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Goemulgaw Lagal: Natural and Cultural Histories of the Island of Mabuyag, Torres Strait.

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COVER
Image on book cover: People tending to a ground oven (*umai*) at Nayedh, Bau village, Mabuyag, 1921. Photographed by Frank Hurley (National Library of Australia: pic-vn3314129-v).

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The geology of the Mabuyag Island Group and its part in the geological evolution of Torres Strait

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The geology of the Mabuyag Island Group, Torres Strait, Queensland is described from field observations carried out in April 2009. Dominant rock units of Pennsylvanian to Cisuralian age (307 to 284 million years) comprise I-type granites belonging to the Badu Suite and the co-magmatic Torres Strait Volcanic Group. A comparison of stratigraphic units within the 'Torres Strait Region' using petrographic and geochemical methods gives context to the geological evolution of the Mabuyag Island Group. Mapping here identified two units within the Badu Suite:

1. The Badu Granite outcrops on Mabuyag, Aipus and some islets around Taleb, with variations on Pulu and Mipa.

2. A red porphyritic microgranite (originally unnamed Cup, now associated with the Horn Island Granite to the south).

The central and southern parts of Mabuyag comprise rhyolitic ignimbrites, lavas, intermediate to mafic volcanic rocks and minor sediments; mapped as undifferentiated Torres Strait Volcanics. These rocks have been compared to the volcanic sequence on the southern Torres Strait islands which comprises the Eborac Ignimbrite, Endeavour Strait Ignimbrite, Goods Island Ignimbrite and the Muralug Ignimbrite. The volcanic rocks on Mabuyag are similar to the Endeavour Strait Ignimbrite and the lower part of the Goods Island Ignimbrite, but probably have come from a separate local source. Quaternary and Tertiary deposits in the Mabuyag Island Group are very limited in extent.

Notes on anthropogenic materials from Pulu yielded descriptions of rocks foreign to the islet, some of which may have been sourced from Mabuyag, others possibly from outside of the Torres Strait region. No mineral resources are known from the Mabuyag Island Group, even though gold, lead, zinc, wolfram and tin are reported from other areas within Torres Strait

❑ *Mabuyag, Mabuiag Island, Torres Strait, geology, Badu Suite, Badu Granite, Horn Island Granite, Torres Strait Volcanics, Eborac Ignimbrite, Endeavour Strait Ignimbrite, Goods Island Ignimbrite, Muralug Ignimbrite, pyroclastics, ignimbrite.*

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The Torres Strait Islands comprise the 'Torres Strait Region' (von Gnielinski *et al*., 1997) which includes volcanic rocks of Upper Pennsylvanian to Cisuralian age (in the old terminology: Late Carboniferous to Early Permian; 307 to 284 million years) intruded by co-magmatic I-type granites. These rocks constitute the northern parts of the Badu-Weymouth Belt along what was originally a very extensive ridge (previously named 'Cape York – Oriomo Ridge'), which were mostly inundated in the Early Holocene. The Torres Strait Region straddles the western margin of the Jardine Subprovince, a part of the igneous Kennedy Province (von Gnielinski *et al*., 1997). Within the Torres Strait Region three physiographic types were previously recognised: the western, central and eastern islands (Willmott *et al*., 1973). The western islands comprise basement volcanic, intrusive and sedimentary rocks forming the peaks of a drowned range which up until 9,000 years ago (McNiven, 2011) formed a connecting landmass from Cape York to Mabaduan on the Papuan coast. The central islands are sand cays composed of accumulations of coral sand and debris on reefs of the platform type. The eastern islands are remnants of Pleistocene (2.5 to 1 million years) volcanic cones and lava flows. A fourth physiographic type may be considered represented by Boigu and Saibai Islands in the northern part of the Torres Strait region close to the Papuan coast. These islands represent dissected remnants of the Morehead Sub-Basin (Fly Platform), comprising the largest tract of low lying land in Papua New Guinea (Ridd, 1976).

This paper reports the results of recent geological fieldwork on Mabuyag (Mabuiag Island), Pulu and other islands belonging to the Goemulgal (the people of Mabuyag), undertaken in April 2009 as part of the natural and cultural surveys for the Pulu Indigenous Protected Area project (Hitchcock *et al*., 2009, this volume). Mabuyag (9°57'S 142°10'E) and its surrounding islands are located on the Boigu 1:250,000 (Sheet SC54-07) and Mabuiag Island 1:100,000 (Sheet 7378) topographic maps.

PREVIOUS STUDIES

The first geological observations of the area were made by early naturalists accompanying vessels charting the shipping channels of Torres Strait. Jukes (1847) on HMS *Fly* mentioned the granitic rocks of the western islands. A report on the geology of Torres Strait by Haddon *et al*. (1894) provided descriptions of rocks from the western islands. Haddon (1898) sketched a number of locations on and around Mabuyag, including the Pulu *kod* site, showing the form of granite boulders in remarkable detail (Figure 1) (see McNiven *et al*., 2009).

FIG. 1. Haddon's 1898 sketch (above) of the Pulu kod and the same area in 2001 (below) during archaeological research led by Monash University (McNiven *et al*., 2009). Haddon has recorded the geomorphological features.

In 1968 a combined Bureau of Mineral Resources (BMR) and Geological Survey of Queensland (GSQ) party geologically mapped the region and produced an overview (Willmott *et al*., 1973), the Torres Strait-Boigu-Daru 1:250,000 Geological Sheet and Explanatory Notes (Powell & Green, 1976; Willmott & Powell, 1977) and the Daru-Maer 1:250,000 Geological Sheet and Explanatory Notes (Willmott, 1969; Willmott, 1972). Pulu was not visited during this project. Some observations were obtained from Mabuyag and some islets to the east. One observation was also made on Koemuthnab (Hamelin Boulders), an islet immediately west of Pulu.

No further government geological investigations were carried out within the Mabuyag island group after 1980, although a chapter entitled 'Torres Strait Region' (von Gnielinski *et al*., 1997) featured in the most recent overview of north Queensland's geology (Bain & Draper, 1997).

METHODOLOGY

Prior to fieldwork a brief literature review and sighting of samples from the 1968 BMR/GSQ project was completed and a plan for fieldwork for geological mapping of Pulu and Mabuyag was tabled, including sampling of rock specimens for geochemical and petrological examination. Aerial photography from 1999 of the island group at 1:8,000 was interpreted under a stereoscope.

To understand major relationships of the volcanic rock units with the plutonic rocks (granites), various key areas were delineated and prioritized for visitation. On Mabuyag three walking traverses were planned to observe representative rock units and their relationships on the island. Since Pulu had never been visited by a geologist, and has been reported as having only one rock type, a walking traverse along the north-south axis of the islet over the highest elevation point was planned.

Field work on Mabuyag and Pulu was carried out during 11-19 April 2009 in conjunction with multidisciplinary work for the Pulu Indigenous Protection Area (IPA). Geological observations included non-invasive inspection of rocks with a 10x and 15x magnifying lens. A geological hammer was used to break some rocks to sample fresh and unaltered specimens, which were not affected by weathering, alteration and (in this case) saline water. Representative specimens for petrological and geochemical work in the laboratory were collected, with selection of samples guided by advice from Mabuyag community members and Ian McNiven to ensure that no culturally important places (including archaeological sites) were disturbed. Two geochemical samples (about 1.5 kg each) and two petrological samples (about 200 g) of fresh pink microgranite were collected from Pulu. These samples were shipped to Brisbane and were processed in the Zillmere laboratory of the Geological Survey of Queensland. A geological compilation of the 1:100,000 maps Mabuiag (7378), Moa (7377), Thursday (7376), Gabba (7478), Sassie Island (7477) and Cape York (7476) was completed by the author in 2010, which was incorporated in the digital geological cover of Queensland at the Geological Survey of Queensland, Department of Natural Resources and Mines (DNRM). Figure 2 shows the relevant part of the geology cover for this paper.

In conjunction with this work other islets in the area were visited on a reconnaissance trip via boat on 18 April 2009. This afforded geological observations on the islets of Woeydhul (Widul), Yaadi, Marthe, Buya, Kuikusagay (Red Fruit Island) and Kuikul Thoelab.

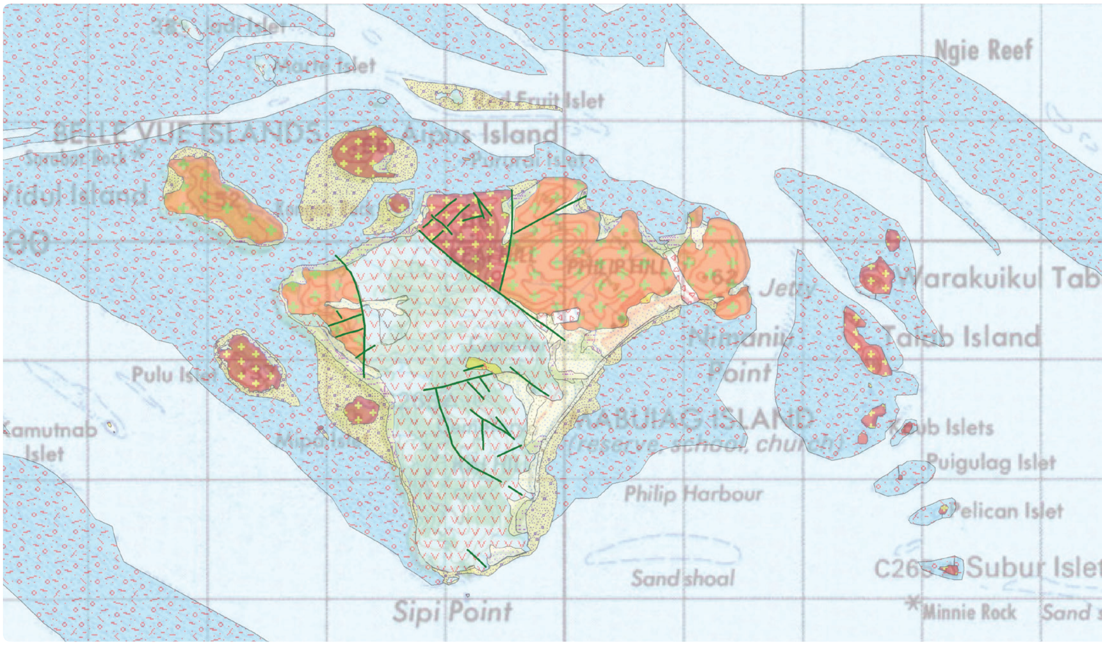


FIG. 2. A plan of general geology of Mabuyag Islands as interpreted by the author using aerial photography, satellite imagery and field observations in 2009-2010. (Four volcanic units in legend are used in Table 1).

Legend

Quaternary

3188, Qhh-QLD, Gravel, sand, silt - man-made deposits generally associated with land-fill or mining (tailings, dumps and rehabilitated areas)

15254, Qhms-QLD (15254), Shoreface/fringing coral reef: lithofeldspathic sublabile sand, muddy sand, sandy mud

12057, Qhcm-QLD (12057), Mud and sandy mud; mangrove swamps; estuarine deposits

12042, Qhmt-QLD (12042), Sand, mud and minor gravel; marine intertidal flat

2549, Qa-QLD, Clay, silt, sand, gravel; flood-plain alluvium

4735, Qr-QLD, Clay, silt, sand, gravel and soil; colluvial and residual deposits

10371, Qhcd-QLD (10371), Quartz sand: blow-out frontal dune

14905, Qhci-QLD (14905), Mainly quartz sand with minor humic component: depressions and low-lying plains between beach ridge barrier units, overlying intertidal or estuarine deposits

13999, Qhcb-QLD (13999), Moderately well-sorted, fine to coarse-grained quartzose to shelley sand and some gravel: beach ridges and cheniers

Late Tertiary to Quaternary

10708, Qr\t-QLD (10708), Boulders and cobbles with interstitial sand and clay; talus deposits

Late Carboniferous to Early Permian

56, Badu Granite,unnamed intrusions, Leucocratic and porphyritic biotite granite, hornblende-biotite adamellite, granodiorite

7636, Horn Island Granite, Porphyritic microgranite

5181, Muralug Ignimbrite, Crystal-rich rhyolitic ignimbrite; rhyolite; volcaniclastic rudite

1442, Torres Strait Volcanics, Rhyolitic welded tuff, rhyolite, agglomerate, volcanic breccia, andesite, siltstone, arenite

1443, Torres Strait Volcanics; sediments and mafic volcanics, Agglomerate, volcanic breccia, andesite, siltstone, arenite, basalt

5182, Goods Island Ignimbrite, Lithics and crystal-rich dacitic to rhyodacitic ignimbrite; tuffaceous siltstone, sandstone

5183, Endeavour Strait Ignimbrite, Lithics and crystal-rich rhyolitic ignimbrite; volcanic rudite and breccia; rhyolite; andesite; some volcaniclastic sedimentary rocks

5184, Eborac Ignimbrite, Crystal-rich rhyolitic ignimbrite; rhyolite; volcaniclastic rudite

All locations of rock samples and geological descriptions were assigned a code number prefixed with three letters identifying the originator of the observations. The GPS coordinates of all locations used in this paper are presented in Table 1. A complete set of geological observation data is available on a data CD annually produced by the Geological Survey of Queensland, Department of Natural Resources and Mines (DNRM) called 'Mineral occurrence and geology observations 20xx'.

GEOLOGICAL EVOLUTION OF TORRES STRAIT

PHYSIOGRAPHY

The group of islands around Mabuyag are part of the western islands as described in Willmott (1973). The islands rise steeply from the sea and are generally over 100 m above sea level. Some peaks reach considerably greater heights like Mount Augustus (399 m) on Mua (Moa Island). Rugged hills and ranges are separated by sand-covered plains and small valleys, particularly on the larger islands.

The sea across Torres Strait is shallow with the islands representing peaks of an otherwise submerged ridge (the Badu-Weymouth Belt). The depth of the seabed around the Mabuyag islands is around 8 to 11 m. Scouring action of swift tidal currents (up to 8 knots) has cut deeper channels into the submerged ridge in various places (Willmott & Powell, 1977).

TORRES STRAIT GEOLOGICAL EVOLUTION

The oldest rocks exposed in Torres Strait are Upper Pennsylvanian (307-299 million years ago) acid volcanic lithologies of the Torres Strait Volcanic Group, and Upper Pennsylvanian to Cisuralian (307-284 million years ago) granites of the Badu (Intrusive) Suite (von Gnielinski *et al*., 1997). Willmott *et al*. (1973) suggested Paleozoic (>359 million years ago) or Precambrian rocks (>542 million years ago), similar to those found further south on Cape York Peninsula, may underlie the Torres Strait Volcanic Group at depth. Within the immediate area of the Mabuyag Island Group the (Badu-Weymouth Belt) ridge comprises a continuous body of granite on which float sheets of volcanic rocks of the Torres Strait Volcanic Group. Due to extensive erosion and inundation of the ridge, it can no longer be established whether these volcanic rocks were connected to the more extensive volcanic units in the southern part of Torres Strait. This ridge of Upper Pennsylvanian rocks is overlain by Mesozoic sediments of the Carpentaria Basin in Cape York Peninsula, and of the Papuan Basin to the north, and may have been more extensively covered by Mesozoic sediments in the past.

VOLCANIC ROCKS OF THE TORRES STRAIT VOLCANIC GROUP

STRATIGRAPHIC FRAMEWORK

The most extensive areas of outcrop and most complete succession of rock packages of the Torres Strait Volcanic Group are found on the 'Prince of Wales Island' group of islands and on the mainland of Cape York Peninsula. Four separate volcanic units have been recognised by Willmott *et al*. (1973) within this area. Lithological differences between the Eborac Ignimbrite, the Endeavour Strait Ignimbrite-Goods Island Ignimbrite, and the Muralug Ignimbrite could indicate that these units originated from three separate sources (von Gnielinski *et al*., 1997).

Current understanding of volcanic units and their defined subdivisions in the region are illustrated in Figure 3 (modified after von Gnielinski, 1996). The rock column representing the Mabuyag and Badu Island Groups is correlated here with representative sections from the Prince of Wales Island Group and the tip of Cape York respectively.

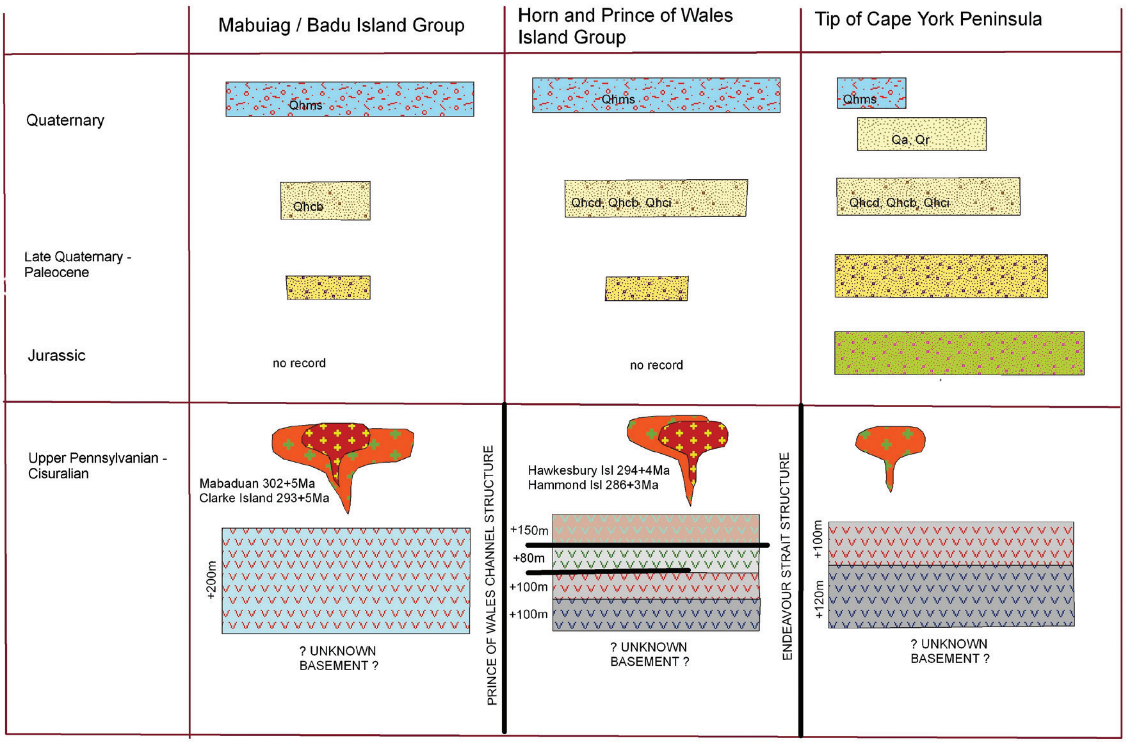


FIG. 3. Schematic time section of geological units in the western Torres Strait Region; see Fig. 2 for legend (Jurassic units in green refer to Albany Pass beds and Helby beds).

GEOCHEMISTRY OF THE VOLCANIC ROCKS

Geochemical analyses of 35 extrusive (volcanic) rocks through Torres Strait were utilized to identify their characteristics. These samples comprise three Eborac Ignimbrites, thirteen Endeavour Strait Ignimbrites, six Goods Island Ignimbrites, eight Muralug Ignimbrites and five undifferentiated Torres Strait Volcanics from the northern Torres Strait islands. Within the total alkali versus silica (TAS) classification diagram (Le Bas *et al*., 1986; Figure 4) samples of the Torres Strait Volcanic Group plot predominantly in the rhyolite field and to a lesser extent in the dacite field. This supports the petrological description of the volcanic specimens.

The volcanic rocks generally plot into the calc-alkaline field on the AFM diagram (Irvine & Baragar, 1971; Figure 5) which suggests a continental crust evolution (compare to granitoid analyses below).

Even though the number of samples is not adequate for subdivision, some compositional trends noted in the megascopic descriptions below can also be interpreted from the geochemical data. The Muralug Ignimbrite and the Endeavour Strait Ignimbrite have a fairly broad geochemical composition ranging from dacite and rhyodacite to rhyolite. The Eborac Ignimbrite and undifferentiated Torres Strait Volcanic Group are strongly restricted to the rhyolite field. The Goods Island Ignimbrite plots in the dacite and rhyodacite fields. This confirms a rough trend to slightly less acidic rocks over time, i.e. the younger rocks exhibit an overall decrease in acidic composition.

Data plotted on the Harker diagrams of SiO2 versus TiO2, FeO (total), MgO, CaO, K2O, Al2O3, Ba, Rb, Sr, Zr, La and Ce reveal linear trends similar to the trends shown by the granitoids (see below) verifying their comagmatic origin. Most samples fall within the metalaluminous (ASI<1.1) field with four samples plotting into the per-aluminous filed (ASI <1.0).

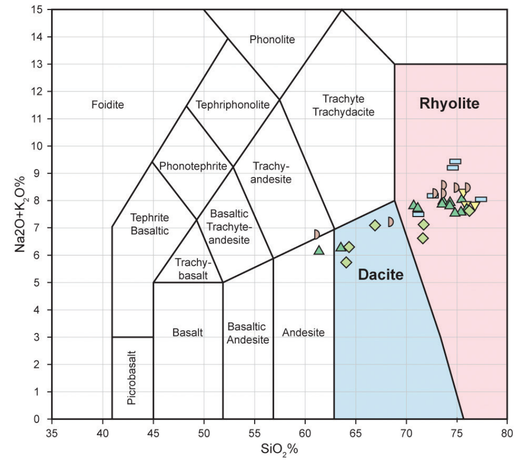


FIG. 4. Total alkali versus silica (TAS) classification diagram after Le Bas *et al*. (1986). The 35 extrusive samples from Torres Strait dominantly plot in the rhyolite and dacite fields.

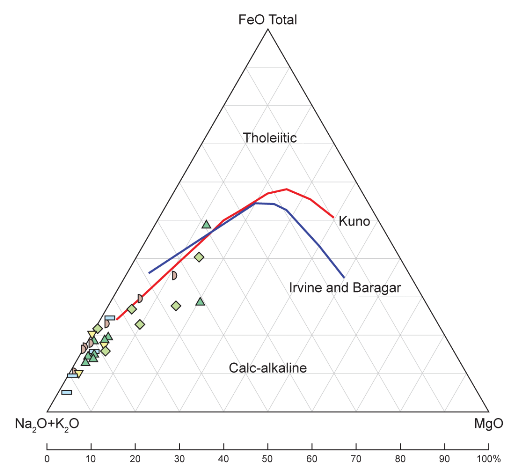


FIG. 5. AFM diagram after Irvine & Baragar (1971). The 35 extrusive samples from Torres Strait plot in the calc-alkaline field suggesting continental crust evolution.

STRATIGRAPHIC COLUMN OF DEFINED UNITS

The Eborac Ignimbrite forms the basal unit with an approximated minimal thickness of 100 m, but the base of this unit is not exposed and much of its outcrop area is covered by sea. The four defined formations do not form a simple succession, but can reach a thickness of over 430 m. The Endeavour Strait Ignimbrite is interpreted to have an unconformable contact at its base (on mainland Cape York Peninsula) and is observed to grade upward into the Goods Island Ignimbrite on Thursday Island. Both the Endeavour Strait Ignimbrite and Goods Island Ignimbrite rocks dip gently to the northwest (as deduced from the orientation of the compressed pumice fragments, which are assumed to be parallel to the surface on which the sheets where laid down). In some areas steeper dips may be attributed to faulting. The main massive welded tuff sheet of the Muralug Ignimbrite appears to be horizontal. Along the northestern margin of the sheet (on Prince of Wales Island) the underlying thin vertical sheets of welded tuff form a prominent linear feature separating the Muralug Ignimbrite from the Endeavour Strait Ignimbrite. These steeply dipping tuff sheets may have been extruded along the boundary fault of a cauldron subsidence area formed subsequent to deposition of the Endeavour Strait Ignimbrite (Willmott *et al*., 1973; Branch, 1966: 19). The most northern parts of the described formations are exposed on Hammond and Wednesday Islands.

WHERE DO THE MABUYAG VOLCANIC ROCKS FIT IN?

North of these islands the 'inundated ridge' is interpreted to dominantly comprise Badu Suite intrusions with floating sheets of volcanic rocks resembling roof pendants (i.e. country rock which has been displaced by the igneous body and disconnected from similar units, coming to rest at the top of the intrusion) in a large magma body (Figure 6). These include the volcanic rocks exposed in the Mabuyag Island Group. Since a relationship to the defined units in the Torres Strait Volcanic Group to the south cannot be established over the ~50 km (north-south distance) of sea cover, a proper definition of the volcanic rocks on Mua, West Island and Mabuyag was not attempted. These rocks are retained in a 'Torres Strait Volcanics undivided' rock unit. Yet the rocks observed on Mua and Mabuyag appear to be most like the Endeavour Strait Ignimbrite and upper Goods Island Ignimbrite.

DETAILED DESCRIPTION OF THE VOLCANIC ROCKS WITHIN THE MABUYAG ISLAND GROUP

Observations made in April 2009 on Mabuyag confirmed the chemical composition of the oldest rocks exposed within the Mabuyag Island Group to be of felsic to intermediate composition. These rocks are predominantly massive boulder-sized rhyolitic pyroclastic flows, air-fall welded tuff and coherent rhyolite (lava flows). Agglomerates and volcano-sediments (mostly fine-grained siltstone and mudstone) interbedded with the dominant rock lithologies were also recognised. To the north of the rhyolite exposures on Mabuyag some black to dark grey pyroclastic flow rocks of dacitic composition were recorded.

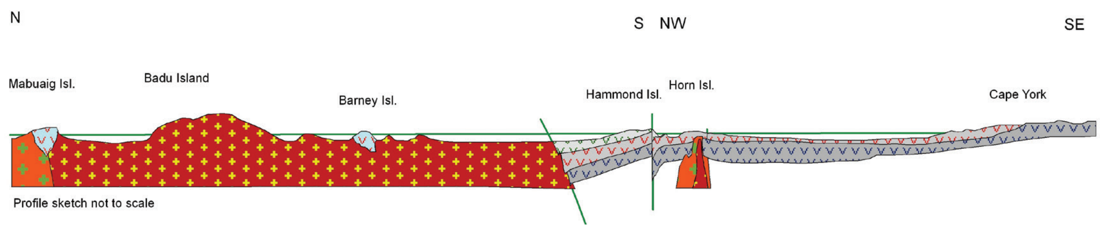


FIG. 6. Profile of the Badu-Weymouth Belt in the Torres Strait sectioning from the Mabuyag Island Group to the Prince of Wales Island Group and then to the south-east on to the mainland of Cape York Peninsula.

The pyroclastic ignimbrites of rhyolitic composition dominate the southern ridges from Sipingur (Sipi Point) to central Mabuyag. In general they are light grey, but can be altered to medium grey or brownish red colours. Quartz phenocrysts are readily identified. Clasts are polymictic, but mostly of volcanic or volcano-sedimentary origin. They comprise crystal and/or lithic-rich rhyolitic to dacitic volcanic rocks and silicified mudstones and siltstones (compare Figure 7). The size of the clasts is highly variable, from centimetres to metres. Clast shapes appear to be sub-rounded to angular. Minor bands of banded rhyolite and fine aphyric rhyolite (ash-fall tuff) were observed, but with the large size of clasts within the pyroclastic flow rocks and the blocky exposures their contact relationships were not readily found. This part of the volcanic sequence on Mabuyag appears to be similar to the Endeavour Strait Ignimbrite on Horn Island.

The thickness of this rhyolitic pyroclastic sequence is interpreted to be in excess of 80 m. Its general dip appears to be moderate towards a northerly to north-easterly direction. Boulder to car-sized fragments inside the pyroclastic rocks suggests that these rocks have originated from a nearby source, and certainly not from the southern islands around Prince of Wales Island. This certainly supports the idea by Willmott *et al*. (1973) that numerous caldera subsidence centres may exist within the Torres Strait Islands. The Mabuyag area is interpreted to comprise numerous pyroclastic flows with ash-fall tuffs and some minor interbedded epiclastic (sedimentary) deposits of volcanic gravel and fines. In the later part of the sequence some coherent rhyolite lava flows are present.

Major joint or fault structures were interpreted from the aerial photography. A vehicle track (Wagadagam Track) leading up to the north-western part of Mabuyag from the old village site of Mui, past a modern rock scrape (road aggregate), appears to follow a structural trend which is interpreted to be a fault depression in the volcanic rocks. At site QFG6978 (629310 8899188 GDA94, compare

FIG. 7. Rock samples from the southern end of Mabuyag on a ridge immediately inland of Sipingur (Sipi Point). Left: QFG7021, a rhyolitic pyroclastic ignimbrite with small clasts of heterogeneous compositions of volcanic origin. Right: QFG7022 a fine-grained rhyolite (ash-fall welded tuff) with minor small bands of rock and crystal-fragments (Photos: Friedrich von Gnielinski, 2009).

FIG. 8. Bedrock exposed to the northwest of Wagadagam Track, central Mabuyag, QFG6978 hematite breccia in rhyolitic pyroclastic flow (in outcrop – top; cut specimen – bottom). Image courtesy: Friedrich von Gnielinski, 2009.

Figure 8) a brecciated rhyolite was observed displaying a hematite breccia, which is interpreted as a fault infill breccia. The host to this breccia is a rhyolitic pyroclastic flow rock with minor associated thin-banded flow-banded rhyolite. The breccia does not appear extensive and would probably have been overlooked if it were not exposed on the vehicle track. Within this area a minor pale brown clay, which may have been a weathered and altered band of fine-grained rhyolite, was also observed. This may support the idea that clay materials could have been sourced locally from Mabuyag for the pottery sherds found at Mask Cave on Pulu and Mui on Mabuyag (McNiven *et al*., 2006; Wright & Dickinson, 2009). However there is no direct evidence that links this particular clay occurrence to the archaeological pottery.

Along the western side of Mabuyag opposite the islet of Mipa, as well as on the south-east coast, the volcanic rocks appear to be dominated by a massive coherent rhyolite flow rock (lava), rich in quartz and K-feldspar crystals (around 2-4 mm), comparable to the rhyolite rocks reported from the Endeavour Strait Ignimbrite on Horn Island (compare Figure 9).

FIG. 9. Top: Mabuyag at start of Wagadagam Track, ridge north of Mui old village site, QFG6975 crystal-rich (quartz & Kali-feldspar) rhyolite lava. Bottom: Western tip of Mabuyag, QFG6988 crystal-rich rhyolite-dacite lava. Image courtesy: Friedrich von Gnielinski, 2009.

In the vicinity of the Wagadagam Track various very fine-grained sediments and aphyric rhyolite and trachyte were recorded. These fine-grained volcano-sediments are similar to lithologies in the Goods Island Ignimbrite unit, but a gradational contact, as recorded on Thursday Island, was not observed on Mabuyag. Further north on Mabuyag, dacitic to mafic pyroclastic rocks were observed but an estimate of the overall thickness is difficult (probably within 40 m). At QFG6991 (628693 8899618 GDA94) (Figure 10) an altered greenish-black pyroclastic rock of more mafic composition (probably

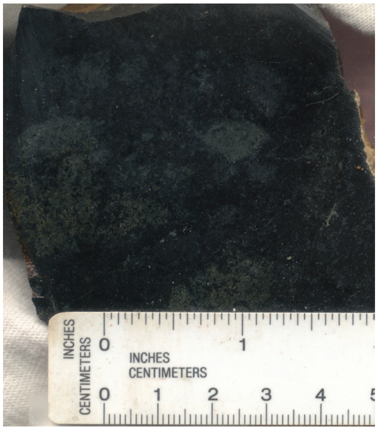
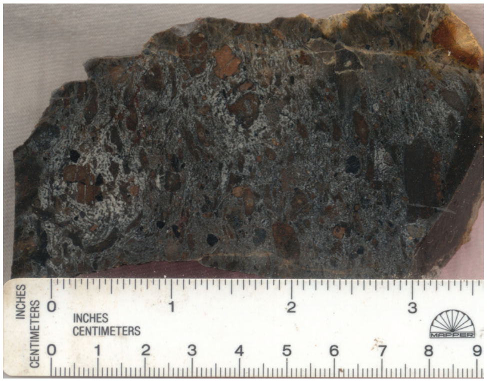


FIG. 10. Top: Mabuyag along Wagadagam Track, QFG6991B hornfelsed dacitic to basaltic pyroclastic rock. Bottom: Mabuyag, QFG6992-4 welded dacitic ignimbrite (pyroclastic flow rock). Image courtesy Friedrich von Gnielinski, 2009.



dacitic to basaltic) occurs together with a pale brown volcano-sediment and a black plagioclase-phyric andesite lava. Alteration may have obscured the original texture of the greenish-black pyroclastic rock. No quartz phenocrysts are seen in these rocks. This strongly chlorite-altered pyroclastic rock appears similar to some material used to make Kiwai axes (in particular specimen E1774) as described in McNiven *et al*. (2004). QFG6992 (628824 8899361 GDA94) (Figure 10) appears to be a more mafic (dacitic) welded ignimbrite. More geological work is warranted to study these rocks.

EVOLUTION OF THE INTRUSIVE ROCKS OF THE BADU SUITE

GRANITES WITHIN THE BADU SUITE

The intrusive rocks within the Torres Strait Region are fairly heterogeneous in appearance, but with rare exceptions they are all of felsic composition. The term Badu Suite has been introduced by von Gnielinski *et al*. (1997) for the Upper Pennsylvanian to Cisuralian (307-284 million years ago) to incorporate defined units comprising the Badu Granite and the Horn Island Granite. Overall they display very similar geochemical signatures throughout and similarities to the felsic components of the Torres Strait Volcanic Group suggest that both rock units derived from the same source. Both units are recognised to be high-level I-type granites.

In previous work (Willmott & Powell, 1977) a body of the Badu Granite and an unnamed porphyritic microgranite (Cup) were mapped in the Mabuyag Island Group. In 2009 more observations and sampling allowed a more detailed petrographic and geochemical description of these rocks. Research work in 1991-1993 resulted in a definition of the rocks within the microgranite group on Horn Island (von Gnielinski, 1996) being named Horn Island Granite. At that stage no field work had been done in the Mabuyag area. While the rocks from Horn Island and Mabuyag originate from areas over 50 kilometres apart, and the lack of evidence of a physical connection, mainly due to water cover, is significant, the geochemical and textural characteristics of rocks from both locations are reasonably similar. A future option may be to name the microgranite rocks on Mabuyag and surrounding islands the Mabuyag Granite.

GEOCHEMISTRY OF THE INTRUSIVE ROCKS

Geochemical analyses of 30 intrusive rocks from Torres Strait were utilized to identify unit associations – 19 samples are associated with the Badu Granite, nine samples with the Horn Island Granite and two samples with late stage intrusive (microgranite) dykes associated with the Badu Suite. The QAP diagram (Streckeisen 1976; Figure 11) shows a fairly concentrated grouping of plots in the granite field close to the granodiorite. The I-type (intrusive origin) versus S-type (sedimentary origin) classification graphs

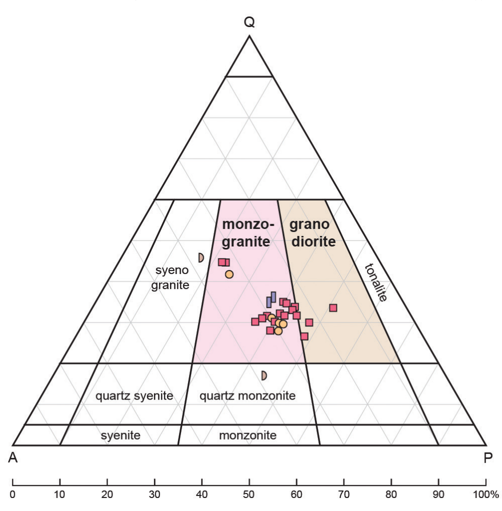


FIG. 11. The QAP diagram (Streckeisen, 1976) shows a fairly concentrated grouping of plots in the granite field close to the granodiorite for the 30 intrusive rocks from Torres Strait.

by Bowden *et al*. (1984), superimposed on the QAP diagram, display the Badu and Horn Island Granites consistently in the I-type field. Some erroneous plots do occur, indicating stronger alteration, with destruction of plagioclase to clay minerals.

Petrographic descriptions of the Horn Island and Badu Granites confirm granodiorite to Ca-rich granite compositions, although alteration of plagioclase, hornblende and biotite were observed, depleting them of sodium and calcium, which causes their geochemistry plots to shift considerably into the K-rich granite field. Therefore, plots of these analyses could be affected by potassic alteration. The granitoids generally plot into the calc-alkaline field on the AFM diagram (Irvine & Baragar, 1971; Figure 12) which suggests a continental crust evolution. Also note that the analyses for the Torres Strait Volcanic Group plot in near proximity of their intrusive counterparts suggesting a similar crustal nature. These rocks are considered to be co-magmatic to the granitoids, meaning they may share a similar or same magma source.

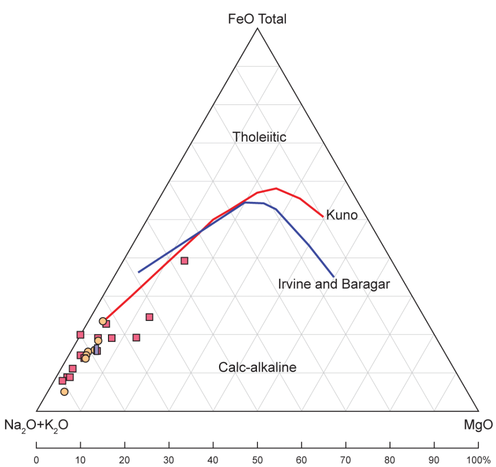


FIG. 12. AFM diagram after Irvine & Baragar (1971). The 30 intrusive samples from Torres Strait plot in the calc-alkaline field suggesting continental crust evolution.

The existing data provide the possibility for interpretation of the origin of the magma and relationships between the granites and the intruded volcanic rocks. The characteristics of the two granite units are well displayed in the Y+NB versus Rb diagram by Pearce *et al*. (1984) in Figure 13. Most of the analyses plot close to the triple point, mainly plotting into the 'volcanic arc granites' (VAG) and 'within plate granites' (WPG) fields. Most major elements display linear trends when plotted against SiO2 on Harker diagrams for TiO2, Al2O3, FeO (total), MgO, CaO and P2O5. Most samples also plot into the high-K field of the K2O versus SiO2 diagram (subject to degree of potassic and sericitic alteration).

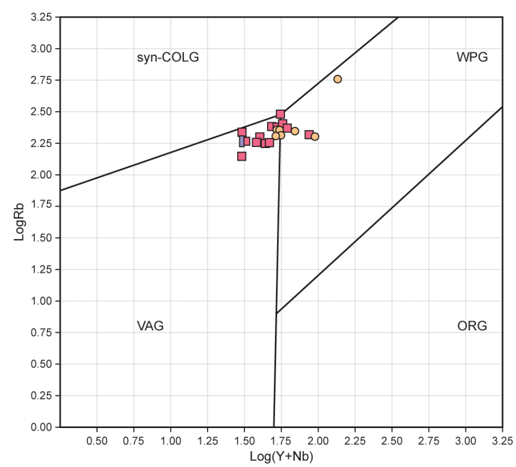


FIG. 13. Y+NB versus Rb diagram by Pearce *et al*. (1984). Most of the 30 intrusive samples from Torres Strait plot close to the triple point, mainly plotting into the 'volcanic arc granites' (VAG) and 'within plate granites' (WPG) fields

THE UNNAMED PORPHYRITIC MICROGRANITE (CUP) FROM THE MABUYAG AREA AND ITS COMPARISM TO THE HORN ISLAND GRANITE

The Horn Island Granite contains phenocrysts of albite, oligoclase and alkali feldspars up to 25 mm long (see Figure 14). It is an I-type granite with biotite and hornblende and it probably formed in close proximity to the Torres Strait Volcanic Group rocks. It is reported to have hornfelsed the Endeavour Strait Ignimbrite (i.e. its heat has recrystallised the volcanic rock and mineral assemblages around its margins). The Horn Island Granite itself has been intruded by equigranular Badu Granite and late stage hydrothermal fluids causing varying degrees of chloritic-sericitic and albite-hematite alterations.

On the Mabuyag Island Group the microgranite rocks also are of high-level I-Type origin, containing biotite and

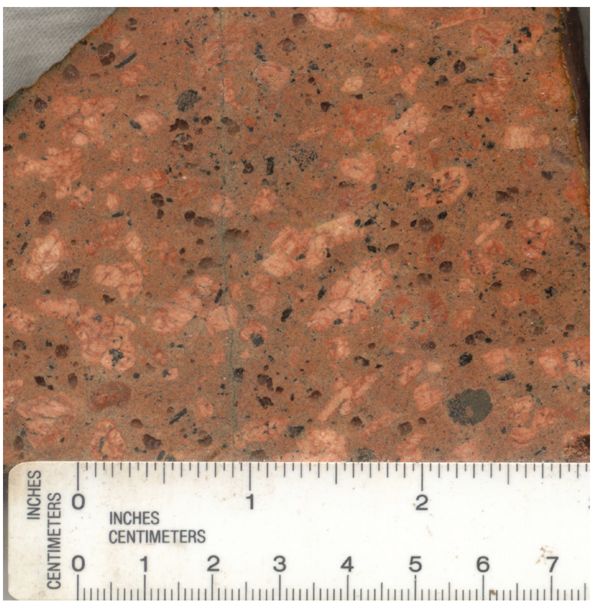


FIG. 14. Above left: Mabuyag along airstrip, QFG6971 albite hematite altered hornblende biotite microgranite.

Above right: Woeydul (Widul), QFG7015 biotite porphyritic microgranite.

Right: Horn Island Granite, QFG1775 heavily altered porphyritic biotite microgranite (Photos: Friedrich von Gnielinski, 1996 & 2009).

hornblende in a feldspar-quartz matrix, which encloses phenocrysts of albite, orthoclase and alkali-feldspars and clear quartz generally 2 to 4 mm long. (see Figure 15). The microgranite rocks were observed on the eastern side of Mabuyag, around Philip Hill and Keai Hill, as well as on the north-western corner of Mabuyag and Woeydhul (Widul). In all these locations the microgranite was observed to show a consistent degree of hematite-albite alteration, which imparts a characteristic reddish brown colour. In places it is difficult to judge if this rock is not a volcanic rhyolite (possibly a coherent rhyolite lava), but volcanic textures of fiamme or flow banding were not observed.

On the northwestern part of Mabuyag greenish-grey altered biotite microgranite was observed which appears to be similar to the microgranite rocks from the type locality of the Horn Island Granite at Kings Point. The epidote-chlorite-sericite alteration commonly observed in the Horn Island Granite has only occasionally been observed in the microgranite of the Mabuyag Island Group.

THE BADU GRANITE AND ITS VARIATIONS ON MABUYAG AND PULU

Since Commonwealth and State Government regional mapping in 1968 (Powell & Green, 1976; Willmott & Powell, 1977), the Badu Granite has been identified and dated on various islands throughout western Torres Strait. Most extensive outcrops are known from Badu and Mua. Other islands with Badu Granite outcrops include Hawkesbury and Hammond Islands. In general, the rocks from these islands are less altered than for example on Horn Island. K-Ar dating provided the following ages: Hammond Island 286±3 Ma, Hawkesbury Island 294±4 Ma, Clarke Island 293±5 Ma and Mabaduan Village (PNG) 302±5 Ma (von Gnielinski *et al*., 1997).

The Badu Granite consists of a number of compositional and textural types of granite including leucocratic biotite granite, hornblende-biotite granite, granodiorite and aplite. They are true I-type granites and are generally regarded as high-level intrusions.

FIG. 15. Above: North-western part of Mabuyag, QFG6987 sericite-chlorite-epidote altered hornblende biotite microgranite.

Right: Kings Point on Horn Island, QFG1752 biotite porphyritic microgranite. Right: Horn Island Granite, QFG1752 heavily altered porphyritic biotite microgranite (Photos: Friedrich von Gnielinski, 1996).

The type area for this granite lies on Badu Island, where it is represented by a pink to medium grey equigranular to slightly porphyritic leucocratic biotite granite containing some hornblende (QDP0719, QWW0723, ZDT5101; see Figure 16). A pinkish-grey, slightly porphyritic, hornblende-bearing, biotite granodiorite is the dominant rock type on Mua (QBW0706 / ZDT5095; see Figure 16) and on some smaller islands to the east (QDP0723; see Figure 16).

Within the Mabuyag Island Group the Badu Granite has been observed on the islets of Mipa, Pulu and Aipus, on the north end of Mabuyag, and on a north-south line of islets east of Mabuyag around Taleb Islet (ZDT5103). The Badu Granite on Aipus and in the northern area on Mabuyag has been reported to comprise a pinkish-grey equigranular biotite granite similar to the granites on Mua (QDP0747, QDP0748).

Pulu is comprised of a pink fine to medium-grained slightly porphyritic hornblende biotite microgranite which has been assigned to the Badu Granite. The rocks here are best compared with some rocks observed on Mua, but also with others on Friday Island to the south (which have incorrectly been grouped with the Horn Island Granite in von Gnielinski, 1996). The microgranite on Pulu is very hard and mostly is exposed as large boulders and tors, but in places forms whaleback exposures. It commonly is fresh to moderately weathered and in

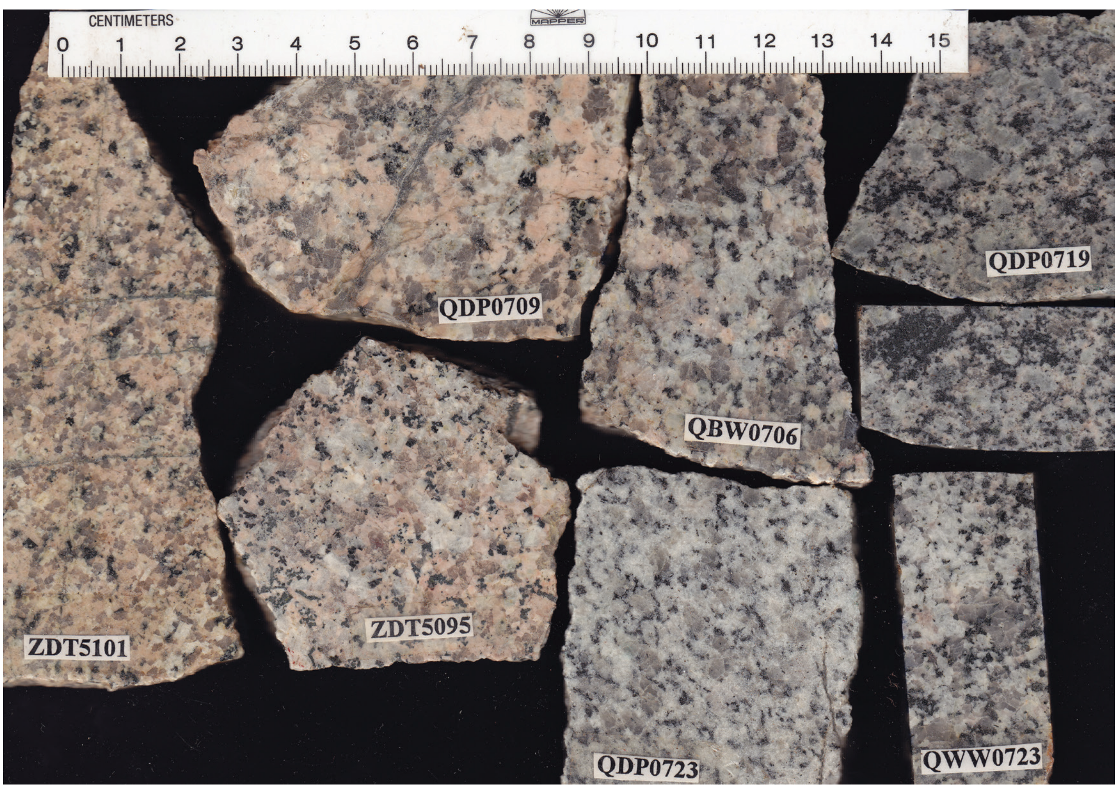


FIG. 16. Varieties of fresh, equigranular, to slightly porphyritic (hornblende) biotite granites of the Badu Granite (Cub) mostly from and around the type area on Badu (QDP0709 / QDP0719 / QDP0723 / QWW0723 / ZDT5101) and from Mua (QBW0706 / ZDT5095) (von Gnielinski, 1996) . Image courtesy: Friedrich von Gnielinski, 1996).

places shows onion peel weathering effects (compare Figure 17).

The mineralogy of the microgranite on Pulu comprises large pink K-feldspar crystals (dominant mineral, 2-4 mm long, around 55%), clear grey quartz (1-2 mm, around 18%), white plagioclase (1-4 mm, around 25%), small black flakes of biotite (0.5-1 mm, ~2%) and minor dark green hornblende (0.5-1 mm, >1%). Modal counts of these minerals vary between exposures. The microgranite also contains inclusions of older rock fragments (xenoliths) in various abundances and sizes. Mostly they are rare and small, between 2 and 6 cm

FIG. 17. Rock specimens showing pink slight porphyritic biotite microgranite. Above: Koemuthnab (Hamelin Boulders, QFG7028). Below: Pulu, QFG6997) Image courtesy: Friedrich von Gnielinski, 2009.

long, light grey to greenish-grey and are of very fine-grained biotite microdiorite. The microgranite rocks at the south end of Pulu are coarser grained, and therefore closer to a true biotite granite.

Mild alteration has also affected the granites on Pulu. The pink to red colouration of the K-feldspar crystals is due to a hematite alteration. The biotite and minor hornblende minerals are affected by chlorite alteration in places. Very thin (1-3 mm) quartz veins were observed, but only in rare instances. No mafic or intermediate dykes were encountered anywhere on Pulu. Some minor pink aplite dykes were observed north of Baidamau Mudh (Tigershark Rockshelter) on the rock platforms at the southern end of the islet.

The granitic landscapes formed on Pulu are a result of extensive weathering and erosion. As erosion gradually removes the great thickness of rock above the granite mass (up to 2 km above current land surface), stresses are released, allowing the granite to expand upwards and crack along fractures (joints), particularly along major 'sheet joints' roughly parallel to the surface (Figure 18.1). These isolate great slabs of rock of varying thickness. The horizontal slabs are then cracked by vertical joints (Figure 18.2). Weathering and decomposition then follows these joints down to the next level. The decomposed granite material has been washed away to leave behind rounded boulders on platform ridges. Eventually knobs (tors) of rounded boulders of fresher granite remain at the top level with talus slopes and boulder colluvium forming at the edge of these ridges (Figure 18.3).

The granitic landscapes have been weathered throughout the Mesozoic and Tertiary and most recently inundated from about 9,000 years ago. The Koemuthnab (Hamelin Boulders) or Mipa are good examples of submerged tors and boulders (Figure 19).

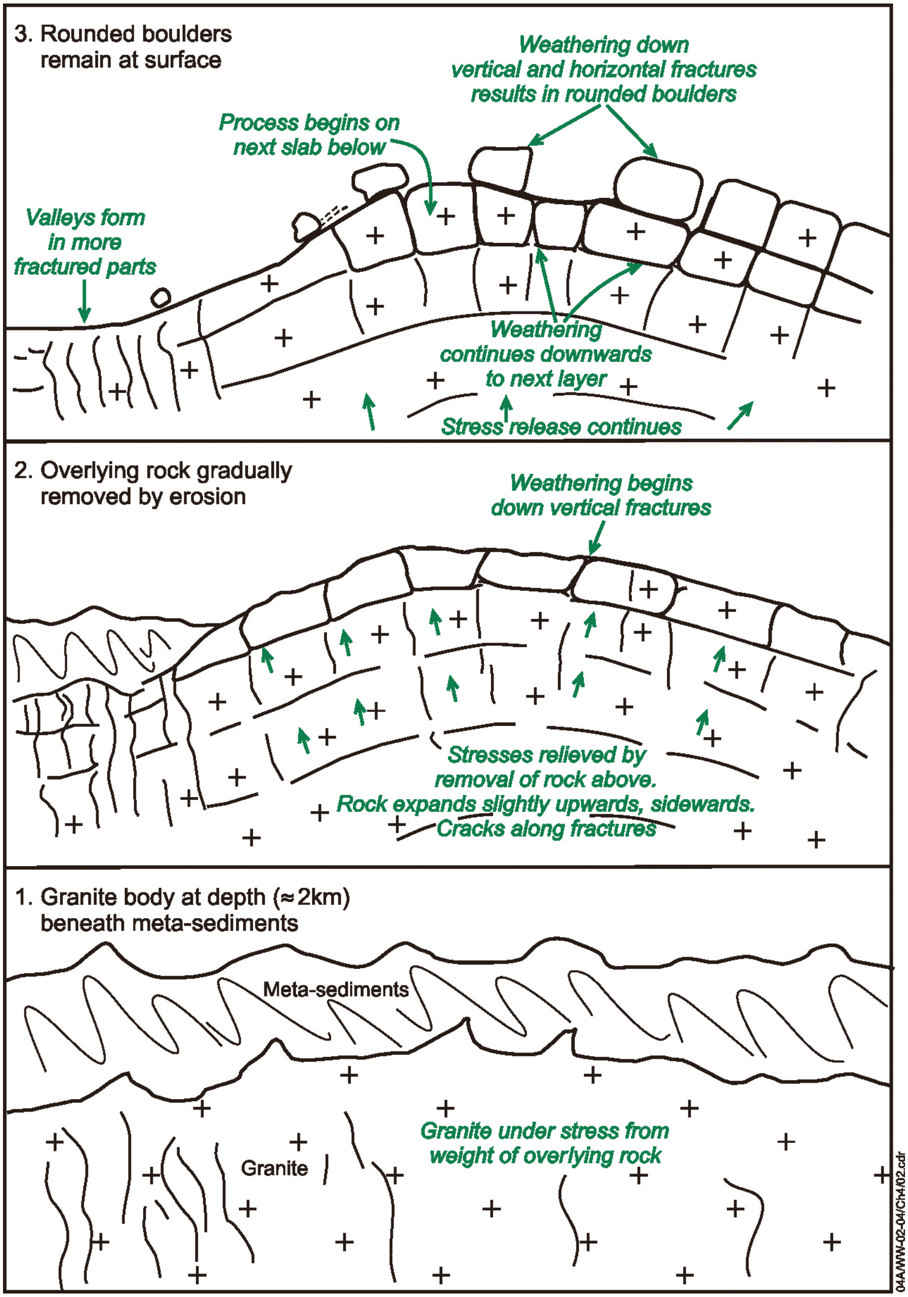


FIG. 18. Weathering and erosion processes leading to the formation of rounded boulders (tors) in granite terrain (Willmott, 2004).

FIG. 19. Submerged terrain of rounded boulders (tors) at Koemuthnab (Hamelin Boulders) taken on reconnaissance trip in March 2009. Image courtesy: Friedrich von Gnielinski.

The granites of the Mabuyag Island Group and on Badu have been intruded by porphyritic microgranite dykes in places. Some contain abundant large potash-feldspar phenocrysts (euhedral, up to 10 mm long) and clear quartz (up to 3 mm) in a grey aphanitic groundmass. On Mabuyag a rare greenish-grey fine to medium-grained dolerite dyke cuts the rhyolite on the waterline east of Sipingur (Sipi Point). These dykes represent late stage intrusions within the Badu Suite.

TERTIARY DEPOSITS

Tertiary deposits in the Mabuyag Island Group are very limited in extent. Tertiary sediments in the form of thin fericrete rubble have only been observed on some larger islands of Torres Strait, capping some hornfelsed volcanic rocks to the southeast of Mua and on Mount Adolphus Island (Willmott & Powell, 1977). Only two smaller areas of minor laterite residual soils have been recorded on Mabuyag in the 2009 mapping: Various talus fan deposits have been noted on central and western Mabuyag as well, in particular on the central part of the Wagadagam Track at QFG6977 (Figure 20) which appear to be reworked ferruginised gravel of possible Tertiary age. They could represent a channel fill from the hill slopes nearby.

FIG. 20. Unconsolidated Tertiary fan deposit with lateritised volcanic cobbles and silt, Wagadagam Track, QFG6977). Image courtesy: Friedrich von Gnielinski, 2009).

QUATERNARY DEPOSITS

Within Mua and the Mabuyag Island Group residual and alluvial sediments are difficult to distinguish and in the past have generally been represented using combined mapping symbols. Within the 2009 mapping various sediments were observed:

ALLUVIAL DEPOSITS

Some alluvial deposits (Qa) have been recognised on the lower part of Wagadagam Track on the central part of Mabuyag. These are of limited extent and mostly very thin deposits.

SAPROLITE

In general, regolith cover over the granites and volcanic rocks consists of shallow stony soils overlying slightly to moderately weathered saprolite. On the steep hill slopes bedrock is mostly exposed at the surface with only minor thin stony debris layers in places. Some grassland sand and silt deposits are probably derived from weathering of the granitic rocks on higher elevation levels. Soil cover is thin, but clay-rich termite mounds with abundant mica minerals have been observed on most ridge areas across Mabuyag.

DUNE DEPOSITS

On the north end of Pulu a coast beach ridge has formed, including a narrow foredune and flat back dune deposits. The quartz-feldspar sands of the foredune are rich in shell debris derived from the shallow reef deposits fringing the islet. The back dune deposits also include minor salt pan deposits. On Mabuyag the southeastern coastline comprises some beach ridge and dune sands. Mabuyag village sits predominantly on Neogene (between 23 and 2.5 million years ago) colluvial deposits, and younger talus wash and minor beach sand. A large part of these deposits have been affected by urbanization. Commonly the coastline is protected by a thin mangrove belt with fine silty to muddy sediments (Figure 21).

ESTUARINE DEPOSITS

The north-eastern fringe of Pulu comprises an estuarine mud deposit strewn with boulder colluvium deposits and outcrop boulder tors. The finer sediments probably deposit here as the area is sheltered from currents and winds by Mabuyag. The fringe around Pulu is generally silt and mud with sandy beaches at the 'high water mark' level.

TIDAL DEPOSITS

Between Pulu and Mabuyag shallow mud flats, subject to tidal sea levels, extend to both coastlines, converting into estuarine mud

FIG. 21. Shallow mud flats (at low tide) converting into estuarine mud with mangrove vegetation on the north-western end of Mabuyag. The northern end of Pulu is visible in the background and the author in the foreground. Image courtesy: Ian J. McNiven, 2009.

when reaching the high water level coastline. All the islands have fringing coral reefs with an average width of 200 m, developed around them. There are also numerous platform reefs, exposed only at low tide, orientated along the dominant water currents. Some smaller sand shoals are developed between the platform reefs.

Sand cays are present on the leeward ends of platform reefs and are formed by foraminifera, shelly, and coral sand and shingle, which are commonly cemented in the intertidal zone to form beach rock. Some blocks of beach rock were observed along the southern beaches of Pulu between massive boulders.

ROCKS FOREIGN TO THE REGION FOUND IN ANTHROPOGENIC SETTINGS

Some foreign rocks were recorded at the Pulu kod site and at Mask Cave (central Pulu). These rocks were generally lithologies which could not have formed within the Pulu environment and therefore are regarded as anthropogenic introductions. Examples are illustrated in Figures 22-23. Smaller rock fragments (e.g. flaked artefacts) observed in the vicinity of Mask Cave constituted predominantly acid volcanic rocks, which may have come from Mabuyag.

MINERAL RESOURCES

Mineralisation in the Torres Strait Region has been reported from various areas. Gold, lead and zinc mineralisation associated with granitic intrusions into a stock work system are reported from Horn and Possession Islands (von Gnielinski, 1996). A compilation of all the mineral occurrence data, including historical records and exploration activities, was produced in Denaro (1993). Historic production of wolfram associated with quartz lodes along volcanic sequences in contact with granite occurred on Mua (Fleischmann, 1953).

FIG. 22. Intensely hornfelsed acid volcanic or highly deformed biotite gneiss cobble found at the Pulu kod site. This rock is regarded as a human import as the closest terrain with comparable rocks is Barney, Browne or Clarke Island (Willmott *et al*., 1973: 103). These rocks were confused by early workers as Precambrian basement gneisses. True metamorphic rocks could only be sourced from Cape York or PNG Highlands. Image courtesy: Friedrich von Gnielinski, 2009.

FIG. 23. Dark green porphyritic basalt or andesite found at the Pulu kod site. This rock is also seen as foreign to Pulu, but could be sourced from the Torres Strait Volcanics. The closest outcrops of volcanic rocks are situated on the southwestern end of Mabuyag. No actual matches with this rock were found during this project field work. Image courtesy: Friedrich von Gnielinski, 2009.

No mineralisation was observed on Mabuyag other than a minor hematite breccia along the Wagadagam Track. Only minor quartz veining or staining was observed in place, but no economic potential exists for any of the Mabuyag Island Group.

DISCUSSION

Our understanding of the geology of the Mabuyag Island Group has greatly improved following field investigations and collection of representative specimens to correlate these rocks with others known from the region. However, not all islands in the group were visited, and further research will be required to document and analyse their geology. Correlation of rock types is also made difficult by the large expanses of water between the islands.

A thorough investigation of the volcanic sequences on Mabuyag would be of major interest. These units may well be a completely separate sequence within the Upper Pennsylvanian to Cisuralian volcanic environment, but they were probably fed by the same general magmatic source as the volcanic units in the southern Torres Strait. It will also be important to establish if the microgranite on western Mabuyag actually is a component of the defined Horn Island Granite or if it can be defined as a new unit, although this may prove difficult, especially with its strong alteration overprint.

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LITERATURE CITED

BAIN, J.H.C. & DRAPER, J.J. (eds) 1997. North Queensland Geology. *Australian Geological Survey Organisation*, Bulletin 240 / *Queensland Geology* 9.

BRANCH, C.D. 1966. Volcanic cauldrons, ring complexes and associated granites of the Georgetown Inlier, Queensland. *Bureau of Mineral Resources, Australia, Bulletin* 76: 19.

DENARO, T.J. 1993. Mineral occurrences – Torres Strait 1:250 000 Sheet Area, Cape York Peninsula, *Queensland. Queensland Geological Record*. 1993/18.

FLEISCHMANN, K.R. 1953. Inspection of the Lockerbie (Cape York) area and wolfram workings on Moa, Torres Strait. *Queensland Government Mining Journal*. December 1953, pp. 933-937.

JUKES, J.B. 1847. *Narrative of the surveying voyage of H.M.S Fly*. 2 vols. (Boone: London).

HADDON, A.C., SOLLAS, W.J., & COLE, G.A.J. 1894. On the geology of Torres Strait. *Transactions of the Royal Irish Academy* 30(11): 419-476.

HADDON, A.C. 1898. Private journal of 1898 expedition to Torres Strait. Envelope 1030, Haddon Papers. (Cambridge: Cambridge University Library).

HITCHCOCK, G., MCNIVEN, I.J. & the PULU IPA COMMITTEE. 2009. Pulu Indigenous Protected Area Plan of Management. Plan presented to the Mabuyag Community and the Torres Strait Regional Authority. June 2009. (Unpubl.). (Arafura Consulting: Melbourne).

IRVINE, T.N. & BARAGAR, W.R.A., 1971. A guide to the chemical classification of the common volcanic rocks. *Canadian Journal of Earth Sciences* 8: 523-548.

LE BAS, M.J., LE MAITRE, R.W. STRECKEISEN, A., & ZANETTIN, B., 1986: A chemical classification of volcanic rocks based on the total alkali-silica diagram. *Journal of Petrology* 27: 745-750.

MCNIVEN, I.J. 2011. Torres Strait Islanders: the 9000-year history of a maritime people. In *The Torres Strait Islands*. Pp. 210-219. Brisbane: Queensland Art Gallery / Gallery of Modern Art.

MCNIVEN, I., DICKINSON, W.R., DAVID, B., WEISLER, M., VON GNIELINSKI, F., CARTER, M. & ZOPPI, U. 2006. Mask Cave: red-slipped pottery and the Australian-Papuan settlement of Torres Strait. *Archaeology in Oceania* 41: 49-81.

McNIVEN, I.J., von GNIELINSKI, F. & QUINNELL, M. 2004. Torres Strait and the origin of large stone axes from Kiwai Island, Fly River Estuary (Papua New Guinea). *Memoirs of the Queensland Museum, Cultural Heritage Series* 3(1): 279-289.

McNIVEN, I.J., DAVID, B. GOEMULGAU KOD & FITZPATRICK, J. 2009. The great *kod* of Pulu: mutual historical emergence of ceremonial sites and social groups in Torres Strait, northeast Australia. *Cambridge Archaeological Journal* 19(3): 291-317.

PEARCE, J.A., HARRIS, B.W. & TINDLE, A.G., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *Journal of Petrology* 25: 956-983.

POWELL, S. & GREEN, D. 1976. Torres Strait-Boigu-Daru, Queensland 1:250 000 Geological Series SC54-12, 7, 8. (Bureau of Mineral Resources: Australia).

RIDD, M.F. 1976. Papuan Basin – On-Shore. *Australasian Institute of Mining and Metallurgy Monograph Series*, No 7, pp. 478-494.

STRECKEISEN, A. 1976: To each plutonic rock its proper name. *Earth-Science Reviews* 12: 1-33.

WILLMOTT, W.F. 1969. Daru-Maer, Papua and Queensland 1:250 000 Geological Series SC54-8 and SC55-5. (Bureau of Mineral Resources: Australia).

WILLMOTT, W.F. 1972. Daru-Maer, Papua and Queensland 1:250 000 Geological Series. Explanatory Notes. (Bureau of Mineral Resources: Australia).

WILLMOTT, W.F. & POWELL, B.S. 1977. Torres Strait-Boigu-Daru, Queensland 1:250 000 Geological Series. Explanatory Notes. (Bureau of Mineral Resources: Australia).

WILLMOTT, W.F., WHITAKER, W.G., PALFREYMAN, W.D. & TRAIL, D.S. 1973. The igneous and metamorphic rocks of Cape York Peninsula and Torres Strait, Queensland. *Bureau of Mineral Resources, Australia, Bulletin* 135.

WILLMOTT, W.F. 2004. *Rocks and landscapes of the National Parks of southern Queensland*. (Geological Society of Australia, Queensland Division: Brisbane).

WRIGHT, D. & DICKINSON, W.R. 2009. Movement of ideas not materials: locally manufactured pottery on Mabuyag Island, Western Torres Strait. *Archaeology in Oceania* 44: 38-41.

VON GNIELINSKI, F.E. 1996. Regional geology, exploration, development and failure of the Horn Island Gold Mine and its environmental clean-up. MSc thesis, James Cook University, Townsville.

VON GNIELINSKI, F.E., DENARO, T.J., WELLMAN, P. & PAIN, C.F. 1997. Torres Strait region. Pp. 159-164. In Bain, J.H.C. & Draper, J.J. (eds) *North Queensland Geology. Australian Geological Survey Organisation, Bulletin 240 / Queensland Geology 9*.