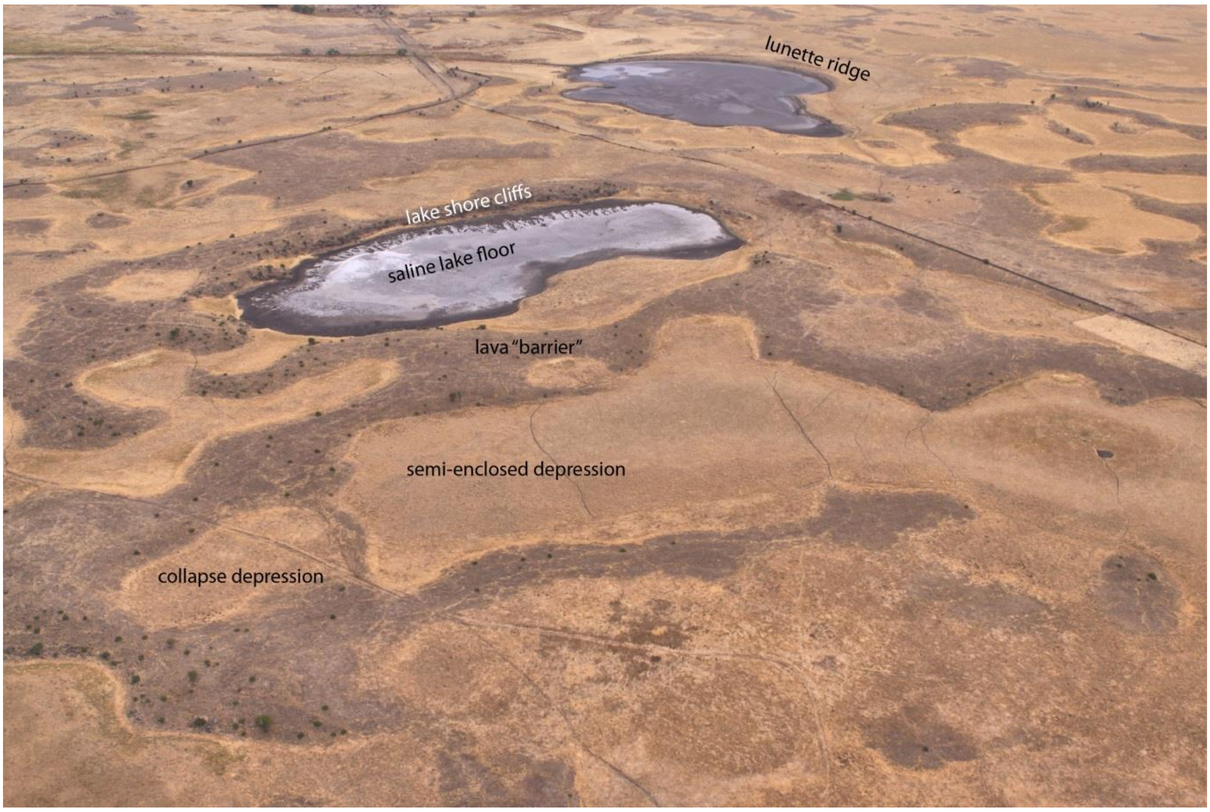
PROPOSED MOUNT FYANS WIND FARM

GEOHERITAGE ASSESSMENT



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Report Prepared for Hydro Tasmania

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EXECUTIVE SUMMARY

This report, prepared for Hydro Tasmania, details the geology and geomorphology of an area proposed for a wind farm north of Mortlake in western Victoria. It describes the nature and origin of the physical landscape, assesses the geoheritage values of the area, considers potential impacts of the construction and operation of the proposed wind farm on these values, and provides recommendations to avoid and/or minimise impacts. The report also outlines other potential geoscience constraints.

The proposed wind farm encloses 12,395 hectares and extends from northwest of Mortlake to the rural district of Dundonnell. The terrain is developed on basalt lava flows of varied age of the Newer Volcanic Province of Victoria. The oldest lavas of the area were emplaced three to four million years ago and covered the existing landscape developed on older rocks of Palaeozoic and earlier Cainozoic age. This initial volcanic landscape has been substantially reshaped by deep weathering and erosion and is now an undulating plain of low relief cut by the deeply incised valley of Salt Creek. This older volcanic terrain has features of moderate to low geoscience significance.

Two areas of younger volcanic activity included in or adjacent to the proposal preserve original volcanic attributes of high geoscience significance. In the northeast the proposed wind farm encloses 2,300 ha of younger lava flows from Mount Fyans volcano although the eruption point is some distance north of this area. No absolute date has been determined for this eruption but comparison of the landscape with other dated lavas e.g. Mount Rouse at Penshurst, suggests a time of eruption approximately 300,000 years ago. The lava field includes very clear examples of primary lava flow surfaces including elongate mounds and ridges little modified by weathering and erosion, and several large, complex depressions containing intermittent lakes fed by groundwater flows. These lava features are part of a broader complex (including Mount Hamilton and other nearby eruption centres) that is of State Significance. The Mondilibi eruption centre, a cone of scoria and lava 11 km north of Mortlake, is contained in the proposed wind farm and is a feature of high geoscience significance, as is the Mount Shadwell eruptive complex immediately north of Mortlake and adjacent to the southern margin of the proposed wind farm.

No lava caves are known from any lava source (including Mount Fyans, Mondilibi and Mount Shadwell) in the proposed wind farm area. An unusual feature of part of the Mount

Fyans lava is a concentration of active freshwater discharge sites with well-defined outflow channels terminating in lake basins. These are some of the best examples of groundwater outflow in any area of the Newer Volcanic Province in Victoria. The irregular primary surface of the younger Fyans lava contains many shallow depressions now with ephemeral and intermittent wetlands. Several of the larger and deeper of these are now well-defined basins with rocky cliffed margins with semi-permanent brackish lakes and remnant beaches and wind-blown lake shore ridges or lunettes. Broad, shallow semi-enclosed basins have also developed at the margins of the Mt Fyans lavas flows.

The area proposed for construction and operation of the wind farm contains sites of geoheritage value. These have a range of significance levels and could be variously impacted by construction and operation of a wind farm. The key geoscience values of the area can be maintained and the effect on individual geoscience sites minimised if the planning, development and operation of the wind farm incorporates the following general principles:

(a) Recognises the nature and extent of geoscience sites as potential constraints.

(b) Avoids building on or otherwise physically reshaping identified areas and features of high geoscience significance.

(c) Locates turbines and associated infrastructure (including roads) and using construction techniques to minimise overall impacts on all geoscience features of significance.

This report contains details of these areas and sites and provides guidelines for construction and operation of the proposed wind farm that will be consistent with maintaining geoscience values.

1 INTRODUCTION

Hydro Tasmania (ABN 48 072 377 158) commissioned Environmental GeoSurveys Pty Ltd (ABN 56079 889 679) by contract signed 10/01/2013 *Mt Fyans Wind Farm: Geoheritage Assessment*, to investigate aspects of the geology and geomorphology of an area of 11,435.7 hectares north of Mortlake in western Victoria (Figure 1).

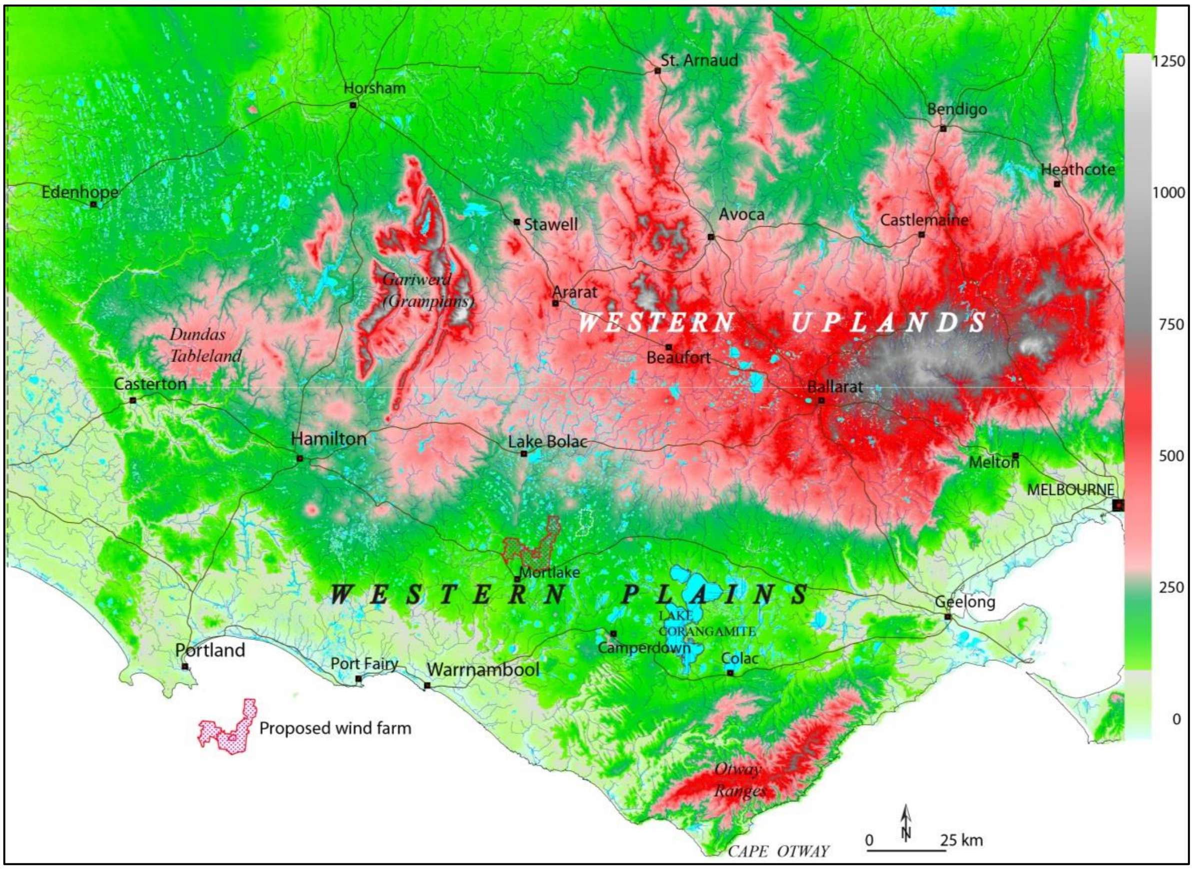


Figure 1. Location of proposed Tasmania Hydro wind farm north of Mortlake, Victoria.

The site extends from the Hamilton Highway 5 km east of Mortlake for 17 km north to the Woorndoo-Dundonnell Road and from Six Mile Lane for 14 km west to Salt Creek (Figure 2). It is rural land used predominantly for beef cattle and sheep grazing with areas of cropping. Mortlake is the only commercial centre close to the proposed wind farm boundary. Apart from a public hall, there are no other community facilities at Dundonnell to the north of the site.

The specific requirements of the contract are to:

- Outline the geology and landforms at a regional and local level
- Outline the methodology for determining geoheritage values
- Map, assess and rank features of geoheritage significance at the Mt Fyans site

- Outline the sensitivity of sites to disturbance.

The report contains four main sections:

- A description of the nature and evolution of landforms in the context of the geological materials and geomorphic processes of western Victoria.
- An assessment of the geoscience/geoheritage values of the areas of the proposed wind farm in the local, regional, state and national context.
- An assessment of the perceived constraints and opportunities for wind farm development based on geomorphology, general geotechnical properties of geology, soil and regolith and geoheritage of the site.
- Recommendations relating to wind farm layout, construction and operation to reduce the impact of the wind farm on areas of geoscience significance.

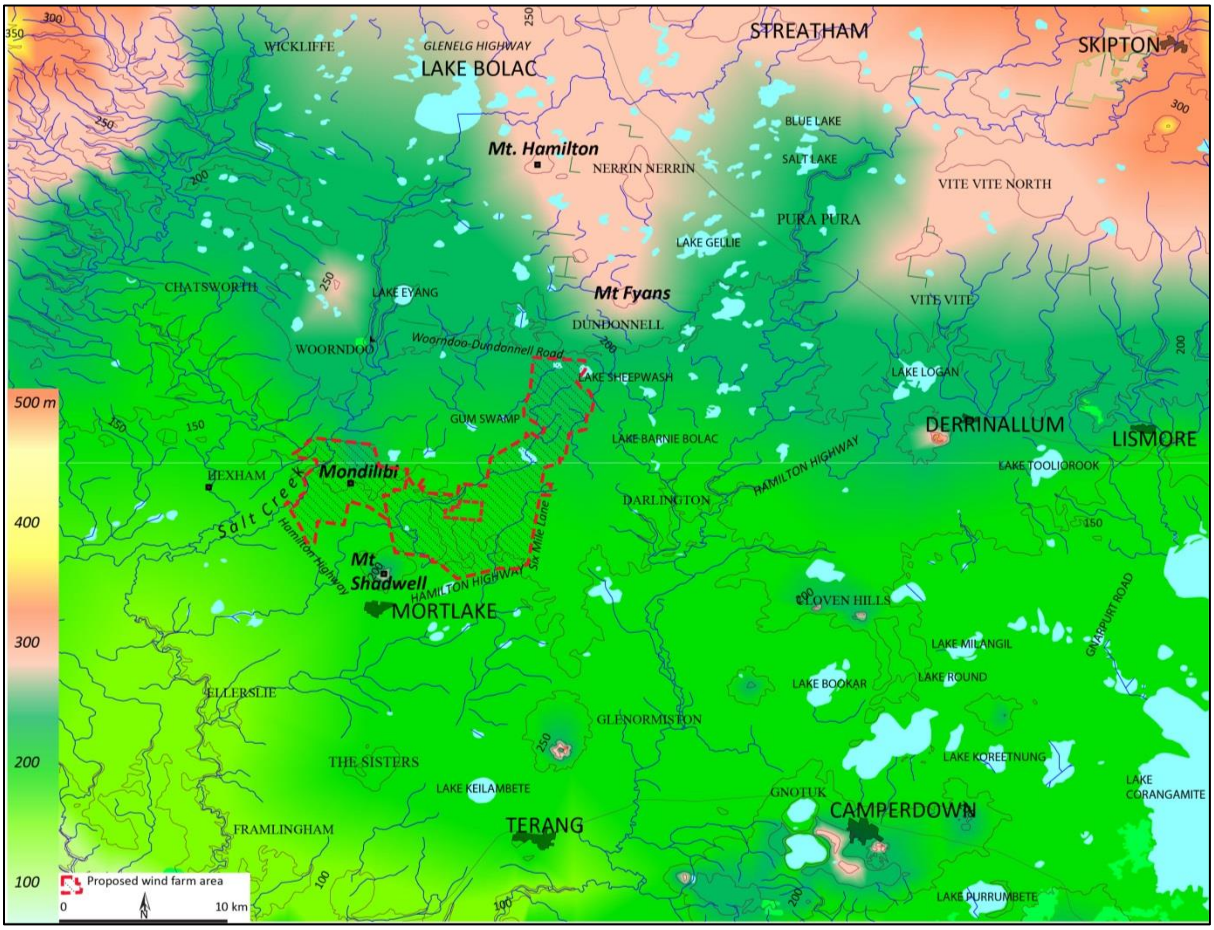


Figure 2. Regional topographical context and towns near proposed Tasmania Hydro wind farm.

The report is based on the author's background knowledge of the volcanic regions of western Victoria gained from previous studies (Rosengren 1994, 1996, 2005, 2006, 2008a, 2008b, 2011, 2012), supplemented by desk and field study of the proposed wind farm area. Details of the earth science properties and values of the site were obtained initially from available literature, topographical, geological and soil maps, aerial photography, satellite and geophysical images and bore records. Tasmania Hydro supplied digital files with high-resolution vertical aerial photography, contours at 0.2m interval and Lidar imagery. From initial photo and Lidar interpretation, areas were selected for detailed field study. With permission from property owners or managers, detailed observations of part of the terrain were made using 4WD vehicle access and walkover on November 19, 2012 and between January 10-13, February 9-11 and March 1-3, 2013. High fire danger including Total Fire Ban days decreased the field inspection time. Low-level aerial inspection and photography was obtained from an Air Warrnambool Cessna 172 aircraft on Jan 14 and March 4, 2013.

Key areas were targeted for field survey: (a) outcrops of stony lava, (b) the floor and margins of lakes, (c) active and abandoned stream channels, (d) the valley of Salt Creek. There was good ground visibility for these field surveys.

Discussion regarding the physical character of the site was held with several property owners engaged in the proposed wind farm, and with geologists Professor Bernie Joyce (University of Melbourne), Mr. Ken Grimes (Regolith Mapping Pty Ltd, Hamilton) and Professor Ray Cas (Monash University) who are specialists in the volcanic terrain of western Victoria.

No specific testing or investigation of the properties of materials was conducted for this report and the geological and landform descriptions and assessments of processes are qualitative or based on previous studies sourced from literature.

2 REGIONAL CONTEXT

2.1 Landform

The proposed wind farm is on the Western Plains of Victoria, a broad low-lying undulating plain formed on Cainozoic volcanic and sedimentary geology. This site is located on volcanic plains of late Cainozoic (Neogene) age and is immediately southeast of an irregular block of higher Palaeozoic bedrock terrain (the Mt Staveley Block) that extends southeast from the southern Grampians as a salient above the volcanic plain (Figure 2).

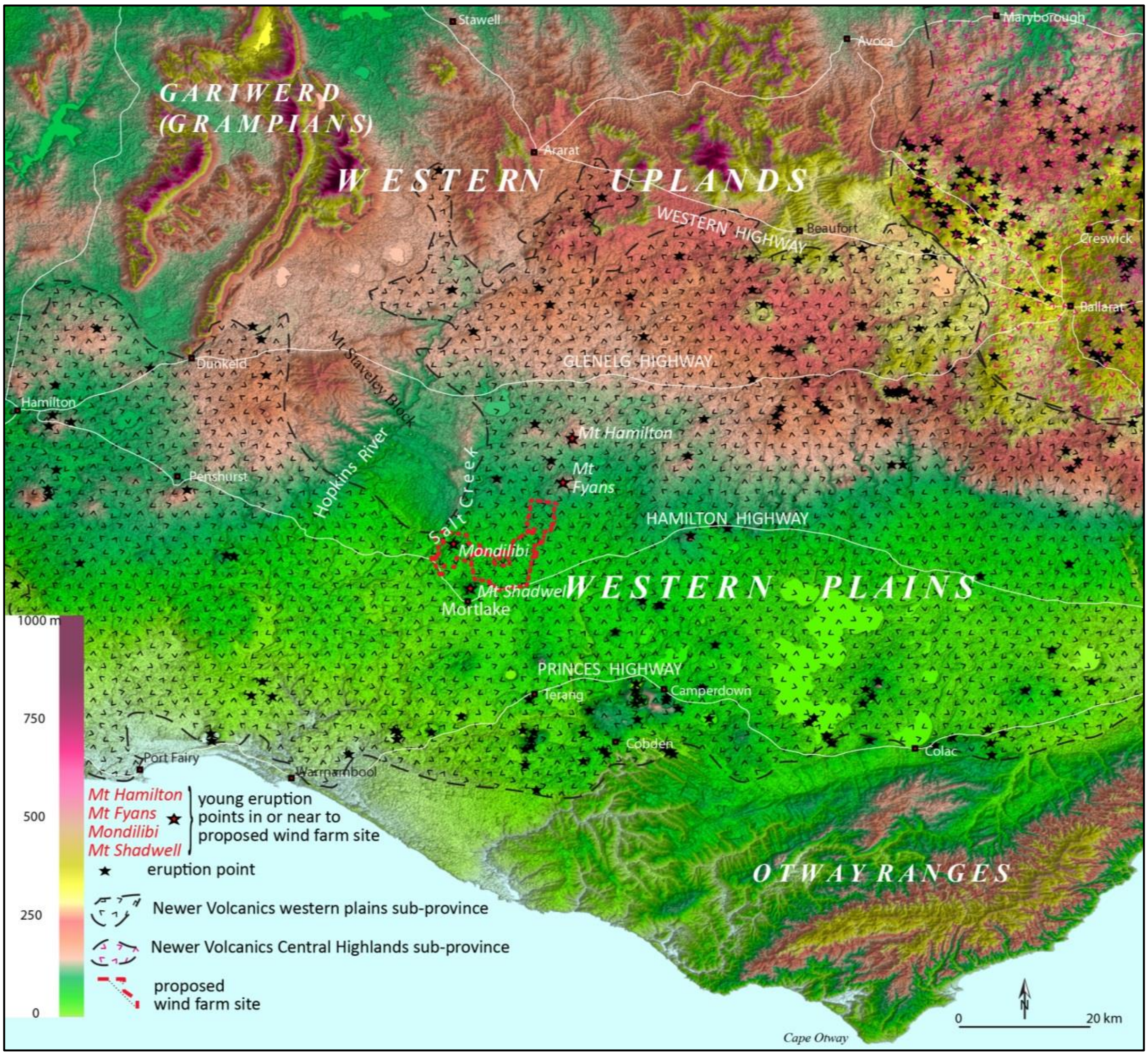


Figure 3. Regional volcanic context of proposed Tasmania Hydro wind farm north of Mortlake.

The terrain of the Staveley Block is typically low rounded hills up to 370 m elevation incised by the valleys of the Hopkins River and Salt Creek. Around the Staveley Block at lower elevation are undulating to flat surfaces of lava plains. Conspicuous hills such as Mount Hamilton that rise above the general elevation of the plains are eruption points of basalt lava. Where the eruptive products include scoria the hills are higher and steeper, such as the multiple mounds and craters of the Mount Shadwell eruption centre north of Mortlake and Mount Elephant at Derrinallum.

Streams draining the southern slopes of the Western Uplands in Victoria have limited catchment area and the relatively low elevation and moderate rainfall reduces runoff. Only the Hopkins River and Mount Emu Creek that rise in areas of higher terrain and rainfall have valleys incised into the lava plains and in places cut through the lava exposing pre-volcanic geology including Palaeozoic bedrock. Smaller local catchments on the plains are weakly incised and often terminate in depressions and lakes. Salt Creek, a tributary of the Hopkins River and a major valley across the western part of the proposed wind farm site carries the overflow from Lake Bolac and is a palaeovalley (former channel) of a larger drainage system now diverted by younger lava flows.

The lava flows of the Western Plains successively disrupted the pre-volcanic and intra-volcanic drainage by diverting or damming streams. New stream systems and numerous lakes and swamps developed in accordance with the changed topography including areas of closed or internal drainage (lakes without surface overflow). A feature of the western plains lava surfaces now is numerous wetlands, ranging from hypersaline to fresh and in scale from the large permanent Lake Corangamite to hundreds of small, ephemeral and intermittent lakes and swamps.

2.2 Geology

The deep bedrock of the area is Cambrian to Silurian marine and non-marine sediments intruded by granites of Devonian age (Buckland 1986). A major geological structure that defines the landforms of this part of the volcanic plains is the Stavely Block including the Mount Stavely Volcanic Complex. This belt of metamorphosed Cambrian sedimentary and volcanic rocks is exposed along north-south trending fault systems and forms the low hills and ridges west of the Hopkins River. Salt Creek follows the alignment of the Woorndoo Fault - a north-south structure downthrown to the east and part of the Woorndoo Fault zone, a north-south tectonic structure of sub-continental proportion and significance (Foster and Gleadow, 1992). The older rocks crop out only to the west of the Woorndoo Fault. Cambrian age sediments and volcanics and Silurian sedimentary rocks have been uplifted to the west where they are largely covered by a Pliocene-Pleistocene laterised sand and gravel unit 15 metres thick overlying non-marine Eocene-Oligocene sands and gravels. Below these is deeply weathered granite (Figure 4). Parallel to Salt Creek on the western valley side and extending from south of Woorndoo to Lake Bolac is a narrow linear outcrop of Silurian sandstone. This forms a prominent low east-facing scarp with relief of 15 to 20 metres and marks the eastern edge of the distinctive non-volcanic terrain of the Stavely Block, compared with the lava and lake dominated terrain east of Salt Creek.

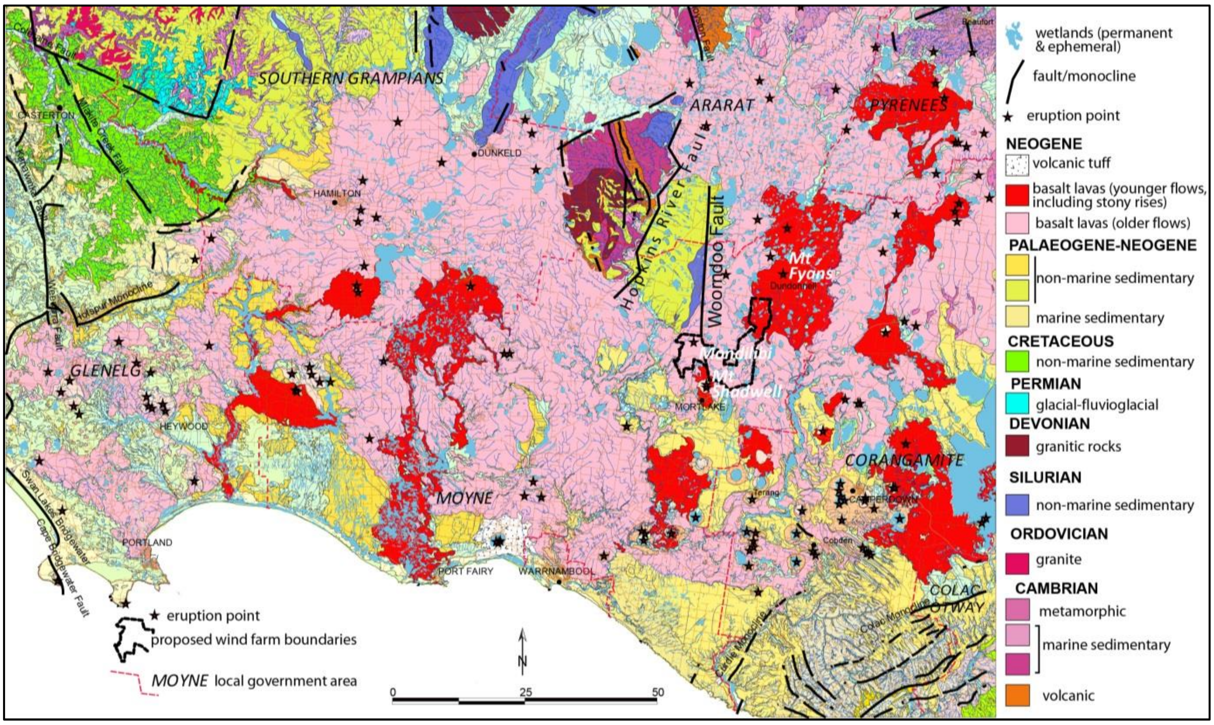


Figure 4. Regional geological context of proposed wind farm (after Geological Survey Victoria 1:250,000 geological maps).

On the uplifted Stavely Block west of the Hopkins River the unconsolidated sedimentary beds have been eroded and the surface is dissected with an intricate network of small streams. By comparison, between the Hopkins River and Salt Creek, the sand body is continuous and is shaped as a series of gently curving parallel ridges and intervening depressions with strings of interconnected saline lakes and swamps. These show clearly on radiometric total count images (Figure 5). Deposits of similar composition, age and landform character occur across many areas of southern and western Victoria into the Murray Basin (Brown and Stephenson 1989, Kotsonis 1995, Holdgate and Gallagher 2003). They are interpreted as marine strandline or foreshore deposits emplaced during successive marine transgressions and regressions between 4 million years and 6 million years ago (Paine *et al.* 2004), and subsequently uplifted. In the downfaulted area east of Salt Creek, occasional outcrops and magnetic and thorium anomalies evident on the radiometric images indicate remnants of these sands continue underneath the basalt. East of the Woorndoo Fault, the downfaulted lower terrain has been covered by successive eruptions of basalt lava. Local accumulations of alluvium and wind-blown sediment occur around active and palaeo-lake depressions.

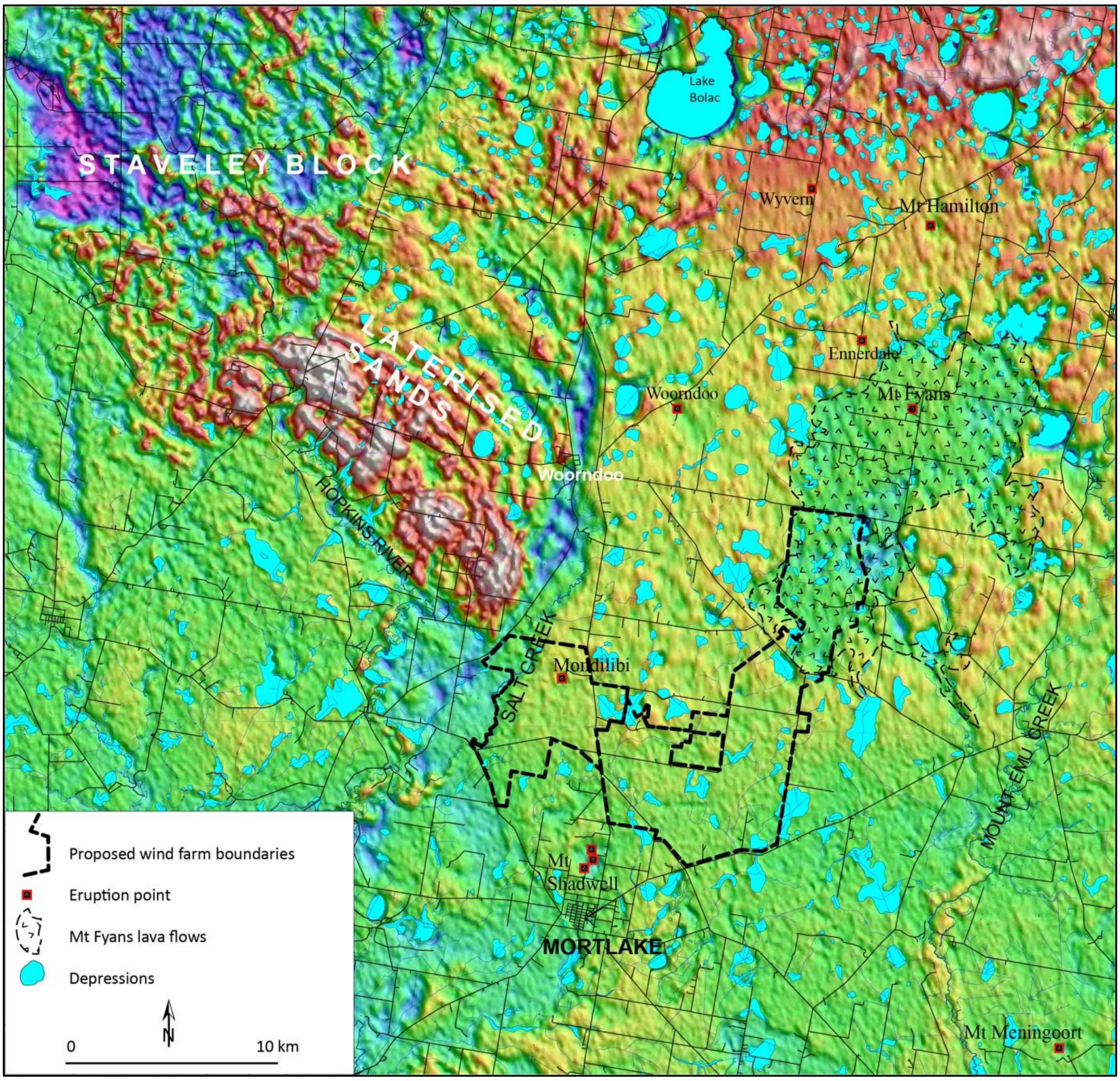


Figure 5. Radiometric total count image of the Staveley Block, laterised ridges and adjacent volcanics including Mount Fyans lava flows (Source: Geoscience Victoria).

2.2.1 Volcanic geology and geomorphology

The volcanic plain of the site is part of a broad basaltic lava province active over the past 6 million years and referred to as the Newer Volcanic Province (NVP) of south eastern Australia. The western Victorian volcanic plain is a sub-province of the NVP. The NVP is now known to be comprised of over 700 known eruption points, the products of which cover an area of 19,000 km^2 (Boyce 2013). This is a much greater number of eruption points and a larger area of volcanic terrain than the previously accepted figures of ~400 eruption points and 15,000 km^2 e.g. (Ollier 1967, Joyce 1988, Rosengren 1994). The most voluminous product was basalt lava issued as cohesive and relatively fluid streams from fissures and low-level vents (i.e. eruption points) as continuous or closely spaced pulses or surges that lasted from a few minutes to several weeks. A continuous surge of lava is referred to as a flow unit and lava from a single eruption point produces multiple flow units over an eruptive episode. The combined flow units of a single eruption point constitute a lava flow.

Most eruptions, such as Mount Fyans, also produced a variable volume of fragmental lava or scoria. The scoria-rich volcanoes are conspicuous as higher, steep-sided mounds or cones such as Mount Elephant and Mount Shadwell while those dominated by lava flows are broad, lower angle domes or ridges such as Mount Hamilton. Some volcanoes have shallow summit craters but in many instances the waning eruption sequence filled the crater with the last lava units. A small group of explosive eruption points formed broad, circular craters now containing lakes or swamp and surrounded by a low rim of basaltic tuff.

The NVP volcanoes are numerous but individually were short-lived with eruptions ceasing after a few months. Most eruption points experienced only one phase of more-or-less continuous activity (monogenetic) and the relatively fluid character of the lava and the short eruption time restricted the vertical growth of individual volcanoes. The NVP is therefore a monogenetic areal basalt field (Joyce 2004).

As with a number of western Victorian volcanoes, lava from some of these eruption points flowed long distances – e.g. tens of kilometres - following shallow, low gradient valleys and in places spilling across the adjacent plains. Lava from high volume effusive eruption points such as Mt Hamilton and Mount Fyans initially flowed in a radial pattern but the main volume of lava moved south of the vent following the regional slope.

Attempts to develop a chronology of eruptions have been based on a variety of direct and proxy methods of determining age of lava emplacement. The most direct and reliable are radiometric dating - mainly potassium-argon of basalt, and carbon 14 dating of organic materials overlying and/or underlying volcanic deposits and in volcanic craters). Recent reviews incorporating earlier and newly determined ages (Gibson 2007, Gray and McDougall 2009) have confirmed the onset of volcanism in western Victoria at around 4.6 million years (Ma) with a peak activity at around two Ma. The youngest eruptions were approximately 30,000 years ago.

2.2.2 Volcanic regolith

As the volcanic eruptions occurred intermittently over several million years, there are varying degrees of weathering and preservation of primary volcanic surfaces. Weathering and soil development results in more subdued topography on the older flows but many have deep valleys developed by stream incision. Qualitative means of aging the lava and distinguishing individual flows was initially based on aerial photographs and field mapping of landform, regolith and soils, supplemented in recent years by high resolution airborne radiometric imagery (individual channel, ternary and total count) and digital elevation models (Joyce 1999, Bennetts *et al.* 2003). These provide more detail than previous studies, including differentiating individual flows and eruption points.

The surface expression of the lava in the project area varies from highly weathered early phase flows now deeply incised by Salt Creek, to younger eruption points of Mondilibi and Mount Fyans. The younger features preserve accumulations of scoria and the original form of the lava fields as an irregular landscape of elongate ridges and mounds with abundant surface stones and outcrop. This distinctive volcanic terrain is known as "stony rises" and is characterised by mounds and ridges of broken basalt blocks enclosing depressions with little or no stone. Local relief of 3 to 10 metres occurs along narrow, steep-sided ridges with local basalt scarps and deep depressions (Figure 6).

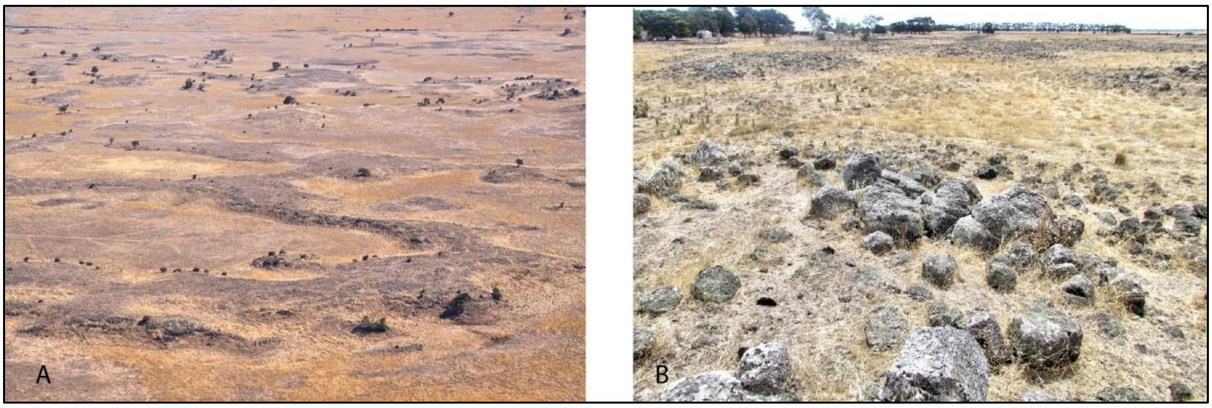


Figure 6. Stony rises, Mount Fyans lava flow south of Woorndoo-Dundonnell Road , aerial oblique (A) and ground photograph (B). (Photographs N. Rosengren, Feb 2013)

The youngest lava surfaces in this study area retain many clear expressions of new lava flows although in parts modified by weathering, agricultural land use (including stone removal and use in buildings and drystone walls), wetland draining and scoria quarrying.

Bennetts *et al.* (2003) recognised three phases of volcanic activity in the Hamilton district and these categories can be applied to the area of the present study. Joyce (1999,

2003) proposed five broad age groups of volcanic activity in the NVP in Victoria based on thickness of weathering and the occurrence of stony rises resulting in different landscape and soils. He named these units after type localities – either volcanic regions or eruption points (Figure 7).

H = Hamilton [region]: earliest/oldest eruptions - 6 million to 4 million years ago

C = [Mt] Clay: earliest eruptions - 4 million to 3 million years ago

D = Dunkeld [region]: intermediate age - 3 million to about 1 million years ago;

R = [Mt] Rouse: younger eruptions - 1 million to about 300,000 years ago

E = [Mt] Eccles: youngest eruptions younger than 300,000 years ago.

The oldest lavas (H and C) form the main body of the western Victorian volcanic plains from Werribee to west of Portland. They feature deep regolith and soil profiles with mottled clays and ironstone nodules and very little surface or near-surface basalt stones. The lavas of intermediate age (D) typically have less than 2 metres of regolith with black swelling clays forming gilgai, (depressions and mounds) and numerous small wetlands on gently undulating, relatively stone-free plains. The youngest lava flows (R and E) have well-preserved flow features, often with rocky outcrops, steep-sided linear ridges and irregular, stony surfaces with relief of ±10 metres (stony rises) and little or no soil cover. These young flows are associated with lakes and swamps both at the margins and on the flow surfaces, due to disrupted drainage. The map by Joyce (1999) [Figure 7] shows lavas in and adjacent to the Mt Fyans site are mainly D (Dunkeld) with an area of R (Rouse) and H (Hamilton).

2.3 Geoscience Significance – Overview

The volcanic and associated terrain features of western Victoria include sites of Local to National geoscience significance. The entire NVP is a geoscience complex of National Significance. It is a key component in understanding tectonic and volcanic evolution of a large area of south-eastern Australia and provides insight to the evolution of a landscape developed by volcanic and post-volcanic processes. When assessed at the landscape scale (e.g. the scale displayed on Figure 4 (page 6) above), the diversity of geological and geomorphological features presents a geoscience complex of National Significance. This rating is based on the diversity of geological and landform features illustrating a range of processes of rock and landform development spanning a time interval of at least 4 million years. There are discrete features and areas inside the proposed wind farm site that are of high geoscience significance and contribute to the regional National regional rating suggested above. The entire Mount Fyans eruption point and associated lava flows are of State Significance and some individual sites in the present study area are assessed as State Significance.

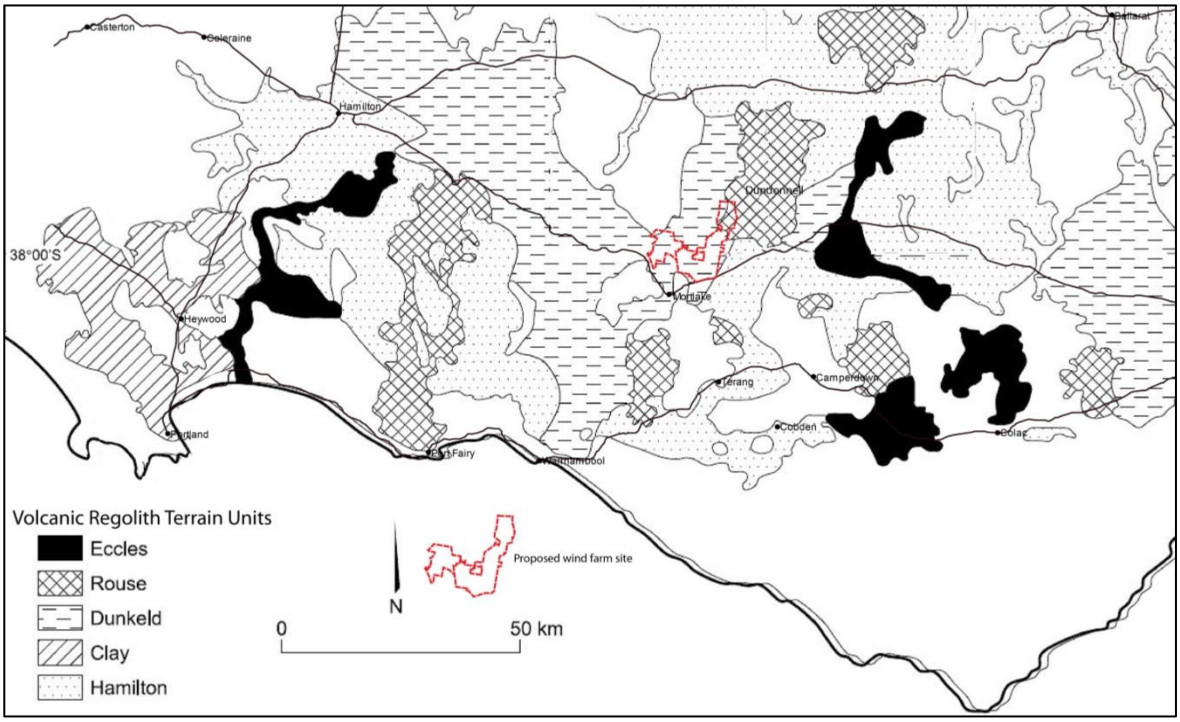


Figure 7. Regolith context of proposed wind farm (after Joyce 1999).

3 PROPOSED MT FYANS WIND FARM – GEOSCIENCE FEATURES

3.1 Geology

The site occurs in that part of the NVP with lava flows of varied ages. It encloses areas of variably weathered basalt lava ranging from the complex terrain of stony rises with continuous outcrop to broad undulating to flat surfaces with no surface stone. Although stony rises occur in places, they are from flows in the several hundred thousand year age bracket and not comparable with the youngest flows (<50,000 years) from Mount Eccles and Mount Napier. The lava areas are from multiple sources including the Mount Fyans, Mondilibi, Woorndoo, Wyvern and possibly Mount Shadwell eruption points (Figure 8).

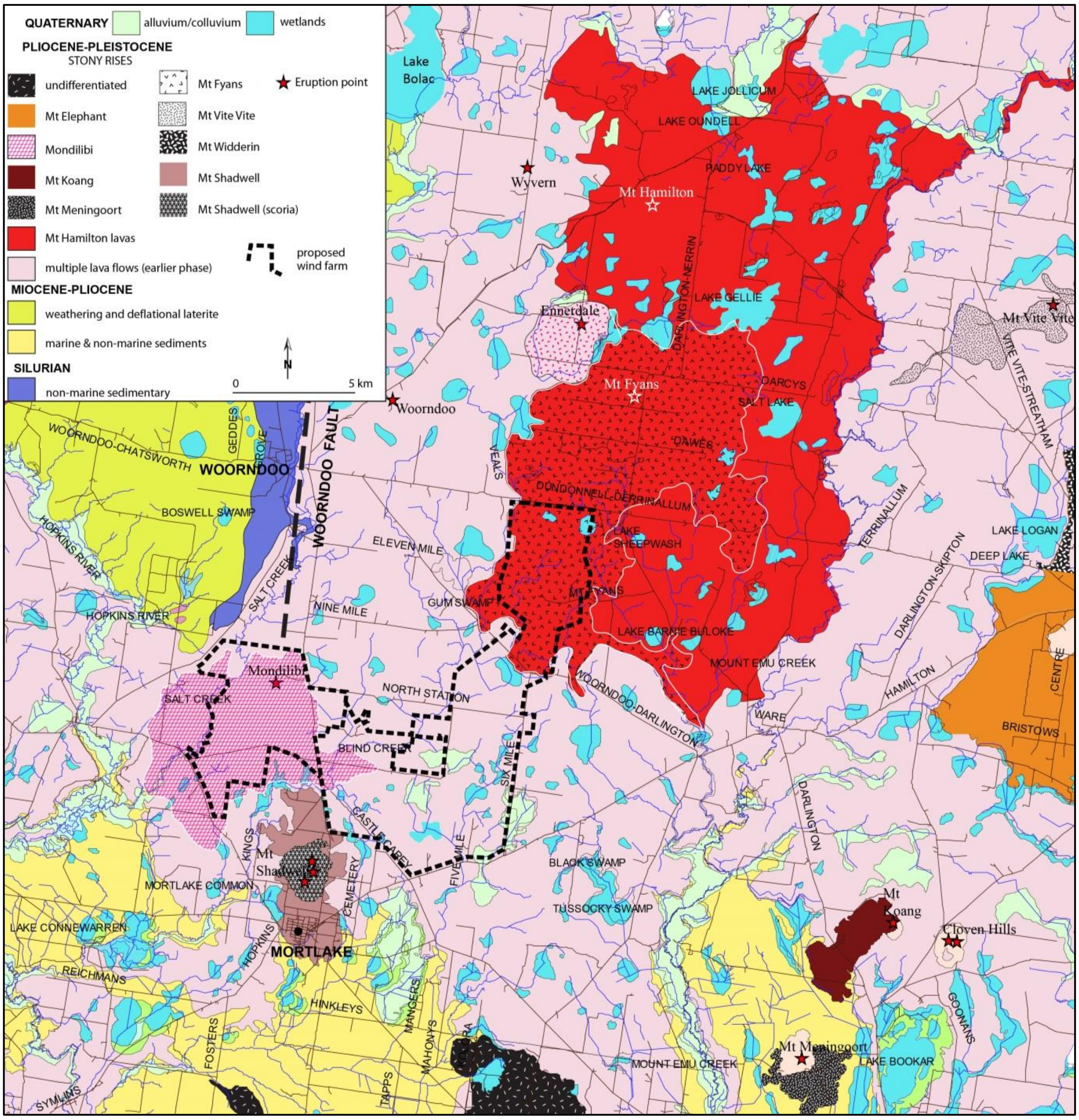


Figure 8. Geology of the region containing the proposed wind farm.

The lava distribution shown on Figure 8 and Figure 9 is based on published geological maps Willaura, Skipton (1:100,000), Hamilton, Ballarat (1:250,000), unpublished Honours thesis mapping MacInnes (1985) supplemented by interpretation of contour, aerial photographs, Total Magnetic Intensity and Lidar images and selective field and aerial inspection between Nov 2012 and March 2013.

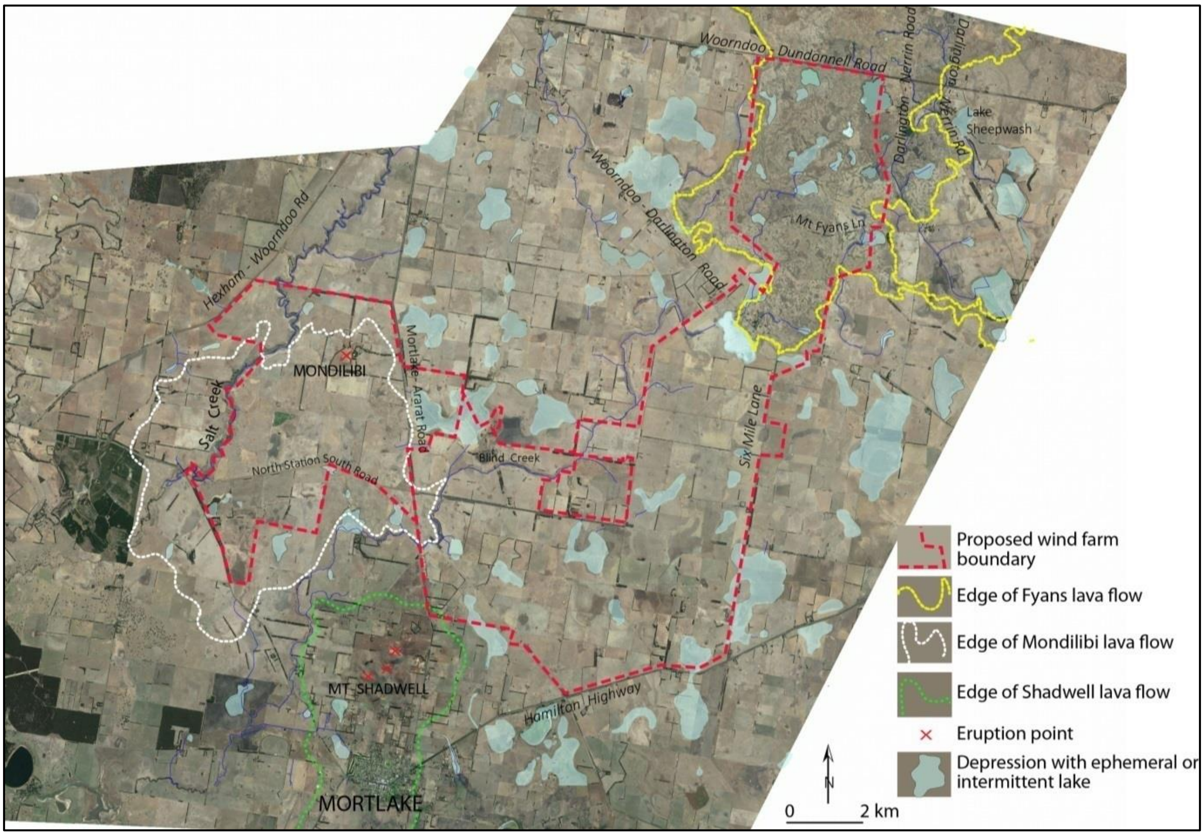


Figure 9. Lava flow boundaries (Mt Fyans, Mondilibi, Mt Shadwell).

3.2 Geomorphology

The site has an irregular to undulating surface with localised areas of flat terrain and the hill of Mondilibi volcano. Salt Creek channel is deeply incised into the lava surface along part of the western boundary of the site. Blind Creek is a defined channel and follows a boundary between lava flows but all other drainage lines are weakly defined. A characteristic of all surfaces are enclosed and semi-enclosed depressions of varying depth and delineation with ephemeral to semi-permanent lakes. Many of these are artificially drained.

The lava chronology and stream and lake sequence developed by the lava flows of the broader region is summarized in Figure 10 (MacInness 1985, Grimes 2006).

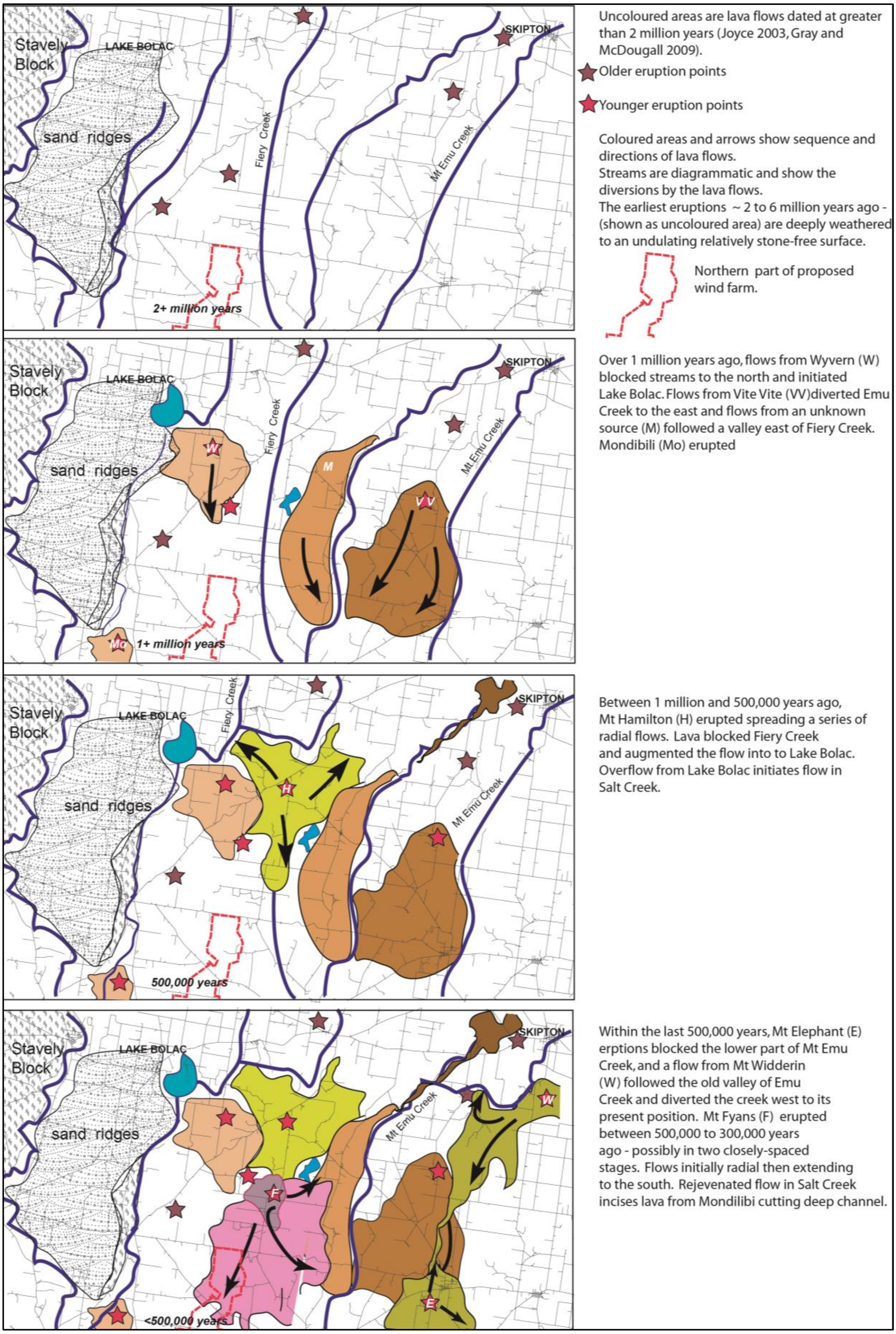


Figure 10. Diagrammatic sequence of lava flows and stream development, Mount Fyans and nearby volcanoes (after MacInness 1985, Grimes 2006).

The modern landscape has been shaped by rapid emplacement of multiple sheets and streams of fluid basalt from discrete eruption centres that were active only for short periods. As well as comprising the rocky surface and sub-surface of the site, the lava flows have controlled the orientation of streams and the development of lakes and swamps at the margins of flows and on the flow surfaces. A wide range of lava surfaces occur. The oldest lavas are deeply weathered forming broad, gently undulating topographically simple surfaces with sparse outcrop. On many properties, remnant loose stone and boulders have been cleared or consolidated into piles. By comparison the youngest flows from Mt Fyans are very complex with much greater relief of rounded and flat-topped stony ridges and hummocks and elongate depressions with thin, intermittent soil cover. Lateral and distal margins of the flows are very obvious in the field and on aerial images.

3.3 Mount Fyans lava

The Mount Fyans eruption centre is five km north of the Woorndoo-Dundonnell Road immediately west of the Dundonnell-Nerrin Road. It is broad, low ridge of lava with a small accumulation of scoria (Figure 11).

Figure 11. Mount Fyans eruption point. (Photo N. Rosengren Feb. 2011).

There are at least two and possibly four phases of Mount Fyans basalt flows and several short-lived episodes of scoria eruption. All lava flows produced substantial stony rise terrain as a result of local lava pooling and release via channels and lava tubes. The youngest event is an eruption of scoriaceous basalt that forms a thin capping on the black scoria exposed in the quarry. The lavas spread predominantly to the south and extend 13.3 km from the vent to the distal margin south of Woorndoo-Darlington Road. In the present study area, lava from Mount Fyans extends seven km south from the Woorndoo-Dundonnell Road in a zone up to five km wide (figure 12). Of the 114 km^2 total area of Mount Fyans lava, 22.3 km^2 or 19.5% is enclosed by the proposed wind farm site, including most of the distal part of the flows.

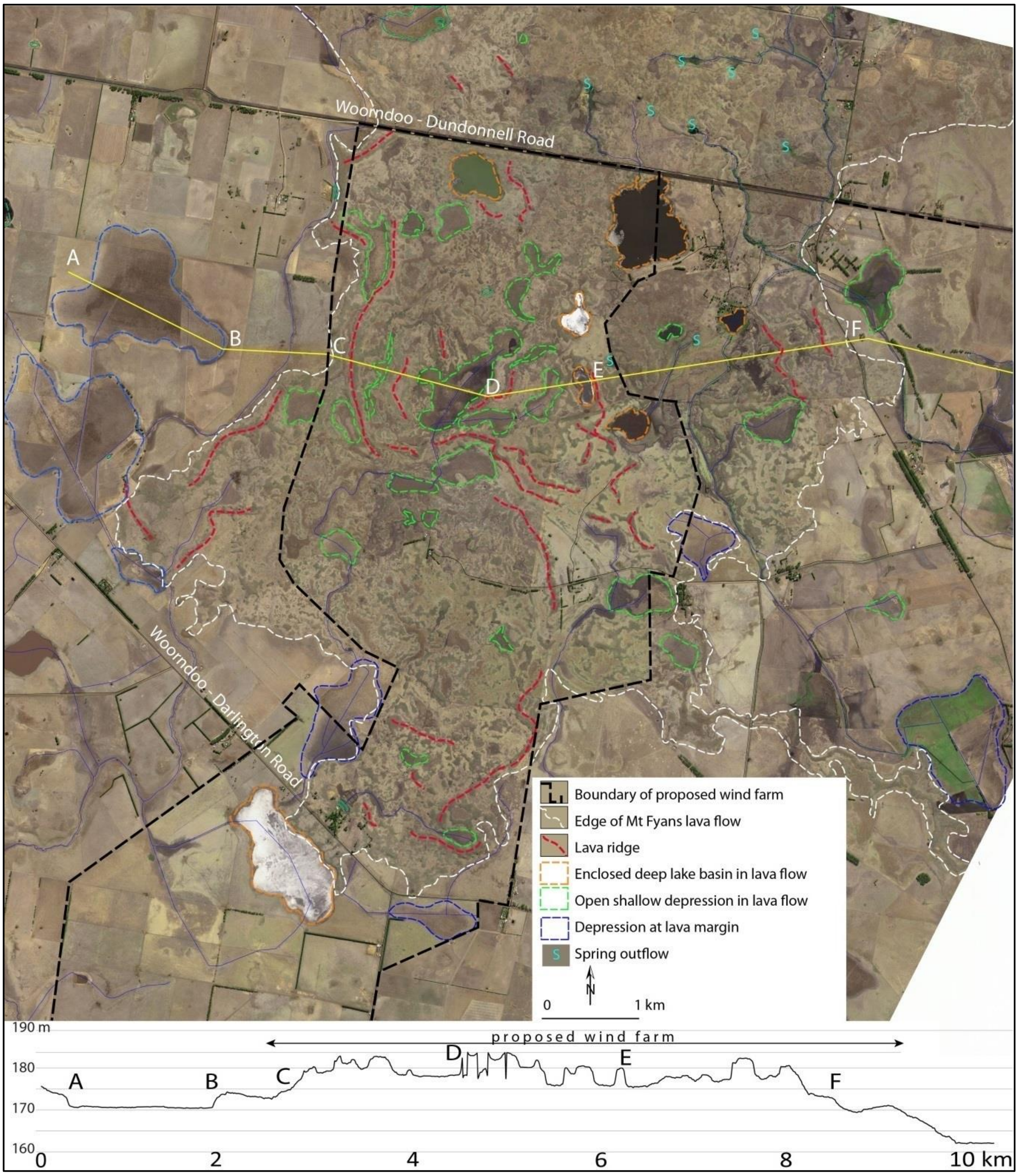


Figure 12. Geomorphic and surface water features of Mount Fyans lava flow in study area shown on a vertical aerial photograph. Profile derived from 1 metre contour DEM.

The lava forms a broad elevated plateau with an uneven surface of elongate lava ridges and depressions and tumuli (high steep rocky mounds). The regional slope of the lava surface declines along the length of the flow, from a high of 3% below the eruption point to 2.7% from Post Office Lane to Woorndoo-Dundonnell Road to 0.5% at the distal end of the flow (Figure 13).

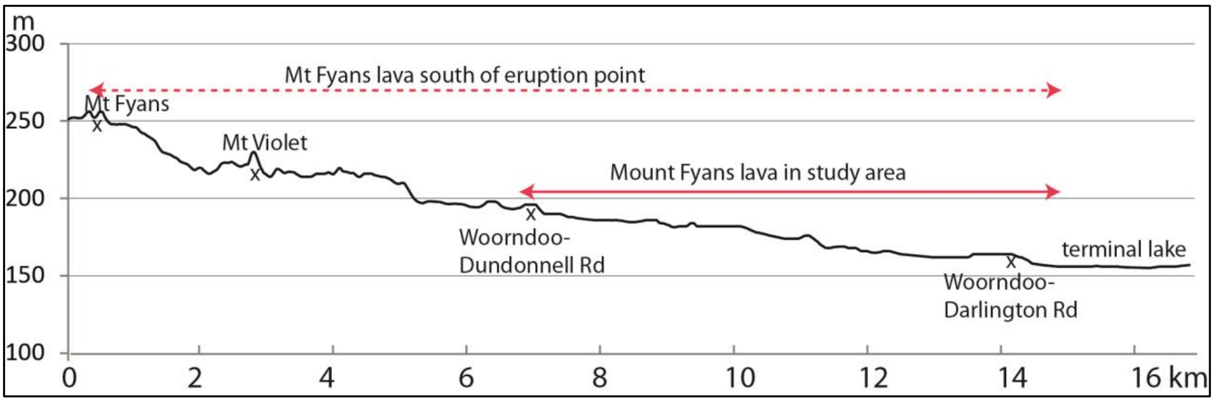


Figure 13. Long profile of Mt Fyans lava south of the eruption point.

With a limited catchment, there are no major stream courses across or lateral to the Mount Fyans lavas and the drainage is disorganised with numerous shallow, enclosed and semi-enclosed internal drainage basins and several larger semi-permanent lakes. Several lakes have high, rocky and in places cliffed palaeo-shorelines indicating prior deeper and permanent water bodies with locally effective wave action to erode these (Figure 14).

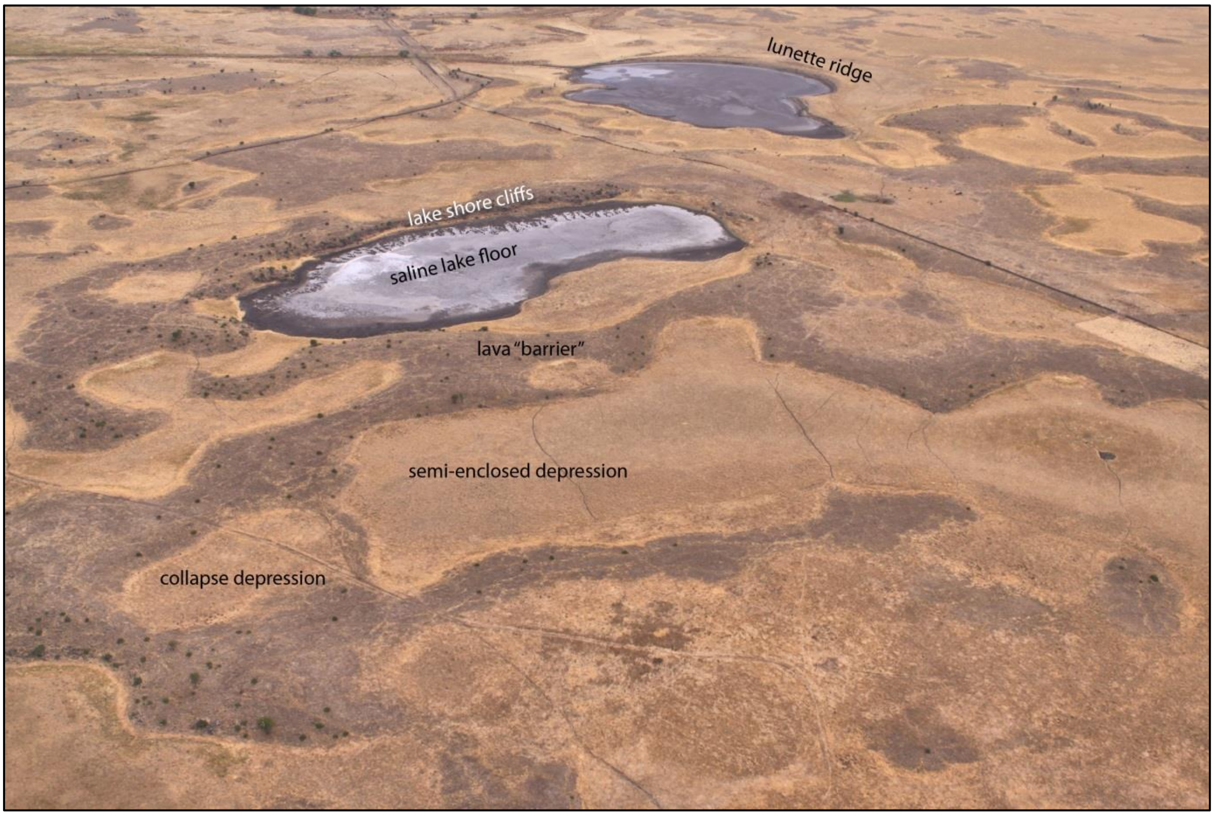


Figure 14. Ridges, depressions and lunettes, Mount Fyans lavas 2.6 km south of Woorndoo-Dundonnell Rd (Photo N. Rosengren Jan 2013).

Groundwater outcrop is a significant local source of surface water flow in the Dundonnell area with several substantive, permanent spring outflows that drain through natural and partly excavated channels and terminate in lakes. The major occurrences are north of Woorndoo-Dundonnell Road and west of the Darlington-Nerrin Road (Figure 8). At least three occur inside the area of the proposed wind farm and several of the lakes south of Woorndoo-Dundonnell Road are fed in part by these including the largest lake immediately south of Woorndoo-Dundonnell Road west of "Mount Fyans" homestead (Figure 15).

Figure 15. Spring (S) and permanent, brackish lakes fed in part by channel from springs (arrows show point of inflow). (Photo N. Rosengren Jan. 2013).

Lunettes occur on part of the margins of some active and remnant lakes. These smooth-surfaced, gently convex ridges of silty and clay were blown from the lake floor and edge during either lake-full or drying episodes. These features indicate long periods of deflation and deposition that has buried the rocky lake-edge topography (Figure 16). They are some of the largest aeolian features on lava flows in Victoria.

Figure 16. Long lunette (broken line) at palaeo-lake shoreline (blue line) burying lava surface. (Photo N. Rosengren Jan 2013).

The Mount Fyans lavas display diverse topography including rocky elongate single and sub-parallel paired ridges and a variety of flat elevated smooth surfaces with a raised stony perimeter (Figure 17). These have relief up to 4 metres and display intricate patterns of fractures and distribution of basalt blocks. The areas between the ridges are soil-covered depressions with a thick cover of black, cracking organic clays.

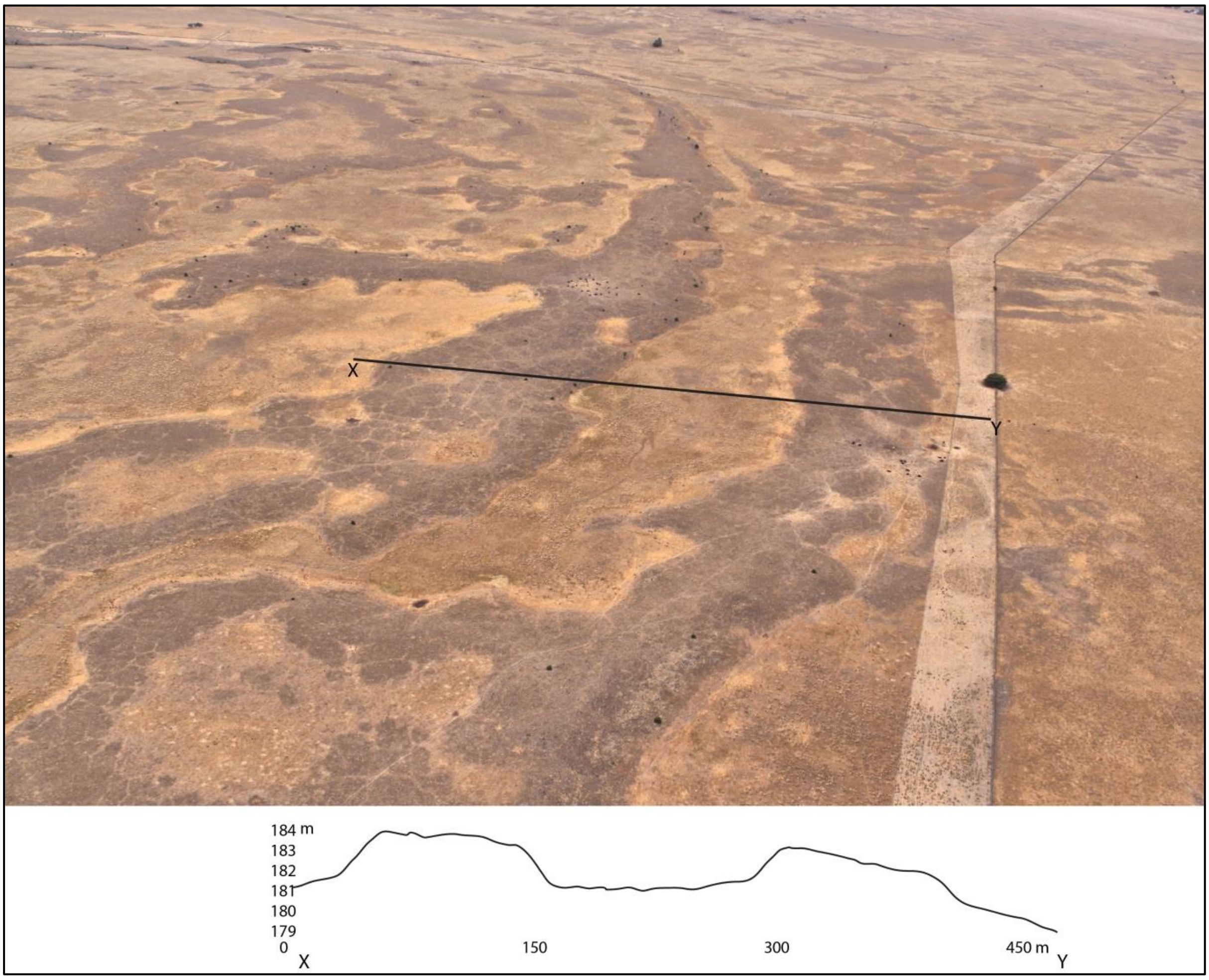


Figure 17. Oblique aerial photograph and profile of lateral marginal ridges (lava barriers) on the Mt Fyans lava flows. (Photo N. Rosengren Jan. 2013).

The lateral and terminal boundaries of the Mount Fyans flows are sharply defined topographically and geologically and marginal lakes have developed at this interface. The younger lavas here present a clear contrast in landform development with the older lavas in the degree of weathering alteration, and preserve many primary surface features of fluid basalt flows including lava levees, pressure ridges, inflation plateau and tumuli mounds.

3.4 Mondilibi lava

Mondilibi is a small composite eruption point rising as a distinctive hill with 40 metres relief above the lava plain east of Salt Creek (Figure 16). The hill is a composite feature with several stages of volcanic activity including a basal lava flow, limited fire-fountaining producing blocky to fine scoria and a late-stage basalt intrusive phase resulting in flat-lying lava disc and blocky lava dome (Figures 18 & 19).

Figure 18. Mondilibi eruption point. (Photo N. Rosengren, March 2013).

Figure 19. Mondilibi - scoria (quarry) and intrusive lava disc and plug. (Photo N. Rosengren March 2013).

The lava flow from Mondilibi extends west and south of the eruption point and predates the Mount Fyans flow. The lava surface is more subdued than the Fyans lava and lacks the widespread and well-preserved primary features.

3.5 Salt Creek

Salt Creek follows an entrenched meandering course across the Mondilibi lava with a gorge cut 25 metres into the lava surface (Figure 20). The lava predates the rejuvenation of this creek by the overflow from Lake Bolac (see lava chronology shown on Figure 10). The base of the Salt Creek gorge has a thin alluvial veneer with basalt exposed on the channel floor. The gorge profile is symmetrical with well-developed interlocking spurred entrenched meanders and high-level abandoned channel sectors across slip-off slope spurs (Figure 21).

Figure 20. Gorge of Salt Creek incised into lava from Mondilibi. (Photo N. Rosengren March 2013).

Figure 21. Spurred meanders of Salt Creek with high-level abandoned channel sectors (X) and perched wetland depression (Z). (Photo N. Rosengren March 2013).

3.6 Blind Creek

Blind Creek is a small, well-defined drainage line with the upper catchment on the western margin of the Mount Fyans lava. The stream is sourced from groundwater outflow and occasional runoff from large, ephemeral wetlands in broad depressions at the lava margin and on the older lava surface. One large feeder depression on older lava occurs east of Mortlake-Ararat Road between North Station Road South and North Station Road. The course of Blind Creek north of Mortlake has a valley defined by the southern boundary of the Mondilibi lava and the northern boundary of Mt Shadwell lava. The creek extends southwest of Mortlake through several elongate valley wetlands south of Lake Connewarren and joins the Hopkins River. Much of the valley is deeply incised and the present channel is under-fit for present small catchment area. It is likely that the present stream occupies a palaeo-valley where the upper reaches have been truncated, buried and diverted by the Mt Fyans lavas.

4 SIGNIFICANT GEOSCIENCE SITES

Geoheritage values are geological and/or geomorphological features of a site that either represents a specific characteristic of a region or are an outstanding or unusual example of a geological and\or geomorphological feature in a wider context. They have special scientific or educational value and form the essential basis of geological education, research and reference for understanding the composition, origin and dynamics of the physical landscape. They function as museums preserving the past and/or laboratories illustrating the present and pointing the way to the future. These features are considered by the geological community to be worthy of protection and preservation. The basic goal of geoconservation is to maintain the full range of earth features and processes ("geodiversity"). This is analogous to the basic aim of bioconservation, which is the protection of the diversity of biological species, communities and ecological and evolutionary processes. Geoheritage sites are chosen to represent the array of landforms and land forming processes, including features that are relict or represent geological processes that are no longer active, as well as sites that are dynamic and allow modern processes and rates of change to be measured and analysed.

4.1 Protocols for determining geoheritage sites

The Geological Society of Australia has a Standing Committee for Geological Heritage with Subcommittee's in each State Division of the Society that develop and update a database of geoheritage sites for each State. The principal objective of the Standing Committe is to "promote the understanding and conservation of the geological heritage of Australia". The GSA defines significant geological features as: *…those features of special scientific or educational value which form the essential basis of geological education, research and reference. These features are considered by the geological community to be worthy of protection and preservation.* Systematic geological heritage assessment is conducted by the Divisional (i.e. State) Subcommittees of the GSA. The author of this present document (Neville Rosengren) is a member of the Victorian Divisional Subcommittee for Geological Heritage (VDSGH) of the GSA. State and national protocols for determining geoheritage sites in Victoria have been established by Joyce and King (1980) and Rosengren (1986, 1994). They include the following principles (although some do not apply to the volcanic sites in this study):

4.1.1 Geological Sites

(a) An outcrop or other exposure which has been used as the type locality of geological material.

(b) A site which displays a contact between geological formations.

(c) An area with extensive outcrop that is used to determine the lithological and structural characteristics of a rock formation or other geological unit.

(d) An exposure of a geological structure or material that is instructive in showing the origin of that geology

(e) A site that is an excellent example of past or present geological process.

(f) Beds that contain fossil material.

(g) Sites which display a rare mineral, or allow more common mineral samples to be collected.

(h) Sites important in allowing the distribution of a geological formation to be mapped.

4.1.2 Geomorphological Sites

(a) Sites which show the influence of lithology (rock type) in landform development.

(b) Sites that display the relationship between geological structures and landforms.

(c) Sites which clearly display the action of a current geomorphological process.

(d) Landforms or materials that clearly reflect the action of a geomorphological process that is not operative at the present time or does not operate with the same intensity as in the past.

(e) Landforms of complex or compound origin representing multiple episodes of landscape evolution.

(f) Sites that show the interaction between plants and/or animals in shaping the land surface

(g) Sites which are clear and representative examples of the landforms of a region.

4.2 Geoscience Significance Levels

A place or feature recognised as of geoscience significance is assigned a rating on a comparative significance scale that ranges from Local to International. Assigning significance ratings is a somewhat subjective procedure (as indeed is the recognition of significant features). It is dependent in part on the context in which the sites or study area occur, the specific professional skills, interests and experience of the investigator as well as their knowledge of the region and ability to make valid comparative assessment of like features in and beyond the study area.

4.3 Significance of the Mount Fyans wind farm site

The Mount Fyans wind farm site encloses a variety of terrain and displays features that have been developed by successive volcanic eruptions and associated lava flows over at least the last 4 million years. It is part of a broader volcanic landscape (the NVP of south-eastern Australia) that has been active over a longer period of time and includes individual and associated features that are of National and International geoheritage significance. This high rating is in part because the volcanicity is geologically young and many volcanic and associated features are very well preserved.

No single feature in the Mount Fyans site has attributes of National or International significance. Mount Fyans eruption complex including all the lava flows stony rises is part of a broader complex (including Mount Hamilton and other nearby eruption centres) that is of State to National Significance. This rating is based on Mt Fyans as a relatively young volcanic complex that experienced several different phases of eruptive activity with eruption features (such as scoria, basalt dykes and small caves as displayed in the quarry), and stony rise features that are unusual in a State and National context and are well preserved. There is great interest by geologists in the mechanisms by which lava can travel long distances over gently sloping terrain, as is the case with the Fyans and Hamilton lavas. Factors that contribute to long lava flows include high and continuous infusion rates, high temperature and large volume of lava, and the development of lava tubes that feed lava from the vent to an advancing front that may be tens of kilometres distant. The continued injection of lava down insulated tubes allows movement over very long distances and gradually thickens the lava by forcing upward the rigid but brittle overlying crust. This process is known as sheet inflation and has been observed in active lava flowing from Kilauea volcano on Hawaii. As some tubes become filled or blocked, preferred lava pathways develop that continue to feed liquid lava to the advancing flow fronts. These pathways are very efficient lava conductors and allow lava travel at rates of several kilometres an hour. As the eruption wanes and lava drains from some of the tubes, the roof of the tube sags or collapses leaving a series of depressions lying below the level of the inflated lava surface. The remnant surface between the depressions forms a series of flat-topped ridges marking the edges of the former lava tubes. The elevation of the ridges is a result of lava surface inflation and result in a reversal of topography. The original valleys that were the lava conduits become filled with crusted lava and are lifted upward (inflated) as liquid lava is continuously fed down the tube. There are excellent displays of long, linear lava flows elsewhere in Victoria and in this regard, as lava flow bodies, the Fyans lavas are of High Regional Significance.

There are six attributes of the proposed Mt Fyans wind farm site of high geoheritage significance:

1. The extensive stony rise complex of mounds, ridges and depressions that occur across the Fyans lavas between Woorndoo-Dundonnell Road and Woorndoo-Darlington Road are an outstanding and little-modified example of features of long basalt lava flows. Although no lava caves are known from these, the mechanism of stony rise development suggests there may be unfilled or only partially collapsed lava tube remnants sub-surface.

2. The flow boundaries of the Fyans lavas are clear and are a major factor in defining landscape character and determining the position and form of marginal wetlands.

3. The large semi-permanent and palaeo-lakes in the northern part of the site are unusual in a Victorian context, particularly the high cliff shorelines and the lunette deposits. The large wetland at North Station Road and Sheepwash Lake east of Darlington-Nerrin Road are also a clear example of lavas surface depressions developed at flow boundaries.

4. The permanent and substantial groundwater discharge sites in the northern part of the site, some of which have incised channels and feed the lakes described in 3 above, are among the most diverse and persistent in the NVP.

5. Mondilibi is an unusual volcano with a range of preserved eruptive features including lava and scoria.

6. Several attributes of the Salt Creek gorge are of High Regional Significance as examples of rapid stream dissection and development of incision remnants. The gorge is also significant in the regional context of volcanic sequences and lava displacement of drainage.

The highest geoscience significance attributes recorded in this study are the complex of ridges, depressions and spring outflows in the area immediately north and extending south of the Dundonnell-Woorndoo Road and comprise a complex of State Significance.

The location of significant geoscience sites and descriptions and detailed maps and illustrations are contained in Section 5 below.

5 SIGNIFICANT GEOSCIENCE SITE DETAILS

5.1 Mount Fyans Lava and Associated features

Figure 22. Significant sites on the Mount Fyans lava flow

Eight large sites are identified on or at the margins of the Mount Fyans lava flows between the Woorndoo-Dundonnell Road and the distal margin of the flow south of Woorndoo-Darlington Road (Figure 22). The sites illustrate a variety of primary volcanic features developed during the emplacement and consolidation of the lava flows, and subsequent landform development including weathering and drainage adjustment on and marginal to the lavas. Individual geoscience sites are described and illustrated in Sections 5.1.1 to 5.8.8 below. For each site, a table provides:

(a) Brief description of geoscience features;
(b) Significance rating as either *low, medium, high;*
(c) Degree of replication across the local and wider volcanic landscape in Victoria on a scale: <u>low, moderate, high</u>;
(e) Assessment of sensitivity to disturbance as **low, moderate or high**, and potential constraints on wind farm construction and operation.
(c) Images: map, vertical and/or oblique aerial or ground photographs.

Site Number (Fig. 22) & Geoscience Features		
1 Description of geoscience features		
Significance Level	**Replication**	**Sensitivity to Disturbance & Potential Constraints**
low, medium, high	**<u>low, moderate, high</u>**	**low, moderate or high**

For each site, details of the sensitive features are identified and guidelines for avoiding for minimising impacts on geoscience significance are described with reference to the images of the site.

5.1.1 Site 1: Groundwater Lake Basin

Site Number 1. Groundwater lake basin			
Enclosed groundwater saline lake basin with overflow lip to the south connecting to a shallow, poorly-defined palaeo-lake. Cliffed margins up to 5 metres high on east. Wide basalt rock platform on west. Saline crust on clay floor (Figure 23, 24, 25).			
Significance Level	Replication	Sensitivity	Potential Constraints
High Uncommon example of a groundwater basin developed by spring sapping. Evidence of long-term higher lake levels. Lake floor sediment potential pollen and dating source.	Moderate. One of largest such features on Fyans lava and uncommon features of NVP basalt plains.	High Potential for damage to inflow and shoreline by earthworks.	**No construction activity in the area of the site**. No vehicles on lake floor at any time. Earthworks in catchment to be secured to prevent sediment runoff.

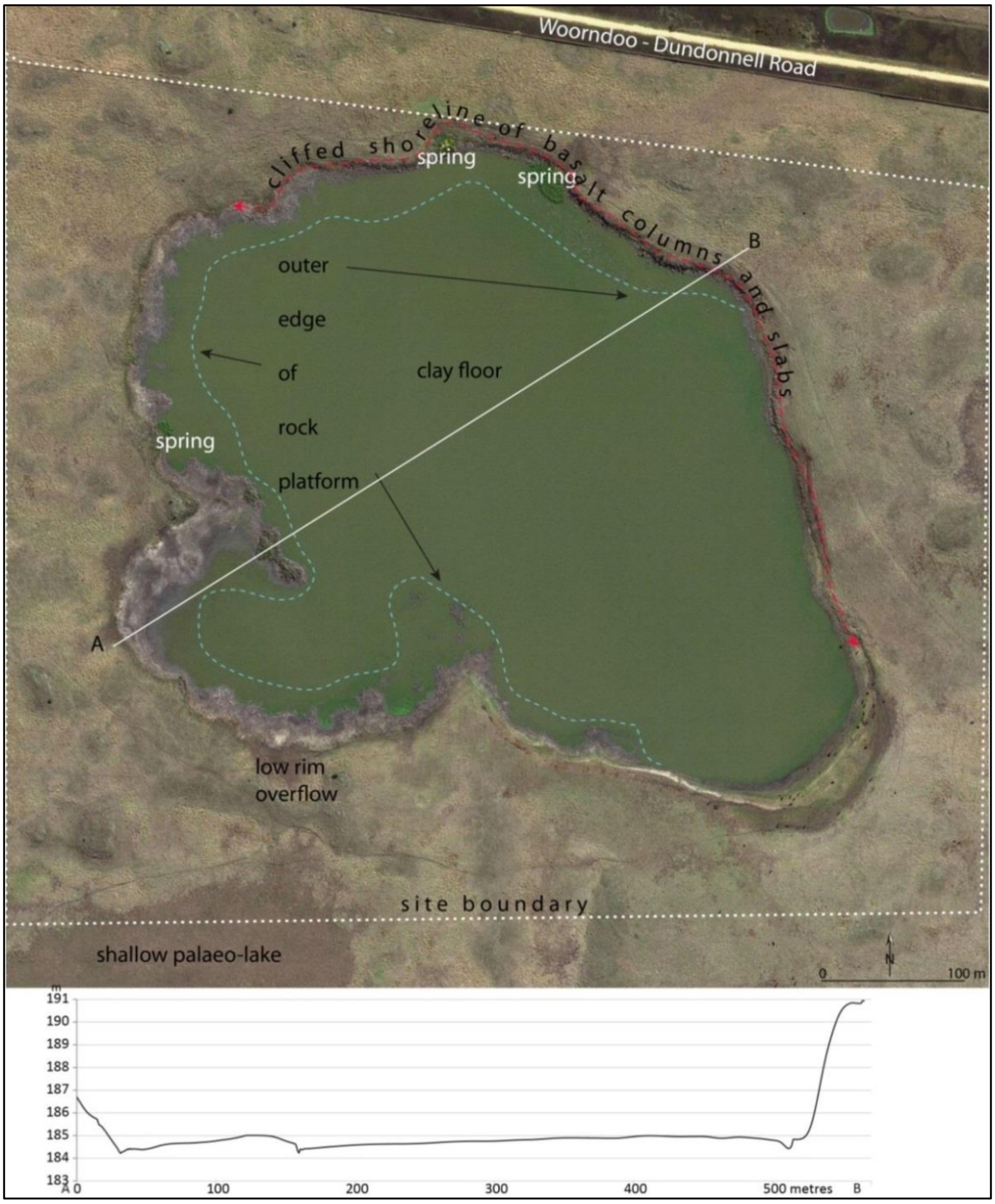


Figure 23. Vertical aerial photograph and profile of intermittent lake, Site 1.

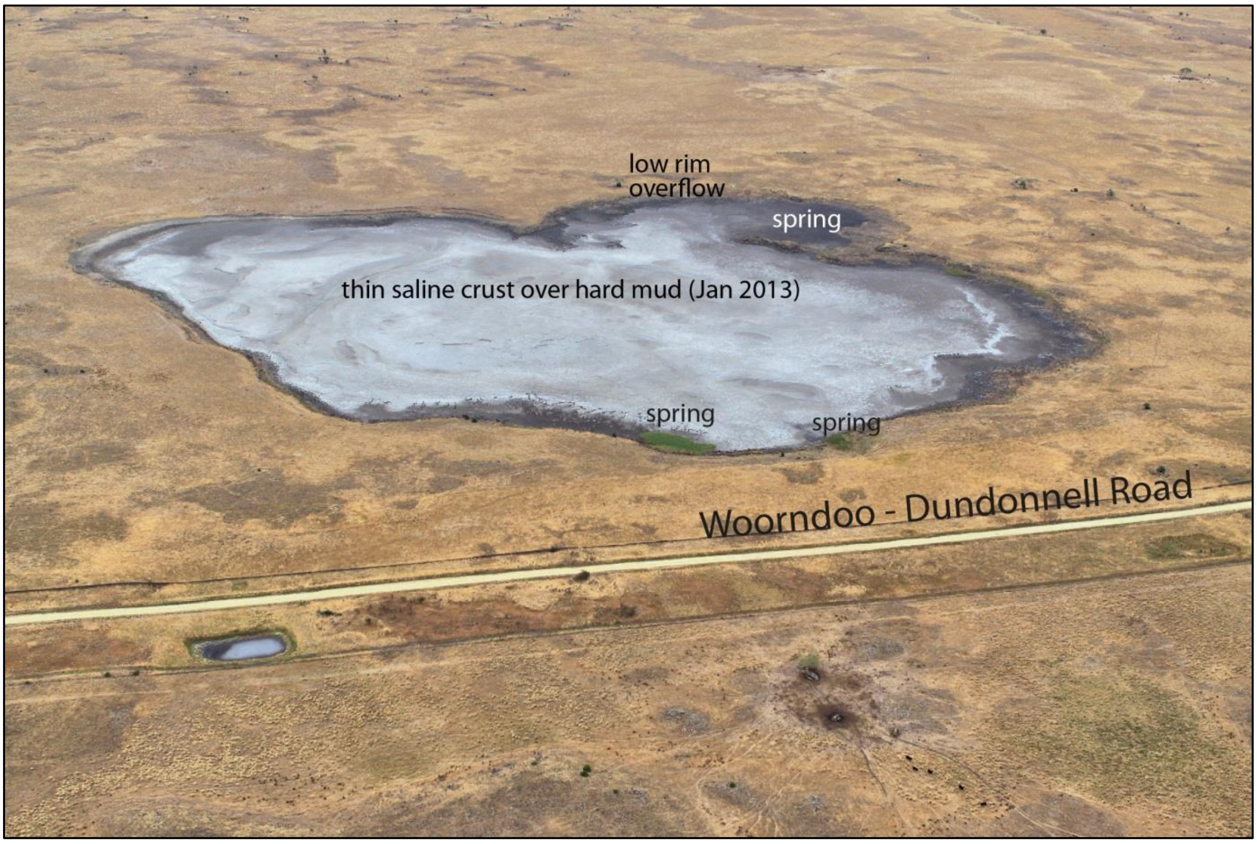


Figure 24. Groundwater-fed saline lake south of Woorndoo-Dundonnell Road. (Photo N. Rosengren Jan. 2013).

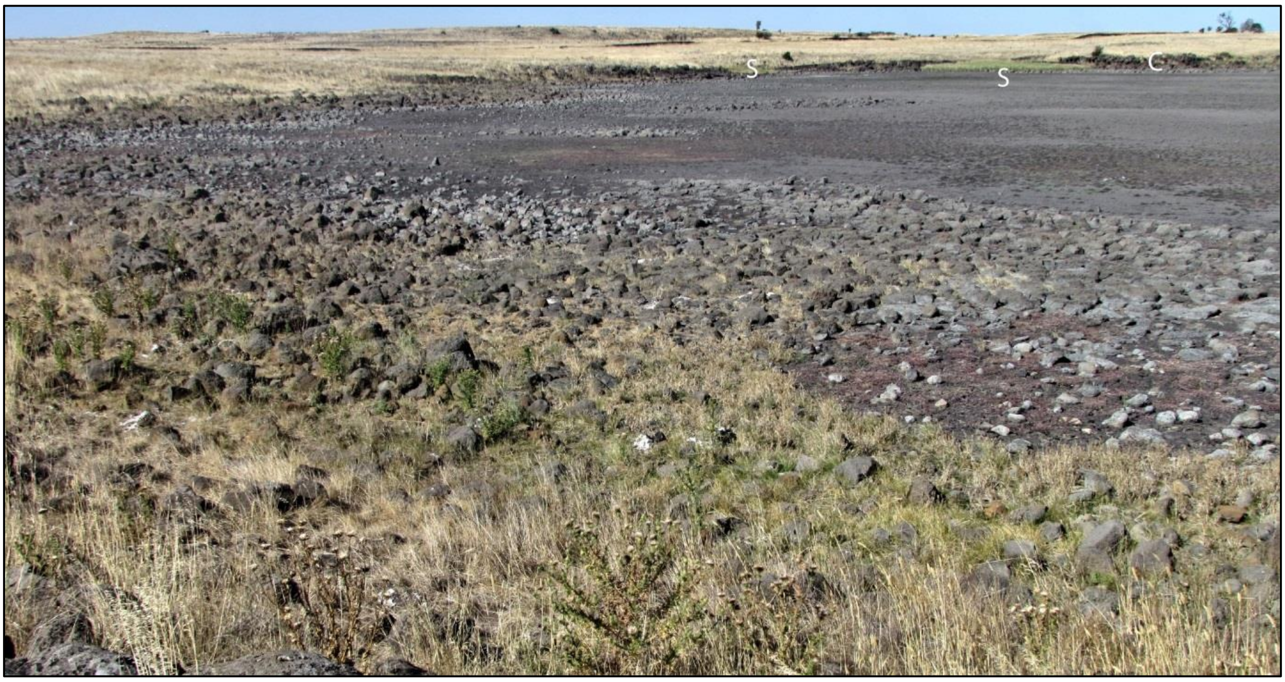


Figure 25. Site 1 saline lake floor. Spring inflow points (S) and high cliffs (C).

5.1.2 Site 2: Flowing Spring Lake Basin

Site Number 2. Flowing spring lake basin			
Large enclosed groundwater and spring overland flow-fed permanent brackish lake basin. Cliffed margins up to 5 metres high with large columnar jointing. Drowned and stranded shoreline features include higher water-level cliffs and terraces and cobble beaches and wide basalt rock platform forming a tessellated pavement (Figure 26, 27, 28).			
Significance Level	Replication	Sensitivity	Potential Constraints
High Uncommon example of a large, deep lake basin fed by overland spring flow to maintain permanent lake. Southern and eastern shores highly irregular with small promontories and bays indicating the lake is residual from enclosure of a depression by lava tongues and lobes. Evidence of wave cliffing and development of a basalt shore platform from long-term higher lake levels. Excellent displays of columnar jointing forming a tessellated pavement. Lake floor sediment potential pollen and dating source.	Moderate Largest feature of this type on Fyans lava and large in the context of the NVP basalt plains.	High Potential for damage to inflow and shoreline by earthworks.	**No construction activity in the area of the site**. No vehicles on lake floor at any time. Earthworks in catchment to be secured to prevent sediment runoff. No removal of surface rock or quarrying.

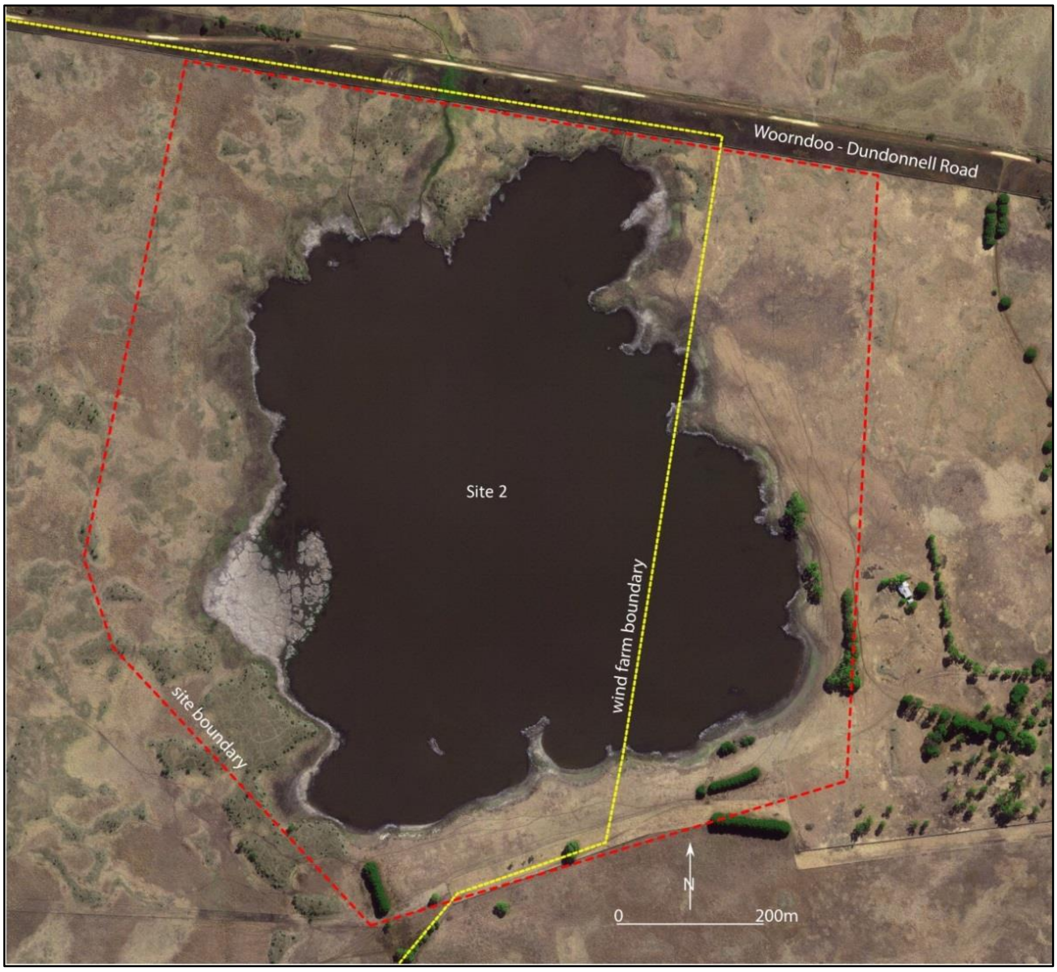


Figure 26. Site 2 vertical aerial photograph.

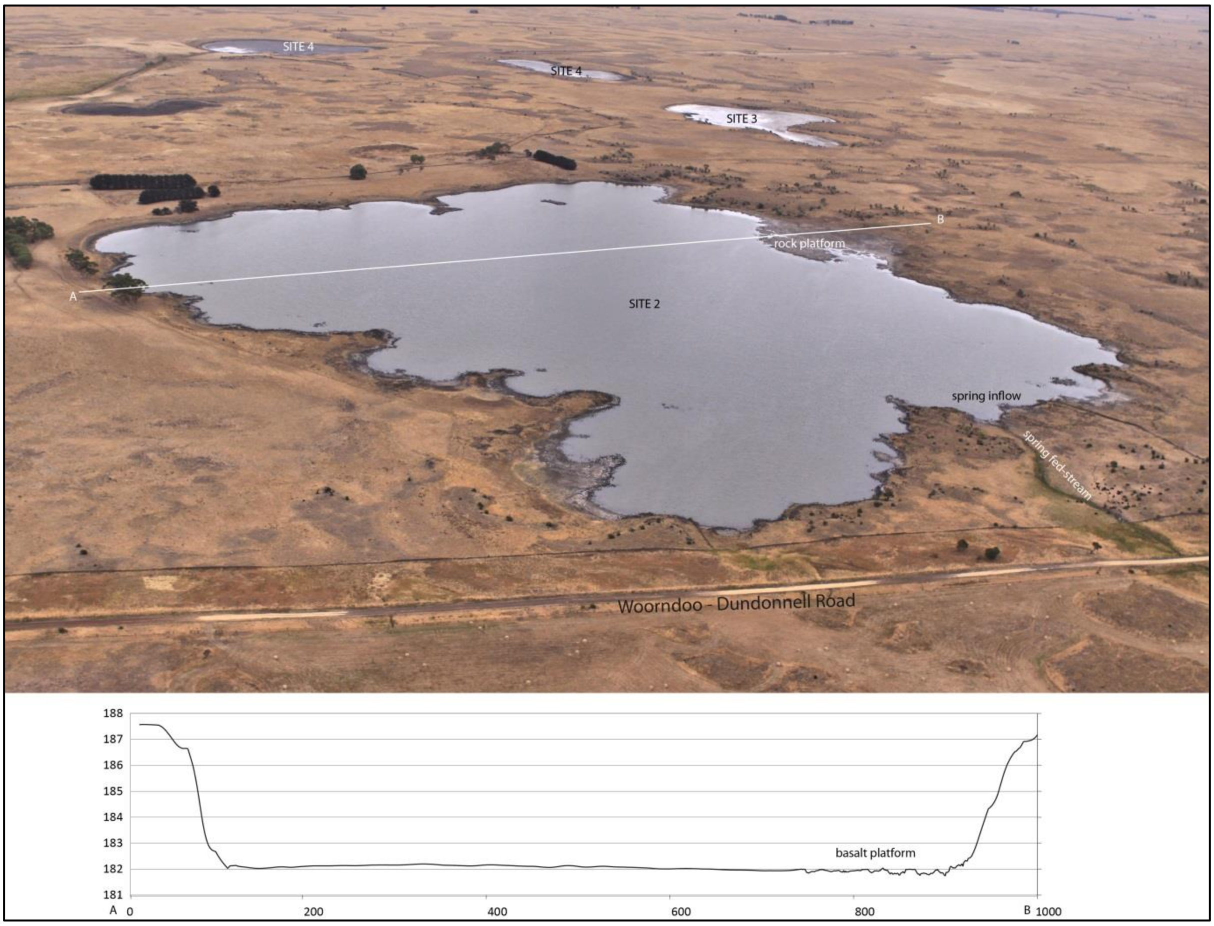


Figure 27. Aerial oblique and profile of lake basin fed by overland flow from spring. (Photo N. Rosengren, Jan. 2013).

Figure 28. Wide bench (rock platform) with tessellated surface on western shore of lake, Site 2.

Figure 29. Stranded higher water-level shorelines, western shore Site 2.

5.1.3 Site 3: Lake in Collapse Depressions

Site Number 3. Palaeo-lake in collapse depressions			
Small, elongate, deep well-defined saline lake basin. Cliffed margins up to 6 metres high with large columnar jointing. Clover-leaf outline indicates this is formed by 4 or 5 coalescing collapse or subsidence depressions of a cooling lava flow rather than enclosure by separate lava lobes. On the south-western edge is a high, narrow lava ridge. There are varied shoreline profiles including cliffs of wide columnar-jointed basalt blocks 4 to 5 metres high, bluffs of weathered basalt fringed by a gently sloping bench 2 metres above the lake floor and a smooth, convex slope (lunette deposit) of wind-blown silt and clay on the southern/south-east margin (Figures 30, 32, 33, & 35). The lake floor has a thin saline crust over heavy clay (Figure 31). The north-south alignment of the depression is consistent with origin as an elongated lava tube system.			
Significance Level	Replication	Sensitivity	Potential Constraints
High Uncommon example of a large, deep lake basin formed by subsidence or collapse of an inflated lava flow. Complex shoreline and backshore features. Evidence of wave cliffing indicating longer periods of inundation and higher lake levels in the past. Good displays of columnar jointing in some cliffs. Lake floor sediment potential pollen and dating source. Unusual lunette on south-eastern margin.	Low Largest feature of this type on Fyans lava and large and uncommon in the context of the NVP basalt plains.	Very High. Potential for damage to inflow and shoreline by earthworks.	**No construction activity in the area of the site**. No vehicles on lake floor at any time. Earthworks in catchment to be secured to prevent sediment runoff. No removal of loose stone or quarrying any marginal material including the lunette.

Figure 30. Site 3 vertical aerial photograph.


Figure 31. Saline crust over black mud and basalt blocks, Site 3 lake.

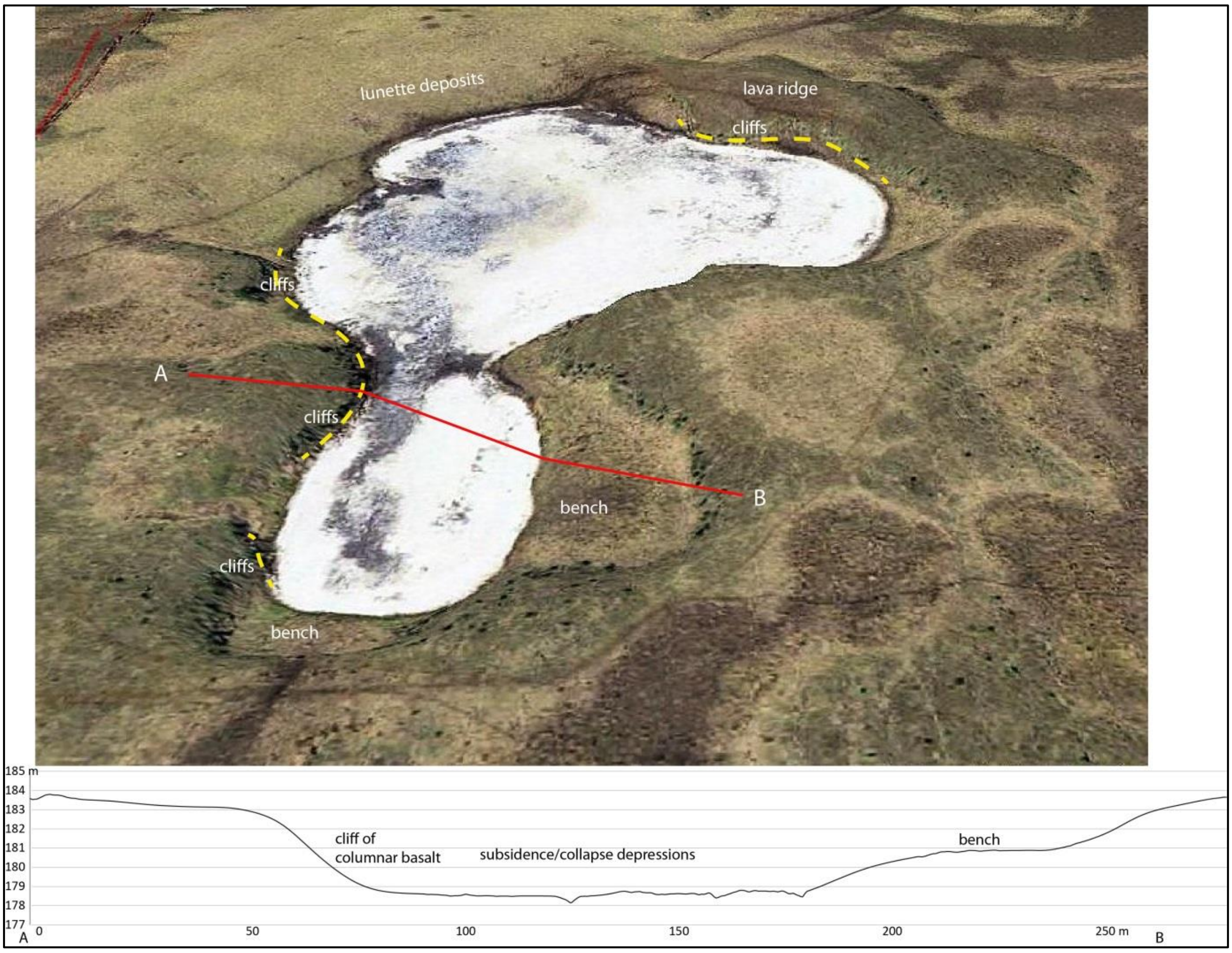


Figure 32. Complex morphology of lake Site 3. (Google Earth oblique image). View towards the south.

Figure 33. Oblique aerial photograph of lake basin, Site 3. (Photo N. Rosengren, Jan. 2013).

Figure 34. Cliff, bluff and boulder scatter, eastern shoreline Site 3.

Figure 35. Wind-blown deposit (lunette), southeast shore of lake, Site 3. (Circular structures are rusted metal drums).

5.1.4 Site 4: Palaeo-lake and Lava Ridge Complex

<table>
<tr><td colspan="4">Site Number 4. Palaeo-lake and lava ridge complex</td></tr>
<tr><td colspan="4">This large site has been selected as it displays a complex of lava surface features ranging from primary flow structures to those that are important in displaying how primary flow features are modified as a result of long-term climatic variations that impact on surface water and groundwater conditions. Lava mounds and low domes have a, regular widely-spaced joint system consistent with inflation of lava flow lobes. There are elongate parallel ridges indicating former lava levees or collapsed lava tubes and two remnants of extended domed tumuli and other forms of inflation mounds.

There are two “active” lakes- Lake 1 and Lake 2 (Figure 36). These are groundwater and spring-fed lakes with varied shoreline features and there are five palaeo-lakes with very flat floors. All active and palaeo-lakes have different floor elevations (Figure 37).

Lake 1 is an excellent example of a large, deep lake basin formed by subsidence or collapse of an inflated lava flow with a complex shoreline and backshore features and columnar jointed blocks in some cliffs. There is evidence of wave cliffing indicating longer periods of inundation and higher lake levels in the past. Around the shoreline along the eastern side of the lake is a scatter of vesicular basalt blocks, some with a breached surface showing an internal hollow that appears to be a small primary lava tube?

Lake 2 is a large shallow lake with a modified (excavated channel) seepage inflow. It has a more extensive alluvial floor now cliffed on the southern margin. There is evidence of wave cliffing indicating longer periods of inundation and higher lake levels in the past. The floor of Lake 1 is 3.5 metres higher than Lake 2 and an overflow connection was likely at times’

The large palaeo-lakes (drained former wetlands) at various elevations are separated by lava ridges and mounds. A cascade overflow connection between these lakes is apparent in the present configuration of sediments and lava sills enclosing and separating the lake basins. This is demonstrated by the network of drains excavated by landholders to connect and dry the surface to allow cultivation. A large wind-blown deposit (a former lunette) buries one of the lava ridges.</td></tr>
<tr><td>Significance Level</td><td>Replication</td><td>Sensitivity</td><td>Potential Constraints</td></tr>
<tr><td>Very High

Example of the diverse nature of NVP stony rises on lavas modified by secondary processes but retaining a range of primary flow emplacement features, including low, broad tumuli, inflation ridges and subsidence/collapse depressions.

Complex lake origins and diverse shoreline features. Excellent examples of lunettes around the largest palaeolake. Lake floor sediment is potential pollen and dating source.</td><td>Low

This is a very diverse surface with a wide range of well-preserved primary volcanic features and very good examples of weathering and sedimentation on the irregular flow surface and depressions. It is one of the group of younger lava flow surfaces in western Victoria and comparable to the lava flows from Mount Rouse that are of similar (~300,000 year) age.</td><td>Moderate to Very High

Potential for damage to the integrity of the active and palaeo-lake features is very high. Sensitivity of lava surfaces is moderate.</td><td>No construction activity in the area of the site. No vehicles on floor of lakes at any time. Earthworks in catchment of lakes to be secured to prevent sediment runoff. No removal of loose stone or quarrying any marginal material including the lunettes and alluvial deposits of the palaeolakes. Part of the area could be utilised for towers, tracks and other infrastructure with appropriate micros-ting.</td></tr>
</table>

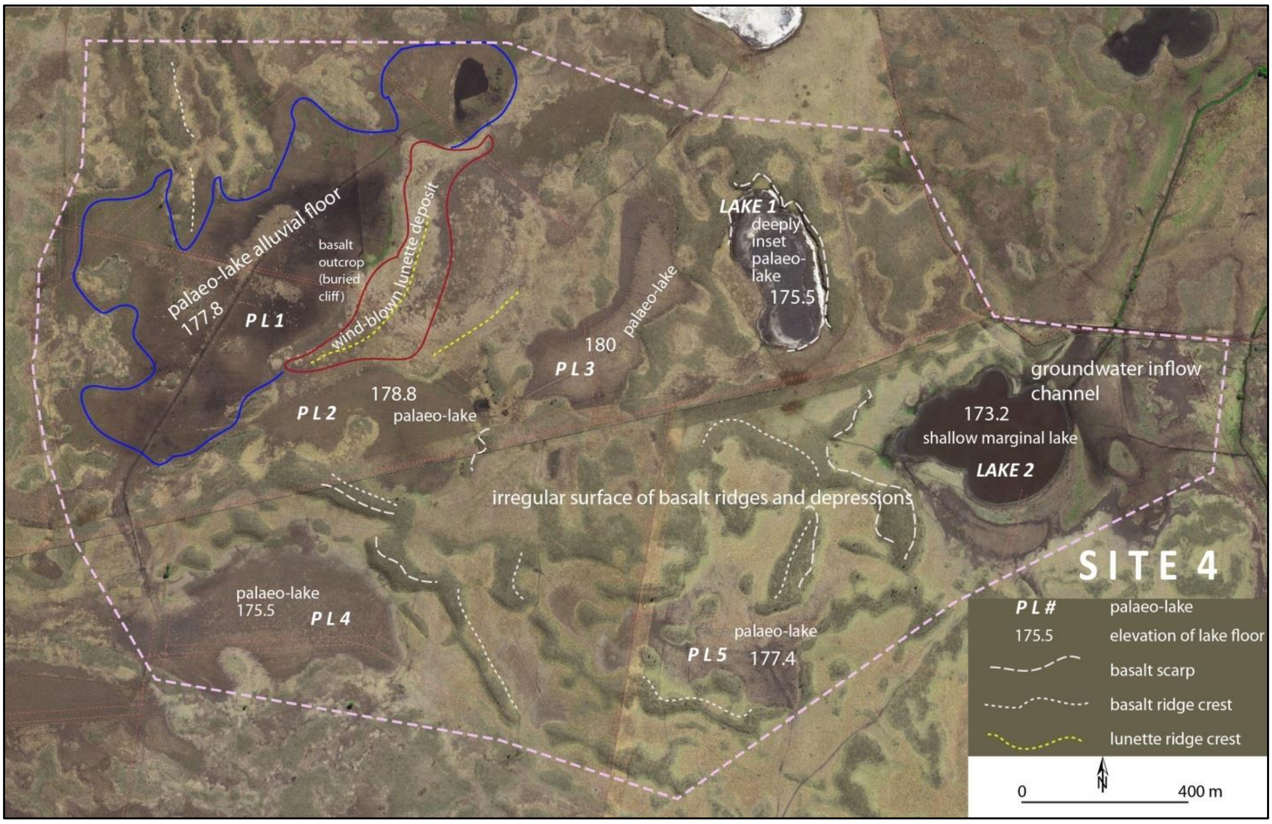


Figure 36. Geoscience features of Site 4.

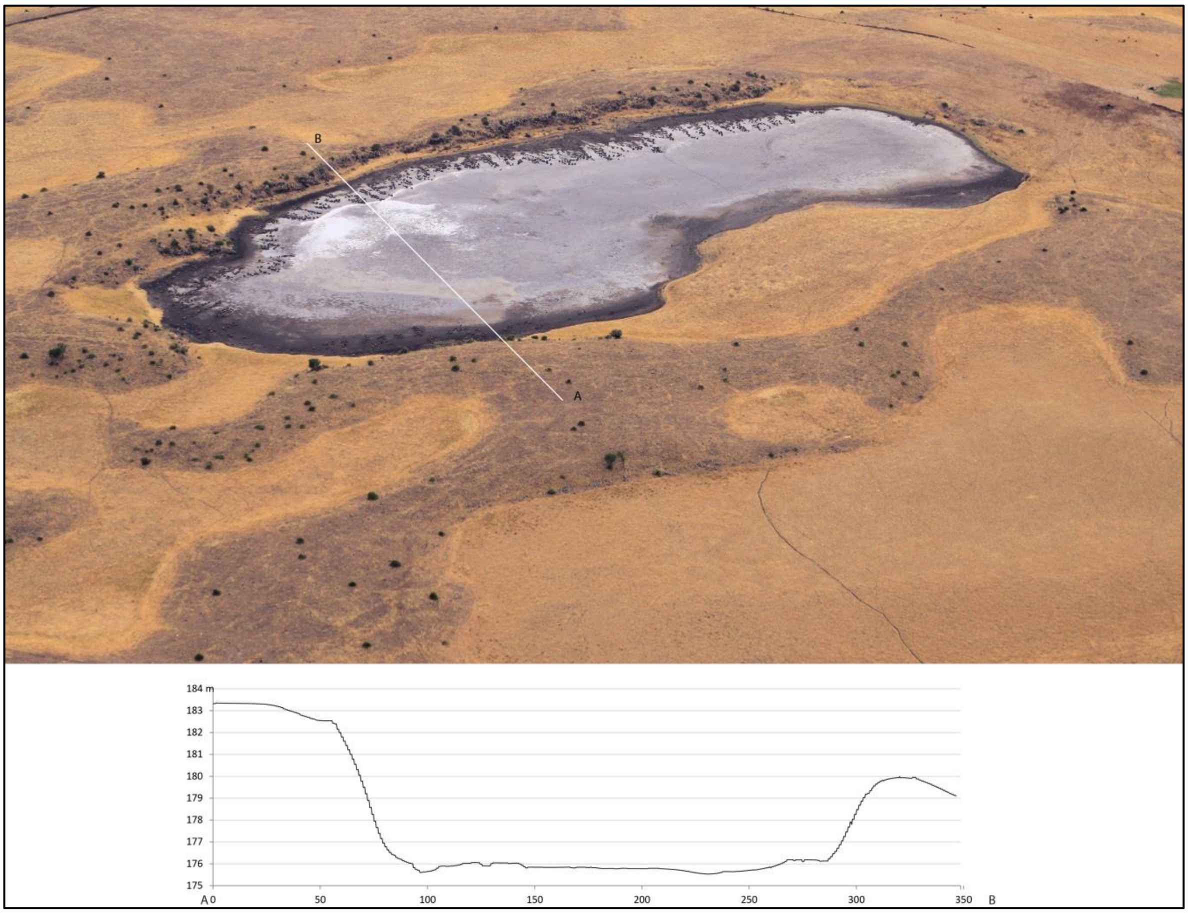


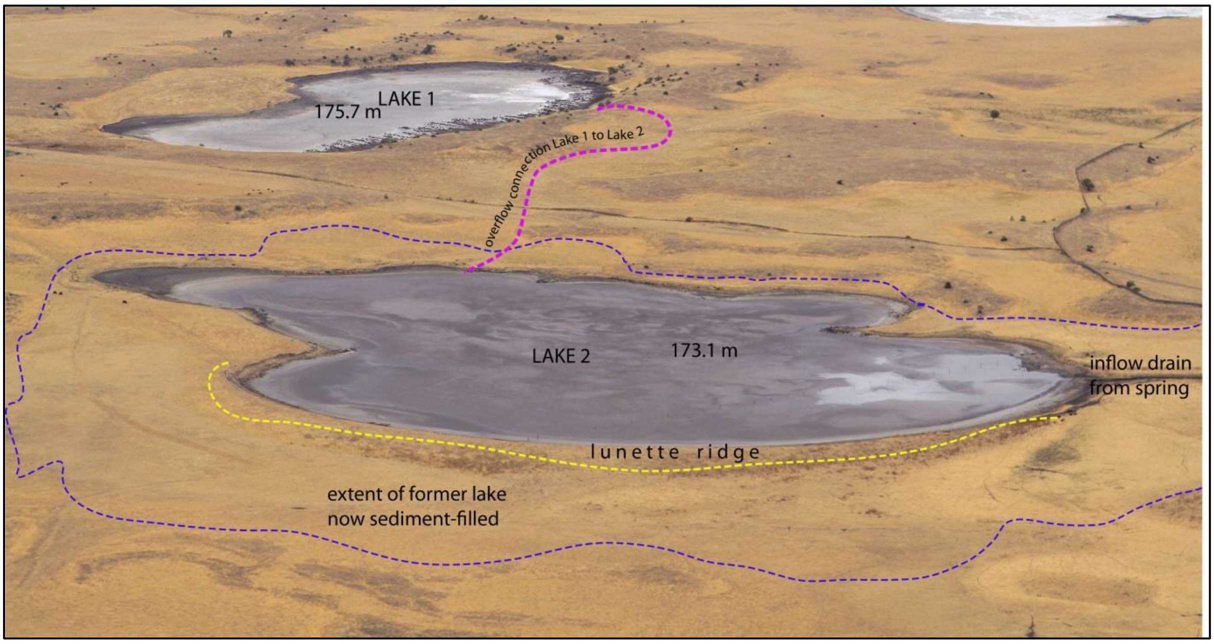
Figure 37. Complex depression enclosing saline lake, part of Site 4. Profile A – B. Note the unusual parallel boulder lines at right angles to east shoreline (see Figure 38). (Photo N. Rosengren, Jan. 2013).

Figure 38. Parallel boulder lines, east shore. It is not obvious how these could be natural features and may be a human artefact (fish traps?).

The lines of boulders shown in Figures 37 and 38 are not easily explained by referral to shoreline processes. In its present configuration, the lake basin can hold about three metres of water before overflow on the central eastern side. It is not fed by a stream or overland flow spring seep. Are these human (Aboriginal or European) artefacts?

Figure 39. Hollows (weathered small lava tubes) northern shore of lake in Site 4.

As lake 2 floor is lower than lake 1, an overflow path is shown in Figures 40 & 41.



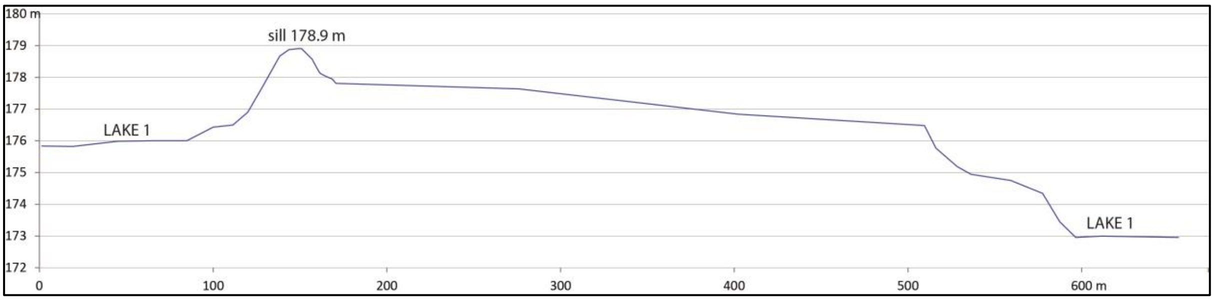


Figure 40. Present and former extent of lakes 1 & 2 and possible overflow connection (profile). (Photo N. Rosengren, Jan. 2013).

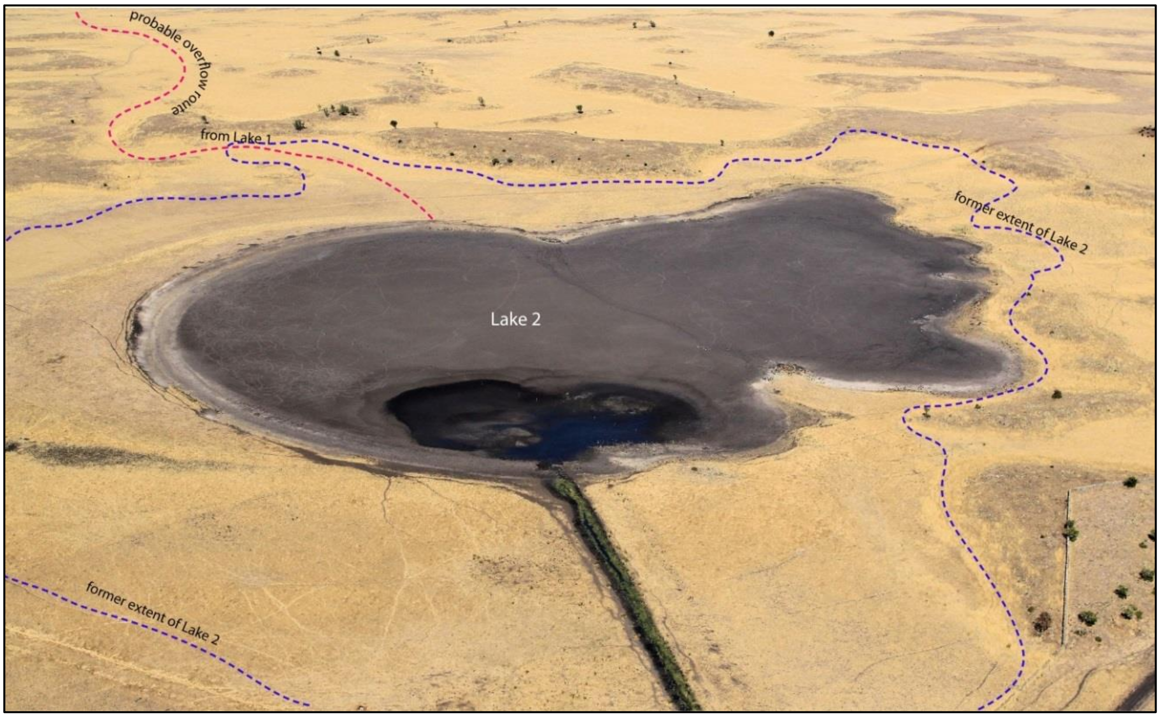


Figure 41. Inflow channel, former extent of Lake 2, connection from Lake 1. (Photo N. Rosengren, March 2013).

The former extent of Lake 2 is shown by the flat surface adjacent to the present basin (Figure 36) and the stratified sequences shown in scarps at the lake edge. These show alternations of white-grey clay and dark organic clay (Figure 42), indicating variations in lake level and salinity. Some of the material is probably wind-blown from a dry and salinized lake surface.

Figure 42. Stratified clay and organic deposits at Lake 2 margin.

The several large palaeo-lakes (PL1 to PL4, Figure 36) are remnants of an extensive and linked wetland system. This system extended along much of the Mount Fyans lava surface and comprised a series of depressions enclosed by lava ridges. The depressions originated by a combination of deflation of lava sheets and inflation of elongate ridges and tumuli at different times during the flow emplacement. The depressions have relatively low thresholds and filled to maximum depths of 2 to 3 metres before spilling across a sill (low point in the bounding lava ridge and into an adjacent depression (Figure 41). Initially, the depressions would have been very permeable with leakage through the joint fractures, but as sediment was washed and blown into the depression they became sealed and held water for longer periods, developing open water bodies and marshy. Since European occupation, drains have been cut into the base of the depressions and the existing overflow points enlarged to allow rapid drainage.

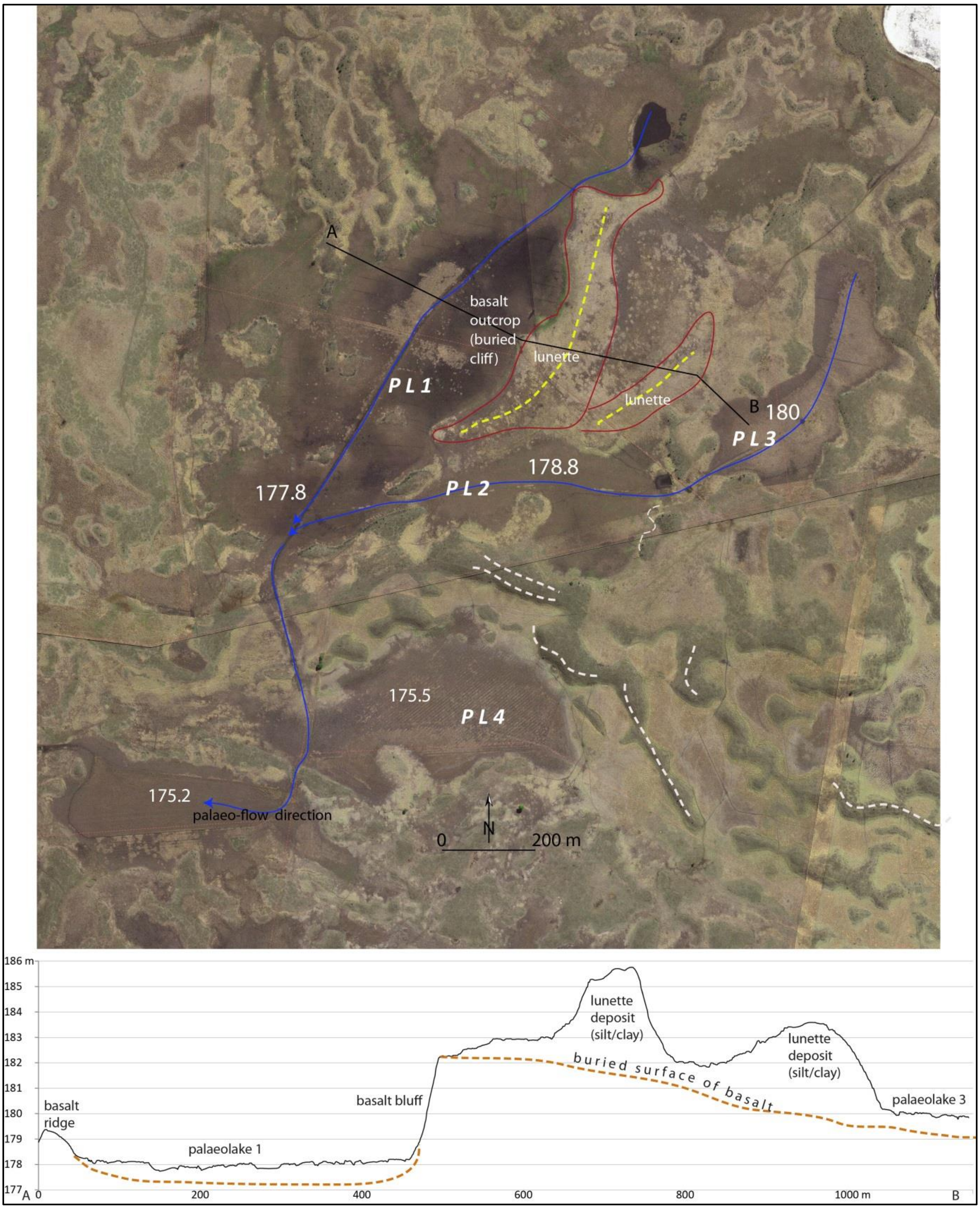


Figure 43. Palaeo-lakes and linked overflow drainage system.

The eastern margin of PL1 has two arcuate ridges of silty clay parallel to the lake margin. The innermost rises over seven metres above the shoreline and rests on a basalt outcrop that forms a bluff at the lake edge. The ridges are interpreted as lunettes of wind-blown lake floor sediment (Figure 44).

Figure 44. Lunette ridge and drainage channels linking palaeo-lakes. (Photo N. Rosengren, March 2013).

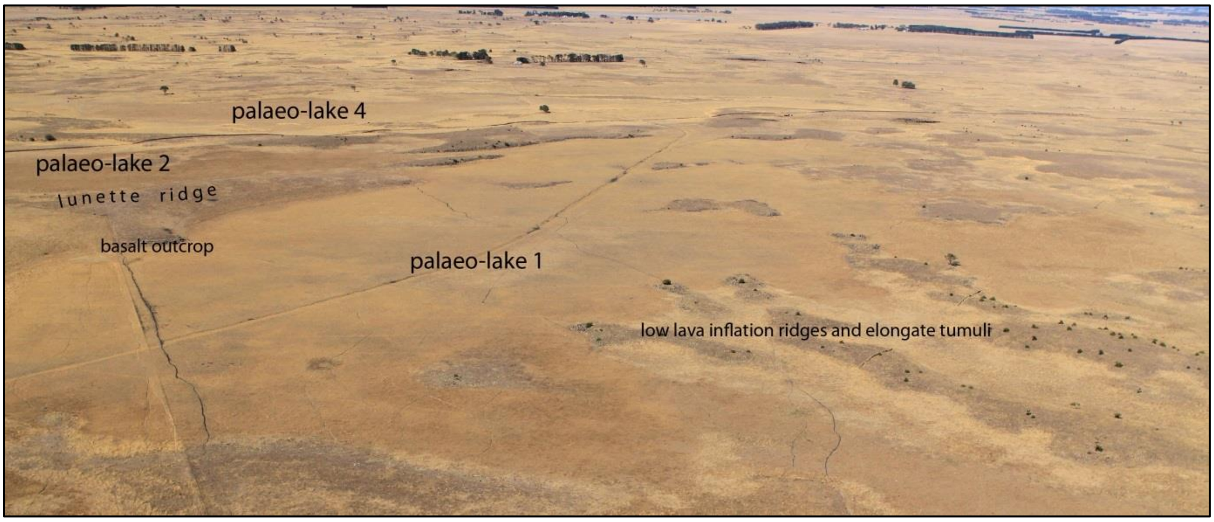


Figure 45. Palaeo-lakes, lunette and lava ridges. (Photo N. Rosengren, March 2013).

Around the western and north-west margin of palaeo-lake 1 is a series of low, dome-shaped elongate basalt ridges, partially buried by the sediment of the palaeo-lakes. They rise 1 to 1.5 metres above the sedimentary surface and decline towards the south (Figure 44 & Figure 45). Similar features occur around the south-west margin. They differ from the higher, broader ridges that occur in other areas of the flow and represent a discrete form of lava cooling and emplacement.

Figure 46. Low, elongate domed lava ridges, palaeo-lake 1.

Figure 47. Site 4 showing detail of significant lava ridges.

5.1.5 Site 5: Elongate Lava Ridges

Site Number 5: Elongate lava ridges and depression			
The site is an elongate set of ridges and a central depression extending 2.5 km north to south. The ridges are up to four metres higher than the depression. The eastern ridge is narrow and continuous for the distance but the western ridge is irregular and forms a series of lobes and low, broad rises. The site is interpreted as a rapidly moving, narrow lava tongue with an initial enclosed cavity carrying high temperature lava. Initially, the lava stream inflated producing a broad, arched structure, but breaching of the lava tube towards the western distal margin diverted part of the flow to the west causing deflation/sagging and collapse and producing the central depression corridor.			
Significance Level	Replication	Sensitivity	Potential Constraints
High Uncommon example of a long and continuous lava unit with a varied history of movement and cooling.	Low Largest feature of this type on Fyans lava and large and uncommon in the context of the NVP basalt plains.	Moderate Potential for change to the geometry and continuity of the structure by earthworks.	Minimise track construction along ridges. Tracks to cross at right angles to ridge. Micrositing of towers on the ridges to minimise excavation and fill.

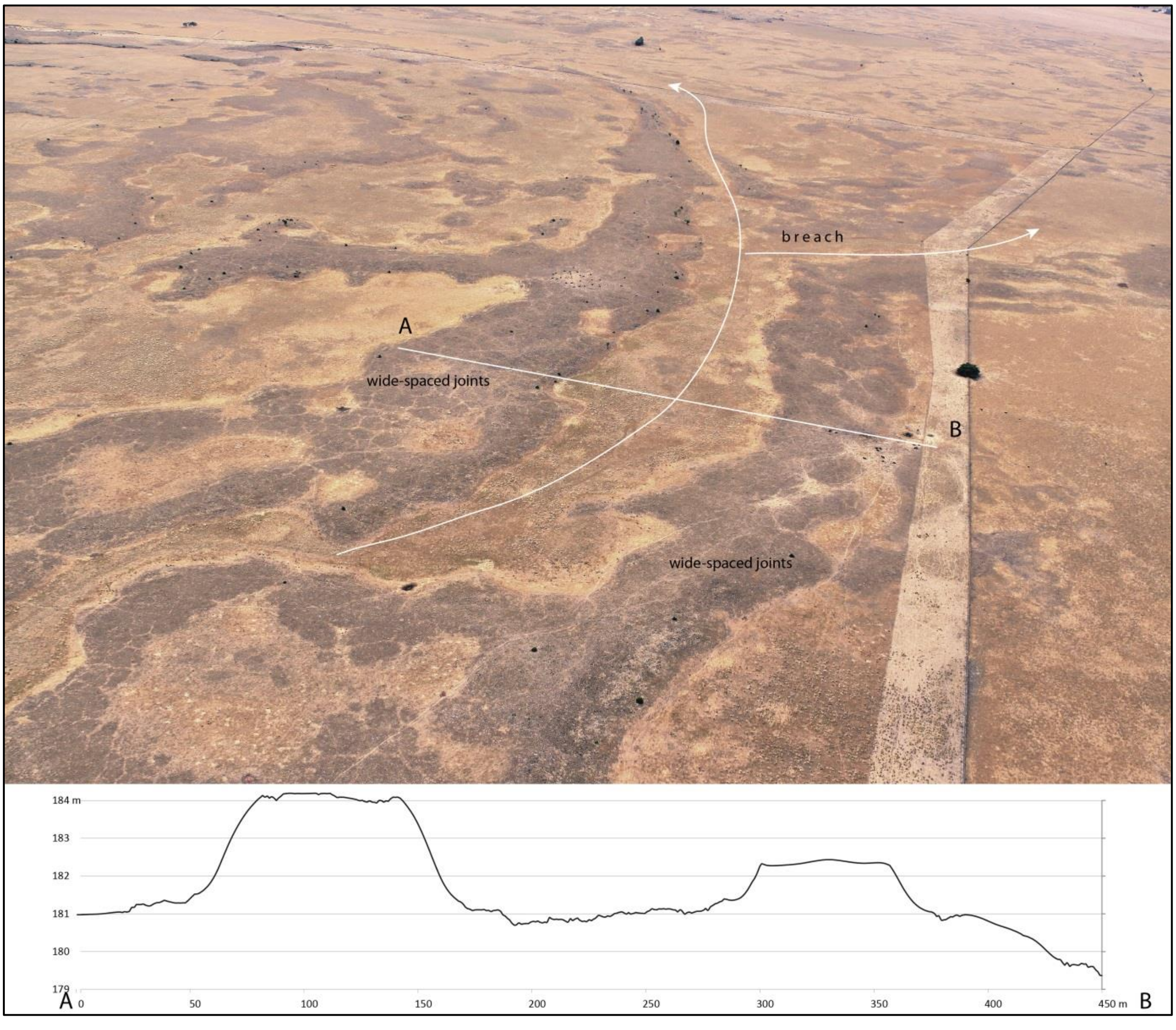


Figure 48. Long lava inflation ridges and collapse/deflation depression. (Photo N. Rosengren, March 2013).

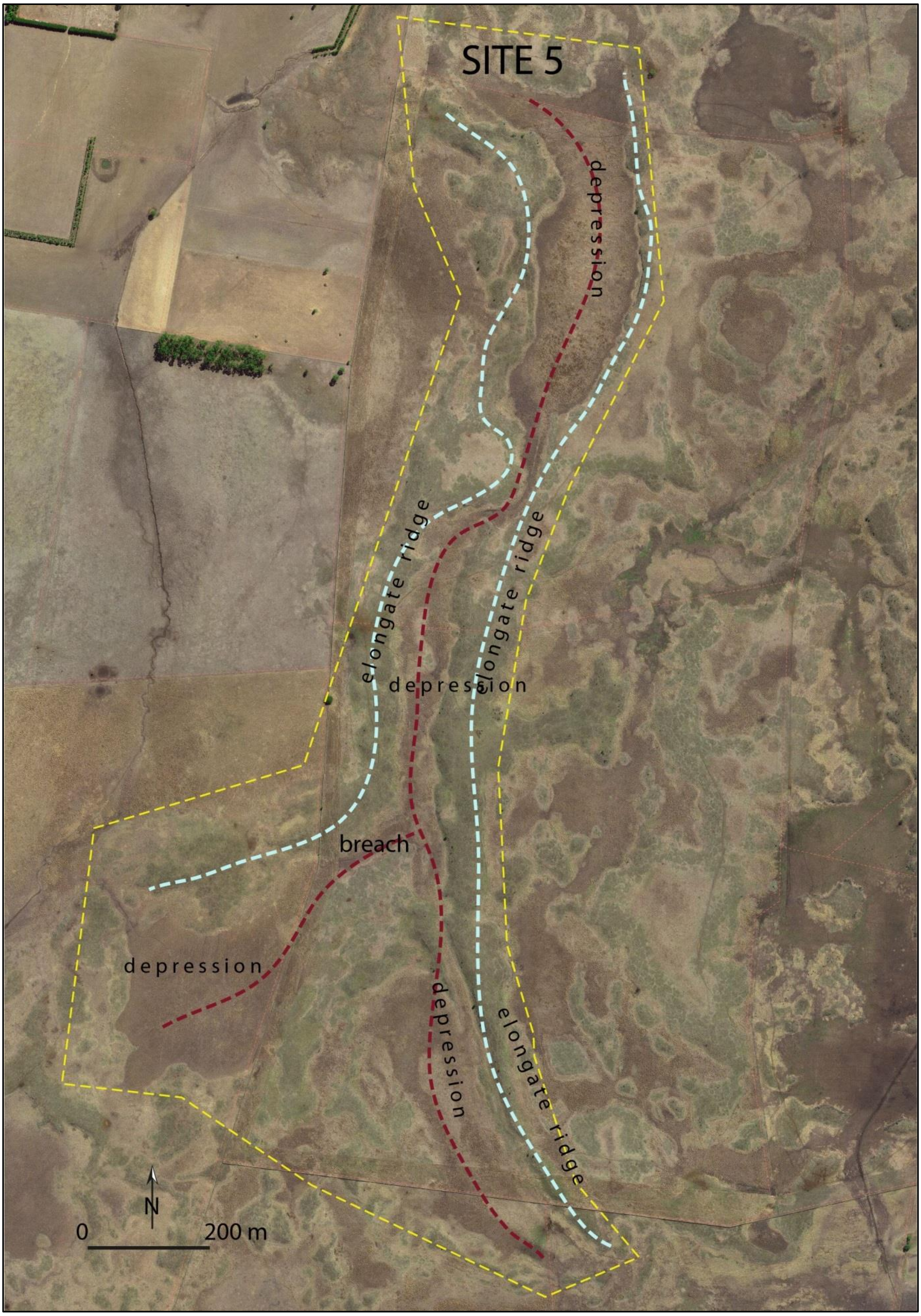


Figure 49. Site 5, elongate lava ridge and depressions

5.1.6 Site 6: Elongate Lava Ridges

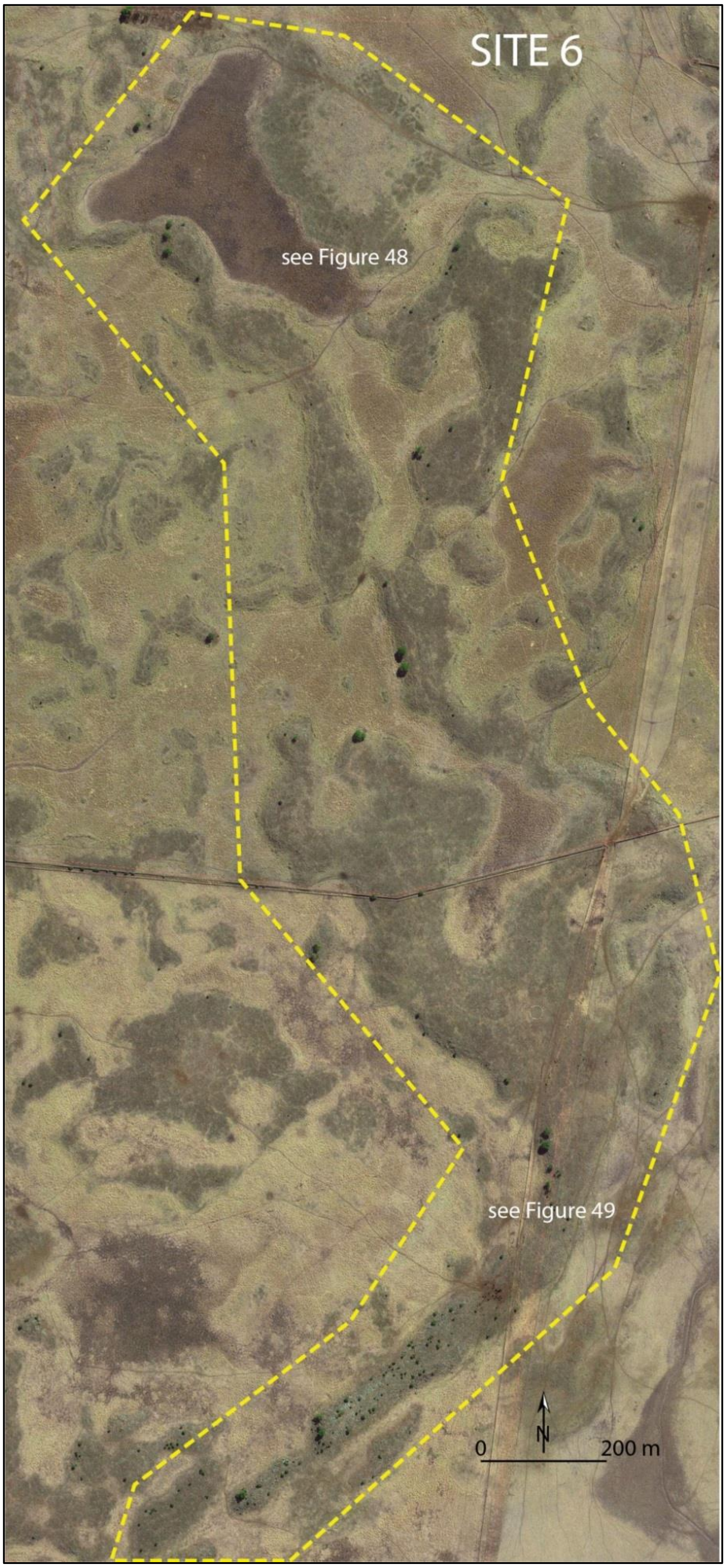


Figure 50. Elevated central part of flow with broad ridges and depressions.

Site Number 6: Ridged lava			
The site is a complex of broad ridges and enclosed depressions at an elevated central position towards the distal end of the Mount Fyans lava flow.			
Significance Level	Replication	Sensitivity	Potential Constraints
Moderate Uncommon example of a long and continuous lava unit with a varied history of movement and cooling.	Moderate Largest feature of this type on Fyans lava and large and uncommon in the context of the NVP basalt plains.	Moderate – low Potential for change to the geometry and continuity of the structure by earthworks.	Minimise track construction along ridges. Tracks to cross at right angles to ridge. Micrositing of towers on the ridges to minimise excavation and fill.

Figure 51. Ridged lava and central depression. (Photo N. Rosengren, Jan. 2013).

Figure 52. Elongate ridge continuous with ridges in Figure 51. (Photo N. Rosengren, Jan. 2013).

5.1.7 Site 7: Lava Depressions and Lava Barrier

Site Number 7: Lava depressions and barrier			
The site includes a deep depression enclosed by broad ridges of lava with steep outer edges. The ridges are at the edge of the flow and form the highest local relief in the central and southern sections of the Mount Fyans lava flows. The large depression has an alluvial floor and opens to the west through a narrow gap in the lava. A weakly-defined depression with a very thin irregular alluvial cover and a low lava rim lies 3 metres above the main depression.			
Significance Level	Replication	Sensitivity	Potential Constraints
Moderate - High Uncommon example of a high lava ridge at the distal end of the flow and a long distance from the lava source. The site is a clear example of how a permeable basalt lava body gives rise to substantial groundwater recharge of a local basin.	Low Only feature of this type on Fyans lava.	High Site would be substantially degraded by excavation and/or fill for tower or infrastructure construction.	No construction in site area.

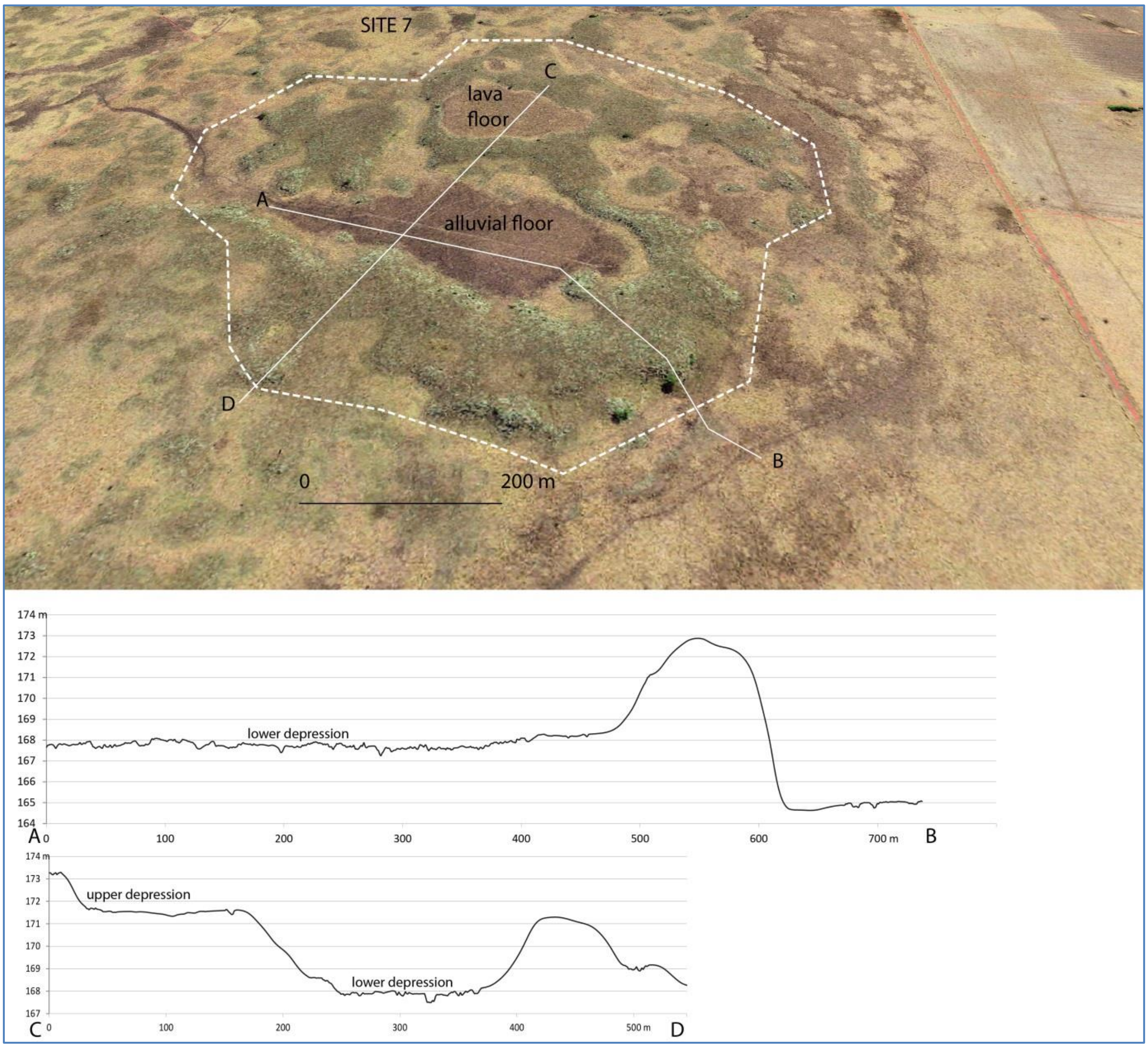


Figure 53. Site 7. 3D image (Google Earth) and profiles of main depression and high lava wall.

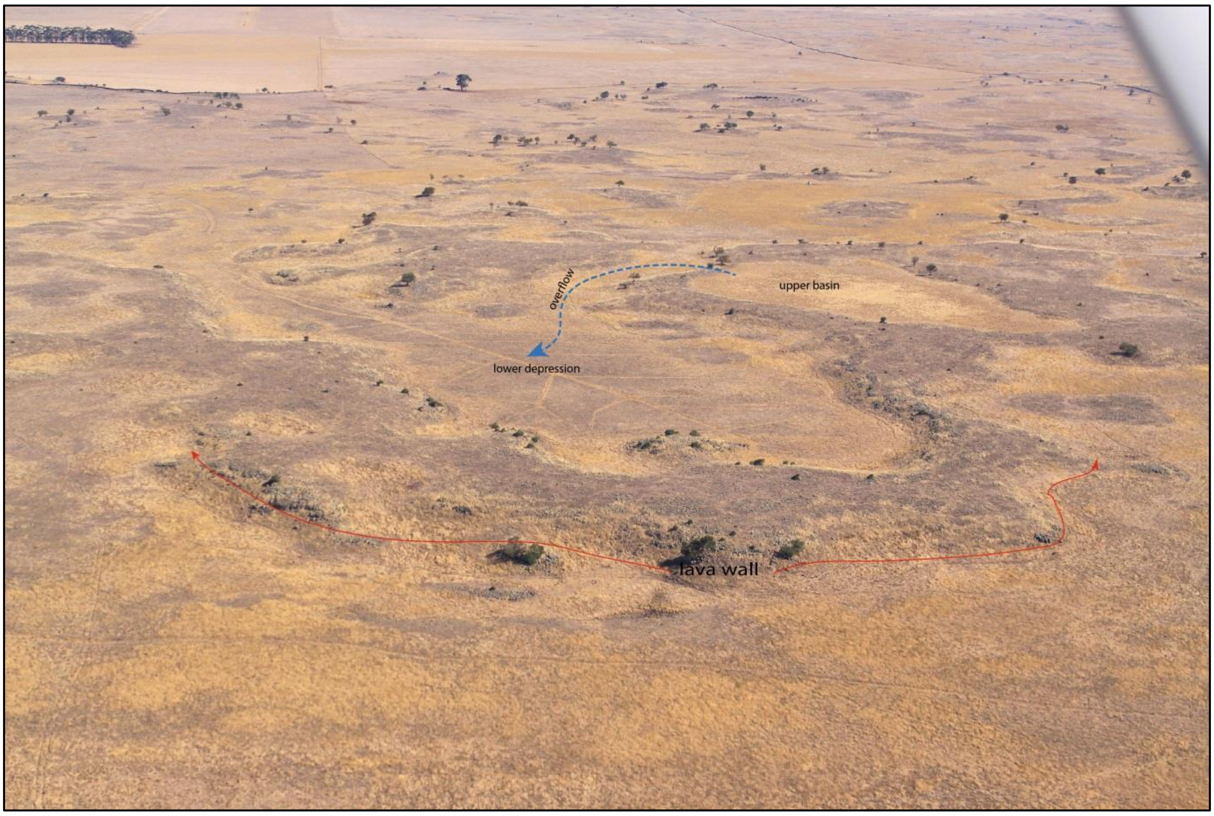


Figure 54. Site 7, aerial oblique photograph (Photo N. Rosengren, Jan. 2013).


Figure 55. Site 7, edge of lava wall.

5.1.8 Site 8: Terminal Lake

Site Number 8: Terminal Lake			
The site is the broad, shallow enclosed depression formed at the distal end of the Mount Fyans lavas. The lava at this point was moving south and down a slight incline on the gently sloping weathered older volcanic land surface. This incline was part of a small tributary stream draining to the southeast. As forward movement of the lava flow ceased with cooling and loss of up-flow nourishment, subsequent lava built the flow vertically rather than extending its length. The distal lava front created the southern rim of a partially enclosed basin that became a shallow lake and overflowed to the south east. The lake has a thin saline crust over heavy black clay.			
Significance Level	Replication	Sensitivity	Potential Constraints
High Outstanding example of lava interacting with surface hydrology to develop marginal and terminal lakes. Analysis of the chemistry of the lake bed deposits would illustrate the transition from a fresh to saline system.	Low Best examples of a defined terminal lake in the NVP of Victoria.	High Site would be substantially degraded by excavation and/or fill for tower or infrastructure construction.	No construction in site area.

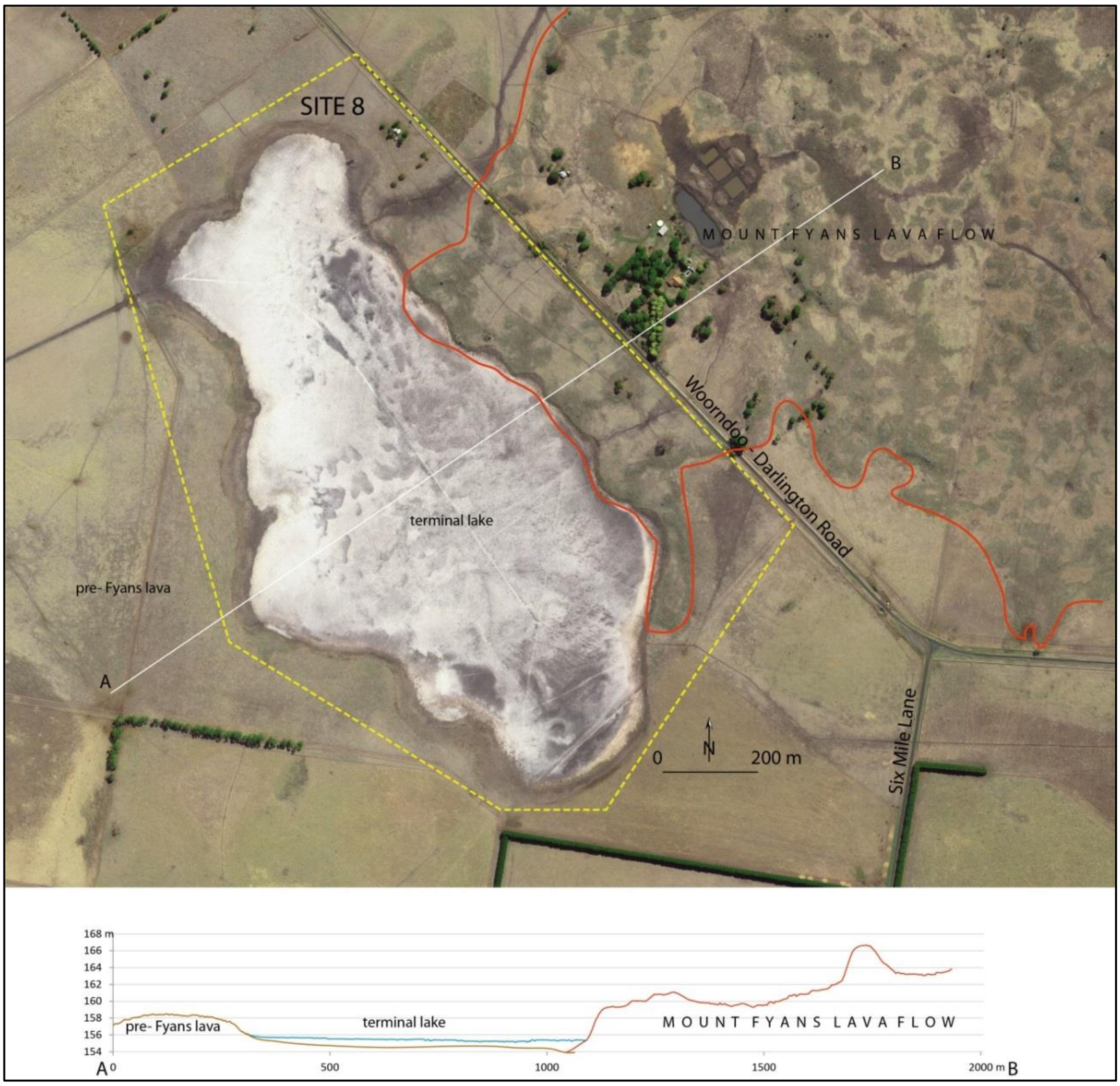


Figure 56. Site 8, terminal lake.

Figure 57. Terminal lake of Mount Fyans lavas at Woorndoo-Darlington Road. (Photo N. Rosengren, Jan. 2013).

Figure 58. Terminal lake and distal end of Mount Fyans lavas. (Photo N. Rosengren, March 2013).

5.2 West Area

Much of the central and western area of the proposed Mount Fyans wind farm is on deeply weathered older lavas which lack outcrop and have no identified eruption points. It is an area of gentle slope and weakly developed drainage systems with little topographical and geological variation. West of the Mortlake-Ararat Road there is greater terrain variation and three areas of geoscience significance are identified: site 9 - the eruption point of Mondilibi, site 10 - the gorge of Salt Creek incised into the western margin of the Mondilibi lava, and site 11 - an area of wetland north of Blind Creek, formed along the eastern margins of the Mondilibi lava.

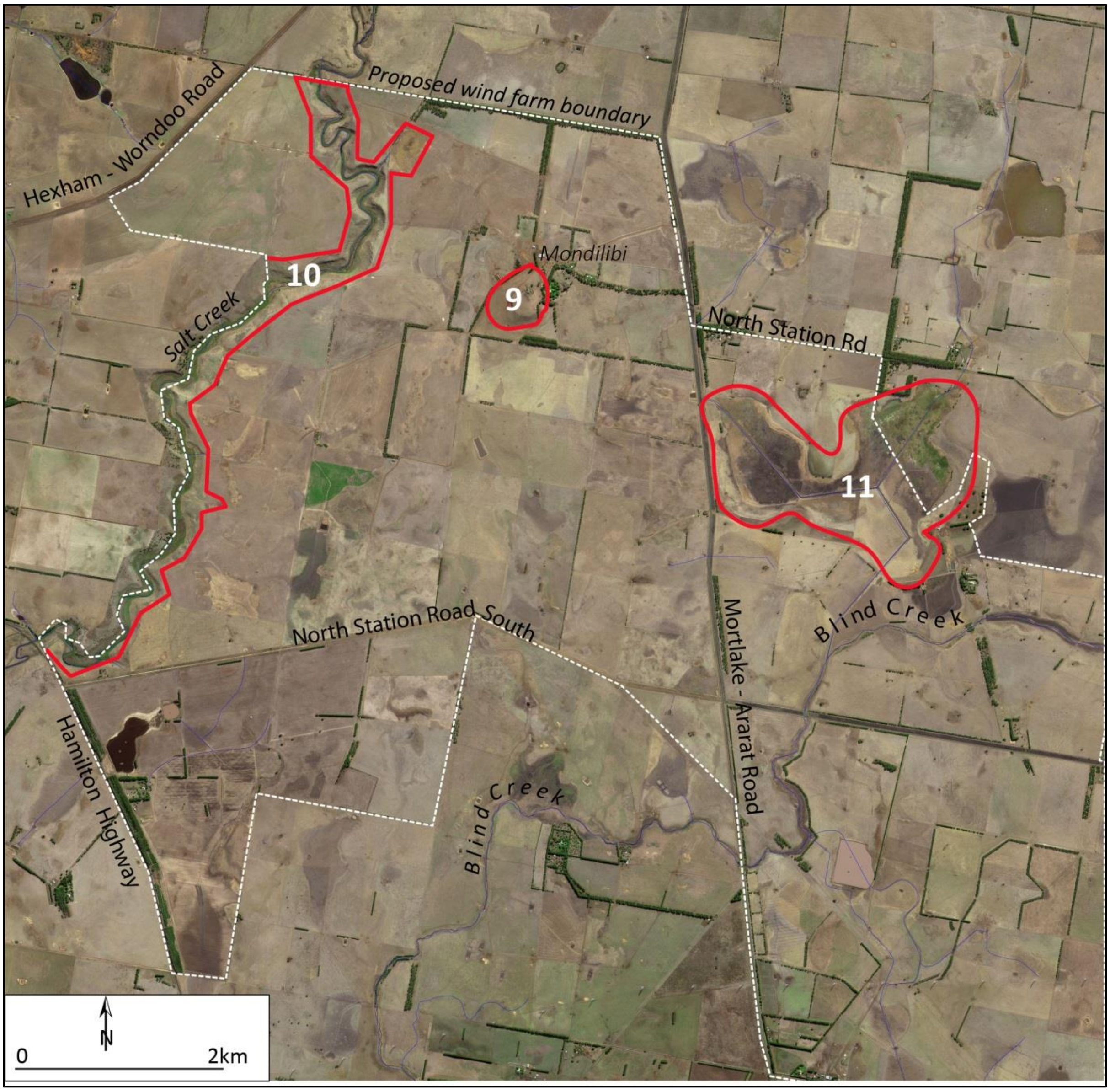


Figure 59. Significant geoscience sites (9, 10, 11), west area.

5.2.1 Site 9: Mondilibi Volcano

Site Number 9: Mondilibi Volcano			
The site encloses the eruption point and lower slopes of Mondilibi volcano. This is a composite eruption feature and displays several styles and stages of eruption. The initial eruptions were a short-lived episode of fire fountaining producing large ropy, vesicular scoria with occasional lava bombs The last eruption produced a thin lava flow that forms a capping and craggy outcrop on the northern slopes.			
Significance Level	Replication	Sensitivity	Potential Constraints
High Outstanding example of a small complex eruption point including fire-fountaining producing blocky to fine scoria, and a late-stage post-scoria basalt intrusive phase resulting in flat-lying lava disc and blocky lava dome capping the volcano. The scoria is of varied composition and form and includes numerous vesicular and ropy lava bombs.	Low A very clear example of an eruption sequence of limited occurrence in the NVP of Victoria.	High Site would be substantially degraded by excavation for tower or substantial extension of the small scoria quarry.	No construction in site area. Limits to the extension of the scoria quarry.

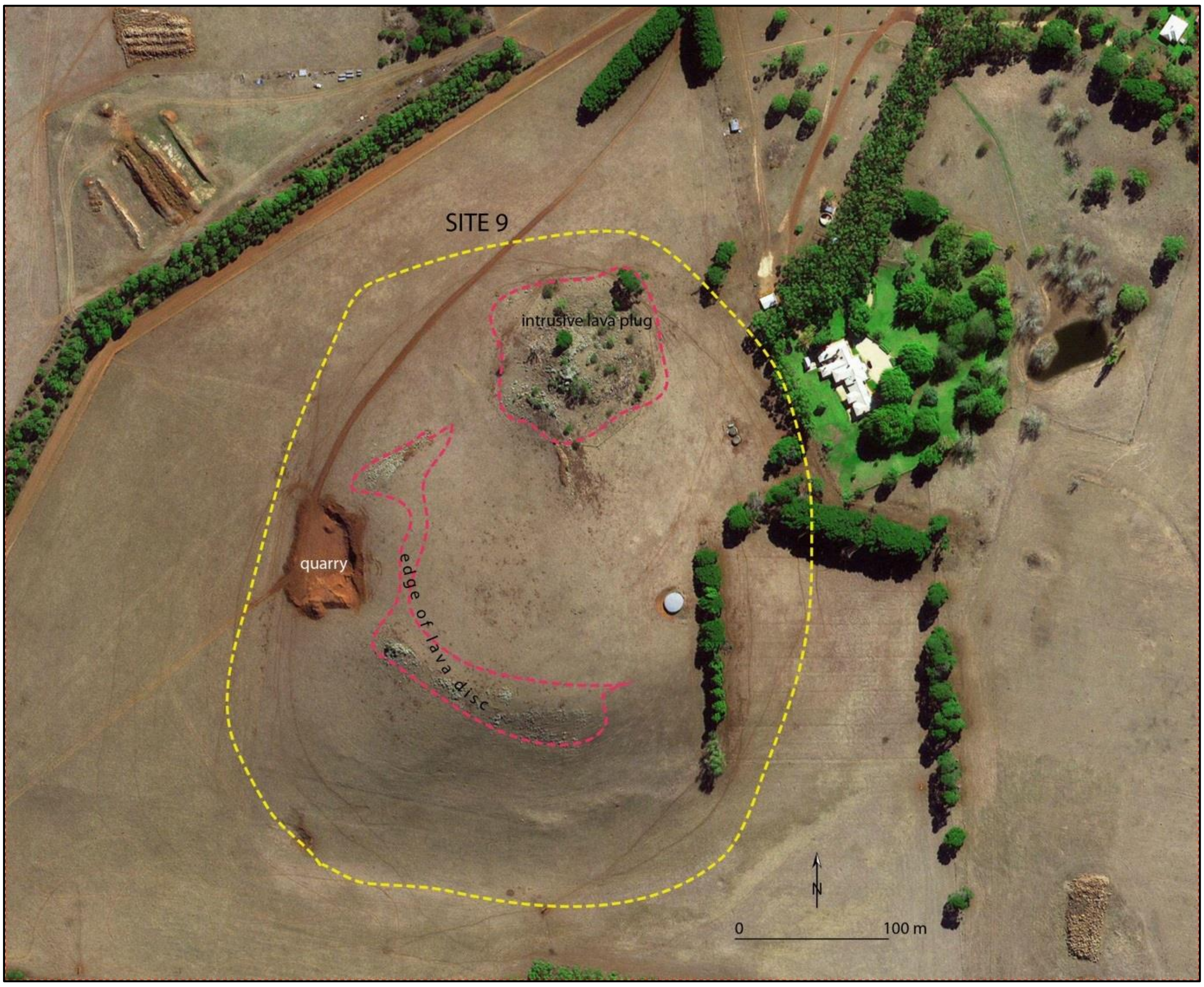


Figure 60. Site 9, Mondilibi eruption point.

Figure 61. Site 9, lava disc of Mondilibi volcano. (Photo N. Rosengren, March 2013).

Figure 62. Lava plug at Mondilibi.

Figure 63. Mondilibi scoria and lava bombs.

5.2.2 Salt Creek Gorge

<table>
<tr><td colspan="4">Site Number 10: Salt Creek Gorge</td></tr>
<tr><td colspan="4">The site includes the 7.2 kilometre long reach of Salt Creek from the northern to southern boundary of the proposed wind farm. Lava from Mondilibi spread west and south of the eruption point and deflected the course of Salt Creek against the escarpment at the eastern edge of the uplifted Stavely Block. The creek maintained a southerly alignment flowing across the lava and now is entrenched in a gorge over 25 metres deep cut into lava of the Mondilibi and earlier eruption centres.

The rim of the gorge is an almost continuous outcrop of basalt and there are intermittent benches and ledges of basalt along lower parts of the walls of the gorge. The rim-to-rim width varies from 200 metres to 350 metres with very little incision by tributary streams. In the north of the site is a 1 km long reach with a valley sinuosity index (SI) of 1.52 but for most of the length is of very low sinuosity (SI 1.18) to almost straight valley reaches (SI 1.08). The long profile is graded with a slope averaging 0.18% and no nick points are discernible on the aerial images or 1 metre DEM contours. The dense rush and sedge vegetation on the valley floor obscures the channel and masks any levee or abandoned channel reaches. In the sinuous northern reach, the channel plan-form is of similar geometry to the valley edge meanders – hence these are entrenched meanders with interlocking meander spurs. Along the reach in the study area there are no abandoned meanders (channel or valley) although there is an abandoned spur in the gorge 500 metres north of the northern boundary.

Figure 64 shows the location of 6 sub-sites with the features of highest geoscience significance in this site.</td></tr>
<tr><td>Significance Level</td><td>Replication</td><td>Sensitivity</td><td>Potential Constraints</td></tr>
<tr><td>High

An outstanding example of an entrenched stream valley cut into resistant rock. The geometry and incised-entrenched meanders of the gorge indicates the channel has been superimposed through the basalt as a result of rejuvenation by tectonic uplift after the Mondilibi volcanic eruptions. This site complements the significance of the broader region of western Victoria that includes the multiple eruption points and lava flows in the Lake Bolac-Dundonnell-Mortlake area. There are many details of the chronology of eruptions and stream displacement and landscape development in this area still to be investigated. The Salt Creek gorge is a key component in this.</td><td>Low

One of the best examples in the NVP of Victoria of stream entrenchment in to basalt as a result of tectonic uplift rather than a result of sea-level fall. Apart from the Werribee River east of Bacchus Marsh, this is one of the deepest and longest gorge sectors on any stream across the volcanic plains.</td><td>Moderate

This is a large site and there are multiple examples of the significant features identified along the length of the site. The features are robust and rely upon repetition and size rather than single sensitive examples. Earthworks and construction that were set-back from the rim and did not alter the configuration of the entrenched meander spurs would be consistent with maintaining the significance of the site.</td><td>Avoid earthworks (excavation or fill) that alter the morphology of the rim of the steepest and highest northern sectors of the gorge. The existing crossing-causeway in the north of the site should be used , and a further crossing at some point in the wider, lower profile areas in the centre and south of the site would be consistent with maintaining the significance of the site.</td></tr>
</table>

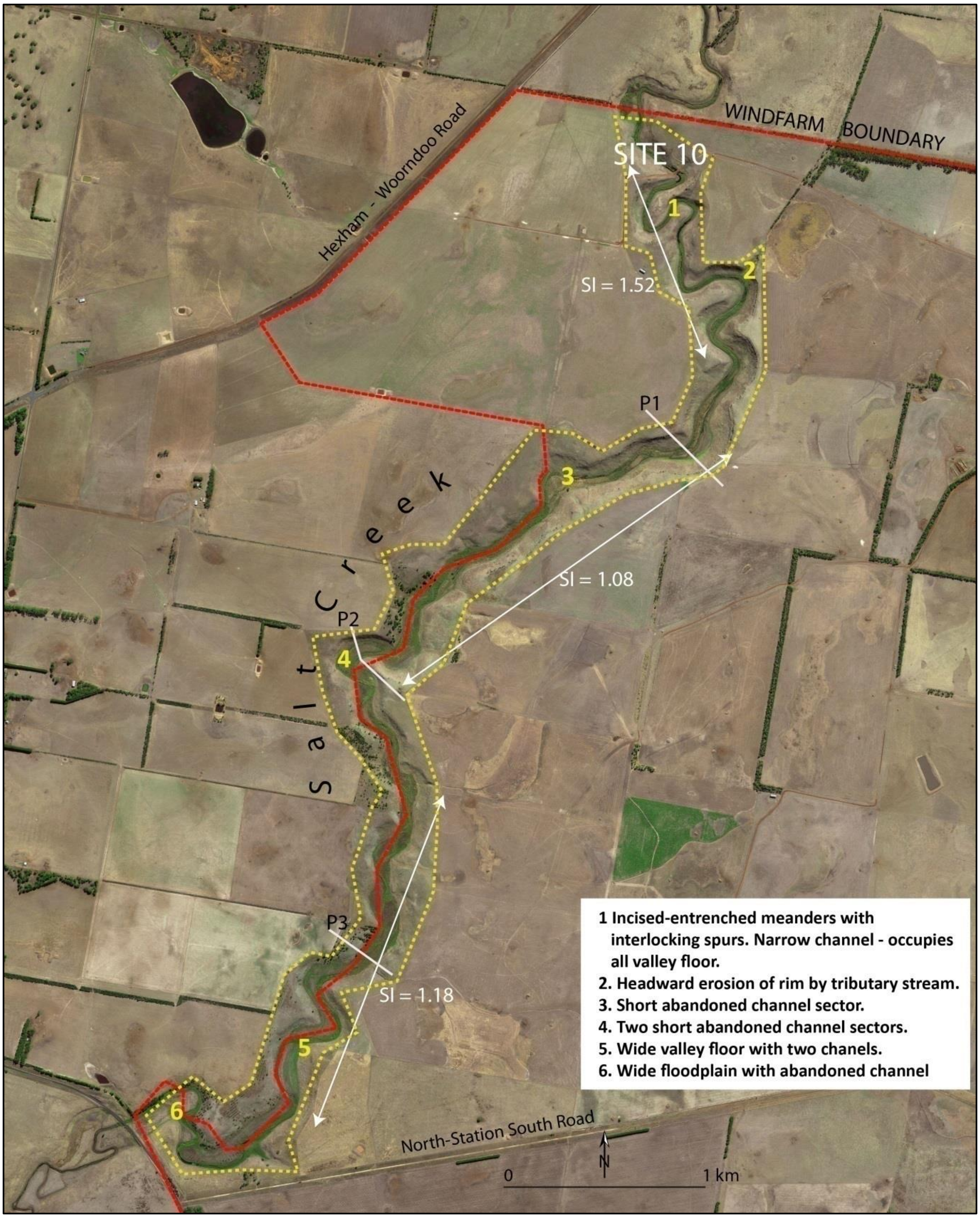


Figure 64. Site 10, gorge of Stony Creek west of Mondilibi. Figure shows details of areas of highest significance and the location of the three profiles shown in Figure 65.

Although the entire length of Salt Creek is shown as a geoscience site (Figure 64), six sub-sites are indicated as these contain key features to display the character of the site. The profiles shown as Figure 65 illustrate the varied geometry of the Salt Creek gorge.

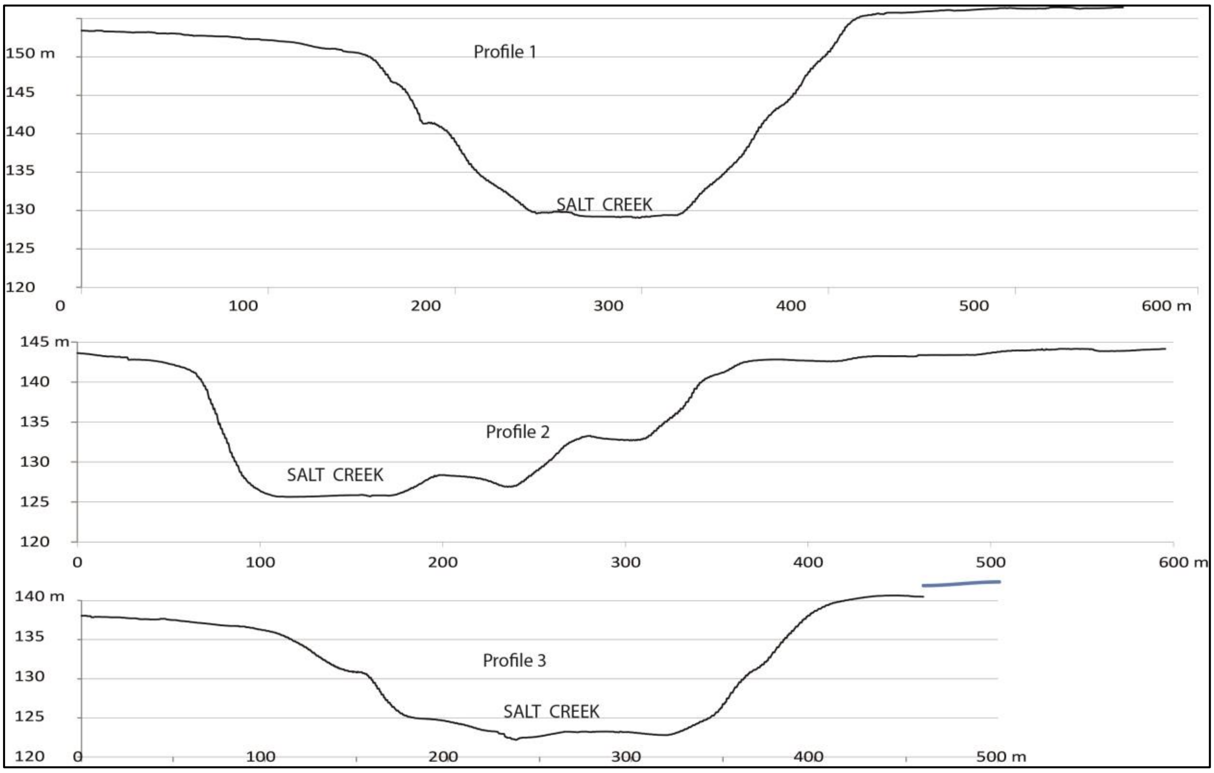


Figure 65. Profiles of Salt Creek gorge. Location shown on Figure 64. All profiles are the same horizontal and vertical scales.

Figure 66. Incised meanders of Salt Creek, sub-site 1 on Figure 64, northern section of site 10 viewed to the south. (Photo N. Rosengren, March 2013).

Figure 67. Channel cut-off - Salt Creek, sub-site 3 on Figure 64. (Photo N. Rosengren, March 2013).

Figure 68. Channel cut-off - Salt Creek, sub-site 4 on Figure 64. (Photo N. Rosengren, March 2013).


Figure 69. Wide floodplain of Salt Creek at crossing by Hamilton Highway, sub-site 6 on Figure 64. (Photo N. Rosengren, March 2013).


Figure 70. Meander spur with high-level channel preserved (broken line), sub-site 1 on Figure 64.

5.2.3 Site 11: Palaeo-lake on older lava surface

Site Number 11: Palaeo-lake on older lava surface.			
The site is a drained wetland in an irregular depression on the surface of the older volcanic surface north of Mortlake.			
Significance Level	Replication	Sensitivity	Potential Constraints
Moderate A good example of a widespread feature on older weathered lava surfaces of the NVP of Victoria. At a time of wetter climate the site would have held a permanent lake.	High Common feature on older lava surfaces	Low Site would not be degraded by construction around former lake margins.	No geoscience significance construction constraints.

Figure 71. Former lake, Site 11. Form lines at 2 metre interval.

6 POTENTIAL GEOSCIENCE CONSTRAINTS

This chapter reviews potential physical constraints on the construction and operation of the proposed wind farm in terms of the character of the surface and near-surface morphology, composition, and processes. Potential constraints imposed by geoscience heritage (geoheritage) values identified during this study are considered in Chapter 7.

6.1 Geological

Geological constraints include the capacity of the surface and subsurface materials to support the built structures, excavations and traffic movement required to build and operate the wind farm. The key engineering properties are rock composition, rock structure, thickness and extent of individual geological units, the nature of the interface between geological units and the degree of weathering and other alteration that has occurred to the primary rock properties. Geological and landform processes that may affect the integrity of the built structures must also be considered.

6.2 Lithology and Rock Structure

There is extensive rock outcrop over that part of the proposed wind farm area on Mount Fyans lavas. The main exposed hard rock units are all variants of basaltic lava derived from Mount Fyans and the weathered lavas from Mondilibi eruption. Areas without outcrop on the Fyans lava flows are either depressions in the lavas backfilled with sediment and/or organic material or small areas of older lavas with *in situ* regolith and soil cover. Borehole records show the Mount Fyans lavas to be up to 50 metres thick in places and predominantly comprised of coherent, solid basalt. The basalt is a high strength rock when massive but is weakened by the presence of numerous fractures (mainly cooling joints) that break the rock into five- or six-sided prisms. The orientation of fractures is usually at a vertical to high angle although near the margins of lava flows may be almost parallel to the ground surface. At depth the joints are closed except where widened by weathering.

The Mount Fyans lavas are comprised of numerous flow units and each may be from one metre to over five metres thick. The discontinuity surface between flow units is a potential failure surface although where there is little time gap between the flows, the surfaces are welded. At Mondilibi, in the west of the proposed wind farm site, some flow unit boundaries may have a thin covering of scoria and fragmental basalt that is not strongly coherent or completely welded.

Thick, coherent, massive basalts are very resistant rocks and may require blasting for footing or foundation excavation.

6.3 Cavities, Lava Caves

Caves (or tubes) in basalt lavas form at the time of lava emplacement, either by the roofing over of surface lava channels or by the draining of still molten material from beneath the solidified crust of a lava flow (Grimes 1995). The NVP in Victoria, with over 50 known separate cave systems, is one of the two major lava cave regions in Australia (Finlayson and Hamilton Smith, 2003). The opportunity for cave development is determined by the temperature and rate of effusion of lava from the vent and a pre-volcanic topography that favours channelling rather than widespread radial emplacement of flows (Webb *et al.* 1983). A range of cave types is known in Victoria, including large and sometimes branched systems, shallow multi-level (stacked), sub-crustal caves and single smaller isolated drained chambers, and possibly lava blisters (Grimes 2002). Caves in Victoria are often associated with elongate or mounded ridges (i.e. stony rises) that indicate localised inflation of lava with the potential for isolated shallow sub-crustal cavern formation. The extent of stony rise development on the Mount Fyans lavas suggests there may be unfilled or only partially collapsed lava tube remnants sub-surface, but in the absence of a surface opening, the presence of a cave may not be obvious.

At Mount Hamilton 11 km north of the northern boundary of the site there are three lava caves, the longest having 1200 metres of repeatedly branching systems (Webb *et al.* 1983). There are no known lava caves in the study area or any other area of Mount Fyans lavas and no likely cavern entrances or open lava flow pathways were identified during this field study. Not all ridges and mounds have been closely inspected and there is the possibility that lava tubes do occur that have not been unroofed by collapse or otherwise exposed. The concentration of strong spring outflows north and south of the Dundonnell-Woorndoo Road and emergence at well-defined depressions may indicate enlarged sub-surface groundwater pathways.

6.4 Future volcanic activity

Recent studies (DPI 2011, Boyce 2013) have identified over 700 eruption points in the Newer Volcanic Province of Victoria with eruptions spanning from 4.5 million years to 5,000 years ago. Earlier studies (Joyce 1988, Rosengren, 1994) had recorded a smaller number of eruption points but had identified over 400 eruption centres, many of which are now known to have closely spaced eruption points not recognized in the earlier surveys. The above studies have estimated eruption frequency (average interval between eruptions) to be between 10,800 years 12,500 years. As the youngest volcanoes have been shown to be between 30,000 and 40,000 years old, another eruption could be expected. The record of shallow seismic and possible offshore volcanic activity in Bass Strait also shows that a future eruption in southeastern Australia will almost certainly occur (Joyce, 2001). It is not possible to quantify this risk apart from using a relative scale based on the eruption history of the region (Joyce, 2001, 2004, 2005).

Joyce (2005) assessed this risk between high and medium in an area south and southeast of Hamilton. In the event of renewed volcanic activity, three types of eruption processes could occur in the region discussed in this report: (a) phreatomagmatic explosive eruptions producing maars (wide, shallow craters such as Tower Hill) spreading volcanic ash over kilometre-wide areas; (b) fluid basalt lava flows (similar to the flows from Mount Hamilton and Mount Fyans) either following existing valleys or submerging planar and sloping surfaces, (c) scoria eruptions similar to Mondilibi. These eruption products would cause damage ranging from total to moderate on infrastructure, depending on the type of eruption and the distance to the eruption centre.

The eruption record of western Victorian volcanoes indicates it is unlikely that past eruption points would again become active, but activity could commence nearby (Blong, 1989). Given the necessarily qualitative nature of the data, volcanic risk is a continuing, but low background factor for southwest Victoria, including the area of the present proposal.

6.5 Seismic Activity

Western Victoria has experienced tectonic uplift in the Neogene and Quaternary (over the past 23 million years) as evidenced by surface topographic features and magnetic anomalies of marine and coastal sediments uplifted or now buried by lava flows Sandiford (2003), Paine *et al.* 2004 and Wallace *et al.*, (2005). In places, e.g. the western flank of the

Otway Ranges (60 km southeast of Mount Fyans), rapid and substantial uplift of up to 200 metres has occurred over this time. Paine *et al.* (2004) also demonstrated substantial uplift in the Staveley Block 25 km west of Mount Fyans. However, they concluded that tectonism was short-lived and had occurred prior to the eruption of the lava flows in the Dundonnell region as no evidence of displacement of lava flows over the past four million years could be detected.

Parts of southwest Victoria have experienced earthquakes in historical time, the largest being 5.3 ML (local magnitude) and 5.6 ML at Warrnambool in July 1903 and another 5.3 ML at Cape Otway in 1960. Both resulted in extensive ground motion and there was moderate damage and ground liquefaction was reported at Warrnambool (Gibson and Brown, 2003). As with the potential for volcanic activity discussed above, the risk of a seismic (earthquake) event in southwestern Victoria is difficult to quantify. As an intraplate tectonic environment, the level of seismic risk in Australia is low relative to active plate margin regions such as New Zealand.

However, damaging earthquakes do occur in Australia and seismic risk maps have been prepared for the continent (Gaull *et al.*, 1990; Brown and Gibson 2004) and for regional areas (Gibson and Brown 2003; Allen *et al.*, 2004). Allen *et al.* (2004) noted that as for most of Australia, quantification of earthquake magnitude for reliable probabilistic hazard studies remains a major source of uncertainty. Earthquake hazard maps (Gaull *et al.*, 1990, Gibson and Brown, 2003) show the predicted incidence of ground motion based on modelling from historical records. These show low hazard ratings for the area of the proposed wind farm.

McCue and Sinadinovski (2001) assessed seismic risk in Australia and concluded that past seismicity is the best guide to future activity. However, they acknowledge there are exceptions and cite instances of three large earthquakes in recent years in Australia in areas where no previous seismicity had been observed. Recorded seismic activity directly affecting the area of this project is very low, and there are no known active faults (Gibson and Brown, 2003). As with volcanic constraints noted above, seismic risk is a continuing, but low background factor for this project.

6.6 Geomorphological (landform) constraints

Potential landform constraints in the proposed wind farm area include slope steepness, rapid changes of slope angle and aspect, areas of groundwater outflow, microtopography and active geomorphological processes. Some of these constraints are closely related to geological and soil conditions.

The landform constraints mentioned above are predominantly on the stony rises of the Mount Fyans lava flows and are related to the occurrence of lava ridges with locally steep slopes and surfaces with a litter of basalt blocks. The irregular, hummocky, rock-strewn surfaces are a constraint on vehicles traversing the site as also are swampy depressions with compressible soils.

6.7 Regolith and soil constraints

The generalized constraints imposed by regolith and soil character are outlined as soil erodibility, soil waterlogging, potential acid sulphate soils, and mass movement (slope failure). These are localized on the Mount Fyans lavas but may be seasonally widespread on the areas of older volcanic terrain.

6.7.1 Soil erodibility

Soil erodibility (also called erosivity) is an index of the potential for soil and regolith loss to occur, particularly as a result of exposing soil surfaces during earthworks. It is determined by the physical, chemical and biological properties that influence the strength and cohesion of the soil surface and subsurface as these determine ambient soil stability and the potential for earthworks to trigger instability and movement. These constraints need to be managed during excavation, stockpiling and back-filling.

Baxter and Robinson (2001) showed that soil erodibility and other soil hazards closely corresponded to the age of the lavas i.e. the regolith landform units. Areas of potential for soil erosion by water (sheet erosion) and gully and tunnel erosion were low for areas of Mount Fyans lavas and moderate potential for some areas of the deeply weathered lavas west of the Mt Fyans flows. Apart from small areas of dry lake bed, the area was classed as having low susceptibility to wind erosion.

6.7.2 Surface drainage, soil drainage and waterlogging

Although Robinson and Baxter (2001) mapped soils over all the project area as having good internal soil drainage, the small scale of their mapping masks the localized occurrence of waterlogging in enclosed depressions. Standing surface water will occur in depressions for parts of the year and will be a constraint on vehicle movement and construction activities. Areas of waterlogged and organic soil also have low load-bearing capacity.

6.8 Mass movement

Apart from the Salt Creek gorge, large scale mass movement of surface and subsurface soil and regolith is limited by the low local relief and the absence of long steep slopes. There is potential for localized slope or boulder movement on the edges of the higher mounds and tumuli of the stony if disturbed by machinery.

6.9 Salinity

Dahlhaus *et al.* (2002) defined 18 groundwater flow systems in the Glenelg Hopkins CMA region, three of which occur in and adjacent to the Mount Fyans site. Groundwater systems in western Victoria are closely related to the landscape character and geology - particularly the degree of fracturing and depth of weathering.

Soil salinity across the Fyans lava surfaces is low, but is mapped as moderate on the older lava surfaces (Baxter and Robinson 2002). Discharge around the western edge of the stony rises may add to the primary salinity of the lakes and wetlands at the margins of the Mt Fyans flows Dahlhaus *et al.* (2002). Saline groundwater and saline stream discharge has been mapped in similar terrain areas to the west of the Stavely Block (Bennets *et al.* 2003), and there may be unrecognised actual or potential salinity at the Mt Fyans site with associated implications for engineering infrastructure.

6.9.1 Acid sulfate soils

Salt affected inland areas also have the potential for acid sulfate soils to develop if suitable soil and groundwater conditions occur. Soil horizons that contain sulfide minerals can be environmentally damaging if exposed to air (reaction with oxygen) by disturbance. Saturated, organic-rich soil conditions promote reducing conditions and can produces pyrite i.e. sulfidic material (Fitzpatrick and Shand 2008). The potential for saline groundwater or surface water providing suitable conditions for acid sulfate soils to have developed in this site is considered to be low at a regional scale (Australian Soil Resources Information System 2012) but may be higher at individual saline lakes on the older lava surfaces.

7 POTENTIAL GEOHERITAGE CONSTRAINTS

7.1 Geoheritage values

The proposed wind farm occupies an area 12,395 hectares of which 2230 hectares is on Mount Fyans lavas. This represents approximately 18% of the total Mount Fyans lava area of 14800 hectares. Additional ground disturbance in the form of access tracks, hard stands and cables and other infrastructure will be up to 2% of the wind farm area.

The site does not include any known points of eruption for the Mount Fyans flows or from other recognised eruption points in the Dundonnell-Woorndoo area. The site does enclose excellent examples of a variety of stony rises, diverging and converging lava lobes, raised lava surfaces and parallel lava ridges and depressions resulting from sagging or collapse of lava tubes. Although there are no known lava caves or open lava flow pathways in the study area, there are extensive cave systems at Mount Hamilton 11 km north of the northern boundary of the site. There is the possibility that lava tubes do occur that have not been unroofed by collapse or otherwise exposed. The concentration of strong spring outflows north and south of the Woorndoo-Dundonnell Road and emergence at well-defined depressions may indicate enlarged sub-surface groundwater pathways.

The site also displays very clearly the development of lateral lakes as a result of blocking surface runoff and shallow stream channels. It also encloses a number of depressions that contain ephemeral lake or swamp sites in the lava flows. These contain lithic and organic sediments that enclose pollen and other material suitable for palaeo-environmental reconstruction.

As stated earlier in this report Mount Fyans and the associated older lavas form a complex of High Regional geoscience significance, and is part of a broader complex (including Mount Hamilton and other nearby eruption centres) that is of State Significance. This assessment applies to the entire volcanic complex although smaller areas of the assemblage have their own discrete or separate values. The site does contain excellent examples of types of stony rises formed by fast-moving, fluid lava tongues. As these occur at the distal sections of the flow, they are important in formulating models of long lava flow development.

An inspection of vertical aerial photographs and high resolution satellite images covering all the Mt Fyans lavas shows that the volcanic landforms in the Mount Fyans wind farm site occur also in areas beyond the present proposal.

7.1.1 Kanawinka Geopark

The proposed wind farm at Dundonnell lies within the boundaries of the newly created Kanawinka Global Geopark. A Geopark is broad concept developed by UNESCO's Division of Earth Sciences that recognises areas with a geological heritage of significance, with a coherent and strong management structure, and where a sustainable economic development strategy is in place. A major aim of the geopark programme is to allow recognition and protection of geological sites and promote their interpretation and sustainable use and to promote tourism to the region. The Kanawinka Global Geopark is a serial Geopark (including several related areas and themes) and extends across part of the coast and volcanic plains of western Victoria and into South Australia. It includes four major themes, two of which - *Lakes and Craters Precinct* and *Lava Flows Precinct* - encompass volcanic features (Kanawinka Global Geopark, 2011). The Mount Fyans site is located in the *Lakes and Craters Precinct* of the Kanawinka Geopark. This precinct identifies and describes a number of eruption points including Mount Hamilton but does not refer to Mount Fyans or associated lava flows or Mondilibi volcano. Tourism (specifically geotourism) is seen as a major component of a Global Geopark but the concept includes socio-economic activities and the use of the resources or a region for sustainable regional development. It does not specifically or generically preclude the use of volcanic land for wind farm development.

7.2 Potential Impact of Proposal on Geoheritage Features

7.2.1 Potential General Impact

The assessment of impact on the geoscience significance is based on the physical impact on both the Mondilibi eruption point and the Mt Fyans lava flows and associated features including lakes and swamps and spring discharge sites. Building and operating the wind farm will locally modify the terrain and surface geology of the areas on which towers and associated infrastructure are built. Modifications will include excavations and/or levelling of surfaces for turbine towers, underground cables and related surface structures and construction of vehicle tracks. This will require regrading slopes by cut and fill and selective removal of regolith and rock, temporary and long-term storage/disposal of spoil, provision of culverts and other drainage work and stockpiling construction materials. The surface and near-surface geology at the construction sites and roadway will be removed and replaced with imported materials. The original geometry and composition of these sites will be permanently altered.

The construction and operation activities will result in a long-lasting change on the existing landforms of the selected areas of Mount Fyans lava flows. This impact would be most conspicuous on narrow and linear features, isolated mounds and depressions and steep slopes – both on ridge and plateau edges and on the margins of enclosed depressions across geoscience sites 1 to 8 on the Mount Fyans lava areas and the Mondilibi eruption site. Of particular sensitivity are the elongate ridges and depressions and any lava caves that may occur.

Given the relatively high intensity and long history of rural land use, and the high visibility and accessibility of the lava surfaces, the likelihood of unknown cave entrances occurring is low. There may however be caverns, either primary lava caves or (although less likely) as a result of weathering, with no surface opening. Geotechnical/geophysical testing at tower sites on Mount Fyans lava surfaces that, based on their geometry and position on the lava flow have the potential to be cavern sites, should be conducted to determine the presence of a cavern. Details of these possible sites and procedures for testing will be provided in a separate document once an indicative tower layout is provided.

The GSA has developed protocols that it recommends be implemented should unknown caves or other significant features such as unusual minerals be encountered during investigation, construction and operation of wind farms.

Regrading of slopes for tower installation and roadway has the potential to impact on runoff and spring discharge and the morphology of the associated drainage lines. Similar impacts may occur on the margins and catchment of the internal lakes and swamps on the lava flow surface. These potential impacts can be minimised by micrositing to avoid sensitive areas around the lake margins, and by adopting a best practice construction and environment management plan.

7.3 Geoheritage Management Plan

The requirements outlined in this section should be included within the environmental management plan prepared for the project. Where development is proposed within geoscience sites or on lava ridges or depressions within the Mt Fyans lava flow area further field inspections may be required to refine geoscience risks and cave potential.

7.3.1 Geoscience sites where development is to be excluded

All development is to be excluded in areas of Geoscience Sites 1,2,3,8,9, the identified areas of Site 4 (see Figure 72) and the area within the shoreline of the former lake in Site 11 (see Figure 71).

7.3.2 Geoscience Sites where development is restricted

The constraints for Geoscience Site 10 are listed in Section 5.2.2 page 58 above.

The following principles are to be applied to development across Geoscience sites 4, 5, 6, and 7:

- Towers and other structures should be avoided on and across the lava ridges and elevated plateaus (Figures 49 to 56 and 73).
- Underground cabling and roadways should be avoided on enclosed depressions (Figures 12 and 72).
- Underground cabling and roadways across high and narrow ridges should be avoided or minimised (Figures 49 to 56 and 72). Where infrastructure is provided it shall be located so that it only occurs in naturally occurring gaps in ridges and should be designed to minimise cut and fill and follow the contours of the land.
- In and around Site 4 development should avoid any crossing, excavation or fill or reshaping of spring outflow sites and lake margins.
- In areas where development is proposed on land involving high and narrow lava ridges or plateau areas with central depressions, geophysical investigation to determine the presence of sub-surface cavities e.g. using resistivity or ground penetrating radar should be used (Figures 49 to 56, 74 and 75).
- Excess rock and imported construction materials shall be shall be removed from the area.
- Where development occurs within these areas it shall be designed to be on older volcanic terrain and involve the minimum amount of earthworks.
- Wherever practicable existing roadways and excavated land shall be used for construction activity.

7.3.3 Management Practices in Mount Fyans lava flow area

The following principles are to be applied to development across the Mt Fyans lava areas outside of the Sites identified above:

- Towers and other structures should be avoided on and across the lava ridges and elevated plateau (Figure 72).
- Underground cabling and roadways should be avoided on enclosed depressions (Figure 72).
- Underground cabling and roadways across high and narrow ridges should be avoided or minimised (Figure 72). Where infrastructure is provided it shall be located so that it only occurs in naturally occurring gaps in ridges and should be designed to minimise cut and fill and follow the contours of the land.
- In areas where development is proposed on land involving high and narrow lava ridges or plateau areas with central depressions, geophysical investigation to determine the presence of sub-surface cavities e.g. using resistivity or ground penetrating radar should be used.

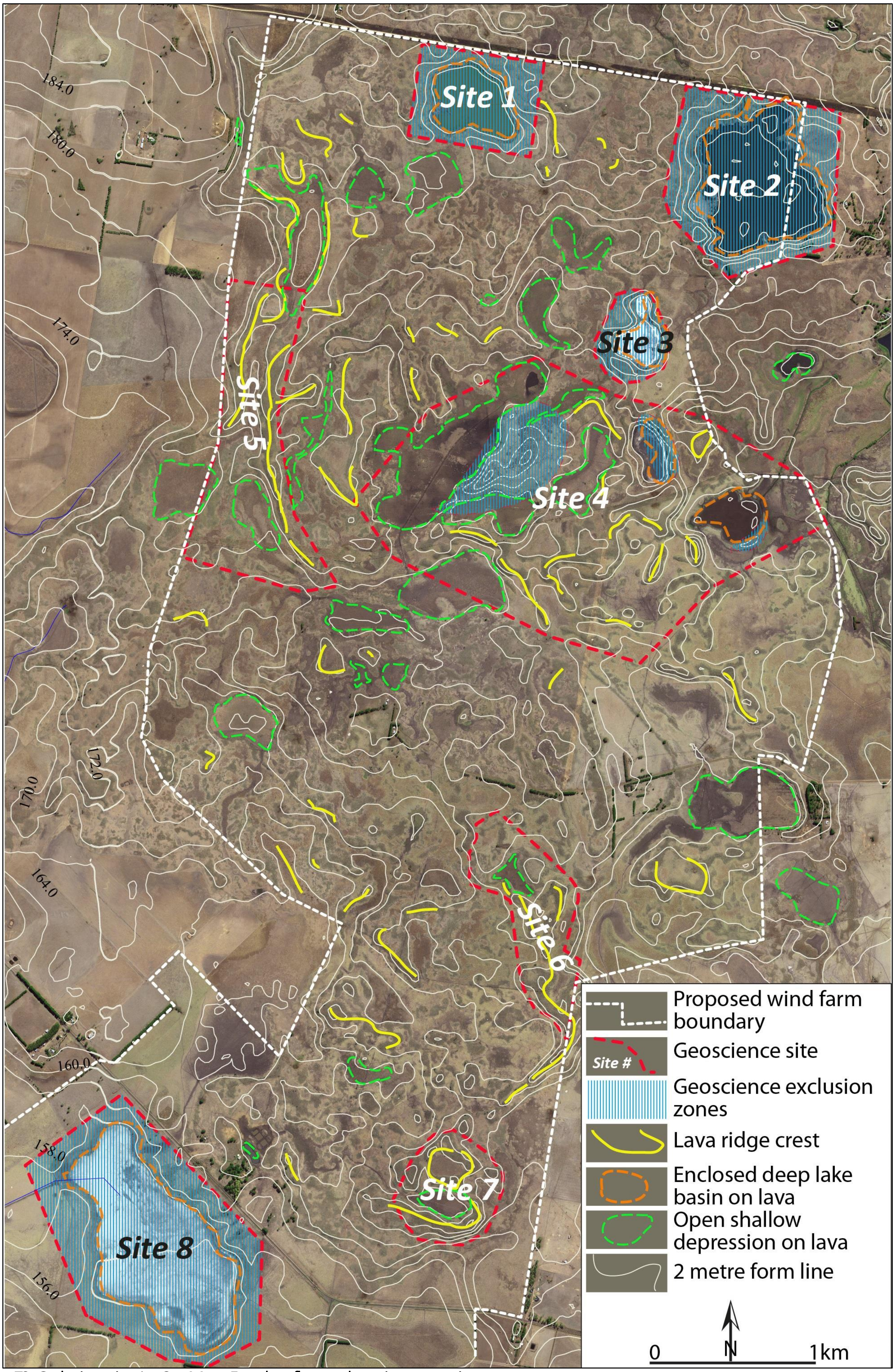


Figure 72. Geoheritage sites 1 to 8 on Mount Fyans lava flows and geoscience constraints.

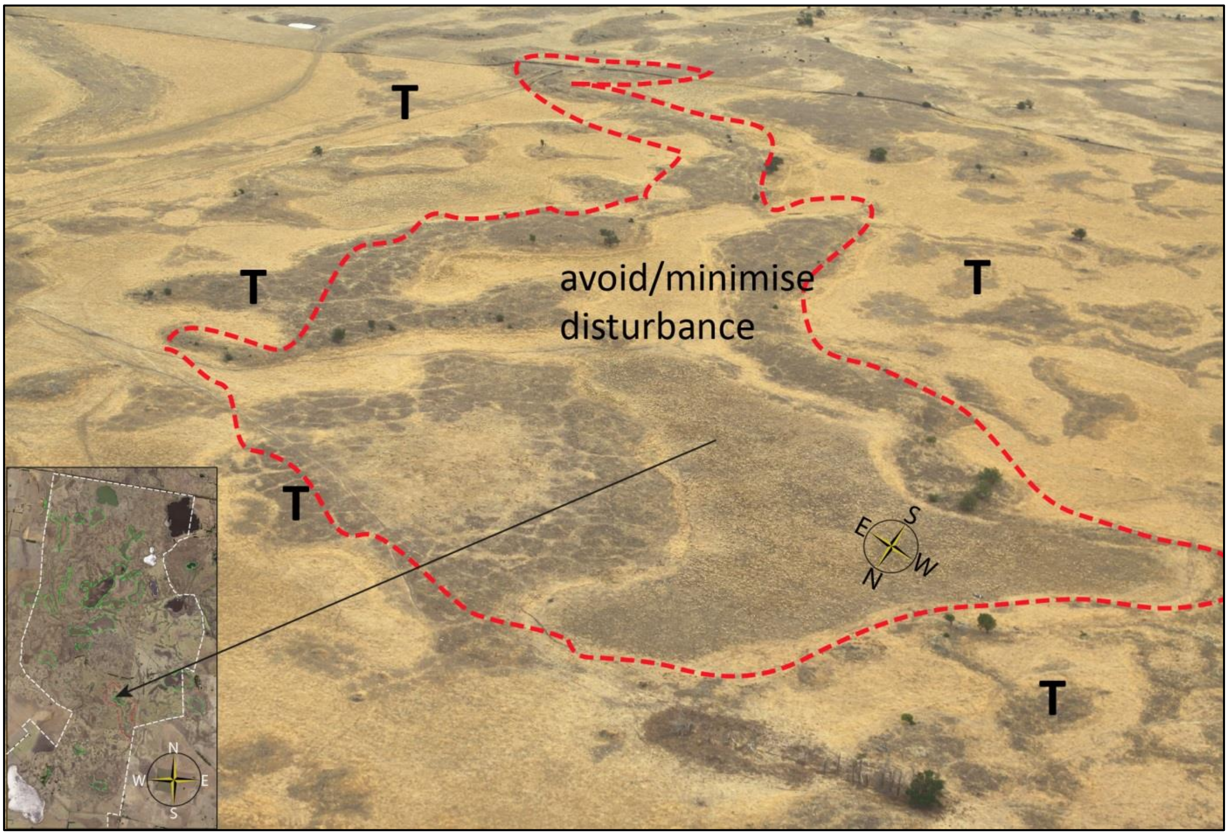


Figure 73. Geoscience Site 6. Areas suitable for tower development (T) and areas to avoid/minimise disturbance.

Figure 74. Part of geoscience Site 4 showing ridge crests possible cavern entrance sites (yellow line) and exclusion areas (blue shading).

Figure 75. Geoscience site 7 indicating ridge crests possible cavern entrance sites (yellow line) and alluvial floor seasonally wet and untrafficable.

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