A GUIDE TO GEOLOGICAL SITES IN SOUTH AND SOUTHWEST

HOKKAIDO

Soltice Morrison, Justin Lo

Alaesha King, Yohei Hamada, Hirokazu Masumoto, Risa Matsumura, Wonji Shin, Toru Takeshita, Main Tokinaga, Virginia Toy

Acknowledgements

First and foremost, a huge thank you to Associate Professor Virginia Toy and Professor Toru Takeshita for your planning and preparation for the Hokkaido Summer Institute Field Trip 2018 and for guiding us as we explored the geological wonders of Hokkaido, Japan. Special mentions to Aleasha King for her time and unbelievable contributions. Much of the work and translations presented here would not be possible without her help. Yohei Hamada, Hirokazu Masumoto, Risa Matsumara, Wonji Shin and Main Tokinaga, thank you all for taking the time to help translate from Japanese to English and for also providing us with local knowledge and insight. We cannot thank you all enough. Special mentions to the 'field trip' crew, Leny Montheil, Drew Lubiniecki, and Natalia Xie. You all made the days cooped up in the tin can actually a lot of fun. Additional thanks to Francesco Cappuccio for sending us good vibes from Sapporo because he was unable to make the trip and providing us with his classic signature uplifting-yet-sometimes-aggravating phrase: "But why?".

Contents

Introduction

Japan is an archipelago composed of four main islands; Honshu, Shikoku, Kyushu and Hokkaido, where the latter is the northernmost island of the collection. Hokkaido was formed in the Mid-Miocene (Kusunoki & Kurima, 1998) with the collision of the Kuril and NE Japan arc. During the collision the Kuril forearc sliver migrated southwestward (Kusunoki & Kurima, 1998). Hokkaido Island is thus divided into three sections; an eastern region comprising the accreted NE Japan Arc, a central arc collision zone and a western region comprising the accreted Kuril Arc. A volcanic front exists in a line similar to that of the trend of the two trenches, striking east-west before propagating southwards (Hasegawa et al, 2011).

Hokkaido's geology is a manifestation of the complex interaction between the North American plate (Okhotsk), the Eurasian plate, and the Pacific plate. Motion of the Okhotsk and the Eurasian plates from 15Ma separated Japan from Eurasia (Barnes, 2003), giving birth to the Japan and Kuril basins. The movement ceased in the mid-Miocene when the Kuril arc began a westward movement into the Japan arc whilst the subduction of Pacific plate continued to occur. This movement formed the Hidaka Collision Zone, which is regarded as the arc-arc boundary and is found in the centre of the island (Ichihara et al. 2016). The obduction of the Kuril arc on to the Japan arc formed the three main geological belts: the Oshima, Sorachi-Yezo, and Hidaka belt. These north-south trending belts are Jurassic to Palaeogene in age (Kiminami et al. 1986) and present an array of lithologies such as deep-sea sediments, ophiolites, metamorphic rocks and basalt (Kiyokawa, 1992).

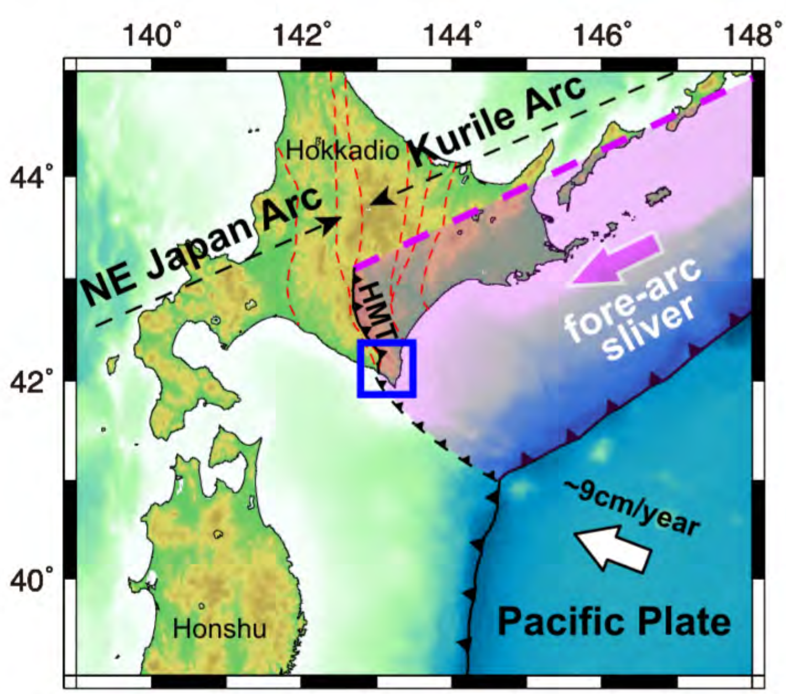

Figure 1: Location of Hokkaido depicting the movement of the active deformation front between the NE Japan arc and the Kurile arc during SE-ward migration of a forearc sliver. The average rate and azimuth of subduction of the Pacific plate is illustrated by the white arrow. The blue box surrounds Cape Erimo (stop 104). The red dashed lines delineate boundaries between geological belts while "HMT" represents the Hidaka Main Thrust (Ichihara et al. 2016).

The field locations presented in this field guide encompass the central and the south-western regions of Hokkaido. Site descriptions are a combination of field observations from our own field excursions during the Hokkaido Summer Institute field trip 2018 and translations from 北海道自然探検- “Hokkaido Natural Explore” (*loosely translated)*, a field guide published by the Geological Society of Japan (2016) which is the inspiration behind this project. This guide is hereinafter cited as the “GSJH field guide”.

Field stop numbers pertaining at each site correspond to field site numbers in “Hokkaido Natural Explore”. We have arranged the site descriptions in the order in which we visited them during a week-long excursion in July 2018. A “how to get there” section has been included for some sites which may be difficult to find (not all sites have this).

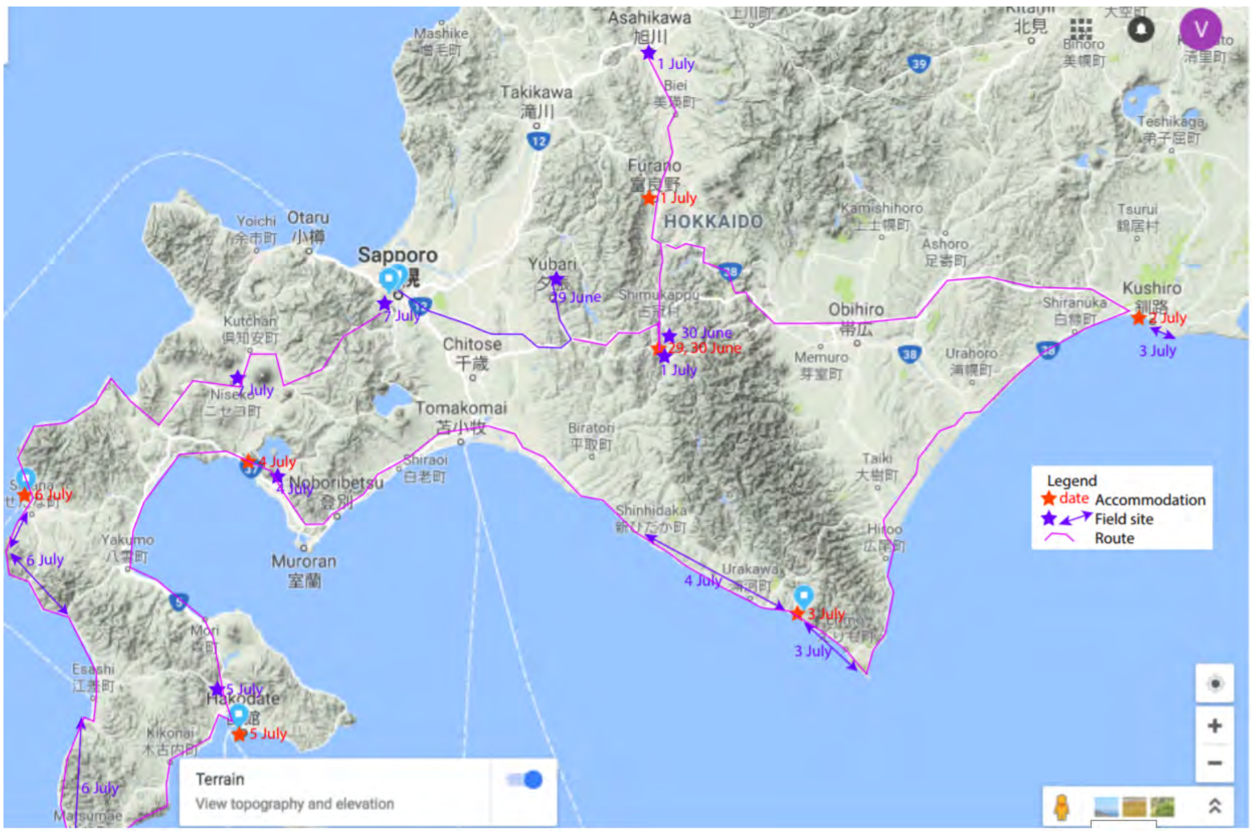

Figure 2: Map showing our original planned field excursion driving route (2018). Deviations were made during the field trip due to time miscalculation and weather conditions. Not all field sites marked on this map were visited and visited sites were spontaneously selected by the group which led to the discovery of other geological sites not in this field guide e.g. Hiratanaiosenkuma Natural Hot Spring.

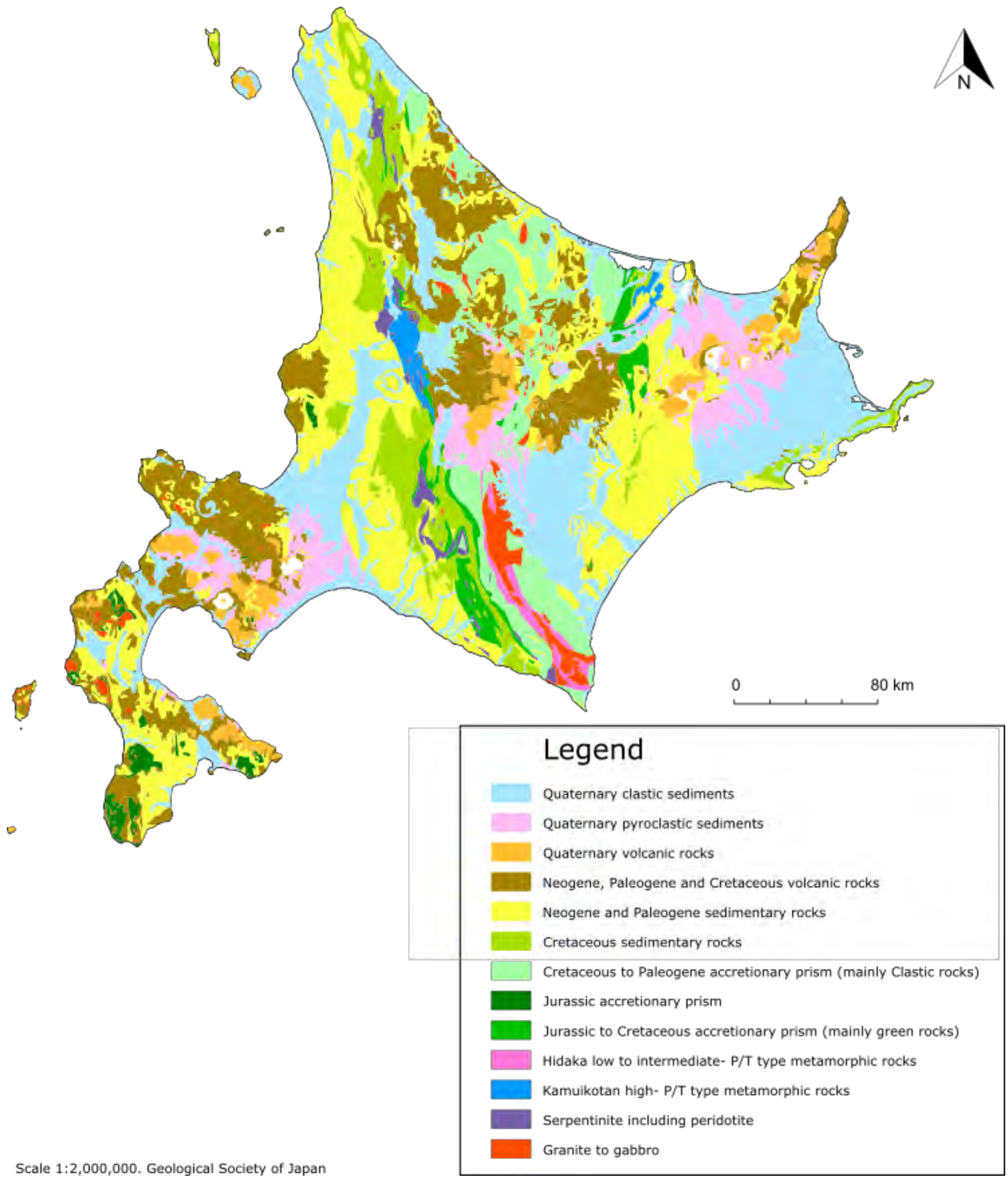

Figure 3: A geological map of Hokkaido published by the Geological Survey of Japan in 1990.

Kawabata Formation - Takinoue Park, Yubari

GSJH field guide: Stop 48
Location coordinates: 42.91166667 N 141.96861111 E

Figure 4: Chidorigataki Falls (千鳥ヶ滝) and (a) Kawabata Formation from (b) suspended bridge NW from the outcrop (accessed 05/09/18: https://good-hokkaido.info/en/takinoue-park-yubari/).

Geological description: The middle Miocene Kawabata Formation is located in the southern basin of the Ishikari-Teisho belt. At Yubari river, aggradational stacking of rhythmic alternating beds of siltstone, laminated sandstone and coarse-grained sandstone can be seen with minor occurrences of upward thickening and thinning trends (Figure 4a). The sandstone layer protrudes outwards while the mudstone layer is more weatherable and appears as a groove. The Kawabata formation in this vicinity is made up of gravity flow deposits that fill the deep basins formed by the Miocene Island collision. The total thickness of the formation reaches 3,000 m.

The dip of the bedding is approximately 60 degrees to the southwest. Since the riverbed is level from the standpoint of the bridge (Figure 4b), the strike and dip of the strata can be easily measured from here. At the bottom of the turbidite sequence, paleocurrent directional sole marks such as flute cast and groove casts may be found. The hyperpycnal sequence is also cut by a number of strike-slip conjugate faults (Figure 5).

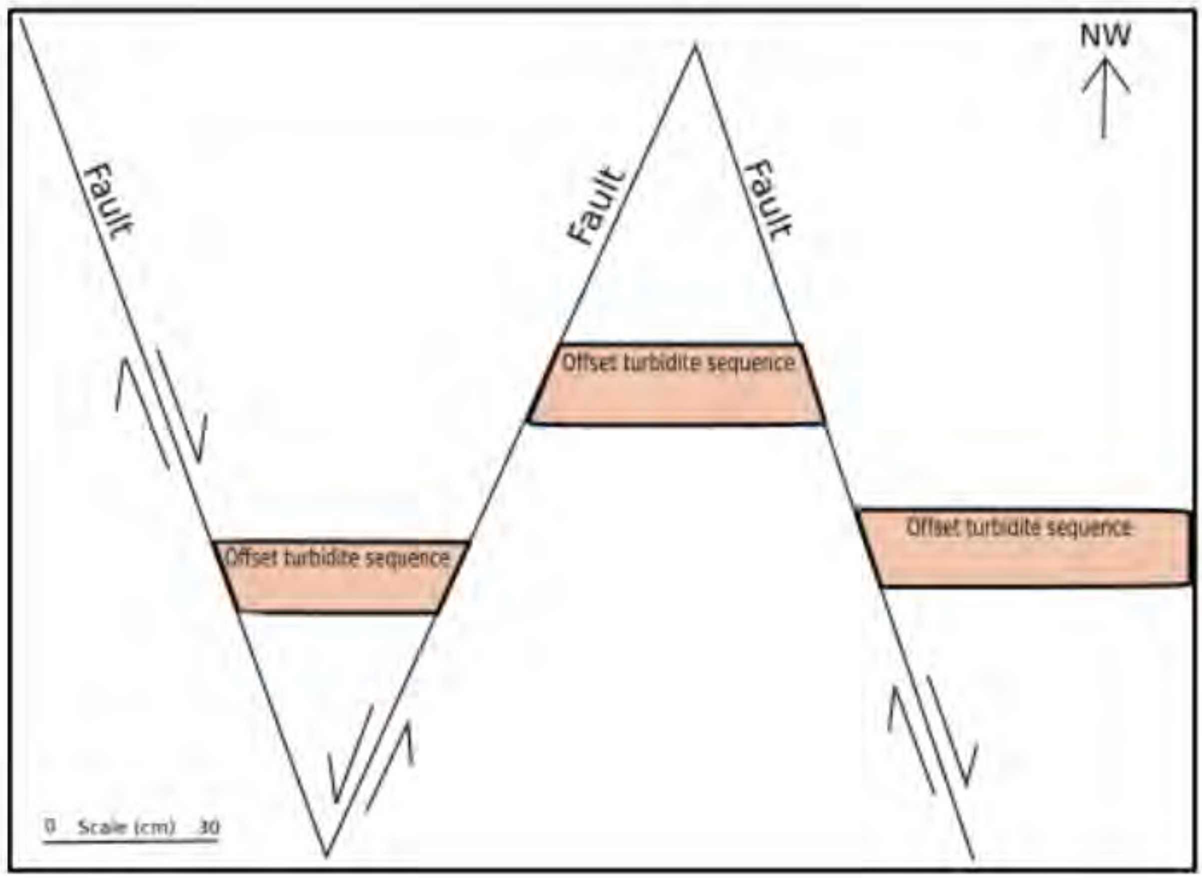

Figure 5: Outcrop sketch of conjugate fault set on top of Kawabata Formation looking NW towards suspended bridge in Figure 4b. Location coordinates: 42° 54.37 N 141° 58.10 E.

How to get there: Takinoue Park in Yubari City is 1 hour 15 minutes to 20 minutes' drive from Sapporo via the Doto Expressway. The site is a 5-minute walk from the JR Takinoue Station and is near the Takinoue Power Plant (滝の上発電所) alongside the Yubari River. There is a free parking lot and restroom around the entrance of the park.

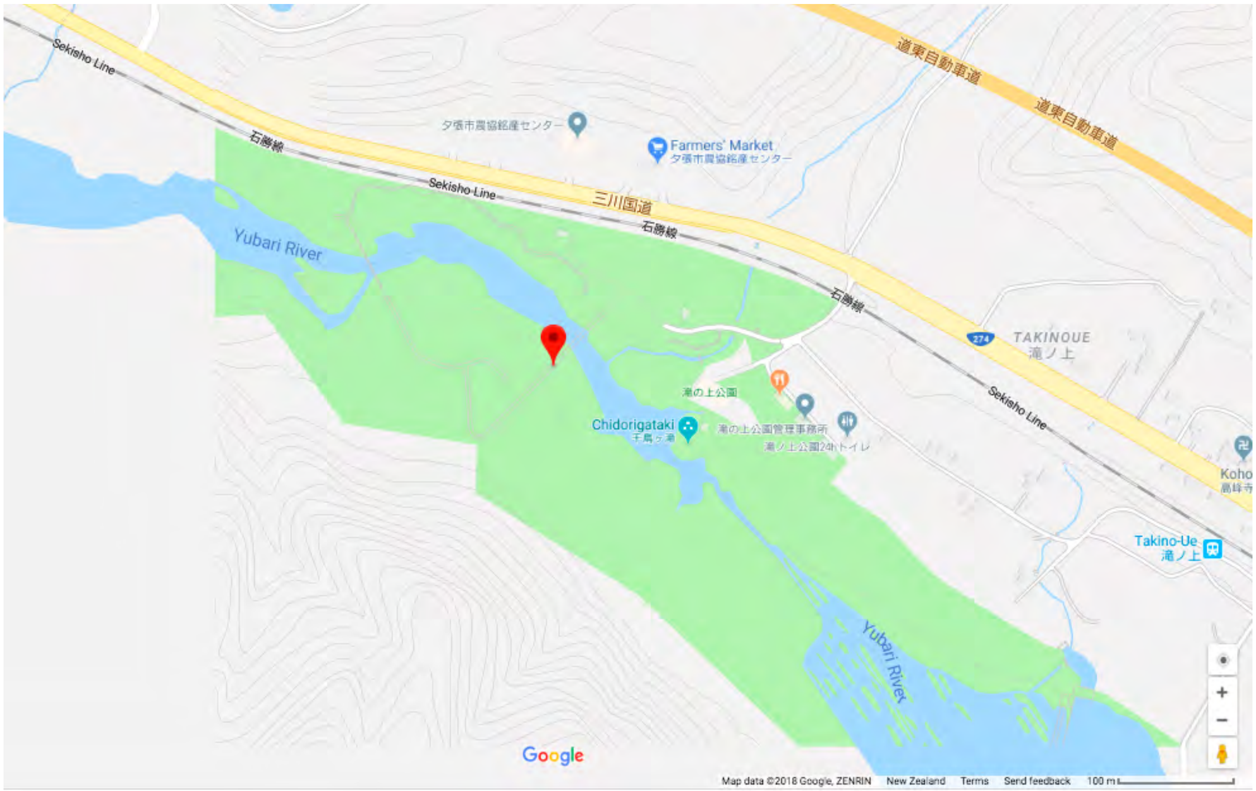

Figure 6: Map with red pin marking the location of Kawabata Formation - Takinoue Park, Yubari (Google Maps).

Asahikawa: Kamuikotan Suspension Bridge

GSJH field guide: Site visited but not in field guide
Location coordinates: 43.732343 N, 142.201258 E

Figure 7: Kamuikotan Suspension bridge (accessed 06/09/2018: http://map.uu-hokkaido.jp/e/asahikawa-kamuikotan/ , CEDARS Communications Co. Ltd.).

Geological description: The Kamuikotan Suspension Bridge (Figure 7) is located over the Ishikari River in Kamuikotan Valley and is part of the of the Sorachi-Yezo belt. Kamuikotan in the ancient Ainu language is literally translated as "Divine Settlement" and this is a sacred area to the ancient Ainu people. A large piece of amphibolite is also displayed next to the main road.

The most noticeable geological features in this area are the large, disharmonic, parasitic folds clearly visible below the Kamuikotan Bridge. The asymmetric folds are compressed in an E-W fashion affecting three main rock types: green-schist, calcareous-schist and pelitic-schist. The three schists are part of the Kamuikotan accretionary complex (Hasegawa et al. 2011) which experienced subduction-related high-pressure and low-temperature metamorphism. The green-schist initially, was blue-schist but experienced retrogression during exhumation. This mafic schist contains chlorite, epidote and actinolite minerals with prevalent quartz veining. Out of the three units, the marble unit was the thinnest with a thickness of up to 1m. Rabbit ear folding and boudins can also be observed in this area (Figure 8).

Strike and dip measurements were taken along various points of the fold and plotted onto a stereonet as shown in Figure 9. We were able to discern the approximate orientation of the fold hinge line by plotting the strike and dip measurements as poles to planes and fitting a great circle to these points.

Figure 8: A rabbit ear fold is exhibited at the apex of this marble fold, the exterior unit outside of this fold is the green schist.

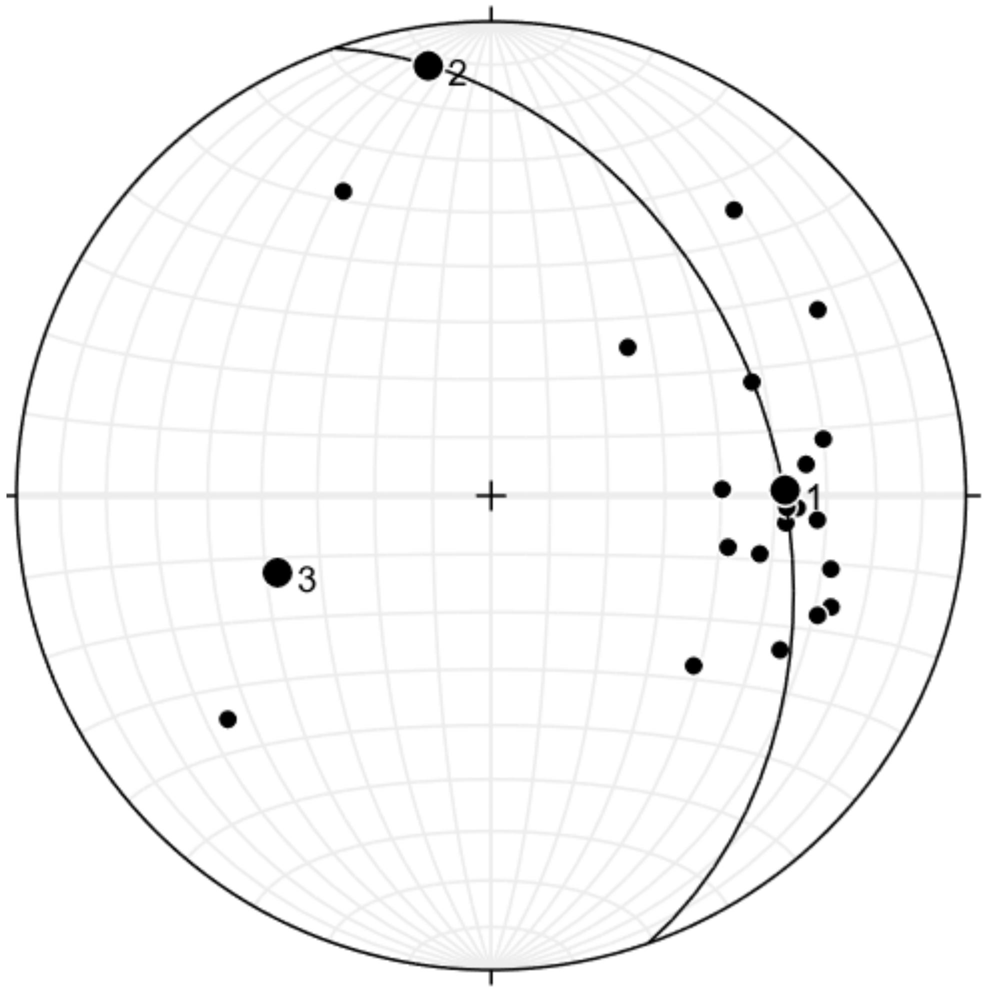

Figure 9: Equal area, lower hemisphere stereonet demonstrating poles to folded layers in outcrops beneath the Asahikawa suspension bridge. The best-fit great circle, which is the profile plane to the average fold, has a strike and dip of 340/39 (right-hand-rule). This composite structure has a hinge line (labelled ‘3’) oriented 50/250. The program Stereonet 10.0 (Allmendinger, 2018) was used to construct this plot.

Okotsu Beach - Kushiro

GSJH field guide: 82
Location coordinates: 42.956598 N, 144.412129 E

Geological description: This field stop is located in Kushiro city, in the Kushiro subprefecture with a population of approximately 175,000 (Statistic Bureau Japan 2015). The rocks found in this area are part of the Tenneru and Yubetsu Formation, and Otanoshike Formation of Oligocene and Pleistocene age respectively (Geological Society of Japan 1970). The Tenneru and Yubetsu formation primarily consists of alternating units of sandstone and mudstone, with sandstone being the younger unit (GSJ 1970). Further inland from the beach there are Quaternary deposits (Otanoshike Formation) made up of sand and gravel and (Kutcharo) dacitic pumice flow deposits.

With almost horizontal bedding, the outcrop at this location (Figure 10) shows sandstone bedding with angular clasts up to 1 cm in diameter, alternating with mudstone units. Coal seams of up to 5 cm can be viewed here as well. Each unit is approximately 1 m thick. Confined in the sandstone units are thin units of distinct matrix-supported conglomerate layers (~30 cm) (Figure 11), with increasing clast size as you go downward in each layer. This increase in size possibly suggests a debris flow of a small magnitude where size sorting was able to occur. Clasts such as chert and amber are identified. Ripples and flame structures can also be seen.

Figure 10: Heavily weathered surface of the Okutsu Beach outcrop showing the bedding between the two sandstone and mudstone layers with a 5cm thick coal seam. Compass against coal seam used for scale.

Figure 11: The above photo shows the thin conglomerate layer found in the sandstone. Clasts are angular and gradually decrease in size towards the base of the layer. A6 notebook used for scale.

Ogon Road Landslides

GSJH field guide: 107
Location coordinates: 42.251665 N, 143.309170 E

Figure 12: Aftermath of the Ogon Road landslide (photo taken in 2018).

Geological description: The rugged sea cliffs along the Ogon Road coast stand at around 250 m high. The main body of these cliffs consists of a Cretaceous to Paleogene aged accretionary prism of interlayered sandstone and mudstone beds with various granitoid intrusions. The first part of the Hidaka complex has been metamorphosed into a hornfels facies. Along the non-metamorphosed part of the Hidaka belt in the vicinity of the Bihoro coastline, slope failures occur mainly from the top of the slope where the lithology is brittle, non-metamorphosed sand and mudstone (e.g. Figure 12). Thus, the size of the falling rock mass is small, the collapsed earth and sand fragments as it falls, the road covered by the rockfall is not destroyed and there is generally very little damage.

The scale and impact of the slope failures and the size of the rock masses that collapse tend to increase along the Uenbetsu area of the coastline where there is hornfels metamorphism. The section that collapsed on the 13th January 2004, was 100 m high by approximately 90 m wide and contained an estimated total volume of 42,000 cubic meters. The ridges protruding along multiple cracks in the hornfel-rich rock collapsed on a large scale. In this landslide the road was completely destroyed and there was one casualty.

How to get there: Drive south along route 336 (otherwise known as Ogon Road) from the town of Bihoro (Figure 15). Landslides will be visible along the way.

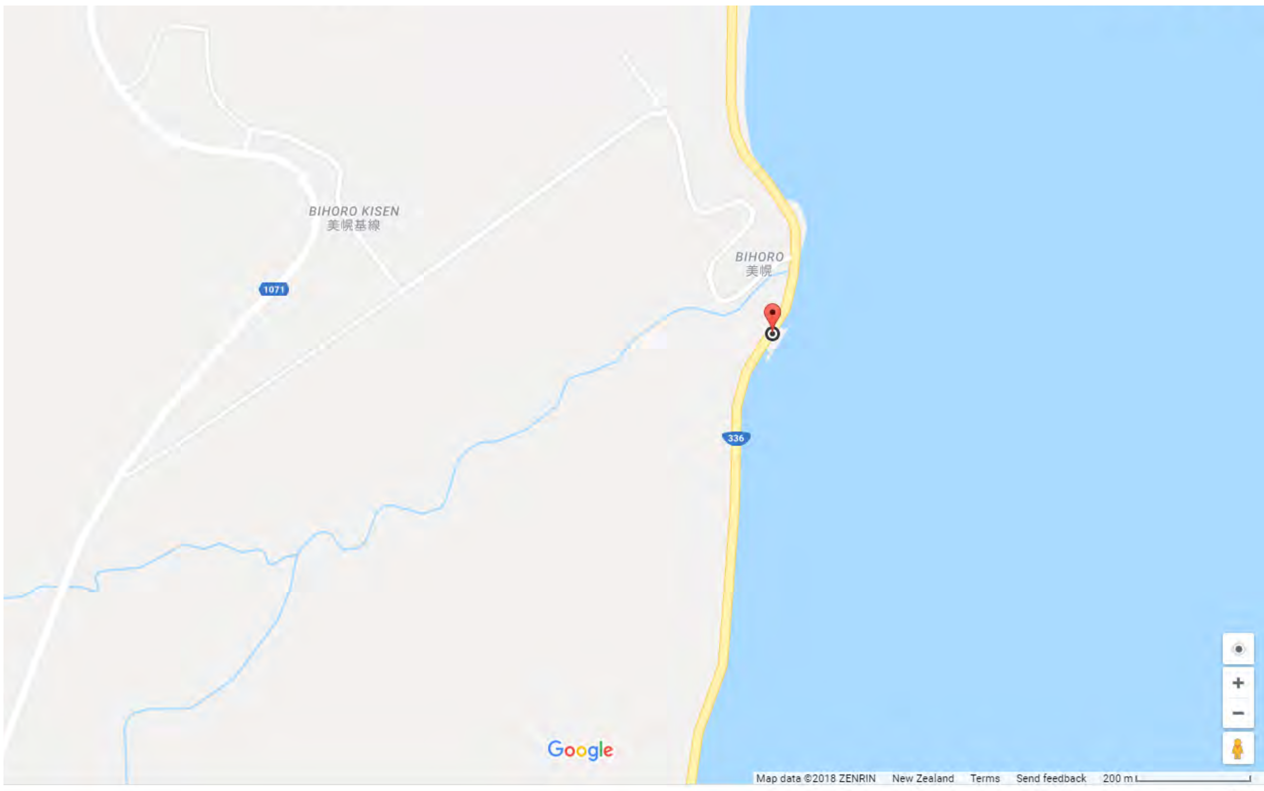

Figure 15: Map with red pin marking the location of a landslide along Ogon Road.

Matsumae Orito Beach

GSJH field guide: 35
Location: 41.435197 N, 140.064262 E

Figure 14: *(Geological Society of Japan – Hokkaido, 2016).* An example of rip up clasts that can be found within the turbidite sequence at Orito beach. The dark coloured mudstone clasts can be seen within the thick, lighter coloured sandstone layer. This photo has been taken from the GSJH field guide so the orientation and scale of the outcrop is unknown. The photographer was Dr. M. Kawamura.

Geological description: The rocks along Matsumae Orito Beach are Jurassic trench-filled sediments of alternating sandstone and mudstone beds. The strata were deposited by turbulent mud flows into a paleo-subduction trench. The sandstone that formed in the sandstone-mudstone interlayer of the Oshima belt has been brought from the margin of the Asian continent. These sediments have been brought together with the motion of a subducting oceanic plate to form an accretionary wedge. Among the sandstone - mudstone layers that are exposed just opposite the parking lot at Orito Beach are very coarse and thick turbidite sandstone packages. However, within these strata can also be seen many very thin, fine grained alternating mudstone and sandstone layers with a striking striped pattern. In some places it is also possible to see depositional deformation structures, such as rip-up clasts (Figure 14).

How to get there: Drive west from the town of Matsumae on route 228. As you drive you will come to two consecutive river crossings, just before you cross the first river is a carpark for Orito beach. The outcrops are easily accessible from this carpark (Figure 15).

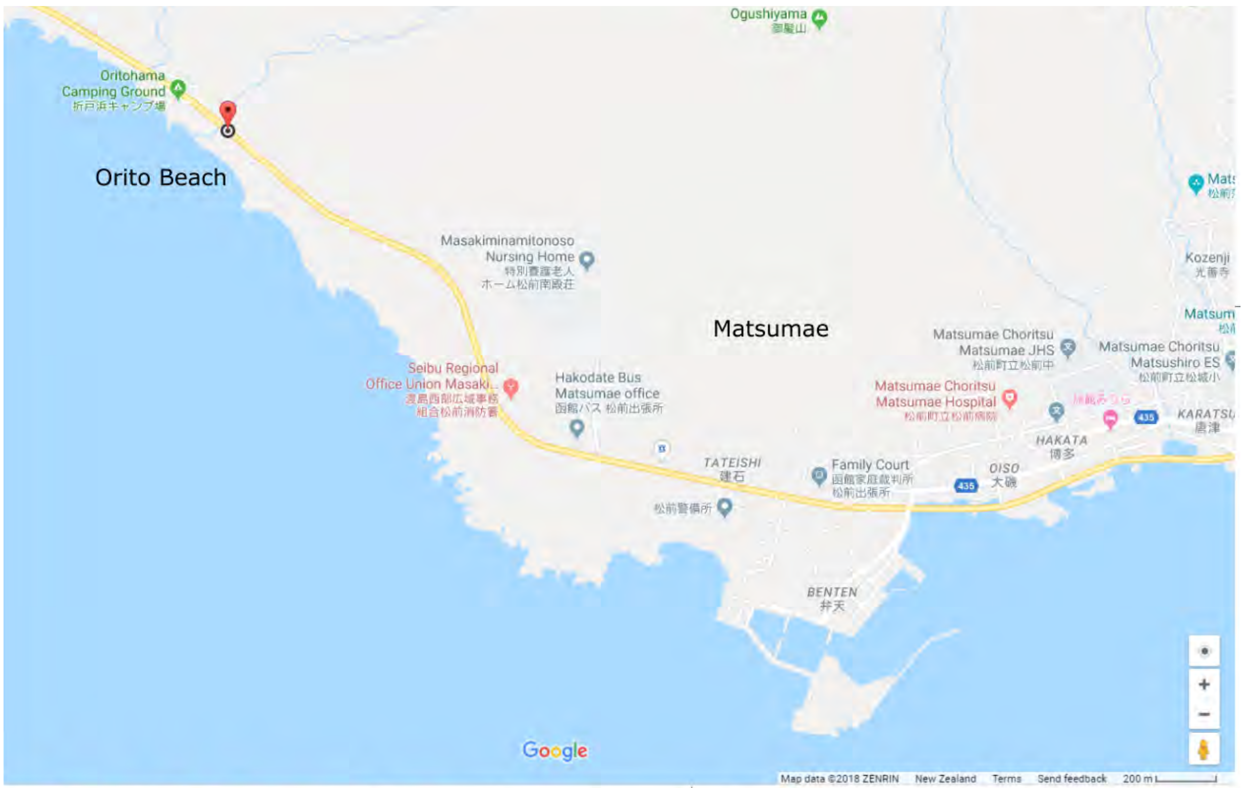

Figure 15: Map marking location of Orito Beach (Google Maps).

Cape Erimo

JSGH field guide: 104
Location coordinates: 41.925107N, 143.249576E

Figure 16: View from Cape Erimo.

Geological description: Cape Erimo (Figure 16) is found in the central south position of Hokkaido (Figure 17). This area is heavily studied since it is the point closest to the triple junction that is found further south where the junction is composed of the Kuril arc and the NE Japan arc. The triple junction was formed by the collision of the Kuril Arc along the southern margin of the Okhotsk plate with the eastern side of the Asian continental margin (Kurima, 1994). Much of the tectonic activity in Hokkaido is associated with the triple junction, where the exhumation of the Hidaka metamorphic rock group is linked with the movement of the Kuril forearc at the junction approximately 12Ma (Kusunoki & Kimura, 1998). A WNW trending, dextral strike-slip fault known as the Horoizumi Fault is found 12 km north of the cape.

The area exhibits two main groups known as the Hidaka supergroup and the Erimo Formation. The Hidaka supergroup is made up of layers of sandstone, mudstone and calcareous nodules and is found north-east of the fault. The rocks found close to the Horoizumi Fault are cataclastically deformed with networks of calcite and quartz veins (Kusunoki & Kimura, 1998). The Erimo formation, exposed on the west side of the cape, can be further divided into a lower conglomerate member (of sandstone and mudstone) and an overlying turbidite layer. The turbidite layer shows evidence of heavy deformation with asymmetric folding, en echelon gashes and crenulation folds. The sandstone in this unit displays precipitated biotites, chlorite and muscovites between grains (Kusunoki & Kimura, 1998).

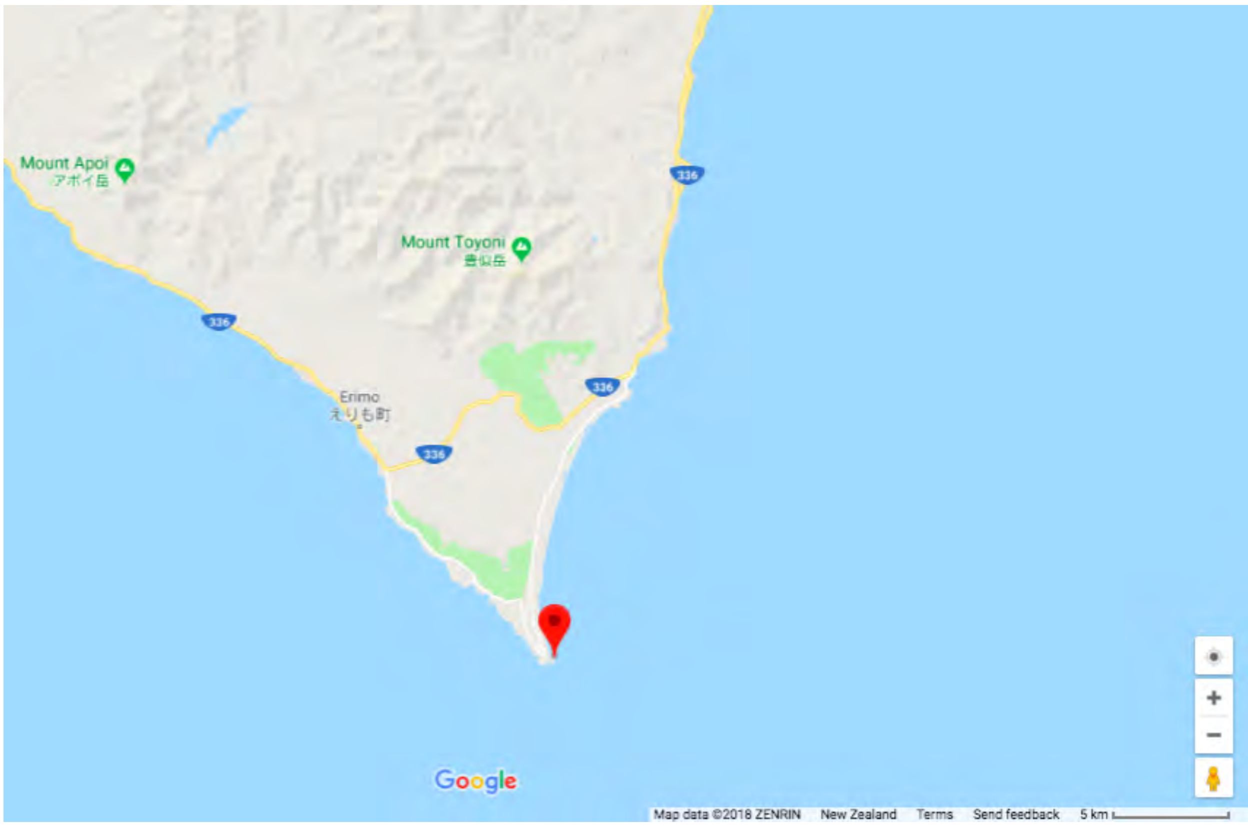

Figure 17: Map with red pin marking the location of Cape Erimo (Google Maps).

Outcrops of the Hidaka Belt exposed at the Coast - Ruran Reef

GSJH field guide: 106
Location coordinates: 42.030297 N, 143.288572 E.

Figure 18: Sequence of alternating units of sandstone, mudstone with thin lenses of shale. Two cross cutting faults can be seen in the bottom left of the photo. Red stars indicate the two lenses of shale above and below the fault we used to determine the approximate maximum offset distance (yellow A5 geological notebook used for scale).

Geological description: At this location there is a high energy beach with outcrops and large pebbles consisting of rock derived from the Hidaka Mountain belt such as: metamorphic biotite gneiss, green-schist, and igneous rocks like biotite granite and granodiorite (Geological Society of Japan, 1970). Sedimentary sequences such as sandstone and clayslate found in this area are part of the Nakanogawa group - a subgroup of the pre-cretaceous Hidaka super-group. Figure 18 displays a sequence of alternating fine-grained sandstone/mudstone units. Layers contain lenses of shale of up to 3 cm thickness. Rip up clasts of schists (~10 cm) can also be found within these units. The large faults that can be seen on these outcrops are apparent reverse faults with an offset of ~55 cm. The faults shown in this figure have a strike and dip of 300/48 NE and 165/55 NE.

Further south along the beach, large gneiss outcrops can be seen (Figure 19). These exposures are heavily fractured with quartz veining and conjugate faulting prevalent throughout all the rocks. Coarse biotite-feldspar minerals and retrograde garnet can be observed. These rocks suggest formation under high temperatures and pressures and exhumation to lower pressures accompanied by fluid flow along fractures including fluid-related alteration and quartz vein formation as well as phase melting due to the presence of pegmatites. A close-up of this outcrop can be seen in Figure 20.

Figure 19: Gneissic exposure further down the beach. Within this heavily fractured rock, distinct phase melting can be seen as well as basaltic enclaves/xenoliths. The photo points out some of these enclaves

while the basaltic xenoliths are not labelled since they are too small to be labelled individually and can be distinguished as black fragmented specks in the photo (yellow A5 geological notebook used for scale).

Figure 20: A close-up of the gneissic outcrop shown in Figure 21. Basaltic xenoliths, quartz veins, and fractures and faults are clearly visible (pencil used for scale).

How to get there: Drive along the Erimo National Road (Route 336) until you reach a fork in the road with a road (Route 34) leading to another part of the Horoizumi district. This beach site is just 1.5 km south of the town of Shoya (Figure 21).

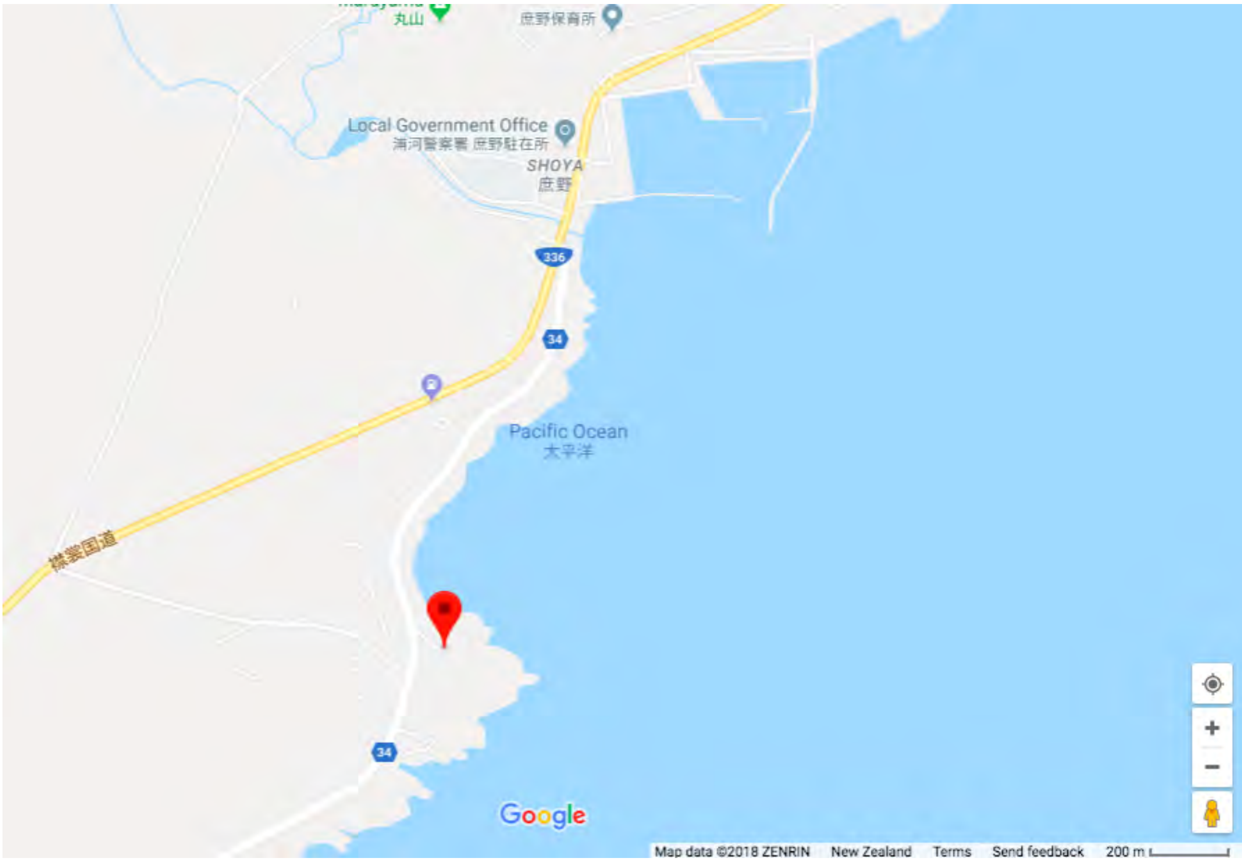

Figure 21: Map with red pin marking the location of Hidaka Belt outcrops exposed at the beach - Ruran Reef (Google Maps).

Mount Apoi

GSJH field guide: Site visited but not in field guide
Location coordinates: 42.111821 N, 142.988620 E

Geological description: Mount Apoi is an 810.2m high mountain found near the fishing town of Samani and is the southernmost tip of the Hidaka Mountain Range (Figure 22). It is home to an extensive variety of flora and fauna, many of which can only be found in Hokkaido such as the *betula apoiensis*. The significance of this area is its large peridotite mass called the Horoman Peridotite. The ultrabasic peridotite provides special conditions for such unique flora to blossom (Geoparks Japan).

Mount Apoi was formed approximately 13 million years ago, during the collision boundary of the Okhotsk (North American) and Asian (Eurasian) plate. At this time, the Horoman peridotite was thrust upwards to the surface from a maximum depth of 60 km in the upper mantle. The Horoman Peridotite Complex also includes: dunite, harzburgite, lherzolite and plagioclase lherzolite (GeoParks App Japan), indicating partial equilibration to lower pressures and temperatures as it was exhumed.

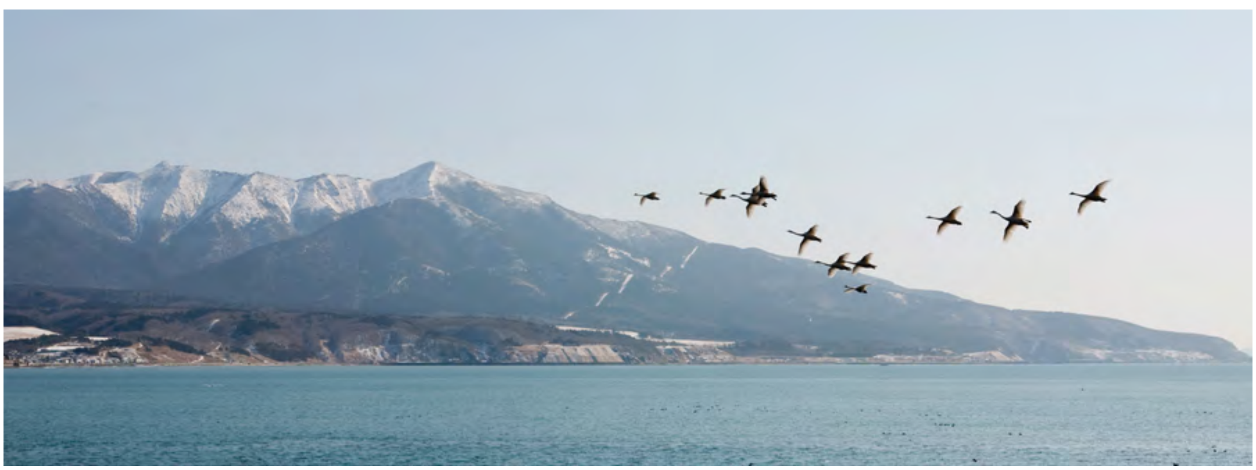

Figure 22: Mt. Apoi, the southernmost tip of the Hidaka Mountain Range (accessed 10/09/2018: http://www.globalgeopark.org/aboutGGN/list/Japan/10129.htm)

Horoman Dam - Peridotite Complex

GSJH field guide: Site visited but not in field guide
Location coordinates: 42.125207 N, 143.068677 E

Figure 23: The Horoman dam.

The Horoman Dam (Figure 23) is located at the Northern end of the Horoman Peridotite complex creating the man-made lake Horoman (Figure 24). Upstream of this point; the topography changes becoming smooth due to a change in the underlying rock type from peridotite to metamorphosed plutonic rocks like amphibolite and gabbro. The dam found in Horomankyo Gorge, was built in 1954 and provides approximately 10,000kW/pw of electricity. Further down the track along the river, sheared metasedimentary rocks can be seen. Quartz veins and augenclasts (i.e. eye-shaped clasts) can be observed in these rocks.


Figure 24: Man-made lake formed by the construction of the Horoman Dam.

The Horoman-gawa Inari Shrine can be found further down the road. This red shrine is at the top of a set of narrow and steep stairs (Figure 25). In this area, fractured, bedded exposures can be seen along the banks of the river. The predominant peridotite found is plagioclase lherzolite (Figure 26). Some of these peridotites are serpentinized and can be identified by the dark blue colour of the rocks.

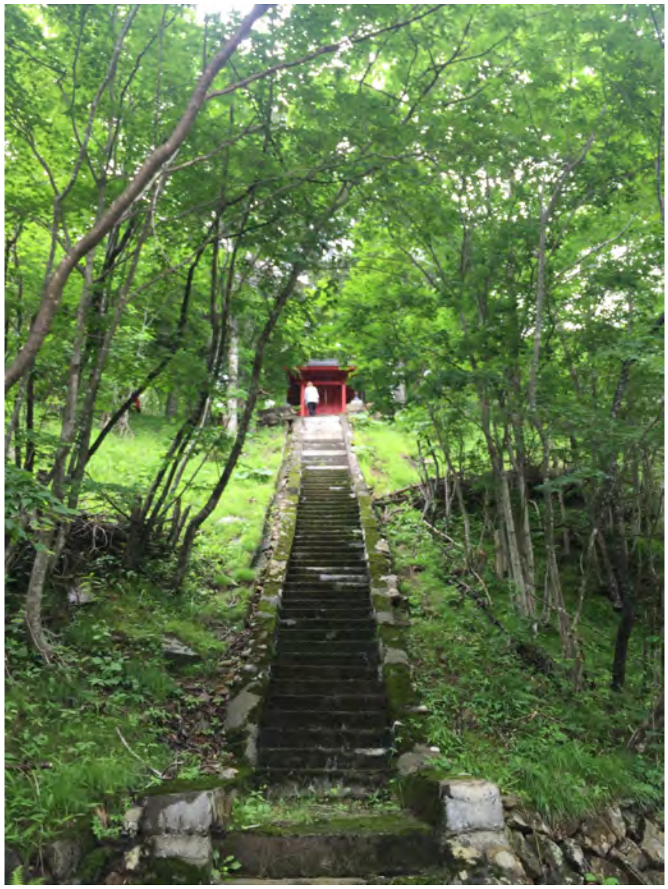

Figure 25: Horoman-gawa Inari Shrine is located at the top of this long narrow set of stairs.

Figure 26: Deeply fractured plagioclase lherzolite found along the riverside. A juvenile mamushi serpent, a poisonous pit viper found in Hokkaido is nestling in the crack adjacent to serpentinized peridotite.

Toya Caldera and Usu Volcano - Shikotsu-Toya National Park, Abuta District Mount Usu

Location coordinates: 42°32'17.4"N 140°49'54.4"E
Footpaths map available on 'Geoparks Japan - powered by Stroly' mobile app

Figure 27: Showa-shinzan at the foot of Mount Usu - active volcano in Shikotsu-Toya National Park, Hokkaido (accessed: 07/09/18, https://asian-images.photoshelter.com/image/I00002S.0Vo1FU0A).

Geological Description: The stratovolcano Mount Usu lies on the southern rim of the Lake Toya caldera. It is one of the most active volcanoes in Japan and has erupted four times within last 100 years (in 1910, 1944, 1977 and 2000).

1910: An eruption produced hot springs at the northern foot of Usu, right by Lake Toya. These now form the basis of Toyako Onsen, a large and very popular hot spring resort with several big luxury hotels.

1944 and 1945: Eruptions created a new mountain at the foot of Usu in what was previously a flat wheat field. This mountain was named Showa-shinzan, meaning 'Showa [the name of the emperor at the time] new mountain'. Now it is a rocky lava dome of reddish rock, which still sends out clouds of sulphurous steam (Figure 27).

2000: Usu's most recent eruption that lasted for five months. It was focused on the west side of Usu, where it created more than 60 new craters. A series of earthquakes over the four days before the eruption began gave enough warning for local people to evacuate. There were no casualties, but there was plenty of damage to buildings and roads. Usu is unusual in that every time it erupts, it radically deforms the land around it, ripping through roads, and creating brand-new hills and valleys. A decision was made to leave the ruins from this last eruption untouched, so that visitors to Usu could witness the power of the volcano first-hand.

Mount Usu - sites of interest:

1. Learn more at the **Toyako Visitor Center and Toyako Volcano Science Museum** (Figure 28): 142-5 Tōyakoinsen, Tōyako-chō, Abuta-gun, Hokkaidō 049-5721, Japan. N.B There is an admission fee to the Toyako Volcano Science Museum.

Figure 28 Toyako Visitor Centre and Volcano Science Museum (accessed 07/11/18: https://ikidane-nippon.com/en/interest/lake-toya).

2. Kompirayama Walking Trail (~40 minutes): This trail starts behind the Toyako Visitor Center and leads to the Nishiyama parking lot. Along the way, you can see various ruins, including a destroyed public bath house, apartment block and bridge. The trail also passes two of the largest craters from the 2000 eruption (Figure 29), as well as large erosion control dams.

Figure 29: Yukun crater on the Kompirayama Trail (accessed 07/09/18: https://footprintsaroundtheworld.com/lake-toya/).

3. Nishiyama Crater Walking Trail (~40 minutes return): From the Nishiyama parking lot, the Nishiyama Crater Walking Trail leads to some more of the newly created craters from the 2000 eruption. Several destroyed buildings, disrupted roads (Figure 30 and broken phone poles have been left untouched for visitors to witness the destructive power of the volcano. Download the mobile app 'Geoparks Japan - powered by Stroly' for brief descriptions of sites.

Figure 30: Nishiyama Crater Walking Trail - Road disrupted during the Mt. Usu's latest 2000 eruption.

Toya Caldera and Usu Volcano - Shikotsu-Toya National Park, Abuta District

Lake Toya

Location coordinates (Toyako Onsen township): 42°33'54.8"N 140°49'27.8"E
Footpaths map available on 'Geoparks Japan - powered by Stroly' mobile app

Geological description: Lake Toya is a nearly circular volcanic caldera lake formed by an eruption 110,000 years ago (Figure 31). In the Toya region, surface rocks overlie the Osaru-gawa formation basement rocks, formed in middle Miocene. The volcanic depression was formed in the late Pleistocene (~30,000 years ago), accompanied by ejection of a huge amount of dacite pumice. After the formation of the caldera in the latest Pleistocene, the Naka-jima lava dome group was formed at the center of Toya caldera as central cones. Then, in the early Holocene, Usu volcano started its activity on the southern rim of the caldera (Nishida, 1984).

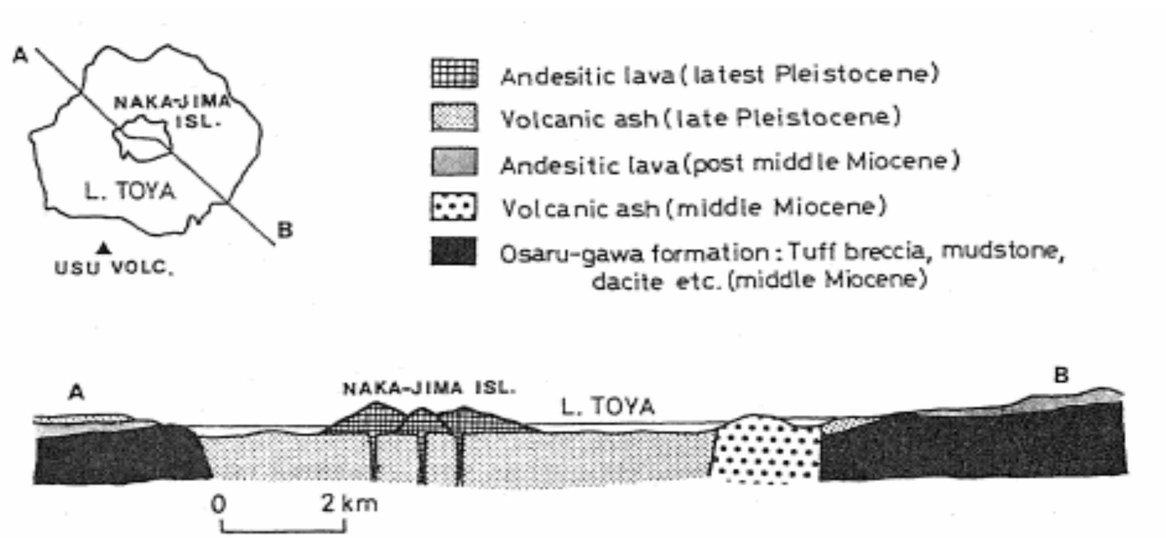

Figure 31: *(Nishida 1984)* Geological cross section of Toya caldera.

Toyako Onsen (洞爺湖温泉, Tōyako Onsen) is a touristy hot spring resort town located along the south shore of Lake Toya, just at the foot of Mount Usu. Several large luxury hotels stand right alongside the lake, offering views of the lake. Visitors who are not guests at the hotels can still use some of the baths during the day for a fee of 500 to 1000 yen.

Oshima Ono Fault

GSJH field guide: 33
Location coordinates: 41.897352 N, 140.635963 E

Figure 32: Oshima Ono reverse fault with hanging wall on the west (left) and footwall on the east (right). The topographic expression of reverse faulting has been accentuated by earthworks here.

Geological description: Oshima Ono is a reverse fault (Figure 32) where the west side is the hanging wall, and the east side the footwall. The fault crosses the Ono river in a north-south orientation. The terraces along the Ono river are cut by faults. Repeated faulting and accumulation of displacement have created a large winding fault scarp. An example of this is the fault scarp that cuts through the stairway to the Shinto shrine. At this shrine location it can be seen that a gravel layer in the scarp was vertically displaced by approximately 3 m (refer to photograph 1 in the GSJH field guide) (Geological Society of Japan – Hokkaido, 2016). It is thought that this displacement involved two separate incidents around 12,000 to 17,000 years ago (late Pleistocene). The fault continues through a field to the south of the shrine where a gravel layer dated at 40,000 years has been displaced by approximately 9 m. Furthermore, on the southern side of the town (area Ni Chome) the accumulated displacement reaches a height of 25 m (photograph 3 in GSJH field guide) (Geological Society of Japan – Hokkaido, 2016). On the other hand, at locations further to the west of the town from the suburbs of Hachironuma to Fumizuki, several rows of faults have caused uplift accompanying the activity of the Oshima Ono fault. The land sandwiched between both faults continued to rise with the fault activity, creating Mount Kannon. A trench survey was conducted on the fault by Hokkaido University of Education in 1995 (photograph 2 in the GSJH field guide) (Geological Society of Japan – Hokkaido, 2016).

How to get there: From Hakodate-Hokuto station, drive south along route 262 and onto 227 (approximately 4 minutes drive) until you reach a shrine on the right-hand side of the road (Figure 34). The fault scarp is visible from the Shinto shrine. The scarp is also visible at multiple locations south of the shrine.

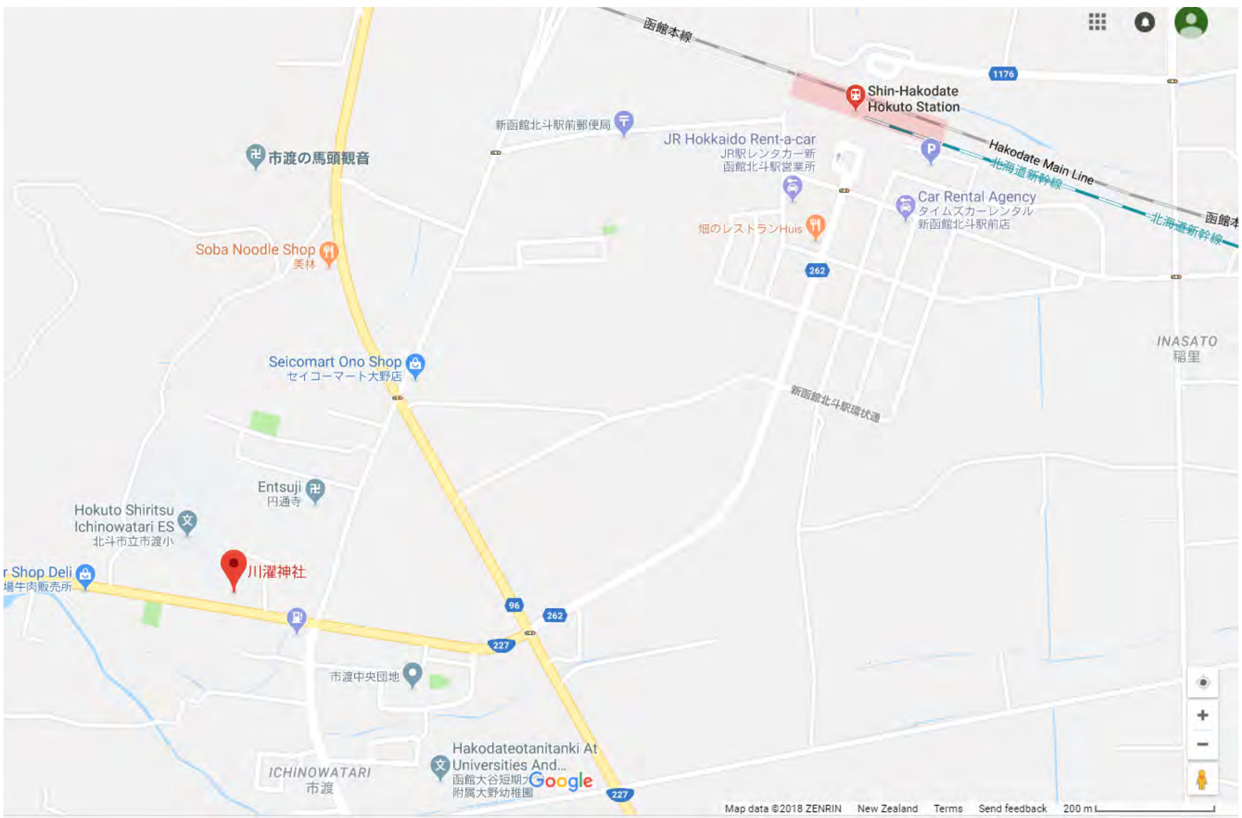

Figure 33: Map with red pin marking the location of Oshima Ono fault at Shinto shrine (Google Maps).

Figure 34: Shinto Shrine - Hakodate-Hokuto. The staircase to the shrine rises up the Oshima Ono reverse fault scarp.

Chalk Cliffs - Cape Tatenosaki

GSJH field guide: 39
Location coordinates: 41.978394 N, 140.130662 E

Figure 35: "Chalk Cliffs" - Cape Tatenosaki. These are actually composed of felsic, tuffaceous siltstone.

Geological description: White and black striped cliffs that are up to 50 m high (Figure 35). On the sea cliffs around Cape Otobe the layers of nearly horizontal strata are splendidly exposed. In the information board in the town of Otobe these are called "Hakua no gake", the "Chalk Cliffs" because they look similar to the chalk cliffs of the Dover Strait. However, the outcrop comprises alternating layers of Pliocene aged felsic, tuffaceous sandstone, siltstone and conglomerate rather than chalk. The siltstone contains a remarkable amount of diatomaceous biogenic material. The conglomerate layer is black in appearance and its structure is considered to be a gravity flow sediment. A slumped layer with a thickness of several meters within these layers indicates these layers were deposited on a paleo-seafloor slope.

How to get there: Follow route 229 north from Otobe towards Yakatano. Just before you drive through the Tatenosaki tunnel the cliffs will be in full view (Figure 36).

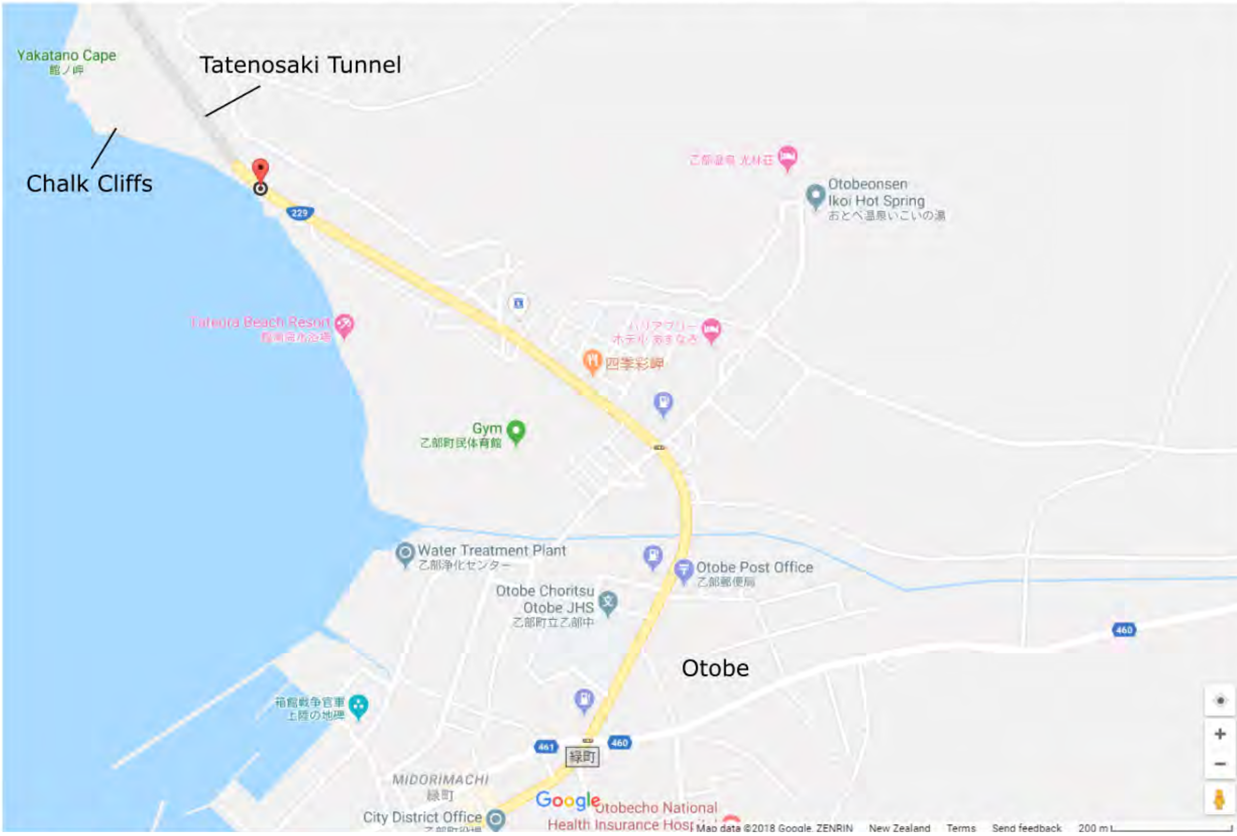

Figure 36: Map with location of 'Chalk Cliffs' - Cape Otobe (Google Maps).

Andesite Columns – Cape Shibinosaki

GSJH field guide: 40
Location coordinates: 42.039975 N, 140.086154 E

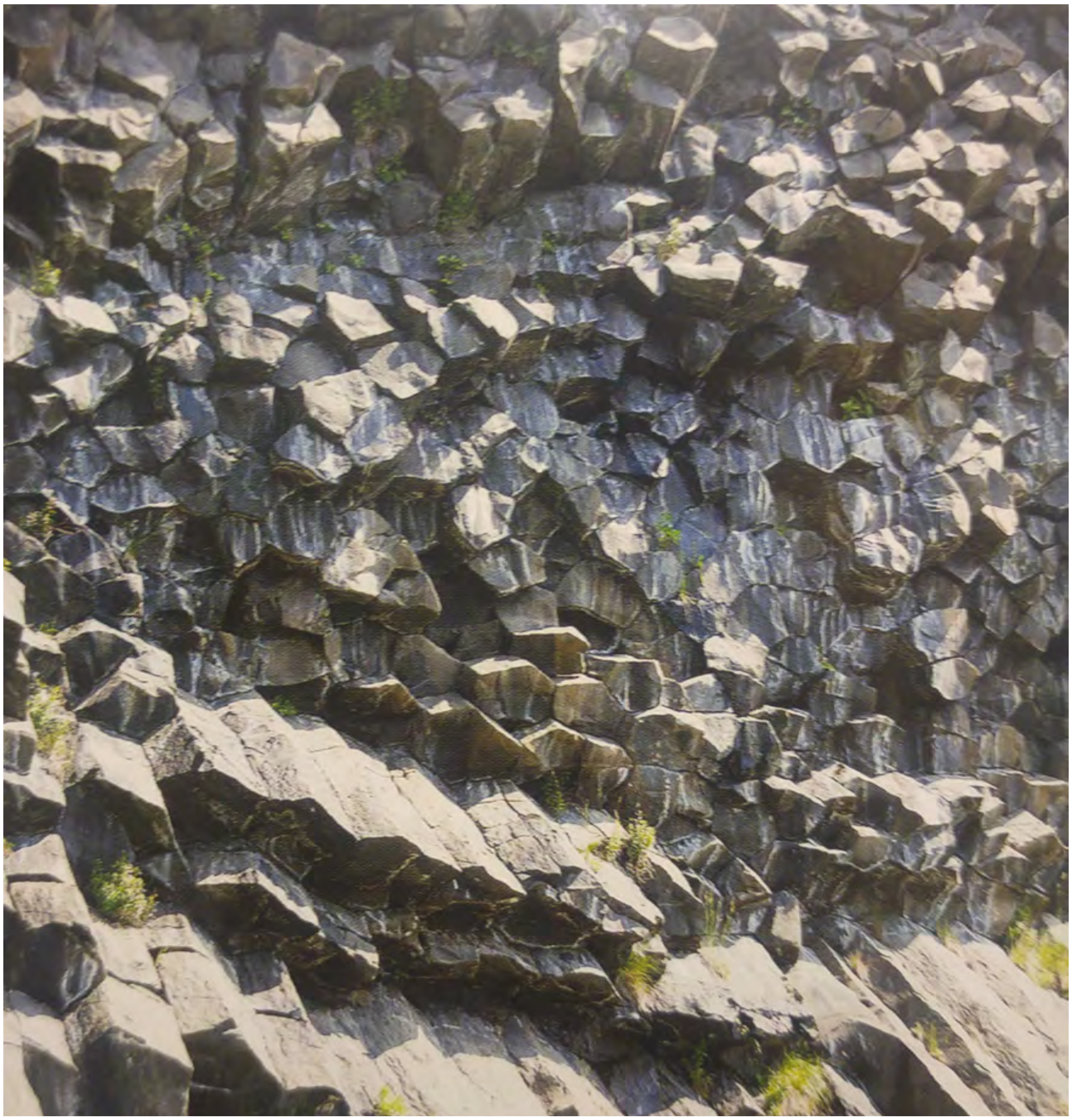

Figure 37: (Geological Society of Japan – Hokkaido, 2016). The andesitic columnar joints at Shibino Cape. The top of the outcrop surface is curved convexly towards the lower right and shows a perpendicular cross section while the lower part shows a vertical cross-section of the joints. The photographer was Dr. M. Kawamura.

Geological description: The columnar joints at Shibino Cape are made of andesitic lavas of the Miocene Tobbu volcanic rocks (Figure 37). Due to their rare pristine formation, the columnar joints here are a natural treasure of Hokkaido. When looking at the cape from a distance, it seems that the columnar joints are like a two-tiered stack from two different lava flows on the upper and lower levels. As you approach the outcrop it appears that the joints are curved into one lava flow where a vertical cross-section is visible at the lower part of the outcrop and a perpendicular cross-section in the upper part (Figure 37).

Columnar joints are like pillars created in volcanic rock. They are formed because the volume decreases when a high temperature magma cools. In the case of lava, the direction of the pillar's cut surface often indicates the direction in which the lava flowed. With the lava flow at Shibino Cape, the lower stage of columns from the two-tiered joint pile flowed almost horizontally and cooled down from the top and the bottom, whereas in the upper stage it was considered to have cooled from the sides.

How to get there: Just south of the town of Hanaiso along route 229 lies Shibino Cape (Figure 38). The basalt columns are visible on the seaward side just north of the cape.

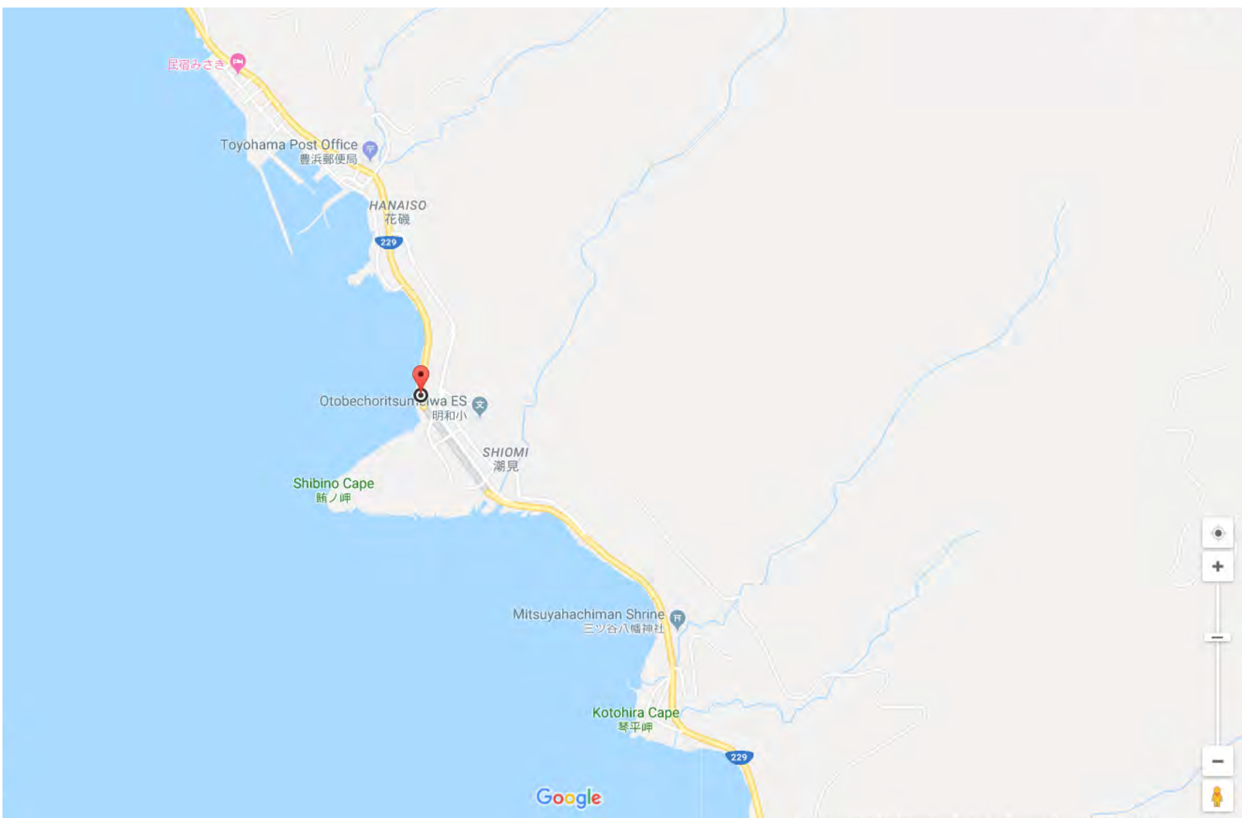

Figure 38: Map with red pin marking the location of the andesitic columnar joints at Shibino Cape (Google Maps).

Hiratanaionsenkuma Natural Hot Spring

GSJH field guide: Site visited but not in field guide
Location: 42.162167 N, 139.997716 E

Figure 39: Hiratanaionsenkuma Natural Hot Spring adjacent to (accessed 29/10/18: https://good-hokkaido.info/en/hiratanai-onsen/).

How to get there: Follow route 229 to Kumaishitairacho and travel northward towards the Kumaishi Youth Travel Village. Continue along this road until you reach the Hiratanaionsenkuma car park (at this point you can drive no further along the road). Walk 5 minutes north on foot to the hot spring (Figure 39) where you can bathe in an outdoor bath on the rock shelf (true right of the river) (Figure 40). There is a small changing hut above the spring adjacent to the river, and a tiny geyser to the left of the trail above.

Figure 40: Map with red pin marking the location of Hiratanaionsenkuma Natural Hot Spring (Google Maps).

Futamata Radium Hot Spring

JSGH field guide: 28
Location coordinates: 42.576785 N, 140.239578 E

Figure 41: Futamata radium spa with looming carbonate terraces behind. View to SE.

Geological description: The huge dome (translates as a “lime flower” in Japanese) is formed by the chemical precipitation of calcium carbonate (CaCO3) from the natural hot spring. The dome that is currently part of the Futamata Radium Onsen Inn (Figure 41) rises up to 25 m high and is formed of calcite and aragonite. It appears that multiple domes have been compounded into one and the size of the base is unclear, but it covers an area approximately 400 by 200 m. It is believed that the dome contains radioactive elements within the sediment deposit, such as radium, which has given rise to the name of the hot spring. The underlying Mesozoic sedimentary rocks, including limestone, are an important geological factor allowing the formation of the lime dome (aka lime flower). It is believed that groundwater dissolving components of this rock was involved in the formation of the hot spring water at this site. Hot spring water which flows down the dome like a river is high in calcium carbonates, precipitating the lime in a terrace like formation (Figure 42).

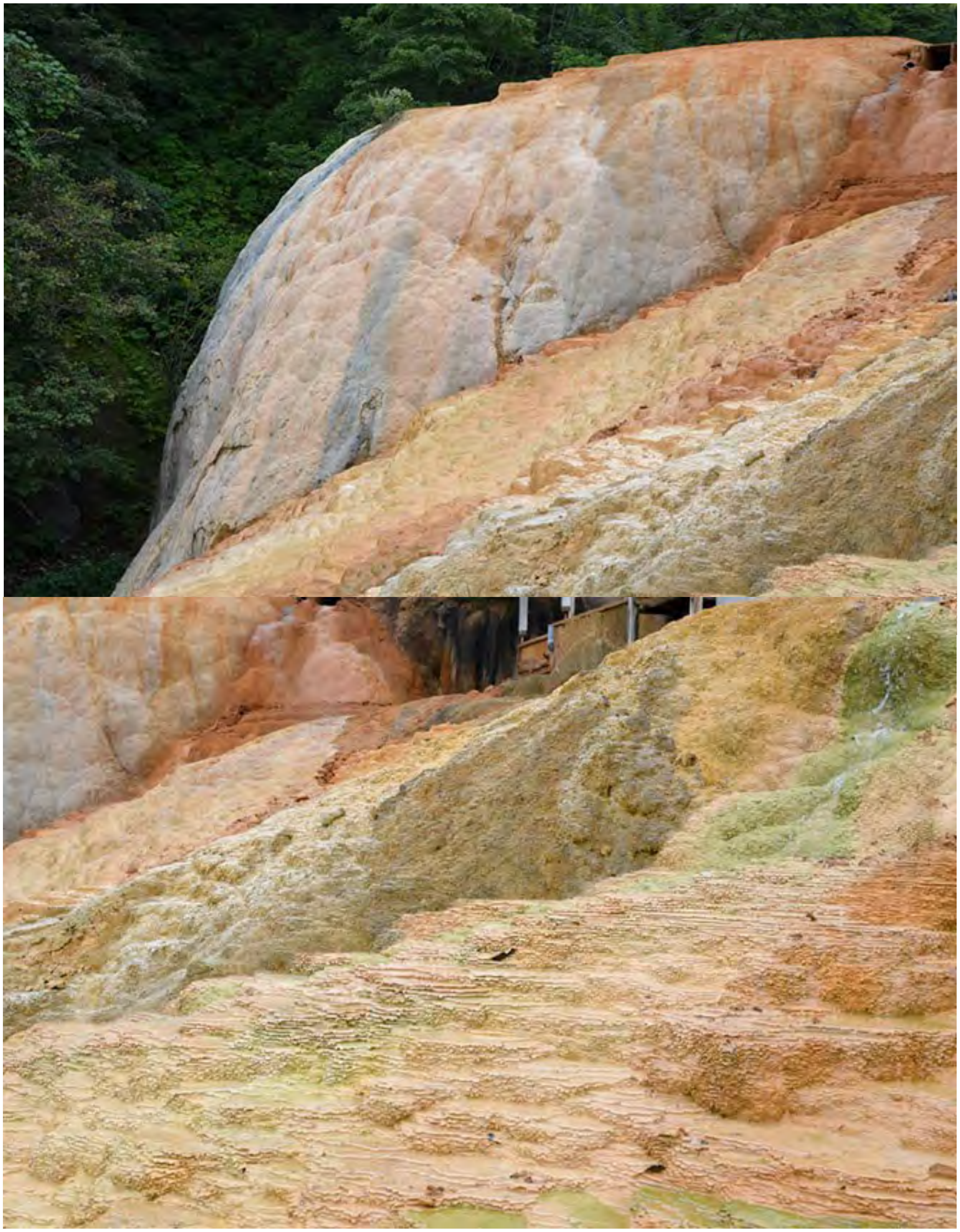

Figure 42: Carbonate terraces viewed from Futamata Radium Onsen Inn (accessed 28/10/18: https://good-hokkaido.info/en/futamata-radium-onsen/).

How to get there: Turn off the national highway 5 onto route 842 and drive for approximately 18 minutes. The hot spring will be on the left (Figure 43).

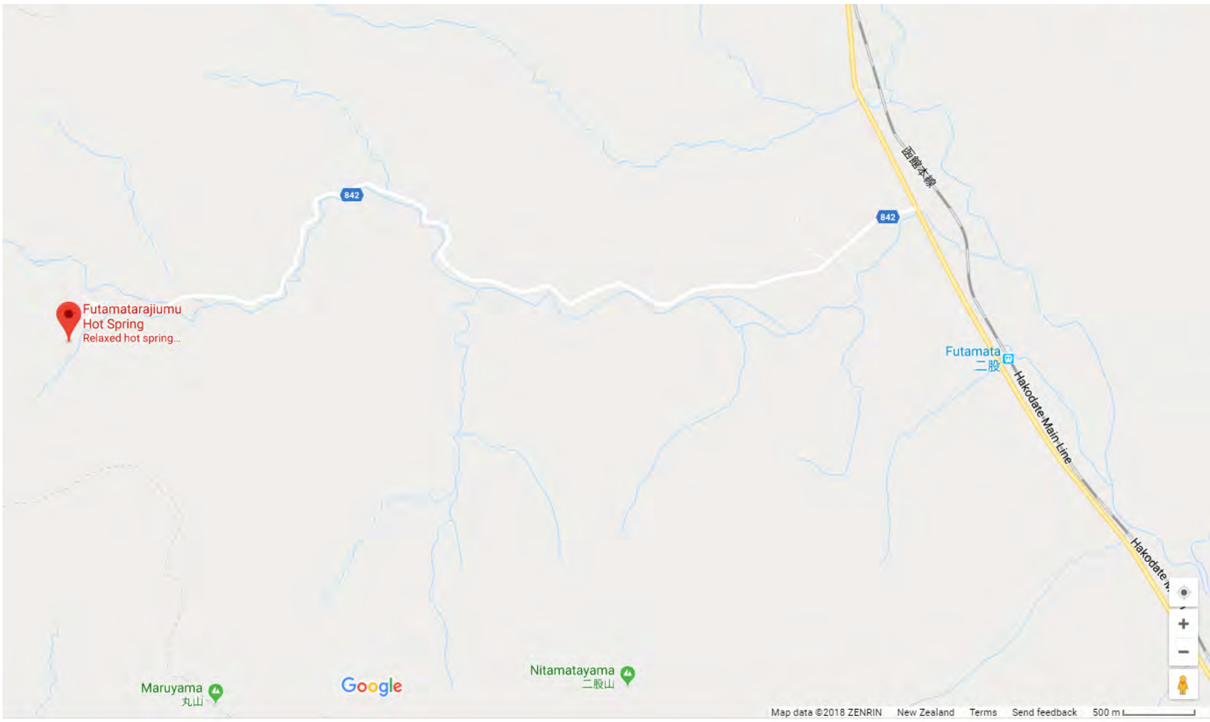

Figure 43: Map with red pin marking the location of Futamata Radium Hot Spring.

Kimobetsu Welded Tuff

GSJH field guide: 27
Location coordinates: 42.768774 N, 140.958835 E

Figure 44: Kimobetsu white tuff cliffs.

Geological description: The Kimobetsu welded tuff cliffs reach up to 10 m in height and consist of a grey-white coloured massive tuff (Figure 44) produced by a pyroclastic flow. For a long time, the source and eruption age of the pyroclastic flow was unclear, however recent research has described the origin as two separate flows produced 50,000 years ago by the Shiribetsu volcano during the rise of Mt Yotei (Goto et al., 2018).

The tuff is primarily composed of volcanic glass welding a suite of millimeter sized phenocrysts of feldspar, pyroxene and amphibole (Geological Society of Japan – Hokkaido, 2016). Larger phenocrysts can also be found within the tuff, including pieces of white pumice (up to 10 cm in size) and fragments of grey andesitic rock (up to several centimeters). The grey andesitic fragments are very angular and consist of a more resistant material than the body of the welded tuff, as can be seen in the way the fragments protrude from the cliff while the tuff is weathered around them (Figure 45). Despite the majority of the tuff being generally unsorted with no evidence of bedding, in certain places horizontal lamination can be seen (Figure 46).

Figure 45: An example of the angular, dark grey fragments protruding from the wall of the tuff cliffs.

Figure 46: *(Geological Society of Japan – Hokkaido, 2016).* The horizontal laminar pattern found within the tuff indicating the direction of pyroclastic flow. Lens cap for scale. The photographer was Dr. Y. Tsukahara.

How to get there: From Kimobetsu Chomin park follow route 230 south and turn onto route 276 at the intersection. Drive for approximately 5 minutes south before turning left at the first intersection onto a gravel road. Cross the river and turn onto the right-hand road. As you drive down this road the tuff cliffs will be visible on the left-hand side (Figure 47).

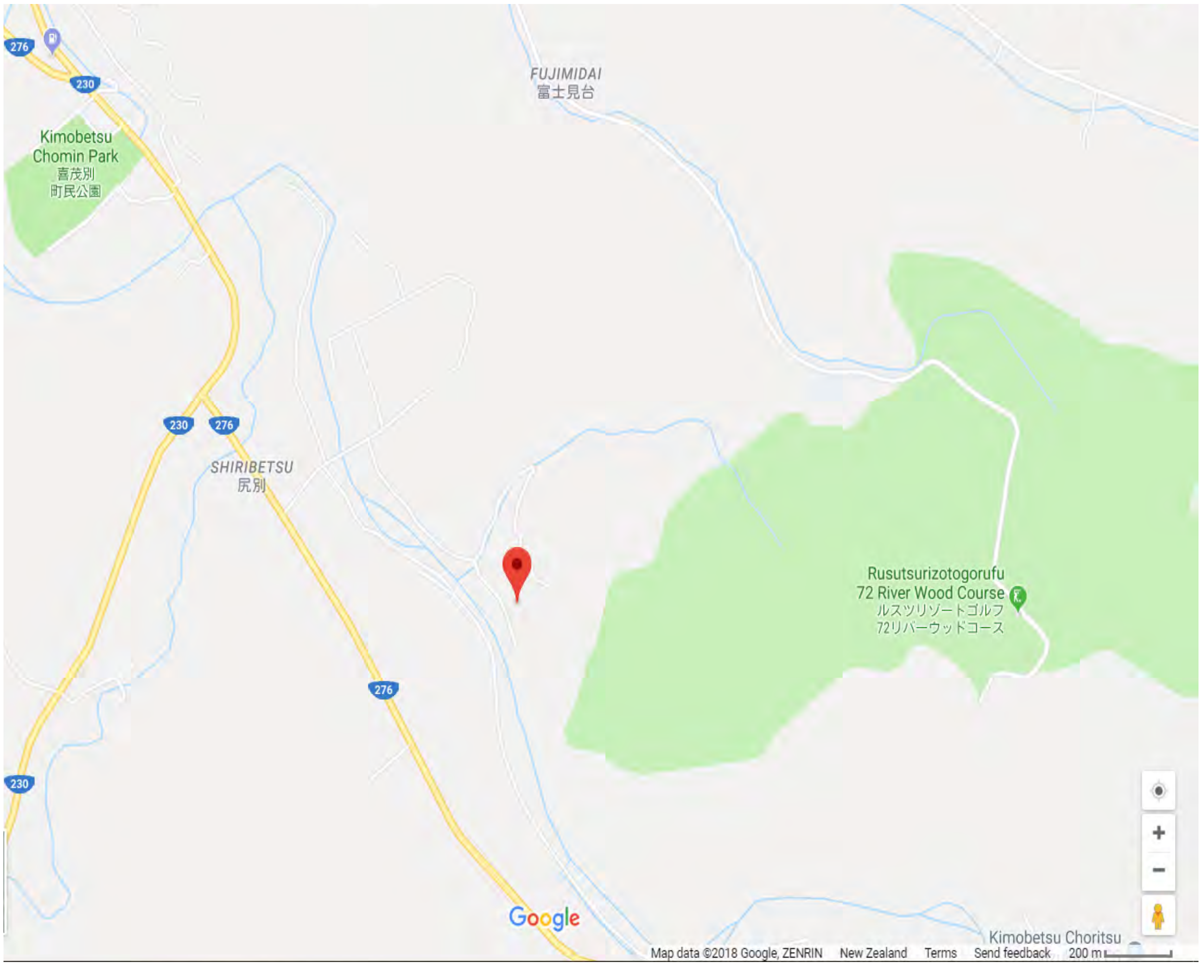

Figure 47: Map with red pin marking the location of the Kimobetsu tuff (Google Maps).

Conclusion

Hokkaido is a tectonically active area with an array of lithologies such as classic basaltic igneous rocks, low-temperature high-pressure metamorphic rocks and deep-sea sedimentary rocks. This guide presents observations from regions to the east (Kushiro) and south western of the island (Hakodate).

This field guide is the brainchild of the Hokkaido University Summer Institute – short course in Geology (2018). We hope this field guide provides guidance and a framework to which further geological data can be added by future HUSI geology students, ultimately producing an English geological bible of the Hokkaido area supplemented with personal observations and knowledge.

References:

Allmendinger, R. W. (2018) *Stereonet 10.0.* Accessed: 1/11/2018, [Online PDF]

Barnes, G. (2003) *Origins of the Japanese Islands: The New "Big Picture".* Japan Review, 15, 3-50.

Goto, Y., Suzuki, K., Shinya, T., Yamaguchi, A., Miyoshi, M., Danhara, T. and Tomiya, A. (2018). Stratigraphy and Lithofacies of the Toya Ignimbrite in Southwestern Hokkaido, Japan: Insights into the Caldera-forming Eruption at Toya Caldera. *Journal of Geography (Chigaku Zasshi),* 127(2), pp.191-227.

Google (n.d.) [Driving directions and general road map of each area]

Hasegawa, H., Sawagaki, T., Takashima, R., Yamamoto, M., Irino, T., (2011) *Geology and Geomorphology along the Ishikari River in Central Hokkaido,* IGCP-581, Evolution of Asian River Systems Linking to Cenozoic Tectonics, Climate and Global Geochemical Cycles-Post-symposium Field Trip Guide Book.

Hokkaido branch of Geological Society of Japan, (2016) "Hokkaido Natural Exploration – Exploring 107 geosites" （北海道自然探検 ジオサイト107の旅）. Ishii, M., Kito, S., Tajika, J. and Miyasaka, S. (Eds), Hokkaido University Press, pp. 360, ISBN978-4-8329-1402-5

Ichihara, H., T. Mogi, K. Tanimoto, Y. Yamaya, T. Hashimoto, M. Uyeshima, and Y. Ogawa (2016), *Crustal structure and fluid distribution beneath the southern part of the Hidaka collision zone revealed by 3-D electrical resistivity modeling*, Geochem. Geophys. Geosyst., 17, 1480–1491.

Kiminami, K., Komatsu, M., Niida, K., Kito, N., (1986) *Tectonic divisions and stratigraphy of the Mesozoic rocks of Hokkaido, Japan,* Monogr. Assoc. Geol. Collab. Jpn., 31 , 1-15.

Takashima, R., Kawabe, F., Nishi, H., Moriya, K., Wani, R., Ando, H., (2004). *Geology and Stratigraphy of a forearc basin sediments in Hokkaido, Japan: Cretaceous environmental events on the north-west Pacific Margin,* Cretaceous Research, 25, 365-390.

Kimura, G., (1994)., *The latest Cretaceous-early paleogene rapid growth of accretionary complex and exhumation of high-pressure series metamorphic rocks in northwestern Pacific margin*, J. Geophys. 99:22, 147-164.

Kiyokawa, S., (1992) *Geology of the Idonnapu Belt, Central Hokkaido, Japan: Evolution of a cretaceous Accretionary Complex.* Tectonics, 11:6, 1180-1206.

Kusunoki, K., Kimura, G., (1998). *Collision and Extrusion at the Kuril-Japan arc junction.,* Tectonics, 17:6, 843-858.

Nishida, Y., & Miyajima, E. (1984). Subsurface structure of Usu volcano, Japan as revealed by detailed magnetic survey. *Journal of Volcanology and Geothermal Research*, *22*(3-4), 271-285.

Statistics Bureau, Ministry of Internal Affairs and Communications (1996), 19-1 Wakamatsu-cho, Shinjuku-ku, Tokyo 162-8668 Japan: Accessed: 1/11/2018.