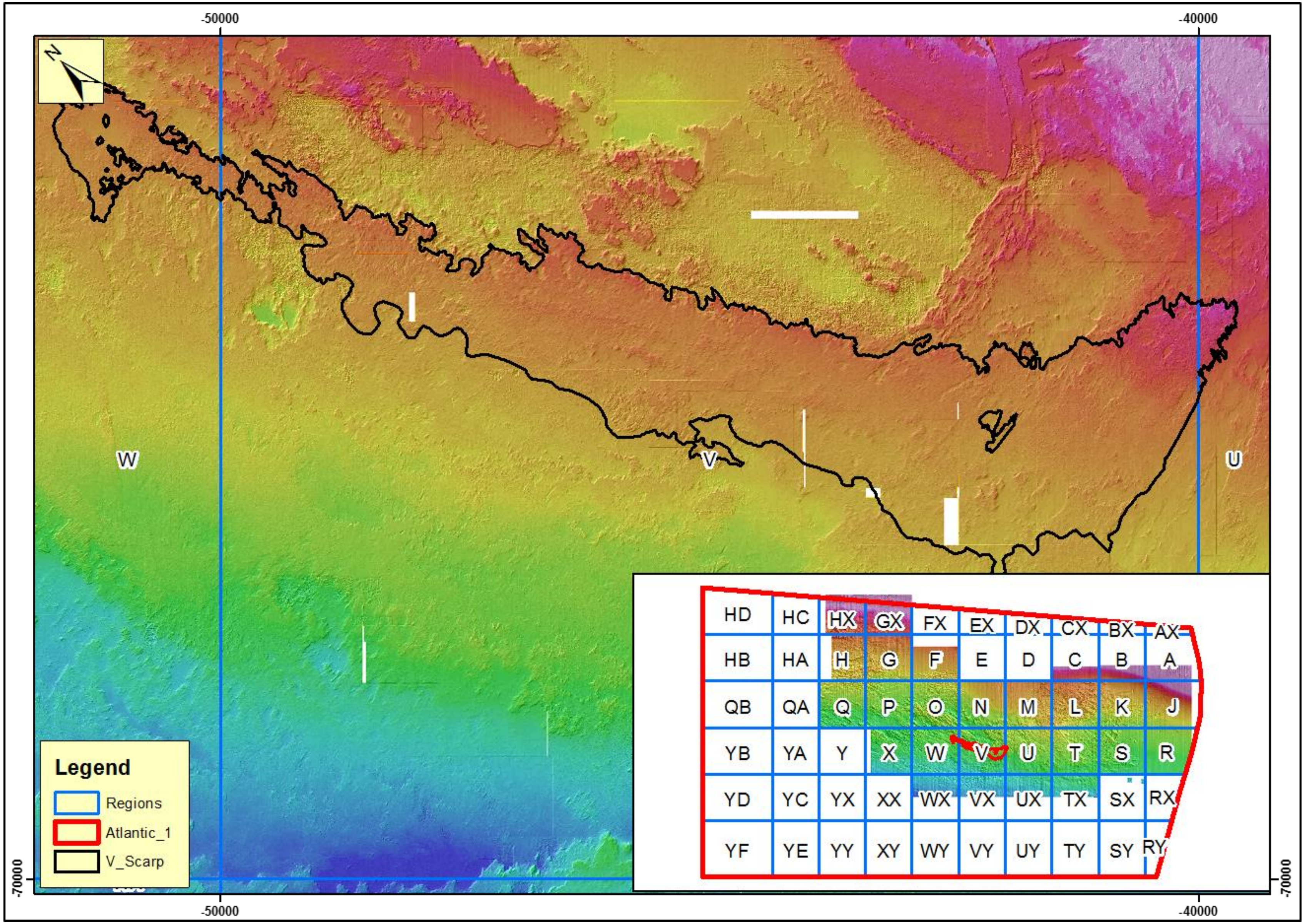


Figure 4.19: *V-Scrap zone locality map in Region V.*

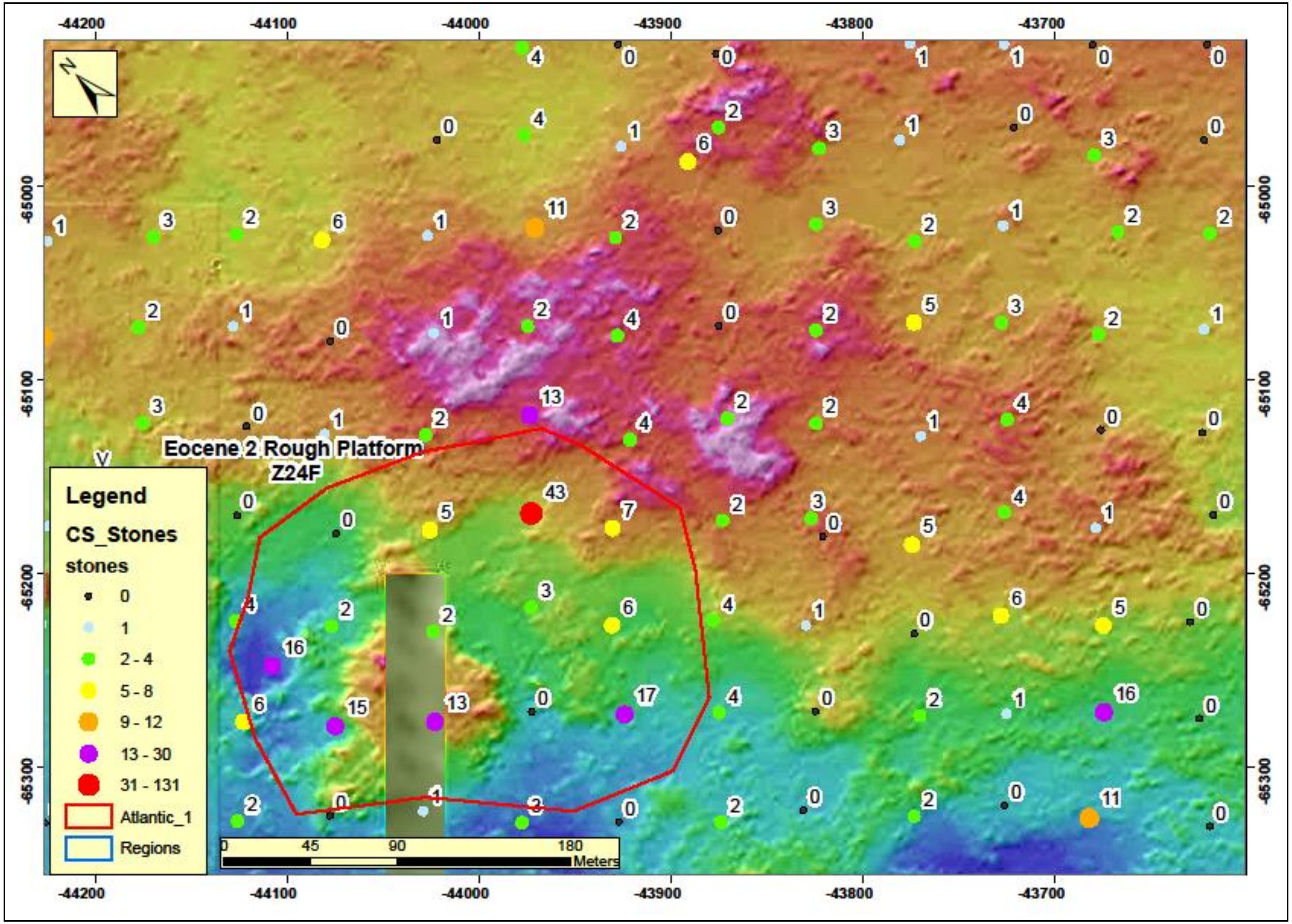
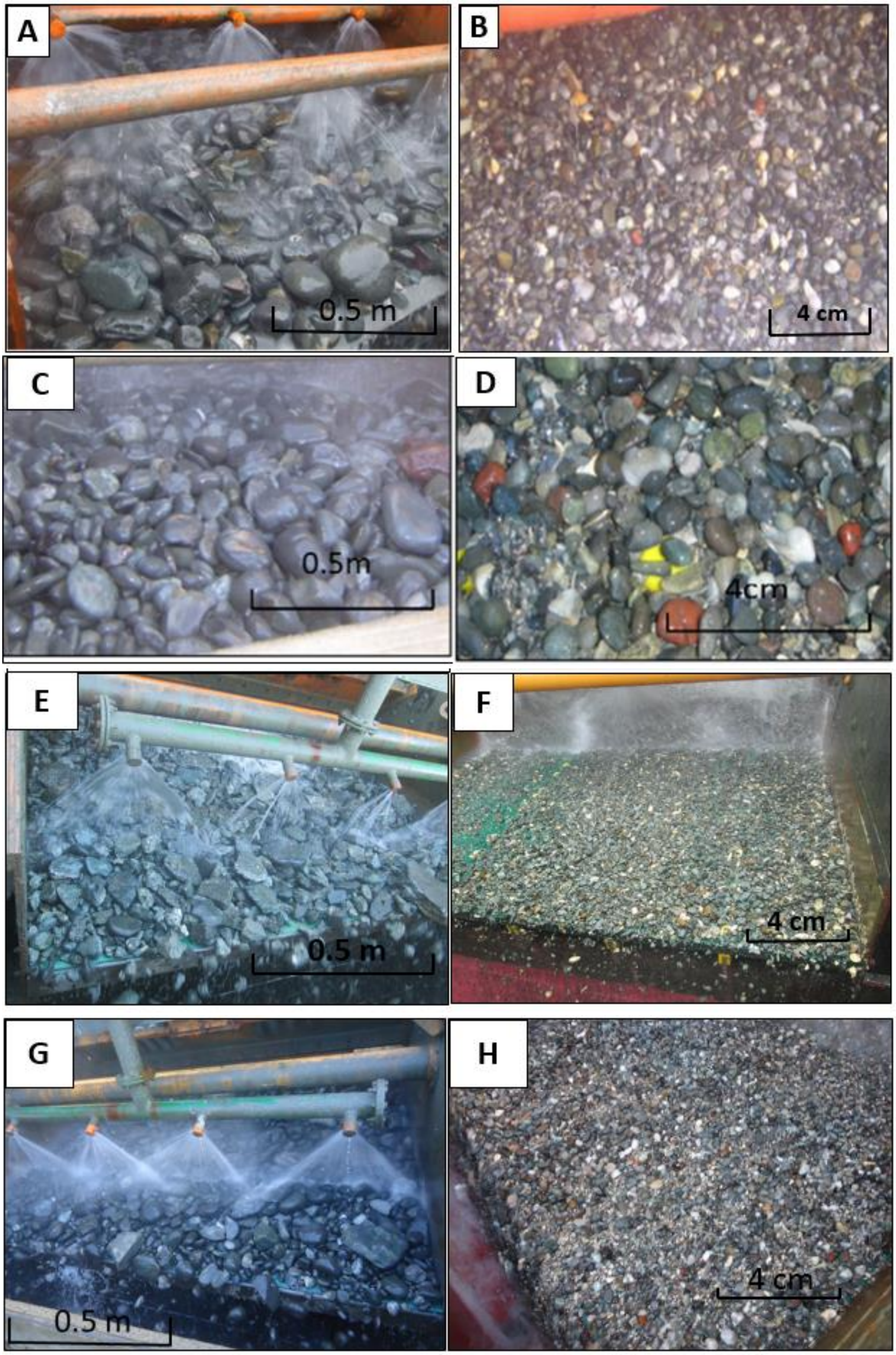


Figure 4.20: *Map showing high stone hits associated with the low-lying part of the V-scrap mineralisation zones.*


A
0.5 m
B
4 cm
C
0.5m
D
4cm
E
0.5 m
F
4 cm
G
0.5 m
H
4 cm

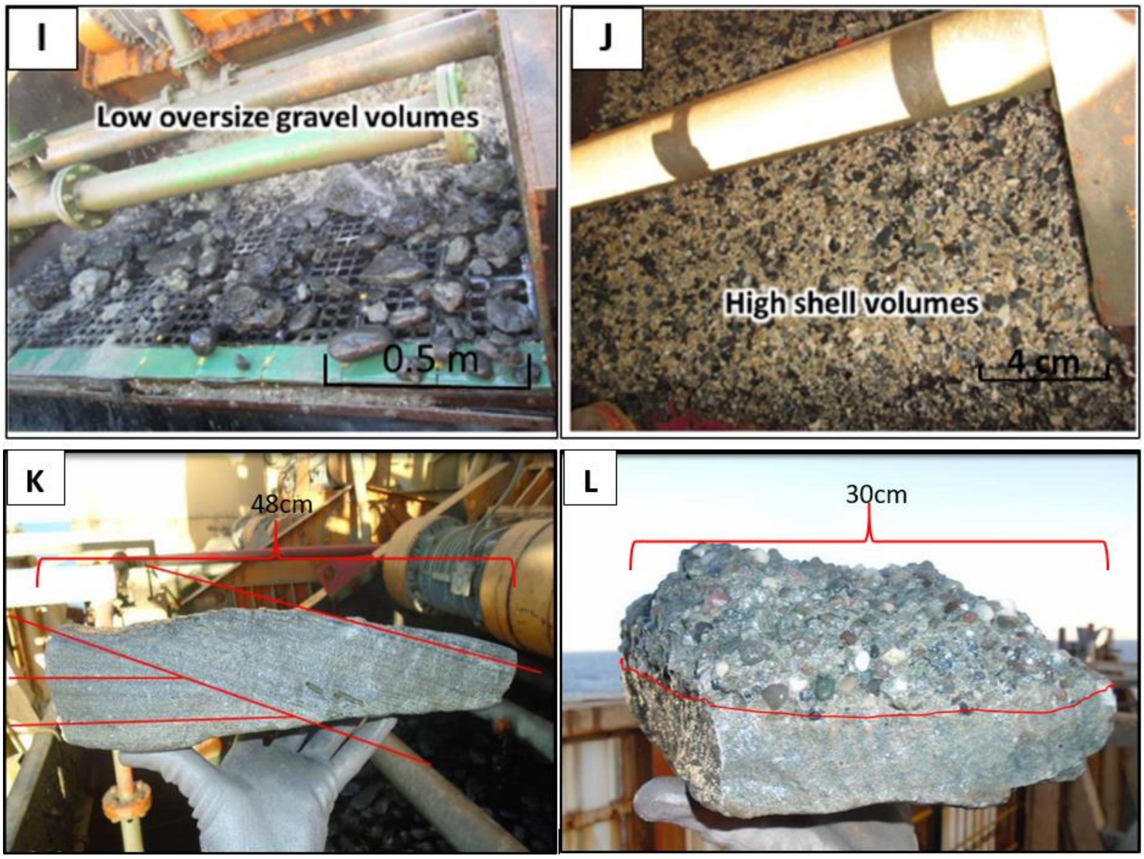


Figure 4.21: *Gravel pictures taken at the vessel screens during mining: A, C, E, G, I, K and L shows the oversize gravel pictures and B, D, F, H and J shows the plantfeed gravel pictures from different Regions in Atlantic 1. Sample J shows high shell volumes from Region N, while K and L reveals the sedimentology and layering structures, which are cross-bedding between cemented footwall capping into beach laminated sandstone (K), and contact between ore gravel and sandstone footwall (L).*

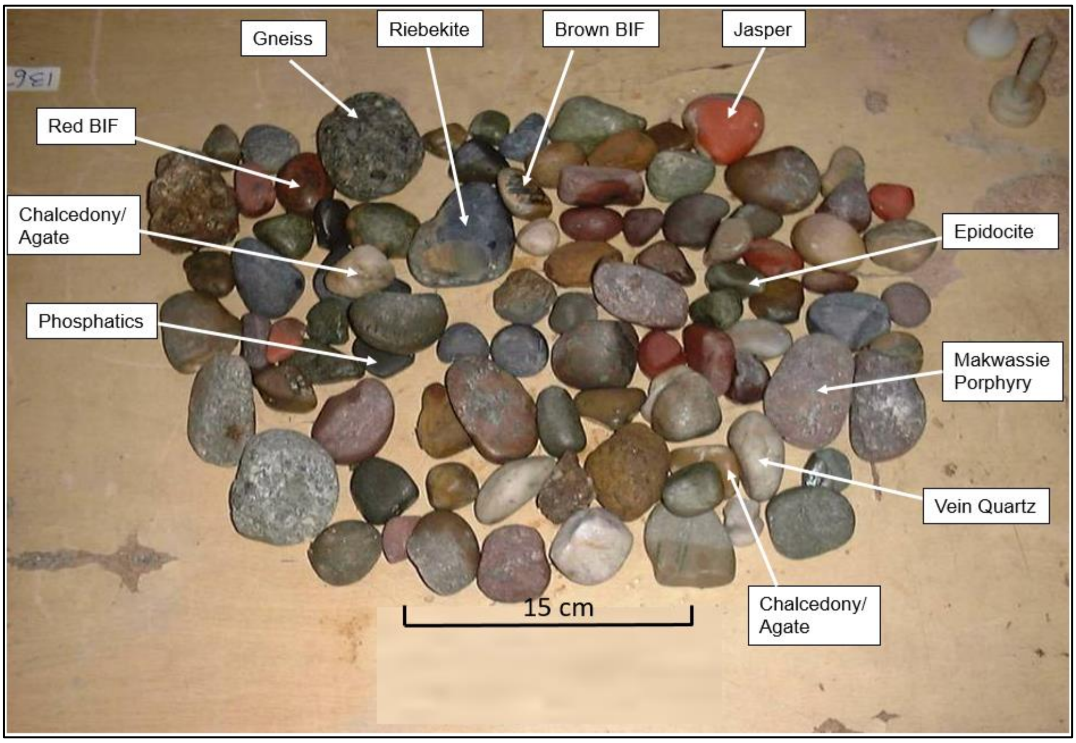


Figure 4.22: *Typical gravel plantfeed from Regions M-U-L-T and K showing the concentration of exotics.*

4.2.2.1 M1J14

Dive target M1J14 is located in the southern offshore side of Region M. Geologically, the target lies on the Eocene 1 weathered sandstone 2 geological zone which is characterised by a rough terrain of outcrops and relatively flat terrain which is the Eocene 1 flat geological zone according to the geophysical data. A close-up view of the planned dive track showing the dive traverse, current geological zones and waypoint (WP) localities is shown in Figure 4.22, with the observed geology presented in Figure 4.23.

4.2.2.2 U3J14

U3J14 dive was situated in the offshore area of Region U in Atlantic 1. The area predominantly lies on three major geological zones namely: flat Eocene 2 with minor gravels (Z21D), Eocene 3 rough platform (Z32A) and the weathered Eocene 3 rough platform (Z33C) (Figure 4.24). The diving process started at WP1 located on the Flat Eocene 2 with minor gravel, which is a relatively flat lying area with infrequent small outcrops, and proceeded on the weathered Eocene 3 rough platform characterised by large outcrops, rough terrain surface with small gullies and cemented elevated features. Figure 4.25 shows the gravel picture captured during U3J14 Jago dive as well as mining recoveries.

4.2.3 W6J14

This dive targeted an area outside the existing blocked resource, and it has recently been rezoned using geophysical datasets that were acquired from the 2013 geophysical survey campaign. The dive ran across the Miocene eroded pavement strata 1 which is defined by a partially weathered and eroded remnant of the cemented sandstone platform (elevated/high lying features) characterised by sand and sandstone footwall depending on the degree of erosion and weathering as well as on depressions (low lying features) which are topographically defined by smooth terrain (Figure 4.26). Figure 4.27 shows the seismic sections interpretation in the area. The yellow lines in Figure 4.29A represent the seismic lines from which the profiles in B & C were generated. The hatched box in Figure 4.29A represent the extend of the seismic profiles. The arrow on the chirp seismic represents the points at which the dive intersects the chirp seismic.

4.3 Grade and Diamond stone size

Another feature that has influenced the diamond spatial distributions is the diamond stone size. Most of the high-grade areas in Atlantic 1 are associated with large stone size diamond areas. In Atlantic 1, large stones are all the diamonds that weigh 34.8 carats per stone and higher. Figure 4.30 shows the localities and stone sizes of the 5 biggest diamonds recorded to date. Figure 4.31 shows the large stone distribution across Atlantic 1.

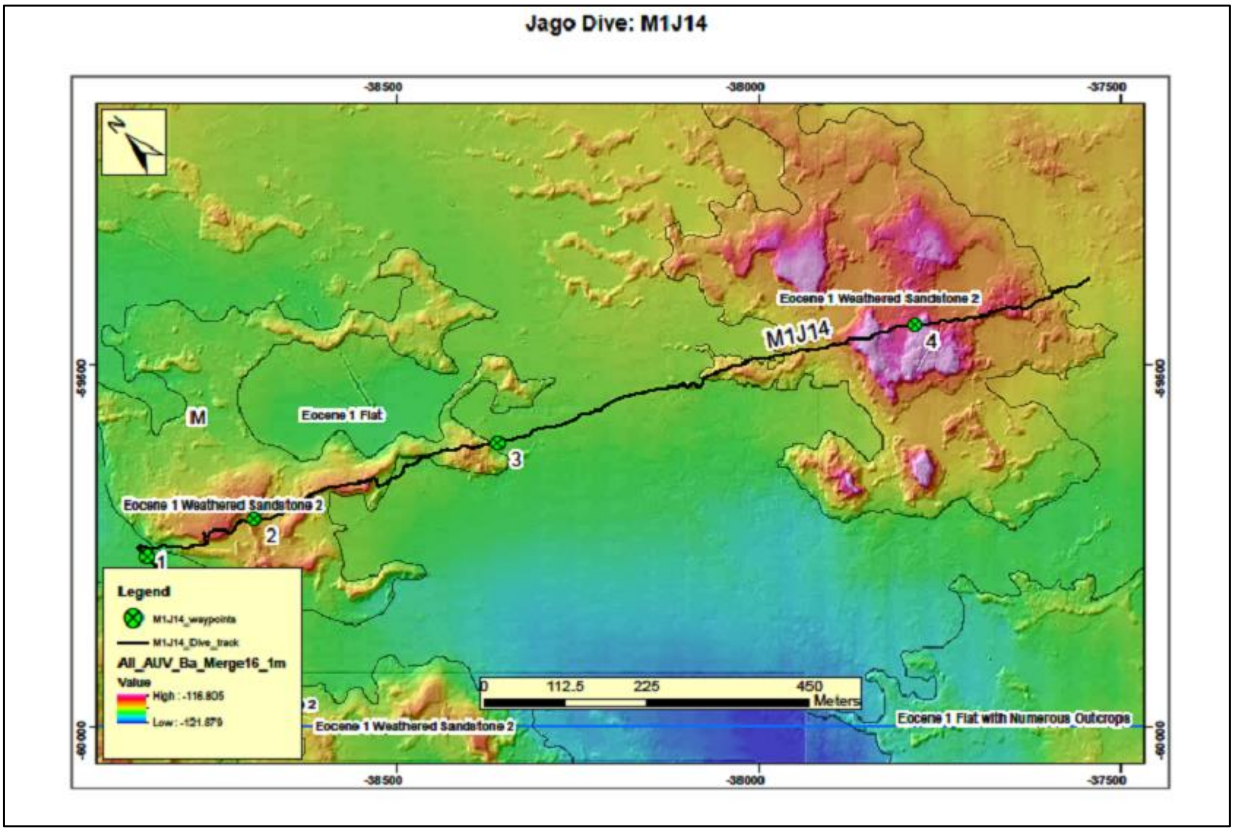


Figure 4.23: *Map showing the M1J14 Jago dive traverse, current geological zones and waypoint localities.*

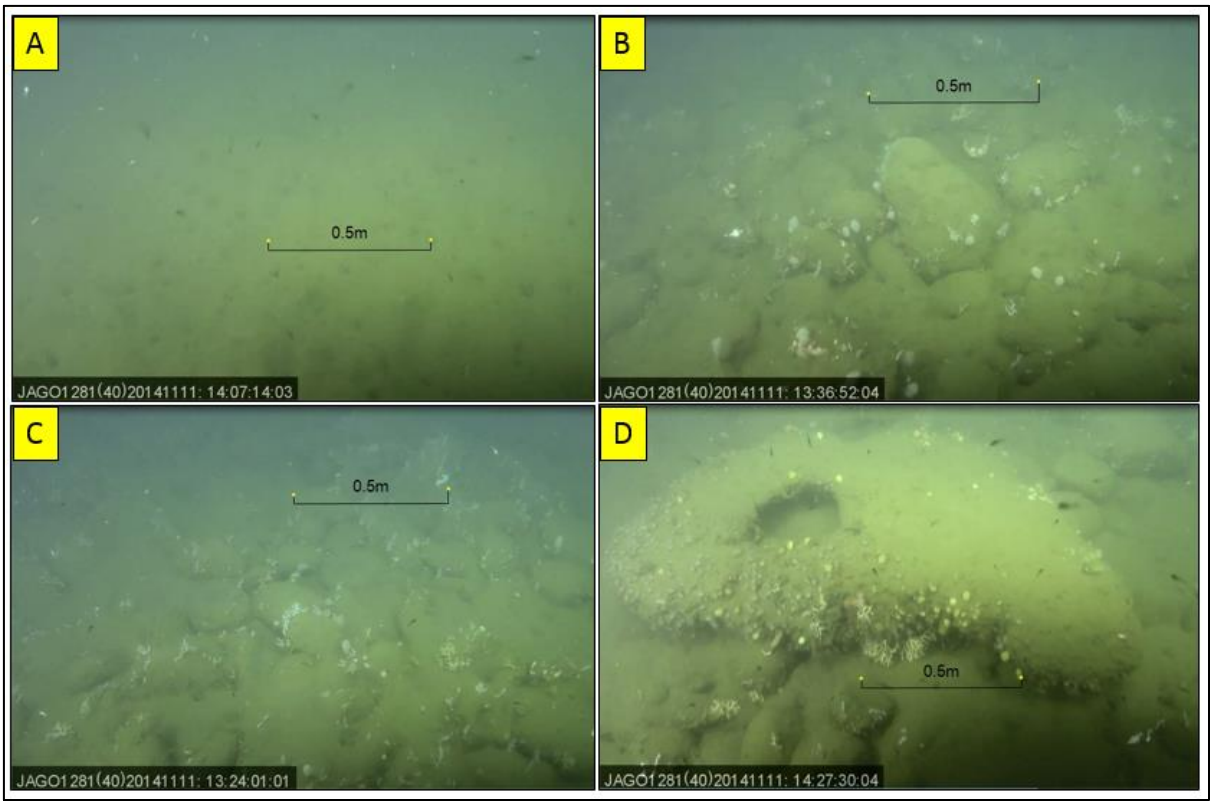


Figure 4.24: *Gravel picture observations during the M1J14 Jago dive. A: mixture of gravel of mostly cobble to boulder sized with marine growth found on a gravel accumulation at WP2. B: a close view of the coarse gravel texture on the elevated features. C: flat smooth layer covered by silt observed at WP4 on the Flat Eocene geozone. D: gravel accumulations with some slabs observed at WP4.*

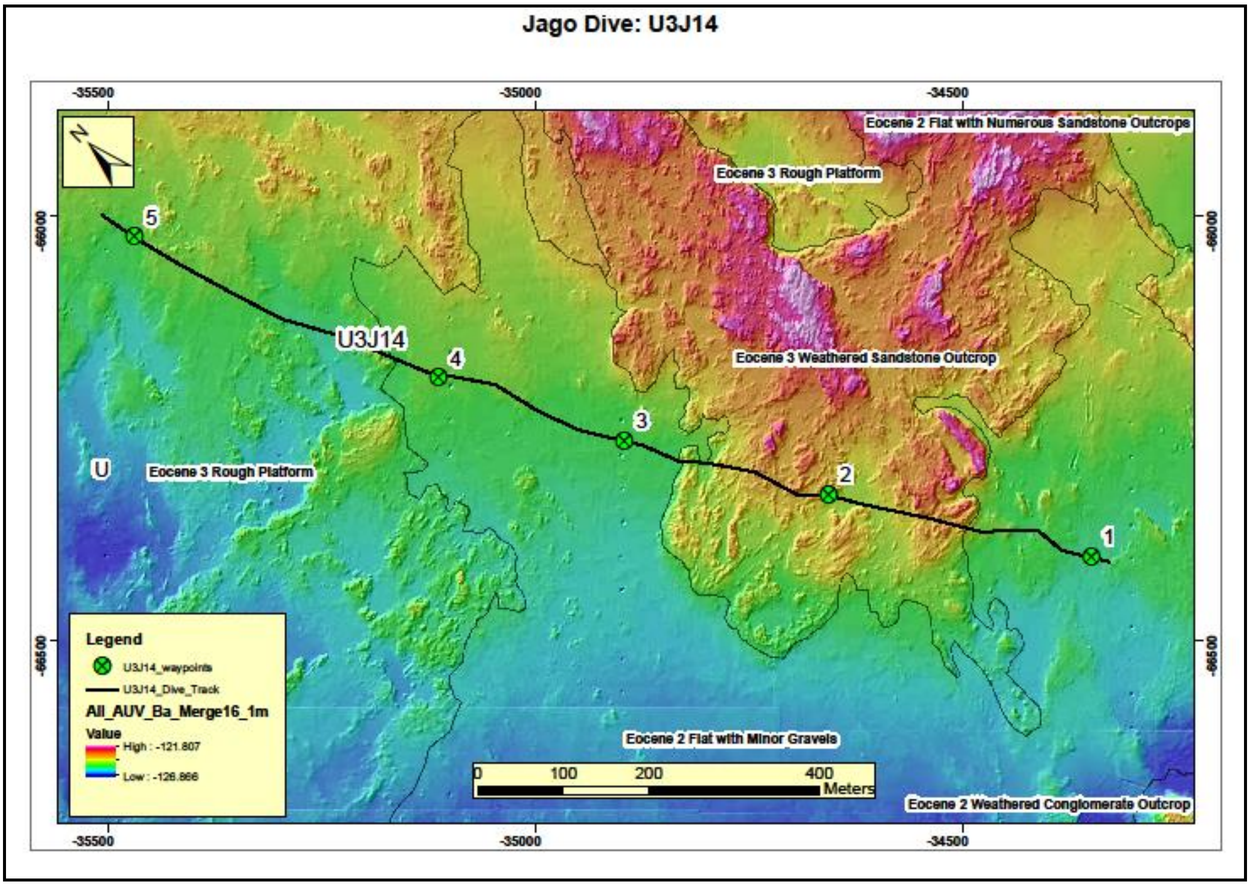


***Figure 4.25**: A map showing dive track U3J14 and the waypoints.*

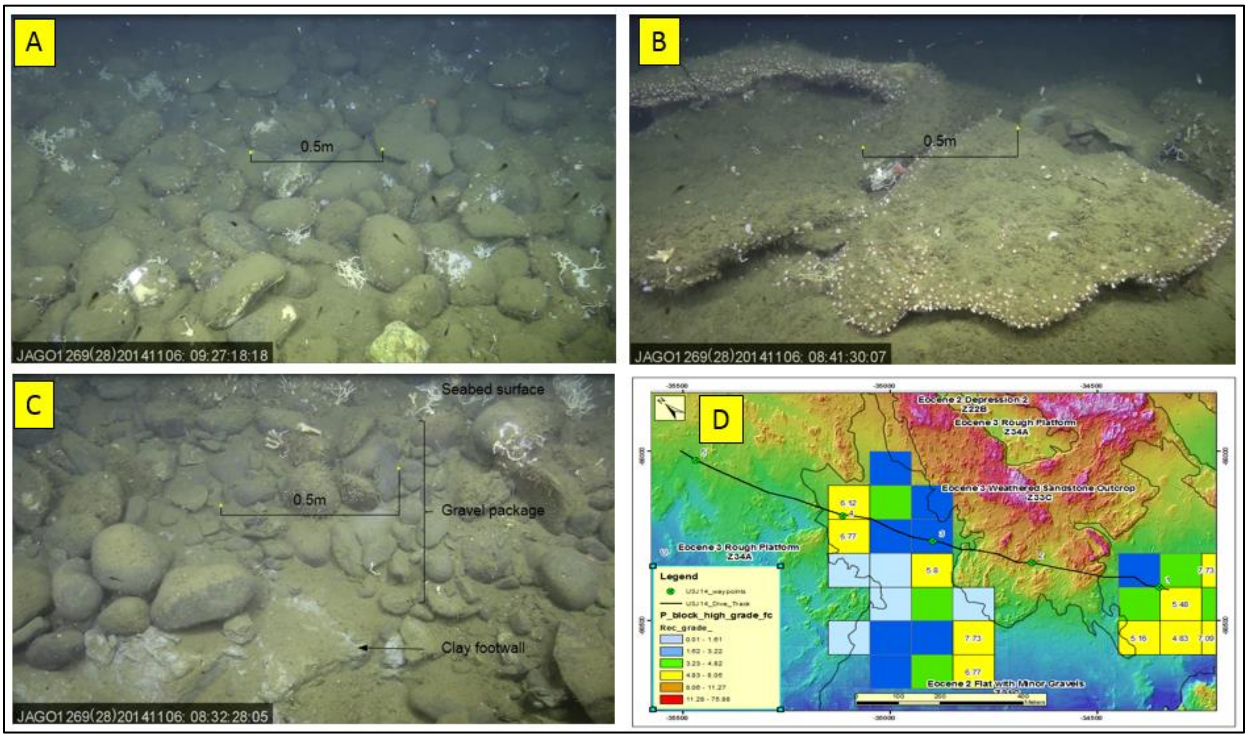


***Figure 4.26:** Gravel pictures of the U3J14 Jago footage and mining observations. A: high gravel volumes observed in the flat surface. B: sampling hole indicating the approximate thickness of the gravel package, the nature of the gravel as well as the clay footwall. C: large sandstone slabs encountered on the elevated feature at WP2. D: high-grade ranging between 5.48 to 6.77 cts/stn recovered in the flat area at WP1 and WP4.*

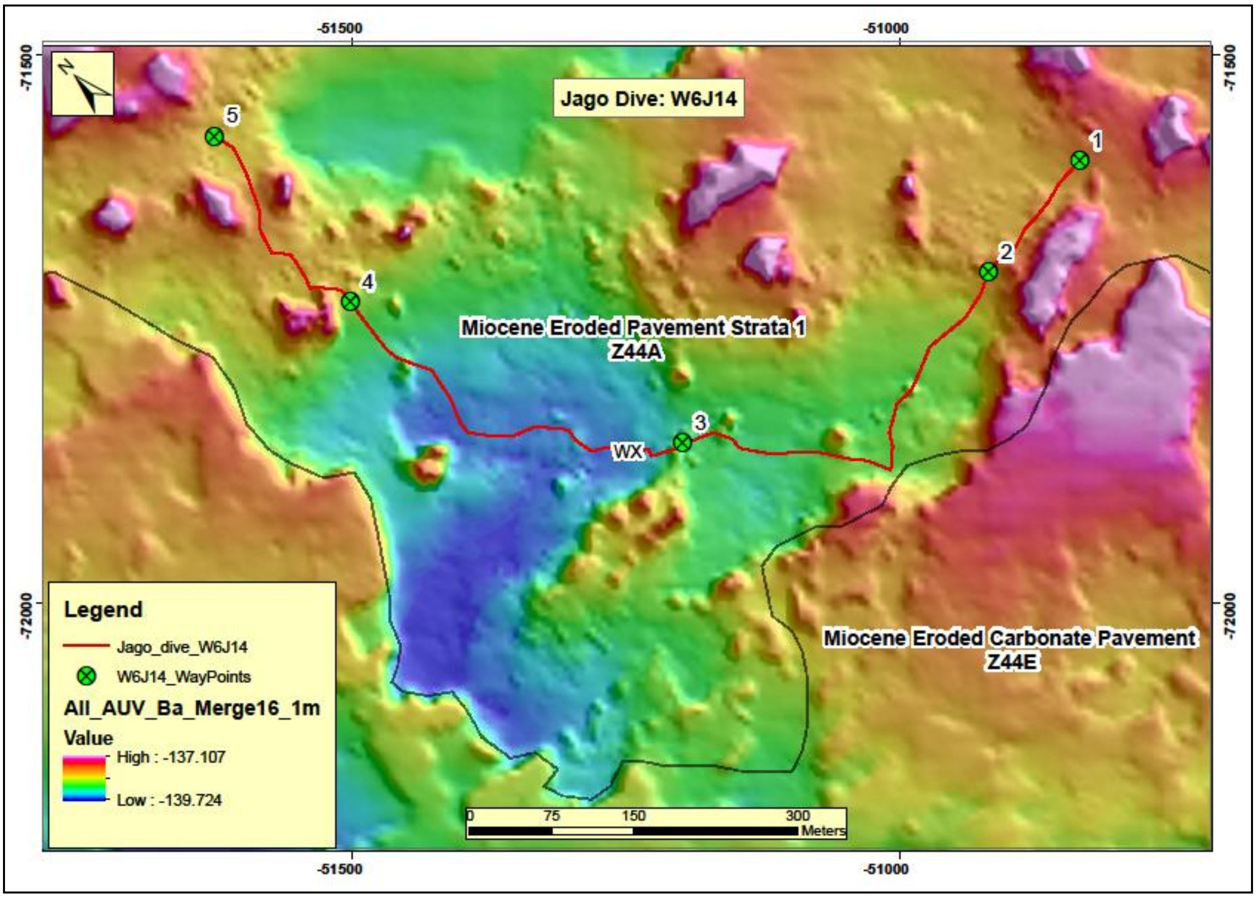


Figure 4.27: *Map showing the W6J14 Jago dive traverse, geological zones and waypoint localities.*

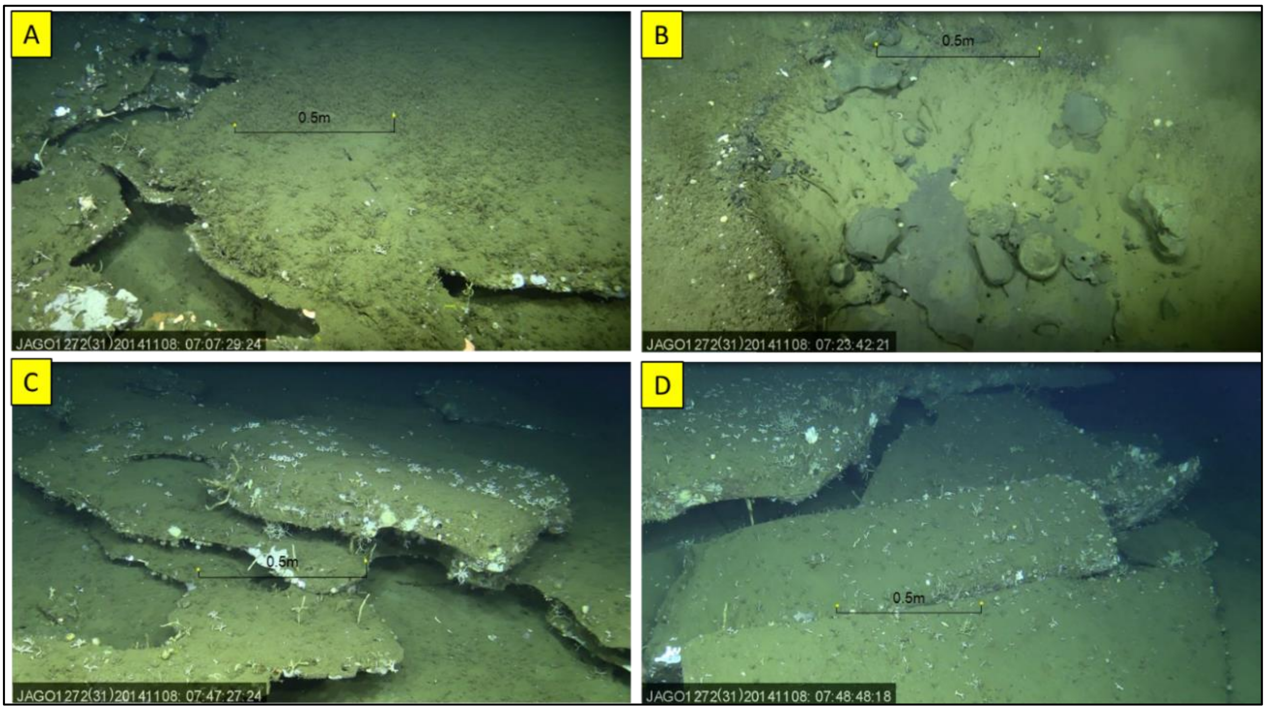


Figure 4.28: *Gravel pictures of the W6J14 Jago footage and mining observations. A: partially eroded and weathered cemented platform. B: an underlying slab with sub-angular and sub-rounded sandstone cobbles. C: in-situ large display of a distinct three layered sandstone outcrop as a remnant of an eroded and cemented platform. D: a rectangular sandstone remnant in close proximity to the weathered and eroded parent rock.*

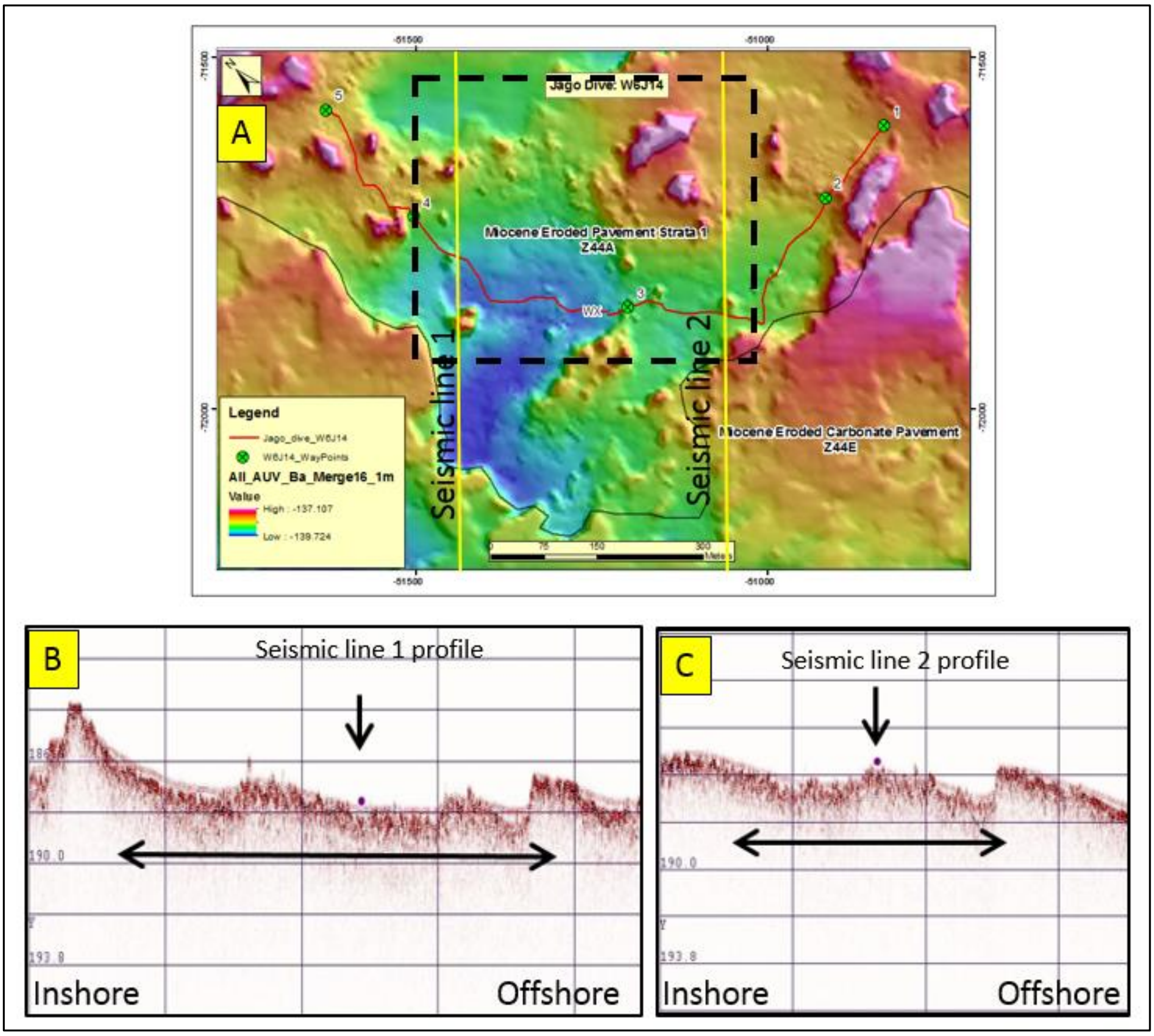


Figure 4.29: *The seismic interpretation. A: the bathymetry topography showing the location on the seismic lines. B: seismic profile from seismic line 1 showing the depressions. C: seismic profile from seismic line 2 showing the elevation. The map (A) was generated using ArcGIS software and the cross-sections were generated from the SeisAvs software.*

4.3 How sea-level fluctuations affect /influence diamondiferous deposits?

The sea-level fluctuations resulted in three main diamondiferous gravel emplacements namely the Pre-proto, the Proto and the Meso (Figure 4.32). The locations of the shorelines during the time of emplacement have been deduced from preferential elevations and internally conducted clast assemblage work by Williamson et al., 2010 (Figure 4.33).

4.3.1 The Pre-proto

The Pre-proto deposits are thought to have been deposited on the shelf towards the end of the Eocene to the middle Oligocene (Jacob, 2005). The deposition of these gravels occurred during a long period of incision by the Orange River, which reached as much as 1 000 m below the planed African surface. This was in response to a period of uplift, which occurred at the end of the Cretaceous/early Cenozoic according to Jacob, (2005). The palaeo-course of the Orange River was highly sinuous at the time (Figure 4.34). During Eocene time when the Pre-proto deposition began the climate was warm and wetter than present, but from the end of the Eocene through to the Oligocene the climate was already beginning to become more arid. The inferred location of the shoreline during the deposition of the Pre-proto gravel is shown in Figure 4.35.

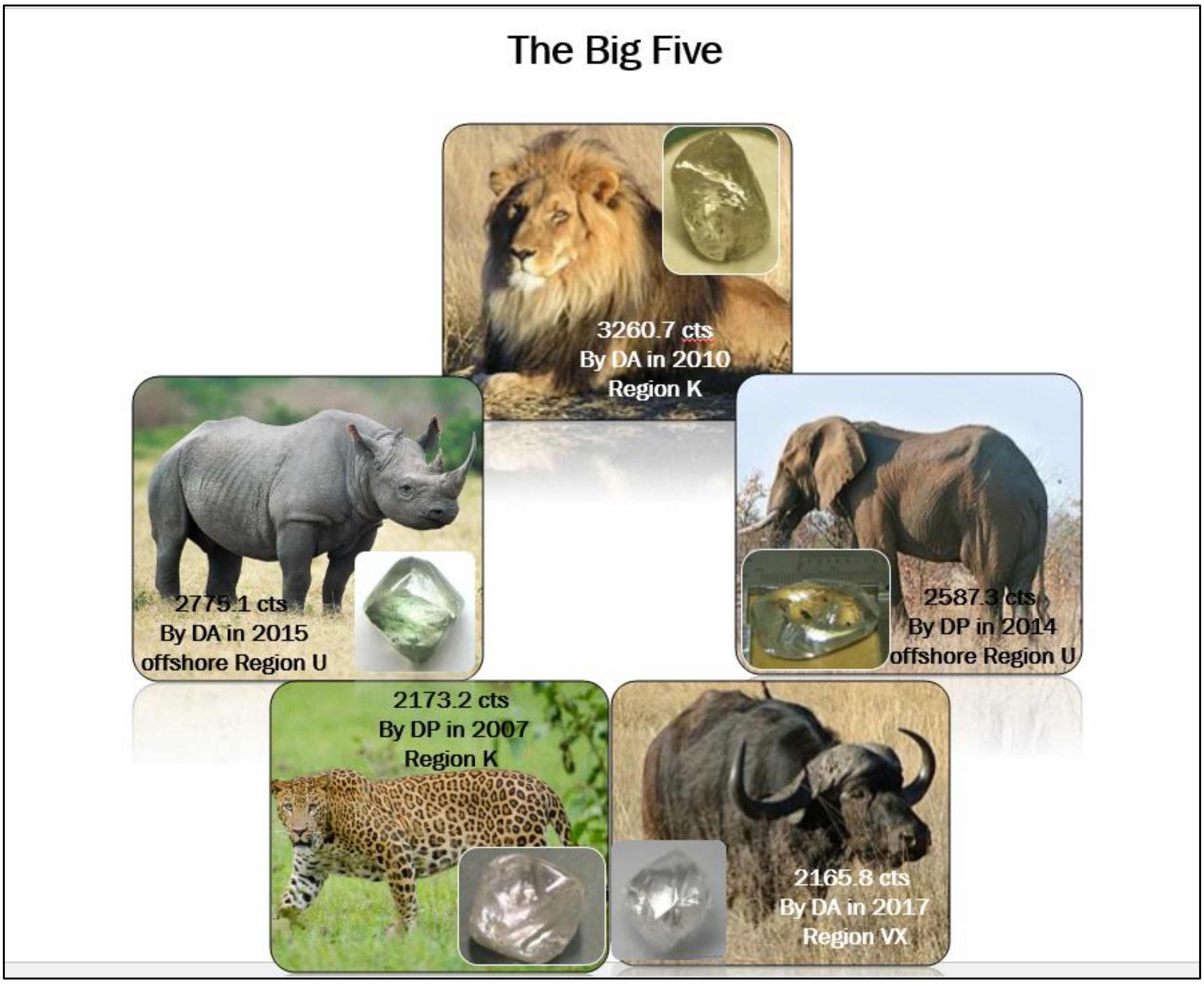


Figure 4.30*: Five biggest diamonds recovered in Atlantic 1.*

4.3.2 The proto

The Proto deposit of the Orange River was thought to have been laid down primarily between the early and middle Miocene (17.5 and 19 Ma) (Jacob, 2005). The palaeo-Orange River was very sinuous at this time with a prolonged period of uplift-induced incision aided by a global lowstand (Figure 4.36). Incision was followed by a long period of aggradation which was caused by a combination of climatic fluctuation, global sea-level rise and natural tributary response (tributaries cutting into the palaoe-Orange channel and adding to the sediment supply) to the incision event. The coastal reaches of the Proto are thought to have been confined with high-energy conditions promoted by high relief. The inferred location of the Proto shoreline is illustrated in (Figure 4.37).

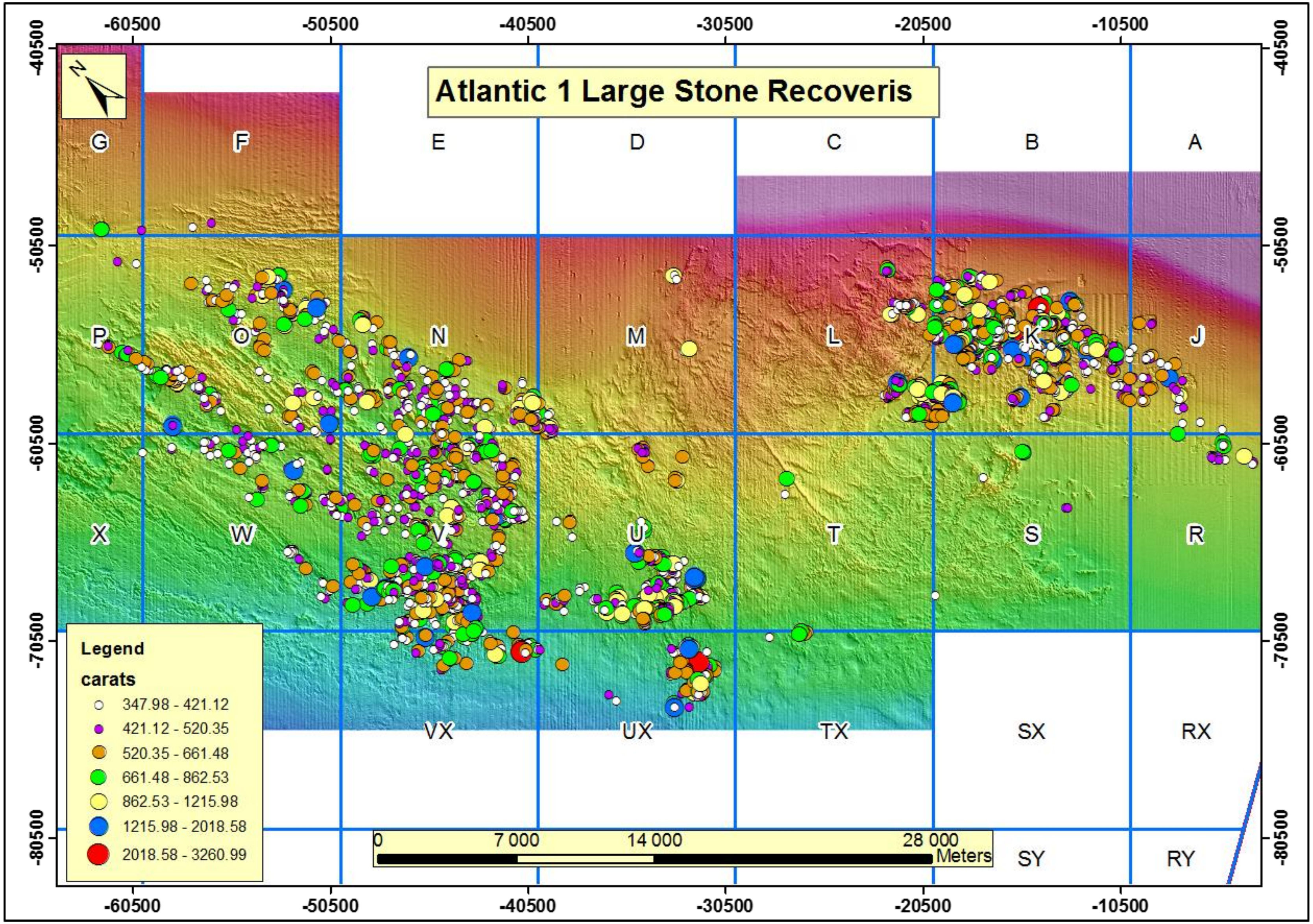


Figure 4.31: *Map showing the large stone distribution across Atlantic 1.*

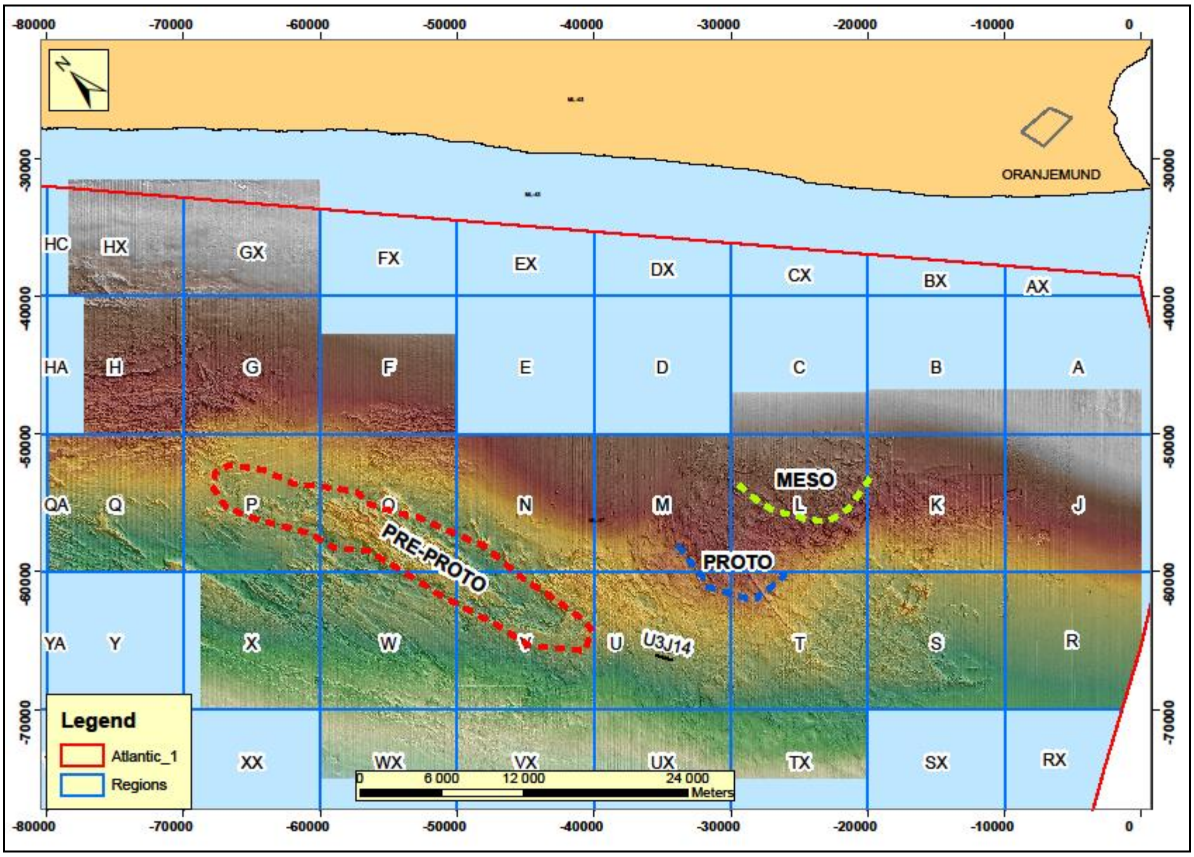


Figure 4.32: *The location of the Pre-proto, Proto and Meso gravels in the Atlantic 1 licence area. The map was generated using ArcGIS with the existing shapefiles of Pre-proto, Proto and Meso deposit boundaries.*

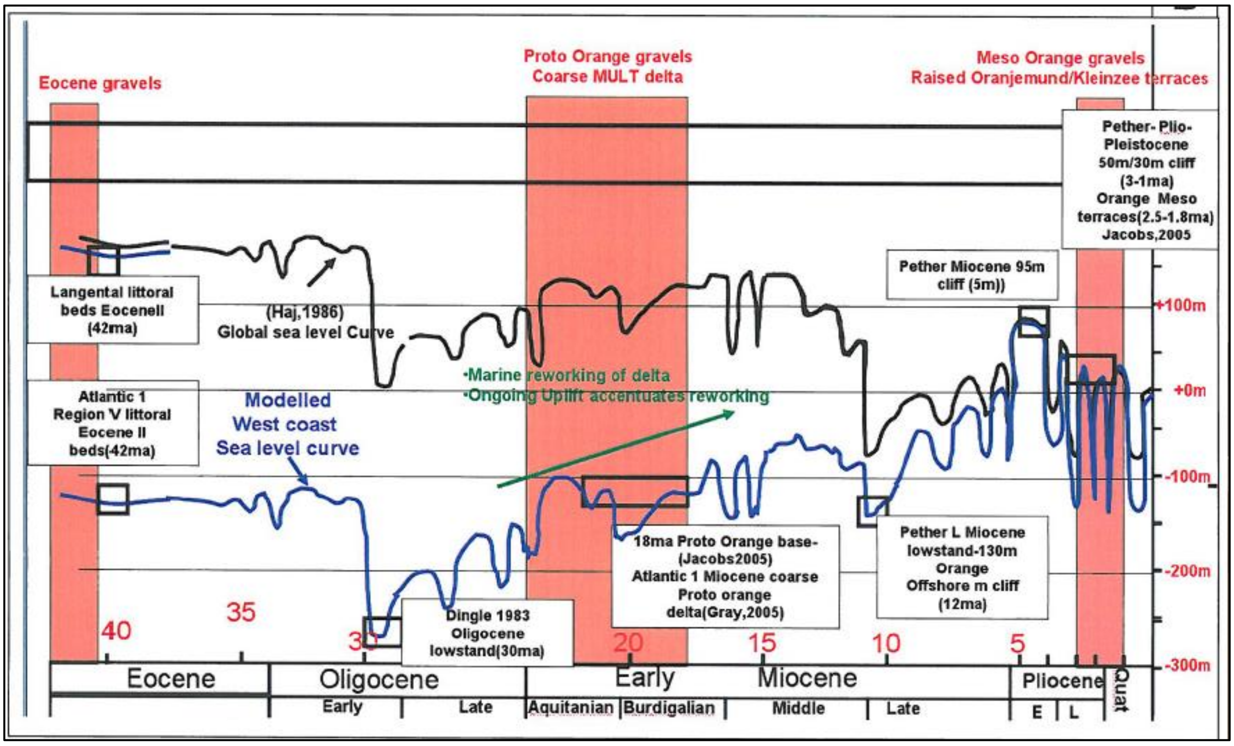


Figure 4.33: *The sea-level curves which shows the main gravel emplacement events (solid pink bands) and the relevant modelled west coast sea-level curve (Williamson et al., 2010).*

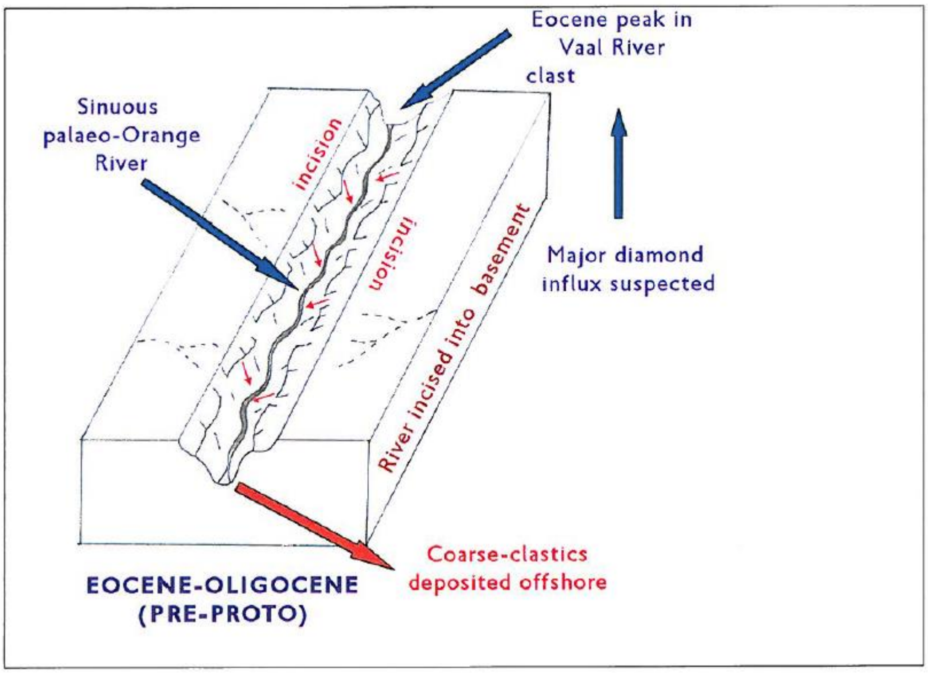


Figure 4.34: *The deposition of gravel during a long period of incision by the Orange River into the basement (Gray, 2011b).*

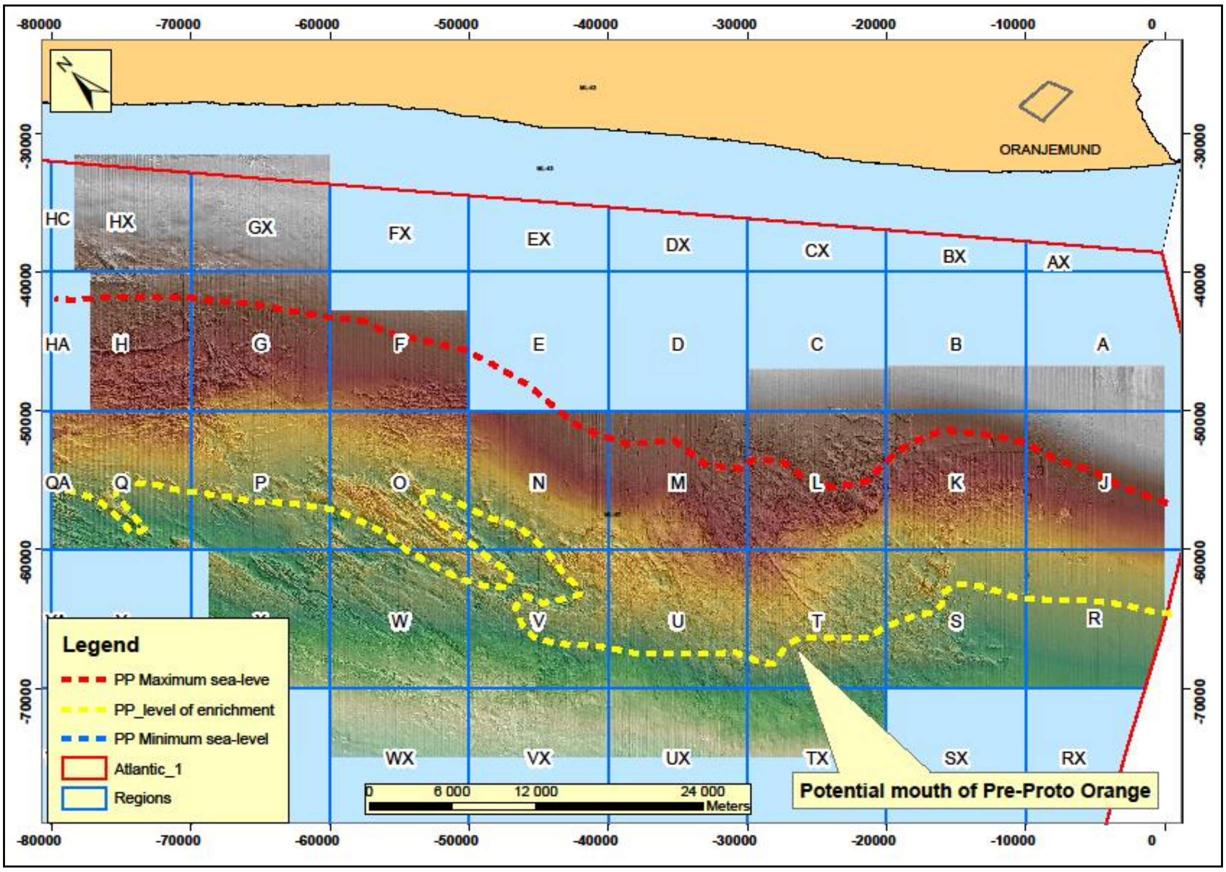


Figure 4.35: *The location of the Pre-proto shoreline. The shoreline is inferred from the -125 m contour, a zone of preferential enrichment consistent with the location of Pre-proto gravel identified by clast assemblage work. During deposition of the Pre-proto gravels the sea-level fluctuated between a minimum of -200 mbsl and maximum of 100 mbsl. The minimum sea-level curve is not shown as it is beyond the extent of the projected dataset.*

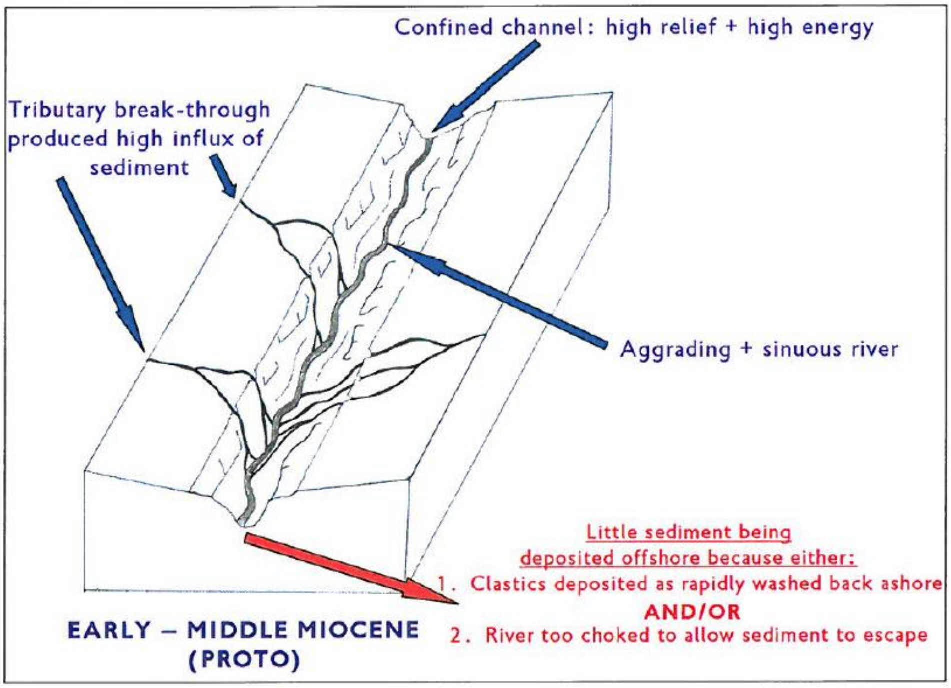


Figure 4.36: *Combination of climatic fluctuation, global sea-level rise and natural tributary response (tributaries cutting into the Palaeo-Orange channel and adding to the sediment supply) to the incision event (Gray, 2011).*

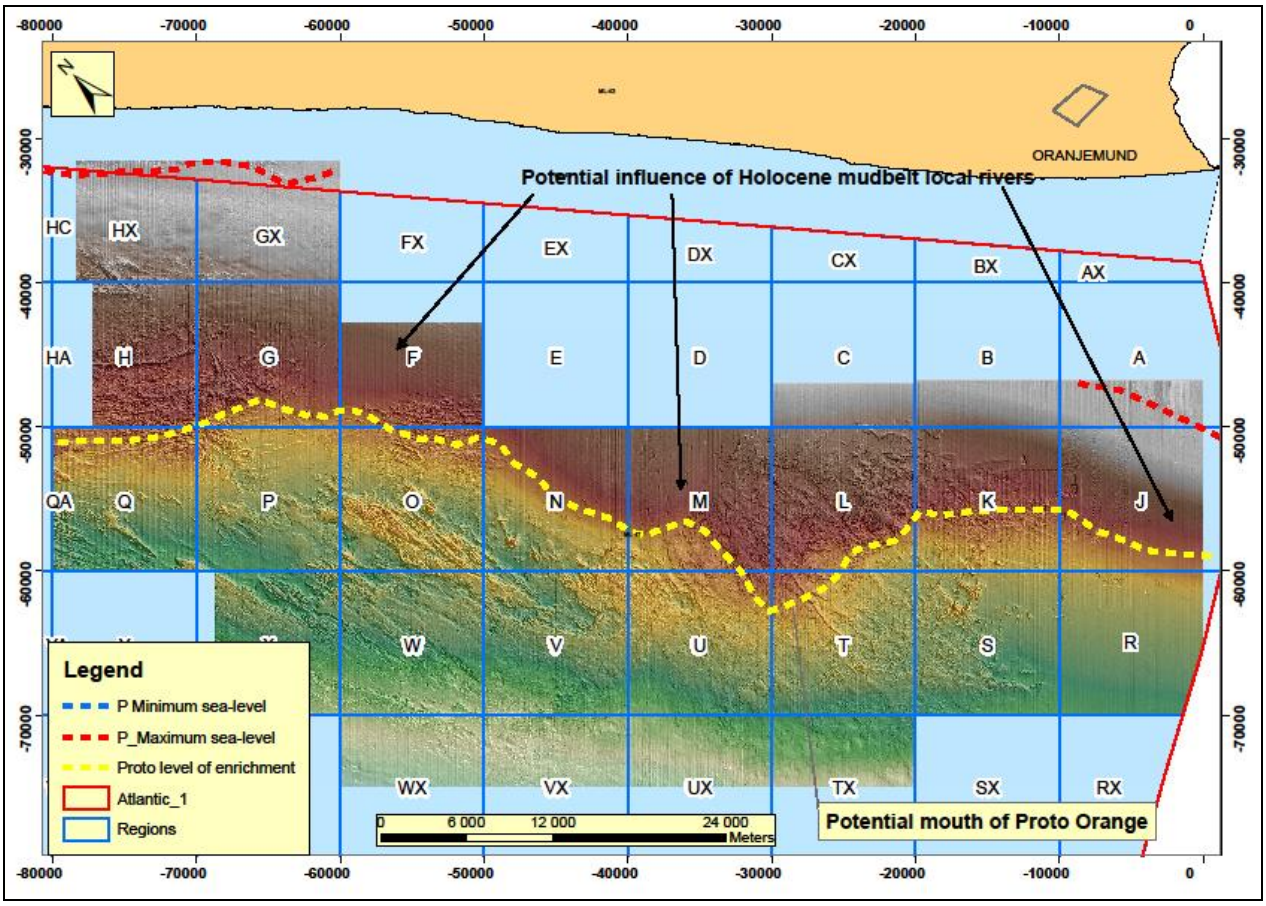


Figure 4.37: *The location of the Proto shoreline. The shoreline is inferred from -115 m contour, a zone of preferential enrichment consistent with the location of Proto gravel identified by clast assemblage work. During deposition of the Proto gravel the sea level fluctuated between a minimum of 180 mbsl and maximum of -60 mbsl. The minimum sea level curve is not shown as it is beyond the extent of the projected database.*

4.3.3 The Meso

The course of the palaeo-Orange river during the deposition of the Plio-Pleistocene Meso gravels was a lot straighter than during Proto time. The straightening of the River course was due to active incision which also scoured deep holes into the landscape (Figure 4.38). The Meso was marked by shorter periods of incisions and aggradation than the Proto, with incision being markedly smaller than during earlier times. The proposed position of the Meso shoreline is depicted in Figure 4.39.

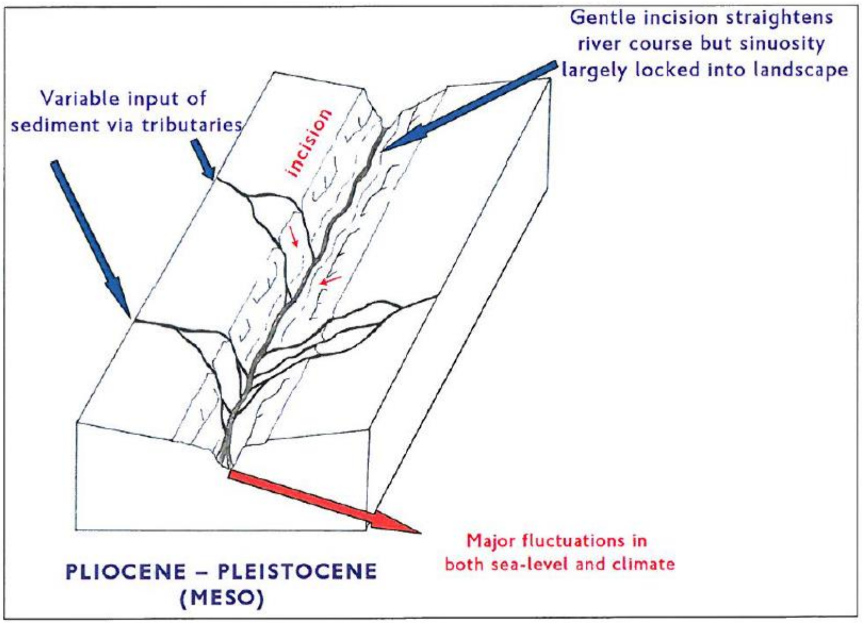


Figure 4.38: *Gentle incision straighten river course with scoured deep holes into the landscape (Gray, 2011b).*

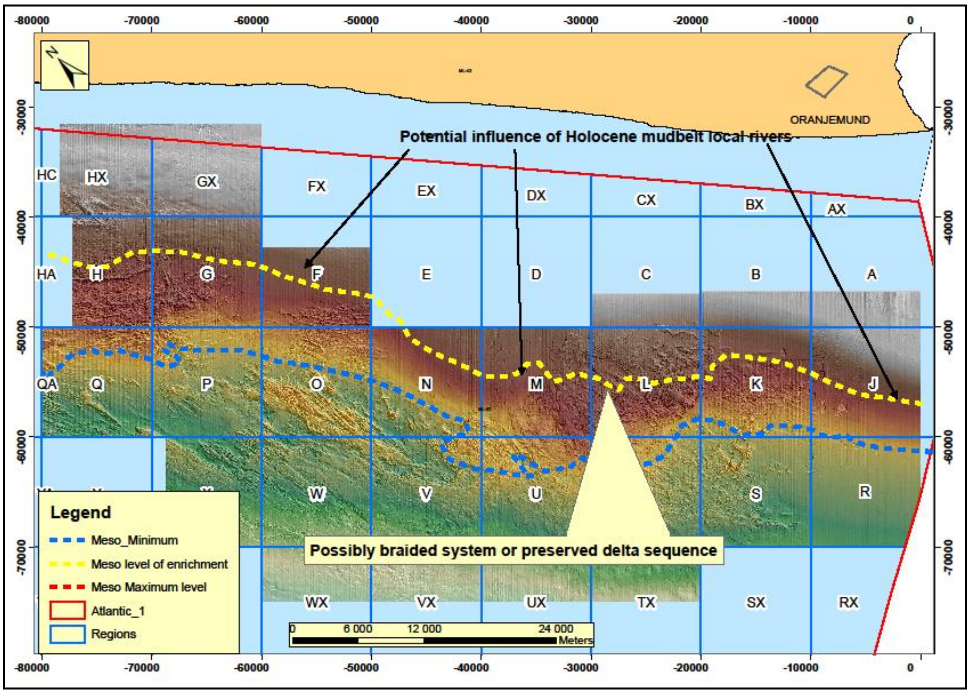


Figure 4.39: The location of the Meso shoreline. The shoreline is inferred from the -150 m contour, a zone of preferential enrichment consistent with the location of Meso gravel identified by clast assemblage work. During deposition of Meso gravel the sea level fluctuated between a minimum of -120 mbsl and a maximum of + 50 mbsl. The maximum sea-level curve is not shown as it is beyond the extent of the projected dataset.

CHAPTER 5

DISCUSSION

The high resolution data in Atlantic 1 which consists of side scan sonar and chirp data sets, typically surveyed in 2 km by 2 km blocks at 25 m line spacing, forms the base of geophysical interpretations in this report. This geophysical data was interpreted in terms of acoustic facies and seismic structures in the contest of high-grade mineralisation in Atlantic 1 mining licence. Both the facies and seismic sections live coverages are located on the company's (Debmarine Namibia) geodatabase and are viewed using ArcGIS. The analysis of geographical and geophysical data of the Atlantic 1 marine deposits has revealed that there are specific localities where marine diamonds are best concentrated resulting in high-grade diamond mineralisation. Such localities are associated with the nature of the surface terrain and favourable depositional environments, which are of great significance to the prospecting for, and the mining of diamonds. High-grade diamond mineralisation is best concentrated in depressions, gullies, gravel beach berms, potholes, scarp slopes and near the outcrops and platforms where turbulence are fixed and where gravel accumulations are stable enough to retain high-grade diamonds. The discussions on the lithostratigraphic framework and mineralisation potential in different Regions was done in conjunction with the analysis of sampling and mining activities. The potential high-grade mineralisation targets was identified from the south to the north. It is however important to note that large portions of inshore Atlantic 1 (Regions A, B, C, D and E) are covered by a thick mudbelt that inhibits sampling and seismic interpretation (Figure 4.1). Therefore, identification of high-grade mineralisation targets in these areas may be inferred.

Diamonds are present in concentration on the west coast in two major units, these being the late Pleistocene gravel lag (e.g. Region V) and the basal Holocene gravel lag (e.g. Region K). The Pleistocene gravel lag is thought to be part of the regressive littoral phase early in the last glaciation. The Holocene lag is part of the transgressive phase at the end of the glaciation. Work by Jacob (2005) has shown that the largest volume of diamonds was deposited during the Pre-proto with the Proto gravel yielding an order of magnitude less diamonds and the Meso representing the coarsening tail of a diamond population that declined over time. The highest grades offshore should therefore come from the Pre-proto deposits, with a lesser but coarse, population located in the Proto and Meso gravels (Figure 4.2).

The gravel accumulations (beach berms, gravel platforms and bars (section 4.1.2 and 4.1.3)) represents a high energy environment where diamonds are generally associated or trapped within cobbles, boulders and pebbles commonly as storm-beach deposits along the base of low cliffs that back wave cut terraces. Beach berms (Figure 4.9) are the sites of accumulation of sediment deposited by waves and currents around the sea margin (Kearey, 1996). They are essentially thick accumulations of gravel which strikes north-south and form a ridge along the beach. The offshore face is steeper than the inshore back beach face and often contains well developed beach cusps (Figure 4.10). Gravel thicknesses vary within Atlantic 1, however the thickest deposit packages are found in the beach berms where the gravel thickness can reach up to 5-7m. The beach berms are excellent trapsites and have been shown to be very well mineralised. Mineralisation is thought to be concentrated at the base of beach foresets. This means that the beach berms are homogenously mineralised with depth. The mineralisation deteriorates rapidly offshore towards the fore-beach scour depression and gradually inshore towards the back-beach depression.

These gravel accumulations (Figure 4.11) are formed by beach processes such as receding waves on the backshore although it is not known if these processes deposited the gravel accumulation or if they just shaped an existing gravel accumulation. In some instances upper Cretaceous sandstone reflectors sub-crop beneath the beach and may have initiated the beach forming processes. Figure 5.1 shows the ideal cross-section of the beach berm gravel feature.

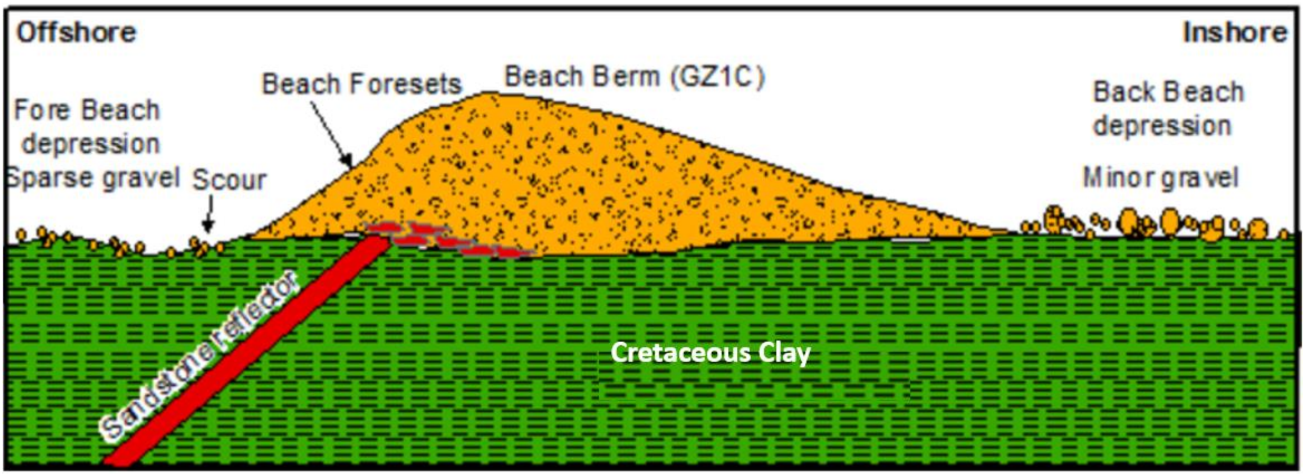


Figure 5.1: *Idealised cross-section of the beach berm, showing accumulation of high gravel volumes.*

From both the sampling and mining results, these zones have shown to be excellent trapsites where mineralisation is thought to be concentrated at the base of beach foresets. These zones are mainly located in the southern part of Atlantic 1 mining licence, covering Regions K, M, U, L and T and the sizes of the beaches decreases towards the offshore (Figure 4.9). The orebody consists of extremely coarse gravel dominated by very well rounded quartzite and quartz with angular sandstone slabs. Gravel in beach berms has a high percentage of exotics and in some areas sand lenses are present. Figure 4.21 show the gravel observation pictures that where taken whilst mining in the beach berm zones, where Figure 4.21A represents the oversize material, and Figure 4.21B represents the plant feed (concentrate) material with a high content of exotics observed. About 5% of the high-grade mineralisation in Atlantic 1 is associated with beach berm zones. Similar characteristics of the beach berms are observed mainly in the offshore Region M, where accumulations of thick sediments are observed through analysis of the geophysical data using the Autonomous Underwater Vehicle (AUV) images (Figure 5.5).

Therefore, the potential targets of high-grade mineralisation associated with the beach berms are expected to be mainly in the offshore Regions M and L. Beach berms are also associated with out cropping areas, where well-developed gravel units are present in the inshore of the conglomerates or sandstone outcrops. All these areas that could be potential targets were analysed together with the estimated high-grade resource as well as recovered high-grade resource in the adjacent mined out areas. Furthermore, this was ground-truthed by the Jago dive done in M1J14 (Figure 4.24) which confirmed that the elevated parts on the AUV are principally made up of gravel accumulations of cobble to boulder in size and highlighted that this is a potential high-grade area and could be a potential target for sampling and resource development. From the analysis, it is clear that the existing high-grade resource could continue into the areas that are identified, as potential targets for high-grade resource, since the terrain topography and the geology is similar. The beach berm related individual features were mapped out or delineated, and the potential exploration targets are outlined in Figure 5.5. Further potential target extending into Region J is shown in Figure 5.6.

Other features that define or control the mineralisation in the inshore southern regions are gravel platforms (Figure 4.11). Gravel platforms are referred to as high-lying gravel accumulations, which generally have a shallow offshore dip. These features are mainly common in Regions K, J and L and are characterised by fairly extensive wave-cut gravel platforms, occasionally interrupted by thick recent gravel bars of very high gravel volumes with coarse gravel texture. Gravel pictures taken while mining on the platforms show well mineralised gravel, with coarse gravel texture and high exotic content (Figure 4.21 C & D). Region K has been one of the mainstays of historical production and has been a reliable “production banker” in terms of the Debmarine annual production targets over the years due to the presence of gravel platform. High-grades associated with major gravel platforms and outcrops have been recovered from this Region. Therefore, this region is mostly drained and the only remaining potential targets would be to the southern offshore and extensions into Region J.

The high-grades in the targeted areas are mainly on the flat areas occasionally interrupted by the outcrops, which trap the diamonds (Figure 5.2). Unfortunately, most of the inshore Regions K and J areas are covered by a thick mudbelt, which inhibits sampling and seismic interpretations. There have been no mining activities in these areas due to heavy mineability challenges associated with thick overburden composed of shell and very high drill durations. The interrupting Recent bars occasionally encountered on the inshore parts may sometimes overlie large volumes of sand and grit. High-grade resource associated with gravel platforms make up about 10% of the high-grade blocks in the Atlantic 1. The gravel platforms have been recognised over the years as good diamond trapsites and the ideal cross-section of the platform is shown in Figure 5.2.

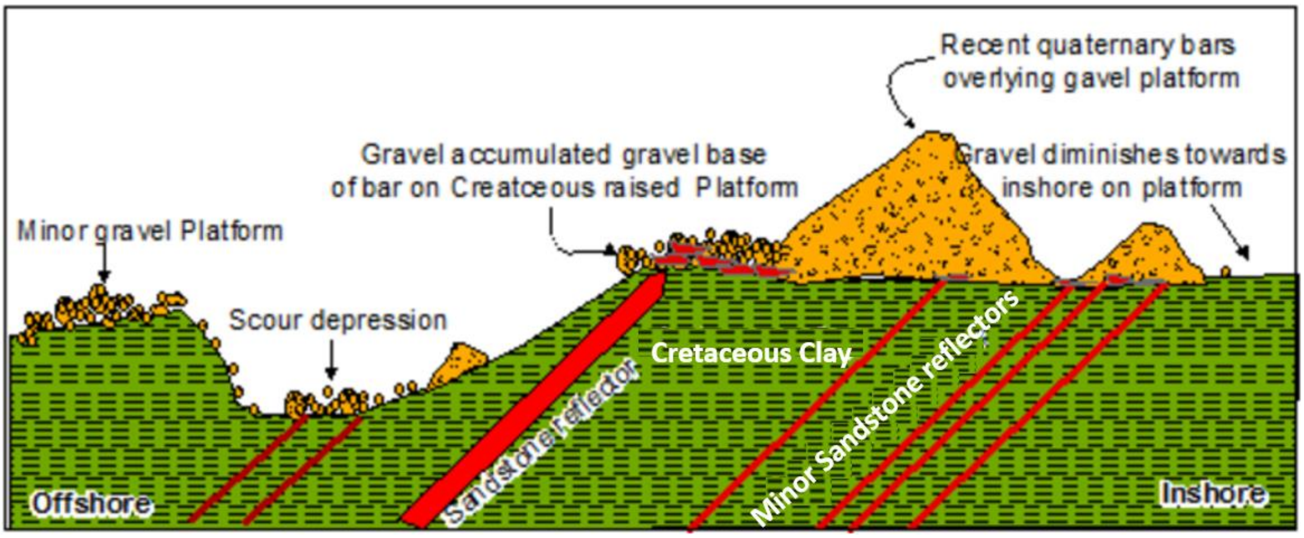


Figure 5.2: *Cross section depicting gravel platforms and associated sandstone reflectors*.

Outcrops are total areas over which a particular rock unit occurs at the surface (Figure 4.13). In Atlantic 1, these features are often isolated and small (Figure 4.12). Heavy minerals mostly prefer to be concentrated on the northern side of south facing bays (leeside of the outcrop) (Figure 5.3). Well-developed gravel units are present in the inshore of the conglomerate or sandstone outcrops. Generally, the outcrops themselves are not mineralised, and often are very hard to penetrate and break through, but the gullied surface nature is a good trap-site. There is normally very sparse gravel on top of the outcrop, and mineralisation potential is very low. However, there is occasionally good stone recoveries from small gullies and in the adjacent zones formed due to the presence of the feature. An ideal cross-section of the outcrop and associated gravel accumulation is presented in Figure 5.3.

Depressions are low or depressed/hollow part of the surface (Figure 4.6). In Atlantic 1 these can be shallow, deep, large-scale (km-scale or regional) or small-scale. Figure 4.14 shows the different depression types mapped in Atlantic 1. In some areas these depressions expose the underlying older strata and are therefore called window depressions. Window depressions are often steeper to the offshore slopes and terminate against the offshore outcrops (Mubita, 2005). Mineralisation potential is low in scours and shallow depressions except near outcrops and on offshore ends where a well mineralised zone occurs directly offshore or to the south. It is thought that the scour depressions were developed post Miocene gravel deposition as the scours generally do not contain gravel. If they had formed prior to deposition they would have been good trapsites. The orebody is very sparse although some gravel may have been "washed" into the offshore end of the depression by wave-driven processes. Well-developed depressions are observed in Region V, where highest grades are recorded associated with the Pre-proto gravel suite.

Targeting for high-grade mineralisation is mainly in deep depressions, where very thick and coarse gravel volumes are contained (Figure 5.4). In many cases the depressions have gravel accumulations in the form of small berms also formed by wave driven processes. About 17% of the high-grade resource are associated with the depressions.

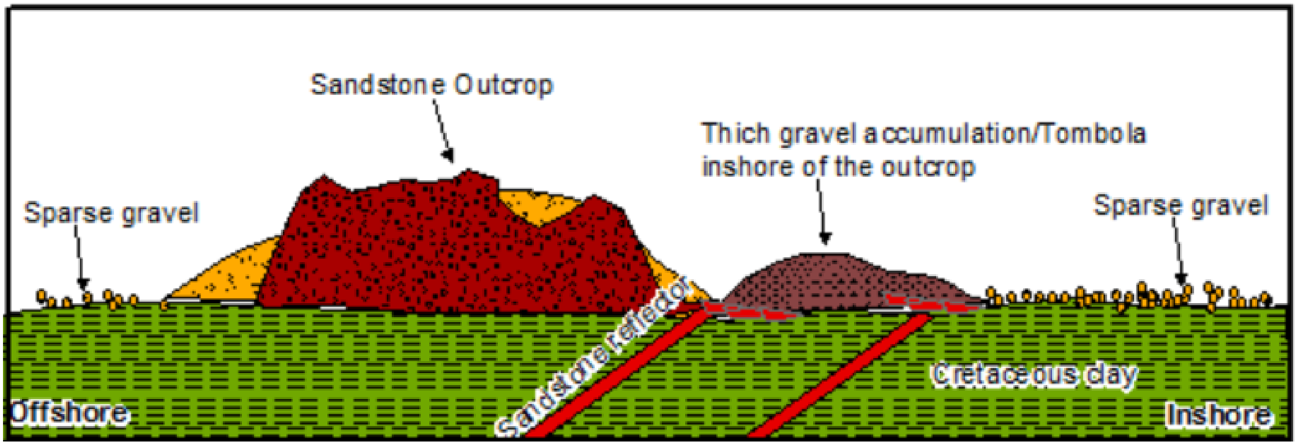


***Figure 5.3:** An idealized cross-section showing the outcropping feature and the associated thick gravel accumulation*.

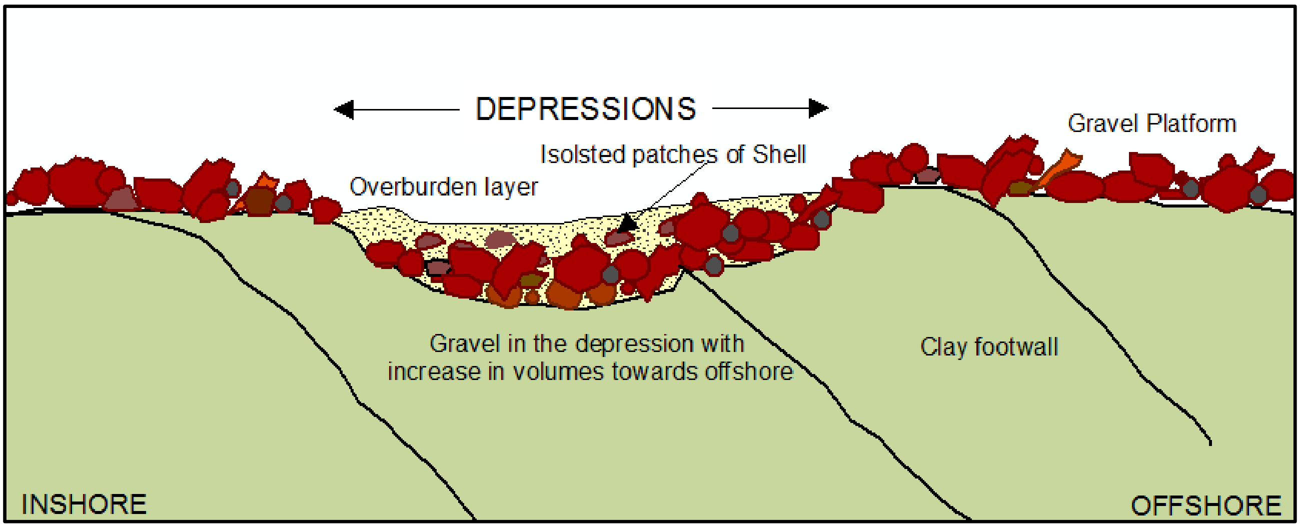


***Figure 5.4:** Idealised cross-section cut through a depression where high gravel accumulation is encountered increasing towards the offshore.*

Regions M-U-L-T-K are characterised by a number of differing footwall types and ages as observed from sampling and mining data. In the northern corner of Region M and in the western corner of Region L the footwall consists of dark grey Cretaceous clays of probable Coniacian age. According to Bosma (2001), these sediments are overlain in the south and offshore by sequences of consolidated Cenozoic sediments of both Eocene II (latest middle Eocene/Bartonian and Eocene I (later middle Eocene/Bartonian) age. The gravel constituents (Figure 4.22) are typically Orange River-derived and contain fairly large amounts of exotics such as jasper, ironstone, agate, epidotes, and chalcedony. Phosphatics, coal and fossilised wood are also present. High-grade mineralisation in the offshore areas of Region U is mainly on the Eocene flat with minor gravels. The potential targets for further exploration around offshore Region U & T are presented in Figure 5.7.

Most of the high-grade areas in Atlantic 1 are associated with large stone size diamond areas. As mentioned in the results, large stones are all the diamonds that weigh 34.8 carats per stone and higher. The biggest 5 large stones recorded in the Atlantic 1 licence area were located in Regions K, U and VX (Figure 4.30). The biggest diamond weighed 3260.7 carats and it was recovered by the mining vessel Debmar Atlantic (DA) in

Region K, followed by a 2775.1 carats diamond also recovered by the mining vessel Debamar Atlantic in offshore Region U (UX). The third largest diamond was recovered by the mining vessel Debmar Pacific (DP) in offshore Region U (UX) weighing 2587.3 carats, which was followed by a 2173.2 carats diamond also recovered by the DP in Region K. The 5th largest diamond was recovered by the DA in offshore Region V (VX), weighing 2165.8 carats.

Looking at the large stone distribution across Atlantic 1 (Figure 4.31), the majority of the large stones are found in the Pre-proto source area, which is the oldest deposit and covered mainly Regions V and U. Further to the north stone sizes are smaller in the northern regions which are O-P-W compared to Regions M-U-L-T and southern regions which are K-J-S-T. The distribution of the large stone decreases northwards mainly due to the strong northward-directed longshore drift, and therefore the tailing-off of the diamond sizes and qualities is much more gradual northwards. Proportioned to area mined, larger stones are mainly found in Regions K-M-U-L-T-V which forms part of Pre-proto and Proto source areas. The larger stones are more easily trapped since they only move under extreme conditions, and thus remains closer to the source areas. The smaller diamond stones move more inexorably further north, and they are easily distributed in any environment. It is therefore crucial to understand and locate the large stone distribution across Atlantic 1 since there is an exponential increase in market value of the large stones compared to smaller stone size diamonds. Taking into consideration of the total area mined in different Regions, the large stones have mainly been recovered in Regions U, K, and offshore V. Gravel textures in the large stones areas are generally coarse with high exotic concentration. Figure 21 G and H, shows the nature of gravel observed from the vessel screens showing high gravel volumes, coarse gravel texture and high exotic content.

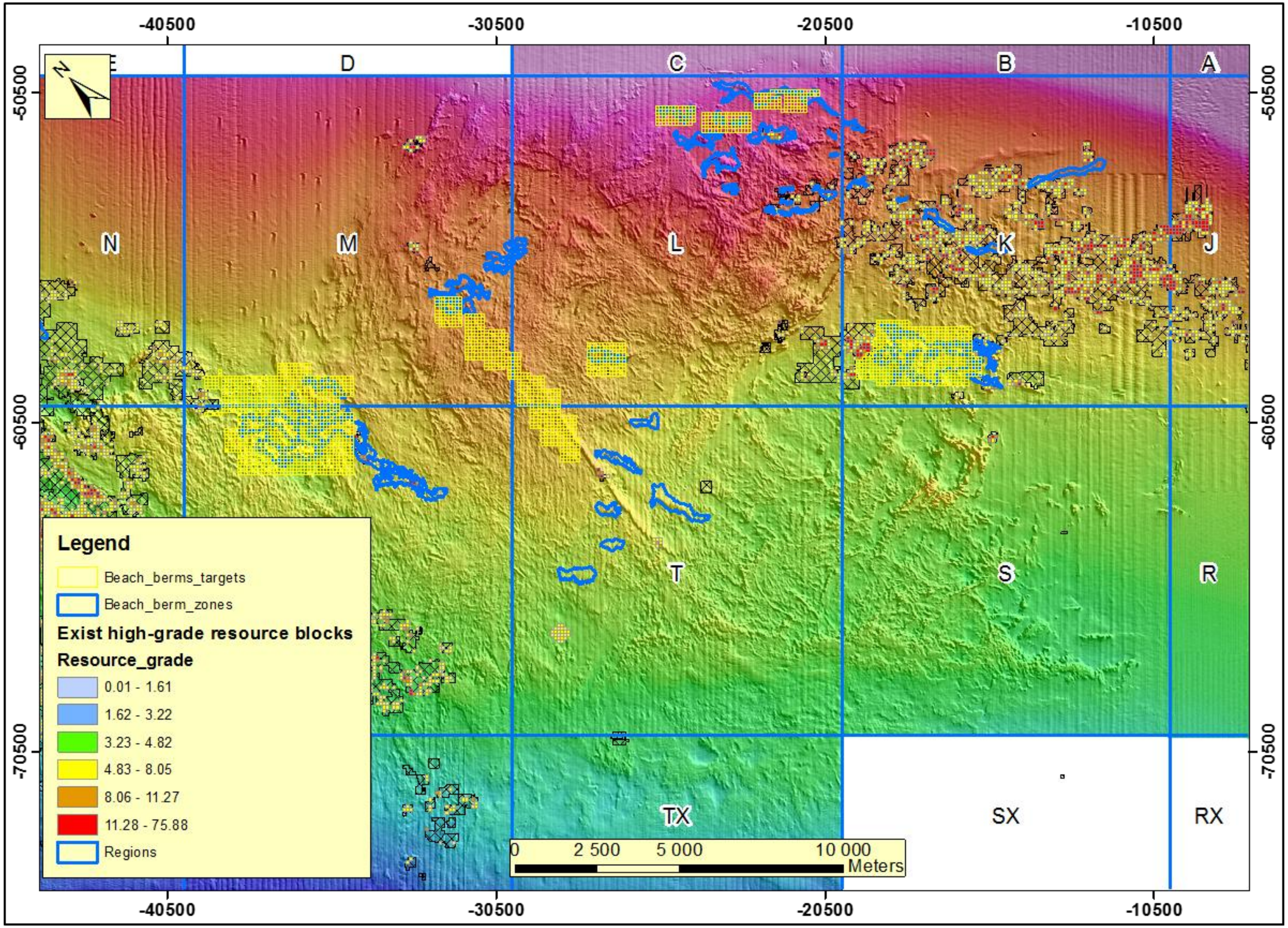


Figure 5.5: *Map showing the location of the beach berm zones in the southern inshore areas of Atlantic 1, the existing high-grade resource, and the depleted/mined out area. The areas marked with yellow hatched blocks are the recommended targets for exploration.*

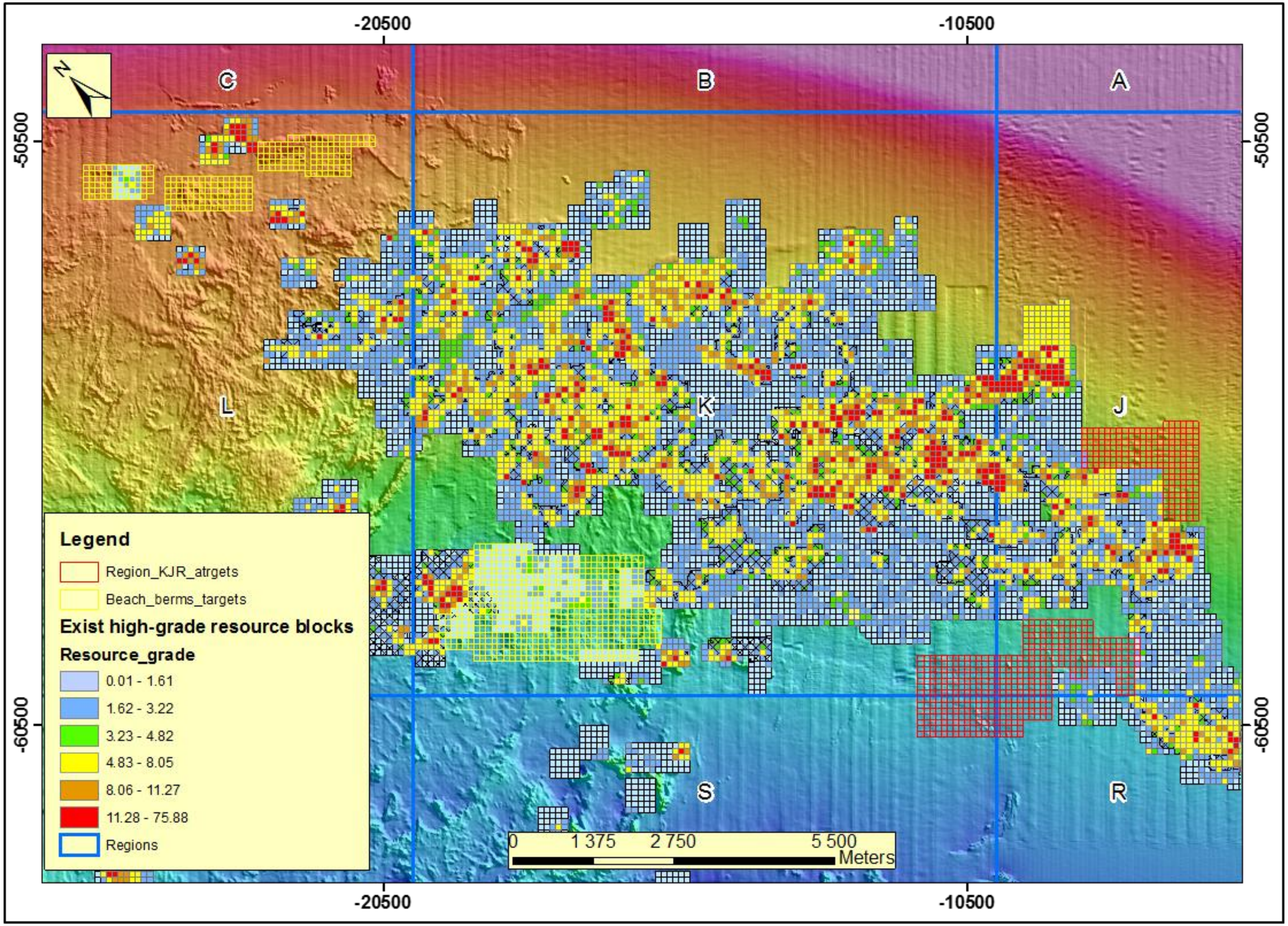


Figure 5.6: *Map showing the existing resource grade in Regions K and J of which Region K resource grade is mostly depleted. The figure also shows the potential target areas for high-grade mineralisation in the southern offshore Region K extending into Region J, mainly on flat surface area.*

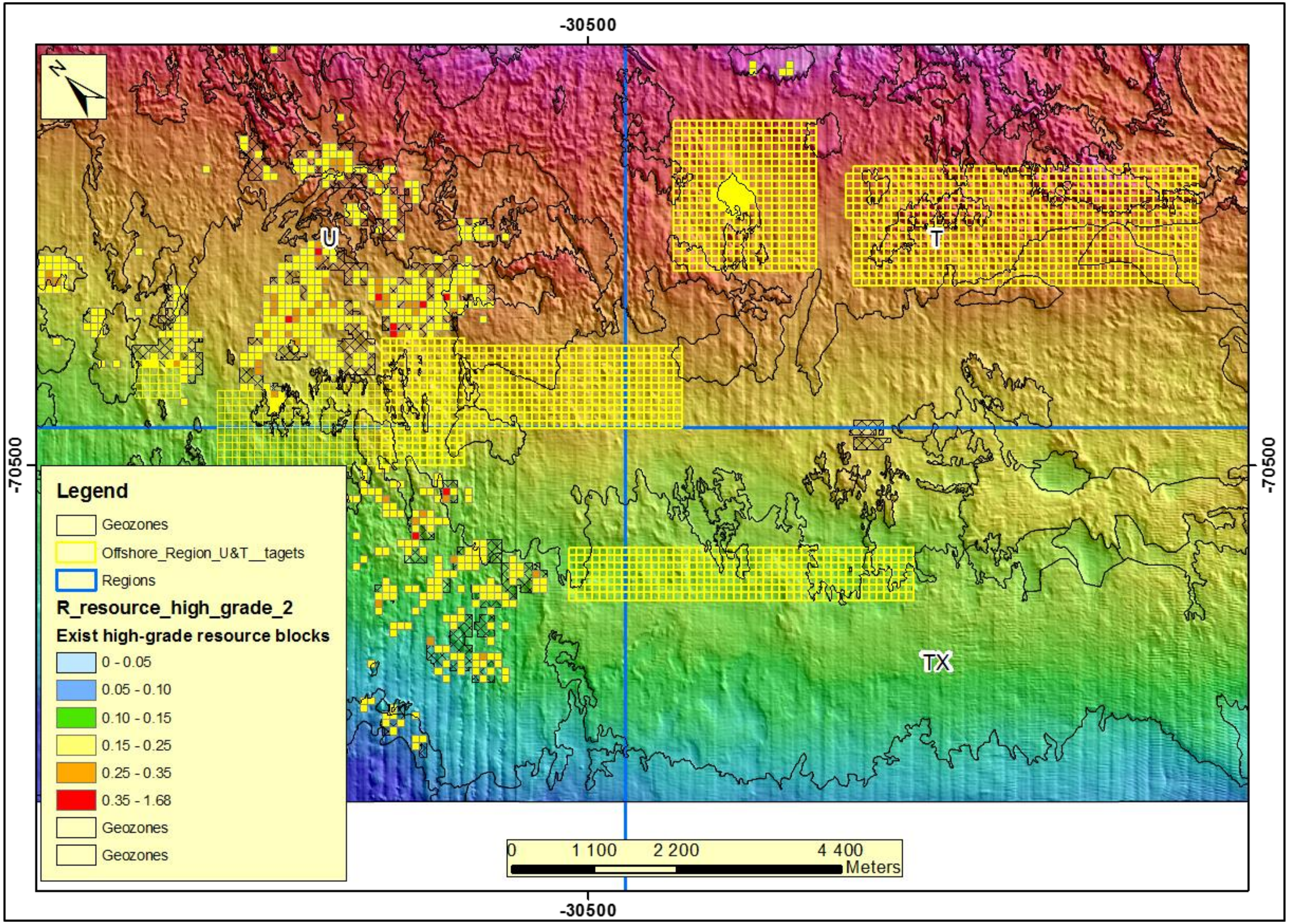


Figure 5.7: *Map showing the existing high-grade resources in the offshore Region U and the potential areas for exploration targets (yellow hatched blocks).*

Gravel ridges and reflectors (Figure 4.15 & 4.16) are rough topographic features consisting of ridges and small troughs/valleys. Ridges are defined by Kearey, (1996) cited in Mubita (2015) as the outcropping extensions of sandstone reflectors. These features are N-S striking and generally strike over large distances. There is often associated faulting and rough topography in the form of troughs and ridges (Figure 4.16), and these areas often contain numerous loose sandstone slabs (Figure 5.8). The faults play an important role in the distribution of diamonds, whereby they change the general strike direction of outcropping strata, which in turn affects the mineralisation trends. Ridges are associated with variable gravel thickness but mostly are quite thick, with a very high volume of very large sandstone slabs due to the closely spaced thick outcropping sandstone reflectors (Figure 5.8). The high volumes of sandstone slabs provide good trapsites and hence high potential for mineralisation in areas of diamondiferous gravel supply especially in the southern areas. As a result, these features have been a major target in Region K, and to date it is the most depleted Region in Atlantic 1. In the northern areas for example in Region O, the surface terrain is normally very rough, and therefore in terms of mineability these areas are mainly suitable for small bit mining tools.

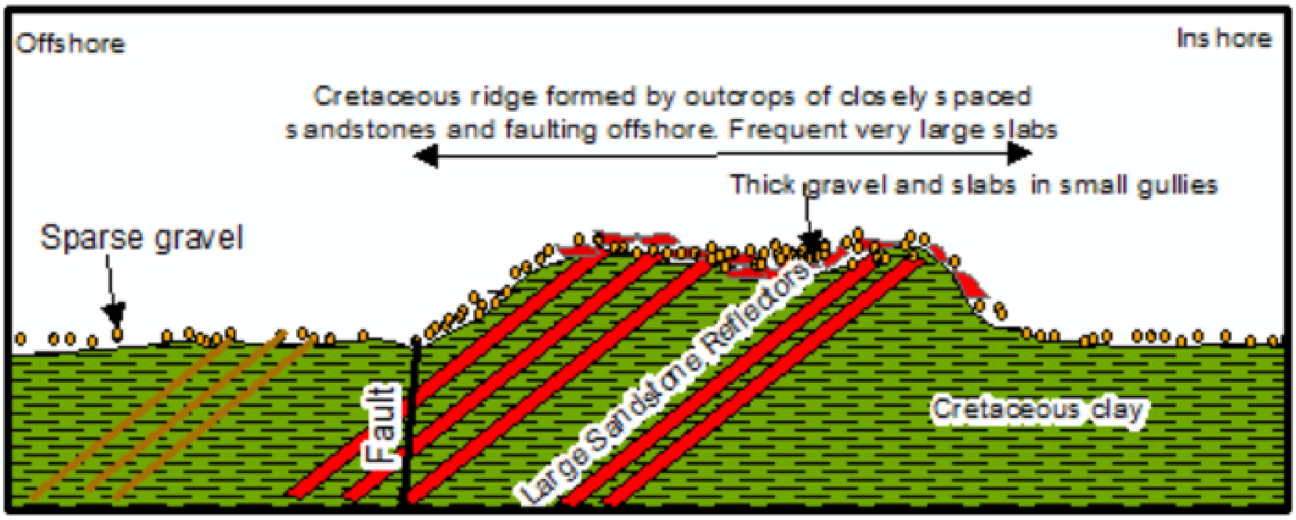


Figure 5.8: *Ideal cross-section of the gravel ridges formed by outcropping reflectors.*

The majority of the Atlantic 1 area is made up of a large flat area consisting of gravel accumulations, outcrops and reflectors. These areas are also interrupted by scours, shallow depressions and raised platforms. Figure 4.17 shows the flat surface related areas with outcrops. The depressions are cut in the lee of outcrops and reflectors. Greater orebody thicknesses are mainly encountered in the inshore of outcrops and reflectors. The gravel comprises variable textures with coarser gravels recorded in the thicker accumulations. The mining and sampling data gathered shows that trap site potential is mainly in the offshore sides of the depressions where the offshore zone is well mineralised, although severe scouring in this area may also have removed much of the gravel. Other areas of potential trapsites are within proximity of reflectors and inshore of outcrops. Orebody texture becomes coarser near outcrops where sandstone slabs are introduced (Figure 5.9). Slab size is determined by the thickness of the sandstone layer. Orebody thickness is sparse on inter-sandstone clays away from the sandstone outcrops and thickens slightly on and within proximity of sandstone outcrops. Away from the outcrops orebody thickness is variable and thin. About 42% of the high-grade resources are located on the flat area where mineralisation is influenced by features that interrupt these areas such as depressions, outcrops, platforms and gravel accumulations.

Mineralisation in cemented and rough platform areas (Figure 4.18) varies as a function of the degree of weathering. Good mineralisation potential occurs in areas where the capping has been weathered, hence exposing the underlying mineralised gravel. Poor mineralisation is associated with low gravel volumes in areas where the persistent cemented sandstone capping is still in-situ, therefore making it difficult for the mining or sampling tools to break through and access the underlying orebody. These features are mainly located in the northern Regions (O-W-V). In highly weathered remnants of the cemented platform areas which have undergone a high degree of weathering, the sandstone capping is totally disintegrated, hence exposing the underlying mineralised gravel and lower sedimentary sequences. Cemented and rough platforms have similar characteristics as V-scalp mineralisation (Figure 4.19). The scarp consists of harder material like sandstone and conglomerate whereas the footwall consists mainly of sand and partially cemented sand. Depending on the degree of weathering and erosion, the capping may expose the gravel layer primarily in the depressions or against the slopes of platform itself.

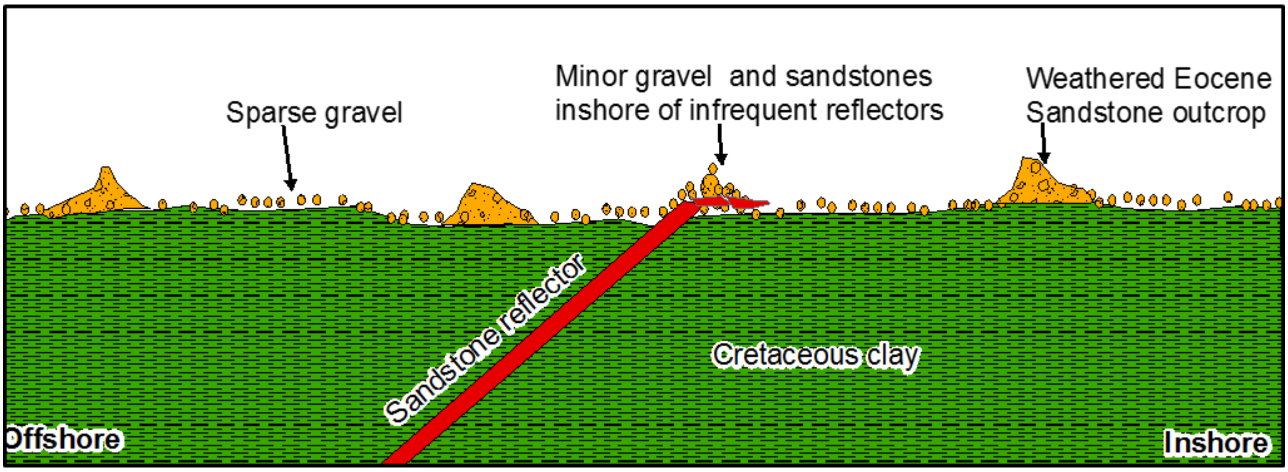


***Figure 5.9:** The cross-section depicting the flat surfaces with minor outcrops which influenced gravel accumulations.*

The degree of weathering and erosion varies hence these zones are characterised by rugged topography, comprising of large ridges and depressions (Figure 5.10). These areas comprise variable gravel thicknesses but fairly thicker gravels due to the total removal of the capping and reworking of the underlying gravel layer. Surface terrane is fairly rough with a high percentage of large to very large sandstone slabs. The gravel layer is underlain by predominantly Eocene 2 sand footwall with minor sporadic occurrences of Eocene 2 sandstone, and clay footwall, depending on the degree of weathering. Good mineralisation potential is associated with sand and clay footwall, while poor mineralisation is associated with low gravel volumes in areas where the persistent cemented sandstone capping is still in-situ, and holes are terminated on sandstone footwall (Figure 5.10).

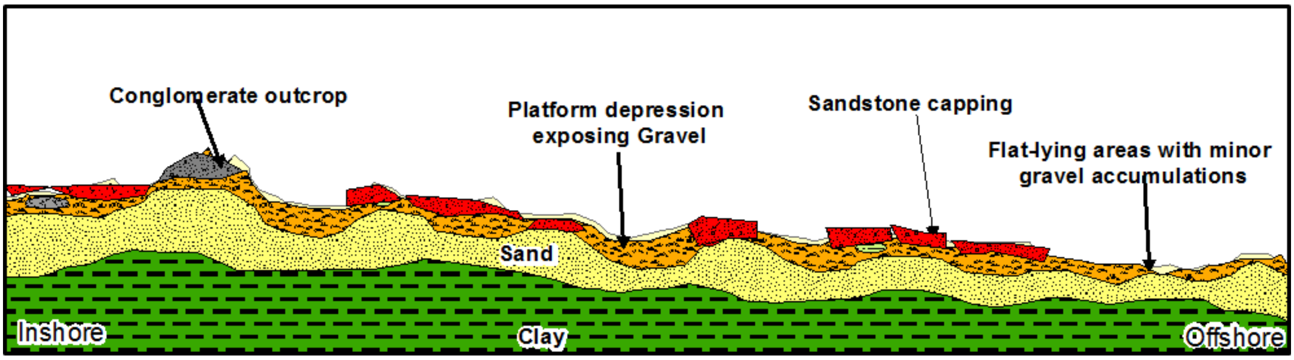


***Figure 5.10:** Highly weathered cemented platform showing the exposed and re-worked underlying mineralized gravel.*

The analysis of the Region V-scarp mineralisation (Figure 4.19) shows that the facies with highest mineralisation potential are shallow and deep depressions, accumulations of slabby gravel material on slopes and reworked material. From the mining recoveries, the analysis showed that in areas where the sandstone capping is still intact the mining recoveries have been very poor since the orebody is concealed. The findings further revealed that the deep and shallow depressions in the V-scarp area are associated with medium stone size, while the scarp slopes and weathered sandstone yielded large stone size. Sampling results in the area revealed that the deep and shallow depressions together with scarp slope and weathered sandstone yielded high stone hits which translate into high-grade mineralisation potential while the sandstone prominence yielded low-grade mineralisation potential (Figure 4.21).The sandstone prominence (cemented features) yielded small stone sizes. The ideal cross-section of the V-scarp is shown in Figure 5.11, where gravel capping, depressions and areas of reworked materials are presented. Gravel pictures showing high slab frequency and angular plantfeed are presented in Figure 4.21 E & F respectively.

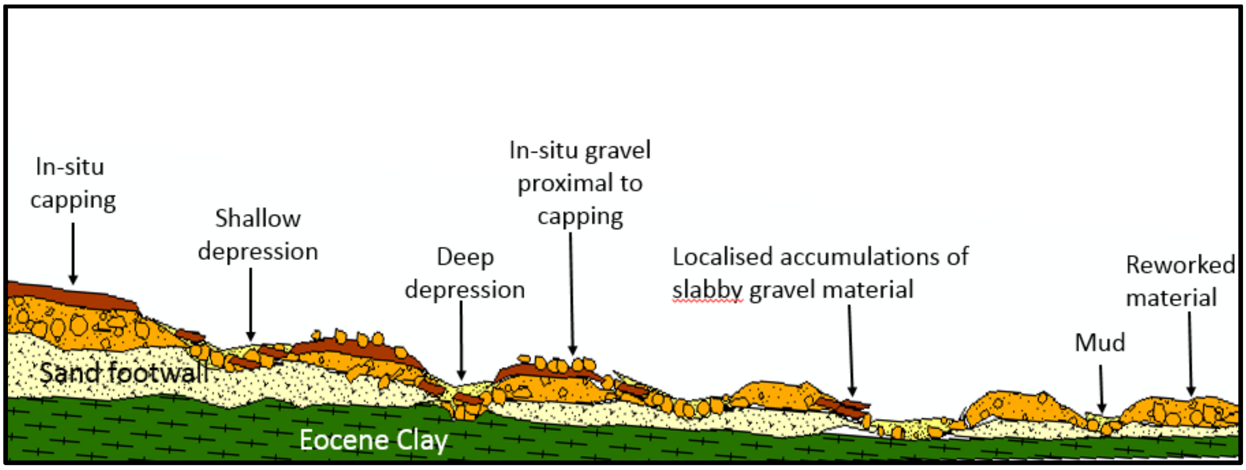


Figure 5.11: *Cross-section of the V-scarp, showing the cemented capping and good mineralised potential in the depressions.*

Another potential target for high-grade mineralisation is the far northern inshore Regions (F-G-O-P) which are mainly characterised by cemented platforms (Figure 4.18). To date, limited resources are being developed in this area mainly due to roughness of the surface terrain. The resource in this area is currently heavily factored due to mineability constraints associated with mining tool penetration challenges. Most of the mining vessels that the company has now cannot efficiently mine this terrain. Roughly, 75% of these regions are covered by a thick Holocene mud overburden. The inadequate mining and sampling activities have revealed that variable quantities of unconsolidated gravel overlie the footwall contact. The most common gravel constituent was sandstone which normally varies in shape from angular to rounded pebbles, cobbles and boulder sized slabs. The second most common gravel constituent is rounded spheroids and discoids of very large quartzite pebbles. On average they constitute 25% of the gravel material. The remaining quarter of the gravel assembly consists of claystone and mudstone of a marine origin. The clasts consists of sub-rounded spheroidal, large pebbles and small cobbles. The rounded to sub-rounded granules of black and shiny phosphatics are the most common constituent of the plantfeed fraction.

Most of Region O orebody is characterised by a variety of reworked, terrigenous slabs and locally derived footwall clasts. These clasts are mainly eroded from offshore dipping reflectors, which dominates this region. In cemented Eocene II areas, in the further offshore part of the Region, the topography becomes more undulating and the trapsites are more prominent (Figure 4.16). The terrain is characterised by north-south orientated strike gullies and potholes which are clearly visible on the bathymetry image (Figure 5.12). These structures such as faults, joints, lineaments, anticlines and synclines which are common in these northern Regions play an important role in the distribution of diamonds and have influenced mineralisation. The potential high-grade resource can be developed in Region O, following the north-south trending features.

Figure 5.13 presents the ideal exploration focus area revealing the outcropping extensions of sandstone reflectors.

The Jago dive target M1J14 (Figure 4.23) is located in the southern offshore side of Region M. Geologically, the target lies on the Eocene 1 weathered sandstone 2 geological zone which is characterised by a rough terrain of outcrops and relatively flat terrain which is the Eocene 1 flat geological zone according to the geophysical data. Mainly two different geologies are visible from geophysical data (the elevated and the flat terrain). The primary objective of the dive was to confirm (ground-truth) the geology of the outcropping features (the elevated ground) which is currently mapped as Eocene 1 weathered sandstone 2. The dive was then to confirm whether these features are really sandstone outcrops or they are actually gravel accumulation zones. The observations made included determination of the thickness and constituency of the overburden layer as well as observing the nature of gravel, the frequency of slabs and the surface terrain.

The dive started at waypoint 1 (WP1) on a flat terrain (Eocene 1 flat geozone) comprising of a thin overburden layer of undisturbed mud and silt with none or very little occurrence of gravel observed (Figure 4.24A). The overburden layer pinched out when the elevated area (which is currently mapped out as Eocene 1 weathered sandstone 2) was reached at waypoints 2 and 4 where accumulations of a well-rounded coarse gravel of mostly cobble to boulder size was observed (Figure 4.24B). The gravel accumulations were irregular in shape, about 1 metre to several metres wide and approximately 1 to 1.5 metres high predominantly composed of quartzite of cobble to boulder size. The height of the gravel accumulations became thinner as the traverse approached the flat terrain at WP3 (Figure 4.24C). Few medium to large slabs were observed on the elevated feature at WP4 (Figure 4.24D).

In summary, the M1J14 dive was able to confirm that the elevated parts on the AUV are principally made up of gravel accumulations of cobble to boulder size. This is basically a potential high-grade area and could be a potential target for sampling and resource development. Currently, this area is outside the existing block resource. The lower lying flat areas comprise silt and mud overburden. A very thin gravel layer was observed which translates to poor mineralisation potential. The dive observations were able to ground-truth various geological zones in the area, and provided better insight in understanding key geological differences between the low lying areas and the outcropping areas on the AUV geophysical image.

Mineralisation controls in U3J14 dive (Figure 4.25) area have been identified in terms of the potential trapsites which are associated with high-grade mineralisation. Potential trapsites identified include small to large sandstone slabs, potholes and gullies in the rough terrain. Terrigeneous clasts were observed of which the material (gravel) was mature and well-rounded and comprised of pebble, cobble and boulder sizes (Figure 4.26A). Therefore, the terrigeneous material is expected to be associated with potential high-grade mineralisation. Large sandstone slabs were encountered on the elevated feature at WP2 where rough mining conditions are expected (Figure 4.26B). The dive covered both the unmined and mined ground as well as few sampling drilled holes done by the sampling vessels, the Explorer (EXP) and Coral Sea (CS).

One of the sampling holes at WP3 presented a better concept of the gravel material in the target area. The observation of the drilled hole was also able to groundtruth the sediment package from the top (overburden) to bottom of the hole (footwall) (Figure 4.26C). Both the sampling and mining results from this area yielded good stone hits with relatively large stone sizes, and hence resulted in high-grade mineralisation as shown in Figure 4.26D. Generally, it can be concluded that this area is rated as a potential target with a thin overburden cover and well developed very high gravel volumes on a flat lying ground.

In summary the Jago track dive U3J14 covered an area with high-grade mineralisation potential and the surrounding area can be a priority target for resource expansion. The mineralisation in this area is mainly associated with high gravel volumes in the depressions (low lying areas).

W6J14 dive (Figure 4.27) targeted an area outside the existing blocked resource, and it has recently been rezoned using geophysical datasets that were acquired from the 2013 geophysical survey campaign. The dive run was entirely across on the Miocene eroded pavement strata 1 which is defined by a partially weathered and eroded remnant of the cemented sandstone platform (elevated/high lying features). The area is characterised by sandstone footwall on the elevations and sand footwall in the depressions (low lying features) (Figure 4.27). The main objectives of this dive were to assess and understand the mineralisation potential in the depression (between WP2 and WP4) versus the Cemented Platform (between WP1 & WP2 and WP4 & WP5), and to collectively understand the factors that control the mineralisation in this area. The findings in this dive will help to make a decision of developing a resource in this area.

The dive started on the pavements WP1 with an introduction of an in-situ weathered and eroded cemented platform, which is observed to be dissected (Figure 4.28A) and in some areas, large, sub-angular, pebbles to cobble sized loose remnants are observed on a fine and burrowed silty seabed floor.

A sediment blow was taken between WP2 and WP3 using the fan attached to the Jago, to determine and understand the nature of the underlying lithology. It revealed the presence of a hard-substrate below a sediment thickness of about 0.2m (Figure 4.28B). The extent thereof could not be observed to conclude as to whether it is an in-situ platform or a loose remnant, nonetheless, small to large, sub-angular, sub-rounded and rounded pebbles were observed on top of this hard substrate. The overlying sediment comprised of small, black phosphatic pebbles as well as minor shell. Traversing between WP3 and WP4 revealed an in-situ sandstone interlayer, which is a remnant of a partially eroded and weathered cemented platform (Figure 4.28C). Furthermore, the observation of in-situ as well as loose occurrences of remnants of, or from a partially eroded and weathered platform continued throughout to the last point WP5 (Figure 4.28D). No mineralised gravel was observed. Although, topographically, the profile between WP2 and WP4 is a depression compared to the relatively higher-lying surrounding, the in-situ occurrence of cemented platforms observed from the Jago suggests that this zone should represent the extension of the surrounding Miocene Eroded pavement strata 1. The high presence of slabs between WP2 and WP6 negates the possibility of easily encountering a clay or sand footwall which is normally associated with the depressions.

Figure 4.29 shows the seismic sections interpretation in the area. The yellow lines in Figure 4.29A represent the seismic lines from which the profiles in B & C were generated. The hatched box represents the extent of the seismic profiles. The arrow on the chirp seismic represents the points at which the dive intersects the chirp seismic sections. The seismic profile (Figure 4.29) reveals the consistent cemented layer, whereby the depression is covered by fairly thick overburden (Figure 4.29B), while in profile 2 the competent layer is exposed (Figure 4.29C). In summary, this dive revealed that this area cannot be a target for high-grade mineralisation as no potential mineralised gravel was observed. The area is highly rugged, with large sandstone slabs (Figure 4.28).

The sea-level fluctuations (transgression, regression and specifically stillstand) play a major role in occurrence and distribution of diamondiferous sediments on the continental shelf of the west coast diamond deposits. Sea-level fluctuations and development of a series of strandlines along the west coast was caused by the tectonic movement of the sub-continent during the Palaeogene era (65-25 Ma). The continual reworking of the older deposits through sea-level fluctuation trapped the diamonds within the gravel lag that were deposited in gullies, potholes and fluvial channels eroded into wave - cut terraces. According to Bosma (2001) diamonds in the Atlantic 1 mine area are concentrated in two major units, these being the late Pleistocene gravel lag and the basal Holocene gravel lag. The late Pleistocene gravel lag is thought to be part of the regressive littoral phase early in the last glaciation. The Holocene lag is part of the transgressive phase at the end of the last glaciation.

The Pre-proto gravels are comprised primarily of locally derived clastic material with a high proportion of Vaal River type (VRT) agate and evidence of banded Iron formation (BIF). The inferred location of the shoreline during the deposition of the Pre-proto gravel is shown in Figure 4.35. Between the ends of the Eocene through to the start of the Oligocene there was generally a very stable sea-level at about -100 m below current sea-level. There was a slight drop of about -30 m at ~34 Ma and major regression marked by Williamson et al., (2010) at 30 Ma. Most of the Pre-proto gravel would have been deposited during the stable sea-level phases or during the Oligocene regression with the latter exposing the footwall to varying degrees of weathering and erosion (Figure 4.34).

The inferred location of the Proto shoreline is illustrated in Figure 4.37.The sea-level during Proto deposition fluctuated extensively from the late Oligocene through to the Aquitanian. The early Aquitanian is marked by the marine transgressive event, which lowered the sea-level by ~-100mbsl (meters below sea level) according to Williamson et al., (2010). At the start of the Burdigalian (20.43 - 15.97 Ma) the sea-level had started to regress by ~ 50 m but by the middle Miocene the sea-level was back to its Aquitanian level (Figure 4.36). Two further regressive events shaped the bathymetry surface during the early middle Miocene with drops in sea-level of about 50 m recorded for both. The remainder of the middle Miocene was relatively stable at about 60mbssl based on the work of Williamson et al., (2010) (Figure 4.33). In terms of gravel characteristics, the Proto gravel suite contains a high proportion of Karoo sedimentary clasts and a diluted BIF signature.

The proposed position of the Meso shoreline is depicted in Figure 4.39. The course of the palaeo-Orange River during the deposition of the Plio-Pleistocene Meso gravels was a lot straighter than during Proto time. The straightening of the River course was due to active incision which also scoured deep holes into the landscape (Figure 4.38). The Meso was marked by shorter periods of incisions and aggradation than the Proto, with incision being markedly smaller than during earlier times.

The climate during the Meso was largely arid with a marked wetter phase at the end of the Pliocene which was probably responsible for flushing out substantial material from the Orange and depositing the Meso offshore delta. The Meso gravels were deposited between the late Pliocene and the Pleistocene (Plio-Pleistocene). During this time the sea-level fluctuated from about +50 m above sea-level to as low as 120 mbsl (Figure 4.33. The Meso gravels are characterised by the presence of BIF and blue riebeckite. Karoo basalts, zeolite and Orange type agate dominate this assemblage.

In summary, all the potential targets for further exploration were identified based on the geological trends and the nature of surface terrains, sampling information and historical mining recoveries. The maps showing all the potential targets for exploration are presented in Figure 5.14. Furthermore, the Atlantic 1 regional geophysical (AUV image) data revealed the several homogeneously north-south trending features (paleo-placer lineaments) which seem to have controlled mineralisation on the regional scale. The existing high-grade resource appears to be following these features (paleo-placer lineaments). From the south, the lineaments are slightly faint, but they are more prominent in the northern areas. In Region K, these lineaments appears to be very small and closely packed. Figure 5.15 shows the north-south striking features (paleo-placer lineaments) from the south to the north of Atlantic 1 as well as the proposed/identified potential targets for further exploration.

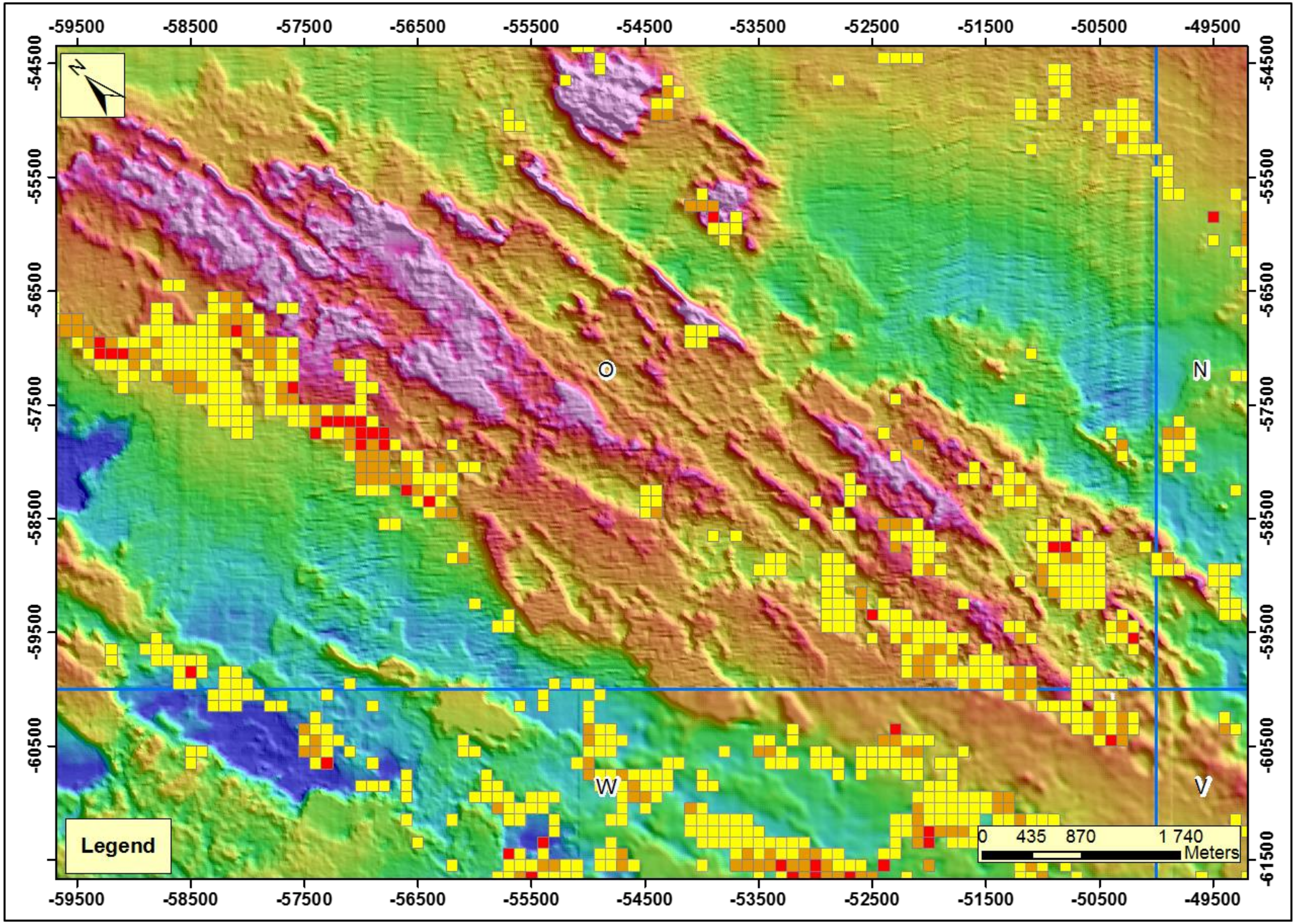


Figure 5.12: *Map showing the high-grade mineralisation following the north-south striking features. High-grade mineralisation is mainly concentrated in the gullies between the undulating surfaces.*

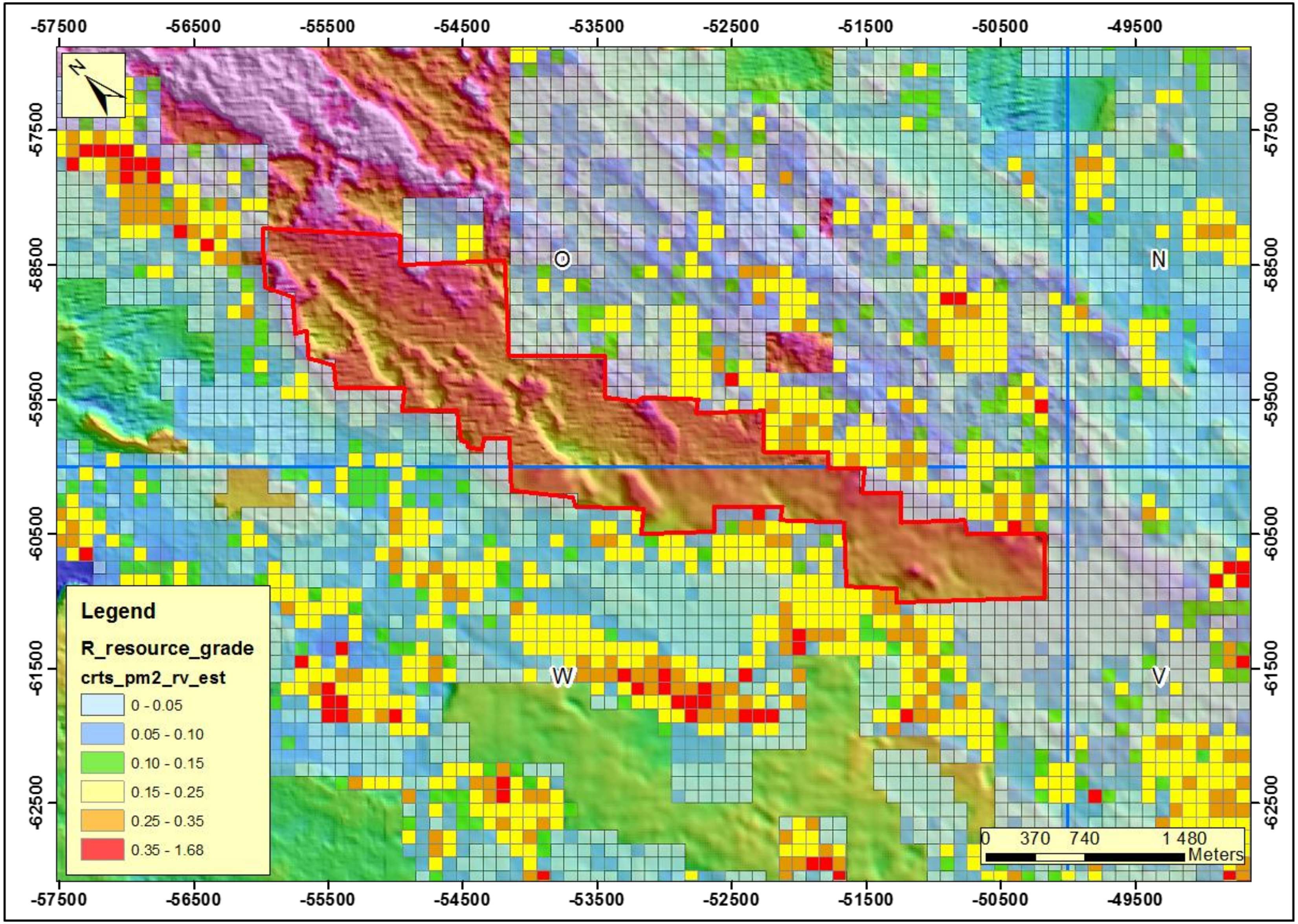


Figure 5.13: *Map showing the existing resources blocks, and the potential target for exploration highlighted red outline. Good mineralisation is expected to follow the north-south striking feature where high-grade mineralisation is mainly concentrated in the depressions.*

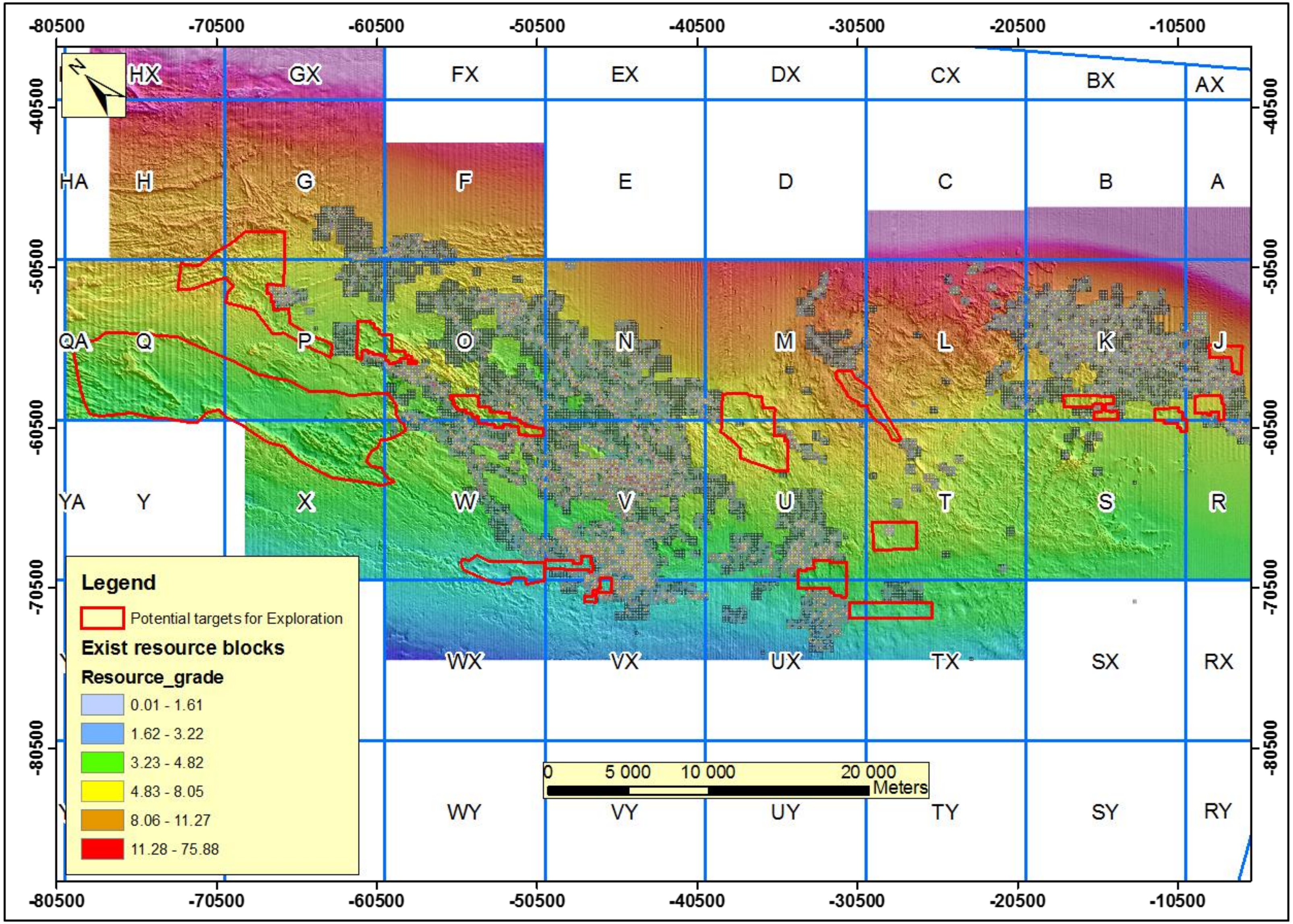


Figure 5.14: *Map showing all the potential targets for further exploration, which were identified, based on the nature of surface terrain, sampling information and historical mining recoveries. The map represents the existing resource across entire lease block and the potential targets for further exploration are outlined in red.*

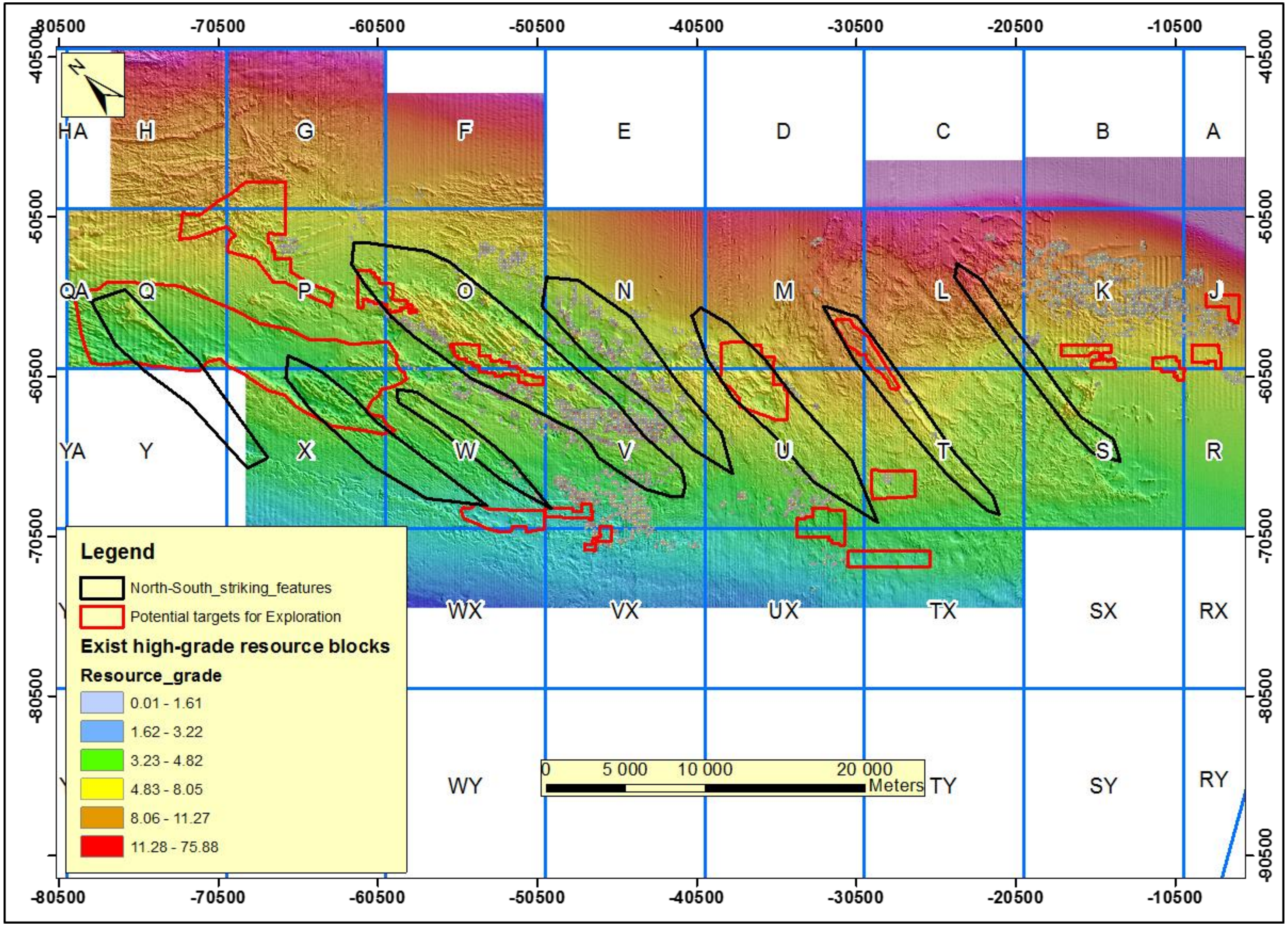


***Figure 5.15:** Map showing the north-south striking features (paleo-placer lineaments) (black outline) from the south to the north of Atlantic 1 as well as the proposed/identified potential targets (red outline) for further exploration.*

CHAPTER 6

CONCLUSION

The primary diamonds are found in kimberlites and lamproites. In kimberlites diamonds are found principally in crater and diatreme facies rocks. Kimberlites do not produce diamonds but merely act as a medium of transportation, bringing diamonds or diamond-bearing mantle xenoliths from within the diamond stability field to the surface.

The diamonds found on the continental shelf of the west coast of Southern Africa were primarily derived from the erosion of onland kimberlite pipes and transported to the coast by rivers. The erosion and transport mechanisms were fluvially driven and peaked during the mid to late Cretaceous periods. Indications are that during mid- to late Cretaceous, two major River systems were responsible for transporting sediment to the coast. One of these was situated in the vicinity of the current Olifants River mouth (the Karoo River) and the other entered the Atlantic via the lower Orange River (the Kalahari River).

The geological history of the marine deposits on the continental shelf off the southwestern African coast is complex and involves the interaction of fluvial, marine and aeolian systems. On the arrival of diamond-bearing terrigenous sediments to the continental shelf, it is thought that marine processes would have dominated. The offshore deposits are contained in composite marine lag gravels, which are the products of repeated reworking of material on the continental shelf during numerous regressions and transgression events. Previous work, mining and sampling data have revealed that the Pleistocene gravel lag is thought to be part of the regressive littoral phase early in the last glaciation. The Holocene lag is part of the transgressive phase at the end of the glaciation. The largest volume of diamonds was deposited during the Pre-proto (which covers Regions V-O-W) with the Proto (Regions M-U-L-T) gravel yielding an order of magnitude less diamonds and the Meso (inshore Regions L-K) representing the coarsening tail of a diamond population that declined over time.

The analysis of geographical and geophysical data of the Atlantic 1 marine deposits has revealed that there are specific localities where marine diamonds are best concentrated resulting in high-grade diamond mineralisation. Such localities which are associated with the nature of the surface terrain and favourable depositional environments can be structurally or geologically controlled. These controls are of great significance to the prospecting for and the mining of diamonds. The data analyses revealed that high-grade diamond mineralisation is best concentrated in the depressions, gullies, gravel beach berms and gravel platforms, potholes, scarp slopes and near the outcrops where turbulences are fixed and where gravel accumulations are stable enough to retain high-grade diamonds. Structures such as faults play an important role in the distribution of diamonds, whereby they change the general strike direction of outcropping strata, which in turn affects the mineralisation trends.

The highest grades in Atlantic 1 were observed from the Pre-proto deposits, with a lesser but coarse, population located in the Proto and Meso gravels. The Pre-proto is the oldest gravel suite, which was deposited during the stable sea-level phases, and underwent through a continual reworking of older mineralised deposits resulting in redeposition of high-grade diamonds in preferable trapsites. The Pre-proto source area forms part of a north-south striking platform feature, which extends through Regions O and V. The mining and sampling data gathered have shown that trapsite potential is good in the gullies and depressions where the offshore zones are well mineralised. Other areas of potential trapsites within the Pre-proto gravel suites are localised gullies in proximity of reflectors and inshore of outcrops.

All the potential targets for further explorations were identified based on the available geophysical, geological, mining and sampling data. Limitations noted during research include the inadequate geophysical data especially for most of the northern and offshore part of the licence area. Another challenge was the limited mining and sampling activities in areas that pose mineability challenges to the vessels. Rough mining terrains for example V-scarp and mainly Regions F, G, inshore O and P as well as the mudbelt areas are currently un-mineable with the current technology and therefore pose challenges in terms of data collection for analysis and interpretations.

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APPENDICES:

Geological Attributes

GZ_ID	ZONE_NAME	DOM_FW	SEC_FW	FW_NAT	GRAV_TEX	SLAB_FREQ	SLAB_SIZE	SLAB_THICK	OS_VOL	PF_VOL	SOURCE	CONFIDENCE
Z01A	Cretaceous Flat 1	CY	SST	HARD	MED	LOW	SMALL	THIN	LOW	LOW	IS	HIGH
Z01B	Cretaceous Flat 2	CY	SST	HARD	MED	MED	SMALL	THIN	LOW	LOW	IS	HIGH
Z01D	Cretaceous Flat 4	CY	NONE	FIRM	FINE	MED	SMALL	THIN	LOW	MED	IN	HIGH
Z01E	Cretaceous Flat with Minor Outcrop 1	CY	SST	HARD	MED	MED	SMALL	THIN	MED	MED	IN	HIGH
Z01F	Cretaceous Flat with Minor Outcrop 2	CY	GSND	HARD	MED	LOW	SMALL	THIN	LOW	HIGH	MESO	HIGH
Z01G	Cretaceous Flat with Conglomerate Outcrop	CY	CO	FIRM	COARSE	MED	MED	THICK	HIGH	HIGH	IS	HIGH
Z01H	Inshore Cretaceous Plateau	CY	NONE	FIRM	MED	HIGH	MED	THIN	MED	HIGH	IN	LOW
Z02A	Cretaceous Window Depression	CY	NONE	FIRM	MED	LOW	MED	THIN	LOW	MED	IN	HIGH
Z02B	Cretaceous Shallow Depressions	CY	SND	STICKY	MED	MED	SMALL	THIN	LOW	LOW	IS	HIGH
Z02C	Cretaceous Gully	CY	NONE	FIRM	MED	MED	MED	THIN	MED	VHIGH	IN	MEDIUM
Z02D	Large Cretaceous Gully	CY	NONE	FIRM	MED	MED	MED	THIN	MED	HIGH	IN	LOW
Z02E	Cretaceous Scour Depression	CY	SND	STICKY	MED	LOW	SMALL	THIN	LOW	LOW	IN	HIGH
Z03A	Large Cretaceous Reflector	SST	CY	HARD	COARSE	HIGH	LARGE	THICK	HIGH	HIGH	IS	HIGH
Z03B	Cretaceous Reflector	CY	SST	HARD	COARSE	HIGH	LARGE	THICK	MED	MED	MESO	HIGH
Z03C	Cretaceous Ridge	CY	SST	HARD	MED	HIGH	LARGE	THICK	HIGH	HIGH	IS	MEDIUM
Z03D	Minor Cretaceous Ridge	CY	SST	HARD	MED	HIGH	LARGE	THICK	HIGH	HIGH	IN	LOW

Z03E	Large Cretaceous Ridge	CY	SST	HARD	MED	HIGH	LARGE	THICK	HIGH	HIGH	IN	LOW
Z03F	Cretaceous Ridge Zone 1	CY	GSST	HARD	COARSE	HIGH	MED	THICK	HIGH	HIGH	IS	LOW
Z03G	Cretaceous Ridge Zone 3	CY	SST	HARD	MED	HIGH	LARGE	THICK	HIGH	HIGH	IN	HIGH
Z03H	Cretaceous Ridge Zone 4	CY	GSST	HARD	COARSE	HIGH	MED	THICK	HIGH	HIGH	IS	HIGH
Z03I	Cretaceous Ridge Remnants	CY	SST	HARD	MED	HIGH	LARGE	THICK	MED	HIGH	IN	LOW
Z03J	Cretaceous Beach Berm	CY	NONE	HARD	VCOARSE	LOW	SMALL	NA	VHIGH	VHIGH	MESO	MEDIUM
Z03K	Large Cretaceous Beach Berm	CY	NONE	HARD	VCOARSE	LOW	SMALL	THIN	VHIGH	VHIGH	MESO	HIGH
Z03L	Minor Cretaceous Beach Berm	CY	NONE	HARD	COARSE	LOW	SMALL	NA	HIGH	HIGH	MESO	MEDIUM
Z03M	Cretaceous Minor Gravel	CY	SST	HARD	COARSE	MED	MED	THIN	MED	MED	MESO	HIGH
Z03N	Cretaceous Tombolo	CY	GSND	FIRM	COARSE	MED	MED	THIN	HIGH	HIGH	IS	HIGH
Z03O	Cretaceous Gravel Ridge	CY	SST	HARD	COARSE	MED	MED	THIN	HIGH	HIGH	IS	LOW
Z04A	Cretaceous Large Gravel Platform	CY	SND	HARD	COARSE	MED	MED	THIN	VHIGH	VHIGH	IS	HIGH