MARCUS R DOBBS, AG LESLIE, TJH DODD, MR GILLESPIE, TI KEARSEY, RS KENDALL, AND T BIDE

Urban Geological Surveying in Singapore

British Geological Survey

Building and Construction Authority

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Kiso-Jiban Consultants Co., Ltd.

Singapore has grown up, out and down

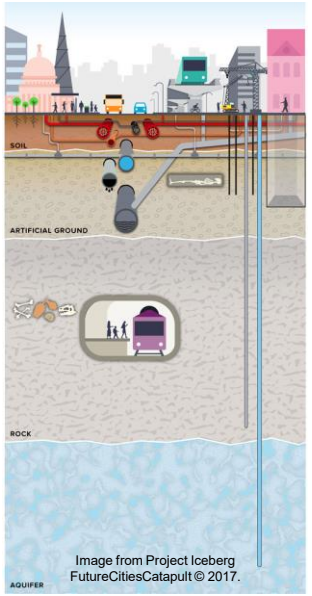
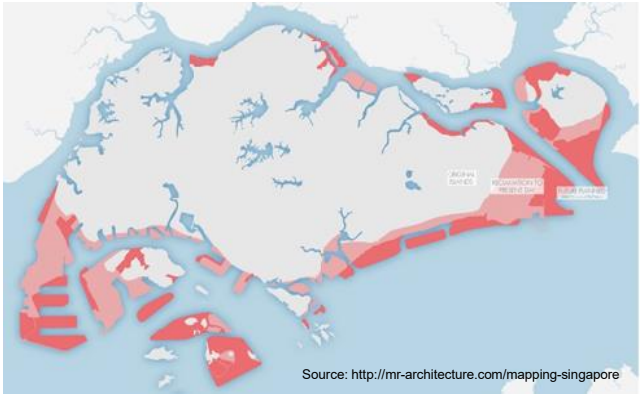


Image from Project Iceberg
FutureCitiesCatapult © 2017.



Source: http://mr-architecture.com/mapping-singapore

Unprecedented social & economic growth since 1965

Land mass increased 22% since 1984; 30% by 2030

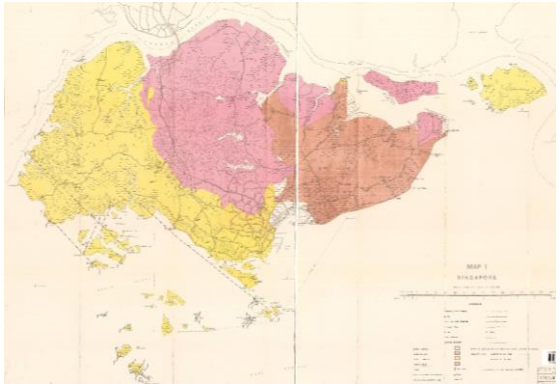
Competing land-use requirements means subsurface development necessary to meet development needs

comprehensive understanding of deep geology is critical for continued development and prosperity

Singapore Geological Legacy: 1851 - 2009

First publication by Logan in 1851; geology separated in to 5 units within 3 geology type: sedimentary, crystalline, superficial deposits

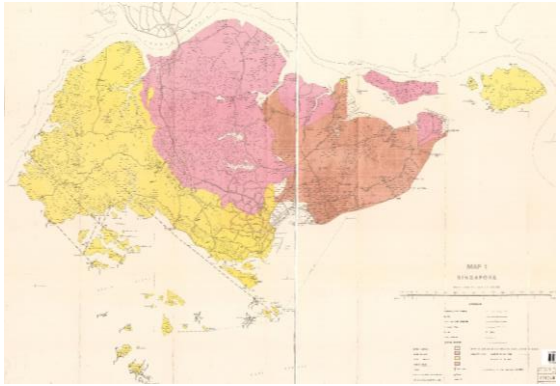
Singapore Geological Legacy: 1851 - 2009

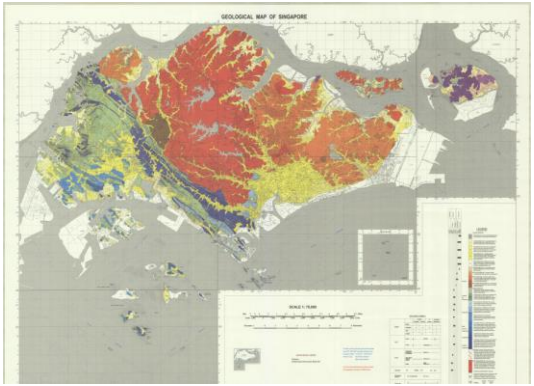


First publication by Logan in 1851; geology separated in to 5 units within 3 geology type: sedimentary, crystalline, superficial deposits

Significant revisions by Scrivenor in 1924 and Alexander in 1950 introducing additional units, ages and faults

Singapore Geological Legacy: 1851 - 2009



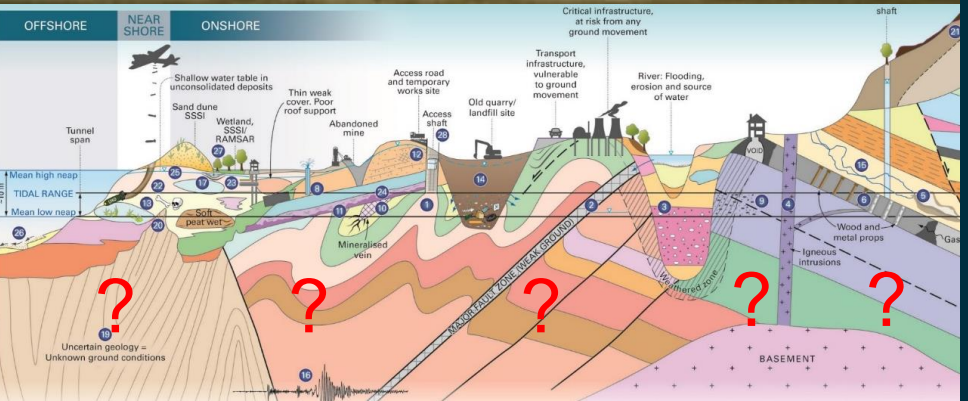


First publication by Logan in 1851; geology separated in to 5 units within 3 geology type: sedimentary, crystalline, superficial deposits

Significant revisions by Scrivenor in 1924 and Alexander in 1950 introducing additional units, ages and faults

First official publication by PWD in 1976: updated by DSTA in 2009: presented as a ‘stratigraphy’

Source: Badmintoncentral.com



What motivated further geological investigation?

Deeper geological knowledge for subsurface development (mainly caverns)

Difficult to extrapolate: lithological heterogeneity, structural complexity, weathering

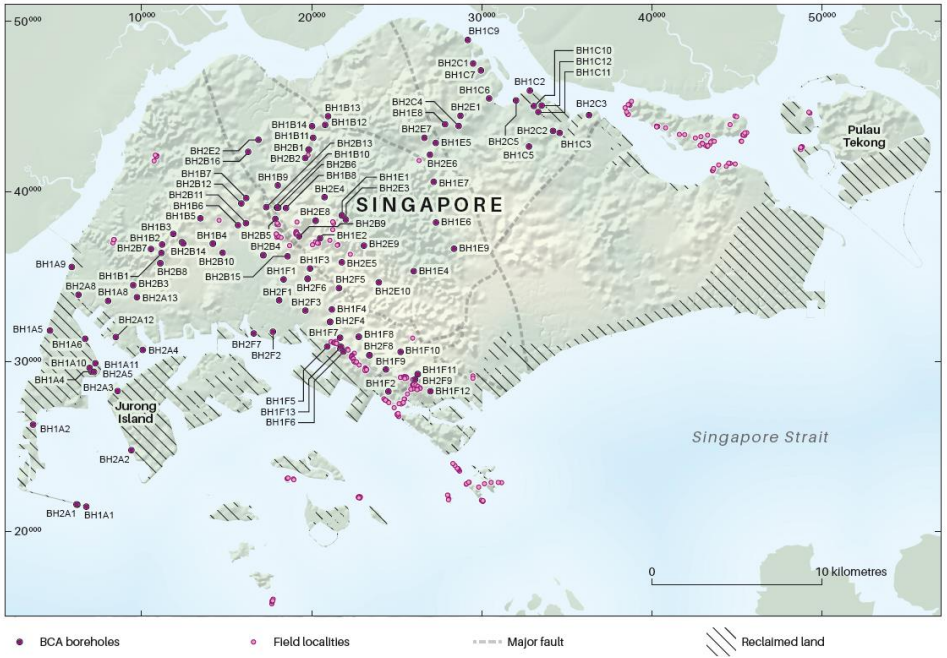
Additional data from GI predominantly shallow, and often contradictory

Robust geological frame required to predict subsurface properties and behaviour

Singapore urban geological survey works

Building and Construction Authority

Kiso-Jiban Consultants Co., Ltd.



Initiated by BCA in 2012: 5 areas in the north, centre and west

Review of >330 documents

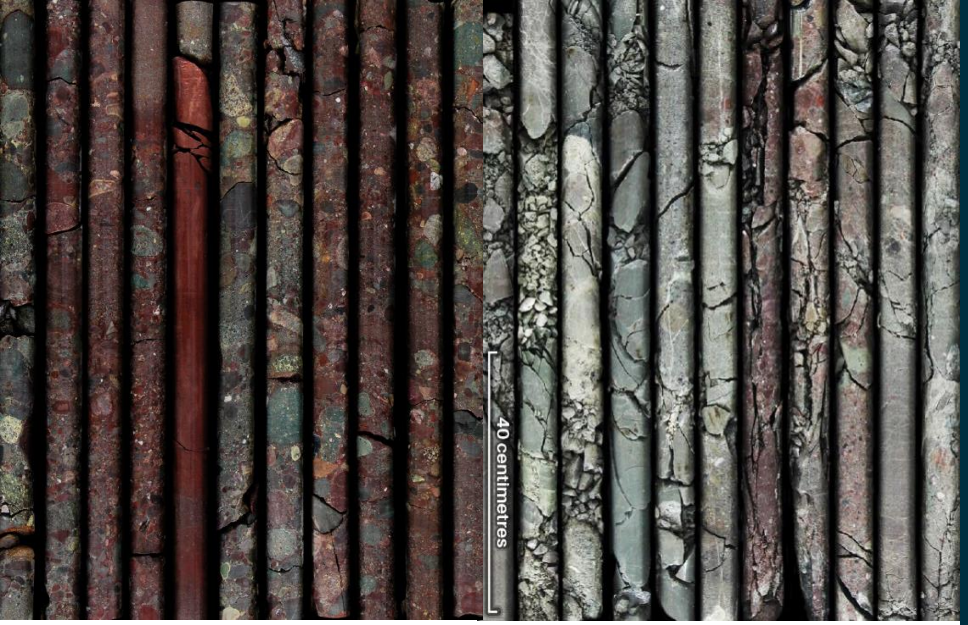
121 boreholes to 200m depth

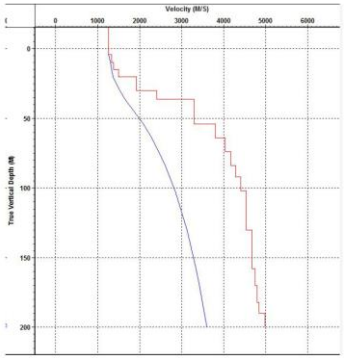
~80km seismic reflection & refraction

235 outcrop exposures mapped

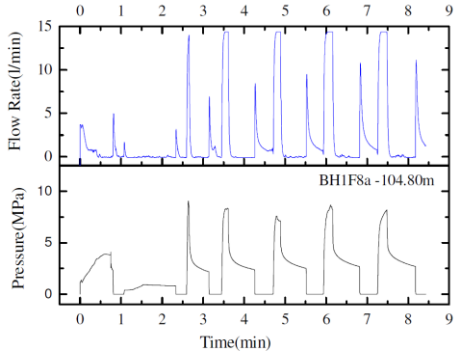
3,400 in situ and laboratory tests (geophys, geotech, min & pet, palaeo, geochem, age dating)

BGS





Vertical seismic profile in BH



Results of hydraulic fracture test used to determine in situ stress

Boreholes

Borehole core recovery exceptional: rotary wireline drilling

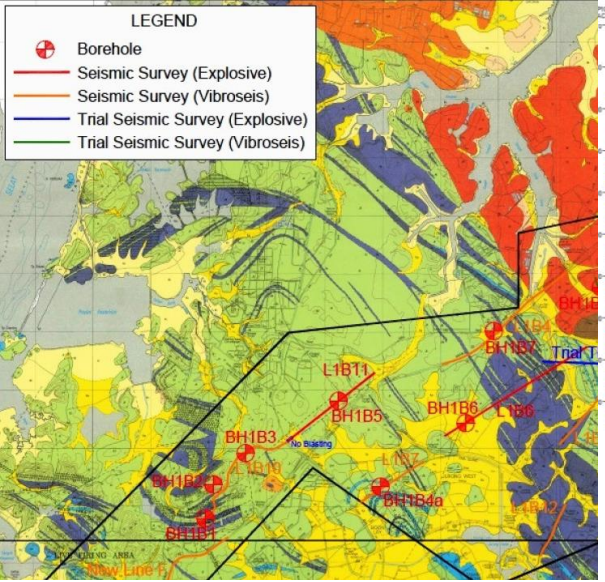
20km core photographed and logged (BS5930 geotechnical standard

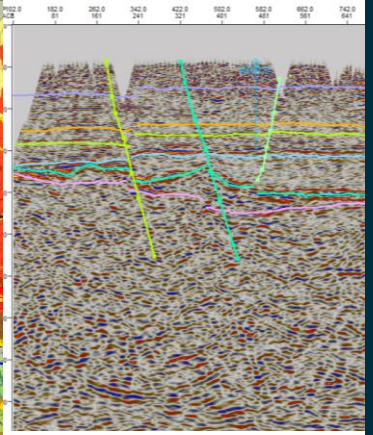
5km subset of boreholes logged in detail by BGS using BGS RCS

In situ downhole temperature, sonic velocity and borehole imaging

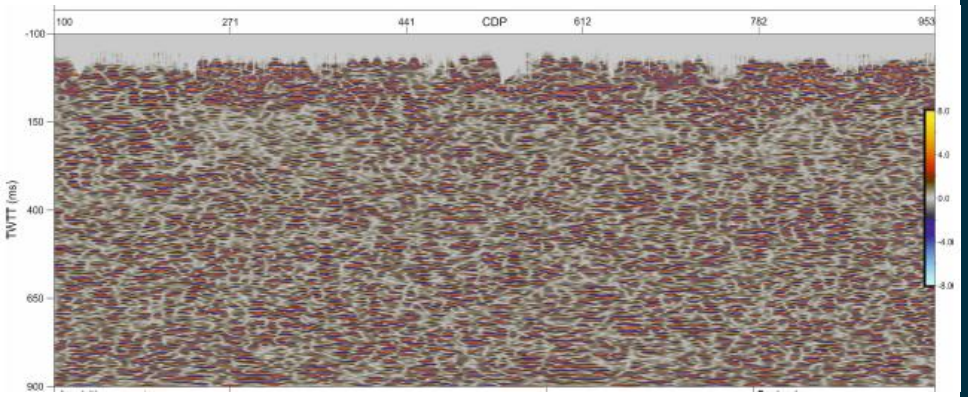
VSP, permeability and in situ stress in a subset of boreholes

Standpipes installed for groundwater level monitoring and sampling





Good reflectivity where superficial deposits overly igneous rocks



Poor reflectivity in meta-sedimentary Jurong

Geophysical survey

Seismic survey lines perpendicular to bedding, boundaries, faults

Effective for imaging engineering rockhead, boundary between superficial and bedrock, larger structures in sedimentary rock

Far fewer reflectors within the sedimentary succession than hoped for: no distinct unit boundaries: very low SNR

Outcrop mapping

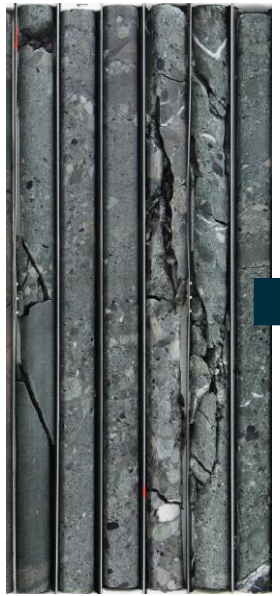
- Good exposures on coastline and outlying islands: sedimentary, structural features
- Igneous rock in quarries in central Singapore and Pulau Ubin
- Informative exposures human-made (both temporary and permanent)
- Outcrops critical for observing geology in 2D & 3D and at larger scale than BHs

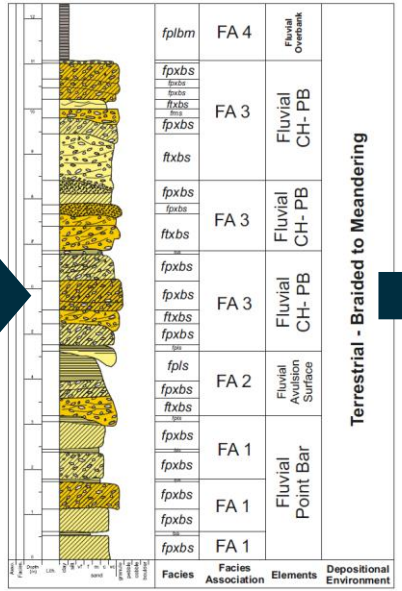
Image top left: Tanjong Lokos Anticline: St John Island

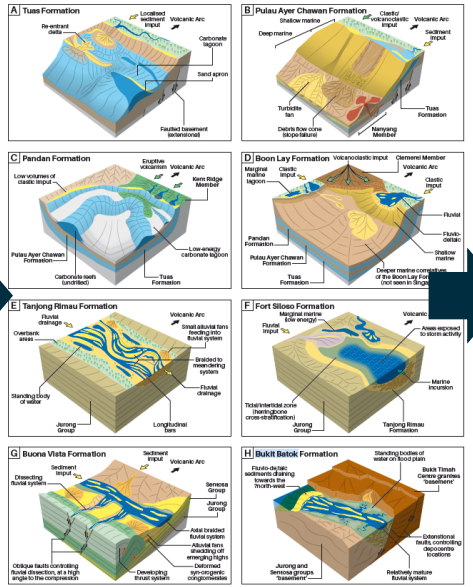
Image bottom left: temporary exposure of newly identified Cretaceous sediments in Bukit Batok during construction

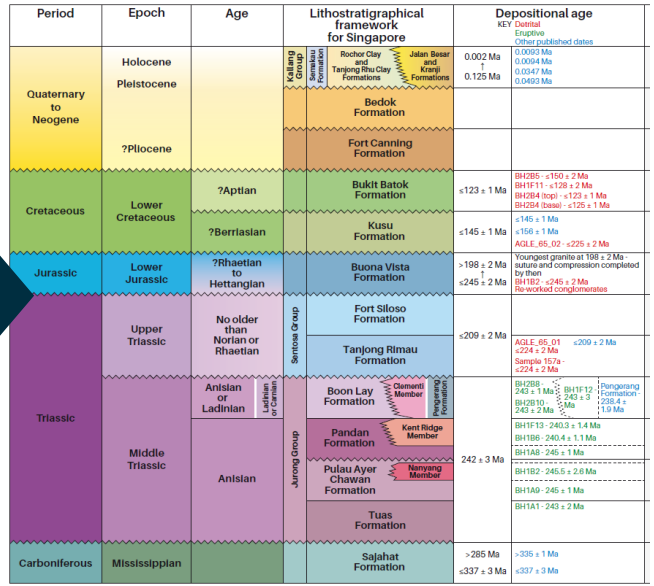
Geological Interpretation

Lithostratigraphic framework development





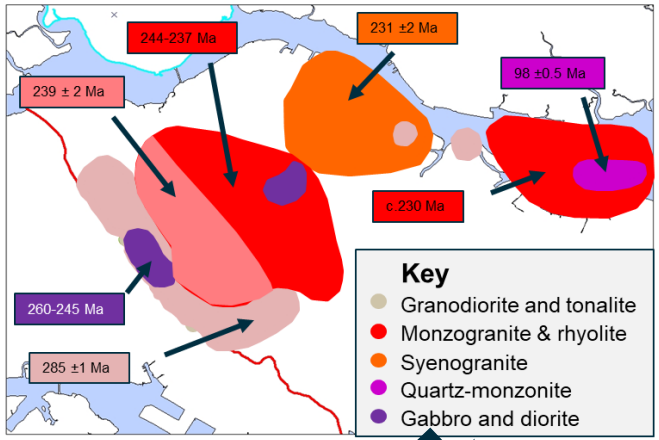


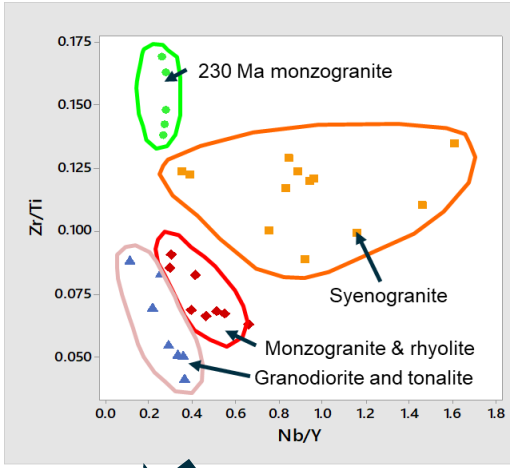


Facies approach used to identify depositions environments, these to define layered units

Units placed within a stratigraphy using observed relationships and U-Pb dating of zircon

Lithodemic framework development



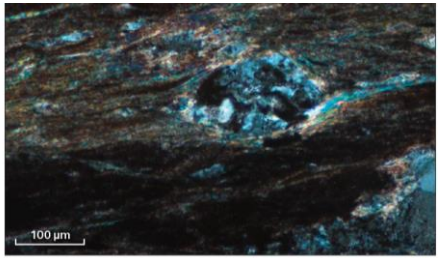


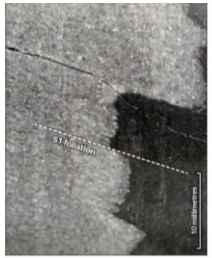
Chronostratigraphical divisions			Lithodemic units and hierarchical rank		
Period	Epoch	Age	Rank 4	Rank 5	Rank 6
Cretaceous	Upper Cretaceous	Cenomanian		Pulau Sekudu Quartz-monzonite Pluton	
Probably no older than Upper Triassic Epoch and no younger than Lower Cretaceous Epoch				Singapore Basalt-andesite Dyke-swarm	Unnamed dykes
Triassic	Upper Triassic	Carnian	Bukit Timah Centre	Simpang Granite Pluton	
	Middle Triassic to Upper Triassic	Anisian to Carnian		Pulau Ubin Granite Pluton	
				Dairy Farm Granite-microgranite Pluton	
Permian to Triassic	Guadalupian to Middle Triassic	Capitanian to Anisian		Gombak Gabbro-granite Pluton	
Permian	Cisuralian	Artinskian		Choa Chu Kang Granodiorite-tonalite Pluton	

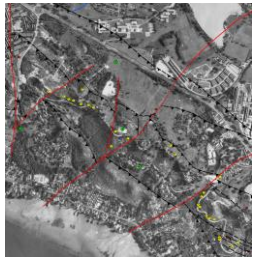
Areas with distinct lithological variation identified

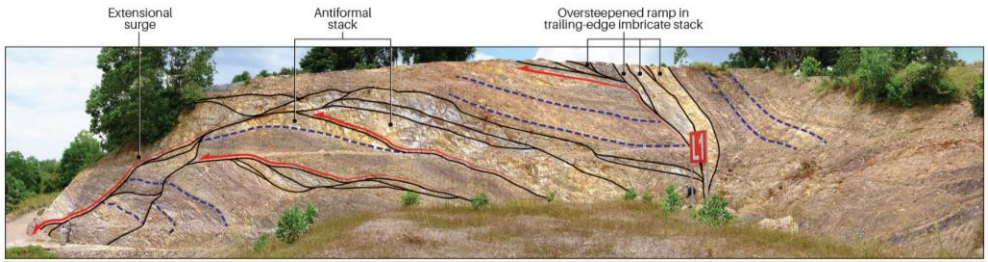
Whole rock inorganic geochemistry, U-Pb dating, observed relationships used to define units and place in lithodemic framework

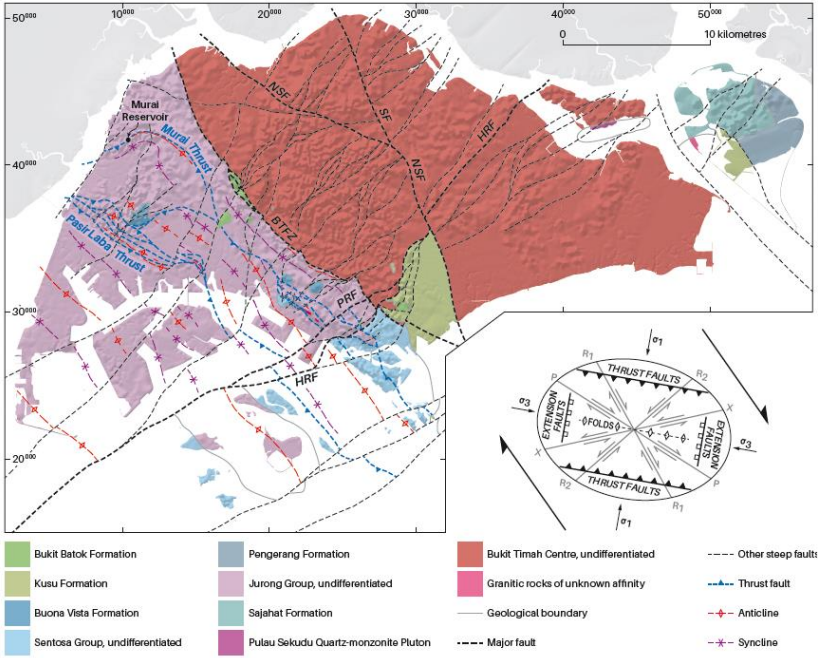
Structural framework development











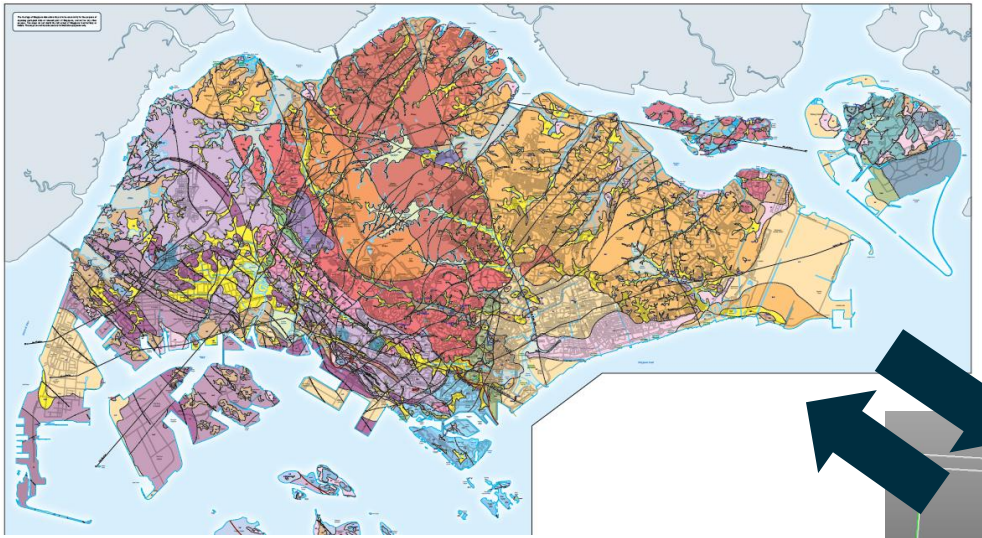
Analysis undertaken from micro- to macro-scale to characterise brittle and ductile deformation

Location and geometry of faults, fault-rock, fractures and foliation identified in BHs & outcrops

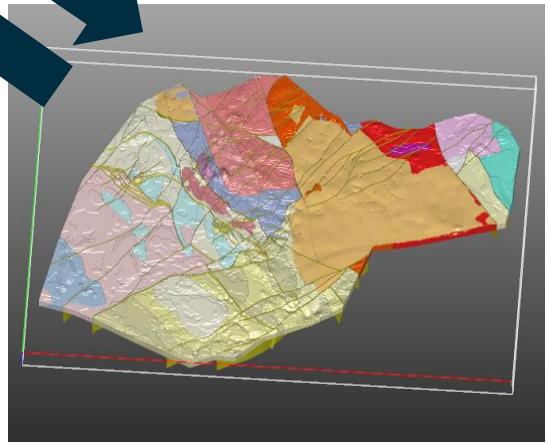
Lineaments at surface identified using DTM, bathymetry and historical aerial photos

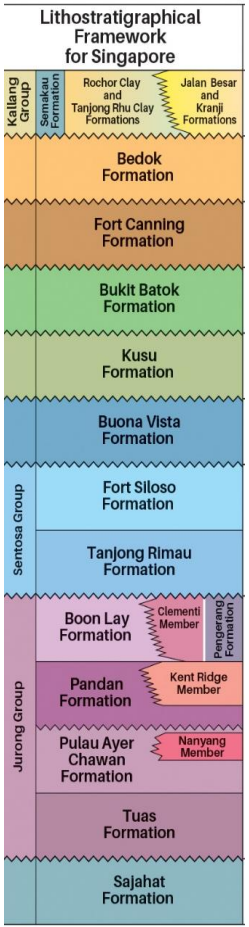
These data and overall nature of deformation used to define new structural framework

Wholly revised bedrock, superficial, structural framework



Lithodemic units and hierarchical rank		
Rank 4	Rank 5	Rank 6
	Pulau Sekudu Quartz-monzonite Pluton	
	Singapore Basalt–andesite Dyke-swarm	Unnamed dykes
Bukit Timah Centre	Simpang Granite Pluton	
	Pulau Ubin Granite Pluton	
	Dairy Farm Granite–microgranite Pluton	
	Gombak Gabbro–granite Pluton	
	Choa Chu Kang Granodiorite–tonalite Pluton	

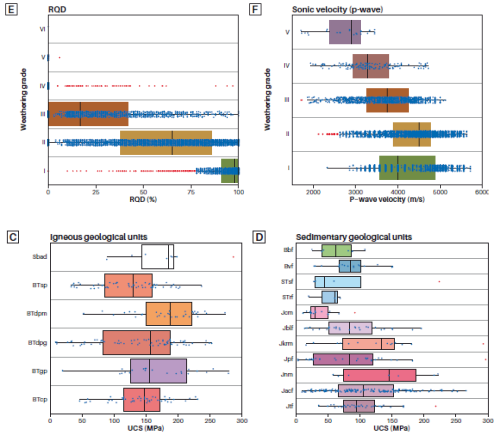




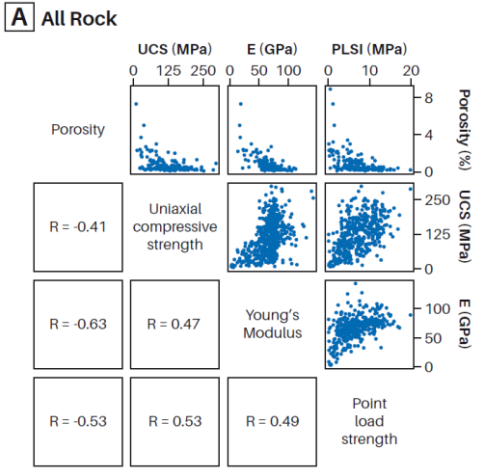
- Components assembled to make geological map
- Boreholes, outcrops, seismic lines and map used to build 3D geological model
- Geological model informed further iterations of the map to make plausible 3D geometries

Geotechnical and engineering geological analysis

- Need to support principal stakeholders in construction and development sector
- Geotechnical properties of each bedrock unit characterised by lithology & weathering grade
- Assessment of geohazard and resource potential of each unit and implications for foundation, excavations, slope stability, material re-use and GI.

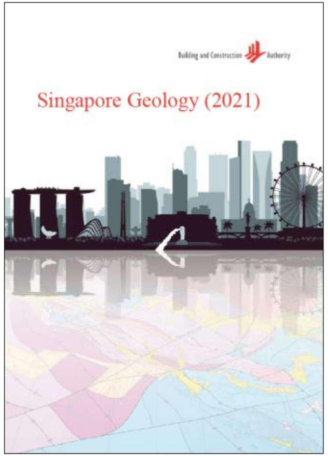


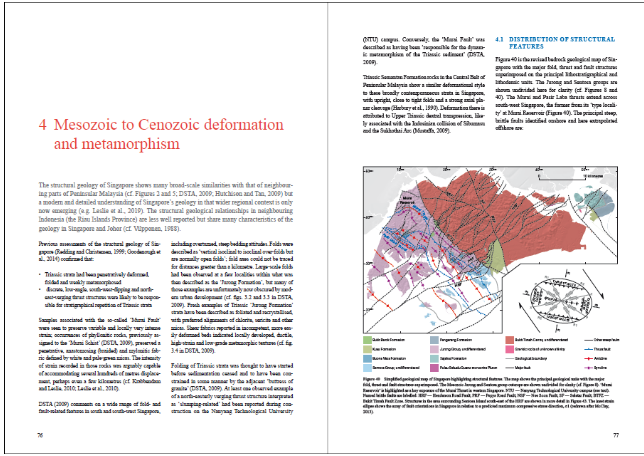
Box-and-whisker plots of geotechnical properties by weathering grade and unit (weathering grades I and II)

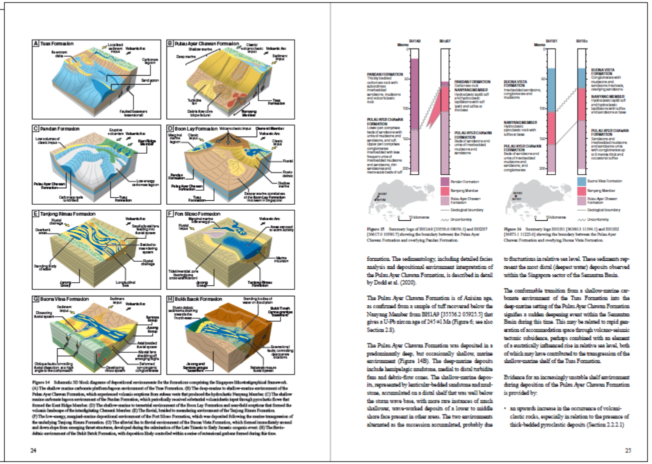


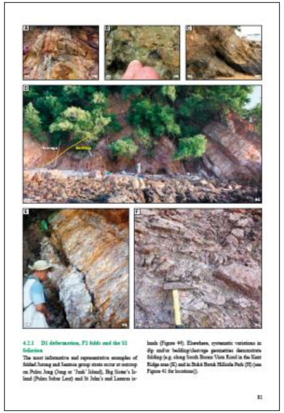
Geotechnical property cross-correlation scatter plots

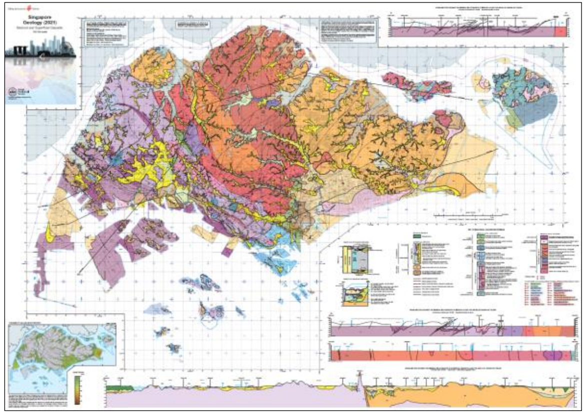
Geological memoir

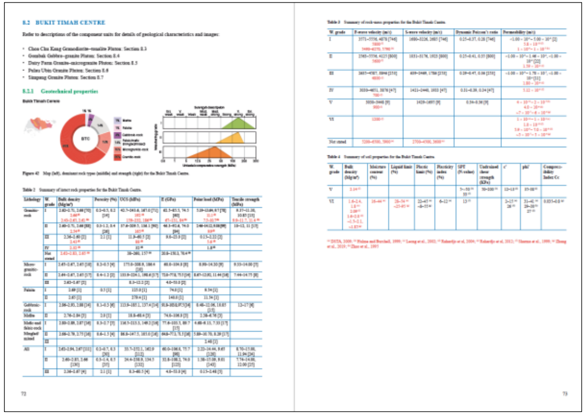




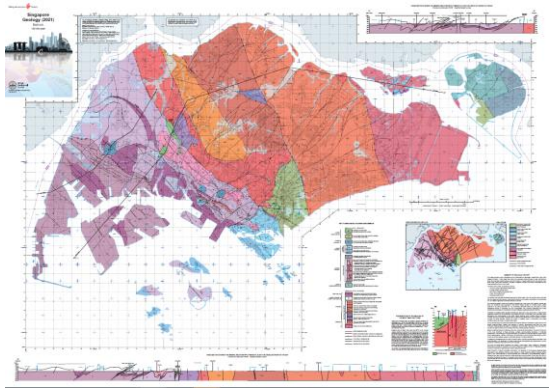


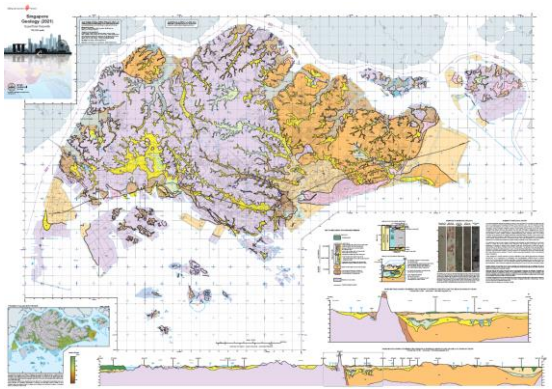


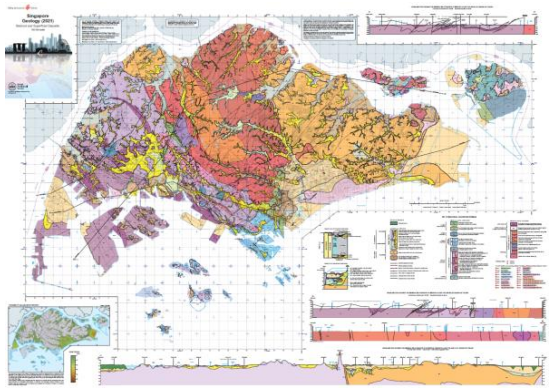


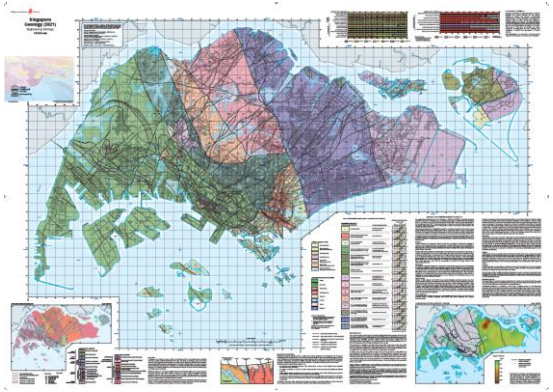


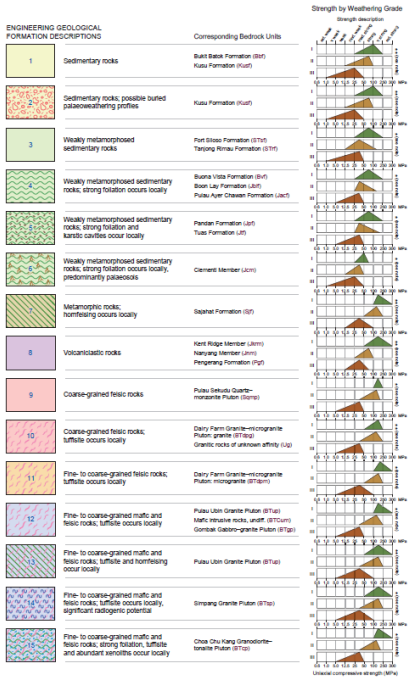
Geological maps

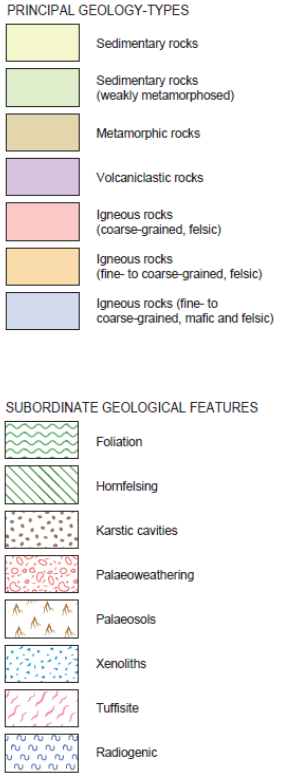












Learning outcomes

GEOLOGICAL KNOWLEDGE AND UNDERSTANDING NEEDS TO EVOLVE AND NOT BECOME A FOSSIL: URBAN GEOLOGICAL SURVEYS ARE A MEANS FOR ADDRESSING THIS NEED.

THE URBAN ENVIRONMENT CAN BE EXTREMELY CHALLENGING: LANDSCAPE MODIFIED; LOGISTICAL CHALLENGES; NUMEROUS RISKS; EXISTING DATA OFTEN POOR

HIGH-QUALITY DEEP BOREHOLE DATA ARE EXPENSIVE, BUT INVALUABLE: WORTH INVESTING IN BEST QUALITY YOU CAN GET

THESE DATA SHOULD THOUGH BE AUGMENTED WITH OUTCROP MAPPING, REMOTE SENSING (ESPECIALLY HISTORICAL IMAGERY) AND GEOPHYSICS (WHERE THIS IS EFFECTIVE)

MODERN URBAN GEOLOGICAL SURVEYS SHOULD BE MULTI-SECTOR AND MULTI-DISCIPLINARY TO BEST SERVE STAKEHOLDER COMMUNITY AND OVERCOME CHALLENGES

ANY NEW UNDERSTANDING NEEDS TO BE COMMUNICATED TO DECISION-MAKERS WITHIN THE URBAN MANAGEMENT SECTOR: THIS WILL INCLUDE NON-GEOSCIENTISTS!

Questions