The Geology of the Falkland Islands

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Plate tectonics have produced some surprising juxtapositions as the Earth's continental fragments have drifted and jostled over the eons. Microplates seem to have enjoyed most freedom of movement, and none more so than that supporting the Falkland Islands. Though this archipelago is situated in the south-west corner of the South Atlantic Ocean, about 650 km east from Tierra del Fuego and the Strait of Magellan, its geology tells of an African heritage. Charles Darwin provided the first evidence for that – although he didn't appreciate it at the time.

HMS Beagle visited the Falkland Islands twice, in 1833 and 1834, and during the first visit Darwin discovered fossil shells, mostly brachiopods. His first impression had been unfavourable, but after that discovery he noted in his diary: "The whole aspect of the Falkland Islands were however changed to my eyes … for I found a rock abounding with shells; and these of the most interesting age." Darwin published his account of Falklands' geology in 1846. The "interesting age" proved to be Devonian, and as more data were acquired a close and surprising similarity was established with the fauna of equivalent age in South Africa. This similarity was soon extended to other aspects of the Falklands rock succession, whilst the geology of neighbouring Patagonia proved to be quite different.

These relationships were not readily explicable without recourse to continental drift, so were largely ignored for many years despite a remarkably prescient interpretation by a South African geologist, Ray Adie, in 1952. Not content with a straightforward African connection, as championed by Alexander Du Toit in his 1937 book '*Our Wandering Continents*', Adie proposed that what we would now call the Falklands microplate had rifted from the east coast of South Africa, and had then been rotated through 180° as it drifted to its present position. His evidence was drawn from the alignment of sedimentological and structural features from the two areas. Half a century later, and though the jury is still out on some of the details, Adie's proposal is looking to be essentially correct. The close geological correlation between South Africa and the Falkland Islands is now put down to their original proximity in a reconstructed Gondwana supercontinent (Fig. 1).

The Falklands' rock succession

The Falkland Islands are made up of two main components, East and West Falkland, a dozen or so largish subsidiary islands, and myriad smaller islands, rocks and reefs. These all add up to a total land area of just over 12 000 km^2, though the islands are spread out over an area about twice that. The oldest rocks seen are the Proterozoic, *ca* 1000 million years old, granite and gneiss of the **Cape Meredith Complex**, which has a very small outcrop on the southernmost point of West Falkland (Fig.2). This 'basement' complex is there unconformably overlain by a thick succession of marine, near-shore clastic strata, demonstrably Devonian but perhaps ranging in age from Silurian to Carboniferous, known as the West Falkland Group.

The lowest of the West Falkland Group's four formations, the **Port Stephens Formation**, comprises about 2500 m of pale brown and grey, quartz-rich but locally arkosic sandstone. Cross-bedding and rippled surfaces are fairly common, and there are plenty of trace fossils, but no body fossils have been found. The Port Stephens Formation forms most of the high ground in the north of East Falkland and the south of West Falkland but the hardness of the sandstone is quite variable and on some of the exposed ridges it has been carved into fantastic monoliths by the sand blasting effect of thousands of years of Falklands' gales (Fig. 3). In an upward, conformable transition the Port Stephens Formation is followed by the **Fox Bay Formation**, a unit comprising about 1500 m of yellowish brown, micaceous sandstone and dark mudstone. These rocks are relatively soft and readily eroded, so form much of the low ground in West Falkland and in the northern part of East Falkland. It was from a coastal exposure in the latter area (Port Louis, Fig. 2) that Darwin collected his fossils. In fact, the Fox Bay Formation is widely fossiliferous – as is the equivalent unit in South Africa, the Bokkeveld Group – with a rich and varied fauna that includes brachiopods (Fig. 4), trilobites, bivalves, snails, crinoids and orthocones. From these can be established an Early Devonian age (Emsian, *ca* 400 Ma). Higher in the micaceous sandstone succession the marine fossils are replaced by plant remains, and the host strata are assigned to the **Port Philomel Formation** which is about 300 m thick.

The loss of the marine animal fauna and its replacement by washed-in plant debris reflects changing conditions along the coast of Gondwana, where the West Falkland Group was deposited, and further change brought about a huge influx of clean, white quartz sand. This now forms the 1000 m or so of quartzite that makes up most of the **Port Stanley Formation**, the highest division of the West Falkland Group. Apart from scattered plant remains, which can locally be quite concentrated, this formation is entirely unfossiliferous. Large-scale, tabular cross-bedding is a common feature (Fig. 5) suggesting deposition of the beds as extensive, migrating submarine sand sheets. The hard, white quartzite of the Port Stanley Formation produces the highest ground in the islands (Fig. 6) and also gives rise to the famous Falklands 'stone runs' – of which more later.

There is a break in the sedimentary record at the top of the Port Stanley Formation that might represent as much as 100 million years, though there is only a slight angular discordance between the quartzite and the succeeding sandstone and mudstone of the **Bluff Cove Formation**. This division, and those above it, make up the Lafonia Group and crop out over the southern part of East Falkland, including the eponymous Lafonia (Fig. 2). The Bluff Cove Formation is about 250 m thick and the presence of rare plant traces shows that the nearby landmass was vegetated. That was about to change. Towards the end of Carboniferous times, as Gondwana drifted into southern polar latitudes, Earth's climate cooled and huge ice sheets expanded.

In the Falkland Islands' rock record the first signs of the approaching ice are the large, isolated boulders, rafted in on icebergs, which appear in the sandstone at the top of the Bluff Cove Formation. Soon the whole area was covered by a floating ice sheet from which rained down mud, sand and erratic pebbles and boulders, the whole assemblage now forming the 850 m thick **Fitzroy Tillite Formation**. The typical lithology shows a mixture of clast types supported in a dark matrix of muddy sand (Fig. 7). Some of the erratic clasts can be likened to rock types in the underlying Falklands' succession, but others are entirely exotic. Spectacular examples of the latter are the boulders of Early Cambrian limestone containing fossil trilobites and archaeocyaths (Fig. 8). In a remarkable confirmation of the Falklands-Africa-Gondwana association, exactly the same types of archaeocyaths have been found in limestone clasts in the Dwyka Tillite, the correlative of the Fitzroy Tillite in South Africa. There is no local source for the Cambrian limestone in South Africa either, and the erratics both there and in the Falklands were most likely derived from a source in what are now the Transantarctic Mountains! Incidentally, the Fitzroy Tillite takes its name from the farming community of Fitzroy, itself named after the captain of Darwin's ship, HMS Beagle.

Once the ice sheets had retreated the Falklands area was once again blanketed by mud and sand that now make up the 400 m of the **Port Sussex Formation**. But by this time tectonic activity was stirring and the upper part of the formation contains layers of volcanic ash. The history of the Falklands was about to get violent. Starting around 280 million years ago, the Falklands' margin of Gondwana became a zone of compression and the rock sequence was crumpled and faulted (Fig. 9) with a strong cleavage imposed in places. A thrust belt developed which, in terms of the Falklands' present-day geography, carried the folded strata southwards. As it did so a mountain range built up and its weight was sufficient to depress the Earth's crust in the vicinity so that ahead of the thrust front a foreland basin was formed. In this was deposited the younger Permian, part of the Lafonia Group. The correlation with Africa is instructive. In the Falklands, the fold and thrust belt moved south with the Lafonia foreland basin ahead of it. In Africa, the equivalent structure, the Cape Fold Belt, moved north with the Karoo foreland basin forming ahead of it. This contradiction was not cited by Ray Adie in 1952, but it certainly supports his idea that the Falklands microplate has rotated from its once contiguous relationship with southern Africa.

The depositional environment established in the Lafonia/Karoo foreland basin was initially one of shallow water, and the basin was perhaps lacustrine for at least part of its history. The older succession ahead of the thrust belt was still undisturbed so in the foreland basin the Port Sussex Formation is conformably succeeded by the sandstone and mudstone of the **Brenton Loch Formation**, up to 3000 m thick. Much of the fine-grained strata are laminated and trace fossils abound; one remarkable type comprising sets of parallel, sinuous lines (Fig. 10) is thought to have been made by fish swimming close to the lake bed and trailing their fins in the mud. Despite that implied presence of fish, the only fossil remains to have been found are a handful of rather bland bivalves.

A few plant fragments are found in the upper part of the Brenton Loch Formation but they become much more abundant in the succeeding **Bay of Harbours Formation**, also up to about 3000 m thick. There is much fine-grained sandstone in this formation, which probably accumulated in a network of inter-connected delta channels; cross-bedding and rippled surfaces are common. The plant fossils come in two varieties: impressions of leaves and stems indicative of *Glossopteris* trees and giant horsetails, and fragments of silicified wood (Fig. 11). By this time, late in the Permian, the compressive structural regime had come to an end, so the Brenton Loch and Bay of Harbours formations remain relatively undisturbed across low-lying Lafonia. But the next phase in the Falklands' geological history was to prove crucially dramatic – the break-up of Gondwana.

Gondwana's fate was probably instigated by a vast upwelling of magma, a mantle plume, which impacted on the crust somewhere in the Africa-Falklands-Antarctica region of the supercontinent (Fig. 1). Its presence is recorded in the Falklands by several intersecting swarms of dolerite dykes, all of Early Jurassic age; individual dykes are up to 30 m wide (only the largest are shown in Fig. 2). The palaeomagnetic signatures of these dykes provides further evidence for the rotation of the Falklands microplate, and contrasts with palaeomagnetic data derived from a later set of Early Cretaceous dolerite dykes. The Cretaceous dykes (Fig. 12) were intruded during the opening of the Atlantic Ocean and so post-date any rotation. They are an onshore manifestation of the extensional tectonic regime that created the Cretaceous-Tertiary offshore sedimentary basins that surround the Falkland Islands. The offshore basins contain up to 5000 m of strata and are currently the focus of oil exploration.

The Falkland Islands onshore geological record ends in the Permian, though there is one tantalising occurrence of tree trunks and branches, underneath a Pleistocene solifluction deposit, which might prove the treeless Falkland Islands to have enjoyed a Neogene forest cover. This would have been wiped out by Pleistocene glacial conditions, though the islands never experienced any substantial ice cover. There were a few small cirque glaciers on the highest peaks, but for the most part the conditions were of deep-frozen tundra. Hence, periglacial processes were active over a long period of time and their interaction with the Port Stanley Formation quartzite has produced extraordinary landscape features – the stone runs. These are vast periglacial blockfields (Fig. 13) and patterned ground developed on such a large scale that its extent can only really be appreciated from the air (Fig. 14). Though periglacial patterned ground is commonplace world-wide, the scale of the Falklands' examples is extraordinary and sets them in a class of their own. They probably owe their size to a combination of the Port Stanley quartzite, a tough rock that naturally forms large and irreducible boulders, and a polyphase development history spread over several ice age stadials. Charles Darwin was rather taken by them too – though puzzled. The best suggestion he could offer was that they had been shaken into place by earthquakes.

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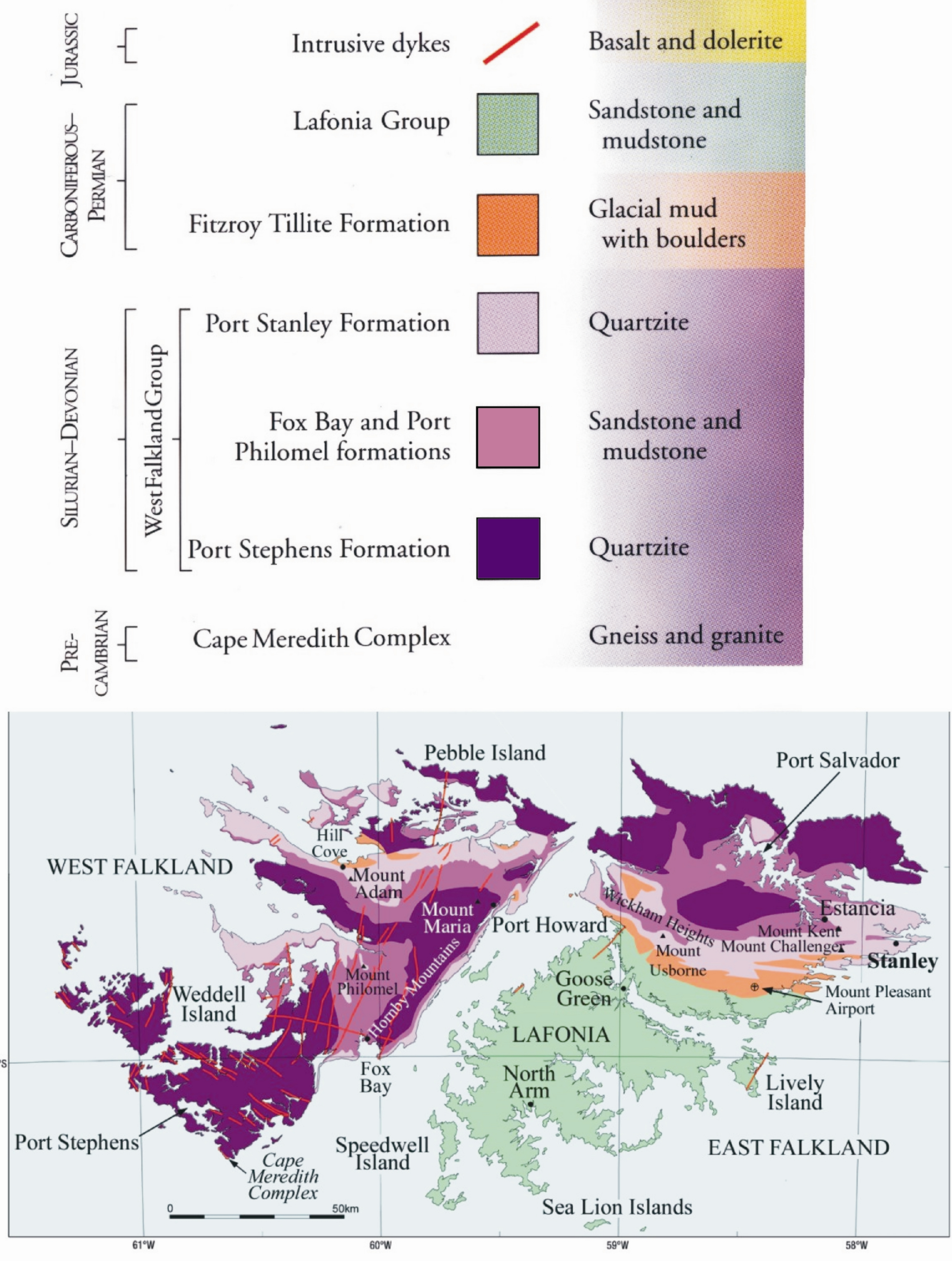
Figure Captions

1. A reconstruction of the Gondwana supercontinent at about 300 Ma. ©BGS/NERC
2. A simplified geological map of the Falkland Islands. The outcrops of the Bluff Cove and Port Sussex formations are thin and on the map these units are subsumed into the Fitzroy Tillite Formation. Within the Lafonia Group outcrop, the Brenton Loch Formation mostly occupies ground to the north-east of the Goose Green isthmus, the Bay of Harbours Formation crops out to the south-west of the isthmus. © Falkland Islands Government
3. A wind-eroded monolith of Port Stephens Formation quartzo-feldsapathic sandstone, Mount Maria, West Falkland. ©BGS/NERC
4. Devonian brachiopods from the Fox Bay Formation, near Port Howard, West Falkland. The larger impressions are internal moulds of *Schellwienella sulivani*, the smaller ones are of *Australocoelia palmata*. The Falkland Islands 2-pence piece is 2.5 cm in diameter. ©BGS/NERC
5. Tabular cross-bedding in Port Stanley Formation quartzite, near Stanley, East Falkland. ©BGS/NERC
6. The rugged terrain formed by the Port Stanley Formation quartzite, looking west towards the Wickham Heights, East Falkland. ©BGS/NERC
7. Cobbles of granite and red quartzite in the Fitzroy Tillite Formation, Hill Cove, West Falkland. ©BGS/NERC
8. Archaeocyath fossils in a block of Cambrian limestone from the Fitzroy Tillite Formation, north coast of West Falkland. The Falkland Islands 2-pence piece is 2.5 cm in diameter. ©BGS/NERC
9. Folded beds of Port Stanley Formation quartzite, Mount Challenger, East Falkland. ©BGS/NERC
10. Trace fossils produced by fish swimming a sinuous course over soft sediment, now preserved in the Brenton Loch Formation (Lafonia Group) near Goose Green, East Falkland. The Falkland Islands 2-pence piece is 2.5 cm in diameter. ©BGS/NERC
11. Silicicified wood from the Permian, Bay of Harbours Formation (Lafonia Group), Bleaker Island, SE of Lafonia. ©BGS/NERC
12. An Early Cretaceous, dolerite dyke cutting Port Stanley Formation quartzite, near Stanley, East Falkland. The author provides a 1.8 m scale. ©BGS/NERC
13. A periglacial blockfield – a 'stone run' – made up of large quartzite boulders eroded from the Port Stanley Formation, south side of Mount Challenger, East Falkland. ©BGS/NERC
14. An aerial view of stone runs, periglacial blockfields and large-scale patterned ground, south side of Mount Challenger, East Falkland. © Falkland Islands Government


GONDWANA
Equator
AFRICA
INDIA
SOUTH AMERICA
Falkland Islands
ANTARCTICA
AUSTRAL
South Pole
ANTARCTIC PENINSULA



Jurassic
Intrusive dykes
Basalt and dolerite
Carboniferous–Permian
Lafonia Group
Sandstone and mudstone
Fitzroy Tillite Formation
Glacial mud with boulders
Silurian–Devonian
West Falkland Group
Port Stanley Formation
Quartzite
Fox Bay and Port Philomel formations
Sandstone and mudstone
Port Stephens Formation
Quartzite
Pre-Cambrian
Cape Meredith Complex
Gneiss and granite
Pebble Island
Port Salvador
Hill Cove
WEST FALKLAND
Mount Adam
Mount Maria
Port Howard
Wickham Heights
Estancia
Mount Kent
Mount Challenger
Stanley
Mount Usborne
Mount Philomel
Weddell Island
Hornby Mountains
Goose Green
Mount Pleasant Airport
LAFONIA
Fox Bay
North Arm
Lively Island
Port Stephens
Speedwell Island
EAST FALKLAND
Cape Meredith Complex
0
50km
Sea Lion Islands
52°S
61°W
60°W
59°W
58°W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FALKLAND ISLANDS 1987


2
FALKLAND ISLANDS 1987


2.5cm