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The Geological Foundations

Hong Kong occupies a compact land area of only 1,068 km², but exhibits a wide range of landforms and ecological environments. This variety is due in part to the geological history of Hong Kong, a legacy that includes rock forming events during the last 400 million years, geologically recent fluctuations in climate and sea level, and human activity during the historical period.

Perhaps the most interesting phase in Hong Kong's geological history was the Jurassic Period, between about 130 to 165 Million years ago. During this period the area that is now Hong Kong was subjected to major upheavals when explosive volcanic activity produced thick and extensive fragmentary volcanic deposits over the land surface, while granite was intruded at depth. Over time, the volcanic deposits were hardened in to rocks, folded, faulted and subjected to the processes of weathering and erosion. Today one of the most fascinating places to examine evidence of Hong Kong's volcanic heritage is in the High Island area of the Sai Kung East Country Park.

The Geomorphological Setting

High Island, and the large High Island Reservoir, are located at the southeastern extremity of the Sai Kung Peninsula (Fig 1). The majority of the peninsula, with the exception of small village sites, is preserved as the Sai Kung East and Sai Kung West country parks. Together, these parks cover an area of around 7,500 hectares. The Agriculture and Fisheries Department (AFD) of the Hong Kong Special Administrative Region Government has established four management centres from which to manage and protect the two parks. This extensive area of almost unspoiled countryside contains some of the finest scenery in Hong Kong.

Although Tai She Teng, the highest point on High Island, is only 278 m above Principal Datum (PD) the relief of the area is very steep and rugged in places. Many angular hills, such as Ngam Tau (150 mPD) and Fa Shan (209 mPD) rise above the dense, scrub-covered slopes. A carpet of low scrubland covers the rounded uplands, while taller trees and shrubs clothe the steeper valleys. Many consider that the greeny-brown vegetation on these volcanic hills and valleys are the "lungs of Hong Kong". However, they provide more than simply oxygen to breath. These hills also capture and filter water, another valuable resource for the large urban population of Hong Kong. Thus the hills surrounding the High Island Reservoir, both High Island to the south and the Sai Kung East Country Park to the north, are an important catchment area to intercept the rainfall that is diverted to the Reservoir for drinking water.

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A Water Works Department road (Sai Kung Man Yee Road) links the West Dam at Yuen Ng Fan to the East Dam on High Island (Fig 2). From Dam to Dam the walking distance is 5 kilometres. However a wide range of fascinating natural features can be observed from this short trail that provides a convenient transect from which many of the geological and geomorphological attractions of High Island can be both studied and enjoyed.

Basic Definitions

Before setting off on this walk, several basic definitions are necessary to aid an understanding of the features that will be observed along the way.

Rhyolite: this is a fine-grained, acidic volcanic rock that most commonly occurs as lava flow or dykes, and typically contains phenocrysts of feldspar minerals (Kearey, 1996).

Tuff: is a compacted volcanic ash deposit generated by pyroclastic processes, or explosive volcanic activity (Allaby & Allaby, 1990), or is a pyroclastic rock made mainly of volcanic ash fragments < 2 mm in diameter (Lapidus, 1990).

Vitric tuff: is a glassy pyroclastic rock (Kearey, 1996)

Caldera: a very large, generally bowl-shaped volcanic depression, the horizontal dimension of which is much greater than its height (Lapidus, 1990).

It will be clear from the above definitions that precisely defining scientific terms is not always easy. But the essentials are here. The rocks that lie beneath the hills of High Island today were largely formed from fine, sometimes glass-like volcanic ash.

Panoramas Across the Reservoir

The distinctive landforms developed over the volcanic rocks of the High Island and Sai Kung East Country Park can be observed from many locations. For example, from the walk on the West Dam or along the first 1000 metres of the Sai Kung Man Yee Road (see Fig 2). An example of a typical panorama is illustrated in Figure 3. Sharp Peak (468 mPD) (S in Figure 3) forms an impressive backdrop to eastward views in this area. This prominent peak, the sixteenth highest in Hong Kong (the highest peak in Hong Kong is Tai Mo Shan with a summit at 957 mPD), is the dominant feature of the Sai Kung East Country Park. The peak, which is formed in flow-banded rhyolite lavas of the Clear Water Bay Formation (Strange *et al.*, 1990), has been isolated slowly over time as the surrounding fine ash tuffs of the High Island area have eroded away. Further along the trail can be seen a blocky tor (t in Figure 3), a monument-like mass of jointed rock that stands on an otherwise smooth hill beyond the reservoir (r in Figure 3). This conspicuous mass of exposed, relatively resistant volcanic rock almost appears to be man-made, especially to a non-geomorphologist more familiar with the vertical man-made landscapes of urban Hong Kong. Tors tell a story, they are a testimony to the forces of differential erosion and weathering, to a long period of time in the geological cycle.

Visible across the waters of the reservoir are orange cliffs, exposures of thick and massive, crystal-bearing, fine ash vitric tuff. Impressive columnar jointing (Tam & Chan, 1983; Strange *et al.*, 1990) can be observed with binoculars from the West Dam or from the roadside. These cliffs are artificial slopes, faces from which rock fill was quarried during the construction of the High Island Dam. Now they present excellent exposures that clearly reveal the impressive structures contained in these rocks.

Hills of Acidic Rock

Walking over the hills of High Island or Sai Kung East Country Park is arduous. The scrubland carpet that blankets the slopes is low, dense, and difficult to penetrate. Exposed, island-like rocky outcrops are scattered over the summits, but these are commonly distant from the footpaths or Country Park and Water Supplies Department roads. Examination of any available outcrops will reveal the hexagonal jointing pattern that defines the upper surfaces of the columnar jointed tuff. In places, these distinctively jointed rocks are more than 400 metres thick (Strange *et al.*, 1990). Geologists have determined that these rocks were originally deposited as great sheets of hot volcanic ash infilling a very large caldera that extended over the Sai Kung area. As the ash cooled, it contracted creating the distinctive hexagonal pattern of joints. A glimpse of this hilltop terrain is captured in Figure 4. As you look at Fig 4 try to visualise what occurs beneath the surface.

Few studies have been made of the shallow soils that have developed over the tuffs. However, it is clear that the characteristic soils of the area are strongly acidic, humic and nutrient-poor (Lawal & Chau, 1996; Dudgeon & Corlett, 1994; Maxwell & Tam, 1999, Maxwell & Wong, 1999).

Shrub and heathland plants tolerant of these poor soils form distinctive communities on the hills of Sai Kung and High Island (Figure 4). The “dwarf mountain pine” (*Baeckia frutescens*), the Chinese New Year Flower (*Enkianthus quinqueflorus*), and the hardy fern *Dicranopteris linearis* are three native species that give character to the vegetation here. Also tolerant of this harsh environment is the exotic paper bark tree (*Melaleuca quinquenervia*), which was introduced to Hong Kong from Australia in the 1940’s as a slope stabilization and reforestation species (Maxwell & Wong, 1999). The detailed ecology of these species, now firmly established on the hills of the High Island area, requires further study (Maxwell & Tam, 1999). Recently, some large-flowered forms of *Enkianthus quinqueflorus*, a plant of cultural importance, were discovered in the Sai Wan Hills adjacent to the High Island Reservoir (Maxwell, 1997).

Weathering of the Tuff: Clues to the Geological Past

At a distance of approximately 900 metres from the starting point on the West Dam, the Sai Kung Man Yee Road climbs steadily as it skirts the lower slopes of Tai She Teng (Figure 2). Here weathered tuffs can be closely examined. Weathering features at this site include exfoliation, cracks and fissures, chemical changes (revealed as a mosaic of colours), water seepage and vegetation establishing a foot hold on rock faces. With the aid of a hand lens (10x magnification) the rock reveals a grey-brown matrix containing white, orange or pink crystalline material within the generally fine-grained matrix. The crystals are mostly feldspar and quartz, which are generally euhedral, about 3-6 millimetres in length and 0.5 millimetres wide (Strange *et al.*, 1990). The high silica rhyolite geochemistry of the High Island Formation remains remarkably homogeneous across its large area of occurrence. This evidence strongly suggests that the fragmentary volcanic material of the High Island Formation was deposited as a single, massive event (Strange *et al.*, 1990), although several pyroclastic flow units are identifiable. The High Island Formation is up to 400 metres thick in places, notably in the High Island and Port Shelter districts. The volcanic event that produced the tuff was probably the collapse of a very large caldera (Strange *et al.*, 1990). Remains of the margins of this former caldera may be defined by the Ma On Shan and Cheung-Sheung-Chek Keng fault zones. High precision dating of the tuffs has given an age of 140.9 ± 0.2 Ma. It is interesting to imagine the landscape at that time, in the late Jurassic or early Cretaceous period, when these pyroclastic flows occurred.

Distant Islands: A Drowned Landscape

About 1600 metres from the start of the walk, an observation point is reached. From this location beside the road, seaward views across the *Baeckia* covered hillsides reveal a panorama that comprises a proliferation of small islands. These islands include Fo Tau Fan Chau (Town Island) with a high point of 73 mPD, Wang Chau and the smaller Wong Nai Chau.

These islands have experienced an interesting recent history. About 1.5 Ma ago the landscape of the region probably appeared more or less as it does today, with a similar pattern of hills and valleys. Since this time, the Pleistocene geological period, sea level has fluctuated considerably in response to the glaciations that affected the higher latitudes. These glaciations took up water from the oceans to form massive, continent-wide ice sheets, causing sea level to fall. During periods of lowered sea level the islands visible from the observation point were hills in an extended onshore landscape of hills and river plains. Following melting of the ice sheets (deglaciation) sea level rose and the landscape was drowned by the rising waters.

Columnar Jointed Tuff: High Island East Dam.

At a point about 5000 metres along the route the East Dam is reached. This locality is characterised by spectacular views from the summit of the dam: a great feat of modern civil engineering and a monument to those who lost their lives during construction of the High Island Reservoir. Figure 5 captures some of this spectacle. Clearly visible from the top of the East Dam are the exposed columnar jointed fine ash tuffs of High Island Formation (Strange *et al.*, 1990).

Tall, vertical, hexagonal columns are visible beside the service road that runs down to the outer protective dam. At many points one can stand beside the columns (Figure 6a) and gaze skyward at these structures that look like giant crystals grown in a colossal laboratory. In places, there is clear evidence of kink-banding (Figure 6b). These large columns rival similar geological examples of spectacular igneous rock formations such as the Devil's Post Pile National Monument in California, USA. There, the columns are five-to-seven sided, grey coloured structures (Tarbuck & Lutgens, 1996), resembling a cluster of giant, vertical, crispy-noodles.

Basalt Invaders

Basalt is a dark-coloured (blackish grey), fine-grained basic igneous rock essentially composed of plagioclase and pyroxene, minerals which are commonly porphyritic (Lapidus, 1990). The basalt in this area occurs as dykes, and contains abundant amphiboles, biotite mica and magnetite (Strange *et al.*, 1990). Generally the dykes are small, but they are widespread, intruding (cutting into) most rock types in the area (Strange *et al.*, 1990). On weathering basalt produces a distinctive reddish brown soil and in coastal outcrops the softer weathered basalt is easily eroded to form sea caves (Strange *et al.*, 1990). A large cave can be seen near the coffer dam, beneath the hillsides opposite the basalt dyke seen in Fig 7.

The basalt dyke illustrated in Figure 7 is clear example of a basalt dyke intruding the columnar jointed tuffs. This dyke follows a well defined kink band (Figures 7a & 7b). It is a relatively easy task to measure the width of this dyke and to examine the basalt with a hand lens. Inspection should reveal the fine-grained blackish groundmass of euhedral feldspar grains visible as tiny rice-like crystals in the rock fabric.

Clearly, the basalt dykes are much younger than the tuffs into which they are intruded. Potassium – argon age determinations (Allen and Stephens, 1971) suggested that basalts in the High Island area were intruded about 65 Ma ago during the early Palaeocene.

Coastal Geomorphology: Rugged Seascapes

The angular facets of the columnar jointed High Island Formation tuffs provide a geomorphological tourist attraction second to none in the world. The South China Sea erodes the bases of the tall, rocky columns around several islands. For example, Po Pin Chau can be seen just beyond the outer dam near the High Island East Dam (Fig 8). Field surveys have shown that the thickest layers of this tuff occur along the coast and off-shore islands (like Po Pin Chau) of eastern Hong Kong.

These coastal and offshore exposures provide yet another insight into the geological anatomy of the High Island area of Hong Kong. As you look at the hills of Sai Kung East Country Park and High Island, try to think in three dimensions and imagine the columnar joints in the tuff that extend for up to 400 m beneath the slopes of these eastern hills.

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