Definition of Teal Flat and Marne River Volcanics and associated shear zone

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Introduction

This geological note describes recent geological mapping and the regional tectonic significance of outcrop at Teal Flat on the Murray River, and Marne River, north of Mannum (Fig. 1). A review and reinterpretation of outcrop at these two sites has revealed that the rocks are of volcanic origin, and the names 'Teal Flat Volcanics' and 'Marne River Volcanics' are formalised herein. The Teal Flat Shear Zone (TFSZ), which overprints these outcrops and may form part of a larger structure extending many kilometres to the north and south, is also defined.

Outcrops at Marne River were interpreted in previous investigations as mylonitic metasandstone and metasiltstone of the Kanmantoo Group (Thomson, 1969). Recent geological mapping and petrographic studies (Mason, 1998) indicated that these outcrops consist of interlayered and metamorphosed volcanics, volcaniclastics, intrusives and sediments that have been metamorphically recrystallised, tightly folded and sheared.

Whole rock chemistry of the Marne River Volcanics indicated these rocks to vary in composition from dacite and rhyodacite to rhyolite, whereas the Teal Flat Volcanics are calc-alkaline basalt, andesite, dacite and rhyolite, based on the Streckeisen (1976) and Le Bas *et al.* (1986) geochemical classification schemes (Figs 2a,b).

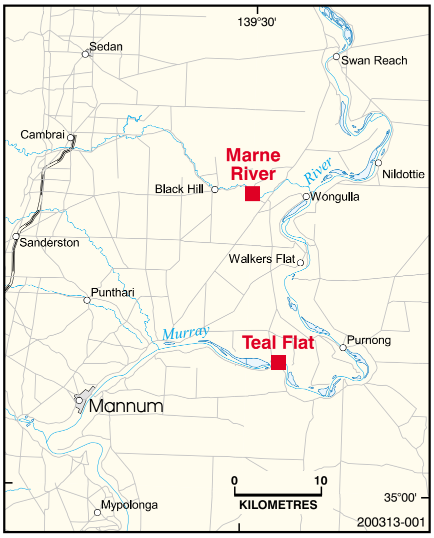


Fig. 1 Location diagram for the Marne River and Teal Flat Volcanics.

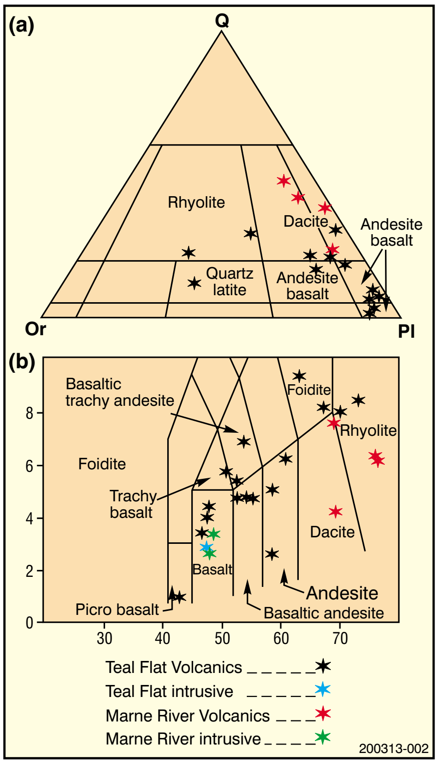


***Fig. 2 (a)** Quartz, plagioclase and orthoclase geochemical classification diagram (after Strekeisen, 1976). **(b)** SiO_2 versus Na_2+K_2O geochemical classification diagram (after Le Bas et al., 1986).*

Recent U–Pb zircon dating (SHRIMP II) of the Marne River Volcanics yielded a crystallisation age of 521±4 Ma. Geochemistry and geochronological dating provide good evidence that the volcanics are linked to the Truro Volcanics (Forbes *et al.*, 1972) and other volcanics within the Heatherdale Shale (Cooper *et al.*, 1992; Gatehouse *et al.*, 1993).

Analysis of TEISA detailed aeromagnetic imagery (Fig. 3) reveals that the Teal Flat and Marne River outcrops coincide with linear, high-magnetic anomalies which are part of a line of such features with north–south strike extent of ~50 km. The occurrence of mineralisation (malachite), and elevated Cu, Zn and Pb levels associated with basalts at Teal Flat, has emphasised the economic potential of this package of linear magnetic highs.

Teal Flat Shear Zone

The TFSZ is interpreted to have formed as a result of compressive deformation late in the Cambro-Ordovician Delamerian Orogeny. Original extensional faults, which allowed extrusion of the Marne River and Teal Flat Volcanics, may have been reactivated during Delamerian compression to form a thrust fault(s) system. The aeromagnetic image (Fig. 3) defines a series of north–south, linear, high-intensity magnetic features which could represent tectonic repetitions of the same magneto-stratigraphic unit in an imbricate-like thrust stack. Alternatively, these magnetic units may represent individual flows or series of flows interlayered with low magnetic intensity metasediments and metavolcanics that have been sheared by the TFSZ.

Kinematic indicators for the sense of thrust transport have not been recognised as these may have been destroyed by a later overprinting strike–slip component on the TFSZ. Thin pseudotachylite veins occur within basalt at Teal Flat, indicating high heat and strain during shearing.

New TEISA aeromagnetic imagery reveals the extent of the north–south-trending TFSZ, which shears and displaces high magnetic features in an apparent dextral sense (Fig. 3). Shearing appears to affect geological units across a wide zone of 10–15 km, which extends for hundreds of kilometres to the northeast and southeast (Fig. 4). The

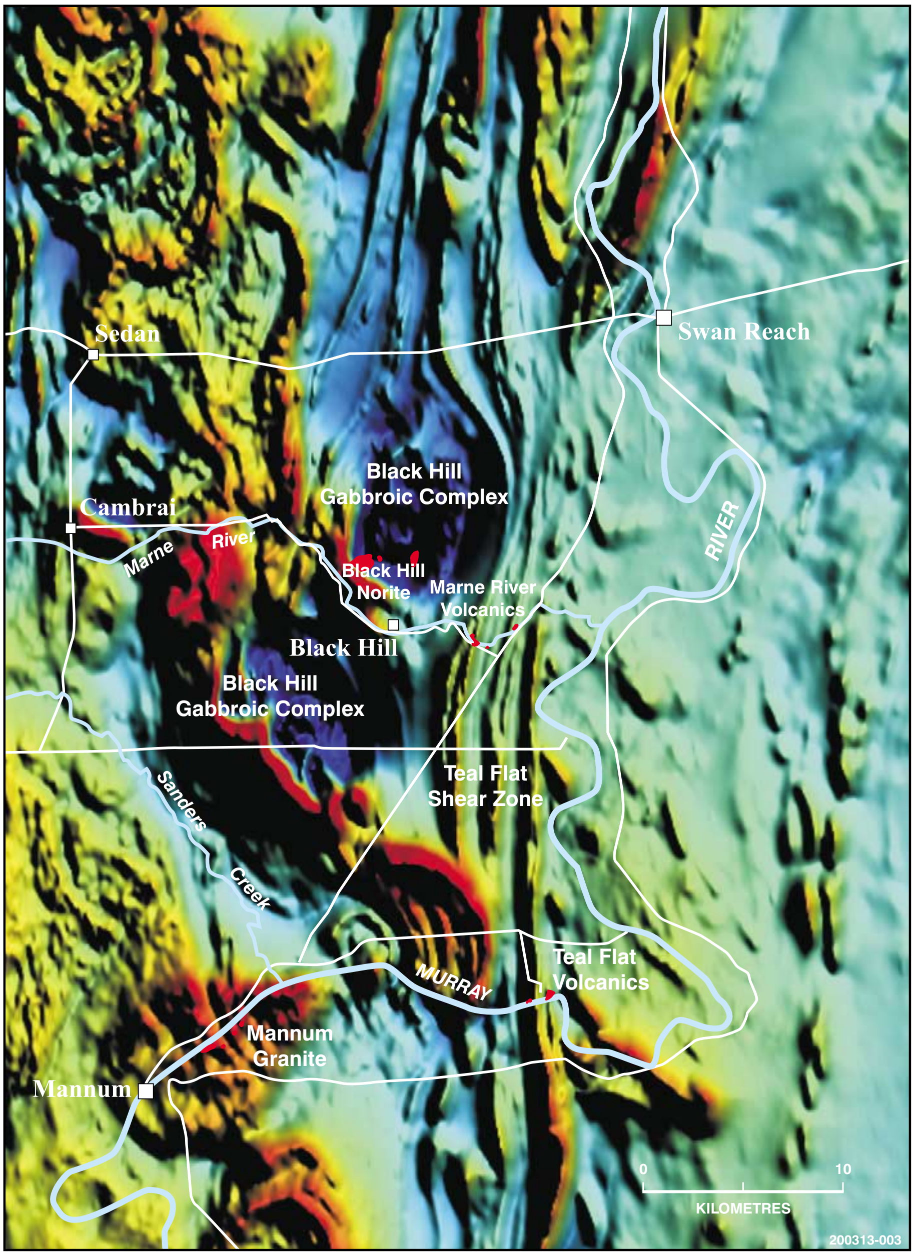


Fig. 3 *TEISA pseudocolour TMI image of the Marne River – Teal Flat area.*

TFSZ forms part of a larger tectonic feature, which may continue north and curve to a northeasterly trend to become the Anabama–Redan Shear Zone. It also appears to continue south and curve to the southeast where a number of sheared volcanic and metasedimentary units are seen on SAEI aeromagnetic imagery (Fig. 4).

Figures 3 and 4 show that the TFSZ wraps around the Black Hill Gabbroic Complex (BHGC), indicating that the BHGC was possibly emplaced before the TFSZ developed. The BHGC has a Sm–Nd total rock isochron age of 489±39 Ma (Turner, 1996), which conforms with the 487±5 Ma (Rb–Sr) and 486 Ma (K–Ar) ages determined by Milnes *et al.* (1977). These ages indicate that the BHGC was emplaced after the peak of the Delamerian Orogeny (i.e. ~515–490 Ma; Preiss, 1995). The interpretation that the TFSZ post-dates the intrusion of the BHGC suggests that the TFSZ is late to post-Delamerian.

Geochronology

Zircons were separated from Marne River Volcanics (sample R214522) using standard crushing and heavy liquid methods. Grains were hand picked from the heavy mineral concentrate and mounted in epoxy, together with the Duluth Gabbro reference zircon AS3 (Paces and Miller, 1993). The disk was polished, and reflected and transmitted light photomicrographs taken, in addition to cathodoluminescence (CL) images of the sectioned grains.

Zircons from sample R214522 are dominantly zoned, euhedral, elongate and doubly terminated crystals. The CL images reveal dominantly simple magmatic zoning from core to rim, but a few grains have darker zones interpreted as inherited cores to magmatically grown zircon. The euhedral, well-formed nature of the zircon grains indicates little or no transport away from the volcanic source of the Marne River Volcanics. Rare vapour trail inclusions, considered an indicative feature of zircon from felsic

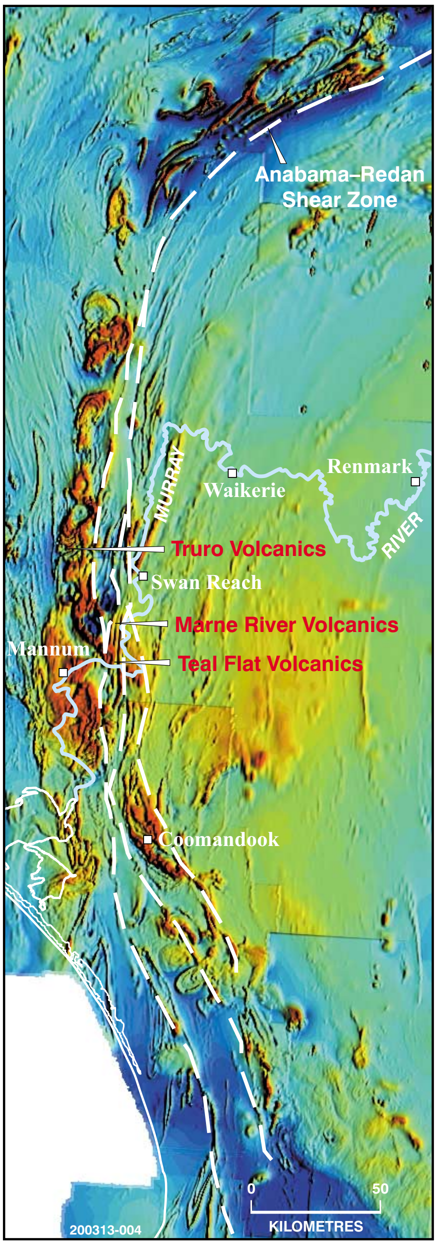
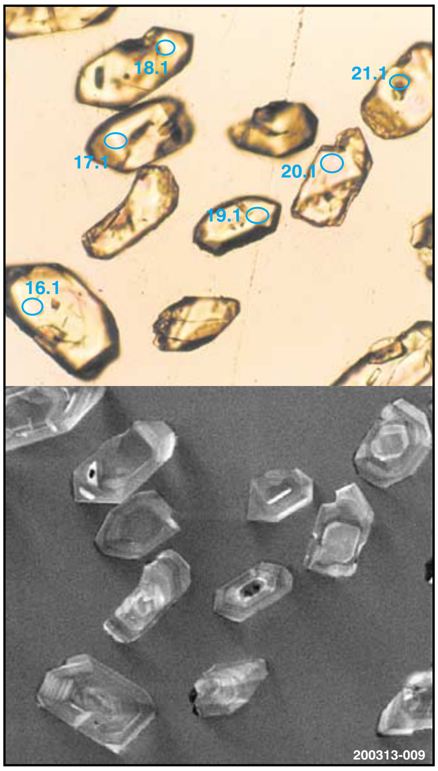


Fig. 4 *Regional scale TMI image of the Marne River – Teal Flat and Padthaway Ridge area of southeastern SA.*

volcanic rocks, provide evidence that the zircon has a volcanic to near-surface origin.

Twenty-two grains have been analysed using SHRIMP II at the Research School of Earth Sciences, ANU. The data have been treated in a manner similar to that described in Compston *et al.* (1992) and Williams (1998). The data are provided in Table 1 and shown on Figure 5. The analyses all cluster near to or within uncertainty of concordia, indicating that the amount of common Pb in these analyses is negligible. On a relative probability plot (Fig. 5b) of the ^{207}Pb corrected ^{206}Pb/^{238}U ages (as per Compston *et al.*, 1992), a normal distribution of the data is evident and a weighted mean of all 22 analyses has no excess scatter, giving an age of 521±4 Ma (95% confidence limits, MSWD = 1.3). It is interpreted to give the crystallisation age of the Marne River Volcanics and indicates that they were extruded at a similar time to correlatives of the Truro Volcanics (i.e. tuff from Sellicks Hill at 526±4 Ma, Cooper *et al.*, 1992).



(top) *Reflected light photo of post-SHRIMP analysed zircon from sample R214522, showing the areas analysed.* ***(bottom)*** *Cathodoluminescence image of the same sample.*

Discussion

The Teal Flat and Marne River Volcanics are considered part of the Neoproterozoic to Middle Cambrian Adelaide Geosyncline basin complex. The geosyncline sediments and igneous rocks indicate at least five major phases of rifting, with several authors (Preiss, 1999; Powell *et al.*, 1993; Crawford and Direen, 1998; Zhou and Whitford, 1994) proposing the break up of the Proterozoic supercontinent Rodinia in the Neoproterozoic (i.e. ~700, 600–580 Ma). In the intervening period, a shelf environment developed in the Fleurieu Arc and Koonenberry (NSW) regions, with deposition of shallow water sediments (Normanville Group, Gnalta Group) before another phase of rifting, volcanism and tectonically controlled basin development. Sediments (Kanmantoo Group, Teltawongee beds) were rapidly deposited into these basins, with cessation of sedimentation caused by the onset of compressional tectonics of the Delamerian Orogeny at ~515 Ma.

Marne River Volcanics have a SHRIMP U–Pb zircon age of 521±4 Ma and are interpreted to represent rift volcanics extruded during development of the Kanmantoo Trough in the Early Cambrian. Similar aged, Early Cambrian, calc-alkaline Mount Wright Volcanics occur in the Koonenberry Belt (525±8 Ma; Zhou and Whitford, 1994). These rocks are interpreted to represent volcanics generated when extension of the upper continental crust produced limited partial melting of the lithospheric mantle beneath a zone of extension (Crawford *et al.*, 1997). The Mount Wright continental rift related volcanics, as well as the Truro Volcanics, volcanics encountered in drillcore of the basement of the Murray Basin, and Teal Flat – Marne River Volcanics indicate a widespread, dynamic period of continental

Table 1 *Summary of SHRIMP U–Pb results for sample R214522.*

Grain spot	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	^{204}Pb/^{206}Pb	f_{206} (%)	^{238}U/^{206}Pb	±	^{207}Pb/^{206}Pb	±	^{206}Pb/^{238}U	±	Age (Ma) ^{206}Pb/^{238}U	±
1.1	199	104	0.52	22	0.000047	<0.01	11.80	0.17	0.0576	0.0009	0.0848	0.0012	524.5	7.2
2.1	267	172	0.65	30	0.000097	0.10	12.01	0.16	0.0586	0.0008	0.0832	0.0011	515.0	6.8
3.1	304	221	0.73	35	0.000112	0.07	11.79	0.17	0.0583	0.0009	0.0847	0.0013	524.3	7.4
4.1	211	122	0.58	18	0.000010	0.04	11.55	0.15	0.0581	0.0006	0.0866	0.0011	535.3	6.5
5.1	219	97	0.44	17	0.000029	0.20	11.99	0.19	0.0594	0.0008	0.0832	0.0013	515.4	7.8
6.1	192	68	0.35	15	0.000114	0.14	11.79	0.16	0.0589	0.0006	0.0847	0.0011	524.0	6.7
7.1	223	111	0.50	18	–	0.23	11.96	0.17	0.0596	0.0006	0.0834	0.0012	516.6	7.0
8.1	198	76	0.39	15	–	0.19	12.00	0.17	0.0593	0.0006	0.0832	0.0012	515.2	7.1
9.1	241	141	0.58	20	0.000115	0.05	11.75	0.15	0.0582	0.0008	0.0851	0.0011	526.3	6.3
10.1	213	116	0.54	17	0.000134	0.20	11.96	0.17	0.0594	0.0006	0.0835	0.0012	516.9	7.2
11.1	174	98	0.56	15	0.000091	<0.01	11.67	0.16	0.0578	0.0009	0.0857	0.0012	530.0	7.0
12.1	387	284	0.73	33	0.000030	0.07	12.05	0.16	0.0584	0.0005	0.0830	0.0011	513.7	6.4
13.1	314	229	0.73	26	–	0.21	12.04	0.16	0.0595	0.0007	0.0829	0.0011	513.3	6.7
14.1	279	199	0.71	24	0.000035	0.06	11.95	0.16	0.0583	0.0005	0.0836	0.0012	517.6	6.8
15.1	242	175	0.72	19	0.000057	0.06	12.11	0.16	0.0583	0.0006	0.0825	0.0011	511.2	6.4
16.1	316	237	0.75	28	0.000010	0.05	11.82	0.17	0.0581	0.0006	0.0846	0.0012	523.5	7.4
17.1	332	154	0.46	26	0.000051	0.04	11.88	0.15	0.0581	0.0008	0.0841	0.0011	520.8	6.4
18.1	178	93	0.52	14	0.000001	0.14	12.25	0.19	0.0589	0.0007	0.0816	0.0012	505.4	7.4
19.1	336	249	0.74	29	0.000100	0.32	11.77	0.14	0.0604	0.0005	0.0847	0.0010	524.1	6.2
20.1	258	158	0.61	22	–	<0.01	11.55	0.15	0.0571	0.0006	0.0867	0.0011	535.7	6.7
21.1	282	186	0.66	24	0.000060	0.09	11.83	0.15	0.0585	0.0005	0.0845	0.0011	522.9	6.3
22.1	316	206	0.65	27	0.000038	0.07	11.65	0.16	0.0583	0.0005	0.0858	0.0012	530.6	7.1

Notes:

1. Uncertainties are given at the one σ level.
2. f_{206}% denotes the percentage of ^{206}Pb which is common Pb.
3. Correction for common Pb made using the measured ^{238}U/^{206}Pb and ^{207}Pb/^{206}Pb ratios following Tera and Wasserburg (1972), as outlined in Compston *et al.* (1992).

rift–extension tectonics and associated volcanism that affected eastern Rodinia in the Early Cambrian (i.e. 525–520 Ma).

Teal Flat Volcanics vary from calc-alkaline basalt to andesite, whereas Marne River Volcanics are more felsic and consist of calc-alkaline dacite, rhyodacite to rhyolite volcanics to volcaniclastics. The transition from mafic to felsic composition indicates bimodal volcanism between Teal Flat and Marne River if the volcanics are assumed to have been extruded at a similar time. Mount Wright Volcanics have similar compositions, varying from calc-alkaline andesite to dacite with intrusions of calc-alkaline microdolerite to microdiorite (Crawford *et al.*, 1997). Both Marne River and Teal Flat Volcanics are intruded by sill-like amphibolite and gabbro pods interpreted to be related to the BHGC or the mafic dykes of Liu and Fleming (1990).

Deformation as a result of the Delamerian Orogeny (i.e. ~515–490 Ma) resulted in development of the TFSZ which has sheared Teal Flat and Marne River Volcanics. This shear zone may form part of a large-scale structure separating the Kanmantoo Trough and Adelaidean units of the Fleurieu Arc in the west, from the poorly understood basement of the Murray Basin to the east.

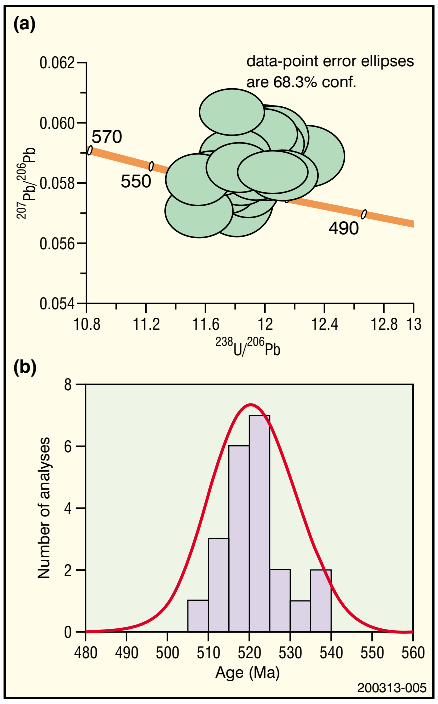


Fig. 5 ***(a)*** *Tera Wasserburg plot of zircon data for sample R214522.* ***(b)*** *Relative probability curve of $^{206}Pb/^{238}U$ ages with stacked histogram indicating number of analyses.*

Dating of metamorphic minerals formed during shearing may help correlate portions of this shear zone in the northern (e.g. Anabama–Redan Shear Zone), central (e.g. Teal Flat and Marne River sheared volcanics) and southern areas (e.g. Coomandook, Yumali and Coonalpyn sheared volcanics; Fig. 4).

Previous studies (Milnes *et al.*, 1977; Foden *et al.*, 1990; Turner, 1996) interpreted the BHGC as a post-tectonic intrusive. Recognition that the TFSZ apparently 'wraps around' and post-dates the BHGC may provide evidence that the TFSZ was formed during a late, previously unrecognised phase of Delamerian deformation, either very late or post-Delamerian Orogeny.

An alternative interpretation may be that the geochronology for the BHGC does not record its emplacement age, but a later tectono-thermal event. In such an interpretation the BHGC may have been emplaced pre- to syn-Delamerian Orogeny. Recent diamond-drilling has revealed undeformed BHGC gabbro crosscut by high-grade shear zones that have possibly been retrogressed due to a high chlorite content within the shear. The timing of these shears relative to the TFSZ and the Delamerian Orogeny is uncertain.

However, evidence for a very late phase of Delamerian deformation may be provided by felsic volcanics in the Didicoolum–Windsong area in the South-East of SA, which have a U–Pb zircon age of 493±7 Ma (Belperio *et al.*, 1998). These volcanics are strongly foliated and moderately metamorphosed, and are found to lie on a shear zone which can be spatially linked (using aeromagnetics) to the TFSZ, suggesting that they formed at a similar time (Fig. 4).

A pervasive shear fabric within Marne River Volcanics is folded into small, tight, steeply inclined, shallowly north-northwest-plunging folds. The timing of this folding event relative to Delamerian Orogeny folding is uncertain and further structural geology studies will be undertaken to clarify this.

Minor mineralisation and elevated base metal values are evident at Teal Flat, indicating potential for economic mineralisation related to Early Cambrian rift volcanics and the TFSZ. This area has significant potential for VHMS and SEDEX mineralisation related to the volcanics, and gold mineralisation related to the medium-grade metamorphic and shearing event that produced the TFSZ. Platinum Group Element mineralisation potential still exists in the under-explored BHGC (Farrand *et al.*, 1989).

Definitions

Marne River Volcanics

Name

After the Marne River; grid reference 362 800mE, 6 158 100mN, RENMARK 1:250 000 map area.

Distribution

Small, scattered outcrops occur 4–6 km east of the township of Black Hill, on the banks of the Marne River. A small flat area and tributary on the northern side of the Marne River also expose outcrops of the volcanics and associated metasediments (Fig. 6).

Type section

The type section is at the Marne River, but the exposed outcrops are discontinuous and highly sheared with an unknown amount of tectonic shortening, and no thickness can be measured.

Lithology

Marne River Volcanics consist of various lithologies, all of which show evidence of metamorphic recrystallisation. Generally they can be described as fine to medium-grained, quartzofelspathic, tuffaceous volcaniclastics with a schistose fabric. The volcaniclastics, which contain scattered K-feldspar crystals (up to 3–4 mm) of probable phenocrystic origin (Mason, 1998), are interlayered with fine to medium-grained, compositionally layered, quartz–biotite–feldspar metasandstone, epidote–garnet calc-silicate and greenish brown to dark grey, very fine-grained metasiltstone. Original volcanic textures are difficult to determine due to strong deformational overprinting.

Intruding the volcaniclastics and metasediments are dark greenish black, blastomylonitic, boudinaged, medium-grained amphibolite and gabbro sills.

Boundary criteria and correlation

Discontinuous outcrop creates difficulty in correlating these units with known sedimentary or volcano-sedimentary units, but a dark grey metasiltstone at the spillway outcrop has an appearance similar to the Heatherdale Shale of the upper Normanville Group (Fig. 6). A crystal tuff interbedded with this metasiltstone is tentatively correlated with tuff layers found in the Heatherdale Shale in a quarry at the base of Sedan Hill. The Marne River sections are therefore possible equivalents of the upper Normanville Group.

Marne River Volcanics may also correlate with volcanics intersected beneath the Murray Basin in the Coomandook area and with the Truro Volcanics in their type section near Dutton, though the Truro Volcanics are more basaltic. Aeromagnetic imagery reveals linear north–south features of considerable strike length on which the Marne River Volcanics lie (Fig. 3).

The Teal Flat Volcanics are coincident with a more westerly linear magnetic high thought to be part of the same shear zone complex. The Marne River and Teal Flat Volcanics are interpreted to be related and to have extruded during a similar episode of volcanic activity.

Amphibolite and gabbro intrusives seen at Marne River are lithologically and geochemically similar to the small pod seen at Teal Flat and are likely to be related to a similar phase of intrusion. These mafic intrusives may be correlatives of the BHGC, which occurs 5 km west of the Marne River outcrops.

Outcrop of Marne River Volcanics, comprising tightly folded feldspar phenocrystic dacite. (Photo 47412)

Age

Zircon extracted from a tuffaceous volcaniclastic (R214522) was analysed using the SHRIMP II U–Pb method, which yielded a crystallisation age of 521±4 Ma with 95% confidence limits. This age indicates that the rocks were extruded or crystallised within the 'Atdabanian–Toyonian' Stage (i.e. 528–509 Ma) of the Early Cambrian Epoch (Shergold, 1996).

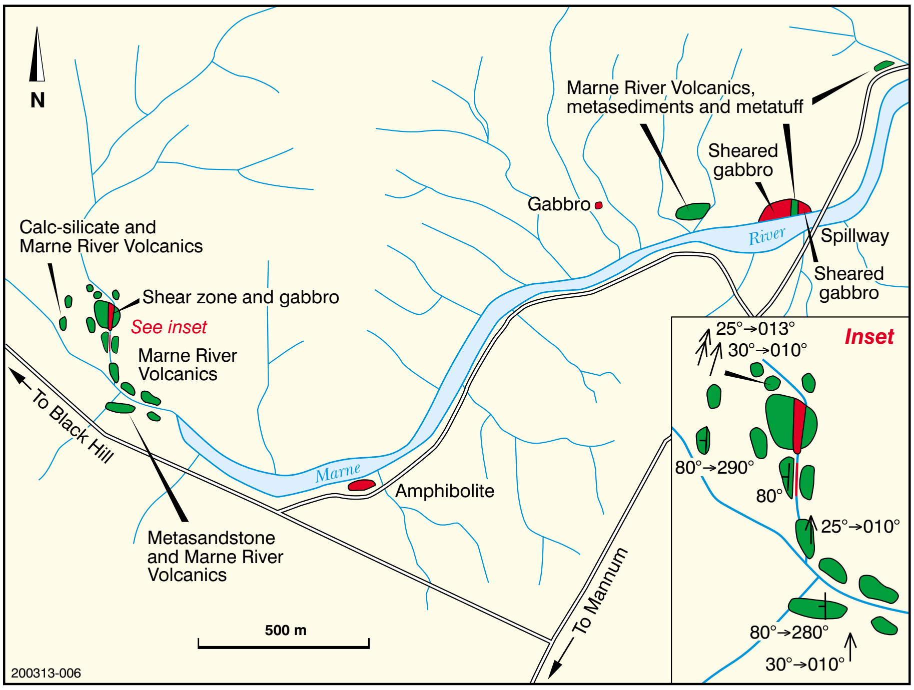


Fig. 6. Outcrop geology of the Marne River Volcanics.

Synonym

None.

Teal Flat Volcanics

Steel (1962), in a geological investigation of the Teal Flat area for a possible dam site, interpreted the outcropping rocks to be undifferentiated Kanmantoo Group greywackes. On the basis of field and petrological investigations, it is now considered that these outcrops are primarily of volcanic origin (Purvis, 1996; Pontifex, 1996; Mason, 1998). Relict plagioclase phenocrysts are preserved in a mylonitic, recrystallised matrix in numerous samples, indicating their volcanic origin. A fragmental volcanic texture is also interpreted for some samples, with the apparent fragments containing fine, phenocrystic plagioclase laths; the strong fabric in these rocks has been generated by mylonitic shearing (Pontifex, 1996).

Name

Derived from the Teal Flat locality; grid reference 366 600mE, 6 140 100mN, RENMARK 1:250 000 map area.

Distribution

Teal Flat Volcanics are exposed along a 70 m section of a small, 10 m high shoreline cliff on the northern bank of an east–west-trending section of the Murray River (Fig. 7). Small, irregular exposures occur in the bank of a creek 100–200 m inland and northwest of the shoreline outcrop.

Outcrop of Teal Flat Volcanics, comprising feldspar phenocrystic andesite to dacite. (Photo 47413)

Type section

At Teal Flat, no thickness can be measured as the exposed outcrops are discontinuous and highly sheared, with an unknown amount of tectonic shortening. Original volcanic textures have been destroyed by mylonitic shearing and a later, dextral-sense brittle faulting phase.

Lithology

All rock types at Teal Flat are considered to be highly deformed original lavas or tuffs with well-developed foliated to mylonitic or phyllonitic tectonic fabrics. Rock types at this location include:

- basalt which has been retrogressively metamorphosed to green chlorite–epidote–actinolite schist
- epidote-altered basalt with silicification and associated magnetite and carbonate
- blue-grey, plagioclase phenocryst-rich andesite with some epidote and silica alteration
- blue-grey, K-feldspar phenocrystic, ?flow-banded rhyodacite (Purvis, 1996; Pontifex, 1996; Mason, 1998).

Some outcrops appear shale like, but these are interpreted as quartz–plagioclase–hornblende–biotite schist derived from plagioclase porphyritic lava (Purvis, 1996). Basalt exposed in the creek section has ferruginous lenses, with limonite formed by lateritic processes. The basalt also shows evidence of minor gossanous boxwork (after pyrite) with associated malachite (ex-chalcopyrite). A small, sill-like pod of black mylonitic amphibolite is exposed to the west of the creek section but relationships with surrounding rock units are not evident.

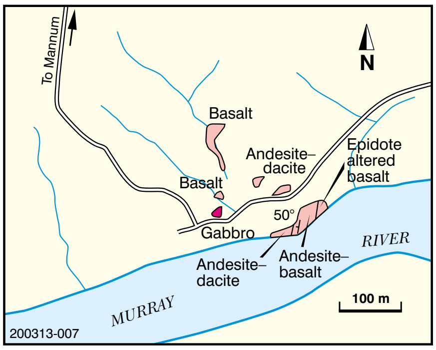


Fig. 7. Outcrop geology of the Teal Flat Volcanics.

Boundary criteria and correlation

Aeromagnetic imagery allows interpretation and extrapolation under Tertiary and younger sedimentary cover, and provides the best indication of boundary relationships and possible correlations.

The aeromagnetic image shown on Figure 3 indicates that the Teal Flat Volcanics may also correlate with the more felsic Marne River Volcanics, suggesting a possible bimodal, mafic to felsic system of extrusives. Teal Flat Volcanics are interpreted to correlate with the Truro Volcanics (Forbes *et al.*, 1972), located 60 km north-northwest of Teal Flat. Both the Truro and Teal Flat Volcanics plot as within-plate to mid-ocean-ridge type basalts on the Pearce and Cann (1973) discrimination diagram (Fig. 8). This may indicate that Teal Flat Volcanics were extruded in a similar extensional tectonic setting to the Truro Volcanics. The Teal Flat and Truro Volcanics may also correlate with volcanics intersected beneath the Murray Basin in the Coomandook, Yumali and Coonalpyn areas, which have similar lithologies, geochemical composition and tectonic setting (Fig. 8; Rankin *et al.*, 1991; Hill, 1995).

Age

Teal Flat Volcanics are assumed to be Cambrian due to the likely correlation with the 521±4 Ma Marne River Volcanics and 526±4 Ma volcanic tuff of Cooper *et al.* (1992).

Synonym

None.

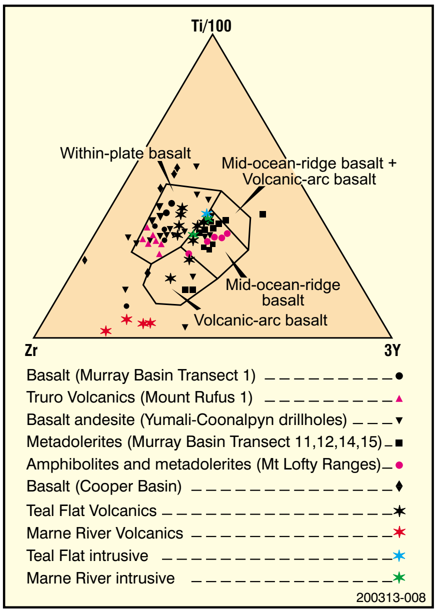


Fig. 8 Pearce and Cann (1973) tectonic discrimination diagram for Marne River and Teal Flat Volcanics.

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