Abstracts with Program

International Symposium of the Society of Resource Geology

“Gold Exploration in the Circum-Pacific”

The Society of Resource Geology

October 14th of 2021

Symposium	International Symposium of the Society of Resource Geology “Gold Exploration in the Circum-Pacific”
Date	October 14th (Thursday) of 2021
Time	From 9:00 am to 4:55 pm JST (UTC+9)
Method	Virtual Meeting (Cisco Webex)
Sponsor	The Society of Resource Geology
Cosponsor	JOGMEC (Japan Oil, Gas and Metals National Corporation)
Cooperation	The Mining and Materials Processing Institute of Japan (MMIJ) The Geological Society of Japan The Society of Exploration Geophysicists of Japan
Conveners	Yasushi Watanabe (Akita Univ.), Shuichi Miyatake (JOGMEC) and Ryohei Takahashi (Akita Univ.)
Registration Fees	SRG Member: 2,000 JPY SRG Member (Student): 1,000 JPY Non-SRG Member: 4,000 JPY

シンポジウム	資源地質学会国際シンポジウム“Gold Exploration in the Circum-Pacific”
開催日	2021 年 10 月 14 日(木)
時間	9:00～16:55
開催方式	オンライン (Cisco Webex)
主催	資源地質学会
共催	独立行政法人 石油天然ガス・金属鉱物資源機構(JOGMEC)
協賛	一般社団法人 資源・素材学会 一般社団法人 日本地質学会 公益社団法人 物理探査学会
コンビーナー	渡辺　寧(秋田大), 宮武修一(JOGMEC), 高橋亮平(秋田大)
参加登録料	資源地質学会正会員: 2,000 円 資源地質学会正会員（学生）: 1,000 円 資源地質学会非会員: 4,000 円

Program

9:00 - 9:10 Opening Speech

Chaired by Yasushi Watanabe

9:10 - 9:35 S01
The Cerro Negro low sulfidation epithermal Au-Ag deposit
Richard Pilco Saraza and Patricio Brividoro (Newmont South America)

9:35 - 10:00 S02
Geology of the Brucejack high-grade gold deposit, British Columbia, Canada
Stephanie Wafforn, Joel Ashburner, Matt McManus and Travis Dawson (Pretium Resources Inc.)

10:00 - 10:25 S03
Miocene caldera hosted epithermal gold silver mineralization in the Western Tethyan -Slovakia and implications for Pacrim exploration
Jason Beckton and Marian Urban (Prospech Ltd.)

10:25 - 10:35 Short Break

10:35 - 11:00 S04
The epithermal mineralisation and exploration success in the Waihi area of New Zealand
Shannon Richards (Oceana Gold)

11:00 - 11:25 S05
Masbate Gold Project: An overview of a world-class gold mine and a classic low sulphidation epithermal deposit
Jane Teves, Danilo Tandoc (Filminera Resources Corporation), Thomas Garagan, Brian Scott and Vernon Shein (B2Gold Corporation)

11:25 - 11:50 S06
The Porgera alkalic low-sulfidation epithermal gold deposit in Papua New Guinea
Marian Moroney (Barrick Gold Corporation)

11:50 - 13:20 Lunch Break

Chaired by Ryohei Takahashi

13:20 - 13:45 S07

Recent breakthroughs and challenges in the exploration of multiple high-grade epithermal gold deposits in Omu project, Hokkaido, Japan

Sofia Marah Frias, Avriel Venis Cirineo, Hidetoshi Takaoka, Haruo Harada and Quinton Hennigh (Irving Resources Inc.)

13:45 - 14:10 S08

A systematic regional exploration appraisal of Japan's main epithermal districts, by the Japan Gold - Barrick Alliance

Andrew James Rowe (Japan Gold Corporation)

14:10 - 14:35 S09

Various styles of Neogene gold mineralization in northern Northeast Japan arc

Yasushi Watanabe, Yuki Konuma, Kazuki Hirata and Haruka Izawa (Akita Univ.)

14:35 - 14:45 Short Break

Chaired by Shuichi Miyatake

14:45 - 15:10 S10

Characterization of epithermal gold-silver deposits in historical Togi mine, Noto, Ishikawa, Japan

Maki Hamada (Kanazawa Univ.), Wataru Kobayashi (Hokuriku Electric Power Company), Yoshihiro Hiramatsu and Noriko Hasebe (Kanazawa Univ.)

15:10 - 15:35 S11

Geology of the Hishikari gold deposit, Kagoshima, Japan

Mitsuo Ichinohe, Tomotaro Odaka and Takayuki Seto (Sumitomo Metal Mining Co., Ltd.)

15:35 - 16:00 S12

Sedimentary deposits of high-sulfidation type ore at the Kasuga deposit and Kurigano prospect, Nansatsu District, Japan

Ryuya Sato, Yuki Tohma (JX Nippon Exploration & Development Co., Ltd), Keiko Koshida (JX Nippon Mining & Metals Corporation) and Ryohei Nakai (Kasuga Mines Co., Ltd.)

16:00 - 16:25 S13

A new geochemical exploration technique for gold by micro-scale elemental analysis of stream sediments

Yoshiaki Kon, Kenzo Sanematsu, Yuki Tsunazawa and Daisuke Araoka (AIST)

16:25 - 16:55 Discussions

S01 **The Cerro Negro low sulfidation epithermal Au-Ag deposit**

Richard Pilco Saraza and Patricio Brividoro (Newmont South America)

The Cerro Negro district sits 600 metres above sea level, located at northwest of the Deseado Massif and is one of two world-class Au-Ag epithermal mines in the Argentine Patagonia. Cerro Negro has three high-grade underground operating mines, Eureka, Mariana Central and Mariana Norte, and two underground deposits being developed, Emilia and San Marcos, as well as five other deposits in late-stage evaluation for development to expand the existing operations in the Marianas Complex and establish operations in the Eastern District, as well as other deposits and exploration targets. The epithermal deposits are related to the evolution of distinct Jurassic magmatic events. Hydrothermal activity took place during the last stages of a volcanic-subvolcanic complex, producing epithermal Au- and Ag-rich veins of low to intermediate sulfidation style that were emplaced in NW striking extensional faults and in WNW to E-W trending strike-slip faults. In the eastern part of the district, basal units of the volcanic complex are overlain by a thick package of rhyodacitic ignimbrites, hosting the NW to EW-striking veins. Volcanism Culminated in a late- to post-mineral rhyolitic event composed of lava-domes and volcaniclastic deposits. The hydrothermal activity and hot springs discharged along main faults. The eastern group of epithermal deposits (Vein Zone, Bajo Negro, Silica Cap and Gato Salvaje) were emplaced ~300 to 400 m below the paleowater table indicated by a silica cap on Cerro Negro hill. They are dominated by silica replacement with high Au grades related to low temperature quartz and late hematite-stained brecciation. The Au-Ag epithermal veins in the western district (Eureka and Marianas-San Marcos) show high Au-Ag grades related to early sulfide-rich ginguro bands, Low-grade to barren quartz stages followed the early Au-Ag stage, and late calcite was deposited. All deposits are genetically related to intrusive activity, and additional Au-Ag mineralization may be explored beneath post-mineral volcanic and sedimentary rocks.

S03 **Miocene caldera hosted epithermal mineralisation in the Western Tethyan – Slovakia and implication for Pacrim exploration**

Jason Beckton and Marian Urban (Prospech Ltd.)

The intermediate-sulphidation precious and base metal deposit of Banská Hodruša at the Rozália Mine has been discovered only in 1990´s accidentally during drilling for deep continuation of base-metal rich veins. The deposit is still in production over more than 20 years produced approx. 300koz Au at 10 g/t Au. The ore body has not been properly outlined yet and the exploration is still ongoing. The mineralisation controls have been poorly understood, however recent study revealed several unique characteristics. The major distinct feature is a complex stockwork located in newly identified low-angle zone of weakness, which is most probably related to an exhumation of the Middle Miocene granodiorite pluton.

Gold rich epithermal mineralization is represented by subhorizontal veins and veinlets with shallow dips to the azimuth of 120° with the inclination (up to 30°). The mineralisation is also presented in moderate to steeply dipping veins and stockworks, which are located to discrete low-angle normal fault (LANF) zone.

Structurally the youngest deformational stage was controlled by extensional tectonic regime with the orientation of the principal tension axis in WNW–ESE direction. During this stage NE–SW conjugate normal faults were developed with moderate inclination on both side. These faults are related to horst-and graben structure (Štiavnica type).

The Štiavnica Stratovolcano has multistage evolution and the formation of a large andesite stratovolcano was followed by denudation and emplacement of granodiorite pluton belonging to the Hodruša-Štiavnica Intrusive Complex. Typical silicified hydrothermal breccias or barren massive silicites with subhorizontal orientation (Svetozár silicite) occur immediately above the granodiorite intrusion.

The mineralization is disrupted by a younger set of quartz–diorite porphyry sills, which were emplaced along the contact zone of the granodiorite pluton and andesites, mostly parallel to the LANF zone. Importantly this style of mineralisation albeit mined since 1992 has not been recognized in the wider Hodrusa Caldera, under Prospech Ltd tenure.

Geophysical and drilling campaigns are underway to attempt to define near term high grade gold zones within the newly defined LANF – Detachment Fault related mineralisation. This mineralisation style is not unique with comparisons to the Emperor Mine within the Pacific Rim and the Ada Tepe deposits within the Tethyan Belt.

S04

The epithermal mineralisation and exploration success in the Waihi area of New Zealand

Shannon Richards (Oceanagold)

Epithermal deposits are known to be challenging deposit types to explore, though once they are discovered they can often present with high rewards. Epithermal vein deposits at Waihi, New Zealand have produced over 8 Moz of gold and sustained gold mining for the last 150 years. Recent exploration of the Waihi District has confirmed significant upside both at the historic Martha mine where a further 1.44 Moz Au of Indicated and 0.72 Moz of Inferred gold resources have been defined, and at the recently discovered Wharekirauponga deposit (WKP) situated 10 km to the north of Waihi where 0.42 Moz of Indicated and 0.72 Moz of Inferred gold resources have been defined.

The mineralization at Waihi is hosted by five main deposits that span a relatively small area of approximately 2 km long and 2 km wide (excluding WKP) that were discovered over a protracted period of time. Each of the veins have idiosyncrasies and interesting exploration stories worth sharing.

The Martha deposit is the largest and most well-known at Waihi. It was discovered in 1879 by two prospectors who identified outcropping quartz veins on a prominent hill that jutted out of the surrounding post-mineral cover. Since the early underground development of the Martha veins, it was recognized that the host rock plays an important control on the occurrence and thickness of veins. The veins in Waihi town are hosted within a thick package of andesites that can be subdivided texturally into an upper horizon lacking any quartz phenocrysts and a lower horizon that contains quartz phenocrysts. Veins associated with the Correnso deposit and hanging-wall veins of the Martha deposit are developed almost entirely within the lower andesite. In general, veins extending up into the upper andesite pinch out abruptly just above the contact. As a result, many of these veins are blind to the surface. Approximately 1 km to the southeast of the Martha deposit, the Trio deposit has developed within both the upper and lower andesite units. Historical mining of Trio was confined to the upper andesite where veins had long strike extents but were narrow and did not yield high gold grades. Exploration drilling around these old workings returned poor results until the lower andesite horizon was targeted. The first hole that intercepted the lower andesite below the old workings encountered wide, mineralised veins that were later mined from underground. The discovery of the Favona deposit situated approximately 1.5 km to the southeast of Martha surprised geologists by being hosted solely within the upper andesite, challenging the previous dogma of a preferential host rock for mineralisation.

The majority of epithermal gold deposits within the Waihi district are hosted by coherent andesitic flows. However, the veins recently discovered at WKP in 2017 have developed within a rhyolite flow dome complex. Here, veining is abundant and well developed both in terms of strike, width and grade within the rhyolites, however vein density and grade decrease dramatically within the surrounding and overlying volcaniclastic units with the main WKP vein blind to the surface. There is no doubt that the host lithology is an important control on the propagation of epithermal veins, however

experience from Waihi has shown that conditions for vein development are different from one vein set to the next even within a relatively restricted district. During prospect selection, areas should not be discounted based on host lithology alone unless the geology is clearly not prospective i.e. post-dates the mineralising event.

Recent exploration success in the Waihi District has also been attributed to the improvements and innovation in diamond drilling over time. The Correnso discovery hole in 2006 used oriented diamond core where the orientation data suggested the vein intercepts were trending north north-west, almost orthogonal to the other known veins discovered in the area. It was soon realized that the Correnso vein had previously been intercepted in a hole drilled in 1986 using unoriented core that had been incorrectly attributed to a nearby north east trending vein.

Often epithermal veins in the district are steeply dipping, consequently shallower angle drilling is preferable to intercept the veins at an optimum angle. The surface topography of Waihi is largely covered by a town where diamond drilling is not possible. Being able to drill long shallowly inclined holes out the side of the open pit or by planning fans of holes from the limited surface drill sites has greatly improved drill targeting and resource definition. The WKP deposit is situated within steep mountainous terrane covered by thickly vegetated forest where drill collar positions are also very limited. The WKP discovery was only made possible by using a fit-for-purpose helicopter transportable drill rig that could drill 500 m+ of diamond core angled at 20 degrees. The drill rig at WKP has a solid recovery unit (SRU) that recycles drilling fluid and drill cuttings providing a clean drilling process and enabling exploration in an environmentally sensitive area.

Resource and reserve definition drilling around Waihi is focused on defining remnant mineralization around 100+ year old historical underground workings. The drilling is challenged by the Waihi town infrastructure above the area of veining and the presence of historical underground voids within the areas of interest. Improvising drilling practices has allowed areas to be explored effectively. Historical stope voids reaching 12 m in width are successfully drilled across using welded rods, leading BQ rod strings and downhole cameras. Geologists have digitized data from historical mine plans and sections into Leapfrog 3D software and can therefore provide the drilling crews with detailed drill plans showing expected ground conditions and voids. The 3D data set of historical workings is continually updated when new information from drilling and underground development is encountered.

Mining and exploration in the Waihi District has been challenging since the first discovery of gold in the region. Many prospective areas today are situated directly underneath post-mineral cover, a town, amongst historical mine workings or under conservation forest. Recent exploration success in the Waihi District can be attributed to improvements and innovation in exploration techniques that will undoubtedly become more important as exploration becomes more challenging worldwide.

S05 **Masbate Gold Project: An overview of a world-class gold mine and a classic low sulphidation epithermal deposit**

Jane Teves, Danilo Tandoc (Filminera Resources Corporation),
Thomas Garagan, Brian Scott and Vernon Shein (B2Gold Corporation)

In 2008, Masbate Gold Project located in Aroroy, Masbate Island, Philippines started production with an estimated 4.55 Moz of Indicated Mineral Resource. The project has since produced a total of 2.14 Moz of gold. At present, the deposit has an updated estimate of 3.54 Moz Indicated Mineral Resource with an average grade of 0.81 grams per tonne gold based on B2Gold's 2020 Annual Information Form filed March 2021. The project remains as the largest gold producer and most sustainable open pit mine operation in the Philippines as of today.

The Philippines is an amalgamation of island arcs and accreted terranes bounded by deep trenches and lies along the Circum-Pacific belt, south of Japan. The Masbate Gold deposit sits at the central segment of the Pliocene-aged Philippine Fault host to many major mineral districts in the country. Geology at Masbate is represented by higher-grade quartz vein/vein breccia domains, surrounded by a quartz stockwork halo zone hosted by highly permeable volcanic and sedimentary packages of Miocene to Pliocene age. These zones are further enveloped by a broad hydrothermal alteration zone that varies from chlorite and clay (kaolinite-smectite-illite) assemblages. Gold occurs as native element, tellurides and as inclusions in pyrites.

Exploration methods appropriate for a low sulphidation epithermal deposit type model were utilized for this project. Work programs completed have included: geological mapping (including mapping of artisanal workings), geochemical sampling (stream sediment, rock chip, channel, trench and soil auger), geophysical surveys (magnetics, radiometrics, and orientation induced polarization or IP survey) and drilling (diamond core and reverse circulation or RC).

This paper reviews the work programs and how the combined methods were instrumental in identifying additional exploration targets around the mine site.

S07 Recent breakthroughs and challenges in the exploration of multiple high-grade epithermal gold deposits in Omu project, Hokkaido, Japan

Sofia Marah Frias, Avriel Venis Cirineo, Hidetoshi Takaoka, Haruo Harada and Quinton Hennigh (Irving Resources Inc.)

The Omu Project, located in the Kitami metallogenic province in northern Hokkaido, hosts multiple high-grade epithermal gold deposits associated with regional back-arc volcanism and hydrothermal activity during the Middle to Late Miocene. Situated approximately 60km northwest of Kohnomai Mine, the third largest Au producer in Japan, the Omu Project features several promising exploration targets for high-grade Au and Ag ores hosted in both vein-type and breccia-type mineralization. Recent exploration efforts in the area are mainly focused in and around historical mines namely the Omui Mine and Hokuryu Mine, and a recently discovered prospect towards the northeast of the property, the Omu Sinter.

The Omu Sinter prospect was discovered by Irving Resources in 2016 during a district reconnaissance along a 1km-long steep slope on the eastern margin of a NE-trending valley. Surface manifestations of ancient hydrothermal activity consists of extensive Au- and/or Ag-bearing silicified rhyolite and breccia outcrops towards the north and silica sinter outcrops with alternating layers of finely laminated and brecciated sinters towards the south. Assay results of silica sinter outcrop and float samples range from 0.046 to 16.850 g/t Au with an average of 0.888g/t Au and 0.500 to 91.000 g/t Ag with an average of 12.028 g/t Ag. Recent exploration efforts aim to find the related epithermal mineralization to this outcropping mineralized sinter. Geophysical surveys involving ground gravity survey, drone magnetic survey, moving-loop EM, IP , and CSAMT surveys were conducted from 2017 to 2019 to guide drill targeting and revealed the following: (1) a linear NNE-trending low magnetic zone interpreted as hydrothermal alteration coinciding with (2) a prominent gravity gradient interpreted as graben-bounding structures underlying the area and (3) multiple high resistivity features interpreted to be possible zones of silicification and several conductive features interpreted to be zones of clay alteration and/or structures important for mineralization. Soil Au anomalies also coincide with the low magnetic-high gravity zone. Diamond drilling campaign coupled with lithogeochemical analysis and SWIR spectroscopy from 2019 to 2021 (17 holes totaling 6839.8m) revealed the following: (1) discovered high-grade veins with a maximum grade of 118.5 g/t Au in 0.32m interval, (2) the high grade Au-Ag ore is mainly hosted in a large multiphase silica matrix breccia-clay matrix breccia body (up to 14.55g/t Au) intersected in the northeastern part of the prospect, (3) the rhyolite flows of Motoineppu Lava are host to mineralization and exhibit widespread kaolinite ± smectite alteration, (4) the silicified subhorizontal bedded sedimentary rocks and silica sinter overlying the rhyolite flows towards the southern part of the prospect still contain significant Au and Ag at depth, (5) a steeply dipping NNE-trending fault zone and unaltered footwall andesitic to mafic volcanic rocks truncate the hydrothermal system at depth. Pre- and post-hydrothermal brecciation quartz veining are present in Omu Sinter.

The Omui prospect, which includes the historical Omui Mine, Sakinyama placer deposit and its surrounding vicinity, is located about 9km south of the Omu Sinter prospect. Historical mine data reported 8 parallel E-W-trending and steeply dipping veins which include the 1 to 1.5m wide Honpi vein and 7 other veins

with thickness between 30cm and 60cm. Recent exploration efforts aim to find extensions of these veins, as well as other mineralized veins and hydrothermal breccias in Nanko and Sakinyama located southeast and southwest of Honpi, respectively. Early exploration activities involved extensive rock-chip sampling from 2016 to 2019, a regional BLEG survey in 2016 and a detailed soil sampling program in 2017. Abundant quartz veins, silicified rocks and silica sinter float samples were collected and analyzed. Soil Au anomalies coincide with the location of Honpi, Nanko and Sakinyama and also appear to be open towards the southeast. Geophysical surveys conducted from 2017 to 2019 consisting of ground gravity survey, drone magnetic survey, and CSAMT survey revealed the following: (1) the gravity gradient which highlighted a graben-bounding fault in Omu Sinter extends southwards to Omui prospect, (2) a NW-trending low magnetic zone extends from Nanko to Honpi which is consistent to the widespread hydrothermal alteration observed in the surface, and (3) multiple high-resistivity features interpreted to be possible zones of silicification or quartz veining pose to be potential drilling targets. Due to the absence of outcropping mineralization, four trenches totaling 453.13m running across Honpi to Nanko were developed to find possible shallow surface extensions of mineralized quartz veins. The diamond drilling campaign in late 2019 and early 2020 focused on Honpi-Sakinyama area (11 holes totaling 3026.5m) while the drilling campaign in mid- to late 2020 focused in Nanko (8 holes totaling 3508.42m). Drilling data coupled with lithogeochemical analysis and SWIR spectroscopy revealed the following: (1) rhyolite flows of Motoineppu lava and underlying older andesitic lavas serve as hosts to epithermal mineralization in Omui, (2) alteration at the shallow level is dominated by kaolinite ± illite ± smectite and transitions to illite ± smectite ± chlorite ± carbonate in the deeper levels, (3) mineralization in the shallower levels is dominated by ginguro- and electrum-bearing massive, lattice-bladed, crustiform quartz-FeOx veins (up to 125g/t Au) and multiphase silica matrix breccias, while lattice-bladed to crustiform silica-replaced carbonate veins (up to 9.17 g/t Au) and barren carbonate stringers were intersected in deeper levels. Structural interpretation of intersected veins in oriented core, which were discovered by the drilling campaign, suggests a dominant E-W trend with steep dip towards the north for Honpi and a dominant NE-trend with steep dip towards both the north and south for Nanko.

The Hokuryu prospect hosts a robust hydrothermal system with great potential for a widespread high-grade gold mineralization coinciding with the historical Hokuryu Au-Ag Mine and its vicinity, Maruyama and Daihoku prospects. Historical underground mining data in Hokuryu suggested at least two mineralized zones whose development included several mining levels and anastomosing underground workings: (1) a NE-trending vein system and (2) an E-W trending vein system. Maruyama and Daihoku prospects also feature several historical workings. Recent exploration activities in the area involved extensive rock chip sampling and systematic soil sampling from 2017 to 2021. Abundant mineralized silica sinter float samples were collected in Maruyama with Au and Ag grades of up to 7.81 g/t Au and 45 g/t Ag. Soil Au anomalies are also widespread from Maruyama to Hokuryu. Despite the limited outcropping mineralization and challenging access due to mountainous terrain and thick vegetation, the subsurface geophysical features interpreted from CSAMT surveys in 2019 show new and encouraging exploration targets. The first phase of diamond drilling activity in Hokuryu commenced in September 2021 and will continue until the end of this year.

Ongoing exploration activities in the Omu Project aim to establish a concrete geologic model with a

focus on reconstructing the paleotopography and the plumbing system of the hydrothermal system underneath.

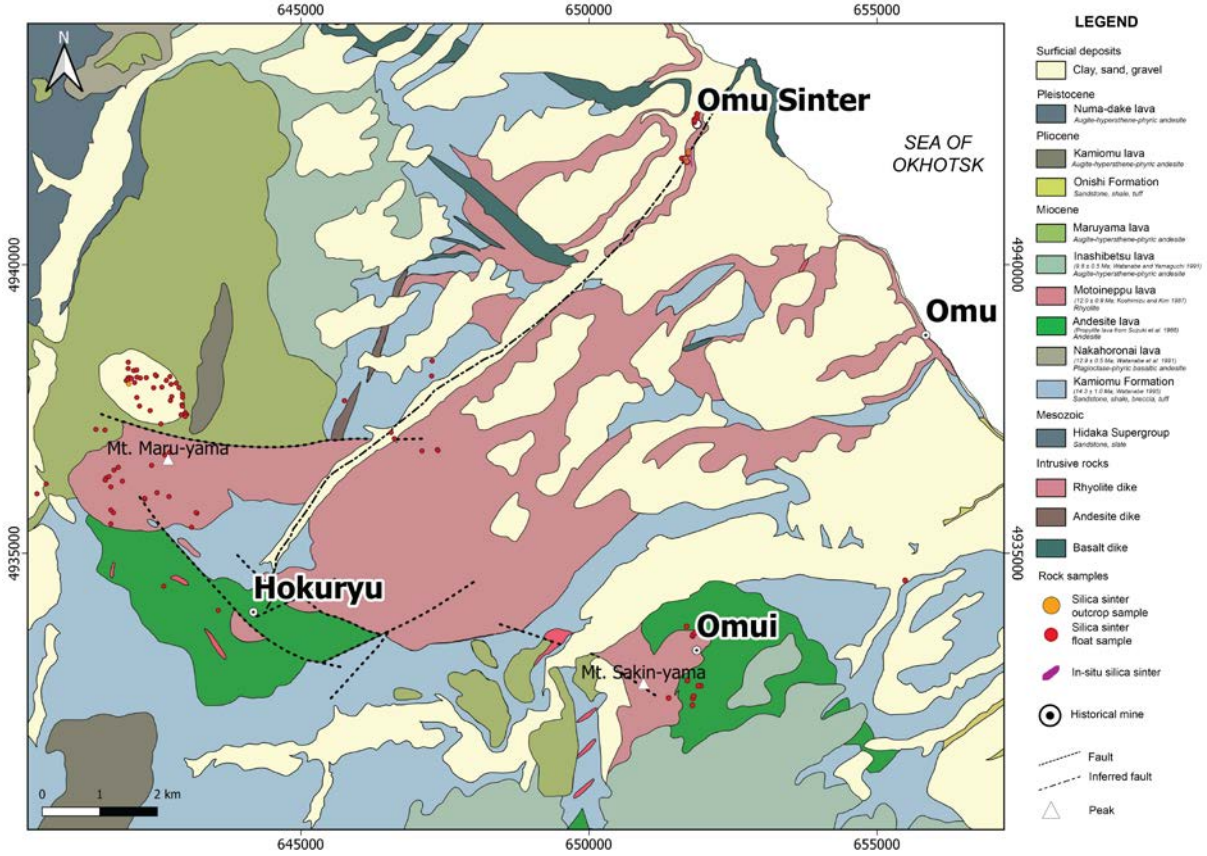

Fig. 1 Geologic map of Omu Project showing the three main prospects of Irving Resources (Omu Sinter, Omui and Hokuryu) and the spatial distribution of collected silica sinter float and outcrop samples. Geologic map is modified from Suzuki et al. (1966) and Zeeck et al. (2021).

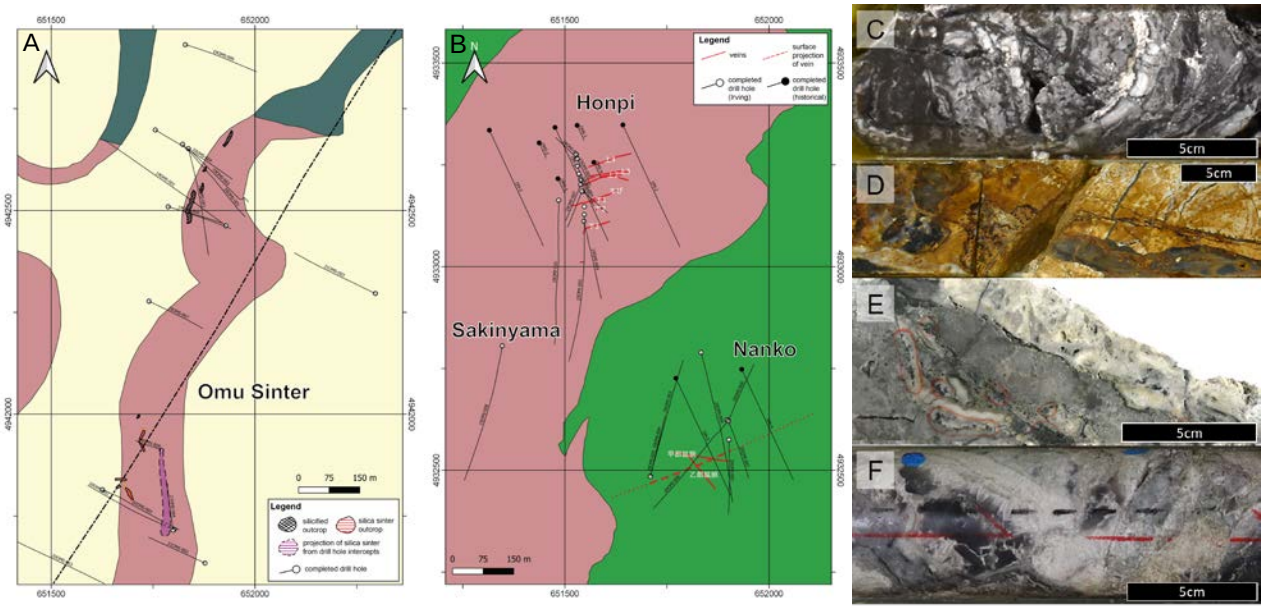

Fig. 2 (A) Plan view of the completed drillholes in Omu Sinter prospect from 2019 to 2021 drilling campaigns. Also highlighted are the locations of silicified rocks and silica sinter outcrops, and silica sinter intervals intersected by drill holes. (B) Plan view of the historical and completed drill holes in Omui prospect from 2019 to 2020 drilling campaigns. Also highlighted are the surface projections of the historical veins in Honpi and Nanko. (C) High-grade crustiform quartz vein (118.5 g/t Au, 1410 g/t Ag) intersected by hole 19OMS-002 from 184.93-185.25m in Omu Sinter prospect. (D) High-grade dark gray quartz-Feox vein (125 g/t Au) intersected by hole 20OMI-001 from 62.47-62.72m in Omui-Honpi prospect. (E) High-grade quartz vein with ginguro and electrum (56.1 g/t Au, 1435 g/t Au) intersected by hole 20OMI-003 from 342.2-342.8m in Omui-Nanko prospect. (F) Silica-replaced carbonate vein (9.17 g/t Au) intersected by hole 19OMI-010 from 369.00-369.32m in Omui-Honpi prospect.

S09

Various styles of Neogene gold mineralization in northern Northeast Japan arc

Yasushi Watanabe, Yuki Konuma, Kazuki Hirata and Haruka Izawa (Akita Univ.)

The Neogene of the Northeast Japan arc yields mainly base-metal rich hydrothermal deposits, which contrast to the dense distribution of precious-metal deposits in northeastern Hokkaido, Izu peninsula and Kyushu. Nevertheless, some of the deposits in the arc were mined for gold and silver, although their deposit types and styles, as well as occurrence of gold have not been well described. We re-examined the Bosawa, Akaishi and Hata deposits in the northern part of the arc (Fig. 1) and describe their types and styles as well as geological environments.

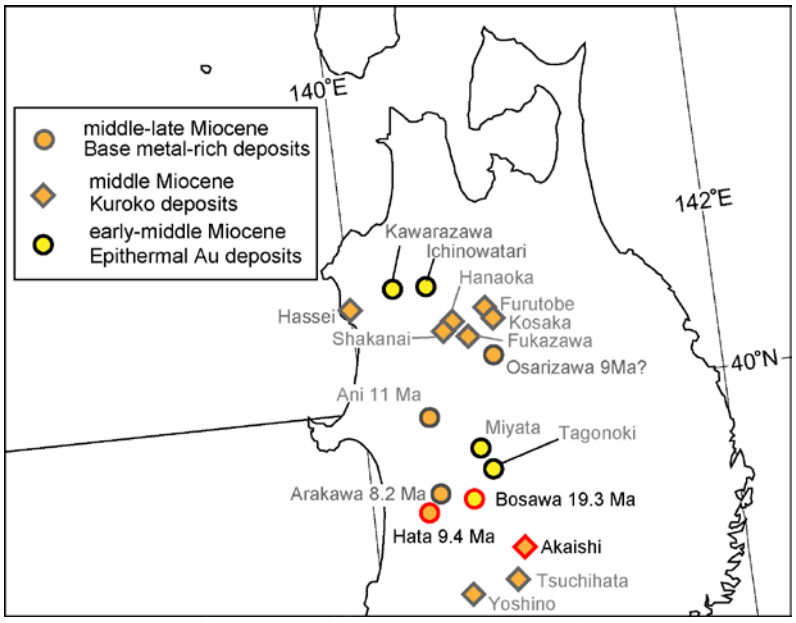

Fig. 1 Distribution of hydrothermal deposits in the northern Northeast Japan arc.

The Bosawa deposit consists of gold-bearing quartz veins, hosted in the early Miocene volcanic rocks. The main ore minerals, gold and argentite, occur in banded quartz with adularia and bladed quartz, typical of low sulfidation epithermal deposit (Table 1). Hydrothermal alteration associated with the mineralization is characterized by illite and adularia, overprinted by kaolinite. Vermiculite is widely detected in the host rocks, which indicates weathering in subaerial environment after the mineralization.

The Akaishi deposit consists of stockwork veins and massive ores, rich in sphalerite, galena and chalcopyrite cemented with barite and quartz. The oxygen and sulfur isotopes of barite indicate that the sulfate was derived from seawater. The orebody of the deposit is inclined nearly vertically, and the uppermost part of the orebody has been eroded and weathered with vermiculite formation. This again suggests weathering in subaerial environment. Gold was mainly recovered from this weathered part of the orebody.

The Hata deposit is hosted in middle to late Miocene sedimentary and volcaniclastic rocks. The deposit consists of base-metal rich lower orebodies and barite-rich upper ones that contain argentite-bearing quartz veinlets. Mineral paragenesis of the deposit indicates that gold mainly precipitated at the latest stage of the base-metal mineralization. The oxygen and sulfur isotopes of barite indicate seawater origin for sulfate. We interpret that the gold mineralization occurred during a rapid oxidation of the ore fluid due to mixing of a deep-sourced fluid with seawater.

In summary, gold mineralization associated with the Miocene hydrothermal deposits in the arc is quite variable in type; low-sulfidation epithermal (Bosawa), Kuroko (Akaishi) and base-metal rich epithermal (Hata), and was triggered by fluid boiling (Bosawa), weathering (Akaishi) and fluid oxidation (Hata).

Table 1 Characteristics of the Bosawa, Akaishi and Hata deposits

	Bosawa	Akaishi	Hata
Type	LS epithermal	Kuroko	Base-metal rich epithermal
Style	vein	stockwork, massive	stockwork
Ore minerals	gold, argentite	sphalerite, galena, pyrite, chalcopyrite	sphalerite, galena, pyrite, chalcopyrite, argentite, gold
Gangue minerals	quartz, adularia, calcite	barite, quartz	quartz, barite
Alternation minerals	illite, kaolinite	chlorite, illite	illite, barite
Weathering minerals	vermiculite	vermiculite	none
FI temperature	Not available	220-232°C	177-230°C (upper) 210-250°C (lower)
Salinity (NaCl eq.)	Not available	5.9-7.9 wt.%	2.9-6.0wt% (upper) 5.3-6.2wt% (lower)
Ore grade	7.0g/t Au,14.9g/t Ag (1936-1957)	4.6g/t Au, 9.4 % Cu (1946-1955)	Au 1.7g/t, Ag 70g/t, Cu 0.5%, Pb 3.8%, Zn 6.5% (1954)
Age	early Miocene (19.3 Ma*)	middle Miocene	late Miocene (9.4 Ma**)
Associated magmatism	dacite, rhyolite	rhyolite	dacite
Environment	subaerial	submarine	submarine

* Suzuki et al. (2020), ** MITI (1986)

References

MITI (1986) Report on Regional Survey in the Tazawa district during the fiscal year Showa 60. Ministry of International Trade and Industry, pp. 151 (in Japanese).

Suzuki, T., Satori, S., Fujimaki, Y., Watanabe, Y. (2020) Early Miocene metallogenic event formed the Bosawa low-sulfidation epithermal gold deposit, Northeast Japan arc. Resource Geology, 70(4), 378-388.

S11 Geology of the Hishikari Gold Deposit, Kagoshima, Japan

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The bonanza-grade, low-sulfidation epithermal Hishikari gold deposit is located in the Plio-Pleistocene volcanic area of southern Kyushu, Japan. The concealed veins were discovered in 1981 and the mine has since produced 5.462 million metric tons (Mt) of ore averaging 44.3 g/t Au (242 t Au) from 1985 to the end of 2018, at which time reserves were 7.98 Mt at 20.9 g/t Au.

The Hishikari deposit consists of the Honko, Sanjin, and Yamada ore zones, which occur in a NE-trending area 2.8 km long and 1.0 km wide. The veins are hosted by basement sedimentary rocks of the Cretaceous Shimanto Supergroup and by unconformably overlying Hishikari Lower Andesites of Pleistocene age. Most of the veins in the Honko and Sanjin zones transect the unconformable contact and exceptionally high-grade mineralization (>100 g/t Au) is spatially associated with this unconformity. In the vicinity of Hishikari, the unconformity forms a structural high, which is detectable as high gravity anomaly zone due to higher density of basement sedimentary rocks than that of volcanic rocks.

Epithermal gold mineralization occurred between 1.25 and 0.61 Ma. Based on the available age data, gold mineralization formed first in the northern part of Yamada zone, followed by the Honko and then Sanjin zones. The youngest known vein at Hishikari is in the southeast part of the Yamada zone. Majority of Hishikari veins have the Au/Ag mass ratio from 2.0 to 2.5, however, early veins tend to have apparently higher or lower ratio.

Temperature-controlled hydrothermal alteration zones occupy an area of >5 km long and 2 km wide. The Honko and Sanjin veins occur within a chlorite-illite alteration zone (paleotemperature >230°C), whereas the Yamada veins occur within an interstratified clay mineral zone (150°–230°C). The marginal alteration comprises quartz-smectite (100°–150°C) and cristobalite-smectite (<100°C) zones. Low resistivity zone caused by hydrothermal activity is developed over the ore zones and high resistivity zone which appear to correspond to basement rocks exists at depth. Several resistivity discontinuities parallel to vein strike imply normal faults related to a depression structure located in southern side of the ore deposit.

The hydrothermal alteration with higher paleotemperature (>150°C) and basement high, related to low resistivity and high gravity anomaly respectively, are key factors of exploration for the blind veins in Hishikari area.

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Sedimentary deposits of high-sulfidation type ore at the Kasuga deposit and Kurigano prospect, Nansatsu District, Japan

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The Kasuga deposit, high-sulfidation type is located in the Nansatsu district, southwestern Kagoshima prefecture. The Kasuga open-pit mine produces Au-bearing silicified ore which is supplied to the Saganoseki copper smelter for use as flux. JX Nippon Mining & Metals Co., Ltd. and Kasuga Mine Co., Ltd. are conducting exploration activities at the Kasuga deposit and Kurigano prospect for increasing the ore reserves.

A tongue-shaped ore body consisting of clasts of the silicified rock and a matrix of clayed soft-sediment was discovered in the southern part of the Kasuga mine. It is continuous from the upper part of the Kasuga main ore body consisting of massive silicified rock. The tongue-shaped ore body extends about 150m north-south and 150m east-west with a Max. 30 m in thickness. It is overlying the Nansatsu Group and is covered by Pleistocene Ata pyroclastic flow. The volume ratio of clasts and matrix is about 1:1. The clasts are mainly composed of subangular and poorly sorted silicified rocks. Magnetic susceptibility results suggest the matrix of clayed soft-sediment was formed by the mingling between clay derived from hydrothermal alteration rocks and volcanic ash. The clayed soft-sediment, mainly composed of halloysite with minor smectite, is rich in limonite and brown in color. The SiO_2 and Au grade of the tongue-shaped ore body is 70-90 % and 0.01-20 g/t, respectively.

The Kurigano prospect is located 1.5km southwest of the Kasuga mine. Topographic features show landslides terrain at the Kurigano prospect. Many silicified rock boulders of 10m or more in diameter surrounded by clayed soft-sediment are found at surface. This prospect presumed to be a sedimentary deposit based on geological observations at surface and drillhole information. Clayed soft-sediment is mainly composed of smectite and halloysite. Au grade is relatively high in the massive limonite on the surface of the silicified rock boulder and some reddish-brown clayed soft-sediment.

In Nansatsu district, landslide terrains are observed in other high-sulfidation type prospects such as Sonomi-dake, Iwado-yama and Misome. In the high-sulfidation deposit, the landslide can easily occur because of the differences in physical and mechanical properties between silicified and alteration rock, and of the sharp contact of both rocks. Furthermore, silicified rock is highly weathering resistant rock. These conditions result in the formation of secondary sedimentary deposit. Because these secondary sedimentary deposits have not been focused on before, it has great potential of exploration for undiscovered gold-bearing silicified bodies and increasing the ore reserves.

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A new geochemical exploration technique for gold by micro-scale elemental analysis of stream sediments

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Geochemical exploration is a method to search for economic mineral deposits by detection of geochemical anomalies of geological samples, such as rock, soil, natural waters, vegetation, and stream sediment. Gold is one of the most common targets of the geochemical exploration, and Au geochemical anomaly of a stream sediment directly indicates the existence of a gold mineralization near by the location. However, gold nuggets, the main container of Au, are heterogeneously distributed at the surface of the ground, because they exist in smaller numbers and have higher density than average silicate minerals. Practically, total weight, grain size, and sampling location at a river have a huge effect on abundance of the gold nugget in the sample. So-called 'nugget effect' causes poor reproducibility of Au analysis of the samples, and still an issue today. In this study, new approach to detect a geochemical anomaly related with a gold mineralization was examined. Gold mineralization is often associated with quartz vein. Generally, minimum Au content of an ore grade quartz vein is about 1–3 μg/g, triple-digit higher than averaged Au content of the continental crust. It suggests that a gold-ore related quartz grain has higher Au content than a barren quartz grain. In contrast to the gold nugget with a silicate mineral, the Au-rich quartz grain should have the same behavior to the Au-poor quartz grain at a surface of the ground. For all these reasons, existence of Au-rich quartz can be an indicator of gold mineralization.

Stream sediment samples were collected from the Kuji River system which runs from the Yamizo mountains to the Pacific. The Tochihara gold mine, located about 50 km upstream from the river mouth, located near boundaries between the accretionary complex and dioritic intrusive rocks. River sediment samples were collected from the upstream and downstream areas of the Tochihara Mine, and samples with a grain size of less than 250 microns were used for the analysis. In order to measure the trace element composition of individual particles constituting the river sediment, micro-scale trace element analysis using LA-ICPMS was performed. A femtosecond laser ablation system and ICP-MS were used to quantitatively analyze 29 elements, including gold, in resin samples containing and polished stream sediments. Two-dimensional distributions of elemental compositions were obtained by scanning a laser beam over a square of 1-2 cm on the surface of a resin sample and analyzing the time variation of the mass spectrum measured by ICP-MS. Based on the obtained elemental compositions, the mineral phases at each analysis point were determined, and the elemental composition frequency distribution of each mineral phase was generated to evaluate the geochemical anomaly originating from the deposit. In addition to the average gold concentration in the minerals, Dn95 values were calculated to quantitatively characterize the gold in the river sediments; the Dn95 value is the maximum gold concentration after excluding the top 5% of gold concentrations in quartz grains. Compared to the whole rock gold content of river sediments, the Dn95 value showed a high repeatability of values. This suggests that this method is useful as an indicator of gold mineralization.