Chapter 3
Sedimentary and Volcanic Rocks

Palaeozoic Rocks

Classification and Distribution

Palaeozoic rocks in the district are represented by the Devonian Bluff Head Formation, the Carboniferous Ma On Shan Formation, and the Permian Tolo Harbour Formation. Collectively, these rocks occupy a significant portion of the district. Based on similarities of lithology, colour and stratigraphical association, Frost (1991) tentatively correlated the Ma On Shan Formation with marble of the Yuen Long Formation in northwestern New Territories.

Bluff Head Formation

The Bluff Head Formation comprises mainly creamy white to pale purplish blue, fine- to medium-grained quartz sandstone, with subordinate intercalated pebble conglomerate and bluish grey to black siltstone. It forms a small remnant of country rock surrounded by granite on the eastern edge of Wu Kwai Sha Tsui and is exposed over the lower northeastern slopes of Nga Ngak Shan and Ma On Shan.

At Wu Kwai Sha Tsui (4356 3284) the Bluff Head Formation consists of white to cream, centimetre-bedded, medium- to coarse-grained quartz sandstone and pebble conglomerate (Plate 2) dipping 26° to the northeast. The sequence is estimated as 10 metres thick and the lithology is very similar to exposures of Bluff Head Formation on nearby Harbour Island (Addison, 1986).

The sedimentary succession on the flanks of Nga Ngak Shan and Ma On Shan has recently been described in detail by Jones (1995) from road cuttings excavated during site formation works for the Ma On Shan water treatment station (Figure 7). In this region, the Bluff Head Formation on dips c.30° to the southeast and Jones (1995) has described two main facies associations: channel and sheetflood (Figure 8).

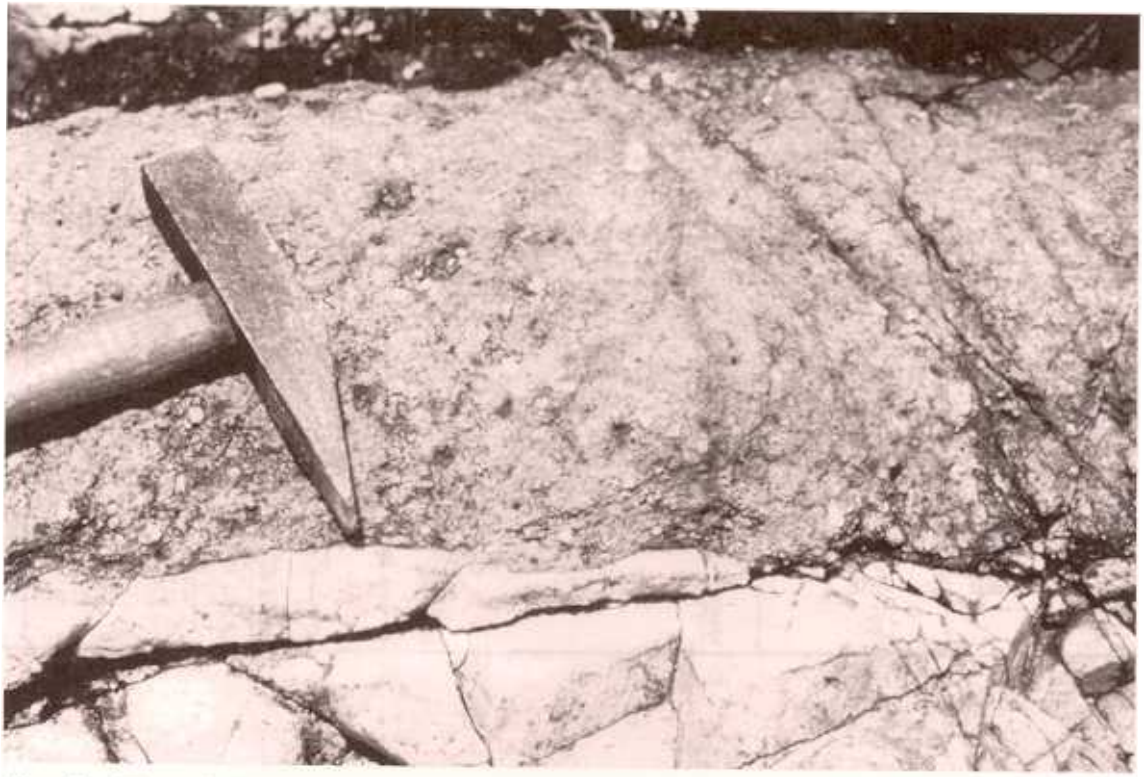

Plate 2 - Thermally Metamorphosed Bluff Head Formation Exposed at Wu Kwai Sha Tsui (4356 3284)

Included within the channel facies association is a multi-story channel sandbody complex (Plate 3) and a cross-bedded sandstone unit interpreted as a channelised deposit (Plate 4). The sheetflood facies association is represented by interbedded sheet sandstones and minor channels (Plate 5).

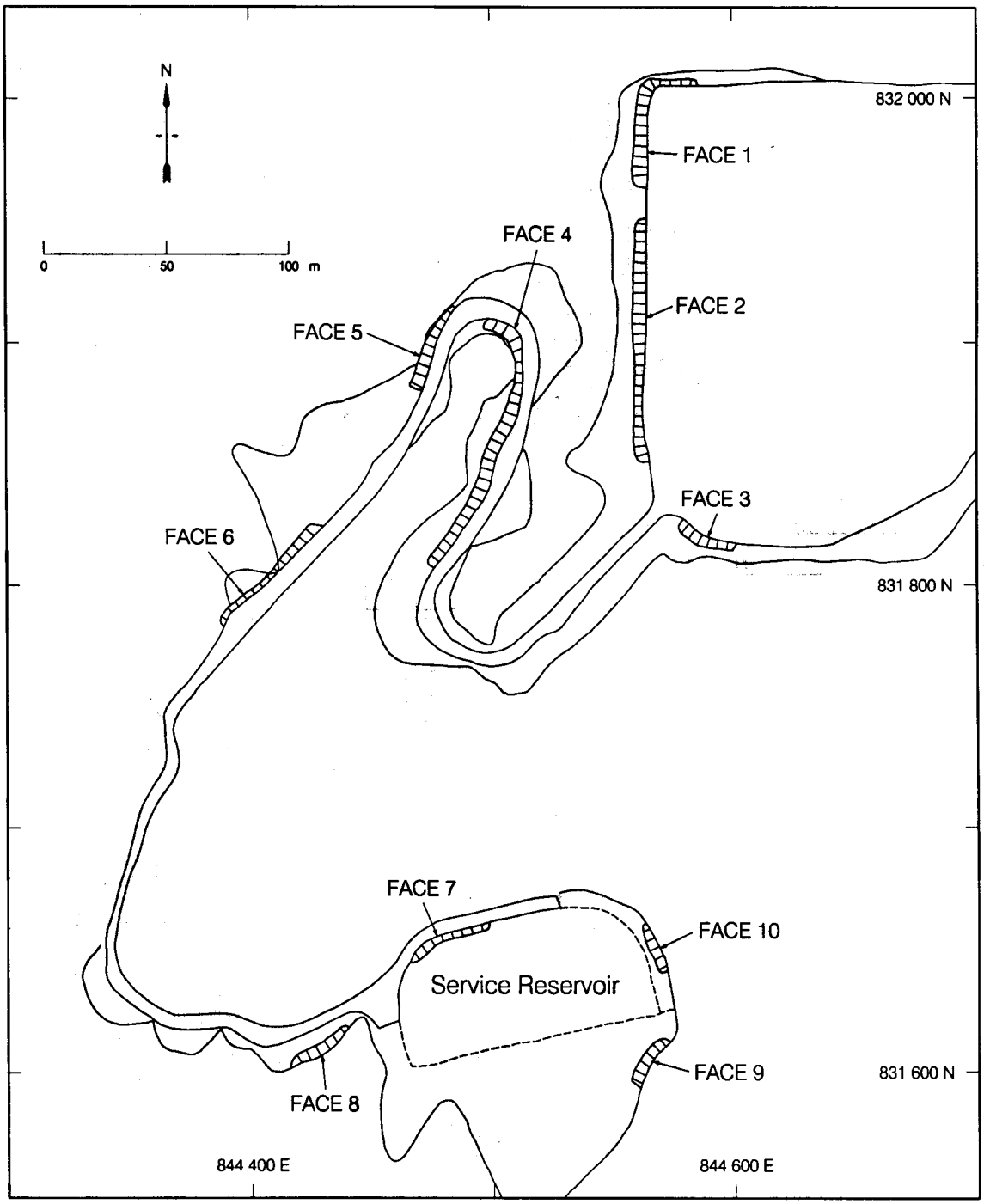

Figure 7 - Map of Temporary Exposures at Kwun Hang Water Treatment Works (after Jones, 1995)

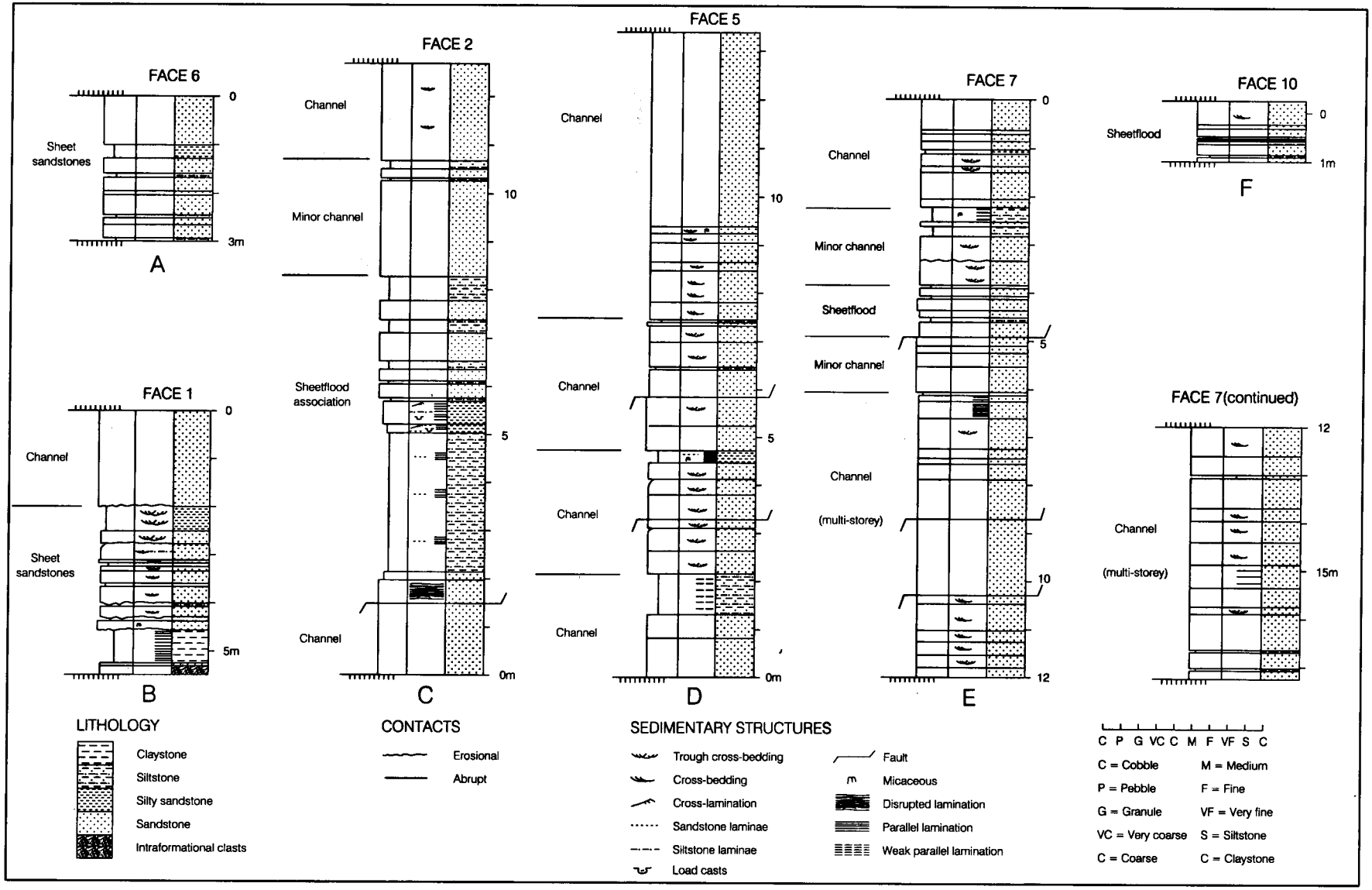

Figure 8 - Graphic Sedimentary Logs of the Bluff Head Formation at Kwun Hang (after Jones, 1995)

Plate 3 - Multi-storey Channel Sandbody Complex Exposed on Face 7, Kwun Hang

Plate 4 - Cross-bedded Sandstone Exposed on Face 7, Kwun Hang

Plate 5 - Interbedded Sheet Sandstones and Minor Channels Exposed on Face 1, Kwun Hang

Jones (1995) has interpreted the Bluff Head Formation succession on the flanks of Ma On Shan as representing the margin of a depositional basin, possibly on a faulted footwall. This may account for the dominance of finer-grained sandstones in the Ma On Shan area compared to the coarser fluvial material found at Wu Kwai Sha which may be closer to the faulted margin of the basin.

On the western flanks of Ngau Ngak Shan (4295 3045; Tiu Shau Ngau), the Bluff Head Formation is thermally metamorphosed and mineralised close to the contact with fine-grained granite. The intensity of metamorphism and mineralisation appears to increase abruptly on the southwestern side of a prominent NW-trending cross-fault (4328 3050). The sandstone is typically hornfelsic and cut by numerous aplite dykes and quartz veins hosting iron mineralisation.

The basal contact of the Bluff Head Formation is not exposed. A minimum estimate of the thickness of Bluff Head Formation exposed in the Ma On Shan area is 775 m.

Ma On Shan Formation

The Ma On Shan Formation is not exposed in the district and is encountered only in boreholes on the northern and eastern edge of the reclaimed area. It consists of bluish grey to off-white, dolomite to calcite marble with thin (< 1 cm) interbeds of dark green to black metasiltstone. The marble displays well-developed solution features and is strongly foliated with a steep angle of dip (typically 70-80°; Plate 6). Jointing commonly parallels the foliation planes, which are frequently coated by chlorite. Clasts of black siltstone within the marble have also been detected in some boreholes, together with weak pyritization along foliation planes.

Borehole records from Ma On Shan site STTL 393 indicate the presence of two major (10 m thick) carbonate-poor layers within the marble sequence. These layers display well-preserved original bedding characteristics and also contain sporadic, coarse-grained thin (<2 m) calcareous interbeds. In thin section, these creamy white fine-grained rocks are composed of roughly equal proportions of quartz and epidote, with traces of pyrite. The original lithology was probably an impure dolomitic siltstone or mudstone, the carbonate and aluminous components reacting with quartz during metamorphism to produce epidote.

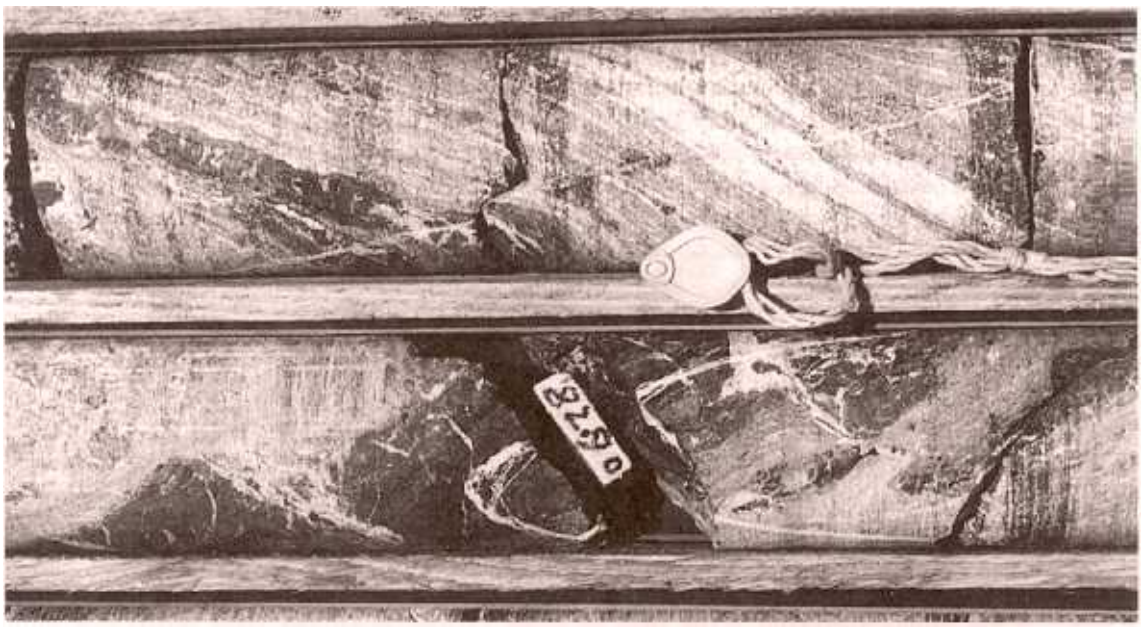

Plate 6 - Steeply-dipping Marble of the Ma On Shan Formation from a Borehole Core on the Northern Edge of the Ma On Shan Reclamation

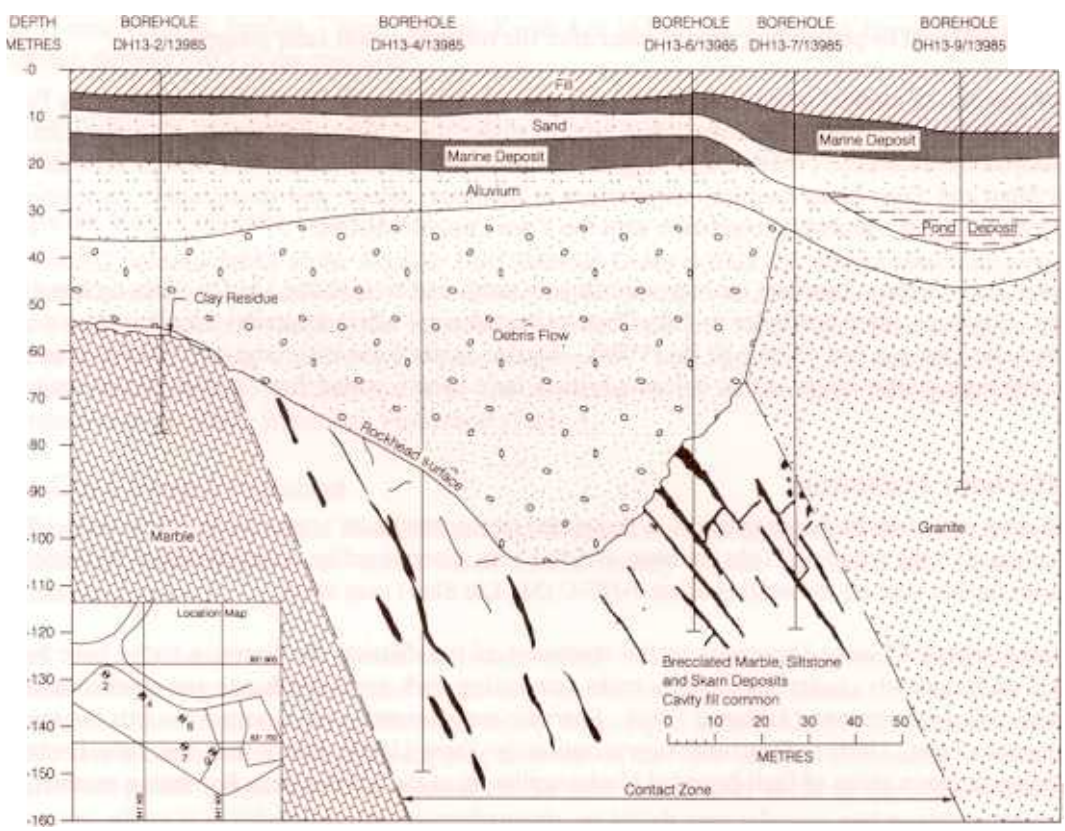

Figure 9 - Cross Section through the Contact Zone between Marble and Granite beneath the Ma On Shan Reclamation (after Frost 1991)

Ground investigations in the western part of Ma On Shan reclamation (4150 3175) have revealed the presence of a broad (10-100 m) NE-trending fault zone separating the Ma On Shan Formation in the northwest from medium-grained granite to the southeast (Figure 9; see Chapter 5). The fault zone has been intersected at depths ranging from 40 m to at least 120 m below ground surface, and comprises highly sheared rock, mineralised and hydrothermally altered deposits and soft fault gouge, and thick, mixed colluvium and debris flow deposits (e.g. Borehole WKS-2). Fractured marble is encountered on the northern margin of the fault zone together with iron-mineralised and hydrothermal deposits. The mineralised deposits vary in thickness from 1 - 3 m and include magnetite-, haematite-, and limonite-bearing skarns interbedded with fault debris.

Three types of solution cavity have been recognised in the Ma On Shan Formation in the district:

a) irregular primary solution cavities (generally 1-3 m high but rarely up to 12 m high),

b) joint-related cavities subparallel to foliation and slip planes (generally <300 mm wide),

c) fault zone-related cavities (generally <30 mm wide).

The smaller cavities are often infilled with soft, black to green, silt and mud, but recovery of such material is not always successful. The sides of larger cavities sometimes show quartz-rich infill cemented to the walls.

The primary cavities could have formed either during subaerial exposure of marble during a low stand of sea level, or by the prolonged action of deep percolating groundwater. Joint-related cavities, which are more common, appear to have formed by movement of water along fracture planes or adjacent to impermeable layers within the marble. Borehole data for Ma On Shan site STTL 393 indicates that cavities are commonly developed at the contact between carbonate-rich and carbonate-poor layers. Here, cavity development is almost certainly due, in part, to ponding of solutions at an impermeable interface. Fault zone-related cavities have been formed in a similar manner to joint-related cavities with voids being enlarged by percolating groundwater after the removal of soft fault gouge.

Thirteen samples of marble, seven from Yuen Long and six from Ma On Shan, were compared by Field & Smale (1991). The analysis involved thin section study, some X-ray diffraction, and examination using cathodoluminescence. The results suggest that there are no discernible differences between the Ma On Shan and Yuen Long marbles. Similarities in lithology, colour, and stratigraphic association (Frost, 1991) suggest a probable correlation with the Yuen Long Formation.

Geological data on the subsurface geology immediately north and west of the Ma On Shan reclamation is sparse. However, three boreholes in Tolo Channel encountered white dolomitic limestone at a depth of 25 m below the sea bed (Wong & Ho, 1986). Marble is not known to crop out elsewhere in the region, although marble clasts within volcanic breccia have been reported from surface exposures near Tai Po.

Tolo Harbour Formation

A small area underlain by Permian rocks is postulated in the northwest corner of the map sheet. The area is situated in the middle of Tolo Harbour, and has been determined by extrapolation of formational boundaries farther west on the neighbouring 7-NE-C (Ma Liu Shui) map sheet.

In the area around Chinese University to the northwest of the district, the Permian rocks have been described as dominantly clastic sedimentary rocks comprising dark green mudstone and sandstone, and laminated, pale grey siltstone (Addison, 1986). Sporadic conglomerates are reported towards the top of the sequence (Frost, 1991). Structural interpretation by Frost (1991) infers that the Tolo Harbour Formation occupies a series of fault-bounded blocks northwest of the Ma On Shan Formation marble.

Mesozoic Rocks

Classification and Distribution

The Mesozoic sedimentary and volcanic rocks of the district include the Lower Jurassic Tolo Channel Formation and the Upper Jurassic to Lower Cretaceous Repulse Bay Volcanic Group. The Tolo Channel Formation consists dominantly of steeply southeasterward-dipping laminated black shale, siltstone and intercalated fine-grained sandstone. The Repulse Bay Volcanic Group is composed principally of mixed crystal- and vitric-rich tuffs and lavas and intercalated volcanigenic sedimentary rocks.

Tolo Channel Formation

The Tolo Channel Formation is exposed in a narrow, northeast-trending strip in the central part of the map sheet. It is partly faulted against granite to the north, and is in fault contact with the Bluff Head Formation to the south. The best exposure is a small coastal outcrop (4422 3278) at Nai Chung where the formation is intruded by medium-grained granite. Here, the formation is characterised by highly cleaved, coarsely laminated siltstone, alternating with finely laminated mudstone, and in places is oxidised to a yellowish brown colour.

The Tolo Channel Formation is exposed in three other localities; at Ma On Shan water reservoir (2650 1310), in a stream near Cheung Muk Tau (4335 3175), and near Tseung Kwan Lei (4395 3245). At Ma On Shan water reservoir (2650 1310), bluish grey siltstone is in fault contact with medium-grained granite (Plate 7; Figure 10). The fault plane dips moderately steeply (60°) to the northwest and slickensides indicate strike-slip movement. Rocks close to the contact are highly sheared and hydrothermally altered, featuring several secondary shear planes. In the stream near Cheung Muk Tau (4335 3175) subvertical, thinly bedded, bluish grey to black siltstone and mudstone are interbedded with dark grey fine sandstone (Figure 11). Although the contact with granite is not exposed, it is inferred to be faulted, based on the intensity of cleavage that is similar to the rocks exposed at Nai Chung. The sequence at Cheung Muk Tau has an estimated thickness of 20 m and is unconformably overlain by quartz-rich volcanic breccia. Near Tseung Kwan Lei (4395 3245), bedded bluish grey siltstone is exposed, dipping (40°) to the southwest.

An Early Jurassic age has been assigned to the Tolo Channel Formation on the basis of a microfossil assemblage collected from Nai Chung (Nau, 1990) although their preservation is poor.

Repulse Bay Volcanic Group

Previously, volcanic rocks of the Repulse Bay Volcanic Group within the district were assigned to the Ap Lei Chau Formation (Addison, 1986). However, on the basis of new lithological and geochemical data (Table 3), the rocks capping the summits of Ma On Shan and Ngau Ngak Shan are more likely to be correlatives of the Lai Chi Chong Formation exposed in Three Fathoms Cove immediately east of the district. Similarly, the volcanic rocks in the southeast corner of the sheet are more likely to be correlatives of the Clear Water Bay Formation (Table 3).

Lai Chi Chong Formation

Within the district, the Lai Chi Chong Formation consists of a heterogeneous suite of silicic lava flows, welded tuff, and volcaniclastic rocks which unconformably overlie Devonian and Lower Jurassic sedimentary rocks.

Basal beds of the formation consist of poorly-sorted, boulder to pebble breccia-conglomerate and tuffaceous coarse-grained sandstone which rest unconformably on siltstone of the Tolo Channel Formation. In a stream section on the north side of Ngau Ngak Shan (4334 3178), volcanic breccia and tuffite rest unconformably on steeply-dipping siltstone of the Tolo Channel Formation. Poorly sorted, quartz-rich pebble conglomerate is exposed on the spur immediately south of the Ma On Shan water reservoir, where it is inferred to rest unconformably on bluish grey siltstone and mudstone of the Tolo Channel Formation. The sharp change in relief at the base of Ngau Ngak Shan is caused by a thick quartzphyric rhyolite lava flow overlying the volcanic conglomerate. The rhyolite flow can be traced eastward around the base of Ngau Ngak Shan, where it pinches out over a distance of 2 km. Overlying the lava is tuffite composed of partly recrystallised quartz-rich volcaniclastic rocks.

Table 3 - Whole Rock Major- and Trace-element Geochemistry for Representative Rock Types in the District. Major oxides in wt%, trace elements in ppm

Sample	HK207	HK9512	HK9519	HK9520	HK9614	HK9610	HK9611
Unit	gm	gf	JLC	JLC	JLC	JCB	JCB
SiO_2	77.93	76.42	79.68	78.96	78.21	76.35	76.47
TiO_2	0.08	0.04	0.09	0.09	0.07	0.12	0.12
Al_2O_3	12.35	12.65	12.03	12.36	11.97	12.44	12.59
Fe_2O_3*	0.92	2.69	1.75	1.31	5.11	1.7	1.68
MnO	0.03	< 0.01	0.04	0.03	0.06	0.05	0.05
MgO	0.12	0.38	0.46	0.18	0.09	0.03	0.05
CaO	0.57	2.27	0.01	< 0.01	< 0.01	0.37	0.41
Na_2O	3.39	4.6	0.1	0.1	0.05	2.91	3.64
K_2O	4.7	0.1	3.54	5.72	1.73	5.19	4.76
P_2O_5	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Total	100.1	99.16	97.72	98.77	97.32	99.18	99.79
LOI**	0.83	0.67	1.9	1.45	2.3	1.05	0.51
Mg #	20.53	21.86	34.23	21.39	3.37	3.38	5.57
Cr	-	3	284	14	14	13	11
Ni	< 1	7	16	10	11	11	10
Co	< 1	3	< 1	< 1	5	< 1	< 1
Cu	4	3	40	36	39	31	28
Pb	47	86	32	83	41	33	33
Zn	19	34	37	34	126	58	61
Sn	6	12	85	61	29	5	9
Rb	372	653	318	337	156	249	212
Ba	70	18	370	519	55	142	164
Sr	52	8	5	32	< 1	19	42
Ga	15	21	25	25	33	25	24
Nb	14	51	24	24	24	22	22
Zr	88	85	126	135	44	184	183
Y	31	156	16	21	46	17	29
Th	30	45	22	23	38	35	33
U	13	4	3	6	5	2	3

* total iron as Fe_2O_3, ** loss on ignition at 1000 °C, Mg # is 100 Mg / Mg + Fe^{2+}

1. HK207 Medium-grained Granite 2860 2875
2. HK9512 Porphyritic Fine-grained Granite 2605 0408
3. HK9519 Porphyritic Rhyolite 4208 0408
4. HK9520 Porphyritic Rhyolite 4195 0370
5. HK9614 Coarse-ash Crystal Vitric Tuff 3430 0170
6. HK9610 Porphyritic Rhyolite 4770 0060
7. HK9611 Porphyritic Rhyolite 4840 0550

Plate 7 - Faults Exposed in a Temporary Cut Slope behind the Ma On Shan Water Reservoir (see Figure 10)

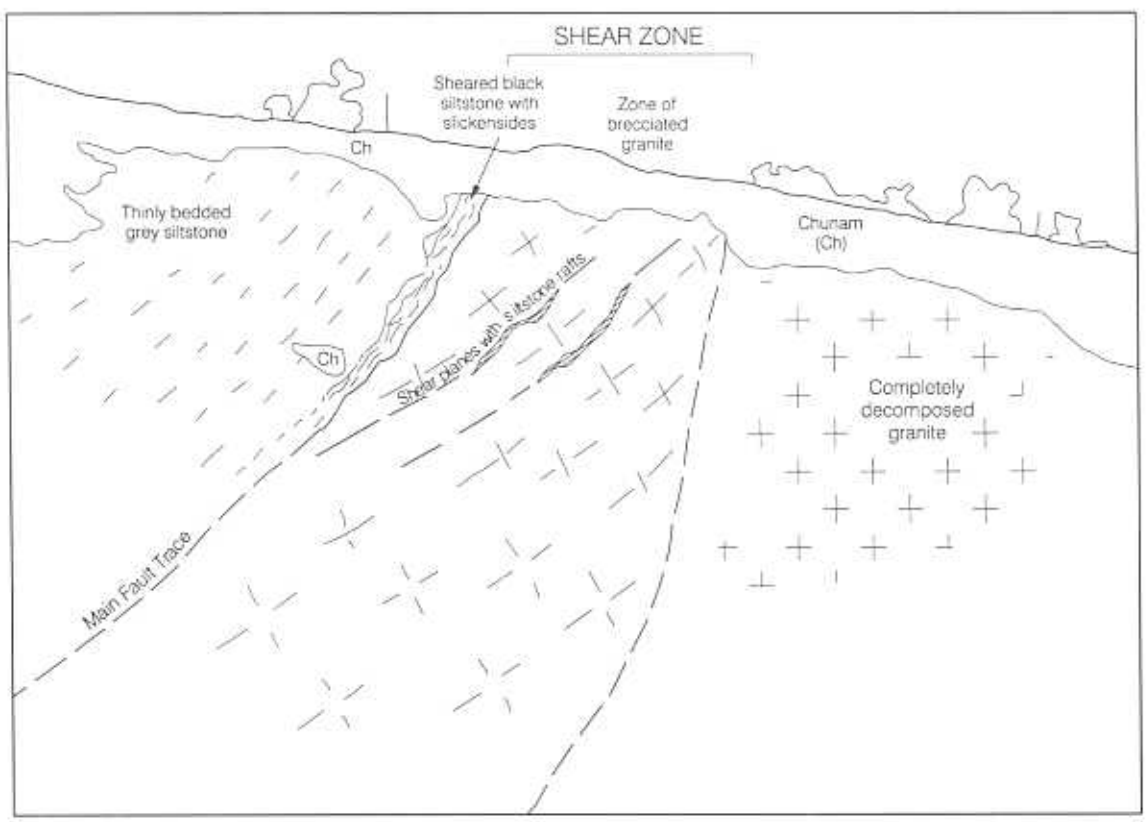

Figure 10 - Sketch of Faults Exposed in a Temporary Cut Slope behind the Ma On Shan Water Reservoir (see Plate 7)

Tuffite capping the summit of Ngau Ngak Shan (4365 3055) and exposed on the northern flanks of Ma On Shan is slightly metamorphosed. Volcanic breccia exposed on the summit of a small hill (4405 3265) immediately west of Nai Chung is thought to represent an outlier of the Lai Chi Chong Formation.

Clear Water Bay Formation

The Clear Water Bay Formation is exposed only in the southeast corner of the map sheet where it is inferred to be in faulted contact with sandstone of the Bluff Head Formation. The formation consists of porphyritic rhyolite and trachydacite lava, and fine-ash vitric tuff. It is distinguished from the Lai Chi Chong Formation by its much fresher appearance, flow-banding and strongly pilotaxitic fabric. Representative geochemical analyses are given in Table 3.

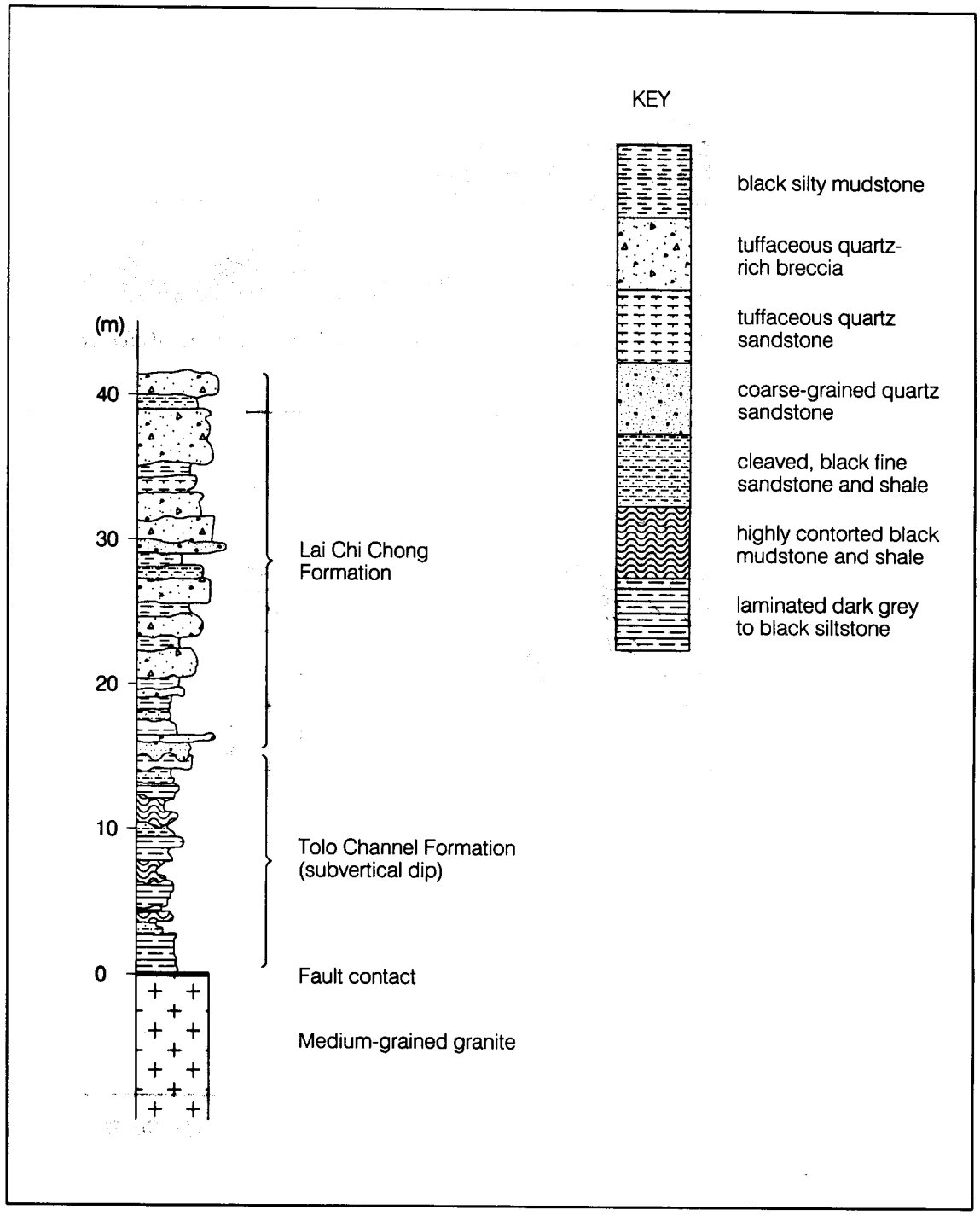

Figure 11 - Generalized Stratigraphic Section of the Tolo Channel Formation Exposed on the Northern Flanks of Ngau Ngak Shan (4334 3178)