OR/15/058 Systematic survey and research: 1966-1977

Stone, P. 2015. The geological exploration of the sub-Antarctic island of South Georgia: a review and bibliography, 1871–2015. *British Geological Survey Internal Report*, OR/15/058.

The sedimentary succession

The development of Trendall's interpretation of South Georgia geology by subsequent workers has been detailed by Macdonald and others (1987)[1] who stressed (and listed in their Table 1) the contributions of geologists from the British Antarctic Survey and the United States Antarctic Research Program.

After a hiatus during the early 1960s, geological interest in South Georgia from both the UK and the USA recommenced in 1966 and gathered pace thereafter. During the 1965–66 austral summer, a limited pilot study of sedimentolgy and palaeocurrent analysis was carried out in the Cumberland Bay Formation by L A Frakes from the University of California. Frakes (1966) described results from Cumberland East Bay and the vicinity of Leith Harbour which showed a variable palaeocurrent flow, interpreted as showing that the Cumberland Bay Formation was derived from both sides of its depositional basin.

The 1965–66 austral summer also saw renewal of South Georgia investigations by the BAS when, en route to the BAS base at Halley Bay, D Brook was able to spend time examining the geology of the area between Cumberland West Bay and Stromness Bay. During the following austral summer, 1966–1967, this work was continued westward from Stromness Bay to Fortuna Bay by M J Skidmore, who also spent time in the Prince Olav Harbour area early in 1969 during his journey north at the conclusion of his Halley Bay posting. Skidmore (1972)[2] described the geology of the Cumberland Bay Formation as seen in the areas studied by himself and Brook. The turbidite sedimentology of the strata was detailed, their volcaniclastic composition quantified and their low-grade metamorphic facies established. The turbidite beds were shown to be incorporated into large-scale folds, overturned towards the north and with a well-developed axial plane cleavage. Skidmore's was the first account in which the significance of plate tectonics was tentatively addressed. He reaffirmed the correlation of the Cumberland Bay Formation with the Yahgan Formation of Navarino Island and noted the similarity of structural style in the two areas, evidence for their having once been in much closer proximity.

The involvement of the BAS in South Georgia was much strengthened late in 1969 by the establishment of a permanent base at King Edward Point, Cumberland East Bay, close to the abandoned whaling station of Grytviken. The first geological beneficiary of this new facility was P Stone, who spent the 1970–71 austral summer surveying the geology of the Barff Peninsula between Cumberland East Bay and St Andrews Bay, and in the process relocating and reinterpreting the important boundary between Cumberland Bay and Sandebugten 'type' strata that had been noted by Aitkenhead and Nelson (1962)[3]. In a report acknowledged as having been submitted for publication in October 1975, Stone (1980)[4] defined the two divisions as formations and regarded the boundary as a thrust that had carried his Cumberland Bay Formation (CBF) over the Sandebugten Formation (SDF). The outcrop of CBF strata at the northern end of the Barff Peninsula was interpreted as a

structural klippe that comprised interbedded Cumberland Bay and Sandebugten 'types'. It was designated the Barff Point Member of the CBF and regarded as the most distal preserved part of the 'Cumberland Bay' thrust sheet.

Stone returned for the 1971–72 austral summer, extending his geological survey southwards from St Andrews Bay, and through the Royal Bay area as far south as Gold Harbour. R B Crews assisted in the Royal Bay area and then worked independently around the Cumberland bays. Stone's work effectively covered the entirety of SDF outcrop. The distinctively quartzo-feldspathic turbidite strata were disposed into broadly upright, tight to isoclinal and chevron folds, with axial planar slaty cleavage, that across the Barff Peninsula formed a NW–SE trending anticlinorium. Southward, the effects of a second episode of deformation became increasingly dominant, with all of the earlier fabrics transposed by a shallow, pervasive crenulation cleavage axial planar to overturned or reclined folds. A second, steeply-dipping crenulation cleavage also increased in intensity southwards, being most apparent to the south of Royal Bay on the Cape Charlotte promontory. Subsequent minor deformational effects were also noted, as were a few small, pre-deformation, intrusive sheets of doleritic rock, now highly altered. On the south side of Royal Bay the thrust contact between the SDF and the overlying CBF was traced from Will Point, across the Cape Charlotte promontory and southwards into Gold Harbour. Belemnite fragments recovered from a CBF moraine cobble at Little Moltke Harbour (Royal Bay) suggested a Late Jurassic to Early Cretaceous age (Stone and Willey 1973)[5]. However, the fauna (together with some subsequently collected material from the same general area) was later reassessed by Doyle (1985)[6] as comprising only indeterminate belemnite fragments that provided evidence for only a broad Jurassic-Cretaceous age.

The 1972–73 austral summer saw the involvement of an American team led by I W D Dalziel and funded by the United States Antarctic Research Program, whilst the BAS geological survey programme was continued by T H Pettigrew and R A S Clayton. Accompanying Dalziel were R L Bruhn, R H Dott and R D Winn: Dalziel and Bruhn were based at Columbia University, New York; Dott and Winn were based at the University of Wisconsin.

Early in 1973 the American team made detailed observations in the Cumberland Bay and Stromness Bay areas, supplemented by brief visits to the Bay of Isles and Bird Island. In Cumberland East Bay, on the Dartmouth Point promontory (now Greene Peninsula) they located a thrust contact between the Cumberland Bay and Sandebugten formations and from structural analyses showed that the deformation in the two divisions was broadly contemporaneous, despite the differences in style (Dalziel and others 1975)[7]. An assessment of palaeocurrent indicators showed dispersal towards the north-west in the Cumberland Bay Formation, but a more complicated pattern in the Sandebugten Formation dominated by a south-directed component; the structural restoration of the data was detailed by Dott (1974)[8]. From a regional perspective, the American team brought the advantage of direct familiarity with the likely correlative geology in the extreme south of South America. This allowed the development of a regional model for the origin of South Georgia (and the South American correlatives) in a marginal basin lying between the continental margin and a rifted continental sliver carrying a calc-alkaline volcanic arc. Sediment was derived from both sides of the basin, with deformation initiated by basin closure and the resulting arc-continent collision (Dalziel and others 1975[7]; Winn 1978).[9] This interpretation brought South Georgia geology squarely into the plate tectonic era.

Pettigrew spent the 1972–73 austral summer on a detailed investigation of the geology of Annenkov Island, submitting his report (Pettigrew 1981)[10] for publication in July 1975. Two members of an Annenkov Island Formation were recognized and had experienced only very minor deformation, allowing a sedimentary thickness of about 2000 m to be measured. A Lower Tuff Member comprised

mostly interbedded tuff and tuffaceous mudstone; an Upper Breccia Member comprised mostly volcaniclastic breccia and sandstone. The lower member is the most fossiliferous although preservation is not good. The assemblage of bivalves, ammonites, fish fragments plant fossils etc., as described by Wilckens (1932[11], 1937[12], 1947)[13] was confirmed, with an additional Early Cretaceous belemnite fauna recovered from the upper member (Pettigrew and Willey (1975)[14]. Both members contain rare interbedded basaltic lavas and are cut by a range of basaltic and andesitic minor intrusions. Pettigrew described the Annenkov Island succession as representing parts of a volcanic island arc and marginal basin and, in collaboration with M. Suarez (Instituto de Investigaciones Geológicas de Chile), developed a regional model in those terms incorporating South Georgia and the southern Andes (Suarez and Pettigrew 1976)[15].

During the 1972–73 austral summer Clayton worked around the Bay of Isles, in the north-west of South Georgia; during the following summer, 1973–74, he extended his mapping across to the south coast of the island, in the Ice Fjord to King Haakon Bay area, accompanied by R N Mortimore. All of this area comprised part of the outcrop of the Cumberland Bay Formation. Detailed sedimentological analysis of the turbidite succession focussed particularly on relative proximality indicators (Mortimore 1979[16]; Clayton 1982a)[17], with a qualitative assessment of the detrital composition and subsequent alteration of the wacke-type sandstones during diagenesis and low-grade metamorphism (Clayton 1982b). Large-scale close to open folds were shown to be asymmetric and locally overturned towards the north, with a pervasive axial planar cleavage (Clayton 1983)[18]. Stereographic analysis suggested that a second phase of open folding had affected the main structures and cleavage, whilst subsequent minor structures were recognised locally. In a more wide-ranging study, Clayton (1982c)[19] compared the whole-rock geochemistry of the Cumberland Bay Formation sandstones in the north-west of South Georgia, to that found in other parts of its outcrop, and extended the comparison to the Sandebugten Formation and Cooper Bay area, utilising specimens collected by Skidmore and Stone. All four of Clayton's papers had been submitted for publication between November 1975 and July 1976.

Stone had also returned to South Georgia for the 1973–74 austral summer, extending his work on the north–east coast southwards to Iris Bay and Cooper Bay; some additional infill work was completed at St Andrews Bay and on the south side of Royal Bay. The polyphase folding of the Cumberland Bay Formation to the south-east of Royal Bay was established (Stone 1980)[4], with an early suite of minor folds thought to pre-date the main, large scale structures that continued the trends seen elsewhere in the island, here with hinges trending NW–SE. The two fold sets were axially co-planar so that a slaty cleavage was cut by a closely sub-parallel micro-crenulation cleavage. A second, locally cross-cutting crenulation cleavage was associated with minor overturned folds.

Farther south, in the Cooper Bay area, deformation proved to be more intense, with an apparently thinly-bedded turbidite succession converted into a series of schistose rocks, slates and cataclasites. Within the metasedimentary succession were widespread boudinaged sheets of a pervasively altered, but originally doleritic intrusive rock. Stone (1982)[20] — a paper submitted for publication in October 1975 — defined the metasedimentary succession as the Cooper Bay Formation and described its polyphase deformation. The earliest small-scale folds, with an associated slaty cleavage, were identified from their interference patterns with a series of tight, minor folds with an axial planar crenulation cleavage. The latter was then folded into large-scale, upright folds to which a steeply inclined, second crenulation cleavage was axial planar; all of these structures were cross-cut by a range of minor, late and locally developed folds and crenulations. At the south-western margin of its outcrop, the structures affecting the Cooper Bay Formation merged into a polyphase, mylonitic shear zone that separated the metasedimentary rocks from Trendall's (1959)[21] South-eastern Igneous Complex.

In summing up the deformation history seen on the north-east coast of South Georgia, Stone (1980)[4] built on the marginal basin model of Dalziel and others (1975)[7], envisaging its sedimentary fill experiencing diachronous, supra-subduction zone deformation as the basin closed. In modern terms this would be described as accretionary tectonics.

The 1973–74 austral summer marked a turning point in the BAS South Georgia geology programme as specialist studies began in parallel with the final phase of the regional mapping work. The structural geology and overall tectonic regime were investigated in particular by P W G Tanner, who spent that summer and the subsequent 1975–76 summer on a wide-ranging field programme. His work, and the rest of the specialist research theme, will be returned to in a later section of this account.

The south-eastern igneous complex

The final phase of the BAS regional geology work on South Georgia focussed on the igneous rocks in the south-east of the island, the South-eastern Igneous Complex of Trendall (1959)[21]. Investigations in this area by C M Bell, B F Mair and B C Storey began in the 1974–75 austral summer. Storey returned in the following summer, 1975–76, to work particularly in the Drygalski Fjord and Ducloz Head area, whilst Mair returned in the 1976–77 summer to work particularly in the Larsen Harbour and Leon Head areas. During this period of field studies Cooper Island was also visited, whilst traverses across the mylonitic shear zone into the Cooper Bay Formation helped to establish the regional relationship of the igneous and metasedimentary rocks.

A series of publications arose from the work in the south-east with the overall divisions established by Bell and others (1977)[22] and Storey and others (1977)[23]. The igneous rocks were divided into the ophiolitic Larsen Harbour Formation (subsequently redefined as a Complex) of submarine basalt lavas and breccias and sheeted basic dykes, and the Drygalski Fjord Complex of mostly gabbroic plutons, with subordinate granitic rocks, intruded into metasedimentary rocks ranging in grade up to siliceous paragneisses. The gabbro bodies were regarded as the root zone of the sheeted dykes and volcanic lavas, intruded into a continental basement of which the metasedimentary units were relics. Storey and Mair (1982)[24] developed these ideas within the marginal basin model for South Georgia describing the ophiolitic Larsen Harbour Formation/Complex, and the pre-Jurassic basement with its gabbroic and granitic intrusions, as remnants of the composite floor of the Cretaceous back-arc basin in which the South Georgia sedimentary successions accumulated. The Larsen Harbour Complex ophiolite comprised pillow lavas and breccias with interbedded tuffs, intruded by mafic and felsic dykes and by gabbro and composite gabbro-plagiogranite plutons. The basement metasedimentary gneisses were intruded by layered gabbro bodies, dioritic and granitic rocks, and by a multitude of mafic dykes.

Some compositional and geochemical data were given by Storey and Mair (1982)[24], with more detailed, comprehensive descriptions and interpretations provided later: for the Larsen Harbour Formation/Complex by Mair (1983[25], 1987)[26] and for the Drygalski Fjord Complex by Storey (1983a)[27]. The Larsen Harbour lava succession was shown to be about 2 km thick, dipping moderately towards the west. It forms the upper part of an autochthonous ophiolite sequence with a broad lithostratigraphical zonation. Breccias with subordinate pillow lavas form the base of the succession, where they are cut by multiple mafic dykes, and are overlain by voluminous pillow lavas, with subordinate breccia and interbedded volcaniclastic sedimentary layers. Compositionally most of the rocks resembled oceanic tholeiites. Within the Drygalski Fjord Complex, Storey (1983a)[27] divided the metasedimentary, continental basement rocks into three formations: Salomon Glacier, Cooper Island and Novosilski Glacier. The Salomon Glacier Formation comprised siliceous

paragneiss and layered migmatite; the other two formations comprised various metasedimentary clastic rocks. After deformation and metamorphism of this 'basement' assemblage, intrusion of a differentiated, tholeiitic magma produced a range of rocks from layered gabbros to granite; other granitic intrusions showed calc-alkaline trends. This intrusive phase was followed by swarms of mafic dykes linked to the generation of the Larsen Harbour Formation ophiolite.

Storey's work extended north-westward to the Ducloz Head area, and north-eastward across the mylonite zone at the margin of the igneous rocks into the Cooper Bay area. At Ducloz Head a succession of volcaniclastic rocks and pillow lava, tuffs and mudstone was defined as the Ducloz Head Formation (Storey 1983b)[28]. The formation had been affected by widespread ductile and brittle deformation and was separated from the adjacent Cumberland Bay Formation by a steep fault zone. Storey recognised similarities with all of the other South Georgia sedimentary divisions, but thought the likely regional association to be as an intermediate between the Annenkov Island and Larsen Harbour formations. At Cooper Bay, Storey (1983a)[27] broadly confirmed the lithofacies and polyphase structural interpretation of Stone (1982)[20], but thought that the structural history within the mylonite zone was more complicated than previously proposed. In particular, the mylonite zone may have been initiated earlier in the structural history than was indicated in Stone's interpretation.

By the time that Mair and Storey published, the first radiometric dates (Rb–Sr) had become available from granite within the Drygalski Fjord Complex and from a granitic intrusion coeval with the later episodes of dyke intrusion in the Larsen Harbour Formation/Complex (Tanner and Rex 1979). The former gave ages in the approximate range 180–200 Ma, the latter gave an age of 127 ± 4 Ma. Storey (1983a)[27] and Mair (1987)[26] incorporated these results, and Storey also described the heterogeneous migmatite aureole that surrounded the intrusive plutonic rocks — but note that Storey (1983b)[28] and Mair (1983)[25] were received for publication in August 1978 and October 1976 respectively, before the radiometric dates were available.

In addition to his work on the Larsen Harbour Formation/Complex Mair also investigated the geology in the Moraine Fjord area of Cumberland East Bay during a short period in 1977. He described a number of small, pre-tectonic, dioritic and gabbroic sheets intruded into strata of the Cumberland Bay Formation, and traced out the structural contact and contrasts between that formation and the structurally subjacent Sandebugten Formation (Mair 1981)[29] to the south of Dartmouth Point (the promontory now known as Greene Peninsula). This was the area from which Dalziel and others (1975)[7] had described a thrust contact between the two formations.

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Navigation menu

Tools

- What links here
- Related changes
- Special pages
- Permanent link
- Page information
- Cite this page
- Browse properties

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