A New Lithostratigraphical Framework Proposed for Singapore

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ABSTRACT: A study was initiated in mid-2013 by Building & Construction Authority of Singapore (BCA) to review the existing stratigraphy framework of Singapore. The new lithostratigraphical framework follows the recommendations of International Commission of Stratigraphy (ICS) and it was developed based on geological fieldworks observations and rock cores examination obtained from new deep boreholes. This paper will only cover on the Jurong Formation, Fort Canning Boulder Bed and Old Alluvium. The Jurong Formation has been upgraded to Jurong group according to ICS stratigraphy guidelines and the Jurong group is sub-divided into three (3) formations, known as Tuas formation, Bukit Resam formation and Pasir Panjang formation. The Fort Canning Boulder Bed and Old Alluvium have been re-classified as Fort Canning formation and Bedok formation respectively.

KEYWORDS: Lithostratigraphical Framework, International Commission on Stratigraphy (ICS), Lexicon

1. INTRODUCTION

The Building and Construction Authority (BCA) initiated a study in 2013 to revise the current stratigraphy of Singapore, which was first published by Public Works Department (PWD) in 1976 and re-edition of the Geology of Singapore in 2009. Many of the lithostratigraphic units described in the Geology of Singapore publications have assigned names and became well-established and widely used by geologist and geotechnical engineers working in Singapore. However, the lithostratigraphy units are not structured and constructed in accordance to the procedure and recommendations by the International Commission on Stratigraphy (ICS). Hence, BCA engaged the British Geological Survey (BGS), which has a strong background and experience in the area of geology, stratigraphy and geoscience studies internationally, to review and proposed a structured classification for all of the lithostratigraphical units of Singapore. The study is mainly based on the desk study review of the geology of Singapore, with a limited amount of fieldworks involving viewing of rock outcrops and examination of rock cores obtained from new deep boreholes carried out by BCA. Besides, a Stratigraphic Working Group (SWG) has been formed, comprised of experienced geologists from BCA and industry, professors from Nanyang Technical University and Earth Observatory of Singapore with robust geology and stratigraphy background, to provide their professional views and advise on the proposed lithostratigraphic framework. The study and revision of the Singapore stratigraphy are important as it helps us to better understand on the distribution and relative age of the different rock units, and also on the geology and geological history of Singapore, which will lead us to have a better insight on the conditions of underlying rocks before commencement of engineering works.

2. CURRENT ISSUES

2.1 Objective

Geological models are used widely in the petroleum and mineral exploration industries for tens of years. In recent years, geological modelling has become popular and used in major underground infrastructure development projects. The geological models are not only important for geological exploration works but also a useful tool for geotechnical engineering projects. This is why IAEG (International Association for Engineering Geology) established Commission 25 in March 2009, on the use of engineering geological models and established a platform to discuss activities relating to geological models around the world. The three-dimension model can be used by professionals to select possible locations at target/ certain depth with minimum impact to the environment. Besides, the model can help to choose appropriate design scheme for underground development projects among the possible alternatives. Finally, a better estimated cost can be made for the development project, which is useful for planners and decision makers.

Stratigraphy and structural geology are prime important in geological modelling. The stratigraphy provides the most obvious visible layering in the model whilst the structural geology presents the three-dimensional distribution of rock units with respect to their deformations in the model. Systematic stratigraphic layers and structural geological elements of complex geology can be displayed and visualized in 3D geological model.

2.2 Shortcoming and Limitation

The current lithostratigraphic units of Singapore are classified as facies in the Jurong Formation which includes Tengah Facies, Queenstown Facies, Rimau Facies, Ayer Chawan Facies, St. John Facies and Jong Facies in the Geology of Singapore (1976). The updated publication of Geology of Singapore (2009) included the Pandan Facies in Jurong Formation which was discovered at Pandan area in 1987. In the Jurong Formation, all the facies were observed to vary with lateral changes and missing in the general vertical succession sequence of lithostratigraphic layers in the geological structure although the depositional environment of lithostratigraphic units differ from each other (see Figure 1 on cross-section from Murai reservoir – to Mt. Faber and to St. John's Island).

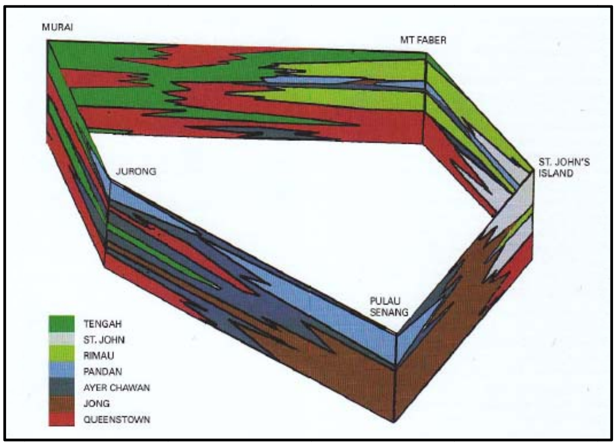

Figure 1 Diagrammatic representation (not drawn to scale) of facies relations in the Jurong Formation (Source: DSTA, 2009)

For this reason, there is a need to review and establish the original depositional environment of sedimentary lithostratigraphic units, which help to develop an appropriate framework to assemble and correlate with the stratigraphy of neighbouring countries.

Concurrently, it is also important to review the evolution of complex geology of the Jurong Formation, especially structural elements such as thrust, faults and folds found in the western part of Singapore and how it fit into the setting of tectonic framework of Southeast Asia.

In addition, the current naming of geological formations is found not consistent with the stratigraphic classification established by International Stratigraphic Guide (1994) and International Commission on Stratigraphy (ICS). A detailed study is therefore needed to re-establish the systematic stratigraphy and structural geology in Singapore.

The study involved visit to sites including offshore islands to find surface outcrops and view rock-cut exposures. In reality, outcrops are very rare on the main island of Singapore as most areas have been developed. In such an urbanised setting, outcrops are few and tend to be highly weathered in nature due to the tropic climate conditions. This is a major limitation encountered, which pose challenge to establish the relationships of lithostratigraphic units in the complex geology of Singapore.

3. LITHOSTRATIGRAPHICAL FRAMEWORK

3.1 Introduction

The context of the lithostratigraphical framework is to produce a lexicon (‘database’) of Singapore stratigraphy as a ready reference for learned person to set up new formations or revise existing ones. These individuals may comprise of experienced geologists who are involved with geotechnical works in Singapore and exposed to various geology during deep borehole drilling, excavation works, cavern construction and tunnelling works. The revision of the framework is greatly dependent on subsurface rocks rather than rock outcrops due to limited exposure of the latter. The study of lithostratigraphic units, based solely on the observation of rock cores obtained from deep borehole drilling pose a challenging task to the geologists as the sedimentary rocks in the western part of Singapore have been folded and thrust, and hence it can be weakly metamorphosed. However, some localities situated on southern islands of Singapore that are not affected by urbanisation and development works may provide rock exposure that represents a good reference section for field logging (see Figures 2 and 3).

Figure 2 Outcrop of sedimentary rocks (interbedded sandstone and mudstone) at Lazarus Island, south of Singapore

3.2 Discussion

This paper will cover only the sedimentary rock units of Mesozoic to Cenozoic (excluding late Pleistocene to Holocene deposits), i.e. Jurong Formation, Fort Canning Boulder Bed (FCBB) and the Old Alluvium (OA). Other older rock units from the Paleozoic such as Sajahat Formation, Paleozoic Volcanics, and igneous rock bodies such as Gombak Norite and Bukit Timah Granite will not be discussed in this paper. The younger deposits from the late Pleistocene to Holocene, namely the Tekong formation and Kallang formation are also not discussed in this paper. All these rock units referred to are mentioned in the Geology of Singapore (2009).

Figure 3 Close-up of sedimentary structure, hummocky cross stratification (sandstone) at Lazarus Island, south of Singapore

In the new lithostratigraphical framework of 2014 (hereinafter referred to as 2014 classification), Jurong Formation has been upgraded to Jurong group. Similarly, the FCBB is also upgraded to Fort Canning formation. Separately, the OA without any reference to geographic locality has been re-named as Bedok formation. The name Bedok is a place located at the south-eastern part of Singapore, previously sandy materials from the area, which is mined for construction works to supply the island with all of its fine aggregate needs. The re-classification conforms to the ranks of lithostratigraphic units as shown in Table 1 and illustrated in Figure 4. In addition, there are two new formations presented in the 2014 classification, namely the Tuas formation (of Jurong group) and Tebak formation.

Table 1 Ranks of Lithostratigraphic Units

Rank	Classification - Hierarchy
(1) - High	Group
(2)	Formation
(3)	Member
(4) - Low	Bed(s), Flow(s)

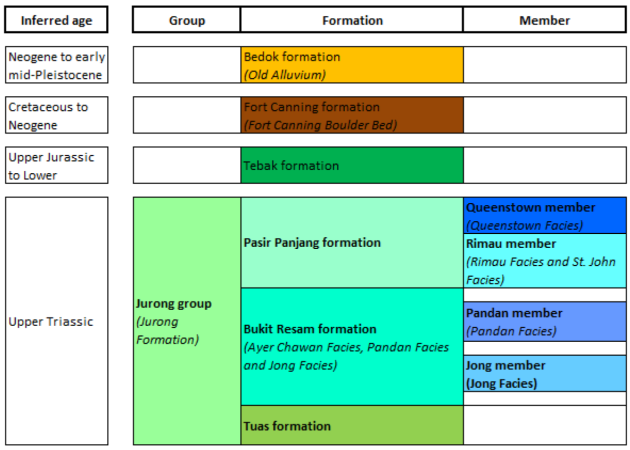

Figure 4 Proposed Lithostratigraphy for Singapore

3.3 Standard Format

The proposed lithostratigraphical units shall comprise of 12 categories of information as explained below. Some categories have to rely on borehole records due to the nature of limited rock exposure in Singapore.

- *Name derivation* – name of stratigraphic unit at formation or equivalent level following the record of geographical area.
- *Previous name(s)* – author or originator of the name, date, original reference.

- *Geographical extent* – description of geographical area(s) in Singapore where the unit is known or inferred to occur at ground surface, including borehole records and rock core sections where applicable.
- *Lithology* – description of composition and or/mineralogy of the rock unit
- *Type area/type section/reference section* – description of the location, nature (e.g. cliff, quarry face, borehole core), geological character and accessibility of the type area and/or type section(s) and/or reference section(s) proposed for the unit.
- *Lower boundary* – description of the nature and defining characteristics of the basal boundary of the unit.
- *Upper boundary* – description of the nature and defining characteristics of the upper boundary of the unit.
- *Thickness* – estimated thickness in meters based on available information (including borehole records). In undeformed units, 'thickness' generally refers to vertical thickness.
- *Age* – geological age of the unit in line with The International Chronostratigraphic Chart (2013 version) of the International Commission of Stratigraphy (ICS), which is downloadable from http://www.stratigraphy.org/index.php/ics-chart-timescale. Where possible and appropriate, an age range (maximum age and minimum age) is given.
- *Subdivisions* – the name of any 'child' units (e.g. members) in the proposed lithostratigraphical classification.
- *Correlation with Peninsular Malaysia* – correlation with other units in neighbouring country of Malaysia (primarily within the State of Johor). The names of the units are written as they are presented in 'Stratigraphic Lexicon of Malaysia' by Peng et al. (2004).
- *Key references* – list of main sources of published information about the unit. Full references for all listed sources are presented in Section 8 of the 'Stratigraphical Guide for Singapore', prepared by British Geological Survey (BGS), 2014.

The full detailed explanations of each categories for the rock units from Paleozoic to Cenozoic (including the late Pleistocene to Holocene deposits) are presented in the unpublished report 'Stratigraphical Guide for Singapore (2014)', which is part of a geological study of Singapore, commissioned by BCA in 2013. This guide is complemented by another unpublished BCA report titled 'An Overview of the Geology of Singapore (2014)' prepared by BGS.

3.4 Jurong group (Upper Triassic of Mesozoic)

The new proposed lithostratigraphy divides the Jurong group into three formations that extends from the largely western region of Singapore towards the neighbouring country of Malaysia especially at the southern State of Johor. These are the basal unit of Tuas formation, followed by Bukit Resam formation, and the upper unit of Pasir Panjang formation. Previously in Singapore of Geology (DSTA, 2009), Jurong Formation is identified by numerous facies, i.e. rock units associated with different depositional processes. Based on the systematic approach in line with ICS guideline, these facies have been upgraded to members of the Bukit Resam formation and Pasir Panjang formation. In a way, these facies have not been totally abandoned, but being retained as members. See also Figure 2. Tuas formation is considered a new entity as both Bukit Resam formation and Pasir Panjang formation have been previously studied and named by other authors, which are mentioned in the 'Stratigraphic Lexicon of Malaysia (2004)'.

The systematic approach adopted by BGS has enabled the three formations to be classified as follows, each with distinctive geological characteristics:

- *Tuas formation* – dominantly volcaniclastic sandstone and mudstone, which has not been recognised at surface, but observed from BCA's deep boreholes in the reclaimed land of Tuas region in the extreme south-west of the island. Believed to represent the deposits of high-energy turbidity currents, probably found offshore within active volcanic islands at the present day.
- *Bukit Resam formation* – includes the previously recognised facies of Ayer Chawan, Pandan and Jong (DSTA, 2009). It is dominated by tuffaceous sandstone and mudstone with subordinate conglomerate, carbonate rock (thick units of limestone) and volcanic rock, deposited in a shallow marine environment.
- *Pasir Panjang formation* – includes the previously recognised facies of Queenstown, Rimau and St. John (DSTA, 2009). It is characterised by interbedded conglomerate, sandstone and mudstone. This formation is deposited in terrestrial (fluvial and lacustrine) to shallow marine environment.

The previously mapped 'Tengah Facies' (Jurong Formation) mentioned in the Singapore Geology (DSTA, 2009) will be excluded from the 2014 classification as it is now recognised as weathered bedrock materials belonging to the different formations within the Jurong group. Hence, 'Tengah Facies' shall constitutes as an abandoned rock unit in the 2014 classification.

3.5 Tebak formation (Upper Jurassic to Lower Cretaceous)

This younger sedimentary succession is recognised in southern Singapore, which was previously mapped as part of 'Rimau Facies' of Jurong Formation (DSTA, 2009). The discovery of this possibly new formation is through field mapping conducted on Kusu Island, which is situated about 4km away from the southern part of Singapore (see Figure 5).

Figure 5 Outcrop of Tebak formation sandstone at Kusu Island

The rock outcrops in Kusu Island are seen as medium to coarse, red brown, quartz-rich sandstone in planar beds up to 1 m thick, some with low angle cross bedding and is correlated with the Tebak Formation found in southern region of Johor State (Malaysia). The composition and texture of sandstone in close-up view is shown in Figure 6. The origin of name Tebak is after 'Sungai Tebak', a river located in south Johor. Tebak formation is interpreted to lie unconformably on the Jurong group. This formation is considered to have been deposited in terrestrial (fluvial, deltaic and lacustrine) environments.

Figure 6 Close-up of sandstone at Kusu Island

Many of the lithostratigraphical units in Singapore can be correlated with units in the state of Johor, Malaysia. In accordance with the ICS recommendations, when two differently named lithostratigraphical units are subsequently correlated, the long established name shall replace the later name. Hence, the name of “Bukit Resam formation” and “Tebak formation” are adopted in this proposed lithostratigraphic framework as they are correlative units with the “Bukit Resam member” and “Tebak Formation” in Johor.

3.6 Fort Canning formation (Cretaceous to Neogene)

Fort Canning formation underlies part of the Central Business District (CBD) in Singapore is well known among the engineers who are involved in foundations, deep excavations and tunnelling works. It has previously been termed as ‘Fort Canning Boulder Bed’ by Shirlaw et al., 2003. It was originally considered as part of the Jurong Formation (by Pitts, 1984), but is now thought to be derived from strata belonging to the Tebak formation.

The Fort Canning formation typically consists of relatively fresh quartzite or sandstone boulders in a hard matrix of fines (silt and clay). The boulders may be derived from the Tebak formation, but the origin of the matrix is currently unknown.

3.7 Bedok formation (Neogene to Mid-Pleistocene)

The Bedok formation, previously termed as the Old Alluvium (OA) in Geology of Singapore (DSTA, 2009) also needs no further introduction as these ‘Quaternary’ fluvial deposits have been extensively recognised across parts of Singapore and Malaysia. It forms a relatively thick and extensive sheet of weakly consolidated to unconsolidated sediments of sand, silt and clay, which are largely derived from a granite source, and to a lesser extent from metamorphic rocks.

The Bedok formation is a new name proposed in the 2014 classification, whereby the term ‘Bedok’ derives from the name place (Bedok district) in the southeastern part of Singapore. This is in line with the ICS guideline of providing a geographic name to the formation. This is further based on the premise that the Public Works Department (PWD) in 1976 and DSTA (2009) proposed “sediments exposed in the Bedok Sand Quarry (GR [38700 35100]) and recorded in the Public Utilities Board Test Hole No. 1 at GR [39000 34100], Bedok, be taken as the type ‘Old Alluvium’ for the Singapore-Johor area”.

4. CONCLUSION

In order to develop a more robust and comprehensive lithostratigraphical classification, it will require more detailed information. BCA will continue to engage consultant to assist in updating the stratigraphy framework of Singapore. The future works will include visiting more exposures including nearby countries to identify the character of unit boundaries, see reference sections and major structural features. More detailed examination and sedimentology logging will be carried on deep boreholes rock cores obtained from BCA’s geological survey works to interpret the sedimentary facies, identify geological units boundary, reference sections, marker horizon and relationship between each formations in term of forming processes, and its architecture. Structural geological data obtained from fieldworks, seismic data, core logging and examination etc. will be assembled and used to study and establish the geological strata and structure, also to understand the occurrence of faults and folds that affect the positioning of the geological formations and rock properties. All these data and information will help to establish the lithostratigraphical framework of Singapore and also be used to refine the geological model of Singapore. This geological model will be a powerful tool to provide the information of rock’s distribution, rock’s properties and the distribution of discontinuities, such as faults in Singapore. With this information, it will enable planners and consultants to identify suitable location for cavern developments and tunnel alignments. The geological model will also help to define the uncertainties and potential risks, such as ground-related hazards for construction works and underground development.

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