# 2016 Heard Island Expedition Project Description

## Definition

**TITLE**

BIOGEOCHEMICAL COMPOSITION OF THE SUBGLACIAL REGIME ON HEARD ISLAND USING GLACIAL STREAMS AS REMOTE SAMPLING PROBES

**Abstract**

We plan to examine the chemical composition and particulate loads of glacial streams at Heard Island as a probe of the geochemical and geophysical composition of the parent rocks, and the microbiological activity of the subglacial till. Given the impressive size and discharge of many of these streams, and their deposition of large amounts of fine sediment in various lagoons and the ocean, these streams are obviously transporting large amounts of material from underneath the glaciers. Lixiviation and direct solution will add solutes to the meltwater, providing a clear chemical signature in samples taken downstream. In addition, subglacial till is a refugium for microbial life which will be carried in the runoff. This work will consist of collecting samples from as many streams as possible, followed by laboratory characterization of the particulates, solutes, and bioactive components.


| | | |
|---|---|---|
| **Principal Investigator** | Fred Belton | Cordell Expeditions |
| **Principal Investigator** | Robert Schmieder | Cordell Expeditions |
| **Co-Investigator** | Gavin Marshall | Tangaroa Blue Foundation |
| **Co-Investigator** | William Mitchell | Cordell Expeditions |
| **Co-Investigator** | Staff | U. S. Geological Survey |
| **Co-Investigator** | Carlos Nascimento | Biochemist |
| **Co-Investigator** | Patrick Quilty | University of Tasmania |
| **Co-Investigator** | Maria Hauger | Consultant |
| **Co-Investigator** | Onsite team members | Cordell Expeditions |


## Context

**Background**

Satellite images of Heard Island taken in 2014 have sufficient resolution to exhibit many glacial melt streams, clearly seen as they approach the shoreline and disappear into the ocean, some entering lagoons depositing large amounts of fine sediment. Most of these streams, especially the longer ones (descending up to 3 km) show classic meanders with periods ca. 30-50 m, implying stream widths 3-5 m. Some streams are observed to disappear underground, others appear abruptly from a fissure in the cliff, while in some instances, a stream can be traced as it goes underground and then emerges more than 100 m distant. In numerous places classic braided channels and bird's-foot deltas are formed, and the streams clearly dump large amounts of glacial till into those lagoons and directly into the ocean.

It is obvious that the streams carry particles and chemicals derived from the geologic materials they traverse, hence can be used as probes of those parent materials. This is particularly interesting for Heard Island, because the geology is incompletely known (cf., geologic map below), mostly because it is practically impossible to access the upper elevations. In addition the streams will certainly carry a wide spectrum of microbiota, which likely will aid comminution.

There is considerable literature about sediment and solute transport in glacial

meltwater streams. For example, in a review, Tranter (2006) provides the following:

> The sediment yield from glaciated catchments (those with >30% glacial cover) is often an order of magnitude greater than those of similar, non-glaciated catchments. … … Glaciers are particularly efficient in dissolving carbonates, sulfides, fluid inclusions, and the surfaces of silicate minerals. … Subglacial chemical weathering is microbially mediated, hence, glacier beds act as refugia for microbial life, which spans the range from fully oxic to fully anoxic conditions.

Thus, glacial streams carry three components that are potentially informative about the inaccessible sub-glacial regions:

- Particulates (particularly glacially-produced rock flour)
- Solutes (particularly carbonates and sulfides)
- Microbes.

The current high rate of melting of the glaciers on Heard Island significantly enhances this sampling opportunity. As noted by Tranter,

> The rate of glacial erosion usually exceeds the rate of transport of material from the catchment, so that following deglaciation sediment yield remains high for periods of $10^3$–$10^5$years.

What this means is that because most of the glaciers on Heard Island have very recently retreated upslope on Big Ben, many well-defined streams have been created that were not there even as recently as a decade ago, and these streams carry a range of materials from higher elevations. Before the retreat, the lower glaciers were frozen, and many streams were inaccessible. Quite reasonably, the ANARE in 1950 could not have carried out this investigation because many of the streams disgorged directly into the ocean.

Thus, in the context of the 2016 Cordell Expedition, we view the glacial streams on Heard Island as a fortuitous tool for accessing information about the volcano without the effort and danger of ascending its heights and cutting through glacial ice to reach the chemically and biologically active layers below. This approach is completely equivalent to using fluids from any complex structure (e.g., a machine or an animal body) to infer properties of the structure that are otherwise inaccessible.

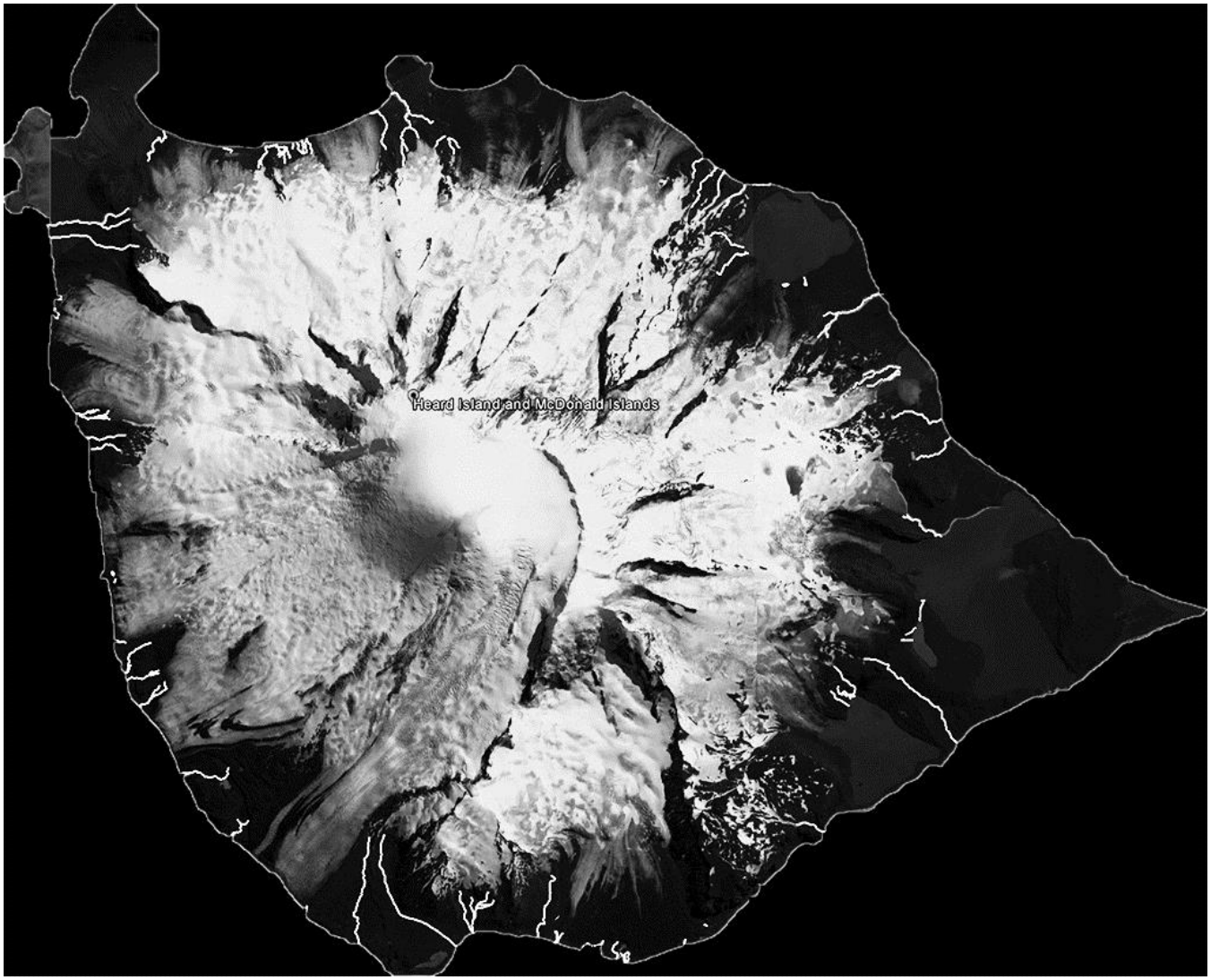
## Motivation and goals

The primary motivation of this project is to contribute to the elaboration of the geology of the Big Ben massif. Our primary goal is to obtain a statistically significant collection of samples of stream water from as many locations as possible. Some *in situ* measurements can be made, such as, pH, turbidity, TDS, conductivity, temperature, etc., but laboratory analysis will be necessary to quantitatively characterize the particulates, solutes, and organic content of the samples. Statistically, the quality of the project will be proportional to the number of samples that can be obtained, and to the number of qualitatively different sampled sites.

In the next section we provide a variety of images of the streams seen in the satellite images of 2014 (DigitalGlobe 2014). The actual procedure is relatively simple, and will be summarized in the following section.

## Sites to be examined

In the following figure we show a combined satellite image of Heard Island and traces of the major streams identifiable in the satellite images. To give slightly more resolution to the streams on Big Ben, we omit the Laurens Peninsula There are a few minor streams there, but they will be included in this project as a matter of course.




*Glacial streams identified in 2014 satellite images. [R. W. Schmieder.]*

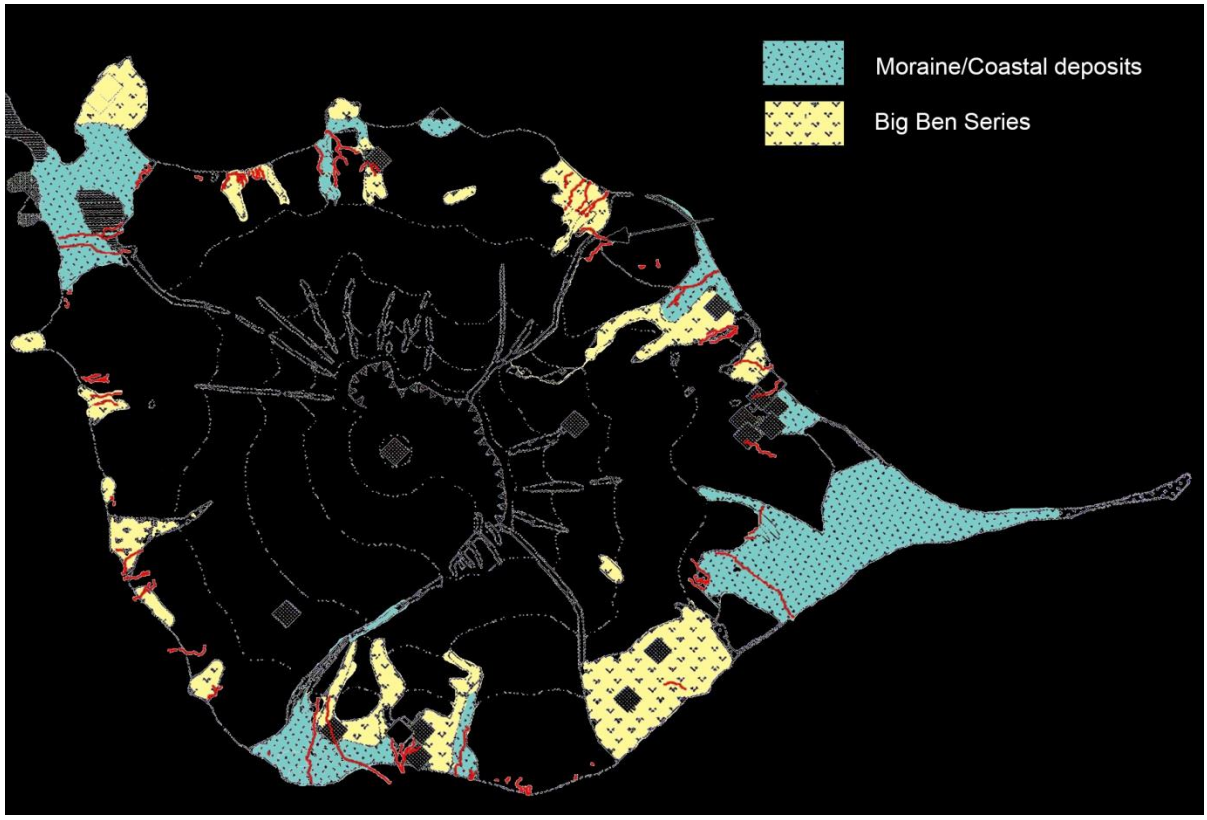
To a first approximation, the volcano is azimuthally symmetric, and the streams are distributed roughly uniformly around its center. The longest streams are ca. 3 km long, and most maintain a roughly uniform width between 3 and 7 m. All the long streams have many meanders, and they clearly erode a wide swath due to the meandering dynamics, but essentially no streams show oxbow lakes. All four major lagoons are located on the east side, and some streams empty into these lagoons.

In this work we essentially neglect the Laurens Peninsula for the following reasons:

- The Peninsula is very old (Holocene), whereas the main volcano (Big Ben) is less than 1 million years old, and is the active part of Heard Island
- There are few major streams on the Peninsula, and practically none that emanate from subsurface sources.

**Streams and the geological map of Heard Island**

There is currently no complete geologic map of Heard Island (Fox, 2015). In the diagram below, we have superposed the observed stream tracks on a legacy geologic map (Barling). While the map and the current satellite outline of the island differ somewhat, the registration is good enough to approximately locate the stream tracks relative to the surface rock types.



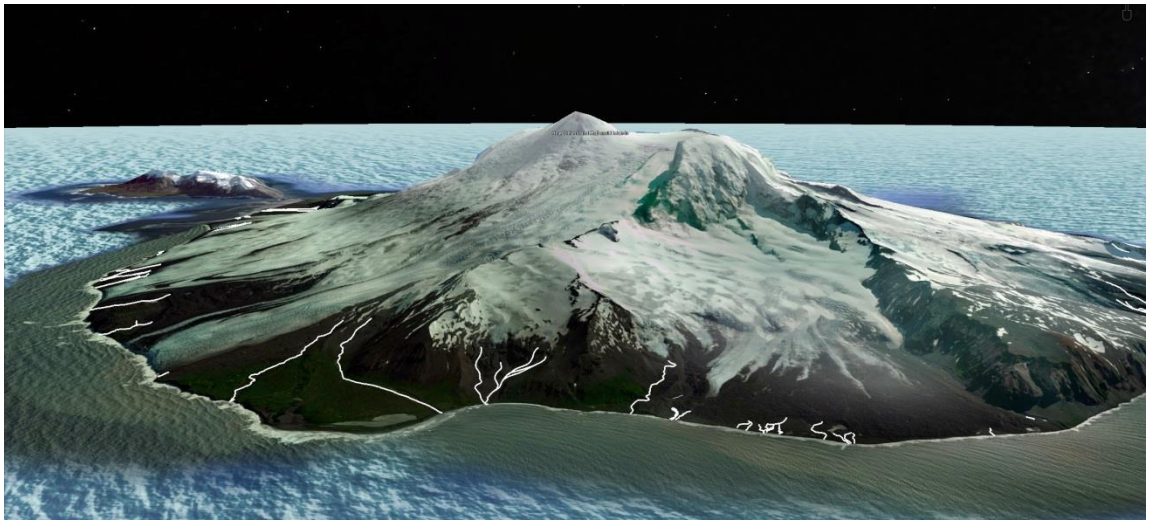

There appears to be some correlation between the known rock exposures and the stream tracks, although it is surprisingly imperfect. This provides a compelling reason to attempt the use of stream analysis to infer composition of the inaccessible interior of the main volcano: Big Ben is young, inhomogeneous, and largely undescribed, and we have precious few ways to learn something of its interior.

Quilty (2014), emphasizing that the geology of the HIMI is far from completely known, points out that Big Ben is probably far younger than 1 million years: "Modern events such as volcanic activity and slumping of the southwestern part of the volcano into the sea to form the prominent avalanche amphitheater may have occurred as recently as 20,000 ypb." Referring to tools that could be used to study the Palaeogene basement rocks, Quilty proposed the following:

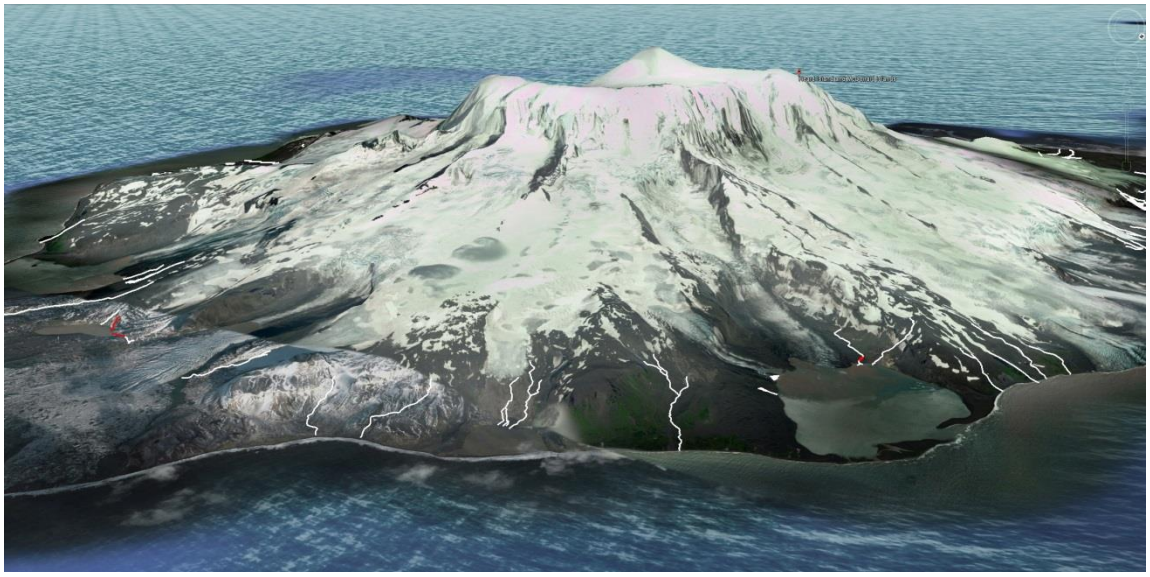
- Dating using foraminifera, coccoliths, palynology etc.
- Establishing rates and environment of deposition, including its change with time
- Evidence of volcanic activity and its type, as evidenced by insoluble residues in sediment
- Palynology to document the flora of the time and its change as the global environment changed.

We note that the present work is essentially the same as Quilty's third proposal.

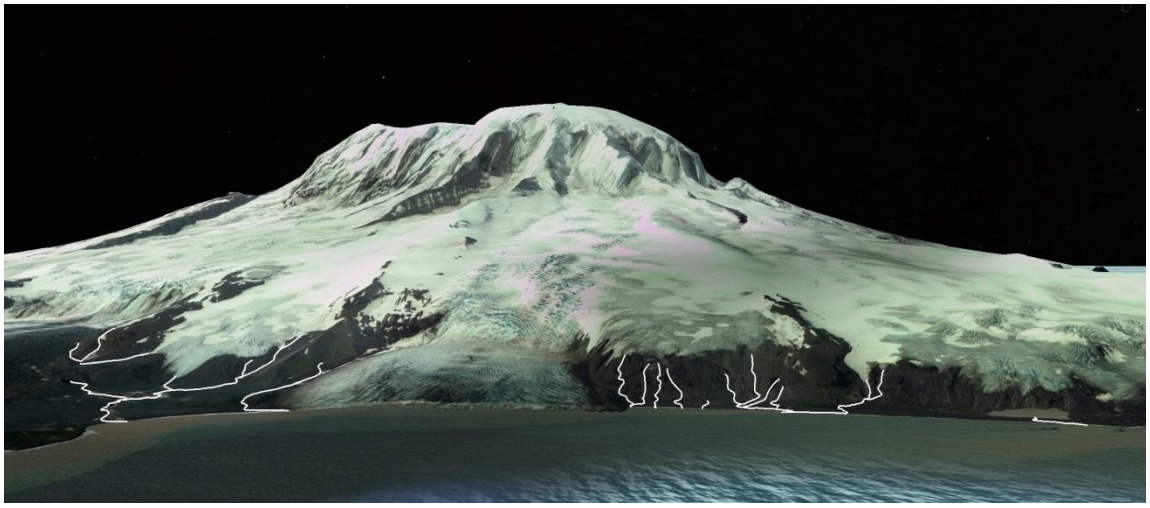
The three images below show perspectives of Heard Island. Clearly, most of the streams empty directly into the ocean, while a few of them empty into lagoons, which as later images will show, provide major sediment loads to those lagoons.



*South side*



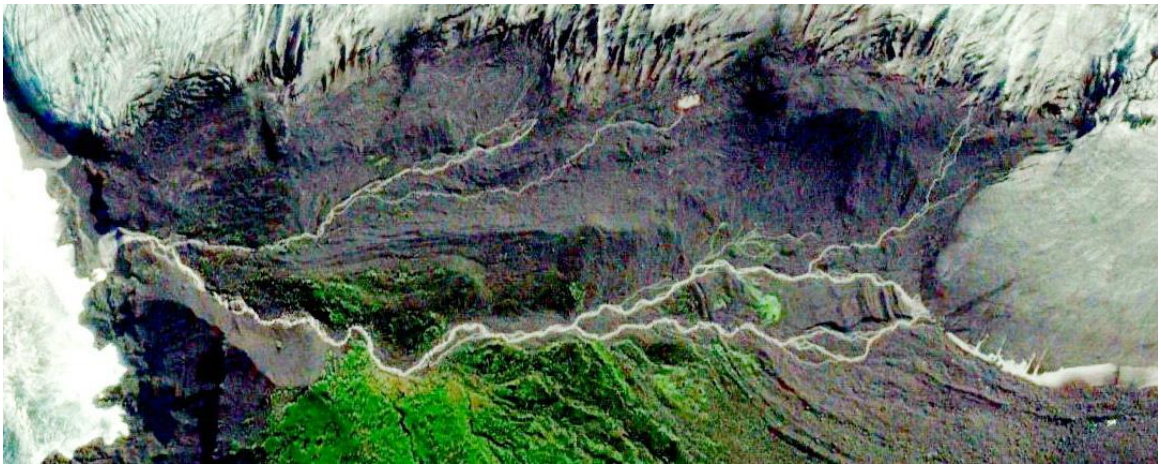
*East side*



*North side*

**Very long glacial streams**

We show here some of the more prominent glacial streams seen in the satellite images (not to precisely the same scale). The steams shown on this page carry water from glaciers to the ocean, 2-3 km away. The streams appear to have relatively uniform width over most of their lengths except for braided intervals), typically 4-6 m.



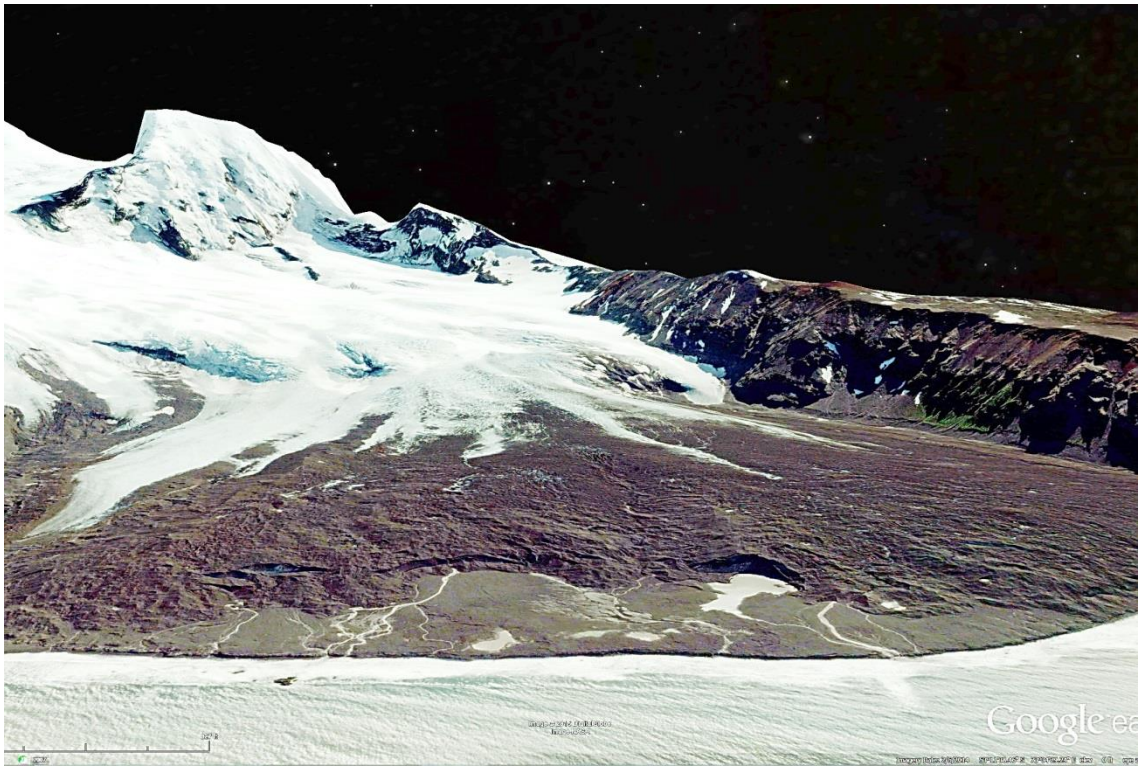
In the images, the streams on Heard Island appear to have very familiar and common behavior: meandering within a floodplain, braiding, high capacity discharge, and relatively normal geometry (e.g., stream width ≈ 0.1 x meander wavelength). What is remarkable is the absence of oxbow lakes (billabongs). The images seem to indicate that many of the streams run through loose, relatively unconsolidated till with minimal clay, unable to maintain structural integrity and prevent drainage. The result is a soured channel approximately the width of the meander wavelength, and no billabongs.

**Streams emerging from rock fissures**

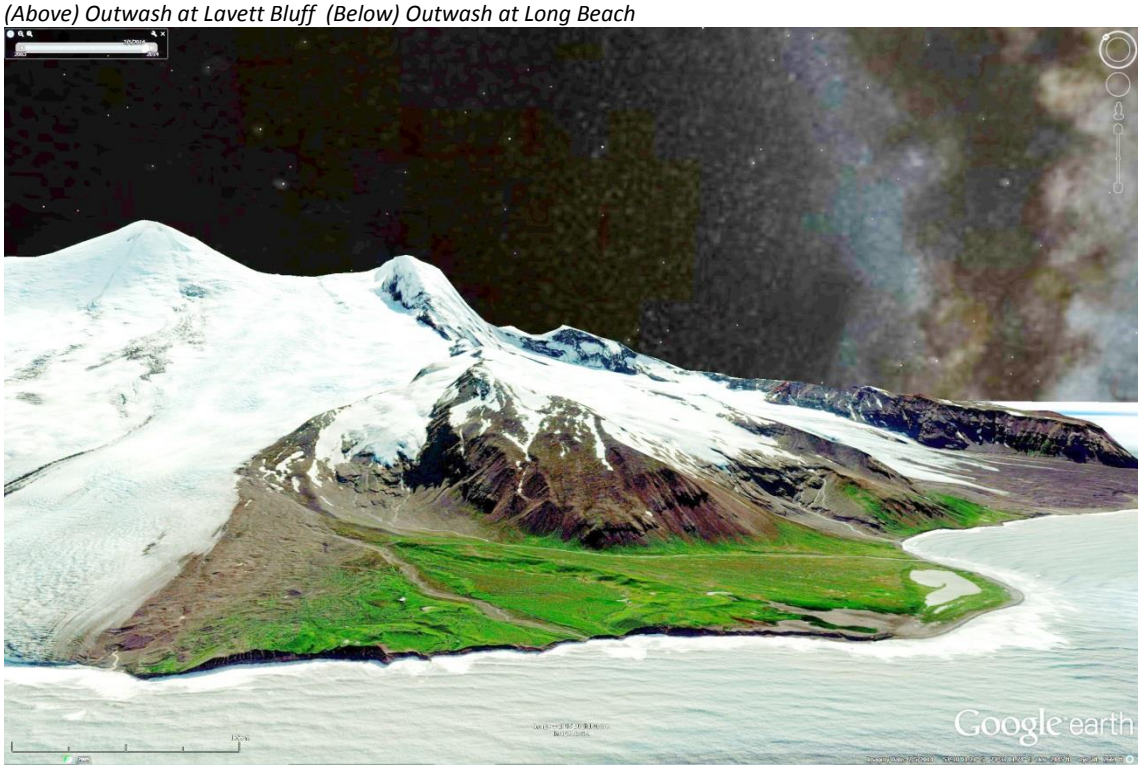
The images on this page show streams that emerge from fissures in the rocks. In the 2014 satellite images, there are perhaps twenty such major streams on Heard Island.

**Streams emerging from lava overburden**

In some areas, multiple streams emerge from under a massive overlying lava flow. The following image, a perspective of the first image on the previous page, shows one of these. Clearly, the streams "bleed" at the contact between the relatively smooth, gray sloping plain and the relatively rough, reddish, lava flow above it. This circumstance is not present in the immediately adjacent unglaciated interval, shown in the following (Long Beach). These images are complelling evidence that the stream loads form different areas will, in fact, be quite different.

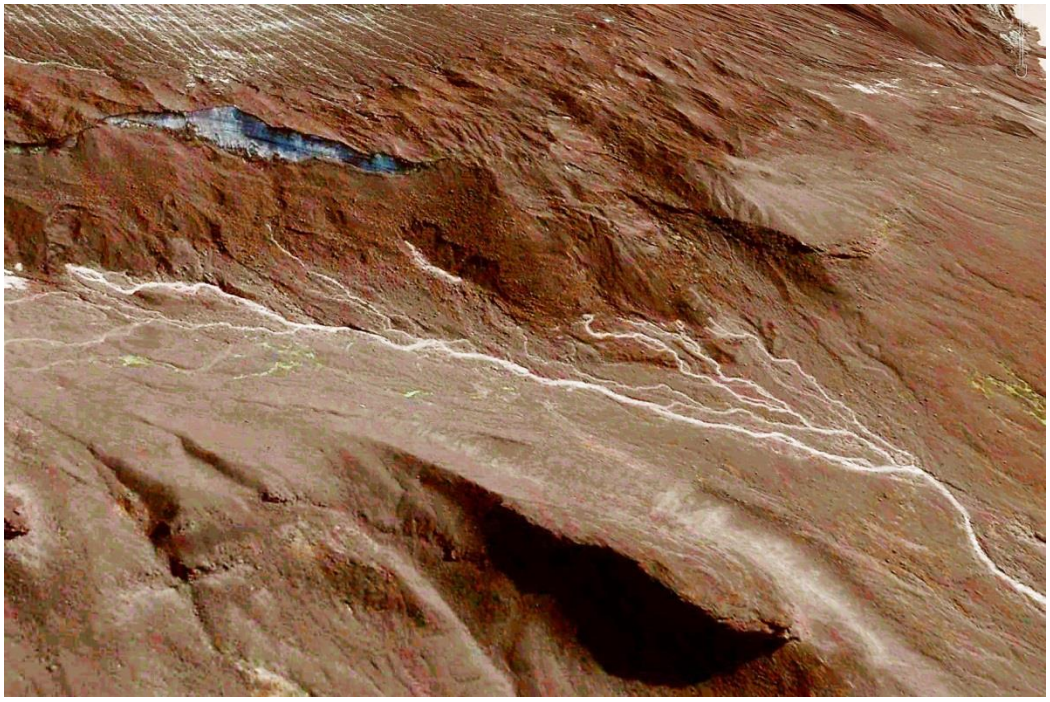



*(Above) Outwash at Lavett Bluff (Below) Outwash at Long Beach*



**Streams created by colluviation**

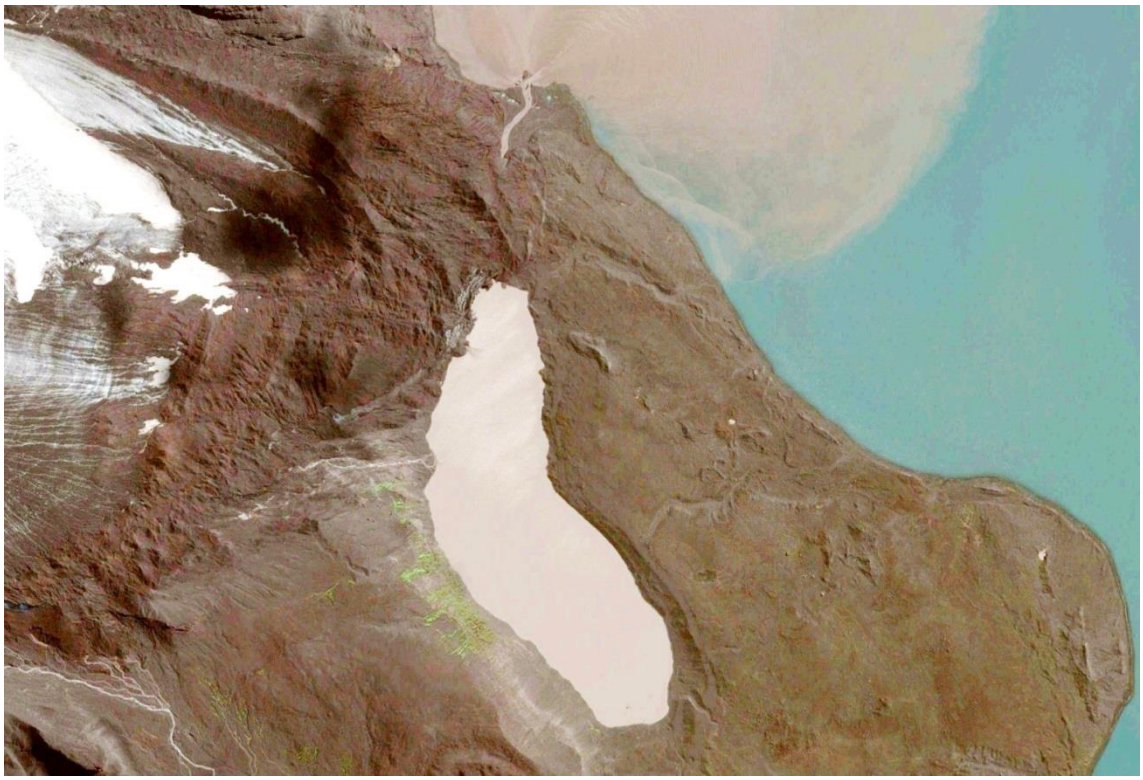
In the description of another investigation planned for the March/April 2016 visit to Heard Island ("Macroscopic inclusions in retreating glaciers on Heard Island"), we show several images of the plateau to the west of the Stephenson-Doppler Lagoon. As described there, the southern slope of this plateau shows a very large bluish "gash" that we interpret as exposure of the underlying glacier as a result of episodic slumping of the overlying reddish sediment.



If the bluish exposure really is glacial ice, it would provide negligible impedance to release of chunks and their immediate slide across/down the gash to its lower edge. Repeated slumping causes the gash to rise on the apron, at an average rate of about 1 ft./month. The annual freeze/thaw cycle would easily provide the release mechanism. In the present context, the colluvium on this apron is a classic weakly-consolidated overlay with a strong source of outwash from above. Thus, the colluvium would be expected to support many emerging streams, and that is exactly what is observed. An enhancement of part of the tributary network is seen here:

**Plunging/emerging streams and sediment deposition**

The upper image on this page shows a stream emerges from the rocks carrying the muddy outflow from the tarn. The stream intake is below the water surface of the tarn, and it travels underground for about 100 m. The lower image (pair) shows the inlet to the tarn. Clearly, a rockfall event sometime after 2007 created a blockage and enabled a geyser-like stream into the tarn.

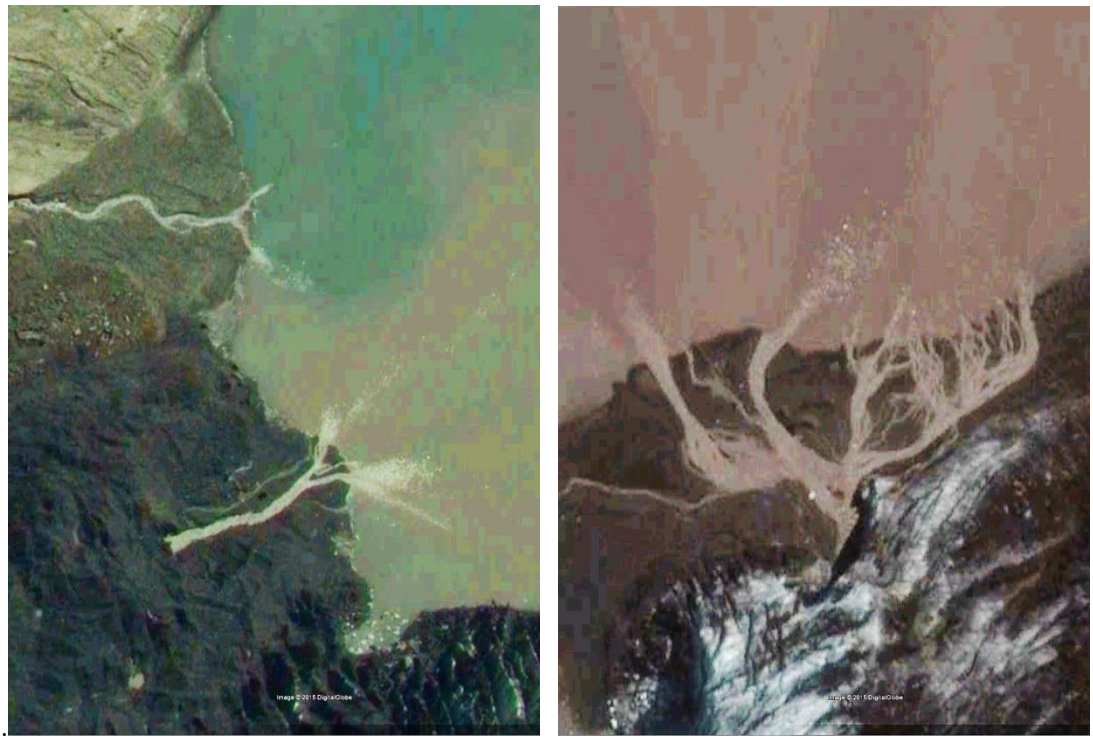


*The outflow of the Stephenson-Doppler Lagoon tarn. The tarn (lower center) is filled by a geyser near its upper left corner, and empties into the lagoon through the stream, the first half underground and the second half above ground. The sediment load from the stream clearly contains a large amount of rock flour.*


*Evidence of the ongoing geological activity of Heard Island. Around 2008 a major rockfall created a pedestal from which a water plume jets ca. 50 m into the tarn just above and west of the Stephenson-Doppler Lagoon. Sampling the plume might give information about the composition of the subsurface rocks.*

**Stream deltas**

In the left image, below two inlets pour water into the Compton Lagoon. Both streams show the classic multipath delta as they arrive at the lagoon. The lower stream emerges from a recent lava flow after traveling underground for 128 m. The right image shows another delta inlet. Images of these features show significant changes over time scales of less than one year.



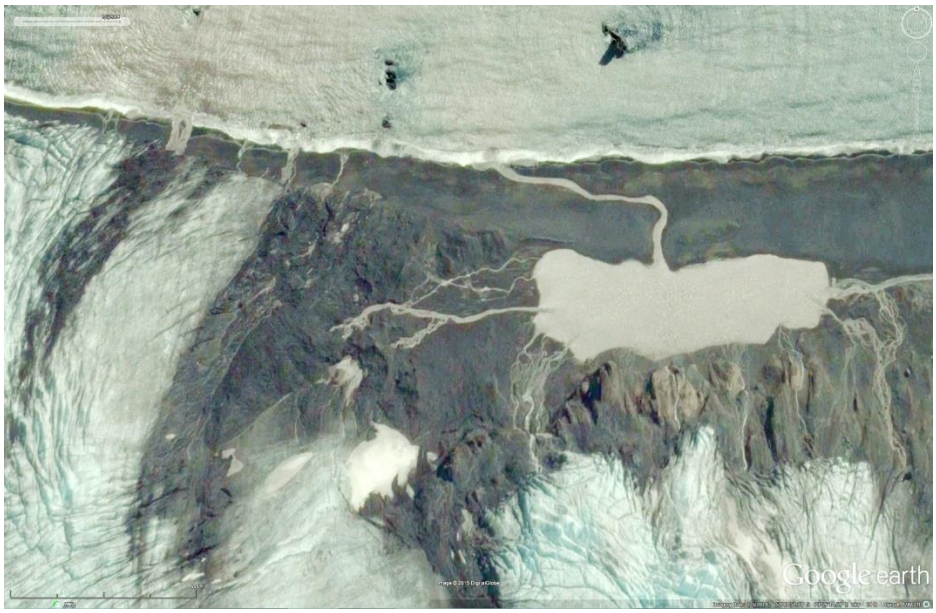
*Inlet stream deltas to the Compton Lagoon [2014].*

The following image is of the inlet from the tarn into the Stephenson-Doppler Lagoon. Like the left-lower stream above, this stream emerges from an underground channel about 100 m long.


*Inlet delta to the Stephenson-Doppler Lagoon [2014].*

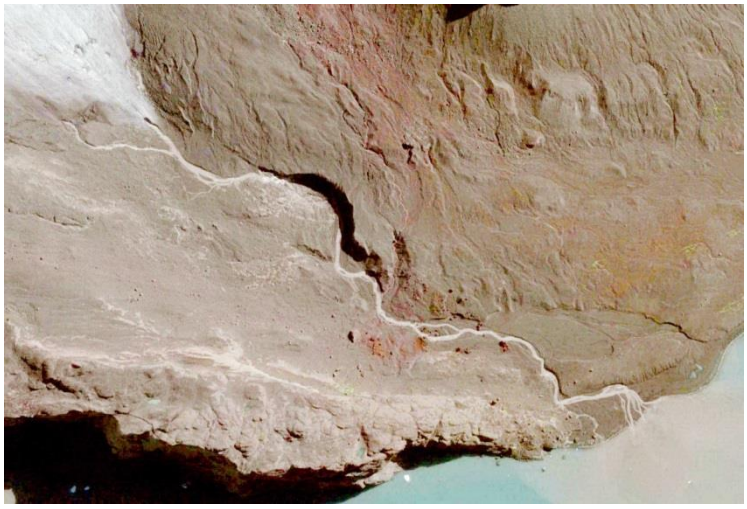
**Beach streams**

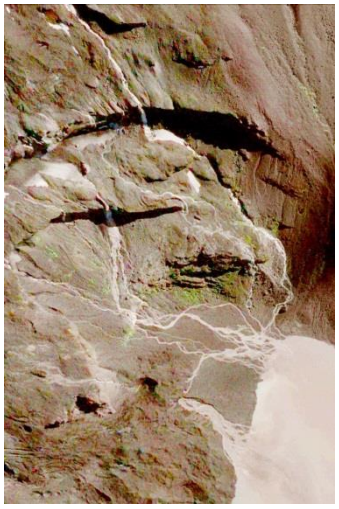
The images on this page are examples of streams appearing on or very near the beach, rather than high on the volcano and flowing over a long meandering course. We have interest in sampling these streams as well as those originating at high altitude.

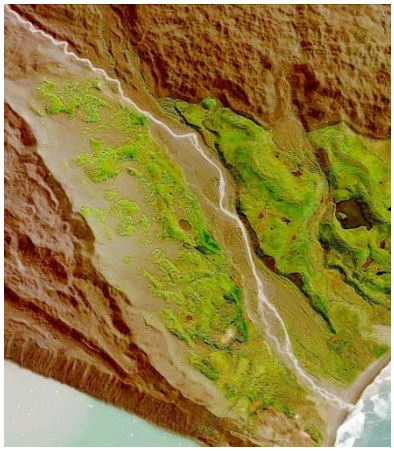



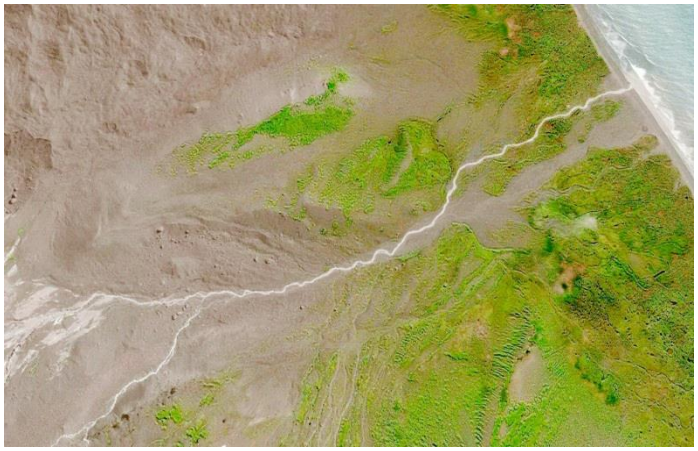
**Vegetation**

The streams are found in all ranges of vegetation, from bare rock to total cover. Note that these images show meandering streams keeping a relatively wide channel relatively clear of vegetation, but not supporting the formation of oxbow lakes.



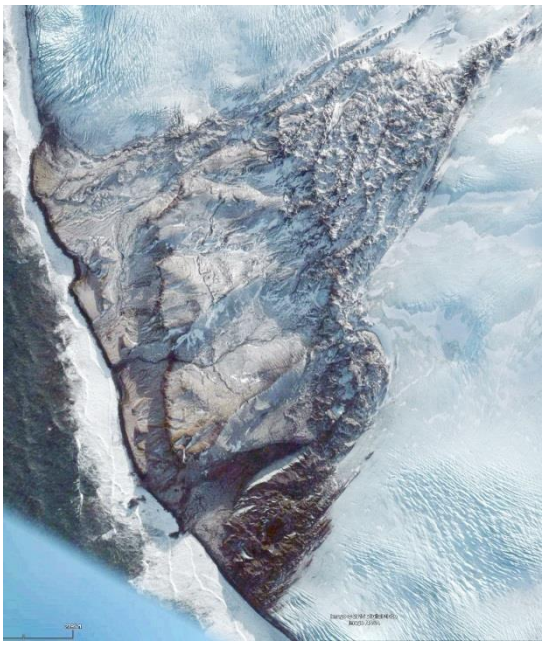




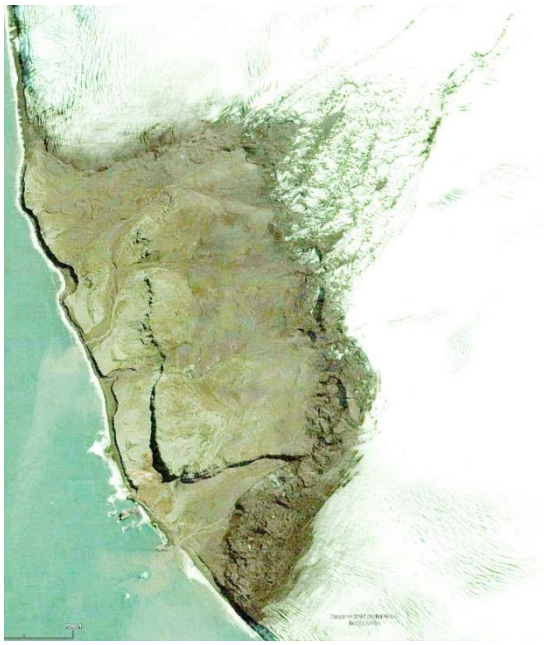


**Changes in time**

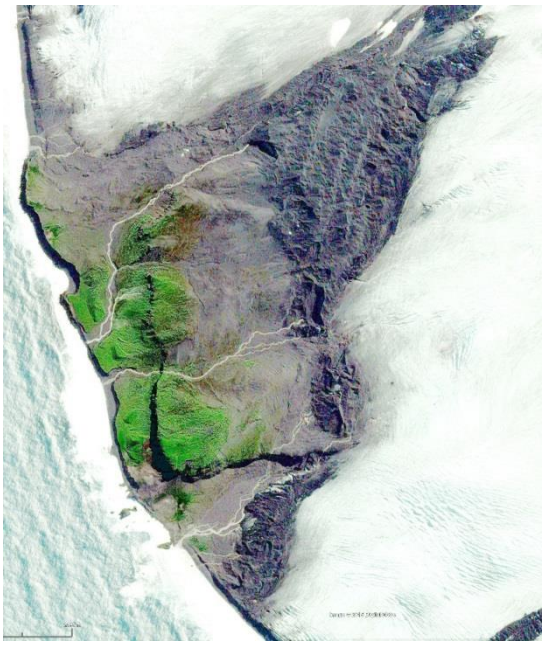
The satellite images contain limited historical versions. The first three images on this page show images of the rocky area between Lied Glacier and the Abbotsmith Glacier in three different years.



*2007*



*2009*



*2014*

*(left) 2009 (right) 2014*

Closer examination of the original images above at larger scale shows that the most prominent streams were present in all three years. However, there were major differences in the discharges of the streams. The lower right pair of images above show a close-up of the 2009 and 2014 streams. In all the streams seen on Heard Island, meandering changes parity with a period of 5-10 years.

## Description

### Onsite

***Equipment***

Sterile containers for samples (jars for water, Ziploc bags for solids)
Field instruments for pH, TDS, etc.
GPS camera, field notebooks

***Location(s)***

The overall plan for the visit is to occupy the main visitor sites in the following order:

- Atlas Cove
- Spit Bay
- Long Beach.

From the main sites, we will move on foot to visit adjacent areas.

***Procedure***

Given the overall plan and range constraint, the priority for sampling the streams will be determined opportunistically. That is, we will make side trips away from the camps on days when the weather and ground conditions allow safe movement. In addition to the scientific materials and supplies, the field party will always have radio contact with the camp, and will carry a satellite telephone and basic emergency supplies.

The field party will have detailed maps and images of the area being investigated. When the party reaches a stream, they will make the decision of where to take samples. There are two priorities for the sampling locations:

- As far upstream as can be safely reached
- As near the outfall into a lagoon as possible.

The rationale for the upstream sample is to obtain suspended load as near to its source as possible, minimizing mixing with lower elevation materials. The rationale for the near-lagoon sample is to obtain as representative samples of the washload entering the lagoon as possible. Having two samples of the same stream will also give an idea of the relative contributions of the subglacial and subaerial till. If the stream appears to be variable along its accessible length, multiple samples will be taken.

For each sampling site, we will go through the following procedure:

1. The area will be documented with GPS photographs.
2. A filter will be installed into the stream to accumulate particles from the suspended load.
3. A sample of the water (ca. 500 cc) will be collected in a sterile glass jar, and various in situ tests (pH, TDS, temperature, etc.) will be made using field instruments.
4. Samples of the solid sediment on the bottom and at the edge (bank) of the stream will be collected into Ziploc bags.
5. The filter will be recovered and placed in a Ziploc bag.

All containers will be labeled by inserting pre-printed labels on waterproof paper completed in pencil. No samples will be fixed in the field; rather, a choice will be made at camp which, if any, to fix and preserve with ETOH.

## Records

| | |
|---|---|
| ***Photo-documentation*** | Within the limits of safety, the entire length of the stream visited by the field party will be documented with overlapping high-resolution GPS photographs. |
| ***Logging*** | A field notebook will record the individual sites and specimens. |
| ***Nonliving specimens*** | The field party may opt to collect unusual or particularly representative specimens of sand, gravel, rocks, or dead organisms along the length of the streams visited. Each would be documented with the procedure just described. |
| ***Live specimens*** | No live specimens will be collected. All these samples will be fixed with ETOH. |

## Post-expedition procedure

| | |
|---|---|
| ***Destination(s) of records*** | Some samples will be kept alive and transferred as soon as possible to specialists for laboratory culture and identification. |
| ***Processing of records*** | A systematic study of the sediment will be made using both microscopy and chemical analysis. This will be done by specialists in various institution, including the NASA Ames Laboratory (Mountain View, CA), University of California (Berkeley), the U. S. Geological Survey, and independent contractors. Among other measures, we expect to be able to measure the sediment size distribution, particle shape distribution, and composition. |
| ***Publication(s) expected*** | Heard Island monograph, Journals of sedimentology, volcanology |
| ***Definition of success*** | This project requires a statistically significant number of samples to provide sufficient contrast in the samples, and to make warranted inferences about the relationship of the observed samples to the parent material on Heard Island. There are perhaps 500 locations where meaningful samples could be obtained that could contribute to this collection, so the goal is to collect as many as possible, from as large a distribution as possible. We consider a collection of perhaps 100 samples from 30 different streams distributed roughly around the island to be a minimum for a statistically meaningful collection. |

# Appendices

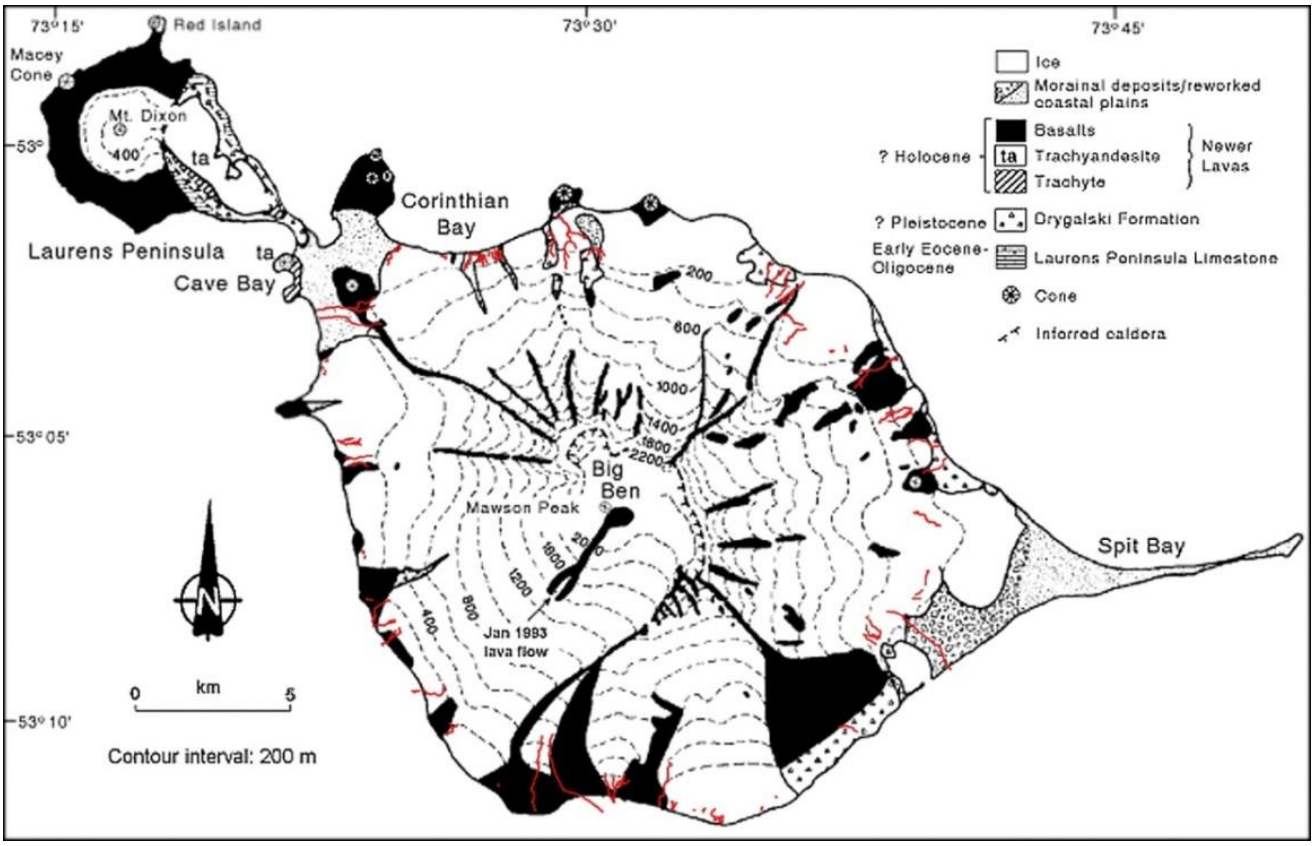
## Appx. 1 Other stream geometries

Some drainage basins have produced classic braided rivers, some extreme. One such is the area called “Little Beach,” near Saddle Point. The following image shows this area in 2014. While fascinating in its complexity, using the stream as a probe of the subsurface composition probably isn’t useful, since it’s load will be dominated by the loose volcanic sediments in the broad plain. The single source in the upper left may be of interest as a subsurface probe, however. Whether this exists in 2016 remains to be seen.

Another case that is of interest geologically but probably not useful for this research is the apparent temporary blockage of a stream by a rockfall, which is about 20 ft. high. Apparently the stream merely rerouted under it. Note, however, the origin of this stream in a fissure .

## Appx. 3 Streams superposed on a different legacy geologic map

We have attempted to superpose the streams on another legacy geologic map of Heard Island. Some distortion was necessary for best fit, although this is not considered surprising. Again, the mediocre agreement between the stream locations and the known outcroppings emphasizes the importance of developing a fully-qualified geologic map as a preliminary to making any detailed inferences about the streams. On the other hand, the 2014 satellite images do provide precise coordination of the streams and visible outcroppings, even in the absence of detailed lithologies. [Origin of the map uncertain]



# References

## References


1. Anderson, J.B., Kurtz, D.D., Domack, E.W., and Balshaw, K.K., 1980, Glacial and glacial marine sediments of the Antarctic continental shelf: Journal of Geology 88, p. 399–414.
2. Barling, .J., 1990a: The petrogenesis of the Newer Lavas of Heard Island, southern Indian Ocean. UnpubL PhD thesis, Monash University: 248 pp. plus appendices
3. Barling, J. & Goldstein, S.L., 1990: Extreme isotopic variations in Heard Island lavas and the nature of mantle reservoirs. *Nature* **348**: 59-62.
4. Barling, J., 1990b: Heard and McDonald Islands. In LeMasurier, W.E. & Thomson, J.W. (Eds): Volcanoes of The Antarctic Plate And Southern Oct"Ans. *Antarctic Res. Ser*. **48**: 435-44l.
5. Barling, J., Goldstein, S.L., Wheller, G.K & Nicholls, La., 1988: Heard Island: an example of large isotopic variations on a small oceanic island. *Chem. Ceoi* **70**: 46.
6. Barling,]., Goldstein,S.L. & Nicholls,La., 1994: Geochemistry of Heard Island (southern Indian Ocean): characterization of an enriched mantle component and implications {or enrichment of the sub-Indian Ocean mantle*. j. Petrol*. **35**: 1017-1053.
7. Boulton, G.S., 1987, Progress in glacial geology during the last fifty years: *Journal of Glaciology* **33**, special issue, p. 25–32.
8. Boulton, G.S., 1996, Theory of glacial erosion, transport and deposition as a consequence of subglacial sediment deformation: *Journal of Glaciology*, v. 42, p. 43–62.
9. Boulton, G.S., Dent, D.L., and Morris, E.M., 1974, Subglacial shearing and crushing and the role of water pressures in tills from south-east Iceland: *Geografiska Annaler* **56**, p. 121–134.
10. Chen, D., and Duan, J.G., 2006. Simulating meandering channel evolution with an analytical model. J. *Hydraul. Res*. 44 (5), 624–630.
11. DigitalGlobe 2014. Satellite images of Heard Island. These images are obtained from Google Earth. They include a set of historical images dating back to 2006.
12. Dreimanis, A., 1988, Tills: their genetic terminology and classification, in Goldthwait, R.P., and Matsch, C.L., eds., *Genetic Classification of Glacigenic Deposits*: Rotterdam, A.A. Balkema, p. 17–83.
13. Dreimanis, A., and Vagners, U.J., 1969, Lithologic relation of till to bedrock, in Wright, H.E., ed., Quaternary Geology and Climate: Washington D.C., National Academy of Sciences, p. 93–98.
14. Duan J. G., and P. Y. Julien, 2010, Numerical Modeling of meandering evolution, *J. Hydrology* **391**, 34-46.
15. Fox, J. Private Communication.
16. Julien, P.Y., 2002. *River Mechanics*. Cambridge University Press, 434p
17. Mazzullo, J., and Ritter, C., 1991, Influence of sediment source on the shapes and surface textures of glacial quartz sand grains: *Geology* **19**, p. 384–388.
18. Mosselman, E., 1998. Morphological modeling of rivers with erodible banks. *Hydrol. Process*. **12**, 1357–1370.
19. Nicholas, A.P., Smith, G.S., 1999. Numerical simulation of three-dimensional flow hydraulics in a braided channel. *Hydrol. Process*. **13**, 913–929.

20. Quilty, P., and Wheller, G., 2000, Heard Island and the McDonald Islands: A Window into the Kerguelen Plateau, *Papers and Proc. Roy. Soc. Tasmania* **133**(2):1-12.

21. Quilty, P., 2014, Heard Island and McDonald Island—unresolved geological issues, unpublished note.

22. Rooney, S.T., Blankenship, D.D., Alley, R.B., and Bentley, C.R., 1987, Till beneath Ice Stream B, 2. Structure and continuity, *J. of Geophysical Research* **92**, p. 8913– 8920.

23. Stephenson, Jon, Barling, Jane, Wheller, Graeme, and Clarke, Ian, 2006, The geology and volcanic geomorphology of Heard Island. In: Green, Ken, and Woehler, Eric, (eds.) *Heard Island: southern ocean sentinel*. Surrey Beatty & Sons, Chipping Norton, NSW, Australia, pp. 10-27.M.

24. Trantor, M., 2006, Sediment and Solute Transport in Glacial Meltwater Streams, in: *Encyclopedia of Hydrological Sciences* **14**: 169, J. Wiley.

25. Tulaczyk, S., B. Kamb, R, P. Scherer, and H. F. Engelhardt, 1998, Sedimentary Processes at the base of a West Antarctic ice stream: Constraints from Textural and compositional properties of subglacial debris, *J. Sedimentary Research* **68** (3) 487-496.

## Evaluation

### HIMI Management Plan

The present project is sanctioned by Items **A5, A10, and B1** of **Table 2, Section 5.5** of the Heard Island and McDonald Islands Marine Reserve Management Plan 2014-2024, *viz.*:

**A5)** Long-term monitoring of climate, glaciers and fauna and flora colonisation of newly deglaciated areas.

**A10)** Systematic geological mapping and monitoring of volcanic activity.

**B1)** Stratified random sampling of the benthos, particularly habitat-forming benthos (such as sponges and corals) in and around the Reserve.

Section 5.5 of the HIMI Management Plan provides the following:

> Research within the Reserve is required for the integrated and ecologically sustainable management of the broader HIMI region. … Scientifically robust evidence is needed to make effective conservation management decisions. … Research and monitoring activities must be undertaken in accordance with the research and monitoring priorities identified in Table 2 and the Australian Antarctic Science Strategic Plan. … Research also facilitates the fulfilment of public reporting requirements.

In combination with the remarks about Table 2 (above), we interpret this statement to mean that the research described in this document is consistent with the AAD mission for management of the HIMI.

The HIMI Management Plan further provides

> … the policies … require … that: any biological resources taken are not intended to be used for commercial purposes; … that samples will not be given to other people … without permission … [Parts of this excerpt are omitted solely for space requirements in this document, and are not meant to be omitted in the agreement.]

We do affirm that this project has no commercial interest or activity, and that Cordell Expeditions guarantees conformance with the above statement, both in words and meaning.

### Priority

This project has the highest priority of the entire Cordell Expeditions 2016 visit to Heard Island. It carries with it considerable capability for new information in numerous fields, including volcanology, glaciology, sedimentology, fluvial transport and deposition, bio-weathering, and many other processes working at Heard Island.

### Specimens

It is patently impossible to get the information just discussed by onsite observation. No sensible amount of information can be gathered without the samples. We plan to collect 100-200 samples of 20 cc each, or a total of 2-4 liters. These will be conserved in glass scintillation vials, which are new and clean. The entire collection will be fixed with ETOH and examined in the laboratory.

### Risks

There are no inherent risks in this research, beyond the obvious risks of party in the field. There is no risk of biological contamination, other than cross-0contamination of the samples, which we will ensure against.