## BAYS, BASINS, ISLANDS AND ESTUARIES OF THE KIMBERLEY COAST

On 5 October 2011, during a visit to Perth, Dr. A. (Sandy) Scott presented an illustrated talk to the Kimberley Society. A retired University of New England academic in science education, he has been a guest lecturer with Coral Princess Cruises on the Kimberley coast for the last 14 years, averaging two to three visits per year. That idyllic existence follows years of leading groups on inland Kimberley excursions. Sandy also works as a consultant developing travel programs to Asia for *Odyssey Travel* and leading many of those trips. A summary of his talk follows, and additional diagrammatic material can be seen on the Society's website.

The Kimberley coast has a rocky shoreline which is segmented into a series of bays, basins, islands and estuaries that have formed on the edge of the Kimberley Plateau. Most of the major landforms are circled by cliffs, rounded headlands and promontories with a lesser proportion of small beaches of boulders or sand and estuary mud flats mostly covered with mangrove communities. Sandy's presentation focused on the major landforms on the Kimberley coast and the significant factors that contributed to their development.

Outstanding features of the coast today include its indentation with many bays and estuaries, the control of NW-SE and NE-SW lineaments, the many islands, the wide continental shelf, the high tidal range on much of this coastline and the fact that the coastal geology is, with the exception of the south-west corner, 'flat and simple'. The characteristics of the five most widespread rock formations of the Kimberley Basin, as found on the coast, include:

- the limited distribution of the youngest, the Yampi Formation.
- that the Carson Volcanics, Hart Dolerite and the Elgee Siltstone are, comparatively, more liable to weathering and erosion than the King Leopold Sandstone, the Warton Sandstone and the Pentecost Sandstone formations.
- that the more resistant formations to weathering alternate with formations that are relatively more easily weathered.
- Hart Dolerite, may intrude King Leopold Sandstone, Carson Volcanics and Warton Sandstone.

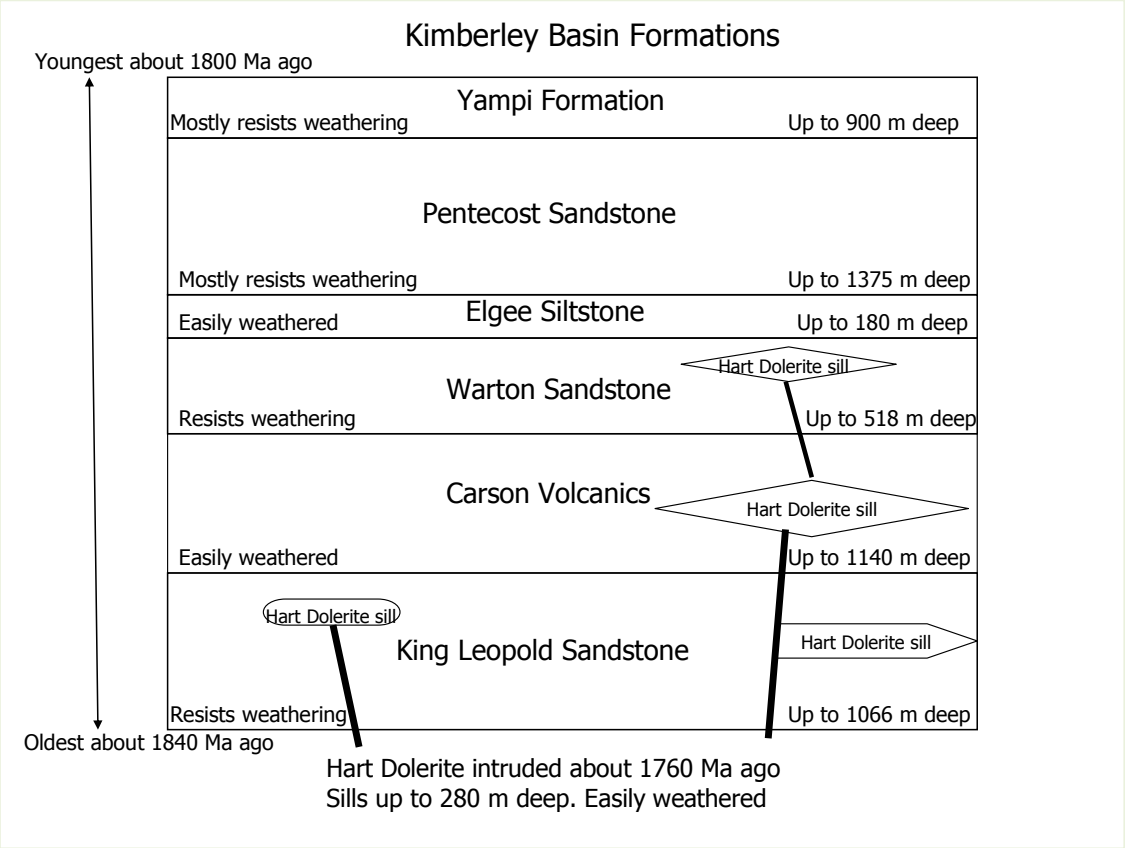



Figure 1. Some characteristics of the Kimberley Basin rock formations as found on the Kimberley coast

Sandy presented several case studies to demonstrate the significant factors in the landforms associated with King George River, Vansittart Bay, Montague Sound, Prince Frederick Harbour, Saint George Basin and Prince Regent River, Brecknock Harbour and Doubtful Bay, finishing with Talbot Bay and Yampi Peninsula. The major points made for each location follow.

*King George River and falls*. Here the river flows through relatively weathering-resistant Warton Sandstone. Uplift of the Kimberley, possibly that of 20 million years ago, formed a plateau and the river flowed off this via a waterfall. The uplift rejuvenated the development of new landforms and headward weathering and erosion by the river followed the joints and possibly a lineament (an extensive surface expression of deep seated faults or fractures) as it cut back into the plateau. This resulted in a zig-zag river course, cliffs of blocky red Warton Sandstone up to 80 metres on either side of the river and twin waterfalls which terminated the steep valley. With the rise in sea level following the last ice age, between 18,000 and 6000 years ago, the river valley has become an estuary.

*Vansittart Bay*. Prior to the processes that formed Vansittart Bay and its islands (including Jar Island), King Leopold Sandstone, the oldest local formation, was covered with Carson Volcanic rock the surface of which had been altered to bauxite. The bauxite acted as a tough capping over the Carson Volcanic. Rejuvenated weathering followed the uplift of 20 million years ago which helped expose some of the relatively easily weathered Carson Volcanics. The weathering and erosion undermined the bauxite capping and the eventual removal of all the Carson Volcanics exposed the 'tough' underlying King Leopold Sandstone such as we see today on Jar Island and along much of the eastern side of the Bay. The western side of the Bay remains covered with a plateau capped with bauxite as does part of Eclipse Hill Island at the mouth of the Bay. The termination of the last ice age resulted in rising sea levels and the formation of a bay over the lowered landscape.

In many locations the sandstone has been hardened to form quartzite and on Jar Island the quartzite has disintegrated into huge boulders and collapsed slabs forming caves and overhangs that have served as Aboriginal occupation sites, tool making sites and surfaces suitable for rock painting.

*Montague Sound.* This diverse section of the coast includes Cape Voltaire, the Maret Islands within the Bonaparte Archipelago and Bigge Island. At Cape Voltaire we find cliffs of Hart Dolerite, a rock that had formed as a sill within the strata of King Leopold Sandstone. Once the dolerite is exposed to the atmosphere it weathers relatively rapidly (similar to basalt in the Carson Volcanics Formation) and in so doing weakens the King Leopold Sandstone about it. The cliffs now stand free of the sandstone.

The Maret Islands have formed as small plateaus or mesas in a process similar to that at Eclipse Hill Island. The Maret Islands are flat topped and have a capping of bauxite or iron dominated laterite. Rising sea levels have isolated these flat topped hills as islands. Wave action and weathering of the underlying Carson Volcanics is causing ongoing weathering and erosion of the islands.

Bigge Island is mainly formed from King Leopold Sandstone. Variation within the sandstone strata has resulted in some strata being more susceptible to weathering than others. One result of such a breakdown has been the development of thick rock columns in this stratum. In some cases there is the development of a cave system supported by many columns but in other cases the columns have become very thin and collapsed bringing down the large slabs of rock they supported.

*Prince Frederick Harbour*. This harbour is the mouth of both the Hunter and the Roe Rivers, rivers which would have 'cut down' to their present level following the general Kimberley uplift many millions of years ago. The predominant local rock is King Leopold Sandstone and it has been extensively intruded by Hart Dolerite in this region. Once the river valleys had exposed the dolerite in times past, its relatively rapid weathering would have undermined the King Leopold Sandstone. Without support the sandstone fell and developed cliffs which gradually receded as the process continued. Where large sections of the dolerite sill have been exposed as headlands, they form rounded promontories rather than steep cliffs. The rivers would have effectively eroded the collapsed sandstone, so widening the valley, and deposited their sediments over the continental shelf. Given that sea level during the past ice age was well over 100 metres below current levels, the river valleys were far enough below sea level to be flooded as the sea level rose.

Extensive mangrove-covered mud flats and some small sand beaches may be found within the harbour. These sediments are the result of ongoing weathering, erosion and deposition.

*Prince Regent River and Saint George Basin*. Unlike the King George River the Prince Regent River follows a straight path on its north-westerly course. The river has followed a lineament for about 100 kilometres and this terminates in Saint George Basin. Most of the upper reaches of the river are narrow and confined to King Leopold Sandstone, but towards the mouth weathering and erosion have exposed sills of Hart Dolerite and this has tended to open and widen the otherwise

narrow valley. Two interesting streams, King Cascade and Camp Creek join the Prince Regent River and like several other tributaries do so at right angles to the main river course.

Saint George Basin formed in quite a different geological environment. The Basin formed following the weathering and erosion of a Warton Sandstone plateau which overlies Carson Volcanics (mainly in the form of basalt). In the past the river would have flowed across the Warton Sandstone most likely following the same lineament as described above. In so doing Carson Volcanics would have been exposed and its subsequent rapid weathering undermined the Warton Sandstone gradually opening up a wide valley eventually reaching this size of the current Basin. It is possible to see all stages of the weathering process especially in the north-western corner of the Bay. Here we see isolated mesas (two on land, Mt Waterloo and Mt Trafalgar, and two islands – St Patrick and St Andrew), with Warton Sandstone capping overlying the Carson Volcanic. There are several cone shaped hills of Carson Volcanic where the more resistant cap has been lost. At the other end of the scale are Python Cliffs capped with Warton Sandstone and forming the edge of an entire plateau.

The Basin is connected to the Indian Ocean via Brunswick Bay and at the time of rising sea levels, prior to 6000 years ago, the Bay and Basin would have been flooded, the islands formed and the Prince Regent River became estuarine for about 30 kilometres from its mouth.

*Brecknock Harbour*. The landward side of the harbour is dominated by Carson Volcanics which in the past would have been capped Warton Sandstone, like the higher parts around Saint George Basin. In the south of the harbour, near Kuri Bay the pre-weathering strata are clearly visible with the highest local peak Mt Lookover formed from Warton Sandstone. Remnants of the weathering are seen at Camden Peninsula, Sheep Island and at Needle Rock near Kuri Bay – all formed from basalt.

*Doubtful Bay.* This bay, like Saint George Basin and Brecknock Harbour formed where a Warton Sandstone plateau, underlain by Carson Volcanics, once existed. Following the uplift of the Kimberley Basin (also known as the Kimberley Block) some 20 million years ago streams running seaward across the current Bay area, like the Sale River and Red Cone Creek of today, would have exposed the Carson Volcanics thus promoting the eventual undermining of the Warton Sandstone and reduction of the land surface to below current sea level. Today some remnants of the original plateau may be seen at the two bluffs east of Raft Point on the south side of the bay. We also see Steep Island as an outlier from the plateau that has resisted weathering and erosion, and Bird Island where the slow disintegration of Warton Sandstone has formed an island less than five metres above the current sea level.

*Talbot Bay and Yampi Peninsula*. This part of the Kimberley has been formed from rock formations of the Kimberley Basin but here rock folding has altered their orientation from nearly horizontal to folds with wave lengths varying from a few metres to kilometres and producing in places strata tilted with nearly vertical orientation. One major folding event occurred 540 million years ago and since then ongoing weathering and erosion have reduced the high mountains to plateaus, ridges and valleys. The ridges represent the stumps of the more resistant formations (King Leopold Sandstone, Warton Sandstone and Pentecost Sandstone) and the valleys, now flooded with sea water, have been formed where the less resistant formations (Carson Volcanics and Elgee Siltstone) once existed.

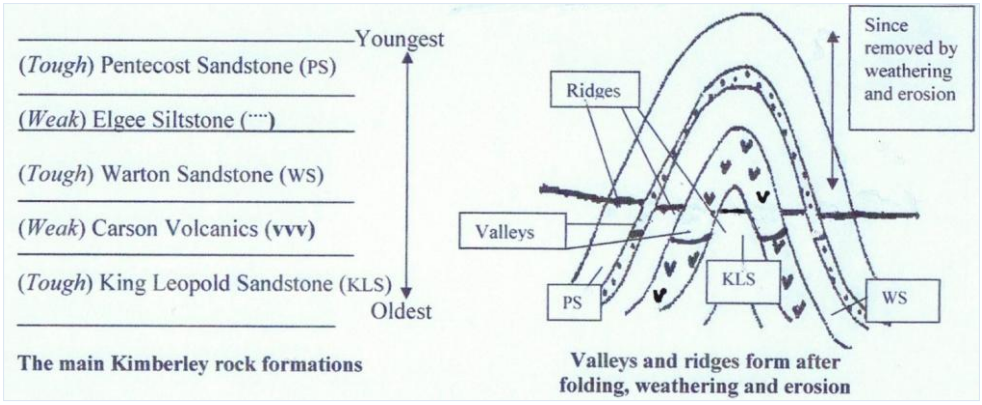



Figure 2. The main Kimberley Basin formations were folded and after long periods of weathering and erosion the folded mountains were reduced to a plateau. Subsequent weathering has removed the less weathering-resistant (weak) strata and left the more resistant (tough) strata as ridges (as described below).

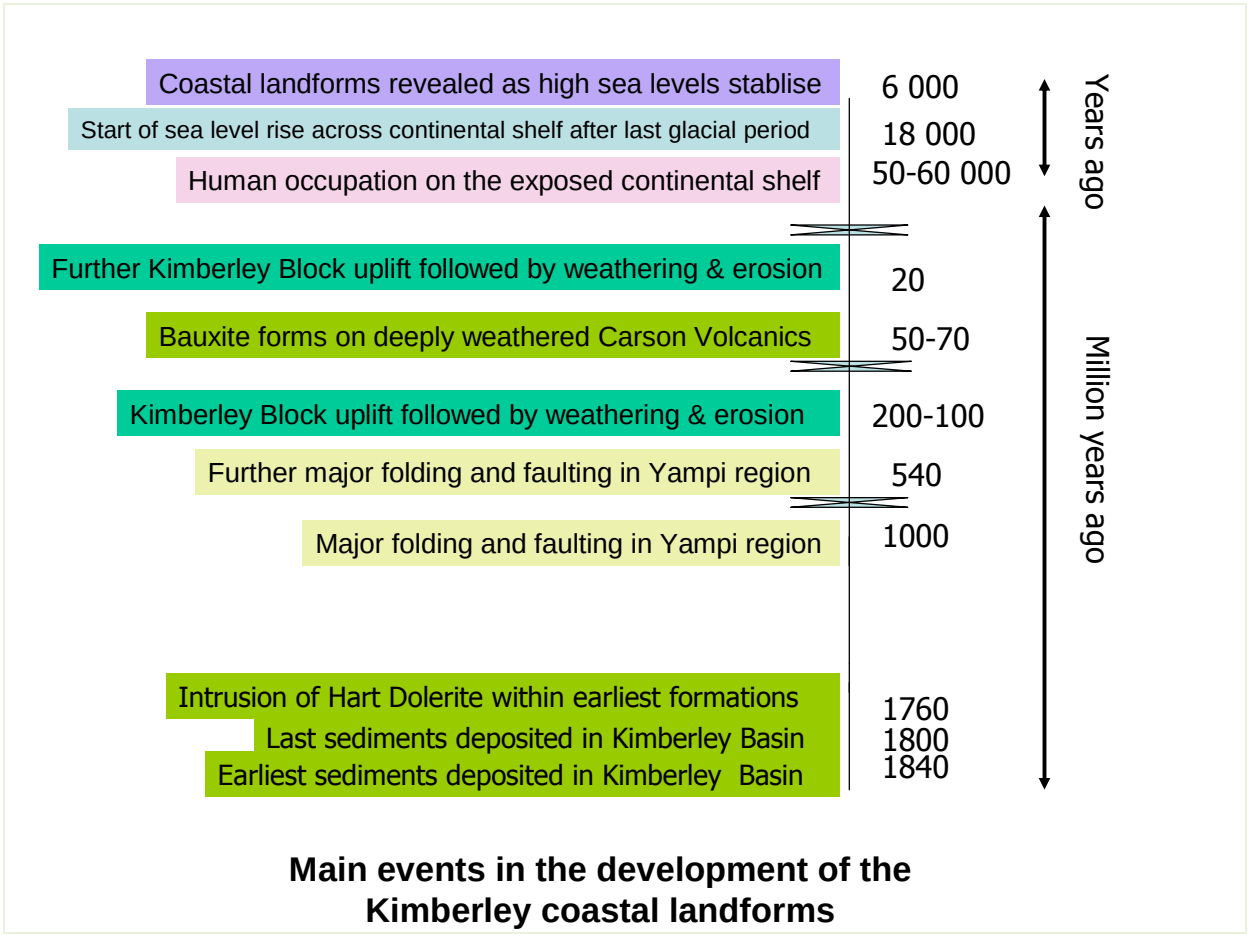
At the Horizontal Waterfalls, an interesting attraction found deep in Talbot Bay, intense folding has tilted the originally horizontal formations through 85 degrees. Stream weathering in the past cut down through joints in the near vertical strata forming gaps in the outer two ridges as water flowed out to sea through a valley in Talbot Bay. At this time the stream may have had to run across the continental shelf for many tens of kilometres westward of Yampi Peninsula to reach the sea. This stream allowed for the weathering and erosion of the two embayments we now see inside the gaps where the two more easily weathered, 'weak' formations were once found. The first gap is through a ridge of Pentecost Sandstone that separates Talbot Bay from the first embayment, the second gap is through a ridge of Warton Sandstone and it connects the two embayments. McLarty Range forms the innermost ridge and it is formed of King Leopold Sandstone. Prior to their weathering and erosion, Carson Volcanics occupied the second embayment and Elgee Siltstone occupied the first embayment and remnants of these rocks may still be found on the walls of each embayment.

View of the Horizontal Waterfalls at slack tide. The first gap leads through a ridge of Pentecost Sandstone into the first embayment. Beyond the boat is the second gap through a ridge of Warton Sandstone leading into the second embayment. This is backed by McLarty Range formed from King Leopold Sandstone.

With the rise in sea levels and the local extreme tidal ranges in-flowing water today builds up in Talbot Bay before flowing 'downhill' through the narrow gap into the first embayment. Similarly water from the first embayment on an incoming tide builds up at the even narrower second gap and forms a second horizontal waterfall as it flows into the second embayment. The process is reversed on the ebb tide. Clearly these tides and the large volume of water exchanged in each tidal cycle will help to move sediments in and out of the embayments. However it is important to remember that the gaps and embayments existed long before the relatively recent sea level rise and the phenomena of horizontal waterfalls.

Yampi Peninsula extends westward onto the Buccaneer Archipelago and most of the rocks on the northern side originated from the Kimberley Basin formations. The Iron Islands and the sections of Koolan and Cockatoo Islands are formed from rocks in the Yampi Formation. This was the last formed Kimberley Basin Formation and parts of it are rich in the iron bearing mineral hematite. On the two islands that have been mined for the iron ore, the hematite containing strata dip steeply, strata on the seaward side plunging below sea level and creating challenges for mining operations.

Before concluding the presentation Sandy showed images of the remarkable folding and over-folding of the colourful Pentecost Sandstone strata at Nares Point.




**Main events in the development of the Kimberley coastal landforms**

During the conclusion to the talk Sandy emphasized that although high sea levels today have flooded the valleys, formed the islands and are adding in a small way to the development of Kimberley coastal landforms, most of what we see involved development processes devoid of sea water. Lineaments and the relative ease of weathering of the five main rock formations of the Kimberley Basin have been most influential in the formation of the wide valleys, basins and isolated hills which, following the last ice age, have become bays, basins, islands and estuaries of the Kimberley coast.