Request for Information

Facilitating the 'Geophysical investigation of Singapore to evaluate suitable applications for the energy sector'

Closing date for submission of information and feedback:
03 June 2022

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1 Background

1.1 The Energy Market Authority (EMA) is investigating the potential of harnessing geothermal energy in Singapore, following new developments in technology that could possibly enable Singapore to tap on heat resource deep underground. If found to be feasible, geothermal energy could serve as an additional source of indigenous clean energy besides solar, and support Singapore in improving energy resiliency and meeting climate change goals.

1.2 Key findings on geothermal energy thus far. Since the 1960s, preliminarily studies have been conducted by the Academia and the Government to assess the potential for geothermal energy in Singapore. The key findings of those studies were that Singapore is sited within a region of high subsurface heat flow, with a possibility of quality geothermal resources at greater depths. However, conventional hydrothermal systems, which harness heat from underground resources of hot water and steam, may not be suitable for Singapore due to the lack of quality resources at shallower depths.

1.3 Recent developments in geothermal technology, such as enhanced or advanced geothermal systems (EGS/AGS), have opened up new possibilities for Singapore. For example, AGS is claimed to be able to harness heat from deep hot dry rock with minimal impact to environment and safety. However, it is important to first ascertain if the geothermal resource potential in Singapore is substantial, before assessing technology options and suitable applications *i.e., adopt a phased approach for geothermal deployment in Singapore*.

1.4 Overview of phased approach for potential geothermal deployment. Figure 1 presents an overview of a possible phased approach for geothermal deployment in Singapore.

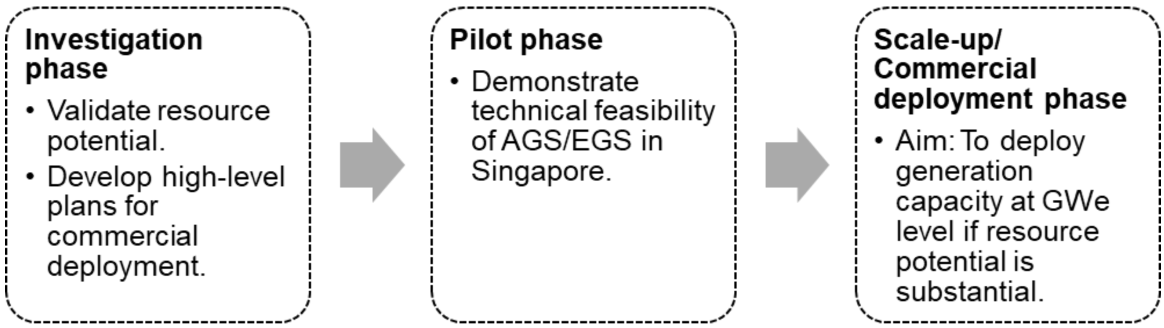

Figure 1: Possible Phased Approach to Geothermal Deployment in Singapore.

1.5 Investigation phase. The objective of the investigation phase is to validate geothermal resource potential and develop high-level plans[1] for commercial deployment. Resource potential needs to be substantial and the viability of extracting

[1] The high-level deployment plan would ideally inform on: suitable locations and land-take requirements; suitable applications and generation capacity; suitable technology developer(s)/ partner(s) who has/ have proved demonstration in geology similar to, and at depths expected for Singapore; estimated CAPEX and LCOE; safety/ environmental risks; and feasibility of scaling up pilot(s) to be part of a commercial-scale plant.

geothermal potential for large-scale deployment in Singapore should be assessed before we transit to the pilot phase.

1.6 Therefore, at the end of resource potential assessment, there should be adequate and accurate information to assess if Singapore's geothermal resource potential is substantial, and assess at high-level the viability of deploying large-scale geothermal systems.

1.7 Ongoing efforts to assess geothermal resource potential (as part of the investigation phase). EMA is working closely with Nanyang Technological University (NTU), Singapore and various ministries and agencies to carry out exploratory studies. These studies will focus on estimating the geothermal resource potential in northern and eastern Singapore, which have been identified to hold geothermal potential, based on their higher surface temperature measurements (e.g., hot springs). The exploratory studies aim to establish preliminary findings by early 2023.

1.8 Plan to conduct a more comprehensive study to assess geothermal potential. In order to ensure a comprehensive assessment of resource potential, **EMA is also planning for a geophysical investigation project ("Project") that will cover the whole of Singapore**. The outcome of the planned project is to ascertain the (i) geothermal potential for the whole of Singapore, and (ii) suitable deployment locations.

1.9 EMA is also exploring the possibility of extending the project to cover other underground-related use cases (beyond geothermal) given potential synergies in survey methods/ modelling i.e., carbon dioxide (CO2) storage potential, and potential locations for underground power plant infrastructure e.g., substation, turbine building, etc.

1.10 The objective of the project will therefore be to:

a. Gain greater clarity on geothermal and CO2 storage (in terms of MWe and tCO2), and feasibility of siting underground power plant infrastructure to help inform policy decisions and positions.

b. Identify suitable deployment locations (i) to exploit geothermal and CO2 storage potential (including expected depths to drill to), if any, and/or (ii) for underground power plant infrastructure.

1.11 If resource potential assessments from the project yield positive results, EMA will explore undertaking further effort to assess the viability and scalability of deploying geothermal systems and other possible applications in Singapore.

2 Objective of RFI

2.1 Given the complexity of the planned project, we hope to consult the Academia and Industry, via this RFI, on possible approaches and methodologies, budgetary requirements, and project timeline/ schedule to execute the project, before launching a Request for Proposal (RFP) to award the project. **Scope of information sought from Academia and Industry is outlined in Section 3.**

2.2 At the end of the RFI, **based on information provided in Section 3**, we aim to have greater clarity on the following:

a. Extent of geographical coverage of project. We are interested in the subsurface/ underground mapping of territorial space of Singapore (including waters and offshore islands), and we aim to seek clarity on the following:

(1) Technical feasibility. Is it technically feasible to map the underground within the territorial waters surrounding Singapore?

(2) If feasible, are there any specific regions of territorial space (e.g., south, northeast, etc.) that the project should focus on?

(3) Trade-offs with respect to the extent of coverage. Should the project cover the whole of Singapore (including territorial waters and offshore islands) or only mainland Singapore? How much more would it cost and how much longer would it take to survey the territorial waters and offshore islands?

b. Need for invasive methods[2] associated with the drilling of boreholes and at which stage if required. Should the project adopt non-invasive methods[3] only or a combination of non-invasive and invasive methods? If invasive methods are recommended, at which stage of the project should they be conducted (e.g., concurrently with or after non-invasive methods)?

c. Information that could be derived from the project. What kind of information could be gleaned from the different survey methods that could advise us on (i) geothermal potential, (ii) CO_2 storage potential, and (iii) potential for deploying underground power plant infrastructure?

d. Recommended geographical scope, approach and methodology. Based on paras 2.2a to 2.2c above, what is the recommended geographical scope, approach and methodology (i.e., key steps to undertake) for the project, and what are the corresponding budgetary requirements and project timeline/ schedule?

2.3 Please note the following **principal considerations/ boundary conditions** in recommending a suitable approach and methodology:

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[2] Invasive methods in this RFI refer to those that require the drilling of boreholes.

[3] Non-invasive methods in this RFI refer to those that rely on active or passive signals e.g., seismic signals for measurements and surveys, and do not require drilling of boreholes.

a. Scope and accuracy. As mentioned before, at the end of the project there should be adequate and sufficiently accurate information (without the need for follow-up studies/ surveys to obtain information) to assess the geothermal resource potential of Singapore, and subsequently assess the commercial viability of deploying geothermal systems for various applications (e.g., power generation, process heating, etc.). This includes being able to identify any safety/ environmental risks associated with geothermal deployment in Singapore.

b. This also applies to the assessment on CO2 storage potential and potential for deployment underground power plant infrastructure.

c. Applications that the project should focus on: Geothermal and CO2 storage potential, and potential for deploying underground power plant infrastructure.

d. Timeline. The planned project should aim to establish preliminary findings by end-2023/ early 2024 on the following:

(1) Geothermal resource potential (in terms of MWe and potential deployment locations and depths).

(2) CCS potential (in terms of tCO2 and potential deployment locations and depths).

(3) Potential for underground power plant deployment (in terms of space and potential deployment locations).

e. Cost of project execution (including that for the different survey methods, manpower, etc.).

3 Scope of RFI

3.1 **Investigation methods for mainland[4] Singapore.** Please advise on the table below for the following applications of: geothermal and CO_2 storage potential, and potential for deploying underground for power plant infrastructure[5] (e.g., substation, turbine building). Where possible, please include a breakdown of the timeline and budget.

	Methods	**Outcomes[6]**	**Accuracy (+/-%)**	**Timeline (months)[7]**	**Budget (SGD)**	**Other important considerations (if any)**
Non-invasive approach	*e.g., Seismic survey*	…	…	…	…	…
	e.g., Gravimetric survey	…	…	…	…	…
	e.g., Data processing and modeling	…	…	…	…	…
Invasive approach	*e.g., Drilling at x sites up to y meters and temperature measurements*	…	…	…	…	…
	e.g., Cross borehole tomography	…	…	…	…	…
	e.g., Data processing and modeling	…	…	…	…	…

Table 1: Scope of Information Required for a Geophysical Investigation of Mainland Singapore

[4] Please refer to Annex A for demarcation of mainland Singapore and offshore islands.
[5] For underground infrastructure for power plants, the project aims to identify suitable locations for deployment based on geology. Hence, there is no need to consider underground space requirements for the infrastructure (unless the space available is very minimal for a given location).
[6] Please note that the methods indicated should be able to collectively address all three applications of: geothermal and CO_2 storage potential, and potential for deploying underground power plant infrastructure. For each method, include a brief description of how it works and indicate what kind of data would be obtained (including the scope of this data in terms of depth and horizontal coverage).
[7] Timeline should include estimated durations to secure approval/clearance from the relevant authorities, secure necessary equipment and engage third parties (if needed) to support the project.

3.2 **Investigation methods for territorial waters surrounding Singapore.** Please advise on the table below for the following applications of: geothermal and CO2 storage potential. Where possible, please include a breakdown of the timeline and budget.

	Methods	**Outcomes**[6]	**Accuracy (+/-%)**	**Timeline (months)**[7]	**Budget (SGD)**	**Other important considerations (if any)**
Non-invasive approach	*e.g., Seismic survey*	…	…	…	…	…
	e.g., Gravimetric survey	…	…	…	…	…
	e.g., Data processing and modeling	…	…	…	…	…
Invasive approach	*e.g., Drilling at x sites up to y meters and temperature measurements*	…	…	…	…	…
	e.g., Cross borehole tomography	…	…	…	…	…
	e.g., Data processing and modeling	…	…	…	…	…

Table 2: Scope of Information Required for a Geophysical Investigation of Territorial Waters of Singapore

3.3 **Investigation methods for offshore islands[4].** Please advise on the table below for the following applications of: geothermal and CO2 storage potential, and potential for deploying underground power plant infrastructure[5] (e.g., substation, turbine building). Where possible, please include a breakdown of the timeline and budget.

	Methods	**Outcomes**[6]	**Accuracy (+/-%)**	**Timeline (months)**[7]	**Budget (SGD)**	**Other important considerations (if any)**
Non-invasive approach	*e.g., Seismic survey*	…	…	…	…	…
	e.g., Gravimetric survey	…	…	…	…	…
	e.g., Data processing and modeling	…	…	…	…	…

Invasive approach	*e.g., Drilling at x sites up to y meters and temperature measurements*	…	…	…	…	…
	e.g., Cross borehole tomography	…	…	…	…	…
	e.g., Data processing and modeling	…	…	…	…	…

Table 3: Scope of Information Required for a Geophysical Investigation of Offshore islands

Note: Any other supporting information may be included as annexes in the submission.

3.4 **Recommended geographical scope, approach and methodology.** Based on information provided in sub-sections 3.1 to 3.3 above, and existing resources/ information (as specified in Annex B), recommend a geographical scope, suitable approach and methodology for the planned project. This should take into account the principal considerations/ boundary conditions specified in para 2.3. The response to this sub-section can be in the format of a simple project proposal.

a. Key guiding questions are as follows:

(1) Which regions/areas of (i) mainland Singapore, (ii) territorial waters and (iii) offshore islands should the project focus on?

(2) Which methods are most effective? Can the project be conducted solely via non-invasive methods?

(3) What is the overall plan and timeline for the project? How should the relevant methods be scheduled/ phased?

b. For the recommended geographical scope, approach and methodology,

(1) List the phases, sequence of steps and associated timeline required for the execution of the project;

(2) Breakdown of project cost in terms of that for methods, manpower, etc.; and

(3) Indicate the pros and cons / limitations / project risks.

3.5 For all the information requested in Section 3, RFI participants are requested to indicate the assumptions where relevant.

4 Submission of Information and Feedback

4.1 EMA invites submission of information as requested for in Section 3 and feedback in general in relation to this RFI. Please submit your written responses to the Energy Technology Branch via email to: Kannan_Arunachalam@ema.gov.sg by **03 June 2022, 2359HRS** (Singapore Time). Please note that anonymous feedback will not be considered.

4.2 Companies and institutes of higher learning (IHLs) participating in this RFI are also requested to submit supporting documents on project experience, technical skills, etc. (relevant to the scope of the RFI/RFP) together with the written responses.

4.3 Please note that participation in this RFI is **recommended** for subsequent participation in the RFP for the planned project.

4.4 Companies and IHLs who intend to work together may jointly respond to this RFI for more complete and holistic submissions.

4.5 For clarifications, you may contact the Energy Technology Branch at the abovementioned email address.

4.6 EMA reserves the right at its sole discretion to make public all or any part or parts of any written submission received by EMA in response to this RFI and to disclose the name of the party from whom the written submission was received ("the Respondent"). Where a written submission contains any matter that the Respondent considers to be of a confidential and/or commercially sensitive nature, the Respondent shall clearly mark this in the written submission, and EMA will take this into account when deciding to make public the written submission or any part thereof. Notwithstanding anything herein, EMA may seek clarification from a Respondent regarding its written submission while the RFI is ongoing.

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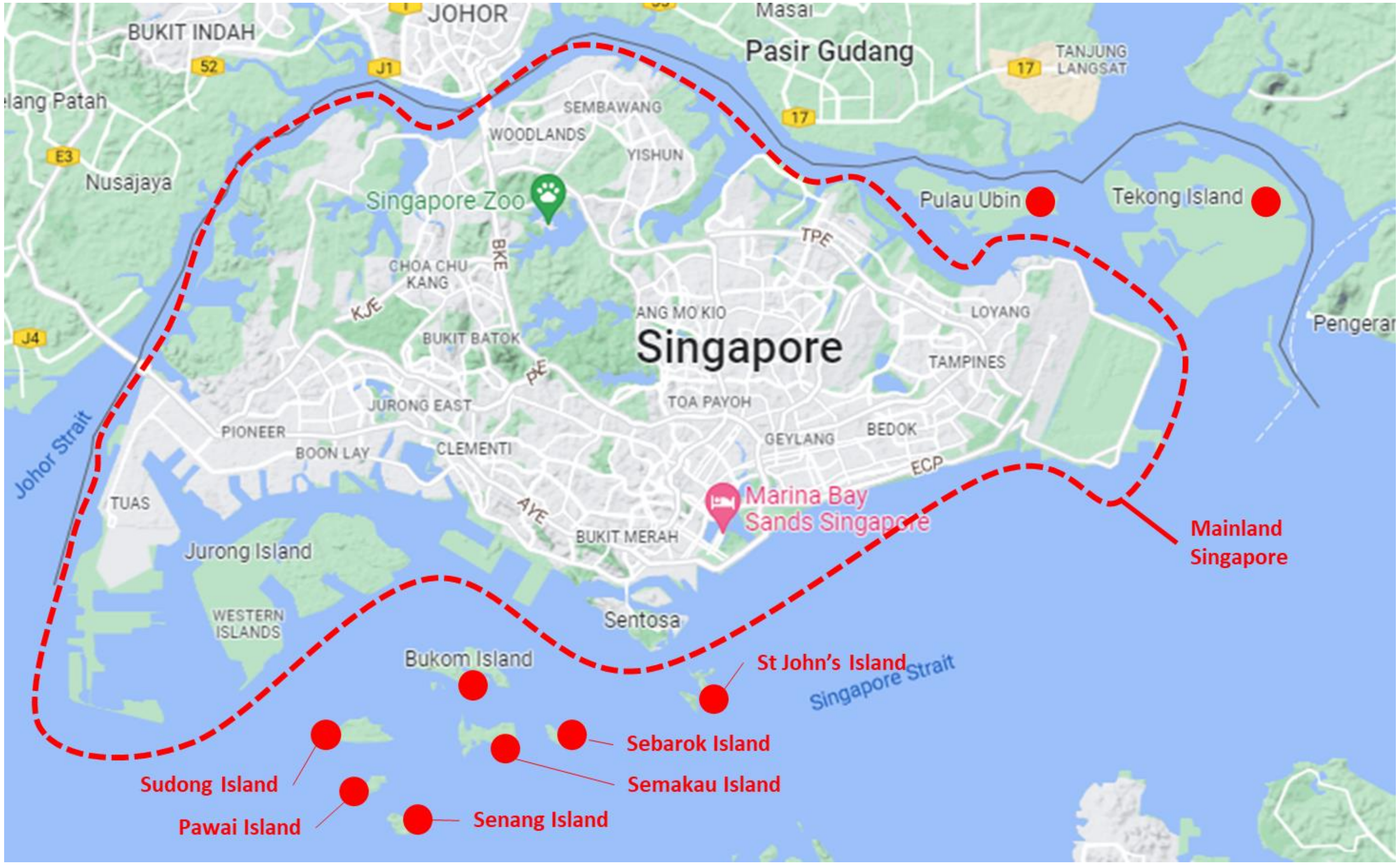
Demarcation of Mainland Singapore and Offshore Islands



<u>Figure A1: Demarcation of Mainland Singapore and Nine Offshore Islands</u>

Annex B

List of Existing Resources/ Information Relevant to Geothermal Energy in Singapore

S/No.	Title	Type	Year published	Source/ Agency
1.	Bundled Geological map & Memoir of the bedrock, superficial and engineering geology[8]	Hardcopy	2021	BCA
2.	Interactive Singapore Geological Map (1:50,000 scale)[9]	Interactive PDF	2021	BCA
3.	Integrated Land Information Service (INLIS[10]): Borehole data from public sector projects (http://www.sla.gov.sg/inlis)	Website	2018	BCA-SLA
4.	GeoSpace[11]: Borehole data from public sector projects	Website	-	-
5.	Preliminary shallow soil resistivity survey result, and possibly seismic survey result, at the deep drilling sites	-	Part of the ongoing geothermal resource potential study in the Northern region	NTU
6.	Preliminary 3D geological model (based on available borehole data, up to ~300m deep) of approx. 15km-by-10km grid of northern half of Singapore	-		NTU
7.	Shallow temperature profiles for Singapore (based on available borehole data, up to ~300m deep) with greater accuracy around the Central to Northern region	-		NTU
8.	Deep borehole data of two boreholes (of about 1.5km depth), by Q4 2023	-		NTU

[8] The bundled set (which can be purchased from BCA) contains one A4-size geological memoir and four A0-size of geological maps. The A4 size memoir includes recent detailed re-appraisals of both the bedrock geology and superficial deposits. The memoir comprises 163 pages which include a chapter on Engineering Geology and contains high resolution photographs of the various rocks and rock outcrop. The composed four A0-Size geological maps are as follows: (i) Singapore Bedrock (1:50 000); (ii) Singapore Bedrock and Superficial Deposits (1:50 000); (iii) Singapore Superficial Deposits (1:50 000); (iv) Singapore Engineering Geology (1:50 000).

[9] The Interactive Singapore Geological Map (iSGM) is an interactive PDF (which can be purchased from BCA) which has three different layer visibility options: bedrock, bedrock and superficial combined, engineering bedrock geology. The digital map will allow for hardcopy printing of the different map configurations within an A0 paper size layout. The map also incorporates baseline data to facilitate geographic location by map users, which include rivers, water bodies, major roads, expressways and MRT lines. GIS shapefiles of Singapore Geological Map will also be included as part of the purchase.

[10] INLIS is only open to users with Singpass.

[11] Data will need to be accessed by EMA and shared with the selected consultant for the RFP.

9.	Geothermal potential (in MWe) for a single deployment, by Q4 2023 location	-		NTU
10.	Deep borehole data in the West (of about 2.5km depth)	-	-	-
11.	Gravity and seismic surveys in the Eastern region (at the planning stage)	-	Part of the ongoing geothermal resource potential study in the Eastern region	NTU
12.	Modelling of subsurface temperature profiles in the Eastern region (at the planning stage)	-		NTU

List of key articles and technical papers published (not exhaustive)

S/No.	Title	Author(s)	Periodical/ Journal	Year
1.	Geological and Geotechnical Features of Singapore: An Overview	Sharma, J.S., J. Chu, and J. Zhao	Tunnelling and Underground Space Technology	1999
2.	A hydrological study of the Sembawang hot spring	Zhao, J., Chen, C.N., and Cai, J.G.	Bulletin of Engineering Geology and Environment	2002
3.	Geothermal energy concept for Singapore	G.J.H. Oliver	South East Asia Petroleum Exploration Society	2009
4.	Engineered geothermal power systems for Singapore	G.J.H. Oliver, A.C. Palmer, H. Tjiawi and F. Zulkefli	The IES Journal Part A: Civil & Structural Engineering	2011
5.	Longman Atlas: Singapore and the World, 1st ed.	Yeoh, Brenda, S.A	-	2002
6.	Construction and Utilization of Rock Caverns in Singapore; Part A: The Bukit Timah Granite Bedrock Resource	Zhao, J	Tunnelling and Underground Space Technology	1996

S/No.	Title	Author(s)	Periodical/ Journal	Year
7.	Construction and Utilization of Rock Caverns in Singapore; Part C: Planning and Location Selection	J. Zhao and K. W. Lee	Tunnelling and Underground Space Technology	1996
8.	A Review of Geology and Engineering Geology in Singapore	Pitts, J	Quarterly Journal of Engineering Geology and Hydrology	1984
9.	The igneous rocks of Singapore: New insights to Paleozoic and Mesozoic assembly of the Sukhothai Arc	Martin R. Gillespie, Rhian S. Kendall, A. Graham Leslie, Ian L. Millar, Thomas J.H. Dodd, Timothy I. Kearsey, Thomas P. Bide, Kathryn M. Goodenough, Marcus R. Dobbs, Michael Kim Woon Lee, Kiefer Chiam	Journal of Asian Earth Sciences	2019
10.	Determination of hydraulic conductivity of fractured rock masses: A case study for a rock cavern project in Singapore	Zhipeng Xu, Zhiye Zhao, Jianping Sun, Ming Lu	Journal of Rock Mechanics and Geotechnical Engineering	2015
11.	A modified seismic reflection approach for engineering geology investigation in fractured rock zones	Yunhuo Zhang, Yunyue Elita Li, Taeseo Kua	Engineering Geology	2020
12.	Underground Cavern Development in the Jurong Sedimentary Rock Formation	J. Zhao, Q. Liu, K. W. Lee, V. Choa and C. I. Teh	Tunnelling and Underground Space Technology	1999
13.	Underground survey to locate weathered bedrock depth using noninvasive microtremor measurements in Jurong sedimentary formation, Singapore	Palanidoss Subramaniam, Yunhuo Zhang, Taeseo Ku	Tunnelling and Underground Space Technology	2019
14.	A new Quaternary stratigraphy of the Kallang River Basin, Singapore: Implications for urban development and geotechnical engineering in Singapore	Stephen Chua, Adam D. Switzer, Timothy I. Kearsey, Michael I. Bird, Cassandra Rowe, Kiefer Chiam, Benjamin P. Horton	Journal of Asian Earth Sciences	2020

S/No.	Title	Author(s)	Periodical/ Journal	Year
15.	Influence of groundwater drawdown on excavation responses – A case history in Bukit Timah granitic residual soils	Zhang, W. G., Wang, W., Zhou, D., Goh, A. T. C., & Zhang, R. H	Journal of Rock Mechanics and Geotechnical Engineering	2018
16.	Rock mass hydraulic conductivity of the Bukit Timah granite, Singapore	J. Zhao	Engineering Geology	1998
17.	Engineering properties of Bukit Timah Granitic residual soils in Singapore DTL2 braced excavations	Zhang, W. G., Zhang, R. H., Han, L., & Goh, A. T. C	Underground Space	2019
18.	Engineering geology and rock mass properties of the Bukit Timah Granite	Zhou, Y.	Underground Space	2001
19.	A study of the weathering of the Bukit Timah Granite Part B: Field and laboratory investigations	Zhao, J., Broms, B. B., Zhou, Y., et al.	Bulletin of the International Association of Engineering Geology	1994
20.	Hydrofracturing in situ stress measurements in Singapore granite	J. Zhao, A.M. Hefny, Y.X. Zhou	International Journal of Rock Mechanics & Mining Sciences	2005
21.	Some engineering properties of soils and rocks in the Bukit Timah Granite Formation of Singapore	Goh, K.H., Zhang, Y.H., Kumarasamy, J.	-	2013
22.	Variability of Mechanical and Physical Properties of Singapore Bukit Timah Granite Rocks and Residual Soils	Han, L., Zhang, W., Wu, C., & Goh, A.	-	2018
23.	Tunnelling Projects in Singapore: An Overview	T, W. Hulme and A. J. Burchell	Tunnelling and Underground Space Technology	2007
24.	Crustal thickness and velocity structure beneath Singapore’s seismic network	Kenneth A. Macpherson, Dannie Hidayat, Lujia Feng, Siang Huat Goh	Journal of Asian Earth Sciences	2013

S/No.	Title	Author(s)	Periodical/ Journal	Year
25.	Digitalization of mechanical and physical properties of Singapore Bukit Timah granite rocks based on borehole data from four sites	Zhang Wengang, Han Liang, Zong Zixu, Zhang Yanmei	Underground Space	2021
26.	Mineralogy and geotechnical properties of Singapore marine clay at Changi	Myint Win Bo, Arul Arulrajah, Patimapon Sukmak, Suksun Horpibulsuk	Soils and Foundations	2015
27.	Deep to shallow-marine sedimentology and impact of volcanism within the Middle Triassic Palaeo-Tethyan Semantan Basin, Singapore	Thomas J.H. Dodd, A. Graham Leslie, Martin R. Gillespie, Marcus R. Dobbs, Thomas P. Bide, Rhian S. Kendall, Timothy I. Kearsey, Kiefer Chiam, Michael Goay	Journal of Asian Earth Sciences	2020
28.	Paleozoic to Cenozoic sedimentary bedrock geology and lithostratigraphy of Singapore	Dodd, T.J., Gillespie, M.R., Leslie, A.G., Kearsey, T.I., Kendall, R.S., Bide, T.P., Dobbs, M.R., Millar, I.L., Lee, M.K.W., Chiam, K.	Journal of Asian Earth Sciences	2019
29.	Near-surface site investigation by seismic interferometry using urban traffic noise in Singapore	Zhang, Y., Li, Y.E., Zhang, H., Ku, T.	Geophysics	2019
30.	Landforms and geomorphic evolution of the islands during the Quaternary	Pitts, J	-	1992
31.	The Age and Origin of the Quaternary Sediments of Singapore with Emphasis on the Marine Clay	Bird, M.I., Chang, C.H., Shirlaw, J.N., Tan, T.S., Teh, T.S.	Underground Singapore	2003
32.	The Old Alluvium	Chiam, S.L., Wong, K.S., Tan, T.S., Ni, Q., Khoo, K.S., Chu, J.	Underground Singapore	2003
33.	Old alluvium of Singapore and the extinct drainage system to the South China Sea.	Gupta, A., Rahman, A., Wong, P.P., Pitts, J.	-	1987

S/No.	Title	Author(s)	Periodical/ Journal	Year
34.	Consolidation and permeability properties of Singapore marine clay	Chu, J., Bo, M.W., Chang, M.F., Choa, V.	Journal of Geotechnical and Geoenvironmental Engineering	2002
35.	Prediction of rockhead using a hybrid N-XGBoost machine learning framework	Zhu, X., Chu, J., Wang, K., Wu, S., Yan, W., and Chiam, K.	Journal of Rock Mechanics and Geotechnical Engineering, 13(6), 1231-1245	2021
36.	Site characterization of reclaimed lands based on seismic cone penetration test	Wang, H., Wu, S., Qi, X., and Chu, J.	Engineering Geology, Vol. 280, 105953. online 1 Jan	2021
37.	Shear strength properties of a residual soil in Singapore	Meng, G.H. and Chu, J.	Soils and Foundations, Vol. 51, No. 4, 565-573	2011
38.	Engineering Properties of the Sajahat Formation in Singapore	Goh, K.H. and Chu, J.	Proc of International Conf on Soil Properties and Case Histories, Singapore, 5-6 Dec	2019
39.	Application of 3D Geological Model in Subway Construction in Singapore	Wu, S., Pan, X., Qi, X., Chiam, K., Goh, K.H. and Chu, J.	Geo-Congress 2022 March 20–23	2022