



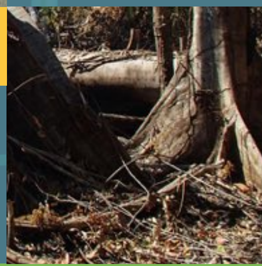

Appendix O

Benthic Video Characterisation

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Purpose of EIS

The EIS has been prepared by, for and on behalf of Wafi Mining Limited and Newcrest PNG 2 Limited (together the "**WGJV Participants**"), being the participants in the Wafi-Golpu Joint Venture ("**WGJV**") and the registered holders of exploration licences EL 440 and EL1105, for the sole purpose of an application (the "**Permit Application**") by them for environmental approval under the Environment Act 2000 (the "**Act**") for the proposed construction, operation and (ultimately) closure of an underground copper-gold mine and associated ore processing, concentrate transport and handling, power generation, water and tailings management, and related support facilities and services (the "**Project**") in Morobe Province, Independent State of Papua New Guinea. The EIS was prepared with input from consultants engaged by the WGJV Participants and/or their related bodies corporate ("**Consultants**").

The Permit Application is to be lodged with the Conservation and Environment Protection Authority ("**CEPA**"), Independent State of Papua New Guinea.

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Any future development of the Project is subject to further studies, completion of statutory processes, receipt of all necessary or desirable Papua New Guinea Government and WGJV Participant approvals, and market and operating conditions.

Engineering design and other studies are continuing and aspects of the proposed Project design and timetable may change.

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Newcrest Mining Limited ("**Newcrest**") is the ultimate holding company of Newcrest PNG 2 Limited and any reference below to "Newcrest" or the "Company" includes both Newcrest Mining Limited and Newcrest PNG 2 Limited.

Forward Looking Statements

The EIS includes forward looking statements. Forward looking statements can generally be identified by the use of words such as "may", "will", "expect", "intend", "plan", "estimate", "anticipate", "continue", "outlook" and "guidance", or other similar words and may include, without limitation, statements regarding plans, strategies and objectives of management, anticipated production or construction commencement dates and expected costs or production outputs. The Company continues to distinguish between outlook and guidance. Guidance statements relate to the current financial year. Outlook statements relate to years subsequent to the current financial year.

Forward looking statements inherently involve known and unknown risks, uncertainties and other factors that may cause the Company's actual results, performance and achievements to differ materially from statements in this EIS. Relevant factors may include, but are not limited to, changes in commodity prices, foreign exchange fluctuations and general economic conditions, increased costs and demand for production inputs, the speculative nature of exploration and project development, including the risks of obtaining necessary licences and permits and diminishing quantities or grades of reserves, political and social risks, changes to the regulatory framework within which the Company operates or may in the future operate, environmental conditions including extreme weather conditions, recruitment and retention of personnel, industrial relations issues and litigation.

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The Company does not give any assurance that the assumptions will prove to be correct. There may be other factors that could cause actual results or events not to be as anticipated, and many events are beyond the reasonable control of the Company. Readers are cautioned not to place undue reliance on forward looking statements. Forward looking statements in the EIS speak only at the date of issue. Except as required by applicable laws or regulations, the Company does not undertake any obligation to publicly update or revise any of the forward looking statements or to advise of any change in assumptions on which any such statement is based.

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Newcrest results are reported under International Financial Reporting Standards (IFRS) including EBIT and EBITDA. The EIS also includes non-IFRS information including Underlying profit (profit after tax before significant items attributable to owners of the parent company), All-In Sustaining Cost (determined in accordance with the World Gold Council Guidance Note on Non-GAAP Metrics released June 2013), AISC Margin (realised gold price less AISC per ounce sold (where expressed as USD), or realised gold price less AISC per ounce sold divided by realised gold price (where expressed as a %), Interest Coverage Ratio (EBITDA/Interest payable for the relevant period), Free cash flow (cash flow from operating activities less cash flow related to investing activities), EBITDA margin (EBITDA expressed as a percentage of revenue) and EBIT margin (EBIT expressed as a percentage of revenue). These measures are used internally by Management to assess the performance of the business and make decisions on the allocation of resources and are included in the EIS to provide greater understanding of the underlying performance of Newcrest's operations. The non-IFRS information has not been subject to audit or review by Newcrest's external auditor and should be used in addition to IFRS information.

Ore Reserves and Mineral Resources Reporting Requirements

As an Australian Company with securities listed on the Australian Securities Exchange (ASX), Newcrest is subject to Australian disclosure requirements and standards, including the requirements of the Corporations Act 2001 and the ASX. Investors should note that it is a requirement of the ASX listing rules that the reporting of Ore Reserves and Mineral Resources in Australia comply with the 2012 Edition of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (the JORC Code) and that Newcrest's Ore Reserve and Mineral Resource estimates comply with the JORC Code.

Competent Person's Statement

The information in the EIS that relates to Golpu Ore Reserves is based on information compiled by the Competent Person, Mr Pasqualino Manca, who is a member of The Australasian Institute of Mining and Metallurgy. Mr Pasqualino Manca, is a full-time employee of Newcrest Mining Limited or its relevant subsidiaries, holds options and/or shares in Newcrest Mining Limited and is entitled to participate in Newcrest's executive equity long term incentive plan, details of which are included in Newcrest's 2017 Remuneration Report. Ore Reserve growth is one of the performance measures under recent long term incentive plans. Mr Pasqualino Manca has sufficient experience which is relevant to the styles of mineralisation and type of deposit under consideration and to the activity which he is undertaking to qualify as a Competent Person as defined in the JORC Code 2012. Mr Pasqualino Manca consents to the inclusion of material of the matters based on his information in the form and context in which it appears.

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Harmony Gold Mining Company Limited ("**Harmony**") is the ultimate holding company of Wafi Mining Limited and any reference below to "Harmony" or the "Company" includes both Harmony Gold Mining Company Limited and Wafi Mining Limited.

Forward Looking Statements

These materials contain forward-looking statements within the meaning of the safe harbor provided by Section 21E of the Securities Exchange Act of 1934, as amended, and Section 27A of the Securities Act of 1933, as amended, with respect to our financial condition, results of operations, business strategies, operating efficiencies, competitive positions, growth opportunities for existing services, plans and objectives of management, markets for stock and other matters. These include all statements other than statements of historical fact, including, without limitation, any statements preceded by, followed by, or that include the words "targets", "believes", "expects", "aims", "intends", "will", "may", "anticipates", "would", "should", "could", "estimates", "forecast", "predict", "continue" or similar expressions or the negative thereof.

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For a more detailed discussion of such risks and other factors (such as availability of credit or other sources of financing), see the Company's latest Integrated Annual Report and Form 20-F which is on file with the Securities and Exchange Commission, as well as the Company's other Securities and Exchange Commission filings. The Company undertakes no obligation to update publicly or release any revisions to these forward-looking statements to reflect events or circumstances after the date of this EIS or to reflect the occurrence of unanticipated events, except as required by law.

Competent Person's Statement

The Wafi-Golpu Joint Venture is an unincorporated joint venture between a wholly-owned subsidiary of Harmony Gold Mining Company Limited and a wholly-owned subsidiary of Newcrest Mining Limited.

The information in the EIS that relates to Golpu Ore Reserves is based on information compiled by the Competent Person, Mr Pasqualino Manca, who is a member of The Australasian Institute of Mining and Metallurgy. Mr Pasqualino Manca, is a full-time employee of Newcrest Mining Limited or its relevant subsidiaries, holds options and/ or shares in Newcrest Mining Limited and is entitled to participate in Newcrest's executive equity long term incentive plan, details of which are included in Newcrest's 2017 Remuneration Report. Ore Reserve growth is one of the performance measures under recent long term incentive plans. Mr Pasqualino Manca has sufficient experience which is relevant to the styles of mineralisation and type of deposit under consideration and to the activity which he is undertaking to qualify as a Competent Person as defined in the JORC Code 2012. Mr Pasqualino Manca consents to the inclusion of material of the matters based on his information in the form and context in which it appears.

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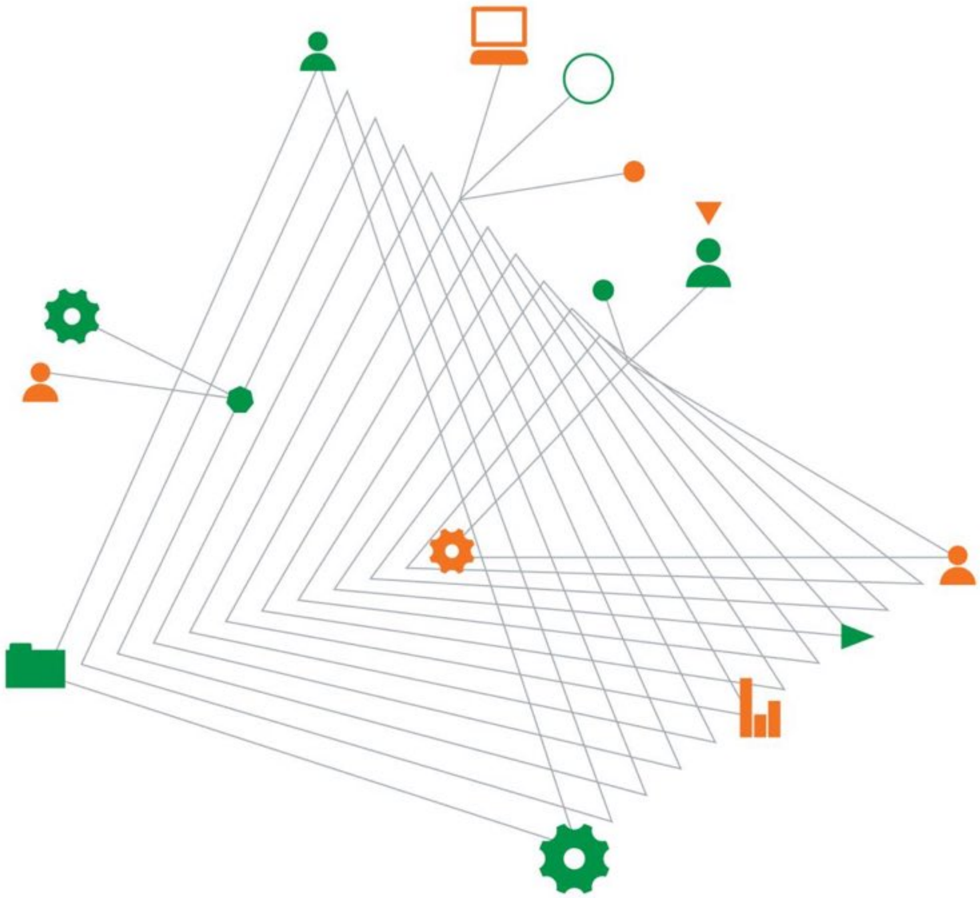
Wafi-Golpu Joint Venture

Wafi-Golpu Project

Benthic video characterisation

25 June 2018



Experience
comes to life
when it is
powered by
expertise

Wafi-Golpu Project

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Executive summary

Background

Wafi Mining Limited and Newcrest PNG 2 Limited (WGJV Participants) are equal participants in the Wafi-Golpu Joint Venture (the WGJV). The WGJV is investigating the feasibility of constructing, operating and (ultimately) closing an underground copper-gold mine and associated ore processing, concentrate transport and handling, power generation, water and tailings management and related support facilities and services (hereafter the “Wafi-Golpu Project” or the “Project”), located beneath Mt Golpu, approximately 300 kilometres (km) north-northwest of Port Moresby and 65 km southwest of Lae in the Morobe Province of the Independent State of Papua New Guinea (PNG). The Project includes ore processing, concentrate transport and handling, power generation, water management, a deep sea tailings placement (DSTP) system for tailings management, access roads to the mine and related support facilities.

The WGJV has commissioned a range of studies to inform the Project’s Feasibility Study Update and to prepare an Environmental Impact Statement (EIS).

This report describes the findings of the benthic video characterisation study. This study is based on investigations undertaken in the Markham Canyon and reference locations in the Huon Gulf outside of the Markham Canyon conducted between 28 November and 1 December 2016.

Objectives

The overall objective of the study was to characterise the benthic marine environment in four key areas (hereafter referred to collectively as the ’study area’):

- Potential areas of tailings density current flow path.
- Potential areas of main tailings deposition.
- Near the proposed Outfall Area.
- Reference locations away from areas of potential tailings deposition.

The characterisation study focussed on the anticipated depth range of the descending tailing density current to depths of approximately 1,800 m, and sought to identify and record the locations and features of the main seafloor habitats in the study area, including observations of noteworthy benthic fauna.

Study area

Nineteen sites were selected to perform UIS deployments and to characterise different types of subsea terrain features at a variety of depths ranging from 220 m to almost 1,800 m (depth limit of the UIS). The study focussed on characterising benthic areas within the expected area of the potential tailings density current and main tailings deposition footprint area, i.e., within the Markham Canyon and basin, as well as slopes around the region of the DSTP outfall pipelines. The study also characterised reference locations in the Huon Gulf outside of the Markham Canyon and away from areas of potential tailings deposition, including more than 3 km south of Lae and further southward toward Salamaua, as well as a site east of the Busu River. The selection of sites was informed by multi-beam sonar bathymetric data collected in August 2016.

Key findings

The key findings of the study are summarised as follows:

- The benthic environment that was observed at all study sites where visibility was sufficient to allow a visual assessment (sites 1, 2, 5, 7, 9, 10, 11, 13, 14, 15, 16, 17, 18 (i.e., 13 of the 19 sites) was low in physical and biological diversity, morphological complexity and habitat features. No out-cropping rocky substrate or complex morphological features such as deep-sea or hydrothermal vents, seamounts, or deep-sea coral colonies were observed at any of the sites.
- No deep sea coral colonies were observed at any of the sites but this was to be expected because a) photosynthetic corals are typically not found below 200 m and b) the high volumes of riverine sedimentation would hinder the growth of deep sea coral reefs in the study area.
- Benthic sediments were observed to display a high degree of homogeneity, and were characterised by fine, easily re-suspended silts and clays, accumulated in layers of unknown thickness. The sediment also formed large aggregates (several centimetres in diameter) that became temporarily suspended in the water column after disturbance of the seafloor by the UIS.
- High turbidity conditions and/or sediment plumes were observed in the water column and/or at the seafloor at sites near the discharge of the Markham River and Busu River (Sites 1 to 6, 8 to 12 and 15 to 19), and in the area of the potential DSTP tailing density current, sub-surface plumes and deposition (i.e., slopes and Markham Canyon floor). Suspended sediments caused by the landing of the UIS on the seafloor were typically seen to be quickly swept away by bottom currents.
- At most sites within the Markham Canyon (i.e., sites 3, 4, 6, 8, 10, 11, 12, 16, 17 and 19) sediment plumes tended to be bottom-attached, with surface and mid-water clarity and visibility generally moderate to high. The exception to this was noted near river discharge sites (Sites 1 to 5, 9 and 19) where a generally thin surface layer (usually from zero to 10 m depth) of turbidity was evident. Reduced water clarity near the seafloor appeared to be associated with bottom attached plumes in some cases extending up to approximately 600 m from the seafloor (Site 16).
- Reference sites 13 and 14 located southwest of the Markham Canyon and beyond the expected areas of DSTP influence (subject to confirmation by modelling) were found to have the highest water clarity and readily observable benthic fauna.
- Evidence of fauna was scarce at all sites, and mostly in the form of seafloor bioturbation, with occasional visible shrimp, sea whips, fish and other organisms insufficiently clear for identification. Diverse or abundant benthic faunal communities were not observed at any sites.
- Cartilaginous and bony fish fauna were very rarely observed.
- During the entire survey, where footage of the seafloor was sufficiently clear (a total of 522 seconds), 22 individual observations of benthic and demersal fauna were made. This equates to 2.53 fauna sightings per minute of footage. Ten of the sightings were at Site 13, which is well removed from the Markham Canyon (some 10 km to the south); however, this site also had the longest duration of footage with visible sea floor. At Site 13 there were 2.65 fauna sightings per minute of visible seafloor footage. Plankton aggregations were commonly observed in areas of high water clarity during the deployment and retrieval of the UIS. While the planktonic fauna observed is likely to include ctenophores (comb jellies), medusae, salps (planktonic tunicates) and chaetognaths (arrow worms), the actual identities will be the subject of separate investigations.

- Other studies (environmental assessment for the Lae Port Development Project and the Wafi deep-slope and pelagic fish characterisation) indicate an impoverished benthic fauna as a result of disturbances primarily related to the high terrestrial sediment load transported from the Markham River as well as other smaller rivers into the Huon Gulf. The results of this study support these findings.
- Seafloor imagery collected during this study showed a high degree of visual similarity with that collected from sites with similar geomorphological and oceanographic conditions, during an independent evaluation of DSTP in PNG (SAMS, 2010b).

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Contents

Executive summary iii
Glossary ix
1. Introduction 1
  1.1. Background 1
  1.2. Objectives 2
  1.3. Existing environment 2
    1.3.1. Huon Gulf 2
    1.3.2. Deep sea fauna 5
2. Methods 6
  2.1. Study team 6
  2.2. Study area and site selection 6
  2.3. Design of underwater imaging system 8
  2.4. Operation of underwater imaging system 8
  2.5. Baited remote underwater video (BRUV) 10
3. Results 12
  3.1. Image quality and performance of UIS 12
  3.2. Visual assessment of benthic features 12
    3.2.1. Benthic habitat features 12
    3.2.2. Benthic fauna 14
  3.3. Visual assessment of water column 18
4. Discussion 23
  4.1. Benthic habitats and fauna 23
  4.2. Comparison with other surveys 24
5. References 25

Figures

1.1: Benthic video study sites 4

Tables

2.1: Benthic survey locations 7
3.1: Summary of fauna and habitat observations at each site 17
3.2: Visual summary of turbidity plumes and water clarity at each site 19

Plates

2.1: MV Surveyor 9

2.2: Underwater Imaging System 9

2.3: UIS bridle configuration..... 9

2.4: Altimeter affixed to UIS (on the top and left bars)..... 11

2.5: Bait bag affixed to UIS during BRUV deployments 11

2.6: Imagery at Site 7 (560 m depth) with baited bag visible. Note burrows in sediment. 11

3.1: Highly turbid water at Site 4 (850 m depth), typical of sites in the Markham Canyon 13

3.2: Typical seafloor observed across study area 13

3.3: Steep seafloor and unidentified fish at Site 15 (likely Family: Macrouridae, centre right of frame, depth 450 m)..... 13

3.4: Re-suspended sediment and very low visibility at Site 16 (1,797 m depth) 15

3.5: Thick brown/grey muddy clay material taken from UIS following deployment at Site 18 (313 m depth)..... 15

3.6: Burrows, tracks and mounds (bioturbation) in substrate at Site 13 (757 m depth) 15

3.7: Two unidentified shrimp (low centre left of frame) at Site 13 (757 m depth). 16

3.8: Sea whip (lower left of frame) at Site 13 (depth 757 m). Note mounds and burrows in sediment. 16

3.9: Unidentified fauna (Site 7, lower right of frame, depth 560 m) 16

3.10: Bioluminescent ‘sparks’, common in the mid-water column at a number of sites. 22

3.11: Unidentified fauna and resuspended sediment following seafloor disturbance (Site 13, depth 757 m)..... 22

Appendices

A - Selected imagery from Sites 1 – 19

Glossary

Abbreviations

º	degrees
ADCP	Acoustic Doppler Current Profiler
BRUV	baited remote underwater video
DSTP	deep sea tailings placement
EIS	environmental impact statement
km	kilometre
m	metres
m/s	metres per second
PNG	Independent State of Papua New Guinea
SAMS	The Scottish Association for Marine Science
UIS	underwater imaging system
WGJV	Wafi-Golpu Joint Venture

Terms

Coastal Area	The Coastal Area includes the proposed Port Facilities Area and the proposed Outfall Area.
hyperpycnal flow	When the concentration of suspended sediment at the mouth of a river is so large that the density of river water is greater than the density of sea water a particular type of turbidity current called a hyperpycnal plume can form.
Ophiuroids	A large group (over 1,600 species) of echinoderms that includes the brittle stars (Ophiurida) and basket stars (Euryalida).
Outfall Area	The area encompassing the Outfall System, pipeline laydown area, choke station, access track and parking and turnaround area.
Port Facilities Area	The area encompassing the proposed facilities located at the Port Area, including the concentrate filtration plant and materials handling, storage, ship loading facilities and filtrate discharge pipeline.
rugosity	An index of surface roughness that is widely used as a measure of landscape structural complexity in studies investigating spatially explicit ecological patterns and processes. As a measure of complexity, rugosity is used as an indicator of the amount of available habitat available for colonization by benthic organisms and shelter and foraging area for mobile organisms. High rugosity is often an indication of the presence of coral, which creates a complex surface as it grows. A rugose seafloor's tendency to generate turbulence is understood to promote the growth of coral and coralline algae by delivering nutrient-rich water after the organisms have depleted the nutrients from the envelope of water immediately surrounding their tissues.
study area	The area extending approximately 6 km southeast, 24 km south and 26 km southwest of the Outfall Area comprising 19 underwater benthic video deployment sites.

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1. Introduction

1.1. Background

Wafi Mining Limited and Newcrest PNG 2 Limited (WGJV Participants) are equal participants in the Wafi-Golpu Joint Venture (the WGJV). The WGJV is investigating the feasibility of constructing, operating and (ultimately) closing an underground copper-gold mine and associated ore processing, concentrate transport and handling, power generation, water and tailings management and related support facilities and services (hereafter the “Wafi-Golpu Project” or the “Project”), located beneath Mt Golpu, approximately 300 kilometres (km) north-northwest of Port Moresby and 65 km southwest of Lae in the Morobe Province of the Independent State of Papua New Guinea (PNG). The Project includes ore processing, concentrate transport and handling, power generation, water management, a deep sea tailings placement (DSTP) system for tailings management, access roads to the mine and related support facilities.

Geographically, the Project occupies a mine to port footprint that extends from the Mine Area to the Coastal Area with an Infrastructure Corridor that links the two areas. Together these discrete areas make up the proposed Project Area:

- **Mine Area**. The area encompassing the proposed block cave mine, underground access declines and nearby infrastructure, including a portal terrace and waste rock dump supporting each of the Watut and Nambonga declines, the Watut Process Plant, power generation facilities, laydown areas, water treatment facilities, quarries, wastewater discharge and raw water make-up pipelines, raw water dam, sediment control structures, roads and accommodation facilities for the construction and operations workforces.
- **Infrastructure Corridor**. The area encompassing the proposed Project infrastructure linking the Mine Area and the Coastal Area, being corridors for pipelines and roads and associated laydown areas. The proposed concentrate pipeline, terrestrial tailings pipeline and fuel pipeline will connect the Mine Area to the Coastal Area. A proposed Mine Access Road and Northern Access Road will connect the Mine Area to the Highlands Highway. New single-lane bridges are proposed over the Markham, Watut and Bavaga rivers. Laydown areas will be located at key staging areas.
- **Coastal Area**. The Coastal Area includes the proposed Port Facilities Area and the proposed Outfall Area:
  - Port Facilities Area. Located at, or in proximity to, the Port of Lae, with a site adjacent to Berth 6 (also known as Tanker Berth) nominated as the preferred option. The proposed facilities will include the concentrate filtration plant and materials handling, storage, ship loading facilities and filtrate discharge pipeline.
  - Outfall Area. Located approximately six kilometres east of the port. The proposed facilities will include the Outfall System comprising the mix/de-aeration tank and associated facilities, seawater intake pipelines and DSTP outfall pipelines, pipeline laydown area, choke station, access track and parking turnaround area.

The WGJV has commissioned a range of studies to inform the Project’s Feasibility Study Update and to prepare an Environmental Impact Statement (EIS).

This report describes the findings of the benthic video characterisation study. The study area for this report is the area extending approximately 6 km southeast, 24 km south and 26 km southwest of the Outfall Area comprising 19 underwater benthic video deployment sites.

Future development of the Project remains subject to ongoing deep orebody drilling and definition (after underground access has been achieved), technical studies, completion of statutory permitting processes and securing Government and WGJV Participants' approvals.

Engineering design and other studies, including environmental studies, are continuing and there is potential that aspects of the proposed Project design, layout and timetable may change.

1.2. Objectives

The objective of the study was to broadly characterise, via digital images, the deep-sea benthic environment in the vicinity of the proposed Outfall Area, in areas of potential tailing density current and at reference sites.

The study intended to cover the anticipated depth range of the main descending tailing density current to depths of approximately 1,800 m, and to identify and record the locations and features of the main seafloor assemblages, including observations of noteworthy benthos, where present. Image data were intended to visually assess bathymetric features identified in previous seafloor mapping studies, observe any evidence of benthic communities, describe habitat features, identify environmental sensitivities, and provide a visual baseline against which potential direct impacts may be compared.

The objectives of this study were also selected with general consideration given to the 'Draft Guidelines and Criteria for mining operations in Papua New Guinea (PNG) involving Deep-Sea Tailings Placement (DSTP)' developed by the Scottish Association for Marine Science (SAMS) Research Services Limited (SAMS, 2010a), primarily regarding the main ecological concerns identified regarding the use of DSTP to manage tailings, including the potential reduction in biodiversity and abundance of marine communities.

The characterisation study data contained herein will be used to inform the marine impact assessment component of the Feasibility Study Update and EIS.

1.3. Existing environment

1.3.1. Huon Gulf

Seismic and side-scan sonar data indicate that the Huon Gulf has a history of carbonate platform growth, drowning and back stepping, during subsidence induced by the subsidence of the Australian continental margin in response to the ongoing collision with the Bismarck arc and encroachment of the Finisterre Mountains (Galewsky et al., 1996). The 5.7 mm/yr subsidence rate in the Huon Gulf is the highest subsidence rate reported from a foredeep setting (Galewsky et al., 1996). Changes in sea level and tectonic activity in the Huon Gulf region has resulted in a number of uplifted and submerged fossil coral reefs. Comparisons of the measured age of aragonitic shallow-water corals with sea-level history (derived from the oxygen isotope record) suggest that ancient reefs may have formed during sea-level lowstands and drowned during rapid rates of sea-level rise (Galewsky et al., 1996). The region exhibits a high degree of tectonic activity, and benthic environments are considered to have been substantially influenced by numerous seismic events (IHA Consult, 2012).

The southern slopes of the Finisterre Range meet the shoreline of the Huon Gulf east of Lae, where offshore slopes lead steeply to the Markham Canyon. To the immediate south of Lae, the inshore region of the Huon Gulf is less steep than the region to the east, however various gullies and valleys punctuate the region and trend eastward. South of this zone the inshore region is characterised by a relatively flat area of submerged platforms and pinnacles while, further south still, well defined canyons with steep bounding walls connect to the Markham Trench in the northeast (IHA Consult, 2012).

The Markham Canyon extends from the mouth of the Markham River immediately to the west of Lae into a broadening submarine canyon trending to the southeast, and serves as the dominant longitudinal sediment transportation conduit for terrestrial sources to the oceanic sink (Hsiung and Yu, 2013). Figure 1.1 shows the bathymetry of the Markham Canyon. The head of the canyon lies in approximately 30 m water depth, and reaches depths of 500 m within 4 km of the shore (Renagi et al., 2010). The canyon trends northwest-southeast, is approximately 235 km long, and can be separated into three reaches (Hsiung and Yu, 2013). The first morphological break occurs at a depth of 2,300 m where the Francisco Canyon joins the Markham Canyon. The second morphological break occurs at a depth of 4,000 m due to an embayment related to the southern tributary canyon, while the third break corresponds to the intersection with the New Britain Trench at a depth of 6,500 m, approximately 180 km southeast of Lae (Davies et al., 1987).

The Markham River largely aligns with the Markham Canyon and discharges directly into the canyon head only 4 km from the shore (Renagi et al., 2010). The canyon is characterised by dendritic drainage patterns, lateral sediment supply via tributary canyons and longitudinal transport in the axial canyon (Hsiung and Yu, 2013). Erosive sediment flows initiated from the mouth of the Markham River erode the canyon floor and drain sediments down-canyon, resulting in a longitudinal profile with a slope of approximately 6 degrees (°) for the initial 2 km of the canyon, reducing to an approximately 3° slope until a depth of about 1,700 m some 35 km from the river mouth (Galewsky and Silver 1997; Hsiung and Yu, 2013; IHA Consult, 2018).

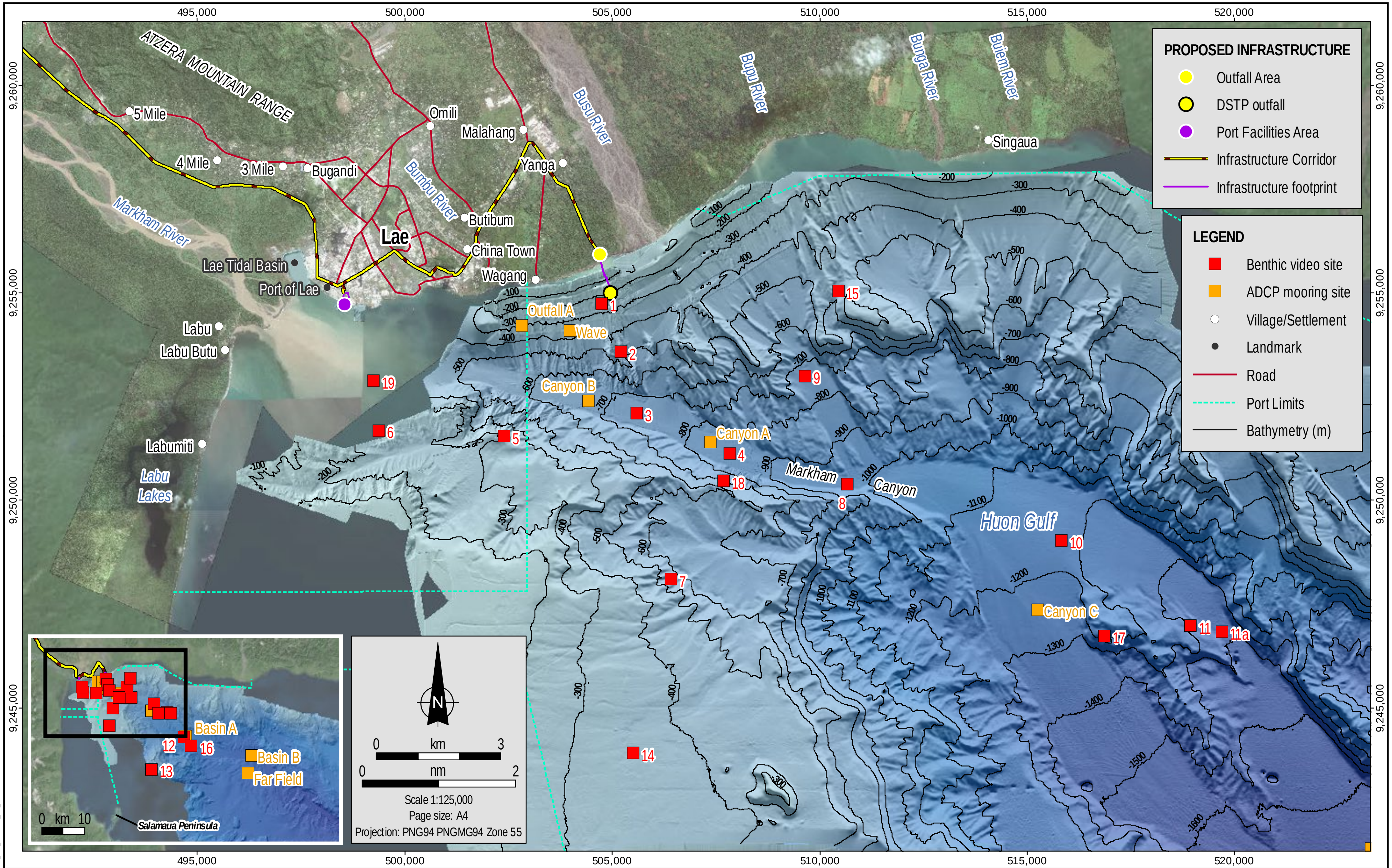
An early study reports that repeated submarine disturbances caused by slumping of mud deposits from the Markham River have been noted by residents in and near Lae, with resulting slump topography evident on some early echograms (Von der Borch, 1972). These records indicated a highly irregular bottom topography that is considered to contrast with the typically smooth contours expected in a depositional area.

The flow of the Markham River enters the sea, first passing through a sequence of standing waves at its shallow mouth. The plume lifts off the bottom to form a stable plume within a few hundred meters of the mouth. The highly visible turbid plume detaches from the coastline during periods of northwest wind to form a thin band of clear ocean water close to the coast. Satellite images of the plumes indicate that these do not generally form shore attached plumes that move along the shoreline. Comparison of Coriolis forces to accelerations due to wind stress from light winds indicate that the Coriolis effect is not a dominant forcing in this region due to proximity to the equator (Renagi et al., 2013).

The terrestrial sediment load into the Huon Gulf is described by IHA Consult (2012), PNG Ports Corporation Limited (2007), Renagi (2009), Renagi et al. (2010), and others. Fine clay to fine sand is transported as suspended load, while sands and gravels are transported as bed load and debris (including rocks) flows down the steep canyon walls. The bed load is then transported along the steep slopes into the head of the Markham Canyon and down the steep canyon walls, while fine silts remain in suspension in the freshwater and spread out on top of the saline waters. Quantitative estimates of sediment loads entering the Huon Gulf from the Markham and Busu rivers are the subject of a separate study.

Three separate sediment transport regimes for sediment delivered to the Huon Gulf are described. These are the: (a) spreading of buoyant freshwater surface plumes; (b) advection of sub-surface plumes along isopycnal[1] surfaces at intermediate water depths; and (c) downslope transport of

[1] Isopycnal surfaces are surfaces of constant density, often displayed graphically to visualise 'layers' of water in the ocean.



Source:
Benthic video and mooring sites, roads and Port Limits from Coffey (Port Limits indicative only).
Villages/Settlements, landmarks and infrastructure from WGJV and Coffey.
Bathymetry from WGJV survey.
Imagery from WGJV (capture date 2016) and ArcGIS Online (capture date unknown).

coffey A TETRA TECH COMPANY

Date: 26.03.2018
Project: 754-ENAUABTF100520DD
File Name: 0520DD_12_F01.01_GIS

WAFI-GOLPU JOINT VENTURE

Wafi-Golpu Project

Benthic video study sites

Figure No: 1.1

MXD Reference: 0520CC_BR_GIS001_v0_7

sediment along the seafloor as hyperpycnal[2] flow (Renagi et al., 2010). The substantial terrestrial sediment input from numerous rivers, primarily the Markham and Busu rivers, is recognised as likely to have had a considerable historical and ongoing influence on the benthic marine environment within the study area (PNG Ports Corporation, 2007; Haywood et al., 2012; WorleyParsons, 2016).

1.3.2. Deep sea fauna

Deep-sea benthic communities generally comprise fauna that live on (epifauna) or in (infauna) the seafloor. Due to the lack of light, photosynthetic flora is absent beyond the photic zone. Benthic organisms are important components of carbon and trophic cycles (Rowe, 1998), as they feed on detritus that settles onto the seafloor, and in turn are consumed by other fauna. Benthic fauna perpetuate a process whereby organic material that would otherwise be lost from ocean food webs is returned to demersal fish populations and other communities (IHA Consult, 2012).

There is no published data on the deep benthic communities of the Huon Gulf. The Biopapua Cruise (Pante et al., 2012) reported benthic sites in the Huon Gulf with sunken wood, and organic-associated fauna. However, the detailed taxonomic results are yet to be published. Canyons which transport terrigenous sediment and organic matter into the deep sea typically have elevated densities of benthic animals (Alongi, 1992). Although such sediments have a high organic content, usually such material has high lignum content and provides low nutritional value for benthic animals (SAMS, 2010b). Based on the evidence provided in these surveys, the seafloor of the Markham Canyon can be characterised as a mobile substrate in which benthic communities are likely to be transient, impoverished or patchy due to the high rates of sediment deposition and intermittent downslope sediment transportation. These predictions match with observations made by Dr J. Moverley on unpublished benthic data collected from habitats similar to the Markham Trench, whereby densities of macrofauna and meiofauna were highly variable and maximum densities were greater than those from non-trench sites (cited in IHA Consult, 2012). Research carried out by SAMS (2010b) on benthic communities of the Rai Coast, Madang Province on the northern side of the Finisterre Range and the Huon Gulf considers that canyons in that region are likely to comprise a relatively low benthic standing stock, with communities dominated by a small number of opportunistic taxa which are readily able to recolonise following disturbances.

The high sediment load transported seaward by the Markham River results in a harsh environment for benthic macroinvertebrates and an overall impoverished species assemblage (PNG Ports Corporation 2007; Haywood et al., 2012).

[2] A hyperpycnal flow is produced when the density of the river water entering the basin is greater than the density of the standing water in the ocean basin.

2. Methods

2.1. Study team

The personnel who participated in the 28 November to 1 December 2016 field trip were:

- Travis Wood (Coffey Senior Environmental Consultant).
- Ivan Steward (Coffey Senior Environmental Consultant).
- Ian Helmond (technical support and winch operation).

Logistics assistance was also provided by crew of the Collins Shipping vessel ‘MV Surveyor’ (Plate 2.1) which was chartered for the study.

2.2. Study area and site selection

The study area, including each of the underwater video sites, is shown in Figure 1.1. In total, 19 sites were selected for the underwater video deployments and these are described further in Table 2.1.

Since the expected DSTP tailing density current and deposition areas will be in the Markham Canyon, the sites for benthic video investigations were largely selected to cover these areas, at least to the 1,750 m depth rating of the camera batteries and lighting. The site selection process included collaboration with WGJV and IHA Consult supported by multi-beam echosounder data. Site selection focused on bathymetric features including canyon slopes, canyon floor, basin floor and elevated terrain in the centre of the canyon, while avoiding the risk of entanglement with oceanographic monitoring moorings deployed for the Wafi-Golpu Project in the study area. The study also characterised reference locations outside of the Markham Canyon, including sites near Labu and further south toward Salamaua.

Sites were selected to characterise different types of seafloor features at depths ranging from 220 m to almost 1,800 m. A qualitative description was made of the features observed in videos and photographs, and all gathered image data subsequently stored as a means of visual characterisation and record keeping. The sites chosen for investigation focused on:

- Areas of potential DSTP influence (i.e., potential areas of tailing flowpath and deposition).
- Likely flowpath of natural sediments toward the Markham Canyon.
- Noteworthy features identified from bathymetric data.
- Reference areas beyond the immediate zone of riverine sedimentation and potential DSTP impacts.

Table 2.1: Benthic survey locations

Site	Easting (mE)[a]	Northing (mN)[a]	Depth (m)	Site description	Seafloor visibility [b]
1	504740	9254739	229	In the vicinity of the indicative DSTP outfall pipelines, approximately 1 km from shore.	Yes
2	505194	9253584	440	In the vicinity of the indicative DSTP outfall pipelines, further downslope, approximately 2 km from shore.	Yes
3	505582	9252093	713	On the Markham Canyon floor about 3 km from the proposed Outfall Area.	No
4	507818	9251139	850	On the Markham Canyon floor proximal to the December 2016 canyon Acoustic Doppler Current Profiler (ADCP) mooring location.	No
5	502389	9251550	261	Reference location approximately 1 km south of the Markham Canyon.	Yes
6	499367	9251682	245	Reference location on flat seafloor adjacent to Labu Miti.	No
7	506401	9248100	560	Reference location approximately 2 km south of the Markham Canyon.	Yes
8	510668	9250391	978	On the Markham Canyon floor at the mouth of the v-shaped depositional area.	No
9	509650	9252994	745	Reference location on the canyon slope east of the Busu River mouth, approximately 2 km north of the Markham Canyon.	Poor
10	515834	9249034	1,167	On the Markham Canyon floor within the large v-shaped depositional area.	Poor
11	518949	9246976	1,338	On the seafloor adjacent to the elevated terrain feature in the middle of the Markham Canyon depositional area.	Poor
11a	519694	9246830	1,338	On the seafloor adjacent to the elevated terrain feature in the middle of the Markham Canyon depositional area. MV Surveyor drifted significantly between the first and second deployment, due to winch motor requiring cooling.	No
12	522767	9241281	1,650	In the Markham Canyon basin proximal to the basin ADCP mooring.	No
13	515255	9233853	757	Reference location approximately 8 km south of the Markham Canyon.	Yes
14	505497	9243906	356	Reference location on relatively flat seafloor approximately 8 km south of the Markham Canyon.	Yes
15	510443	9255044	450	On the canyon slope east of the Busu River mouth, approximately 5 km north of the Markham Canyon.	Yes
16	524488	9239305	1,797	In the Markham Canyon basin.	Poor
17	516858	9246734	1,176	On the elevated terrain in the middle of the Markham Canyon fan.	Yes
18	507680	9250474	650	Steep canyon slope section proximal to the Markham Canyon ADCP mooring.	Yes
19	499239	9252879	320	In the Markham River plume near the head of the Markham Canyon.	No

a Coordinates given in PNG94 PNGMG94 Zone 55.
b Categories of visibility are: ‘Yes’ (can clearly see the seafloor); ‘Poor’ (can partially see the seafloor for limited time periods, although visibility is restricted due to high turbidity); and ‘None’ (cannot see the seafloor at all due to turbidity).

2.3. Design of underwater imaging system

The underwater imaging system (UIS, Plate 2.2) comprised:

- Two 'GoPro Hero 4' cameras enclosed in fit-for-purpose 'Benthic 2' deep-sea housings, rated to a depth of 2,600 m.
- Two 'Nautilux Custom' extreme depth flashlights rated to a depth of 1,750 m, providing up to 3,500 lumens of neutral white light using two high output Cree light-emitting diodes.

This equipment was attached to a frame constructed from 316 marine grade stainless steel, including 40-mm-diameter round bar and 5-mm-wide side plates. Acetal plastic fittings were used to support the flashlights. The cameras and lights were mounted using adjustable hinges to regulate their horizontal perspective, in order to maintain the optimal angle for lighting and video capture of benthic features. Positioning of the camera provided a field of view of approximately 1.5 m wide and 3 m deep, depending on water clarity. Direct communication with the manufacturer (Group B Inc.) of the depth-rated components indicated that depth ratings were conservative, and submersing the equipment to depths not significantly greater than 1,750 m was not likely to pose a risk of damage.

The UIS was attached to the winch cable with a four-leg bridle using wire rope (Plate 2.3). This ensured a stable orientation of the UIS in the water and a higher degree of security when attached to the winch, to prevent equipment loss at depth.

A general purpose housing (rated to 1,750 m containing additional batteries that connected to the cameras) was incorporated into the UIS. This supplied the cameras with sufficient power to function for the entire deployment at deeper sites (typically beyond depths of 1,000 m). The UIS was also fitted with an altimeter (Plate 2.4) to relay depth readings for observation aboard the vessel.

2.4. Operation of underwater imaging system

At each site the UIS was prepared for deployment on the deck of MV Surveyor following vessel stoppage to identify direction of drift. Preparation included checking winch connection for integrity, fitting batteries into lights and cameras, and inserting cameras into the housing. The idle period helped to determine the vessel's orientation and likely effect of drift in relation to deployment and positioning of the UIS.

Following activation of the lights and cameras, the UIS was lowered to the seafloor via winch at speeds of approximately 1 m/s to 2 m/s. The study team then monitored the altimeter readings (depth below surface level and distance to the seafloor) from the wheelhouse. Within approximately 50 m of the seafloor, the team would notify the winch operator via radio to decelerate the winch deployment, and communicate depth readings to the winch operator at approximately 5 m intervals. At approximately 2 m before the UIS reached the seafloor a directive would be issued to pause the descent for several seconds. This was intended to stabilise the UIS and maximise the capture of benthic imagery (if not too turbid), prior to the inevitable disturbance of sediments caused by contact with the seafloor. The unit was then lowered very slowly to the seafloor and the winch operator notified when maximum depth was reached.

The UIS remained stationary on the seafloor for approximately 20 to 30 seconds to capture video footage, and was then elevated 20 m to 50 m prior to a second or third deployment to the seafloor being completed. Additional deployments were conducted to increase likelihood of obtaining video footage for visual assessment of benthic features, overcoming impediments such as unfavourable camera angle due to contact with strongly sloping seafloor, or poor visibility resulting from suspended sediments.

Photo credit: Coffey

Plate 2.1
MV Surveyor

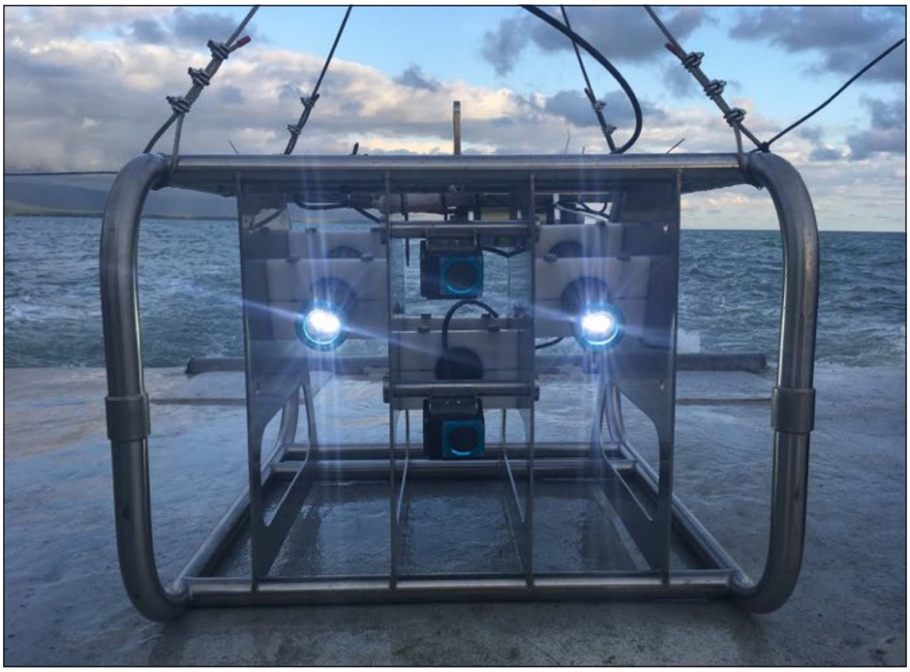


Photo credit: Coffey

Plate 2.2
Underwater Imaging System

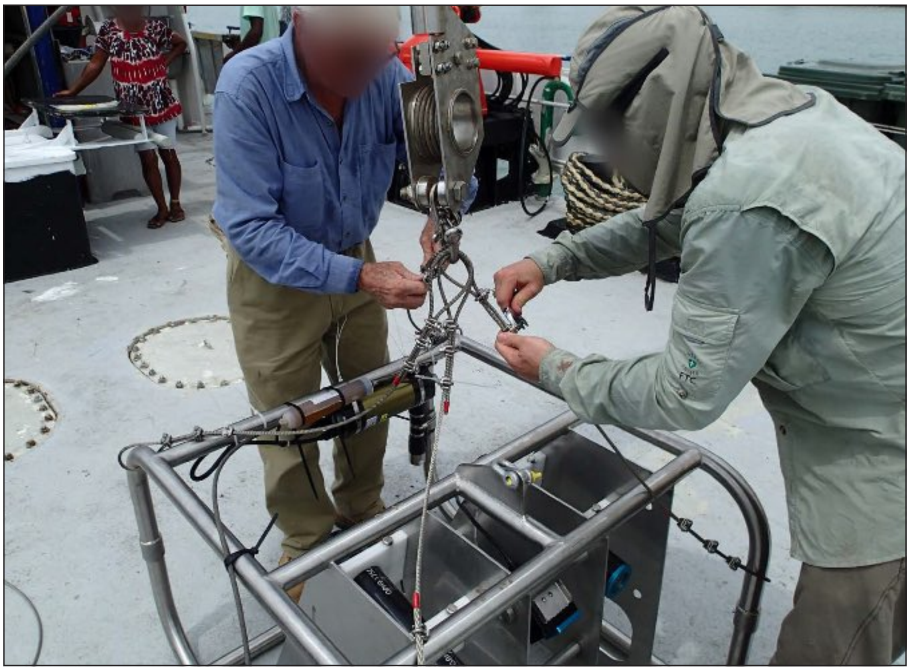


Photo credit: Coffey

Plate 2.3
UIS Bridle configuration

Following a sufficient recording interval, the UIS was winched onto the vessel and immediately rinsed with freshwater. The housings were dried and opened in order to stop recording, remove the cameras and switch off the lighting. The cameras were then connected to laptop computers in the wheelhouse and the video files transferred to electronic storage devices. The footage was reviewed by the team in situ for quality control and image verification purposes while underway to the next site. The thickness of turbidity plumes observed in videos was approximated by recording the number of seconds the UIS collected image data during ascent/descent in these settings, using an assumed rate of ascent/descent of 1 m^{-s} (the approximate speed of deployment). Site depth, GPS coordinates and time of deployment were recorded.

2.5. Baited remote underwater video (BRUV)

Surveys using baited remote underwater video systems (BRUVs) provide several major benefits over traditional capture-based methods, particularly since these are largely non-destructive and non-invasive, and because they inflict minimal damage to the benthic environment (Brooks et al., 2011). BRUVs can detect large, mobile animals that are generally averse to divers and active fishing surveys, and all animals attracted to the vicinity of the bait are potentially ‘captured’ independent of the effectiveness of the capture process (Brooks et al., 2011). BRUV surveys have become the standard approach for investigating larger-bodied, more cautious reef fishes, including sharks.

The BRUV sample technique was used at Site 6 (a relatively shallow location west of the Markham Canyon near where locals were observed to fish using handlines from outrigger canoes), Site 7 (south of the Markham Canyon and beyond the immediate area of influence of the Markham River plume), Site 8 (a narrow section within the Markham Canyon expected to be heavily influenced by the natural turbidity current), and Site 9 (northern wall of the Markham Canyon). The BRUVs involved mounting a pole to the UIS in line with the centre of the upper field of view of the cameras, and attaching a baited bag (including mackerel and trevally) to the end of the pole, approximately 80 cm from the front of the UIS (Plate 2.5). The BRUV method was intended to record image data of fauna attracted to the bait within the field of view of the camera (Plate 2.6). The longest BRUV deployment was at Site 6 where it was suspended in the water column for 15 minutes at depths of 75 m and 230 m to investigate the likelihood of pelagic fish in the area. These depths corresponded to 155 m and less than 5 m above the seafloor, respectively. After being suspended for 15 minutes the UIS was lowered to the seafloor. The implementation of the BRUV was an opportunistic addition to the main benthic focus of the study. However, associated time and resource constraints precluded extensive BRUV deployment, or its use at all sites.

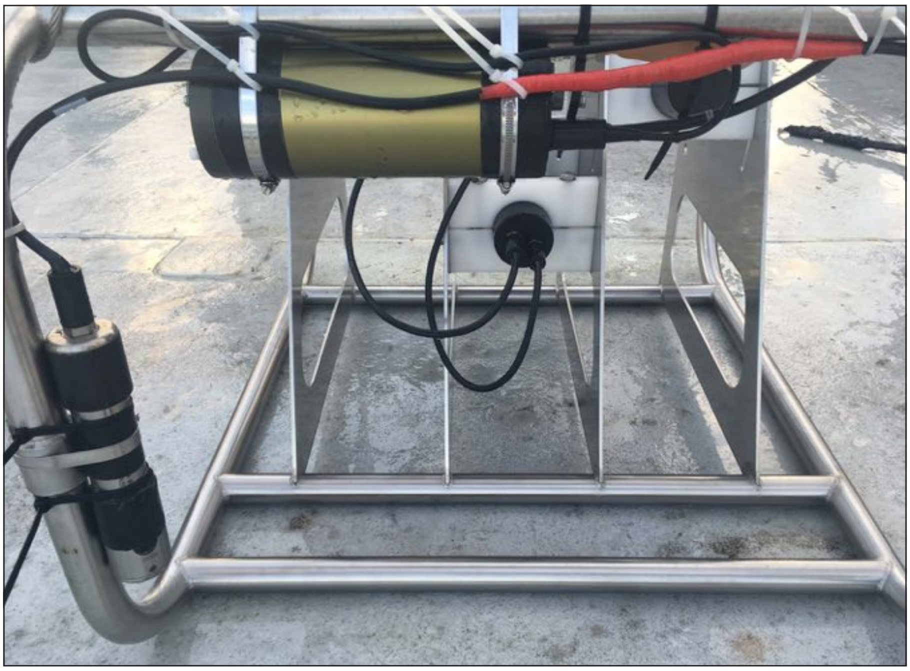


Photo credit: Coffey

Plate 2.4
Altimeter affixed to UIS (on the top and left bars)

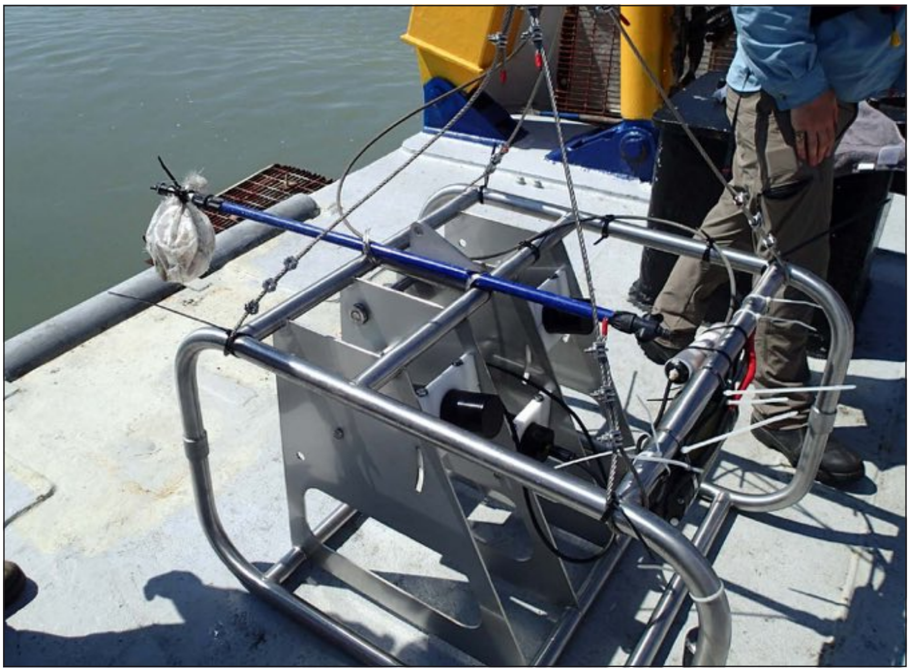


Photo credit: Coffey

Plate 2.5
Bait bag affixed to UIS during BRUV deployments

Photo credit: Coffey

Plate 2.6
Imagery at Site 7 (560 m depth) with baited bag visible. Note burrows in sediment.

3. Results

3.1. Image quality and performance of UIS

The maximum recorded survey depth was 1,797 m at Site 16, situated at the south-eastern end of Markham Canyon, and all equipment functioned adequately at this depth. A small amount of condensation was observed within the camera housings following deployments at the three deepest sites, and was likely due to the rapid change in temperature between the ocean surface and seafloor. This did not materially affect the quality of imagery captured.

Image quality was influenced heavily by the prevailing environmental conditions at each survey site. Typically, visibility was low on account of high turbidity due to the sediment entrained in the water column. Assessment of image data indicated distinct differences between footage captured in areas influenced by river plumes and those more distant from the mouths of rivers which were generally clear of heavy sedimentation. These differences were observed at varying depths both within and between sites, and provide a partial illustration of the stratification of subsurface plumes throughout the water column.

High sediment loads and low visibility were periodically encountered leading to a 'black out' where no useable imagery was captured. Accordingly, image quality could not be assessed in these situations, apart from the record of the period of time while passing through a sediment plume or density current.

To varying degrees the benthic environment was visible at locations outside of the Markham Canyon, and occasionally visible on the canyon slopes. Seafloor water clarity was highest at Sites 1, 5, 7, 13 to 15, 17 and 18. At Sites 2, 6, 9, 11 and 16 there was typically partial and generally very poor seafloor visibility. Sites within the Markham Canyon or in the path of sediment plumes from Markham River (Sites 3, 4, 8, 10 to 12, 16 and 19) were generally highly turbid and the seafloor could not be seen at most of these sites (refer to Table 2.1).

3.2. Visual assessment of benthic features

3.2.1. Benthic habitat features

Highly turbid sites within the Markham Canyon with corresponding low visibility (i.e., Sites 3, 4 (Plate 3.1), 8, 11,12 and 16 to 19) typically constrained the ability to make detailed visual benthic habitat assessments. However, at all sites where benthic features were at least partially observable as a result of sufficiently clear water at the seafloor (i.e., Site 17 on the Markham Canyon floor; Sites 1, 2, 5, 7, 9, 15 and 18 on the canyon slopes away from turbid sediment density currents and subsurface plumes; and Site 13 located several kilometres to the southwest of the Markham Canyon), it was evident that habitats were of very low physical and morphological complexity and displayed a high degree of homogeneity. These habitats were characterised by fine, silty, easily re-suspended sediments, occasionally accumulated in deposits of variable thickness (Plate 3.2). The seafloor was generally flat or gently sloping and lacked complex three-dimensional structure (all sites had very low rugosity[3]) for colonisation by benthos. Obvious slopes were observed at Site 2 (Plate A2 in Appendix A), Site 15 (Plate 3.3 and Plate A15 in Appendix A) and Site 18 (Plate A18 in Appendix A).

[3] Rugosity is an index of surface roughness that is widely used as a measure of landscape structural complexity in studies investigating spatially explicit ecological patterns and processes (Du Preez, 2015)


Photo credit: Coffey

Plate 3.1
Highly turbid water at Site 4 (850 m depth), typical of sites in the Markham Canyon

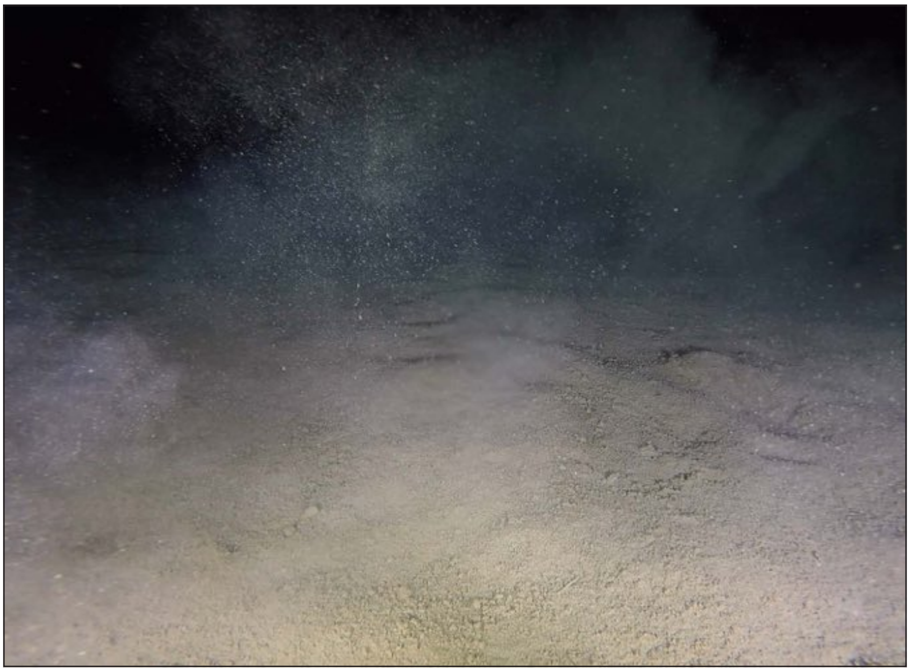


Photo credit: Coffey

Plate 3.2
Typical seafloor observed across study area


Photo credit: Coffey

Plate 3.3
Steep seafloor and unidentified fish at Site 15 (likely Family: Macrouridae, centre right of frame, depth 450 m)

Assessing slope and topography is problematic using static camera deployments at depth, however the perspective and tilt of the UIS was usually level. Complex morphological features, hydrothermal or deep-sea vents and deep-sea coral colonies were not observed. Rocks (apparently small boulders and cobbles), appearing to be of riverine origin, were seen at Site 1. The elongated region of higher relief in the Markham Canyon (Site 17, Figure 1.1) lacked outcropping rocks. Instead, video footage showed that the surface of these steeply sloping 'hills' in this area consists of fine-grained sediments similar to those observed at other sites. The height of this feature was more than 100 m above the surrounding seafloor, as indicated by depth contours from 1,300 m to 1,200 m at the centre of the Markham Canyon (Figure 1.1). However, it could not be readily determined whether this feature constitutes a mass of accumulated or slumped sediment deposits or an underlying rock structure that has trapped sediment and become smothered by subsequent accumulation. The seafloor here was observed to slump (with the top one metre or so of surface collapsing) as the weight of the UIS was lifted off the seafloor (Plate A17 in Appendix A).

There was marginal benthic visibility at Sites 16 (Plate 3.4) and 17 (Plate A17 in Appendix A). However video footage still indicated that the substrate was comprised of fine, light-coloured, highly uniform materials similar to those encountered at other sites. This material was readily re-suspended by currents and by disturbance resulting from contact of the UIS with the seafloor. Some coagulation flocculation of the material (low density flocs of several centimetres in diameter) was also observed once the material was suspended. On one occasion at Site 18, some sediment remained attached to the UIS upon retrieval (Plate 3.5). This sediment was a thick dark brown / grey mud that appeared to differ from the fine material observed in situ and contained a brittle star (ophiuroid).

Selected images from each site are shown in Appendix A.

3.2.2. Benthic fauna

At all sites, a layer of sediment was present as the only existing medium available on the seafloor for colonisation by epi-benthic fauna. No rock, rubble, aggregate reef or other hardstand surface features were readily observed to be habitat available for colonisation. Visible observations of macrobenthos were very sparse. The presence of benthic infauna was visually discernible via evidence comprising mounds, burrows, and faecal casts (see Plate 2.6 and Plate 3.6) at most sites with adequate seafloor visibility. Unidentified species of shrimp (Plate 3.7), sea whips (Plate 3.8), ophiuroids and other unidentified fauna (Plate 3.9) were observed in very low numbers (typically solitary) at sites 7 and 13 to 16. Occasional opportunistic sightings of other fauna that could not be identified also occurred at sites where useable image data was collected.

Diverse or abundant benthic faunal communities were not observed at any sites between 220 m and approximately 1,800 m water depth. Table 3.1 provides a summary of fauna and habitat observations made at or near (within one to two metres) the seafloor at each site. Table 3.1 also shows the total amount of time the seafloor was visible at each site, and the number of benthic or demersal fauna observations made during that time, i.e., at Sites 1, 5, 7, 13, 14, 15, 17, and 18 where water clarity was sufficient to make an assessment. A total of about 522 seconds (eight minutes and 48 seconds) of sufficiently clear benthic habitat footage was captured, yielding 22 individual faunal observations (mainly comprising fish and shrimp). Almost half of these observations occurred at Site 13. Utilising the BRUV method did not appear to attract any fauna, and captured no footage of any fish or other species.

Plate 3.4
Re-suspended sediment and very low visibility at Site 16 (1,797 m depth)

Photo credit: Coffey

Plate 3.5
Thick brown/grey muddy clay material taken from UIS following deployment at Site 18 (313 m depth)

Photo credit: Coffey

Plate 3.6
Burrows, tracks and mounds (bioturbation) in substrate at Site 13 (757 m depth)

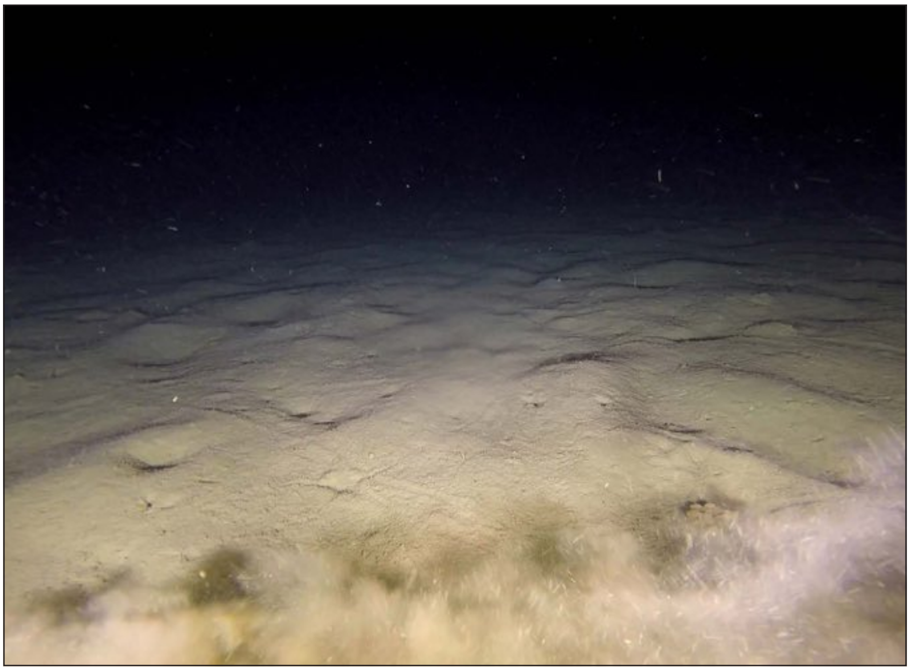


Photo credit: Coffey

Photo credit: Coffey

Plate 3.7
Two unidentified shrimp (low centre left of frame) at Site 13 (757 m depth)

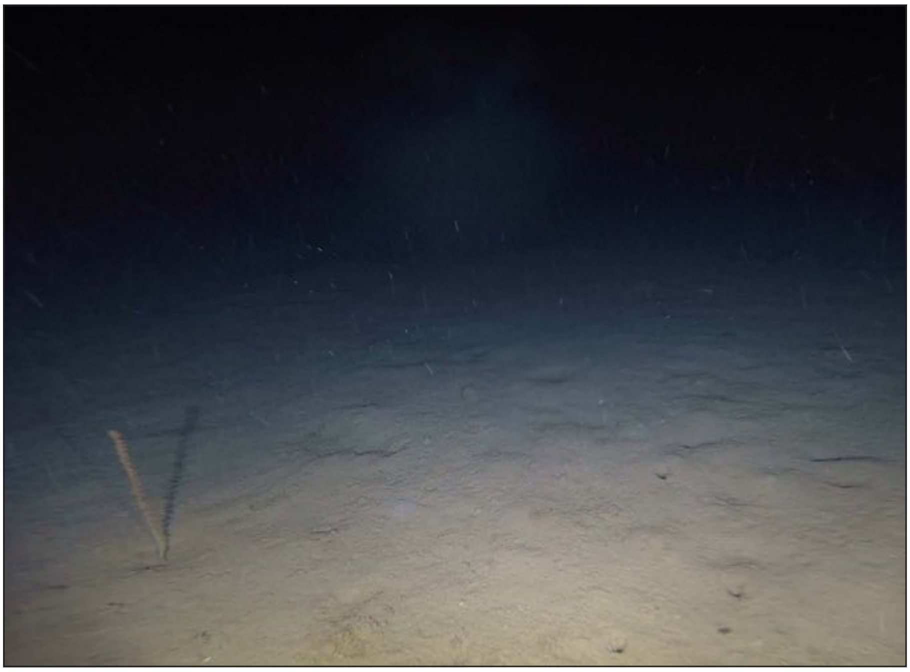


Photo credit: Coffey

Plate 3.8
Sea whip (lower left of frame) at Site 13 (depth 757 m). Note mounds and burrows in sediment.

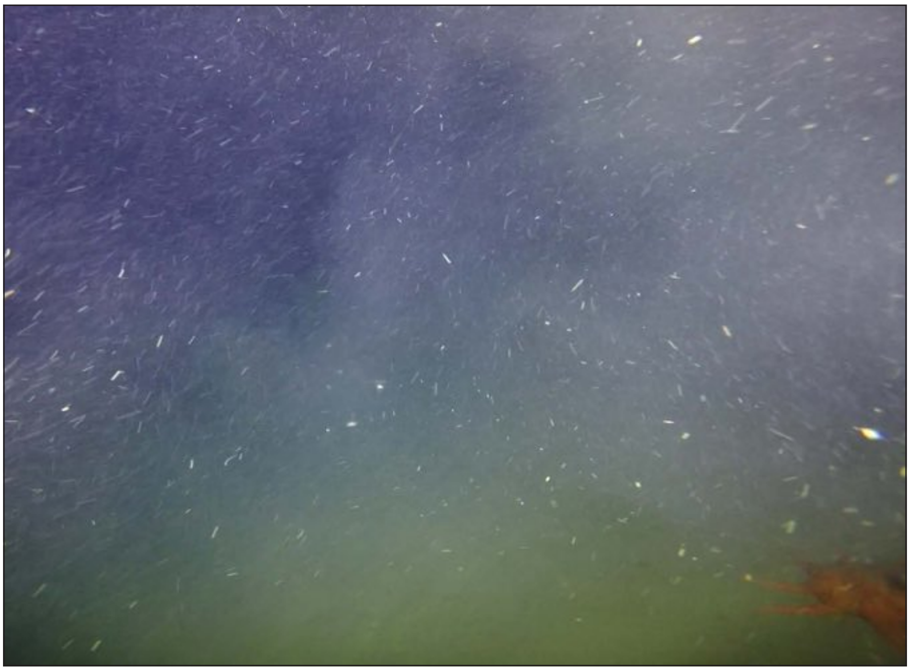


Photo credit: Coffey

Plate 3.9
Unidentified fauna (Site 7, lower right of frame, depth 560 m)

Table 3.1: Summary of fauna and habitat observations at each site

Site	Fauna observed	Indirect evidence of fauna observed (i.e. mounds, burrows, casts)	Habitat type(s) observed	Total duration of footage where seafloor is sufficiently visible and number of fauna observations
1	1x unidentified organism	None	Fine seafloor sediments. Large cobbles / small boulders	32 seconds 1 observation
2	Inadequate visibility	Inadequate visibility	Fine seafloor sediments	Nil
3	Inadequate visibility	Inadequate visibility	Inadequate visibility	Nil
4	Inadequate visibility	Inadequate visibility	Inadequate visibility	Nil
5	Yes – 1x shrimp	Burrows	Fine seafloor sediments	12 seconds 1 observation
6	Inadequate visibility	Inadequate visibility	Inadequate visibility	Nil
7	Yes – 1x shrimp, 1x unidentified organism, 1x fish	Burrows, mounds and tracks.	Fine seafloor sediments	119 seconds 3 observations
8	Inadequate visibility	Inadequate visibility	Inadequate visibility	Nil
9	Inadequate visibility	Inadequate visibility	Fine seafloor sediments	Nil
10	Inadequate visibility	Inadequate visibility	Inadequate visibility	Nil
11	Inadequate visibility	Inadequate visibility	Fine seafloor sediments	Nil
12	Inadequate visibility	Inadequate visibility	Inadequate visibility	Nil
13	Yes – 4x shrimp and 2x shrimp (different, unidentified species), 1x whip coral, 2x fish (likely to be same species) 1x unidentified organism.	Burrows, mounds, tracks and casts.	Fine seafloor sediments. Sparse terrestrial vegetation fragments	226 seconds 10 observations
14	Yes – 2x shrimp, (different species)	Burrows, mounds, tracks and casts.	Fine seafloor sediments. Sparse terrestrial vegetation fragments.	82 seconds 2 observations
15	Yes – 2x fish (solitary, different species)	Burrows, mounds, tracks and casts.	Fine seafloor sediments. Terrestrial vegetation fragments	44 seconds 2 observations
16	Inadequate visibility	Inadequate visibility	Fine seafloor sediments	Nil

Site	Fauna observed	Indirect evidence of fauna observed (i.e. mounds, burrows, casts)	Habitat type(s) observed	Total duration of footage where seafloor is sufficiently visible and number of fauna observations
17	None	Inadequate visibility	Fine seafloor sediments	17 seconds No observations
18	Yes – 2x Ophiuroids 1x fish	Burrows, mounds, tracks and casts.	Fine seafloor sediments	9 seconds 3 observations
19	Inadequate visibility	Inadequate visibility	Inadequate visibility	Nil

Note: 'Inadequate visibility' does not necessarily mean the seafloor could not be seen but that visibility was not sufficient to allow adequate assessment of the presence or evidence of fauna and habitat.

3.3. Visual assessment of water column

Although not the primary objective of this study, this section summarises opportunistic observations made from the UIS footage as the unit descended/ascended through the water column.

Subsurface sediment plumes could be identified as the UIS transitioned through the water column, as indicated by the attenuation of visible light (from the UIS) due to adsorption by suspended particulate materials and chromophoric dissolved organic matter (i.e., organics that absorb light of certain wavelengths, Markager and Vincent, 2000). A distinct brown / grey coloration (see Plate 3.1) was primarily observed at various depths at sites in the path of the Markham River plume and within the Markham Canyon (including Sites 3, 4, 8, 10, 11, 12 and 19). No clear pattern was evident with regard to the overall size of sediment plumes observed during the study.

The thickness of turbidity plumes was approximated by recording the number of seconds the UIS collected image data during ascent/descent in these settings, using an assumed rate of ascent/descent of one metre per second (which was typically the approximate speed of deployment).

The thickness of the plumes was variable (typically between about 50 m and 300 m), and while some areas of reduced water clarity were encountered at various depths in the mid-water column and at the ocean surface, most sediment plumes and the lowest water clarity were observed at and near the seafloor. At sites within the Markham Canyon (i.e., sites 3, 4, 8, 10, 12, 16, 17 and 19) the sediment plumes appeared to be constantly moving in one direction (i.e., down-slope) suggesting these are bottom-attached density currents.

At Site 8, a plume exceeding 400 m in the lower mid-water column (observed from about 500 m depth and extending to the seafloor at 978 m depth) was recorded during the UIS descent through the water column, where some ten minutes of imagery showed dense, billowing, brown plume material. An extensive portion of the deep-water column at Site 16 was also observed to be turbid. Water clarity at this site transitioned progressively from high to low between approximately 1,100 m depth until the seafloor at almost 1,800 m depth, where there was almost no visibility. Plate A21 in Appendix A shows a water column profile (at Site 19) from the surface to about 500 m depth, with alternating strata of turbid and clearer water.

A summary of the characteristics of turbid plumes and water clarity observed while the UIS transitioned from the ocean surface to the seafloor is provided in Table 3.2.

Table 3.2: Visual summary of turbidity plumes and water clarity at each site

Site	Site Depth	Plume location (surface, mid-water, bottom-attached)	Approximate plume thickness / depth	Notes
1	229	Surface	Present from 0 to 40 m (approximately 40 m thick)	Water clarity improved following passage of UIS through surface plume. Visible particulate matter and small (mainly gelatinous) planktonic organisms present in water column outside of turbid plume.
2	440	Surface	Present from 10 to 130 m (approximately 120 m thick)	Water clarity improved following passage of UIS through surface plume. Visible particulate matter and small planktonic organisms present in water column outside of turbid plume. Occasional brief observations of zones of reduced water clarity.
3	713	Surface Bottom-attached	Present from 0 to 20 m (approximately 20 m thick) Present from 430 m to seafloor (approximately 283 m thick)	Water clarity improved following passage of UIS through surface plume. Visible particulate matter and small planktonic organisms present in water column outside of turbid plumes. Occasional brief observations of zones of reduced water clarity. Progressively lower water clarity as UIS descended into very thick bottom attached plume of concentrated sediment. Zero visibility at and near seafloor.
4	850	Surface Bottom-attached	Present from 0 to 10 m (approximately 10 m thick) Present from 650 m to seafloor (approximately 200 m thick)	Plume at surface was small and of relatively low turbidity. Water clarity generally high through mid-water column. Occasional brief observations of zones of reduced water clarity. Progressively lower water clarity as UIS descended into very thick bottom attached plume of concentrated sediment. Zero visibility at and near seafloor.
5	261	Surface	Present from 0 to 15 m (approximately 15 m thick)	Readily observable presence of particulate matter and occasional small/planktonic organisms present in water column outside of thin turbid surface plume. No obvious bottom-attached plume.
6	245	Bottom-attached	Present from 200 m to seafloor (approximately 45 m thick)	Readily observable particulate matter and occasional small planktonic organisms present in water column. Near bottom visibility was very low, though slightly higher than at locations such as Sites 3 and 4.
7	560	No plume observed	N/A	Very thin layer of turbidity and low water clarity at surface, though no obvious plume. High water clarity through most of UIS descent through upper water column. Occasional brief observations of zones of reduced water clarity with depth. No bottom-attached plume.

Site	Site Depth	Plume location (surface, mid-water, bottom-attached)	Approximate plume thickness / depth	Notes
8	978	Bottom-attached	Present from 500 m to seafloor (approximately 480 m thick)	High water clarity through most of UIS descent through upper water column. Conspicuous presence of zooplankton in shallower waters. Occasional observations of brief zones of reduced water clarity. Very thick turbidity plume observed from midwater column until seafloor. Zero visibility at and near seafloor.
9	745	Surface	Present from 0 to 10 m (approximately 10 m thick	Readily observable zooplankton in shallower waters. Visibility near and at seafloor was very low, though no obvious plume is apparent.
10	1,167	Bottom-attached	Present from 1,000 m to seafloor (approximately 170 m thick)	High water clarity through most of UIS descent through upper water column. Readily observable zooplankton in shallower waters. Occasional observations of brief zones of reduced water clarity at depth prior to observation of bottom-attached plume.
11	1,338	Bottom-attached	Present from 950 m to seafloor (approximately 390 m thick)	High water clarity through most of UIS descent through upper water column. Readily observable zooplankton in shallower waters. Gradual decrease in water clarity as proximity to bottom-attached plume increases. Zero visibility at and near seafloor
12	1,650	Bottom-attached	Present from 1,300 m to seafloor (approximately 350 m thick)	High water clarity through most of UIS descent through water column. Readily observable zooplankton in shallower waters, and less suspended material observed throughout water column than other sites such as Sites 1, 2 and 3, until closer to the seafloor and the bottom-attached plume where clarity decreases. Zero visibility at and near seafloor.
13	757	No plume observed	N/A	Relatively high water clarity at all depths. Readily observable zooplankton in shallower waters, and less suspended material observed throughout water column than most sites.
14	356	No plume observed	N/A	Relatively high water clarity at all depths. Readily observable zooplankton in shallower waters, and less suspended material observed throughout water column than most sites.
15	450	No plume observed	N/A	Moderate to high water clarity at all depths. Visible particulate matter and small gelatinous planktonic organisms present in water column at all depths. Occasional brief observations of zones of reduced water clarity to 240 m, then deteriorated to zero prior to reaching the seafloor and the bottom-attached, billowing turbidity plume. Sediment / turbidity plume essentially affects entire water column.

Small planktonic fauna were observed at most sites where water clarity was not appreciably affected by suspended sediments, i.e., where brown coloration was not apparent. Much of this planktonic fauna displayed bioluminescence (appearing as streaks of light in Plate 3.10), characteristic of bathypelagic and mesopelagic organisms observed in the water column below the photic zone. Ctenophores (comb jellies), medusae, salps (planktonic tunicates), and chaetognaths (arrow worms) are expected to have been present throughout the water column. However detailed characterisation of this fauna could not be completed via rapid visual assessment, and are the subject of separate investigations.

Shrimp and other fauna were occasionally observed near the seafloor at sites west and south of the Markham Canyon, including Sites 7, 13 and 14 (Plate 3.11), but could not be identified due to insufficient video imagery resolution and suboptimal perspective. While the image data is unclear and an accurate species identification could not be made, at Sites 15 and 18 the presence of a grenadier fish or rattail of the family: Macrouridae appears likely (see Plate 3.3). Similarly, while accurate identification was not possible, solitary dwarf gulper sharks (possibly *Centrophorus atromarginatus*) appear present at Sites 7 and 15 in imagery captured just prior to UIS contact with the seafloor.

No schooling pelagic fishes (e.g., tuna, wahoo), sea turtles or marine mammals (e.g., cetaceans) were observed in any of the videos recorded during the study.

Plate 3.10
Bioluminescent 'sparks', common in the mid-water column at a number of sites

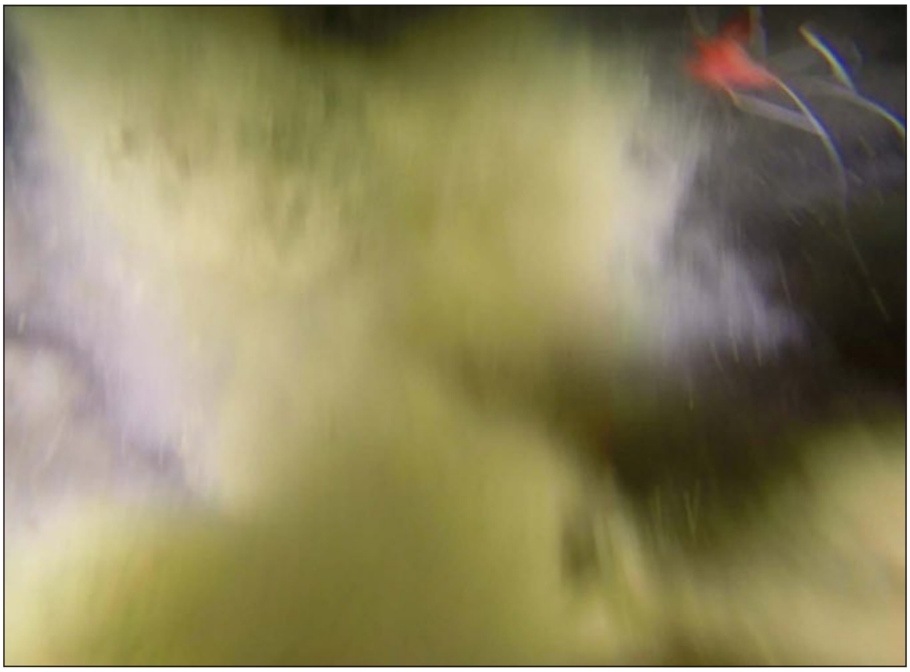


Plate 3.11
Unidentified fauna and resuspended sediment following seafloor disturbance (Site 13, depth 757 m)

4. Discussion

4.1. Benthic habitats and fauna

The sites investigated during the study represent a series of discrete locations that provide a ‘snapshot’ and visual confirmation of the benthic features present across a range of depths in the Huon Gulf.

The main reason for the BRUVs not attracting any fish was likely due to the short period of time that the system could be left at any one site during the study. Previous research in temperate regions has found that more than 36 minutes is required to obtain measures of the majority of fish species, and that 60 minutes is advisable to include targeted fish species (Watson et al., 2005). Given the short duration of time spent using the BRUV, and the lack of complex habitat features and associated fauna encountered during the study, (such as those observed around seamounts, deep-sea coral reefs, and other heterogeneous benthic environments characterised by high species richness, diversity and abundance), this result was largely expected. It is also a finding that is consistent with the scarcity and low diversity of deep slope fish fauna, that was observed during the deep-slope and pelagic fishing study (Coffey, 2018).

Benthic habitats visually assessed in the study area displayed a high degree of uniformity and were characterised by fine, largely homogenous sediments that were easily disturbed and resuspended; these sediments were present at all sites and are expected to be mainly terrigenous in origin (Renagi et al., 2010; Haywood et al., 2012; IHA Consult, 2012). Although these sediments appeared to be primarily fine grained, large aggregates several centimetres in size were commonly seen when the sediments were disturbed and resuspended.

Benthos was visibly scarce and generally comprised infauna communities, as evidenced primarily by mounds and burrows and small-scale biogenic relief. Occasional observations of solitary fish on or just above the seafloor, and shrimp, constituted the main fauna observations, when visibility near the seafloor was sufficient. During the entire survey, where footage of the seafloor was sufficiently clear (a total of approximately 522 seconds), 22 individual observations of benthic and demersal fauna were made. This equates to 2.53 sightings per minute of footage. Ten of the sightings were at Site 13, which is well removed from the Markham Canyon (some 10 km to the south); however, this site also had the longest duration of footage with visible seafloor. At Site 13 there were 2.65 sightings per minute of visible seafloor footage. Diverse or abundant benthic faunal communities were not observed at any sites between 220 m and approximately 1,800 m water depth. Investigations of benthic infauna are the subject of a separate study.

The visual assessment generally supports findings of earlier studies and limited published literature pertaining to the Huon Gulf near Lae, in that the region is largely characterised by a low diversity benthic fauna strongly influenced by high sedimentation (Haywood et al., 2012; IHA Consult, 2012). Opportunistic, albeit rare sightings of unidentified species of fish, shrimp, and other fauna were anticipated. These sightings occurred at sites with higher visibility such as Sites 13 and 14, and those located at greater distances from the main influences of sedimentation. The dwarf gulper sharks likely present in the video footage from Sites 7 and 15 is supported by the results from recent deep-slope and bottom fishing studies undertaken for the Project, which caught this species almost exclusively.

These findings are also consistent with general trends observed in other studies, i.e., a region of relatively low (from a localised perspective) faunal diversity, due to ongoing sediment transportation and associated disturbances to the seafloor such as those related to submarine landslides, sediment slumping and tectonic activity.

The area of higher relief within the Markham Canyon floor investigated at Site 17 and other regions of sloping bathymetry may require further investigation in order to determine whether these are comprised entirely of accumulated terrigenous sediments, or whether a rocky bottom provides the underlying foundation of these features.

The findings of this study suggest that the deep sea benthic environment in the area of potential DSTP discharge is one already highly influenced by high natural sedimentation and episodic mass movement events over the main Markham Canyon floor. The low diversity, low complexity ecological assemblages observed likely reflect tolerance in the depositional areas and variable stages of opportunistic colonisation of the areas subject to mass movement of sediment. The receiving benthic environment appears to contain few environmental sensitivities. Consequently, benthic faunal communities, while differing across various depth strata, are likely to be present in the Huon Gulf in areas beyond the study area, and as such, unlikely to be rare or localised. However, analysis of benthic fauna is the subject of separate studies.

Assessment of additional control sites further from the areas of potential Project influence prior to the commencement of any DSTP discharge may serve to further characterise the ecological richness of the benthic communities in the Huon Gulf, and provide a comparative perspective between areas where different sedimentation regimes are observable.

4.2. Comparison with other surveys

In 2008, SAMS completed marine field investigations for the Misima (closed), Lihir (operating) and Ramu (proposed) mines in PNG. As part of this work, SAMS completed benthic image surveys of the deep-ocean sea floor in areas potentially affected by DSTP. Of these, the baseline surveys for Ramu are most relevant here.

Much like the Huon Gulf, the Rai Coast region of PNG (approximately 180 km northwest of the Huon Gulf) is recognised as one of notable geologically activity (Van Der Borch, 1972; SAMS, 2010b). High rainfall in the proximity of the Finisterre Range results in large sediment volumes carried by rivers to the coast and into the sea, where deeply eroded canyons are present in water depths from 100 m to 800 m on the steep continental slope. The presence of more deeply incised canyons differs from the present study area but at depths beyond 800 m the erosional canyons broaden into depositional flat-floored turbidity channels, supplying sediments into the Vitiaz Basin. Estimates indicate that the Vitiaz Basin contains deep-water sediments approximately 2 km thick, primarily the product of down-slope terrigenous sedimentation (SRSL, 2012). The geomorphological and other environmental factors in this context indicate that work completed on the Rai Coast may be a useful comparison location for the present study, particularly as benthic studies have determined the benthic community composition and abundance (SAMS, 2010b; SRSL, 2012).

Seafloor photography from low-disturbance seafloor stations along the Rai Coast near Basamuk, Madang Province indicated a diverse range of biogenic features on fairly smooth, flat sediment surfaces, suggestive of a relatively low-disturbance benthic environment (SAMS, 2010b). Other sites displayed evidence of more recent seafloor disturbance and lower diversity benthos. The causes of disturbance were not stated by SAMS, however indications are that they may be related to downslope sediment slides. A visual comparison of seafloor photography indicates a large degree of similarity, though imagery from this study indicates a less irregular seafloor than at sites photographed along the Rai Coast. Biogenic traces, burrow openings, larger pits or depressions, faecal casts, brittle stars and occasional land-derived vegetation identified by SAMS imagery largely corresponds with the observations of benthic features identified during this current study.

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Appendix A - Selected imagery from Sites 1 – 19

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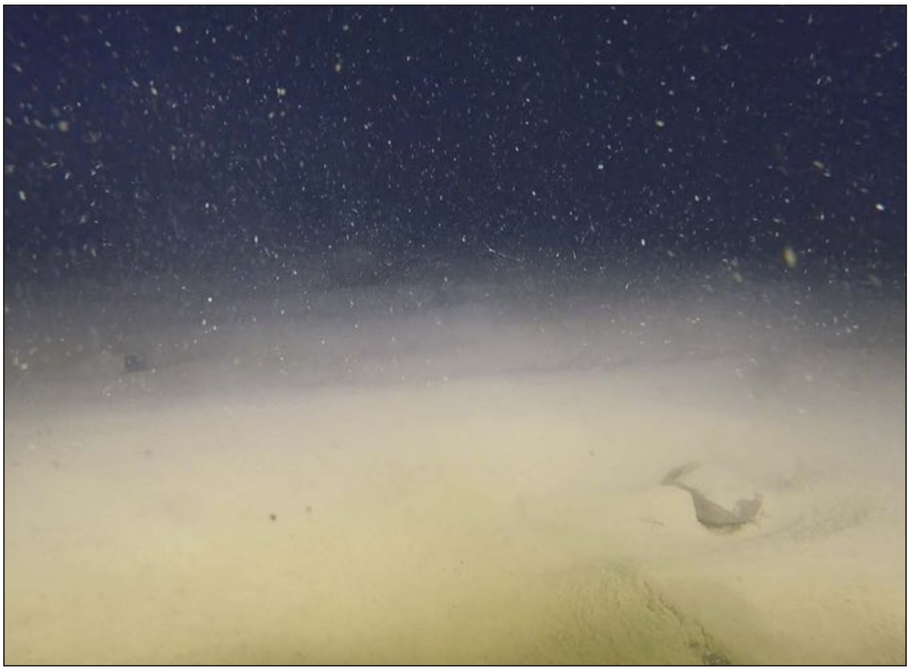

Plate A1
Site 1, 229 m depth

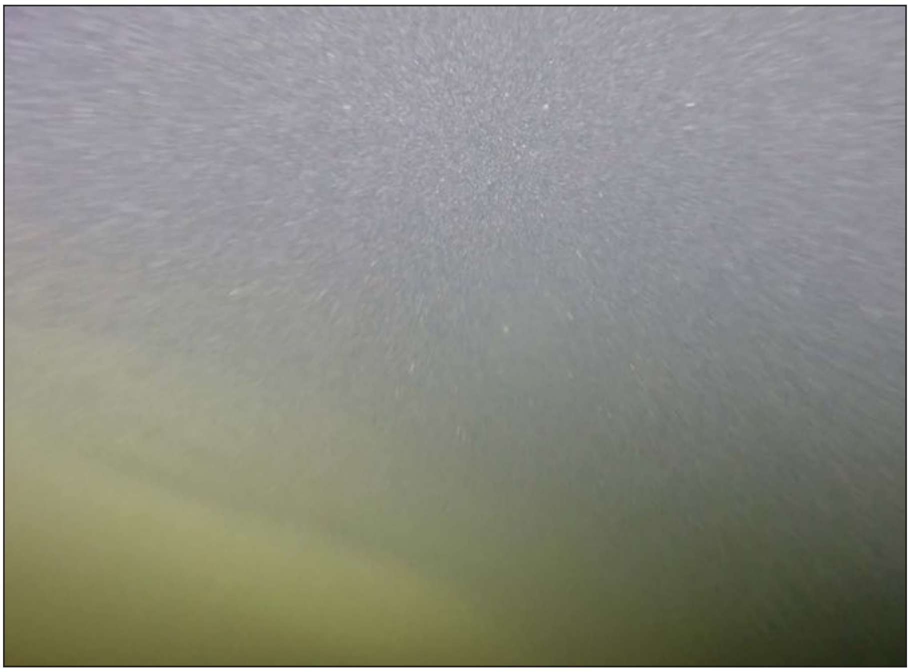

Plate A2
Site 2, 440 m depth

Plate A3
Site 3, 713 m depth

Photo credit: Coffey

Plate A4
Site 4, 850 m depth

Photo credit: Coffey

Plate A5
Site 5, 261 m depth

Photo credit: Coffey

Plate A6
Site 6, 245 m depth

Plate A7
Site 7, 560 m depth

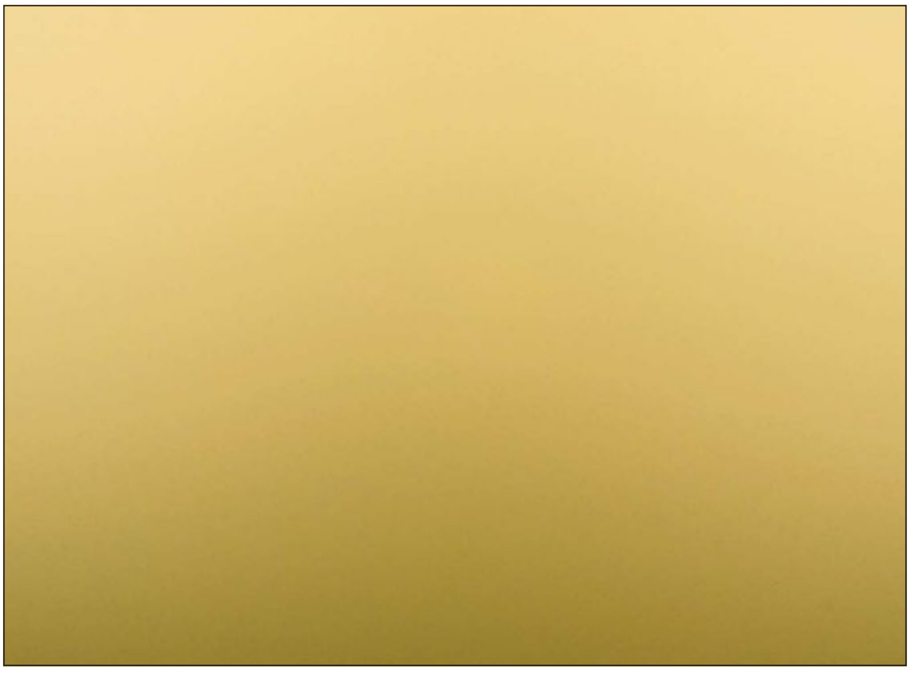

Plate A8
Site 8, 978 m depth

Plate A9
Site 9, 745 m depth

Photo credit: Coffey

Plate A10
Site 10 1,167 m depth

Photo credit: Coffey

Plate A11
Site 11, 1,338 m depth

Photo credit: Coffey

Plate A12
Site 12, 1,650 m depth

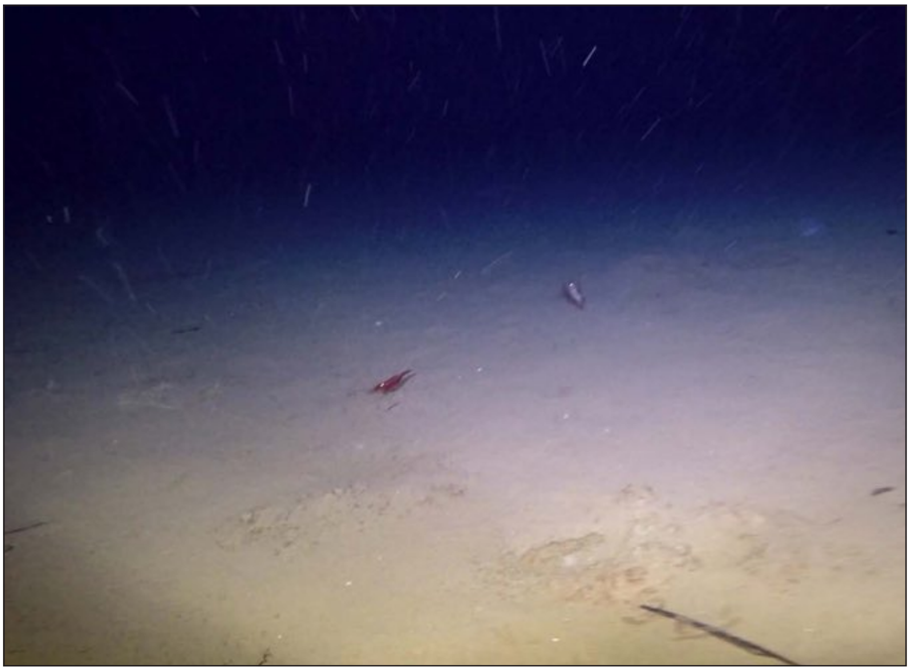

Photo credit: Coffey

Plate A13
Site 13, 757 m depth

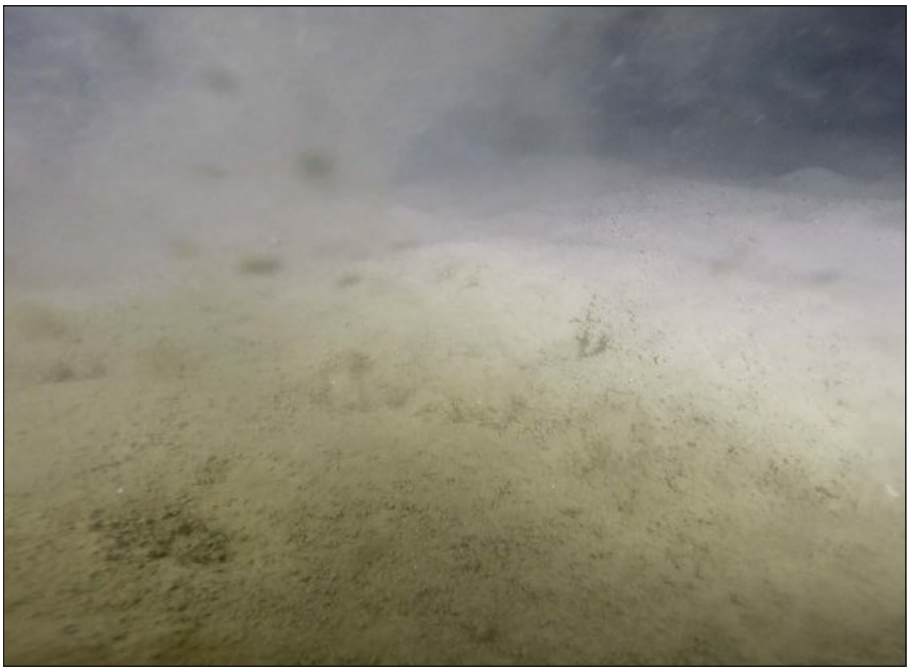

Photo credit: Coffey

Plate A14
Site 14, 356 m depth

Photo credit: Coffey

Plate A15
Site 15, 450 m depth

Plate A16
Site 16, 1,797 m depth

Plate A17
Site 17, 1,176 m depth

Plate A18
Site 18, 650 m depth

Photo credit: Coffey

Plate A19
Site 19, 320 m depth

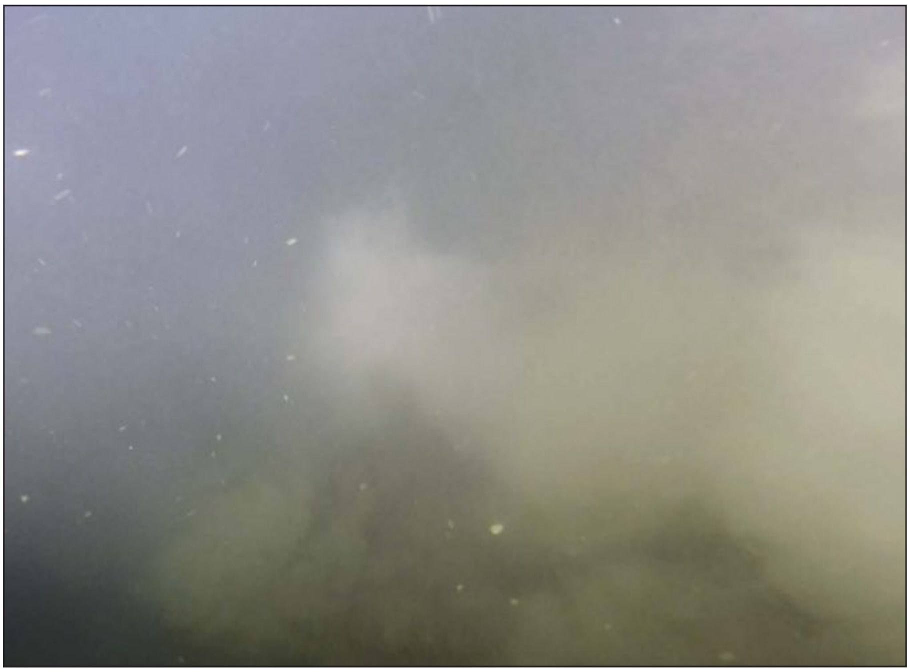

Photo credit: Coffey

Plate A20
Typical aggregations of suspended bed sediment observed after disturbance of the seafloor by the UIS

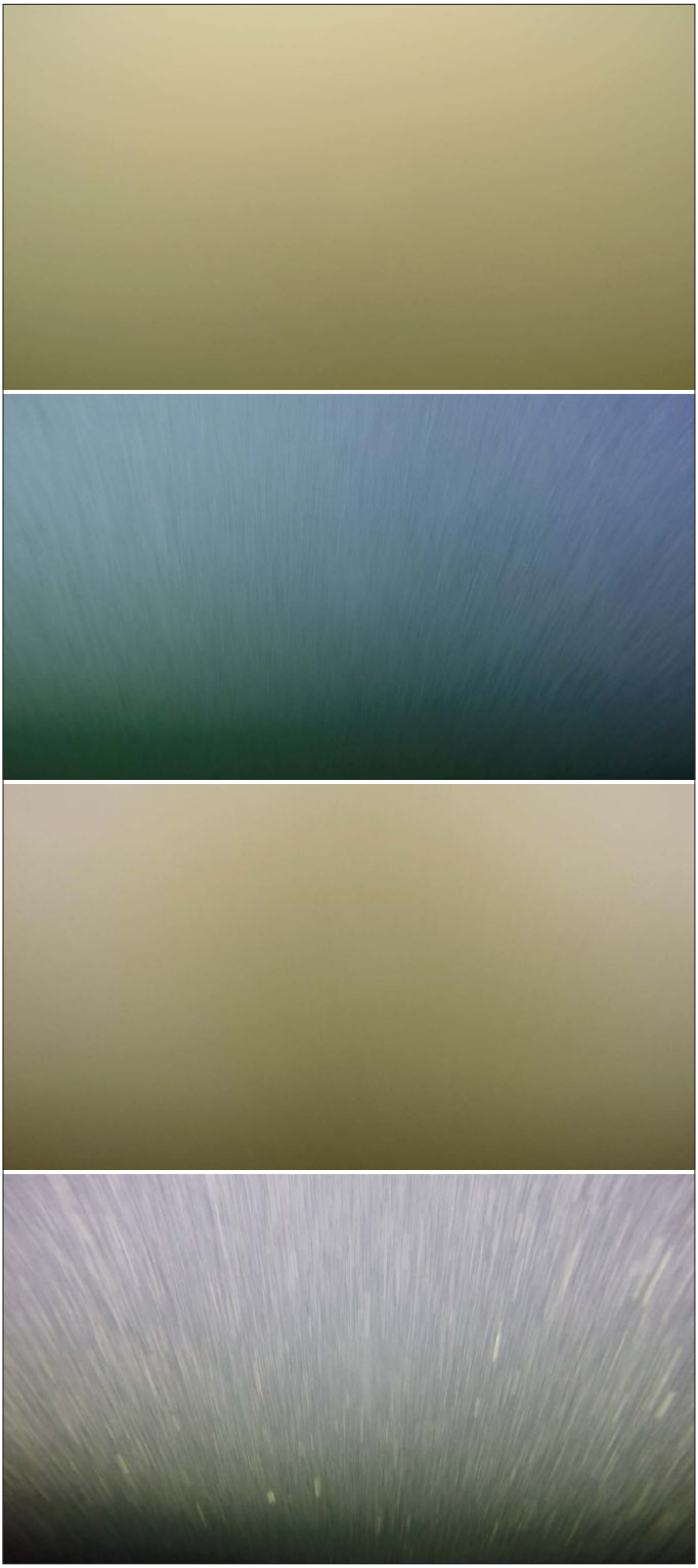

Photo credit: Coffey

Plate A21
Typical alternating strata of turbid and clearer water in the water column - observed at site 19 between the surface and approximately 500 m deep