The State of Knowledge of the Bismarck Sea Deep Seabed

◀ North Su, active subsea volcano
Image credit: Nautilus

The deep seabed environment, which is the proposed location of the Solwara 1 mine, is a unique area.

The Solwara 1 site is located 30 km off the shore of PNG in the Bismarck Sea near an area known as the "Coral Triangle". This area occupies approximately 2% of the Earth's seafloor, yet it contains 76% of the world's coral population and 37% of the world's coral fish population.[29] The proposed Solwara 1 mine site is not near the coral reef area, as it is located 30 km offshore at a depth of 1,600m, far below the phototrophic level where sunlight reaches.

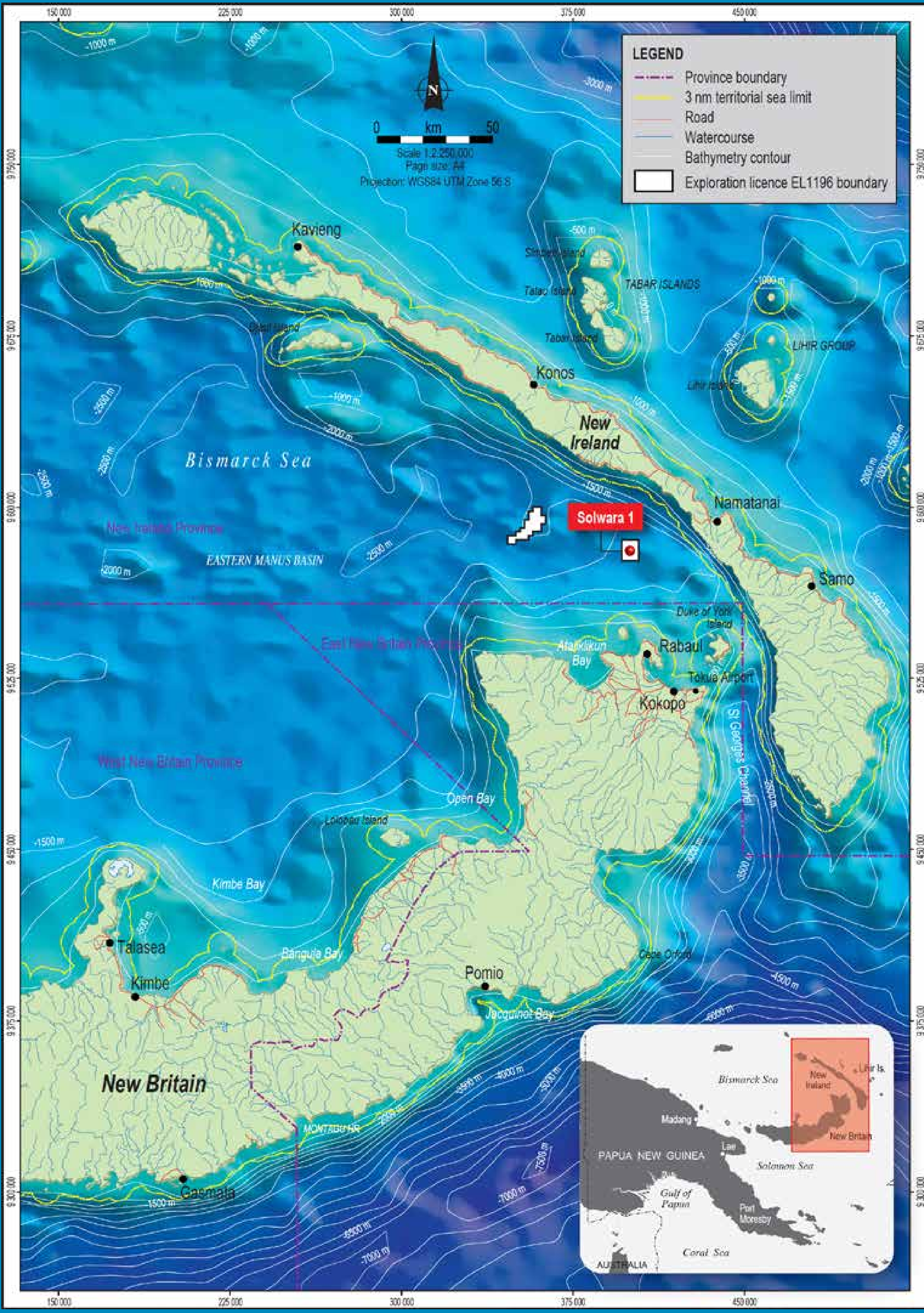
The proposed mine site is located in an area with a great deal of volcanic, seismic and hydrothermal activity that causes regular disturbances, estimated to be comparable to the disturbances caused by mining activities.

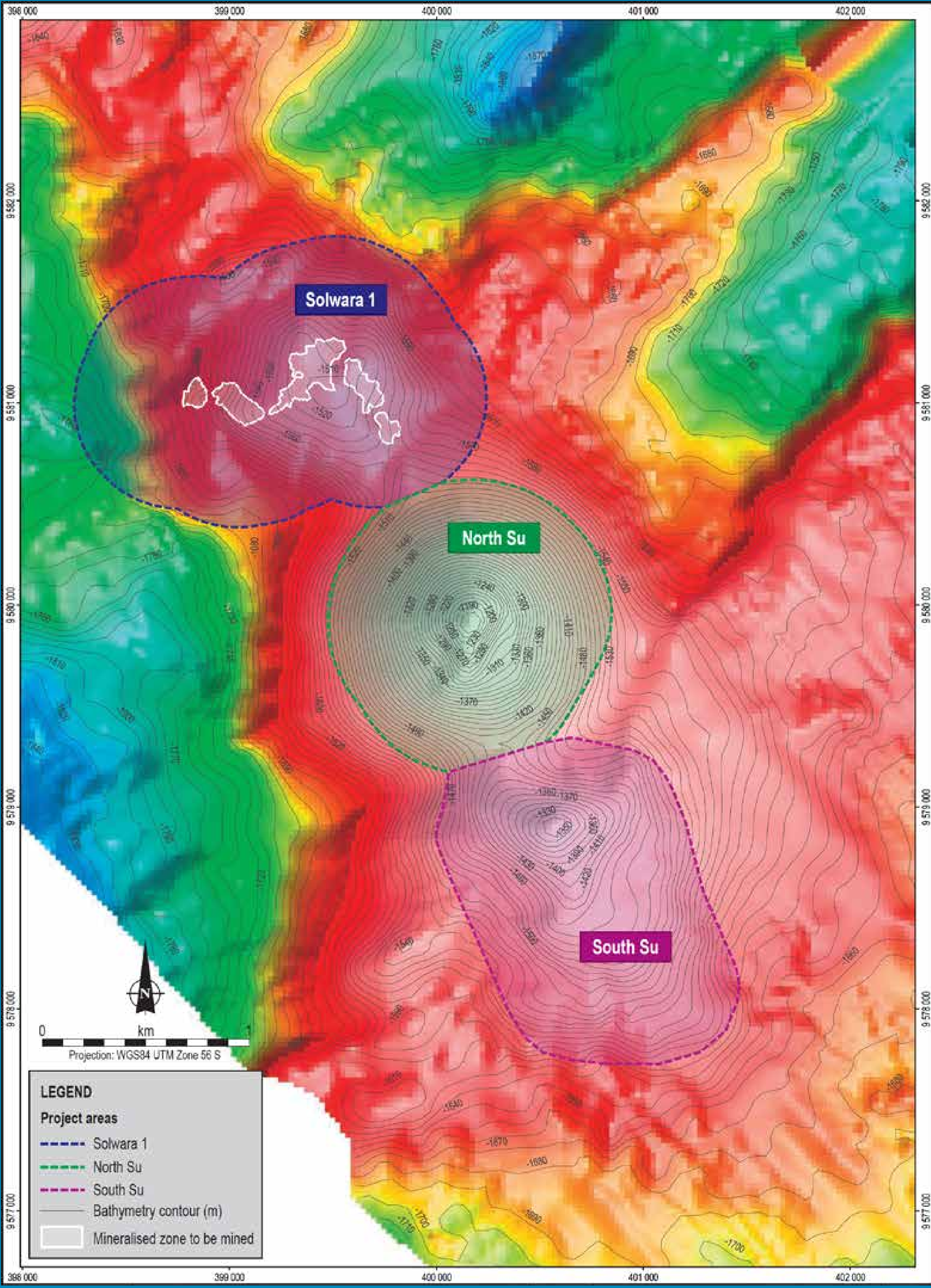
The proposed mine site is located in an area that boasts several underwater volcanoes, and thus there is already a great deal of volcanic, seismic and hydrothermal activity in the area that causes regular disturbances that are estimated to be comparable to the disturbances caused by mining activities. The North Su underwater volcano has been erupting for many decades and has a plume much larger than the mine disturbance is predicted to be. The plume also extends higher than the predicted mine impact plume, and there is no evidence to date of the volcanic plume extending into the epipelagic (upper) part of the ocean, even though it occurs higher in the water column than the Solwara 1 mine plume will occur.

Vent fauna is naturally more abundant at sites such as Solwara 1 that are actively venting, than at other deep seafloor areas where venting does not occur. However, species density and diversity at both Solwara 1 and the South Su reference site is low for all habitat zones when compared with other vent systems worldwide.[30] A full list of the species at Solwara 1 can be found in the publicly available Nautilus Environmental Impact Statement. High levels of genetic diversity amongst microorganisms have also been found at the Solwara site, with few "dominant" species.[31] Typical ranges for any given species are generally below one meter. Species only feet away from each other might have little to no relation or shared genetic material.[32] This may be due to limited data, not limited microbial migrations as the current provides mobility.[33]

Vent systems in the Solwara 1 mine area exhibit dramatic disturbance, with vents naturally turning on and off with variations in volcanic activity. When vents turn off, the associated vent fauna dies off almost immediately, and newly formed vents are colonized by larval recruits.[34] Areas of inactive venting where hard substrates occur are also influenced by the venting activity, potentially utilizing active vents as an upstream food source, although it is more difficult to discern

▶ Location of the Solwara 1 site
Image credit: Nautilus


LEGEND
Province boundary
3 nm territorial sea limit
Road
Watercourse
Bathymetry contour
Exploration licence EL1196 boundary
0 km 50
Scale 1:2,250,000
Page size: A4
Projection: WGS84 UTM Zone 56 S
N
Kavieng
Konos
New Ireland
Namatanai
Samo
Solwara 1
Bismarck Sea
New Ireland Province
EASTERN MANUS BASIN
East New Britain Province
West New Britain Province
TABAR ISLANDS
LIHIR GROUP
Lihir Island
Tabar Island
Tatau Island
Simberi Island
Djaul Island
Duke of York Island
Rabaul
Ataliklikun Bay
Tokua Airport
Kokopo
St Georges Channel
Open Bay
Lolobau Island
Kimbe Bay
Talasea
Kimbe
Bangula Bay
Pomio
Jacquinot Bay
Cape Orford
New Britain
Gasmata
MONTAGU HR
Bismarck Sea
New Ireland
Lihir Is.
New Britain
Madang
Lae
PAPUA NEW GUINEA
Solomon Sea
Gulf of Papua
Port Moresby
Coral Sea
AUSTRALIA
150 000
225 000
300 000
375 000
450 000
9 750 000
9 675 000
9 600 000
9 525 000
9 450 000
9 375 000
9 300 000



398 000
399 000
400 000
401 000
402 000
9 582 000
9 581 000
9 580 000
9 579 000
9 578 000
9 577 000
Solwara 1
North Su
South Su
N
0
km
1
Projection: WGS84 UTM Zone 56 S
LEGEND
Project areas
Solwara 1
North Su
South Su
Bathymetry contour (m)
Mineralised zone to be mined

The area surrounding Solwara 1 is among the best-studied deep seabed areas in the world, having been studied and surveyed by research teams since 1993.

the relationship between active and inactive hard substrates.[35] As Nautilus indicates, this natural phenomenon may indicate that the mine site could recover relatively quickly following disturbance, if adequate hard substrates and larval recruits are available. Research in the East Pacific Rise seems to support this expectation.[36]

The 1,600 m depth of the Solwara 1 site, the high level of background sulphur content, and the significant natural shocks that already occur in the terrain surrounding the mine site[37] suggest that it is unlikely that the Solwara 1 project could significantly and permanently alter this deep seabed ecosystem. However, Nautilus has also adopted a precautionary principle-based approach to environmental management and has identified a reserve area, South Su, for preservation as a source for larval recruitment following mining.[38] The suitability of this site as a reserve for Solwara 1 was determined with a series of scientific investigations carried out by independently contracted genetics specialists.[39]

Finally, the Solwara 1 site is small, a mine site area of 11 hectares, with a total maximum predicted disturbance of 14 hectares, and well-studied. By all indications, this location appears to be preferable for deep sea mining. The mining and rehabilitation process will enable Nautilus and research institutions to gather more data from the deep seabed of both undisturbed and disturbed environments, and to monitor the recovery of the area and species after mining is completed.

30+

INDEPENDENTLY PUBLISHED ACADEMIC ARTICLES RELATED TO SOLWARA 1

Deep seabed environments are generally not well-studied due to the constraints of time, expense, and logistics. However, the area surrounding Solwara 1 is among the best-studied deep seabed areas, having been studied and surveyed by a number of deep seabed research teams since 1993. The Woods Hole Oceanographic Institute provides a study of the general state of knowledge concerning life associated with deep seafloor massive sulfide deposits. The study shows the dearth of knowledge about these ecosystems compared to the relative abundance of knowledge about the Solwara 1 site.[40] There are over 30 independently published research articles relating to Solwara 1, in addition to the internal studies completed by Nautilus. These articles are publicly available and independently peer reviewed. A summary of these studies is provided in Table 1 below.

◀ Topography of the Solwara 1 site; Image credit: Nautilus

▼ **Table 1. (following pages)** Summary of Independently Published Articles on Solwara 1

No.	Report Title	Full Citation
1	A biological survey method applied to Seafloor Massive Sulphides with contiguously distributed hydrothermal vent fauna	Collins P.C., Kennedy R., Van Dover C.L. (2012) A biological survey method applied to seafloor massive sulphides (SMS) with contagiously distributed hydrothermal-vent fauna, Marine Ecology Progress Series, vol. 452, pp. 89-107.
2	Application of biological studies to deep-sea governance and management of deep-sea resources	Van Dover, C. L., Arnaud-Haond, S., Clark M., Smith, S., Thaler, A. D., Van den Hove, S. (2011) Application of biological studies to deep-sea governance and management of deep-sea resources. Biological Sampling in the Deep Sea, Wiley-Blackwell Publishing, 488pp.
3	Biogeography ecology and vulnerability of chemosynthetic ecosystems in the deep sea	Baker, M. C., Ramirez-Llodra, E. Z., Tyler, P. A., German, C. R., Boetius, A., Cordes, E., E., Dubilier, N., Fisher, C., R., Levin, L., A., Metaxas, A., Rowden, A. A., Santos, R. S., Shank, T. M., Van Dover, C. L., Young, C. M., Waren, A. (2010). Biogeography, Ecology and Vulnerability of Chemosynthetic Ecosystems in the Deep Sea, Life in the World's Oceans: Diversity, Distribution, and Abundance, McIntyre, A, D. (Ed), Chapter 9, pp. 161-182, Blackwell Publishing Limited.
4	Bone-eating marine worms- habitat specialists or generalists?	Vrijenhoek, R. C., Collins, P, and Van Dover, C. L. (2008). Bone-eating worms: habitat specialists or generalists? Proceedings of the Royal Society, doi:10.1098/3sbp.2008.0350.
5	Characterisation of 9 polymorphic microsatellite loci in Chorocaris sp. (Crustacea, Caridea, Alvinocarididae) from deep-sea hydrothermal vents	Zelnio, K. Z., Thaler, A D., Jones, R. E., Saleu, W., Schultz, T. F., Van Dover, C. L., Carlsson, J. (2010). Characterisation of nine polymorphic microsatellite loci in Chorocaris sp. (Crustacea, Caridea, Alvinocarididae) from deep-sea hydrothermal vents, Conservation Genetic Resources, vol 2, no. 1, pp. 223-226.
6	Characterization of 10 polymorphic microsatellite loci in Munidopsis lauensis, a squat-lobster from the southwestern Pacific	Boyle, E. A., Thaler, A. D., Jacobson, A., Plouviez, S., Van Dover, C. L. (2013). Characterization of 10 polymorphic microsatellite loci in Munidopsis lauensis, a squat-lobster from the southwestern Pacific, Conservation Genetic Resources, vol. 4, no. 4, doi 10.1007/s12686-013-9872-1.
7	Characterization of 12 polymorphic microsatellite loci in Ifremeria	Thaler, A. D., Zelnio, K. A, Jones, R. E., Carlsson, J., Van Dover, C. L., Schultz, T. F. (2010). Characterization of 12 polymorphic microsatellite loci in Ifremeria nautilei, a chemoautotrophic gastropod from deep-sea hydrothermal vents. Conservation Genetic Resources, vol. 2, pp. 101-103.
8	Characterization of 18 polymorphic microsatellite loci from the deep-sea hydrothermal vent mussel Bathymodiolus manusensis	Schultz., T., F., Hsing, P., Eng, A., Zelnio, K., A., Thaler, A. D., Carlsson, J., Van Dover, C. L. (2010). Characterization of 18 polymorphic microsatellite loci from Bathymodiolus manusensis (Bivalvia, Mytilidae) from deep-sea hydrothermal vents, Conservation Genetic Resources, vol. 3, no. 1, pp. 25-27.
9	Characterization of host-symbiont relationships in hydrothermal vent gastropods of hte genus Alviniconcha from the Southwest Pacific	Suzuki, Y, Kojima, S, Sasaki, T, Suzuki, M, Utsumi, T, Watanabe, H, Urakawa, H, Tsuchida, S, Nunoura, T, Hirayama, H, Takai, K, Nealson, K. H, Horikoshi, K. (2006). Host-symbiont relationships in hydrothermal vent gastropods of the genus Alviniconcha from the southwest Pacific, Applied and Environmental Microbiology, vol. 72, no. 2, pp. 1388-1393.
10	Macrobenthos community structure and trophic relationships within active and inactive Pacific hydrothermal sediments	Levin, L. A., Mendoza, G. F., Konotchick, T, and Lee, R. (2009). Macrobenthos community structure and trophic relationships within active and inactive Pacific hydrothermal sediments, Journal of Deep Sea Research II, doi: 10.1016/j.dsr2.2009.05.010.
11	Comparative population genetics of two hydrothermal-vent-endemic species, Chorocaris spp. and Olgasolaris tollmanni from southwest Pacific back arc basins	Thaler, A., Plouviez, S., Zelnio, K. A., Jacobson, A., Jollivet, D., Carlsson, J., Schultz, T., Van Dover, C. L. (2012). Comparative population genetics of two hydrothermal-vent-endemic species, Chorocaris spp. and Olgasolaris tollmanni from southwest Pacific back arc basins, Poster from 13th International Deep-Sea Biology Symposium.

No.	Report Title	Full Citation
12	Designating networks of chemosynthetic ecosystem reserves in the deep sea	Van Dover, C. L., Smith, C. R., Ardron, J., Dunn, D., Gjerde, K., Levin, S., Smith, S. (2011). Designating networks of chemosynthetic ecosystem reserves in the deep sea, Marine Policy, vol. 36, pp. 378-381.
13	Distribution and Sources of Trace Metals in Volcaniclastic Sediments of the SuSu Knolls Hydrothermal Field, Manus Basin, Papua New Guinea	Hrischeva, E. H., and S. D. Scott. (2007). Distribution and Sources of Trace Metals in Volcaniclastic Sediments of the SuSu Knolls Hydrothermal Field, Eastern Manus Basin, Papua New Guinea. American Geophysical Union Fall Meeting Abstracts, vol. 1, p. 0750.
14	Host-Symbiont Relationships in Hydrothermal Vent Gastropods of the Genus Alviniconcha from the Southwest Pacific	Suzuki, Y., Kojima, S., Sasaki, T., Suzuki, M., Utsumi, T., Watanabe, H., Urakawa, H., Tsuchida, S., Nunoura, T., Hirayama, H., Takai, K., Nealson, K. H., and Horikoshi, K. (2006). Host-Symbiont Relationships in Hydrothermal Vent Gastropods of the Genus Alviniconcha from the Southwest Pacific, Applied and Environmental Microbiology, vol. 72., no. 2, pp. 1388-1393.
15	Evidence for a chemoautotrophically based food web at inactive hydrothermal vents	Erikson, K. L., Macko, S. A. and Van Dover, C. L. (2009) Evidence for a chemoautotrophically based food web at inactive hydrothermal vents (Manus Basin), Deep Sea Research II, vol. 56, pp. 1577-1585.
16	Evolution of the Metallothionein gene family in bathymodiolin mussels	Hsing, P., Carlsson, J., Jones, R., Sobel, A., THaler, A., Van Dover, C. L., Schultz., T. (2014). Evolution of the Metallothionein gene family in bathymodiolin mussels, Poster for VentBase Workshop, Wellington, 2014.
17	Facilitating fine-scale population genetic studies at Manus Basin hydrothermal fields	Carlsson, J., Jones, R., Schultz., T., Sobel, A., Thaler, A., Zelnio, K., Van Dover, C. L. (2014). Facilitating fine-scale population genetic studies at Manus Basin hydrothermal vent fields, Post for VentBase Workshop, Wellington, 2014.
18	Food Web Structure at Manus Basin Hydrothermal Vents	Honig, D. L., Hsing, P., Jones, R., Schultz, T., Sobel, A., Thaler, A., Van Dover, C. L. (2008). American Geophysical Union Fall Meeting Abstracts, no. 12.
19	Comparative Population Structure of Two Deep-Sea Hydrothermal-Vent-Associated Decapods (Chorocaris sp. 2 and Munidopsis lauensis) from Southwestern Pacific Back-Arc Basins	Thaler, A. D., Plouviez, S., Saleu, W, Alei, F, Jacobson, A., Boyle, E. A, Schultz, T. F., Carlson, J., Van Dover, C. L. (2014). Comparative Population Structure of Two Deep-Sea Hydrothermal-Vent-Associated Decapods (Chorocaris sp. 2 and Munidopsis lauensis) from Southwestern Pacific Back-Arc Basins, PLOS ONE, vol. 9, no. 7, e101345.
20	A biogeographical perspective of the deep-sea hydrothermal vent fauna	Tunnicliffe, V., McArthur, A. G., and McHugh, D. (1998). A biogeographical perspective of the deep-sea hydrothermal vent fauna, Advances in Marine Biology, vol. 34, pp. 354-442.
21	Genetic differentiation of populations of a hydrothermal vent-endemic gastropod, Ifremeria nautilei, between the North Fiji Basin and the Manus Basin revealed by nucleotide sequences of mitochondrial DNA	Kojima, S., Segawa, R., Fujiwara, Y., Hashimoto, J., Ohta, S. (2000). Genetic differentiation of populations of a hydrothermal vent-endemic gastropod, Ifremeria nautilei, between the North Fiji Basin and the Manus Basin revealed by nucleotide sequences of mitochondrial DNA, Zoological Science, vol. 17, pp. 1167-1174.
22	The SuSu Knolls hydrothermal field, Eastern Manus Basin, Papua New Guinea: An active submarine high sulfidation copper-gold system	Yeats, C. J., Parr, J. M., Binns, R. A., Gemmell, J. B., Scott, S. D. (2014). The SuSu Knolls hydrothermal field, Eastern Manus Basin, Papua New Guinea: An active submarine high sulfidation copper-gold system, Economic Geology, vol. 109, pp. 2207-2226.
23	Habitats of the Su Su Knolls hydrothermal site	Beaudoin, Y. and Smith, S. (2010). Habitats of the SuSu Knolls hydrothermal site. In Harris, P. T. And Baker, E. K. (eds). (2010). Seafloor Geomorphology as Benthic Habitat: GeoHAB Atlas of Seafloor Geomorphic Features and Benthic Habitats, Elsevier.
24	Hydrothermal Input into Volcaniclastic Sediments of the SuSu Knolls Hydrothermal Field	Hrischeva, E. H., Scott, S. D. (2005). Hydrothermal input into volcaniclastic sediments of the SuSu Knolls hydrothermal field, Eastern Manus Basin, Bismarck Sea, Papua New Guinea, American Geophysical Union Spring Meeting Abstracts, no. V52A-06.

No.	Report Title	Full Citation
25	Metalliferous sediments associated with presently forming volcanogenic massive sulfides	Hrischeva, E., Scott, S. D., Weston, R. (2007). Metalliferous sediments associated with presently forming volcanogenic massive sulphides: the SuSu Knolls hydrothermal field, Eastern Manus Basin, Papua New Guinea, Economic Geology, vol. 102, pp. 55-73.
26	Mining seafloor massive sulphides and biodiversity – what is at risk	Van Dover, C. L. (2010). Mining seafloor massive sulphides and biodiversity: what is at risk?, ICES Journal of Marine Science; doi:10.1093/icejms/fsq086.
27	Molecular phylogenetic analysis of a known and a new hydrothermal vent octopod: their relationship with the genus Benthoctopus (Cephalapoda: Octopodidae)	Strugnell, J., Voight, J. R., Collins, P. C., Allcock, A. L. (2009). Molecular phylogenetic analysis of a known and a new hydrothermal vent octopod: their relationship with the genus Benthoctopus (Cephalapoda: Octopodidae), Zootaxa, vol. 2096, pp. 442-459.
28	Molecular taxonomy and naming of five cryptic species of Alviniconcha snails (Gastropoda: Abyssochrysidae) from hydrothermal vents	Johnson, S. B., Waren, A., Tunnicliffe, V., Van Dover, C. L., Wheat, C. G., Schultz, T. F., Vrijenhoek, R. C. (2015). Molecular taxonomy and naming of five cryptic species of Alviniconcha snails (Gastropoda: Abyssochrysidae) from hydrothermal vents, Systematics and Biodiversity, vol. 13, no. 3, pp. 278-295.
29	Population Genetics of Species Associated with Deep-Sea Hydrothermal Vents in the Western Pacific	Thaler, A. D. (2012). Population Genetics of Species Associated with Deep-sea Hydrothermal Vents in the Western Pacific, Doctoral dissertation, Duke University.
30	The spatial scale of genetic subdivision in populations of Ifremeria nautilei, a hydrothermal-vent gastropod from the southwest Pacific	Thaler, A. D., Zelnio, K., Saleu, W., Schultz, T. F., Carlsson, J., Cunningham, C., Vrijenhoek, R. C., Van Dover, C. L. (2011). The spatial scale of genetic subdivision in populations of Ifremeria nautilei, a hydrothermal-vent gastropod from the southwest Pacific, BCM Evolutionary Biology, vol. 11, no. 372.
31	Two species of caridean shrimps (Decapoda: Hippolytidae and Nematocarcinidae) newly recorded from the Manus Basin, southwestern Pacific	Komai, T., Collins, P. (2009). Two species of caridean shrimps (Decapoda: Hippolytidae and Nematocarcinidae) newly recorded from the Manus Basin, southwestern Pacific, Crustacean Research, no. 38, pp. 28-41.
32	Ecological restoration in the deep sea: Desiderata	Van Dover, C. L., Aronson, J., Pendleton, L., Smith, S., Arnaud-Haond, S., Moreno-Mateos, D., Barberi, E., Billett, D., Bowers, K., Danovaro, R., Edwards, A., Kellert, S., Morato, T., Pollard, E., Rogers, A., Warner, R. (2014). Ecological restoration in the deep sea: Desiderata, Marine Policy, vol. 44, pp. 98-106.
33	A primer for use of genetic tools in environmental impact assessment: selecting and testing the suitability of set-aside sites for deep-sea seafloor massive sulphide mining.	Collins, P., Tunnicliffe, V., Carlsson, J., Gardner, J., Lowe, J., McCrone, A., Metaxas, A., Sinniger, F., Swaddling, A., Boschen, R. (in press). A primer for use of genetic tools in environmental impact assessment: selecting and testing the suitability of set-aside sites for deep-sea seafloor massive sulphide mining, (no publication details yet).
34	Tighten regulations on deep-sea mining	Van Dover, C. L. (2011). Tighten regulations on deep-sea mining, Nature, vol. 470, pp. 31-33.
35	Genetic diversity and connectivity of deep-sea hydrothermal vent metapopulations	Vrijenhoek, R. C. (2010). Genetic diversity and connectivity of deep-sea hydrothermal vent metapopulations, Molecular Ecology, vol. 19, pp. 4391-4411.

▶ Snails on a deep sea vent
Image credit: Nautilus