PROPOSED WILLATOOK FARM

GEOHERITAGE ASSESSMENT

Environmental GeoSurveys Pty Ltd

(Neville Rosengren)

Mount Rouse - Penshurst lava flow north of McGraths Road, Orford
(Photo: Neville Rosengren Sept 2017).

Report Prepared for Willatook Wind Farm Pty Ltd

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EXECUTIVE SUMMARY

This report, prepared for Willatook Wind Farm Pty Ltd, details the geology and geomorphology of an area of 6750 hectares proposed for a wind farm located between Hawkesdale and Orford in western Victoria. The report describes the geological and landform context of the project area, assesses the geoheritage values of the area of the proposed windfarn, 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 terrain of the proposed Willatook Wind Farm is comprised of volcanic rocks of the Newer Volcanic Province of Victoria. There are two groups of volcanic rocks: (a) lavas of Pliocene to early Pleistocene age (two to four million years ago) derived from multiple eruption points between Hamilton and Warrnambool. Vine Bank, a gently rounded low conical hill with 25 metres relief (altitude 122 m AHD) justg south of Woolsthorpe-Heywood road at Dunmore (2.5 km east of Hamilton - Port Fairy Road) is one of these older lava shield volcanoes.(Rosengren 1994). Since emplacement of these lavas, the initial volcanic landscape has been reshaped by deep weathering and stream incision and is now an undulating plain of low relief with features of moderate to low geoscience significance; (b) lava derived from the eruption centre of Mount Rouse near Penshurst some 30 km to the north and dated around 300,000 years. The boundaries of the Mount Rouse flows are clearly defined in the landscape by a distinctive stony terrain that is very different from the older flows they cover. Although partly modified by ambient processes since the eruption, and by various types of rural land uses, these areas of younger volcanic activity preserve volcanic attributes including elongate mounds and ridges little modified by weathering and erosion and are of high geoscience significance for the study of long lava flows. These lava features are part of a broader complex (including Mount Hamilton and other nearby eruption centres) that is of State Significance[1] (Brocx & Semeniak 2007). No lava caves are recorded in the proposed wind farm area.

[1] This significance level is an informal rating used by the Geological Society of Australia to define the geographical context of occurrence of a geoscience feature. However, there is no State legislation, nor any formal systematic process for the identification, conservation and management of sites of geoheritage significance

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.

It is considered that given the constraints noted in this report, the construction and operation of the proposed Willatook Wind Farm is consistent with maintaining the high level of geoscience significance of the site and the broader aspects of Mount Rouse and associated lava flows.

1 INTRODUCTION

1.1 Proposed Willatook Wind Farm

This report addresses aspects of a proposal by Wind Prospect Pty Ltd to develop and operate the Willatook Wind Farm (WWF) in western Victoria (Figure 1).

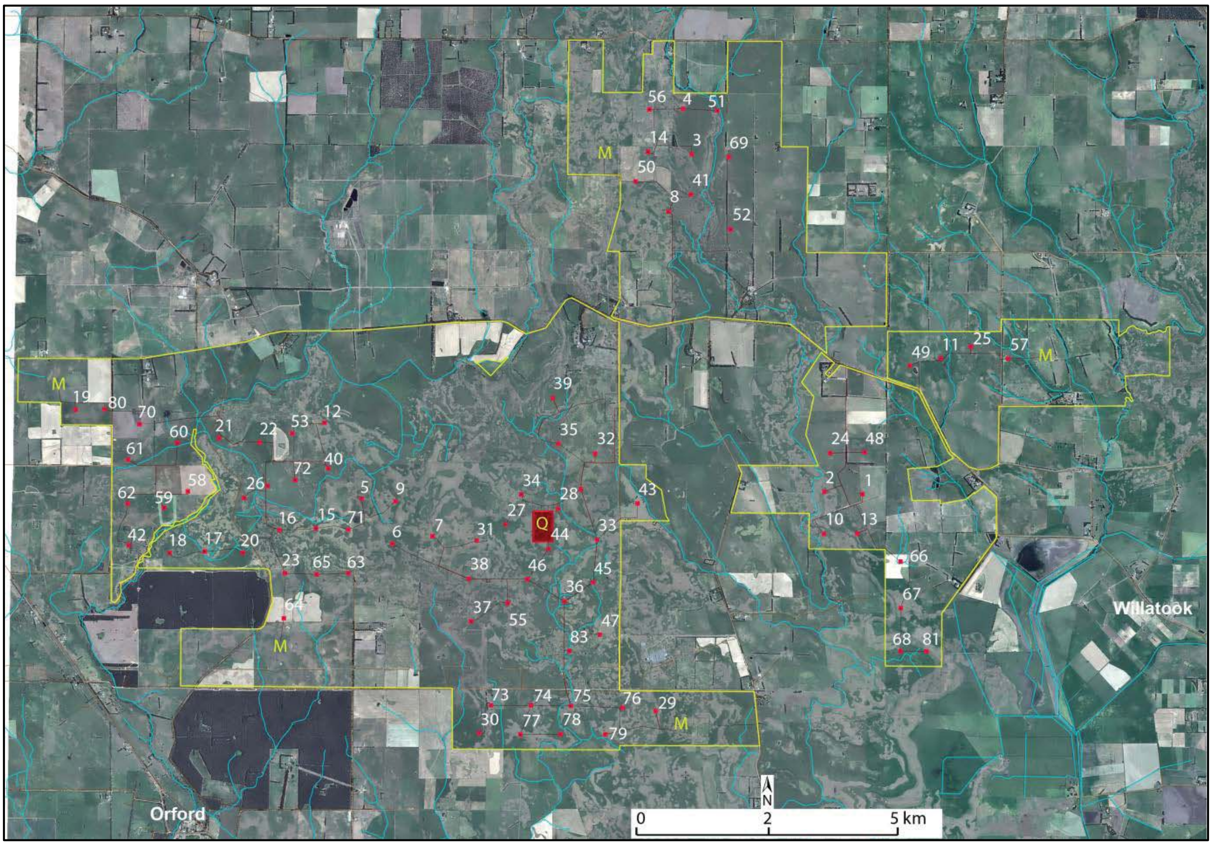

Figure 1. Willatook Wind Farm boundary, proposed turbine location, cables and tracks. M = Meteorological mast, Q = proposed quarry site. (Data from Wind Prospect Pty Ltd).

The site is located three km north east of the township of Orford, approximately 22 km north of Port Fairy and 245 km west of Melbourne. Hawkesdale is the nearest significantly sized settlement approximately 7.5 km to the East of the windfarm. The wind farm boundaries enclose 6,750 hectares. The proposed development will comprise of up to 83 wind turbine generators (WTGs) as well as permanent infrastructure including:

- Approximately 64 km of site access tracks
- Creation and improvement of up to 7 access points from public roads
- Four Permanent anemometry masts
- Approximately 100 km of underground cabling
- Approximately 14.5 km of overhead wires
- A collector substation and connection of underground cables to overhead line

- Connection to the Heywood-Moorabool 500 KV power line through the existing Tarrone substation.

Temporary infrastructure will include construction compounds, turbine component lay down areas, and a concrete batching plant/s and potentially an on-site quarry.

1.2 Scope and Purpose of Present Report

The present report addresses physical characteristics of the site of the proposed wind farm. The report has four 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 area of the proposed wind farm in the local, regional, state and national context.
- A review of the perceived constraints and opportunities for wind farm development based on geology, geomorphology, regolith[2], soil and geoheritage features 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.

1.3 Methodology

This is a desktop study supported by limited field work. The report is based on the author's background knowledge of the volcanic regions of western Victoria gained from previous studies including assessments for other proposed wind farms (Rosengren 1994, 1996, 2005, 2006, 2008a, 2008b, 2011, 2012, 2014).

Topographical and geological data were obtained initially from available literature, digital maps and data sets, Google Earth Pro satellite imagery, geophysical images and bore records. No topographical information better than 10 metre contour resolution was available and no LiDAR data was available. Vertical aerial photography was limited to low resolution (125 cm) georeferenced images (Glenelg-Hopkins Shire 2003) and 20 cm (capture scale) non-georeferenced PDF images from GeoVic (http://er- info.dpi.vic.gov.au /sd_weave/registered.htm) downloaded in small tiles to give best resolution and georeferenced. Field inspection between 20 - 23 September 2017 was restricted as much of the site was not accessible due to very wet ground conditions. A further field inspection of

[2] Regolith is the entire column of unconsolidated cover derived by weathering and/or deposition f transported sediment that overlies coherent local bedrock. It includes fractured rock, soil organic accumulations and alluvial, colluvial and aeolian deposits.

selected turbine sites was made on Dec 8 - 10 2017. The most satisfactory overview of the terrain was by low-level aerial inspections and photography from an Air Warrnambool Cessna 152 aircraft on a 1.8 hour chartered flight on 23 September 2017 and a further 1.2 hour flight on 9 December 2017.

2 REGIONAL GEOLOGY AND GEOMORPHOLOGY

2.1 Newer Volcanic Province

The proposed Willatook Wind Farm is to be located on the southern margin of the Western Plains of Victoria north of Port Fairy (Figure 2).

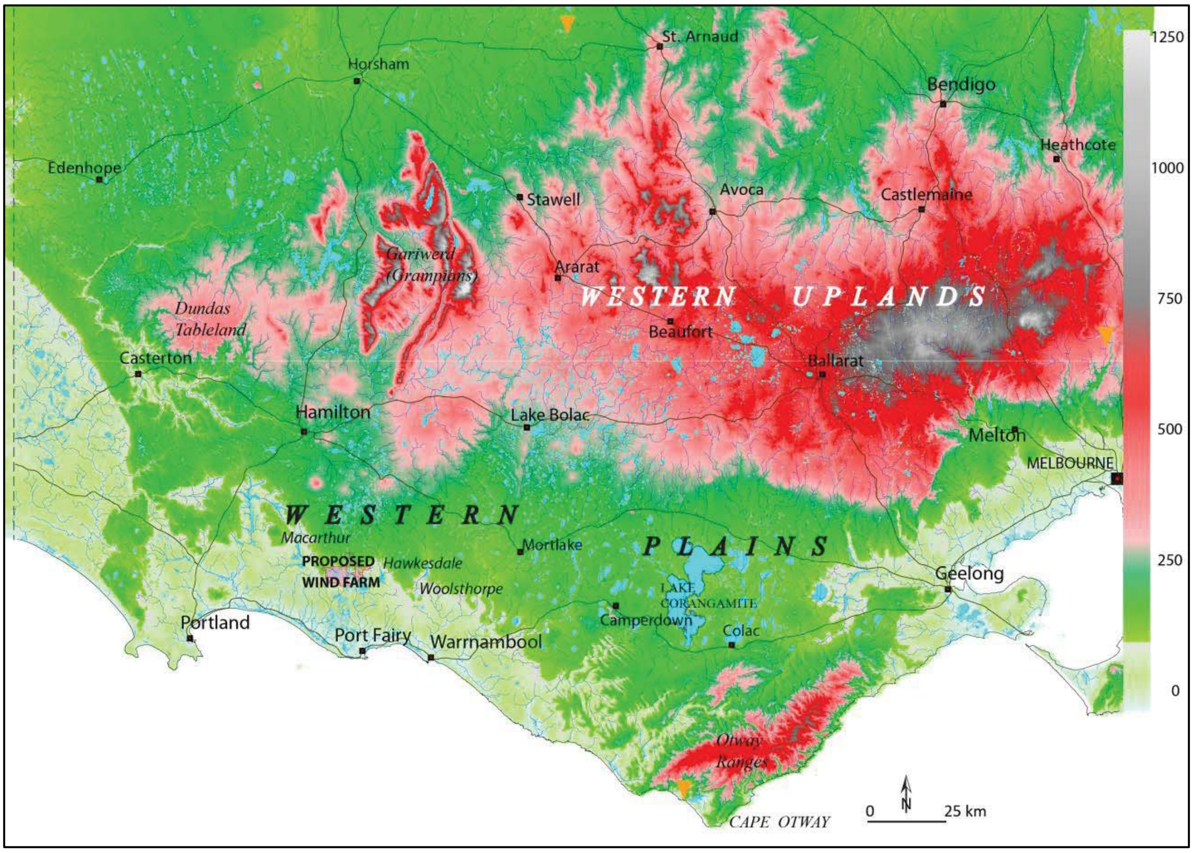

Figure 2. Location of proposed Willatook Wind Farm in context of the Western Plains.

The Western Plains is a landscape developed mainly on volcanic rocks with enclaves of older sedimentary rocks and extends 220 km west from Geelong to north of Portland. The volcanic regions of the Western Plains are part of a broad basaltic lava province active over the past six 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 (Figure 3).

2.2 Eruption Points

The NVP is now known to be comprised of over 700 eruption points grouped into 416 eruption centres, 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 increased number is the result of improvements in image technology and mapping allowing recognition of multiple eruption points (termed eruption centres) previously regarded as a single volcano, and identifying some low rises in lava flows also as an eruption point.

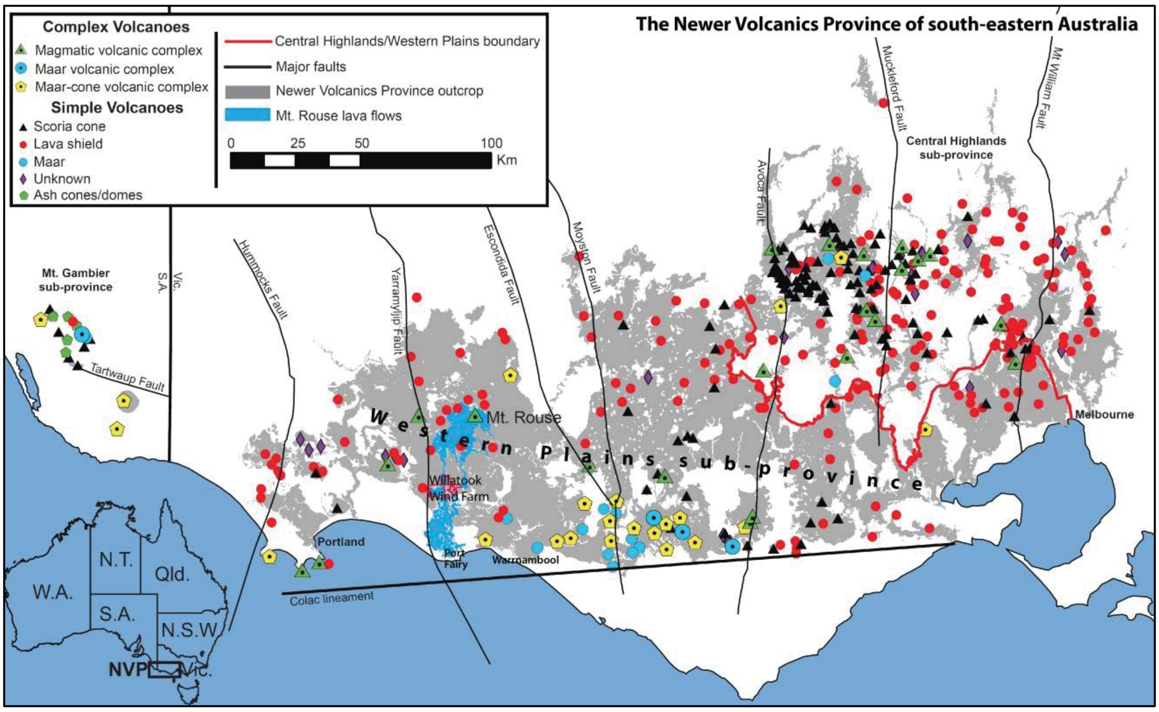

Figure 3. Newer Volcanic Province: eruption types and lava extent (after Boyce 2013).

The most voluminous product of the NVP was basalt lava issued as cohesive and relatively fluid streams from fissures and low-level vents 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 that may last from weeks to months. The combined flow units of a single eruption point constitute a lava flow. Some eruptions in their later stages also produced fragmental lava (scoria and tuff). The scoria-rich volcanoes are conspicuous as higher, steep-sided mounds or cones such as Mount Elephant and Mount Rouse, while those with only 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 distinctive group of explosive eruption points—Tower Hill being the largest example—formed broad, circular craters now containing lakes or swamp surrounded by a rim of basaltic tuff.

The NVP volcanoes are numerous but individually were (geologically) short-lived with eruptions ceasing after a few months of activity or persisting only over years or decades rather than millenia. Most eruption points experienced only one phase of more-or-less continuous activity and the relatively fluid character of the lava and the short eruption time restricted the vertical growth of individual volcanoes. The highest and steepest eruption points are those made of a mix of coherent lava flows and mounds of fragmental lava (scoria and tuff).

2.3 Lava Flows

The NVP is referred to as a monogenetic areal basalt field (Joyce 2004), implying single magma batches and uncomplicated evolutions. However, recent research e.g. Boyce *et al*. (2015) has shown that the magmatic process are more complex and involve multiple stages and sources of volcanic effusion. In that respect, several prominent eruption points such as Mount Rouse are the focus of on-going research and comprise a significant scientific and educational resource.

A variety of proxy and direct methods has been used to determine the ages of the NVP eruptions. Qualitative or relative ages are obtained by comparing the degree of weathering or erosion of volcanic materials and surfaces and the thickness of regolith/soils developed on lava flows—or conversely by the preservation of original volcanic features—such as the Ollier and Joyce (1985) regolith-terrain units (Figure 4).

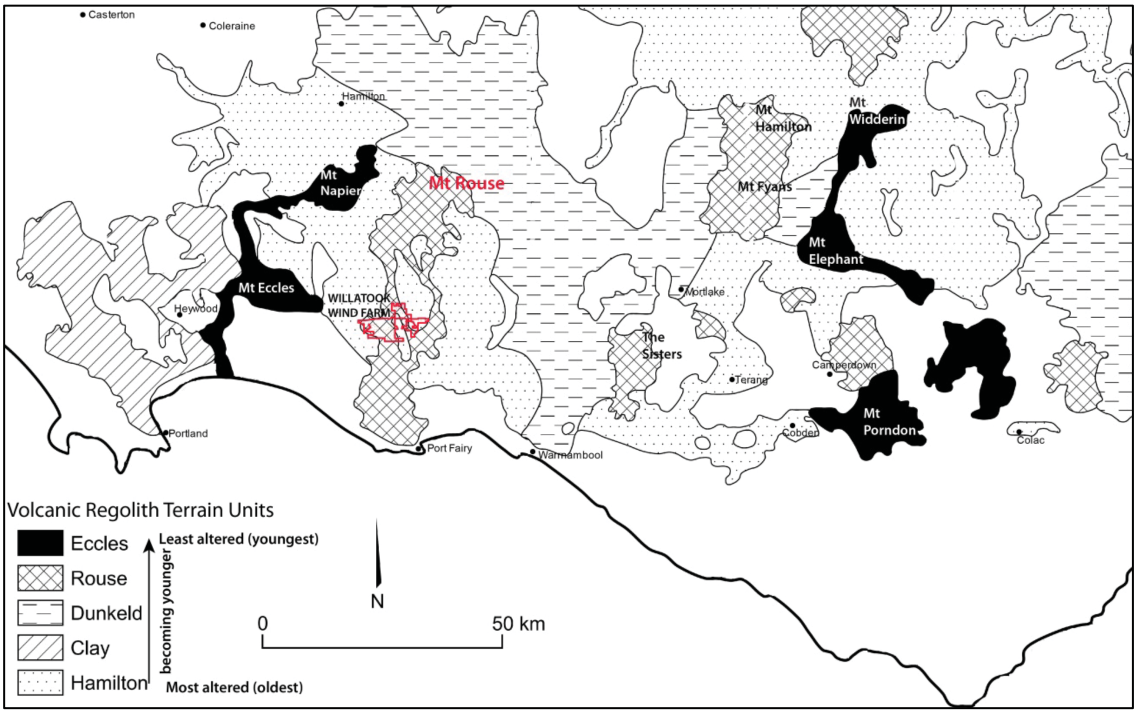

Figure 4. Regolith Terrain Units (RTU) on volcanic materials (after Ollier and Joyce 1985). The Eccles and Rouse RTU's are stony rises of varying degrees of roughness.

On a landscape scale, two broad groups of volcanic surfaces are recognized based on the preservation of primary lava features: (a) *younger flows, including stony rises* where boundaries of individual flow units are clearly defined topographically and with stony surfaces characterised by elongate and hummocky ridges and closed depressions and shallow stream valleys, (b) *older flows* with undulating surfaces, minimal stone exposure, flow units are not distinguishable and with incised valleys (Figure 5). Lava from high volume effusive eruption points such as Mt Hamilton and Mount Rouse initially flowed in a radial pattern but as eruption progressed, lava flowed long distances—initially following shallow, low gradient valleys and soon filling these and spilling across the adjacent plains following the regional slope.

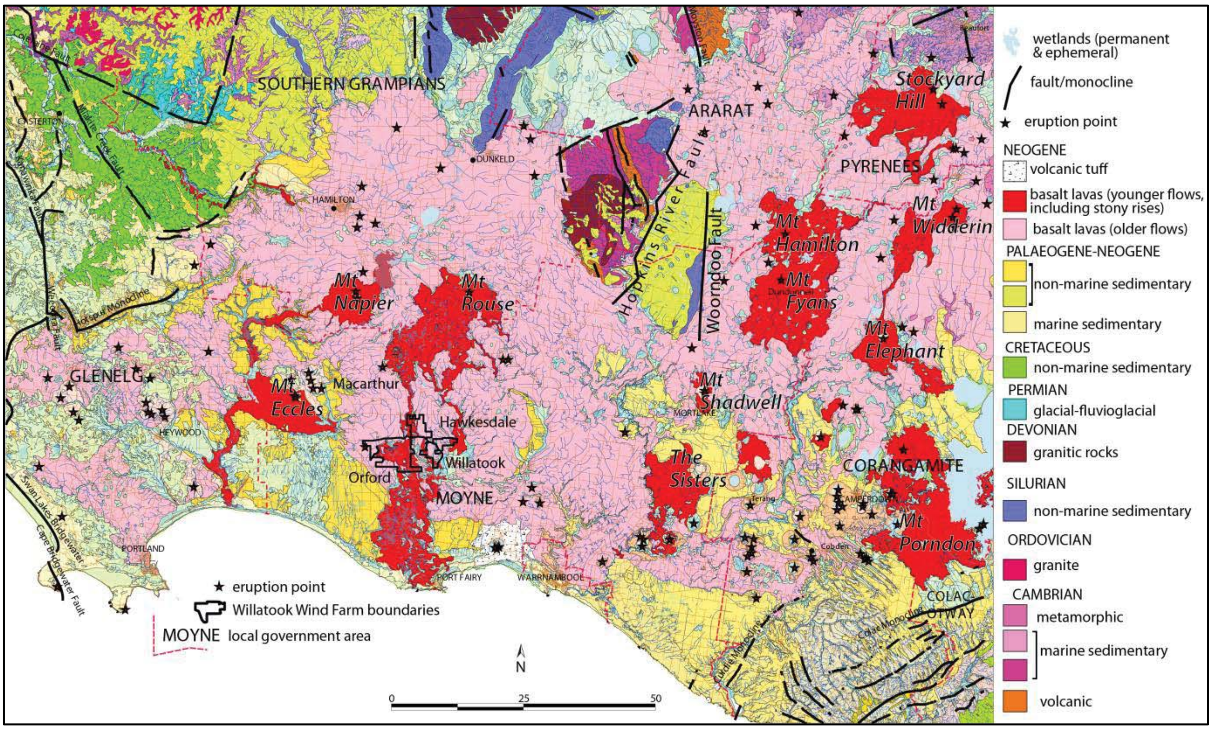

Figure 5. Geology of south-western part of NVP showing the younger and stony rise lavas from several eruption points including Mount Rouse. (After 250,000 geological maps Portland, Colac, Hamilton, Geological Survey of Victoria).

The lava flows 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 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.

2.4 Age of Volcanoes

Radiometric decay dating has been widely applied, including carbon-14 dating of organic materials overlying and/or underlying volcanic deposits and in volcanic craters, and potassium-argon dating of basalt lava flows (Aziz-ur-Rahman and McDougall 1972; Wellman 1974; McDougall & Gill 1975; Ollier 1985; Gray & McDougall 2009). The most currently reliable method is mass spectrometer argon isotope radiometric dating. This directly measures age of mineral crystallisation, and is much more precise than the earlier methods. Recent reviews incorporating earlier and newly determined ages (Gibson 2007, Gray and McDougall 2009) have confirmed the onset of extensive volcanism in western Victoria at around 4.6 million years (Ma) with a peak activity at around two Ma. Cosmogenic chlorine isotope analysis (that records the time a rock has been exposed to cosmogenic radiation) has been applied to samples of surface lavas from Mt Eccles (Budj Bim) and Mt Napier (Stone *et al.* 1997, Gillen *et al.* 2010). The technique has provided consistent ages of 33,000 to 40,000 years for these lavas making them the youngest known eruptions in Victoria.

3 MOUNT ROUSE ERUPTION CENTRE

Mt Rouse— approximately 28 km NNE of Willatook and immediately SE of Penshurst—has a summit at 356 m above sea-level rising 120 m above the surrounding plain. It is a complex eruption centre comprised of at least seven scoria cones and craters (Figure 6). Smaller eruption points have been identified a short distance south west of the main centre. The scoria cones are the last stages of an eruption sequence that produced voluminous lavas. Mount Rouse is the largest eruption source in the NVP in terms of lava volume erupted and area covered.

Figure 6. Scoria cones and craters of Mount Rouse at Penshurst. Southern Grampians in background. (Photo: Neville Rosengren Feb 2012).

The boundaries of the Mount Rouse flows are clearly defined in the landscape by a distinctive stony terrain that is very different from the older flows that they cover.

3.1 Mount Rouse Lava Flows

The lavas from Mt Rouse cover an area of more than 450 km^2 extend over 60 km to the south, (Figure 7) outcropping along the present coast at Port Fairy partly covered by dunes and alluvium. The lava extends out to sea - but offshore geophysical surveys suggest it does not continue far from the beach (Grimes 2008). This complex of lava flows is the longest known in the volcanic province of Western Victoria and one of the longest in Australia (Joyce and Sutalo 1996). There are six major groups of flows distinguished by distribution, geochemistry, petrology and eruption sequence (Whitehead 1986, Sutalo 1996, Matchin and Phillips 2011, Boyce 2014). The lavas are dated at 294,000 years (Matchan & Phillips 2011).

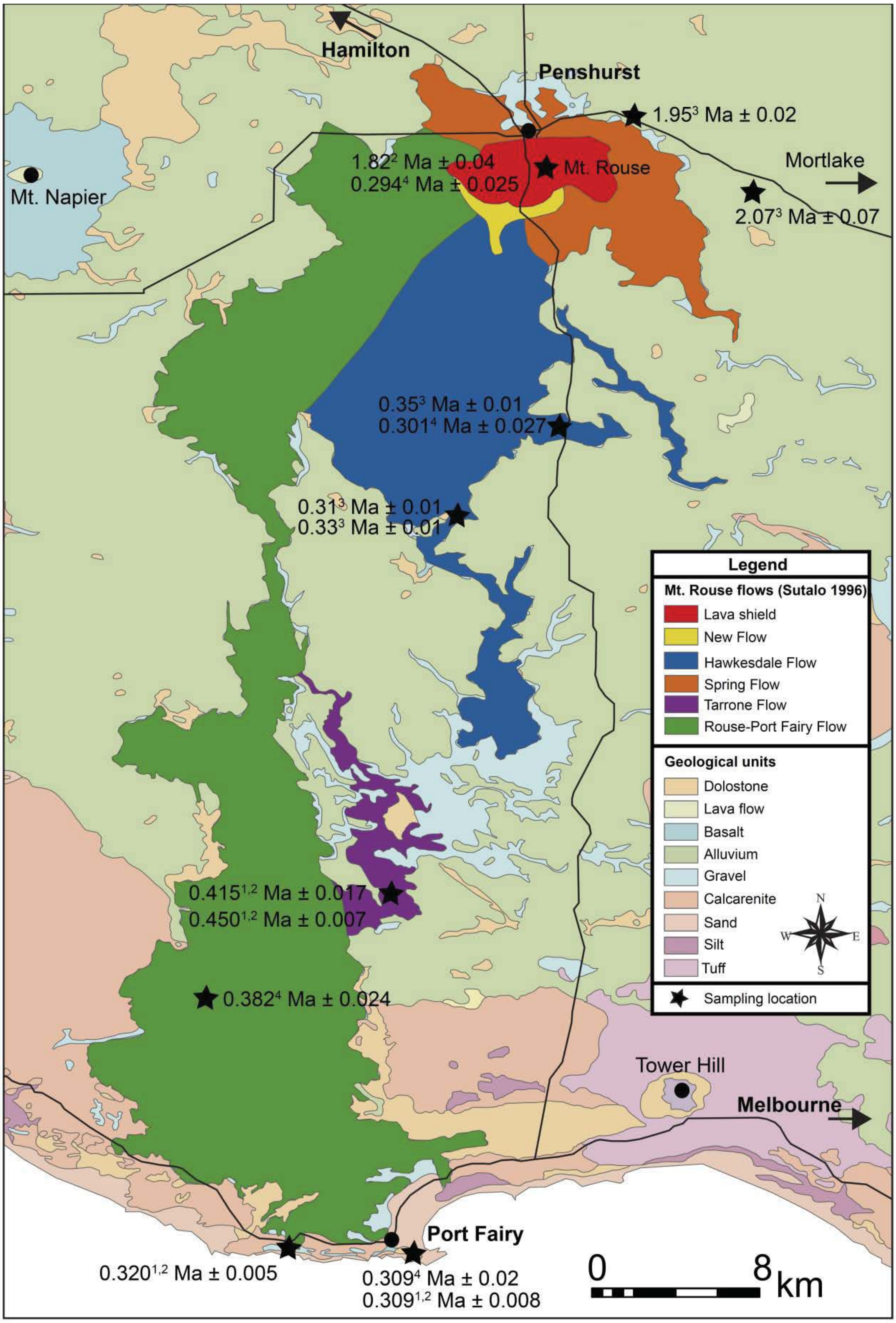

Figure 7. Generalised boundaries of lava flows from Mount Rouse (after Boyce 2014) and wind farm layout.

Although these studies use different approaches to classifying the character and distribution of the lavas, they are convergent in identifying the boundaries of the six main flows of the Mount Rouse lava field. The youngest flow is the “lava shield”—a stony surface extending west-east for three to five km on either side of the mountain. This overlies the restricted “new flow” and the more extensive “spring flow”.

The Willatook Wind Farm boundary encloses parts of three of the Mt Rouse lava flows—the main “Rouse - Port Fairy flow“, the shorter “Tarrone flow” and the complex “Hawkesdale flow” (although no infrastructure is planned on this flow), and an older eruption point at Dunmore (Vine Bank) (Figure 8).

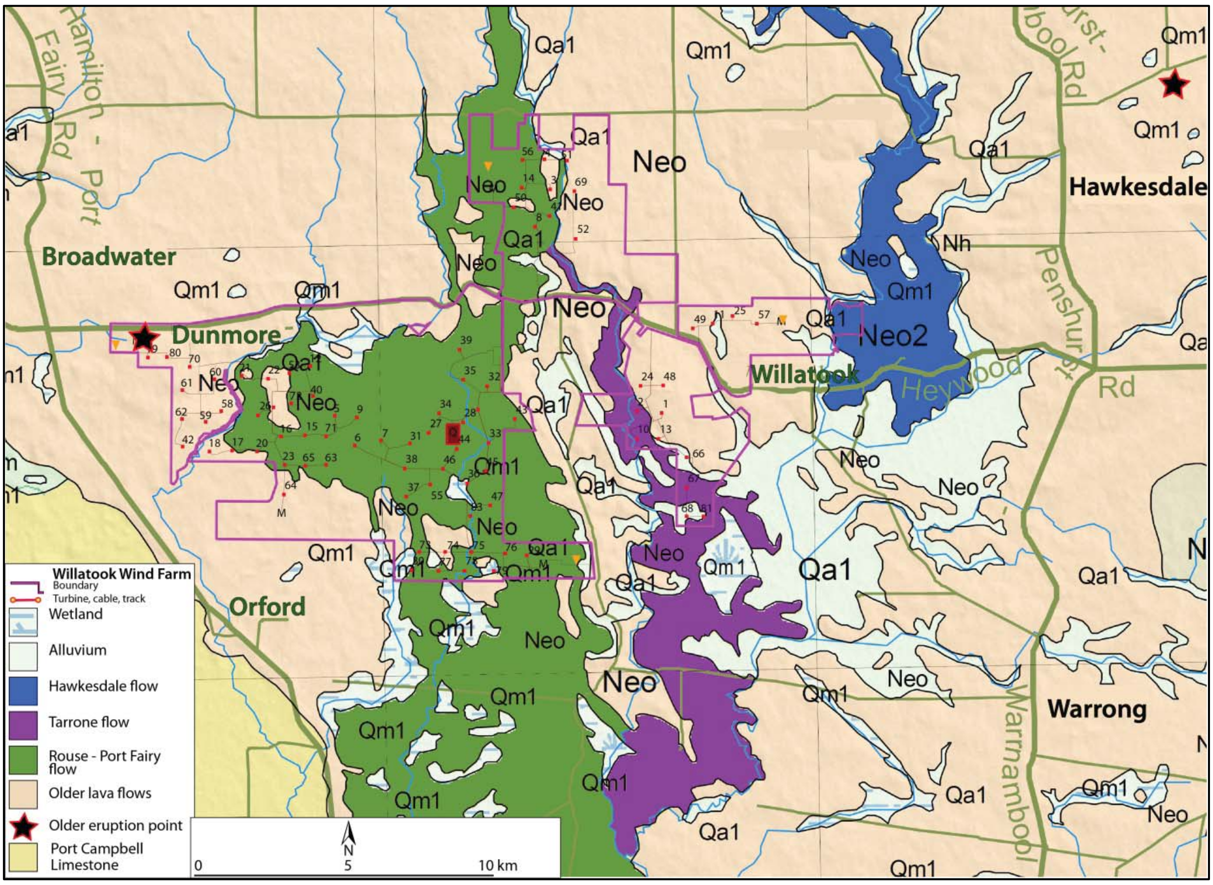

Figure 8. Parts of Rouse lava flows inside proposed Willatook Wind Farm boundary. (Geology after Welsh *et al.* 2011).

The Hawkesdale and Port Fairy flows are elongated lava fields connected by narrow lava-filled valleys, in places enclosing or surrounding ‘steptoes’ (islands of older volcanic rock). A widespread feature of these flows is their irregular surface with numerous hummocks, low plateau, elongated ridges and enclosed depressions (Figure 9) forming a landscape referred to as “stony rises”. Prominent ridges that occur at the flow edges are locally known as “barriers”, and this term is used in geological literature to describe higher, elongate, lateral sections of lava flows.

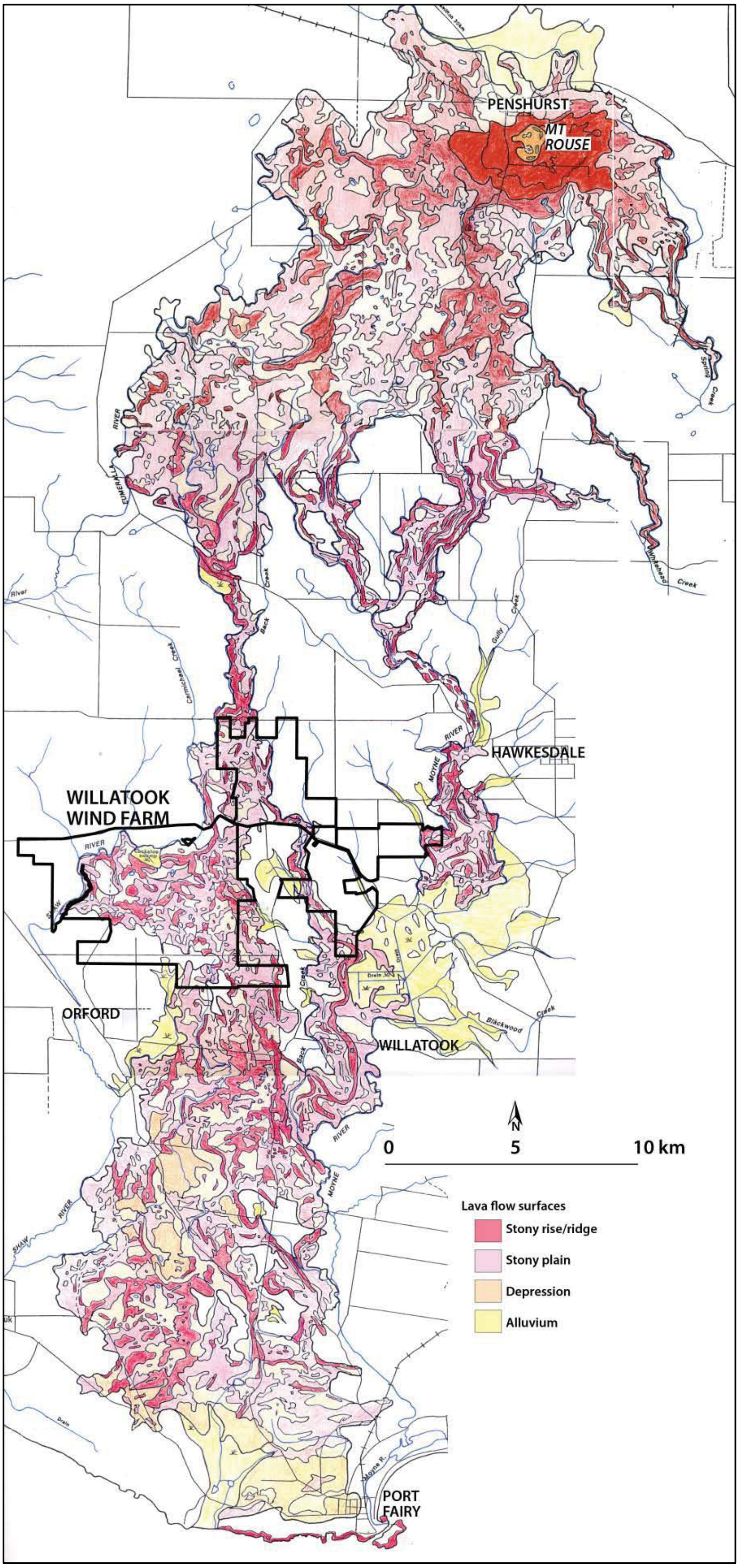

Figure 9. Lava flow surfaces classified as stony rises, stony plain and depression (Sutalo 1996).

The lava flows followed and filled existing shallow valleys in the older volcanic surface of the pre-Mount Rouse landscape. These valleys were the ancestors of the modern Eumeralla, Shaw and Moyne Rivers. Subsequent to the eruptions, these streams and tributaries have developed new channels, usually adjacent or lateral to the new lava but in places crossing over it. The upper reaches of the Eumeralla River is lateral to the northwestern parts of the Mount Rouse lavas and Carmichael Creek, Kangaroo Creek and Shaw River are lateral to the western margin of the very long Rouse - Port Fairy flows. The Moyne River has a complex lateral association with the Hawkesdale flow and crosses it in several places.

3.1.1 Hawkesdale Flow

The elongate, branching and converging "Hawkesdale flow" extends 27 km south from Mt Rouse, ending at Willatook. A small part lies inside the eastern margin of the Willatook Wind Farm although no infrastructure is planned on this flow.

The Hawkesdale flow comprises the central eastern part of the Mount Rouse lavas. In the north it is a broad lobe diverging around a topographical high (possibly a much older eruption point) north of *Stonefield,* thus forming two flows that further separate around steptoes before merging about eight km north of Hawkesdale. In places, this flow is less than 200 metres wide. West of Hawkesdale the flow widens and terminates at Willatook, apparently before reaching the Blackwood Creek and not abutting the longer Rouse - Port Fairy flow. The surface of these flows is very rugged with low escarpments of columnar basalt and boulders protruding from the soil. Numerous parallel, gently curving ridges several hundred metres long, from 30 to 100 metres apart and rising to more than 10 metres are a feature of this flow. Between the ridges are depressed areas, some completely enclosed by low, rocky escarpments. Apart from a rock scatter around the edges, the depressions are generally free of surface rock and are floored with a dark, organic soil overlying the same weathered basalt of the ridges. The depressions hold water after rain but do not appear to intersect the water table.

The Moyne River, back Creek and tributaries form pronounced lateral streams with weakly incised channels following the outer margins of the flows and in places along the inner edge of the steptoes.

3.1.2 Rouse - Port Fairy Flow

The Rouse - Port Fairy lava is the westernmost and longest of the flows and extends for over 60 km south where it crops out along the coast from Cape Reamur to the mouth of the Moyne River. West of Penshurst it is a composite flow of multiple and diverging lobes but further south it is a single flow where it is crossed by the Macarthur to Hawkesdale Road at “Fairview” and narrows to less than 400 metres wide at “Brandon”. South of the Glengleeson to KangertongRoad, the flow splits and rejoins and a complex pattern of lava tongues and steptoes occur in the broader southern section of the flow. The topography of this flow is broadly similar to, but more subdued than, the Hawkesdale flow with broader, lower ridges with a relief typically less than five metres. Lateral stream development is pronounced with Eumeralla River closely following the western margin of the flow southwest of Penshurst and Shaw River as a lateral stream for some distance before diverging north of Orford (Figure 10).

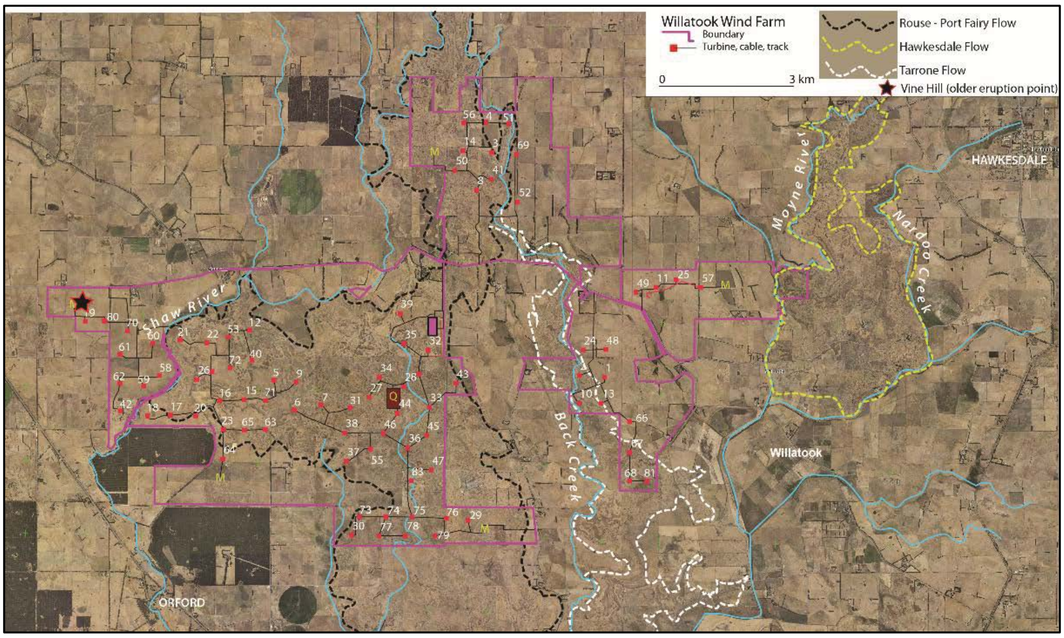

Figure 10. The three branches of the Rouse lava flows west of Hawkesdale and older Vine Hill eruption point.

3.1.3 Tarrone Flow

The Tarrone flow has similar composition to—and is considered to be a branch of—the Rouse - Port Fairy flow. The detail of the history of these flow units is not known in detail. The topography suggests the main flow was following the palaeochannel of Shaw River until a constriction developed diverting the lava into the palaeochannel of Back Creek. The lava followed Back Creek for about 10 km to the south until it converged with the main flow body thereby creating the Tarrone flow.

4 GEOLOGICAL AND GEOMORPHOLOGICAL SIGNIFICANCE OF MOUNT ROUSE AND ASSOCIATED LAVAS

4.1 The Concept of Significant Geoscience Sites

Sites of geological and/or geomorphological significance (referred to here as geoscience or geoheritage sites) are selected on the basis either that they represent a specific characteristic of a region or they 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. They are of interest to people who wish to understand 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. Sites of significance 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.

Geology is a diverse science which deals with the physical and chemical properties of rock materials, their internal texture and structure, external geometric form and dimensions and their mutual relationships in time and space. Geological investigations range in scale from the sub-atomic, e.g. the internal structure of minerals and crystals to the continental and global, e.g. the division of the earth into tectonic plates and the study of the evolution and mobility of these global units. While in part a field-based science, detailed analysis of some features may only be completed or undertaken in the laboratory. Much geological data is obtained by recovery of materials from deep sub-surface (by drilling) or by remote sensing of their properties, e.g. by analysis of seismic wave motion generated by earthquakes or by artificially introduced shocks from explosion or percussion. The present report considers surface geological features and materials and does not include an assessment of potential significance of features accessible only by deep drilling or remote sub-surface survey. It therefore does not consider mineral deposits or groundwater resources.

Geomorphology is that branch of geological science traditionally concerned with the origin and configuration of landforms. All landforms to some degree reflect the nature of geological materials. More recent work recognises the importance of measurement of processes operative in landscape development rather than the mere description and classification of surface configuration. This involves a rigorous approach to the measurement of the movements of liquids and gases in the atmosphere, on the surface, and sub-surface in soil, sediment and rock. Geomorphological sites are selected on the basis of both approaches to the study of landforms and sites which have potential for detailed process studies have been included in this site assessment.

4.2 Protocols for Recognising Geoscience Sites

Protocols for determining geoscience sites in Victoria have been established by Joyce and King (1980) and Rosengren (1986, 1994). They include the following principles:

4.2.1 Geological Sites

(a) An outcrop or other exposure (including quarries and cuttings) 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.

4.2.2 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.

4.3 Geoscience Significance Levels

A place or feature recognised as of geoscience significance is assigned a significance rating on a comparative 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.

4.3.1 Geoscience Significance of Mount Rouse Volcanic Complex

The Mount Rouse Volcanic Complex— the several eruption points immediately south of Penshurst and the associated lavas—form a composite geoscience unit of at least State and potentially National to International geoscience significance. This significance assessment is based on four main factors:

(i) Mt Rouse is a complex eruption centre with different magma types, eruption styles and related volcanic landforms.

(ii) Mount Rouse is the source of the longest lava flows in Victoria and some of the longest in Australia. The lava flows are a geoscience feature of very high significance in their own right as well-preserved examples of very long lava flows.

(iii) The eruption centre is a young volcanic complex and the explosive eruption features (scoria, craters, spatter), and the morphology of the lava flows are well preserved.

(iv) The entire volcanic complex is an outstanding example of the relationship of lava flows to palaeo and modern stream systems.

As the proposed Willatook Wind Farm is confined to a section of some of the lava flows at least 30 km from the Mount Rouse eruption centres, it has no direct impact on the geoscience values of the eruption sources. The present report is therefore confined to an evaluation of the significance of the Mount Rouse lava flows and related landforms, and an assessment of the potential impact of the wind farm proposal on these lavas as geological and landform features.

4.3.2 Significance of Mount Rouse lava flows

There is great interest in the mechanisms by which lava can travel long distances over gently sloping terrain. The overall gradient of the Mount Rouse lavas is one in 200, (a fall of 300 metres over a distance of 60 kilometres), and at the distal end of the flow (furthest from the volcano) is one in 500. 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 elongate ridges marking the edges of the former lava tubes (Figure 11). The ridges may be continuous and parallel for hundreds of metres (Figure 11), but often form broad lobate and irregular terrace surfaces with smaller surface depressions containing ephemeral wetlands (Figure 12).

The branching, converging and isolated lava ridges and depressions along the Mount Rouse lava flows are not a consequence of erosion and dissection of a more extensive lava body. Rather it is a very well-preserved and outstanding example of the initial morphology fluidity and mobility of these lava flows. Mount Rouse and its associated lavas therefore provide an outstanding series of localities to study the results of a specific type of volcanic emplacement which is widespread in eastern Australia and notably in the Newer Volcanic Province.

Figure 11. Parallel ridges marking edge of former lava tube at the western margin of the Tarrone flow west of Hawkesdale. Moyne River is a lateral stream. (Photo: Neville Rosengren Sept. 2017).

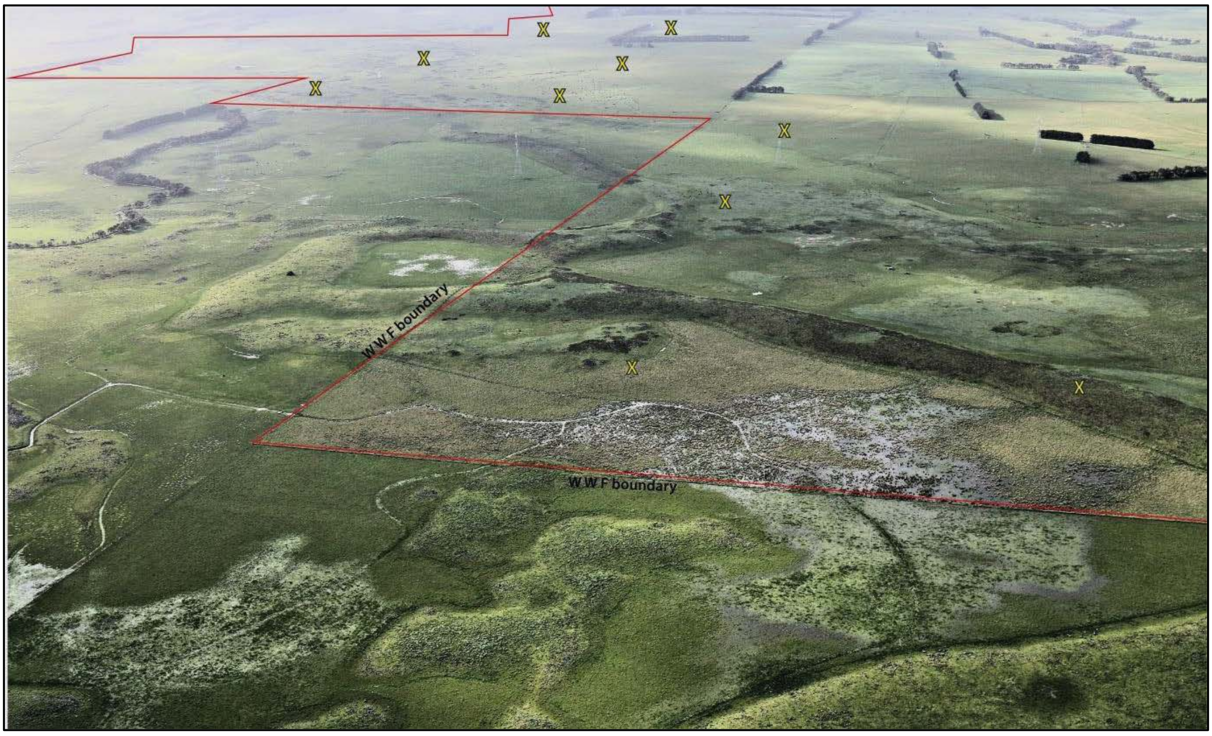

Figure 12. Ridges and depressions of the Mt Rouse - Port Fairy flow at Coomete Road (**X** marks position of planned turbines). (Photo: Neville Rosengren Sept. 2017).

The significance of the lava flows as geological and landform entities are at least State and potentially National significance level.

5 WILLATOOK WIND FARM: GEOLOGY AND GEOMORPHOLOGY

5.1 Surficial Geology

The continuous solid geology across the proposed Willatook Wind Farm is entirely basaltic lava with a regolith of basalt stones, weathered basalt and a variable thickness of alluvial and swamp deposits. Of the 83 turbines proposed, 48 are located on the Rouse - Port fairy flow, 5 turbines on the Tarrone flow and 30 turbines are on older lavas (Figure 13).

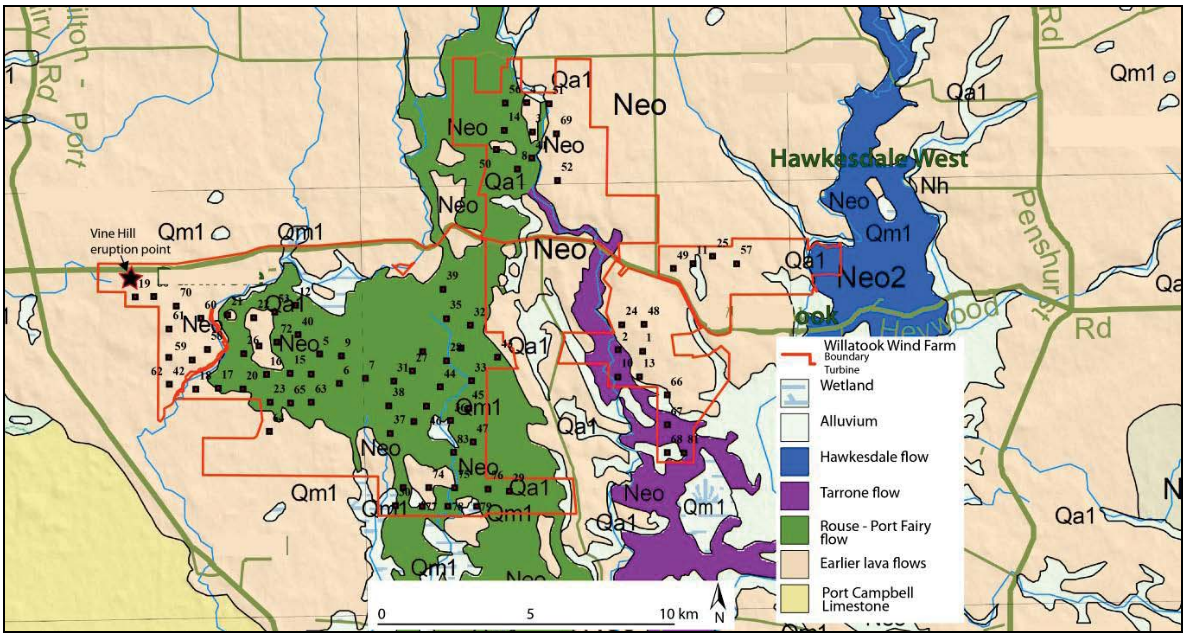

Figure 13. Lava flows and proposed turbine layout of Willatook Wind Farm (Geology after Welsh *et al.* 2011).

Over most of the areas of the younger lava flows, basalt is exposed at the surface as blocks, boulders and locally continuous outcrop. Lithological logs (driller's logs) of the small number of boreholes across the area record less than two metres of soil/regolith on the younger lavas ("rubbly stone", "stone", "stone and clay") overlying basalt. Borehole 52129 on the older lavas at Dunmore (south of Woolsthorpe-Heywood Road) recorded:

From	To	Comments
0.0	0.3	SANDY LOAM
0.3	9.75	RED & GREY MOTTLED CLAY
9.75	15.55	YELLOW CLAY
15.55	27.43	DECOMPOSED BASALT GREY
27.43	32.31	RED WEATHERED BASALT
32.31	35.05	BROWN BROKEN BASALT

(http://er-info.dpi.vic.gov.au/sd_weave/).

The basalts of the Mount Rouse lavas are vesicular and strongly fractured into angular blocks of variable size.

5.2 Geomorphology

The proposed wind farm occupies a site of relatively low relief and slope but with pronounced local topographical variation. Elevation ranges between 75 metres AHD along the Moyne River valley to 130 metres on the rises on the northern boundary of the wind farm along KangertongRoad. The only defined hill is the broad rounded summit of Vine Hill eruption point at 120+ metres AHD. Regionally the fall is to the south and this is the direction of slope of the drainage channels. The landform features of the site are determined by the character of the lava flows from Mount Rouse and the interaction of these flows with the pre-existing terrain and subsequent re-establishment of the drainage system.

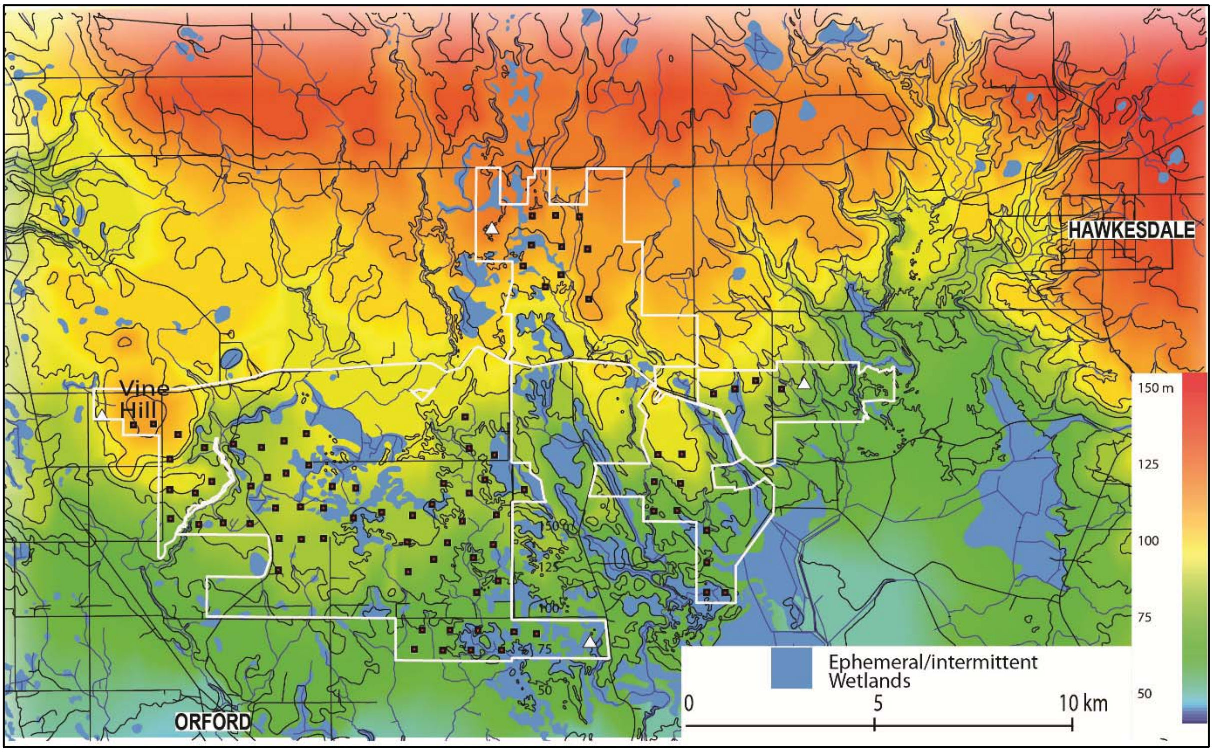

Figure 14. Topography and ephemeral wetlands.

Prior to the eruptions of Mount Rouse, the topography was flat with narrow, weakly incised streams with a general southerly slope (Ollier 1985). A low east-west ridge at about the present position of Mount Rouse formed a drainage divide between the south-flowing streams and those flowing northwest to the Glenelg River. The topography west of Penshurst is remnant of this terrain as it has not been covered by the Mount Rouse lavas.

The high temperature and fluid lavas of the earliest eruptions from Mount Rouse spread out from the volcano towards the west and banked up against the higher topography of the palaeo-Eumeralla River valley as a series of narrow lava tongues and lobes. Lava tubes became conduits for the rapidly moving lava and diverted the lava from the higher western valley side into the south-sloping valleys, thus forming the elongated Rouse - Port fairy flows. As eruptions ceased, the lava tubes either became filed with congealing lava or sagged and/or collapsed leaving parallel, steep-sided ridges forming stony rises topography. The ridges partly enclosed depressions that developed small ephemeral lakes and swamps. This is the typical topography west of Tarrone North road. Since emplacement of the Mount Rouse lavas, drainage adjustment has developed either as lateral streams to the lava body or on the lava surface such as Back Creek and the more deeply incised Moyne River.

5.3 Regolith-Landform Units

Regolith-Landform units (RLU) are land areas characterised by similar landform and regolith attributes. Five RLU's of the Mount Rouse lavas are described below (5.3.1 to 5.3.5) based on Sutalo (1996), Sutalo and Joyce (2004) and incorporating land systems units of Gibbons and Downs (1964) and Baxter and Robinson (2001) for the older volcanic terrain.

5.3.1 Deeply Weathered Slopes

This is the undulating terrain of the older volcanic surfaces not covered by the Mount Rouse lavas. Regolith is several metres thick and soil profiles are deep and kaolinised with reddened and friable sub-zones with buckshot nodules (Gibbons and Downes 1964). Maher and Martin (1984) describe these soils as acid to neutral mottled-yellow duplex soils. On the higher slopes there may be scattered surface boulders surrounded by well-developed soil profiles.

5.3.2 Stony Lava Ridges

This is the most widespread terrain unit across all of the Mount Rouse lavas. It consists of elongate broad to sinuous ridges with flattened to sub-rounded crests forming an irregular, non-patterned surface. Ridges sometimes occur as sub-parallel pairs for short distances but are generally discrete units. They have relief of up to and sometimes above 10 metres and range from 10 metres to over 150 metres wide (Figure 15). Numerous short, discontinuous ridges give a hummocky topography with a stony surface. A distinct sequence of slope, outcrop and drainage occurs from the ridge crests to the ridge foot. Ridge crests have an array of large angular broken blocks with skeletal soils developed in rock fractures. Regolith thickness (depth to solid basalt) is generally less than one metre. Below the crests of the stony ridges are steep slopes with a cover of large, rounded, honeycomb-textured basalt boulders partly covered in decomposing basalt and soil. Regolith thickness is over one metre.

Figure 15. Stony lava ridges (A) and depression marsh (B). (Photo: Neville Rosengren Sept 2017).

5.3.3 Stony Plains

These are slightly elevated, gently sloping to flat surfaces with a dispersed scatter of rounded, weathered basalt stones and cobbles with occasional isolated boulders. There is an almost continuous soil cover with organic, cracking grey-brown loamy topsoil overlying more clayey subsoil. Regolith depth is between 1.0 to 2.0 metres. Parts of this unit are poorly drained and shallow ponding and seasonal inundation occurs (Figure 16).

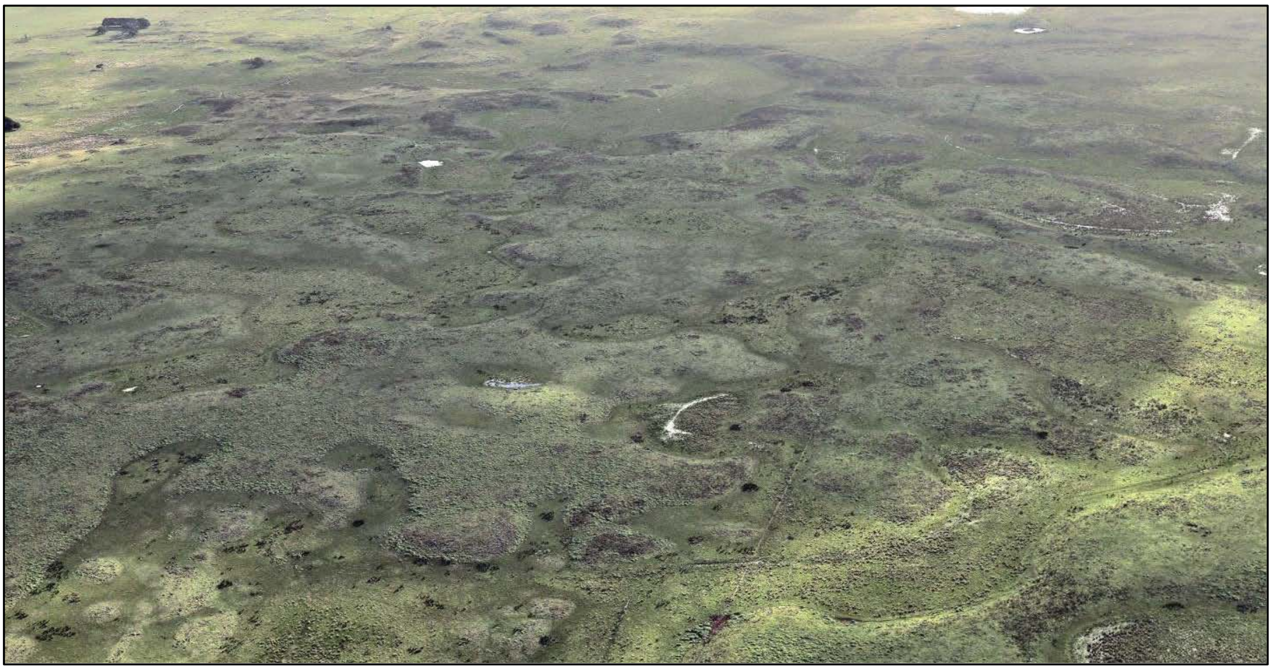

Figure 16. Stony plains with enclosed depression marsh units. (Photo: Neville Rosengren Sept 2017).

5.3.4 Depression Marsh

This is the area of lowest elevation on the Mount Rouse lavas and is characterized by broad to elongate flat or bowl-shaped depressions. These areas have developed either as the base of collapsed lava tubes, or where lower-lying land has been partially or wholly surrounded by thin, overlapping lava lobes. Soils are clayey, often with gilgai (hummocky) surfaces caused by shrinking and swelling clays. These are areas of impeded drainage and even when drained for agriculture, remain marshy for longer periods in wetter months and with high water tables and areas of open water. Locally areas of peat have developed. Regolith depths are likely to be three metres or more in places. This unit is extensive across all the Mount Rouse lavas as shown on maps and photographs Figure 14 to, Figure 20.

Figure 17. Composite landscape of stony ridges (A), stony plains (B) and depression marsh (C). (Photo: Neville Rosengren Sept 2017).

5.3.5 Stream Valleys

Shaw River, Back Creek and Moyne River are lateral streams with occasional incursions across the lava surfaces. The streams typically mark the boundary of the Rouse lavas and the older volcanic terrain (Figures 19 & 20). At the lava margins the channels have boulders and rock outcrops with intermittent alluvial deposits and terraces with areas of peaty and swampy soil with regolith to two metres thick.

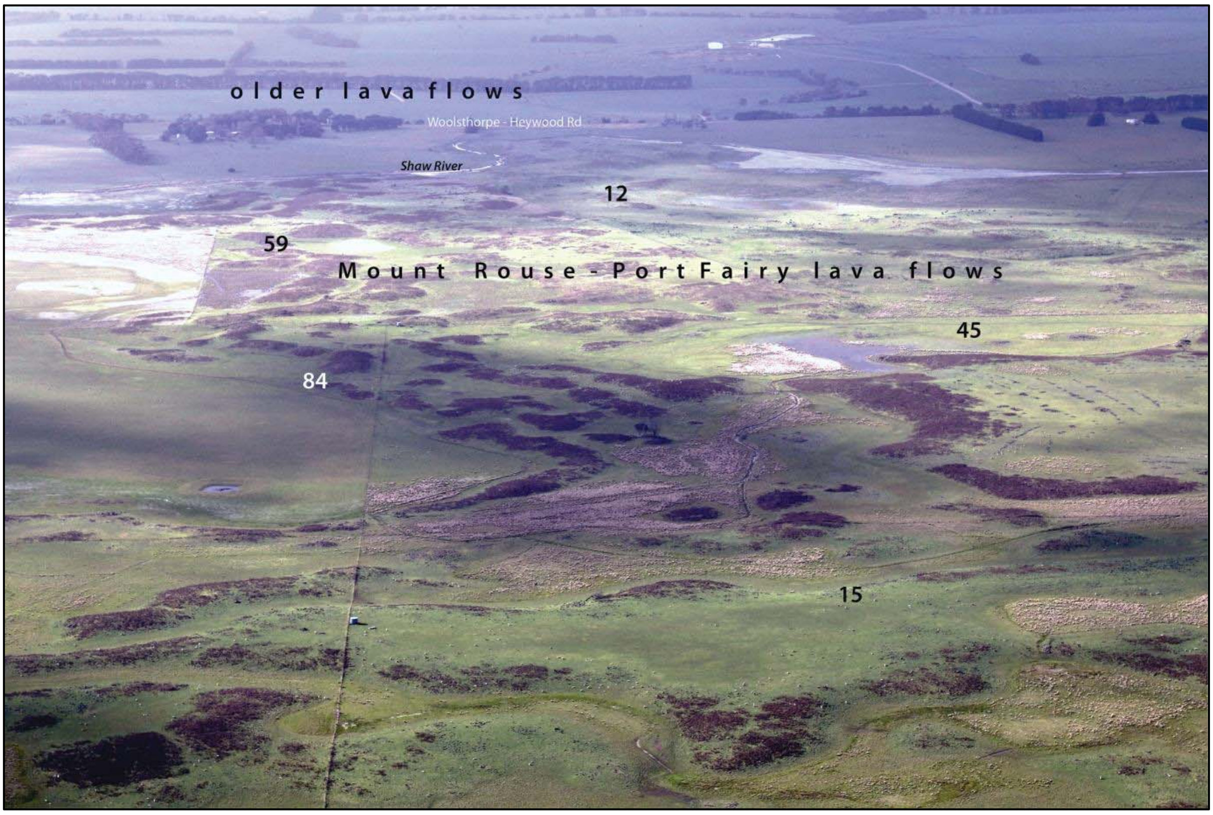

Figure 18. Complex of ridges and wetland depressions at the western margin of the Rouse - Port Fairy lava flows north of McGraths Road. Shaw River is a lateral stream at the boundary of the younger flows. Numbers show approximate position of five wind turbines (Photo: Neville Rosengren Sept 2017).

Figure 19. Ridges and wetland depressions at the western margin of the Rouse - Port Fairy lava flows north of McGraths Road. Numbers show approximate position of four wind turbines (Photo: Neville Rosengren Sept 2017).

6 ASSESSMENT OF GEOSCIENCE SIGNIFICANCE OF PROPOSED WILLATOOK WIND FARM

6.1 Overview

The proposed Willatook wind farm site contains excellent examples of lava barriers and sag depressions formed by fast-moving, fluid lava tongues, features important in formulating models of long lava flow development. It also clearly shows aspects of post-volcanic stream developments. Overall, the complex including the present area has been assessed as State to National Significance (Chapter 4 page 20 above). Specific landforms and areas inside the Willatook wind farm boundary contribute to this high level of significance (as outlined in Chapter 4 above) and recommendations for a management plan to minimise impact on that significance is provided in Chapter 7 below.

6.2 Lava Flows

The site includes excellent examples of three of the lava flows associated with the Mount Rouse volcano. There are clear examples of lava flow features including narrow flow sections, diverging and converging lava lobes, raised lava surfaces and parallel lava ridges and depressions resulting from sagging and collapse of lava tubes. Although there are no known lava caves or open lava flow pathways in the study area, two lava caves including a substantial collapse cavern are recorded in the Mount Rouse lavas further north (near Surkitts Lane). There is the possibility that tubes do occur in the present study that have not been exposed by roof collapse, or that have very small entrances concealed by surface rubble. All landowners contacted were asked if they were aware of cave entrances occur but no positive response was recorded.

6.3 Lateral Streams and Wetlands

The site displays very clearly the development of lateral streams including Shaw River, Moyne River and Back Creek. It also encloses a number of depressions that contain ephemeral lakes and there is at least one instance of a lake floor hydrological sink and adjacent resurgence. These lake/swamp sites also contain organic sediments that contain pollen and other material suitable for palaeo-environmental reconstruction.

As stated earlier in this report (Section 4.3, page 18 *et seq*.), Mount Rouse and the associated lavas form a complex of at least State geoscience significance and are part of a volcanic region of National geoscience significance. This assessment applies to the whole Mount Rouse volcanic complex although smaller areas of the assemblage have their own discrete or separate values. The cones and craters of Mount Rouse eruption points along with the entire lava complex that issued from these comprise an area of potentially National Significance. The known lava cave (outside the present study area) is an individual feature of significance as are lava ridges and lateral barriers developed on the very narrow sections of the Rouse - Port Fairy flow and Hawkesdale flow west of Hawkesdale.

An example of a feature of High Regional Significance inside the boundary is given in Figure 20. The features include an excellent example of a reach of Moyne River as a lateral stream at the western margin of the Hawkesdale flow as well as long parallel lava ridges representing the margins of a collapsed lava tube.

Figure 20. Part of the Hawkesdale lava flow 5 km SW of Hawkesdale showing excellent example of Moyne River as a lateral stream and complex lava topography including parallel ridges. The lava and stream features of this site have a high sensitivity to disturbance by construction activities. Broken red line is wind farm boundary (Photo: Neville Rosengren Sept 2017).

The extensive array of semi-permanent and seasonal/ephemeral wetlands across part of the area studied is a direct result of the complexity of the lava surface and the interaction of the lava flows with palaeo- and modern drainage systems and groundwater.

6.4 Present Condition and Status of Geoscience Features of Mount Rouse Lava Flows

6.4.1 Prior Landscape Disturbance

The complexity of the surficial geology of stony rises and lava ridges— abundant loose stones at the surface and shallow depth in regolith—gives some uncertainty in interpreting whether a surface is an inherent component of the lava flow or is an expression of modifications by humans. Modification has occurred and continues at a variety of scales and may be of Aboriginal or post-contact origin. Aboriginal people utilised aspects of the stony terrain for resource (utilitarian e.g. fish traps, shelters, hearths) and/or cultural purposes and local movement and/or removal of stones from lava flows is recorded for some lava surfaces in Victoria (Lane 2009). Aboriginal stone removal or arrangement is relevant at the local scale (tens to possibly hundreds of metres) and along short reaches of streams but unlikely to the extent that has altered the essential geomorphology of the stony rises and watercourses. It is very likely that stone arrangements of Aboriginal origin have been altered, removed or masked by post-contact activities.

Pastoral and cropping activity following European occupation of the volcanic plains for over 150 years has modified the pre-contact landscape. Changes are widespread and locally intensive and have impacted the stony rises and ridges on a hectare to square kilometre scale. The most common modifications are removal/relocation of stones, construction of walls, fences and buildings and draining former wetlands. The intensity of this impact varies on a property and paddock basis. Loose stones in paddocks that can be cultivated are moved into piles or onto the sides and crest of stony ridges or crushed *in situ* and removed for use as aggregate elsewhere. In the present study area, there is local evidence of stone relocation (Figure 21) but not on a scale that has altered the fundamental geomorphology of the lava flows. By comparison with other areas of Mount Rouse lavas outside the present study, there are relatively few remnants of stone walls or other stone structures.

6.4.2 Present Land Use

The area of the Mount Rouse lava flows is predominantly utilised as grazing land (cattle and sheep) with some dairying on properties that have sufficient non-stony terrain. Depressions with minimal stones or where stones have been removed or buried are often used for hay. Extensive cropping and other cultivation are confined to the weathered soil-covered surfaces of the older lava flows. A few instances were observed of more recent stone clearance.

Figure 21. Stone removal and use as a wall near Turbine 46 off Landers Lane (Neville Rosengren Sept 2017).

The area has a substantial number of historical drainage schemes maintained to reduce the submergence of wetlands and provide flood protection. At least two instances of drains cut across lava ridges were recorded in the field work Figure 22).

Figure 22. Drain linking two wetlands cut across lava ridge near WTG09. (Neville Rosengren Sept 2017).

The area is crossed by pylons carrying the 500kV transmission line to the Portland aluminium smelter and the pole line from the MNacArthur Wind Farm.

7 POTENTIAL IMPACT OF THE PROPOSAL ON GEOSCIENCE FEATURES

7.1 Context

All the activities associated with the Willatook Wind Farm are confined to lava flow terrain of various ages and none will have physical impact on the composition and form of the Mount Rouse eruption points. The nature of the lava flows and their geoheritage values are outlined in Chapter 4 above. This chapter assesses the potential impact of the proposed wind farm on geoscience significance of the specific sites on the lava flows and related landform features.

The Mount Rouse lava flows extend over an area of approximately 510 km^2. The proposed wind farm encloses an area of 67.5 km^2, of which 33 km^2 would be Mount Rouse lavas. This latter figure represents approximately 6.5% of the area of the entire area of Mount Rouse lava flows. However, proposed infrastructure would be sited on a smaller area of $$ km^2 or $$% of the entire lava flows. The proposed wind farm does not enclose any known points of eruption for the Mount Rouse flows but includes the older eruption point of Vine Hill.

7.2 General Impact on Geoscience Significance

In this volcanic terrain, the geoscience significance is predominantly how the varied surface expression of the lava flows preserves information on the mechanisms and rates at which lava can flow over long distances. The morphology of individual features on scales of tens to hundreds of metres is therefore of interest. The integrity of these features may be compromised at the scale of wind farm built structures such as towers and hardstand pads (Figure 23). Although single tower and cable connectors have a narrow and limited footprint, wind farm structures are repetitive across a site and cumulatively amount to a larger surface imprint. This impact needs to be evaluated in the context of present ongoing and past use and modification of the volcanic landscape.

Of secondary (lesser) significance is the variation in geochemistry and other petrological features of the basaltic rocks as these are displayed over a more widespread area. The completed and operating Macarthur Wind Farm immediately north of the Willatook proposal is also partly built on lava of Mt Rouse - Port Fairy flows with similar terrain (Figure 23) and provides a basis for assessing specific and general potential impact on geoscience features

Construction and operation of a wind farm further modifies the terrain and surface geology of the area on which the turbines and associated infrastructure are built. Engineering actions across part of the site installing turbines, hardstand, related structures, access roads and transmission lines, include excavation and/or levelling of surfaces, removal of surface rock, soil and some thickness of regolith, consequent creation of spoil, emplacement of exotic rock material and cement as fill, and trenching for underground cables. The surface and near-surface geology at the construction sites and roadway is removed and replaced with different materials, and the geometry (geomorphology) of the surface directly under these structures is permanently altered and geomorphic processes of a broader area altered to varying degrees.

The structures related to construction and operations of a wind farm are selective rather than areally continuous in land cover. Wind turbines and adjacent hardstand are point features with a defined consistent footprint size. By comparison, transmission lines (above and in-ground) and tracks are narrow linear alignments, but are extensive and continuous and road surfaces must be maintained for vehicle access (Figure 23, Figure 24). The impact on geoheritage values is determined by the nature and size of the significant features. A small areal impact may be significant if it destroys a critical component of a larger geoscience feature or introduces exotic rock or synthetic materials.

Figure 23. Turbine construction at Macarthur wind farm on terrain similar to much of the proposed Willatook wind farm. (Photos Neville Rosengren A, B Feb. 2012, C, Dec. 2017).

Figure 24. Point and linear impacts of turbine, hardstand, tracks and in-ground cables, Macarthur Wind Farm. (Photo: Neville Rosengren Dec. 2017)

Geoscience features inside the wind farm boundaries have a range of sensitivity to disturbance. Sensitivity is a function of a number of physical properties of the site including scale (size/dimensions of the landform), and the context and replication of the geoscience feature in the immediate and wider surroundings. The principal geoheritage character of the Mt Rouse lavas is the degree of preservation of their original geometry and the way this represents the nature, movement and consolidation of the active lava flow at times of eruption. There are literally hundreds of individual components that comprise the entire lava field. Assessment of potential of impact is therefore the degree to which wind farm structures may compromise the appearance of sufficient number of features so as to degrade the presentation of the individual and collective character of the lava flows.

A broader question in relation to geoscience values is the overall visual effect of a turbine field and associated infrastructure on the presentation of the lava flows as landforms linked to Mount Rouse. This is a qualitative issue and converges on the amenity or aesthetic aspect of “landscape” as well as the geomorphological presentation of an irregular landscape such as stony rises. The stony rises are a distinctive landscape that in Victoria is preserved only on the younger volcanic terrain. Their extent is determined entirely by their volcanic origin, age and the pre-existing plains topography. They are part of a continuum of landscape initiated by volcanic activity and modified by subaerial processes (see Figure 4 page 7 above). Although of complex morphology, the minimal local relief (typically less than 10 metres) allows few viewpoints from where the extent and character of the complex terrain can be appreciated. A further restraint in this regard is that almost all the lava flow is on private property and not generally available for public access.

The stony rises landscape has been modified over the period of European occupation by addition and removal of material such as constructing stone walls, fences, buildings, roads and transmissions lines. These activities have (probably without exception) been undertake with no assessment of impact on geoscience values. By comparison, the proposal for a wind farm is taking geoscience values into account and providing a means by which potential further degradation can be avoided and/or minimised. It is considered that further altering the landscape appearance of the stony rises by adding wind farm infrastructure will not unduly degrade their current geoscience values.

Figure 25. Surface of Mount Rouse flow south of Riordans Road with turbines 29 & 76, cable/track and met mast position. Site is of moderate geoscience significance but low sensitivity to degradation by wind farm construction disturbance. (Photo: Neville Rosengren Sept 2017).

Figure 26. Another view of the surface of Mount Rouse flows south of Riordans Road with proposed turbines 29, 76 and 79. (Photo: Neville Rosengren Sept 2017).

7.3 Specific Impact Assessment

This section examines the sites for turbines and associated infrastructure of the proposed Willatook Wind Farm to identify geoscience significance and assess potential impact. For convenience, the area is divided into seven sectors and the potential impact of the proposal is considered for each sector. The assessment is based on interpreting landforms from aerial oblique photographs supplemented by ground-truthing to determine significance and sensitivity. In all sectors, the impact of excavation for turbine foundations, levelling for adjacent hardstand, trenching for in-ground cables and cut and fill and surfacing and grading for vehicle tracks is considered for (A) the overall significance of the Mount Rouse lava flows; (B) individual landforms or associated groups of landforms.

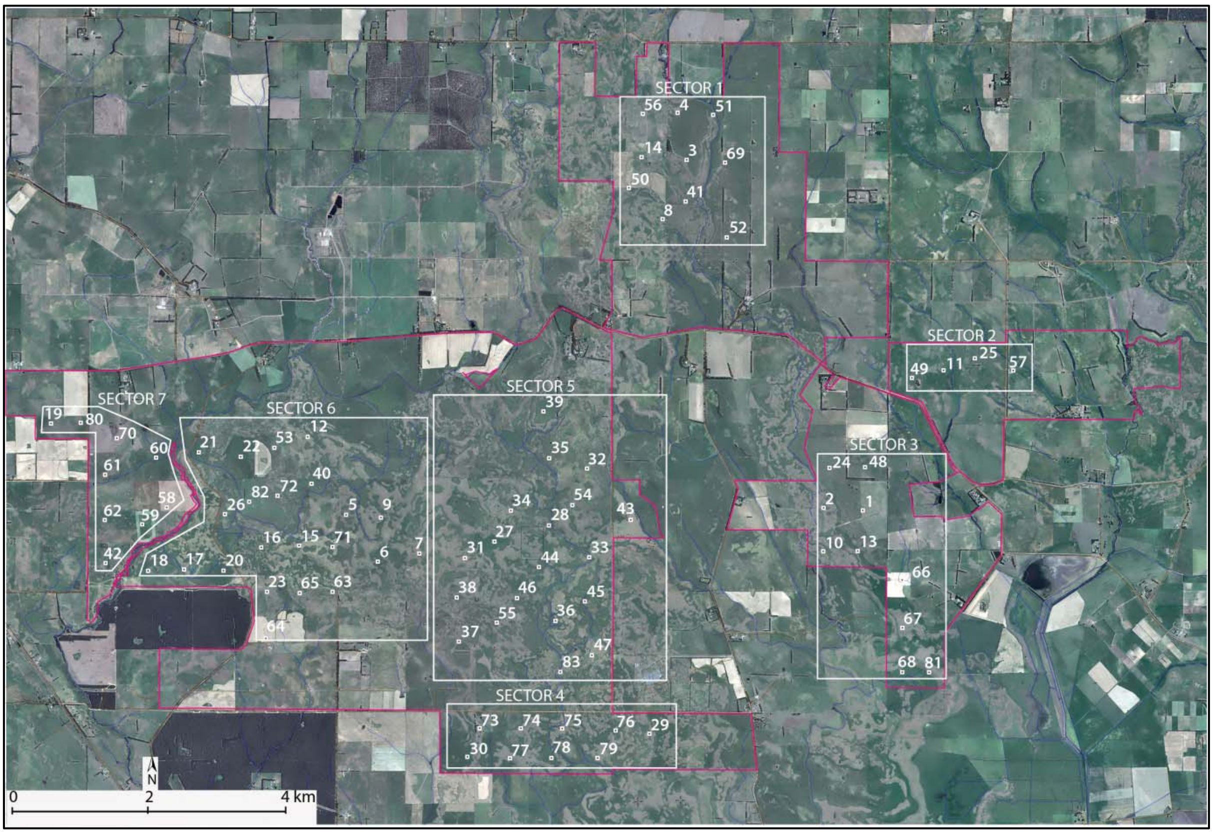

Figure 27. Sectors for impact assessment with turbine numbers (Google Earth Pro composite image 2016)

7.3.1 Sector 1: Kangertong Road

The northern part of the proposed wind farm is south of Kangertong Road and includes 10 turbines and a meteorological mast (Figures 28 to 31). In this sector, the Mount Rouse lavas are in a narrow corridor between the twin lateral streams of Shaw River and Back Creek with steptoes of older terrain in places (Figure 28). Four turbines are east of Back Creek on older lavas and have no impact on significant features. There will be one cable and road crossing of Back Creek.

Figure 28. Indicative turbine locations and cable/road crossing site of Back Creek. (Photo: Neville Rosengren Dec 2017).

Figure 29. Indicative turbine locations west of Back Creek. (Photo: Neville Rosengren Dec 2017).

Figure 30. Indicative turbine locations west of Back Creek south of KangertongRoad. (Photo: Neville Rosengren Dec 2017).

It is considered that the planned turbine locations and cable and roadways will not have a significant impact on the geoheritage values of this part of the Mount Rouse lava flows and no alteration to location is needed.

The northern met mast was initially to be located on a prominent ridge north of turbine 60. This ridge is the best defined elongate continuous ridge in this part of the lava flow (Figure 31) and would have been adversely impacted by construction and cabling. The mast has been relocated to the south and hence will not impact this significant landform.

Figure 31. New position of northern met mast south of KangertongRoad. Broken line shows the significant lava ridge will not be impacted by proposed infrastructure. (Photo: Neville Rosengren, Dec 2017).

7.3.2 Sector 2: Nagorkas Road

This eastern sector of the wind farm between Back Creek and Moyne River has four turbines and a met mast. The boundary extends east across Moyne River onto the Hawkesdale lava flow but all proposed structures are on a corridor of older volcanic terrain between the narrow Tarrone Flow to the west and the Hawkesdale flow (Figure 32).

No significant features in this sector are impacted under the present plan for the wind farm. The Moyne River at the western edge of the Hawkesdale flow is an outstanding example of a lateral stream.

Figure 32. Sector 2 is the western edge of wind farm (shown by broken red line). No structures are planned that will affect the Hawkesdale lava flow or Moyne River lateral stream. (Photo: Neville Rosengren, Sept, 2017).

7.3.3 Sector 3: Woolsthorpe - Heywood Road South

This sector contains 10 turbines east of Back Creek. Back Creek is a lateral stream to the narrow Tarrone lava flow and switches from the eastern to the western side of the flow between turbine 1 and turbine 10 (Figure 33). Six turbines are on the lava flow, the other four turbines are on older lava west of the Tarrone Flow. The main Tarrone lava ridge has complex lava topography of high regional significance. As only a small area will be impacted by the proposed structures the potential for degradation of significant features is low and acceptable within the context of the wind farm project.

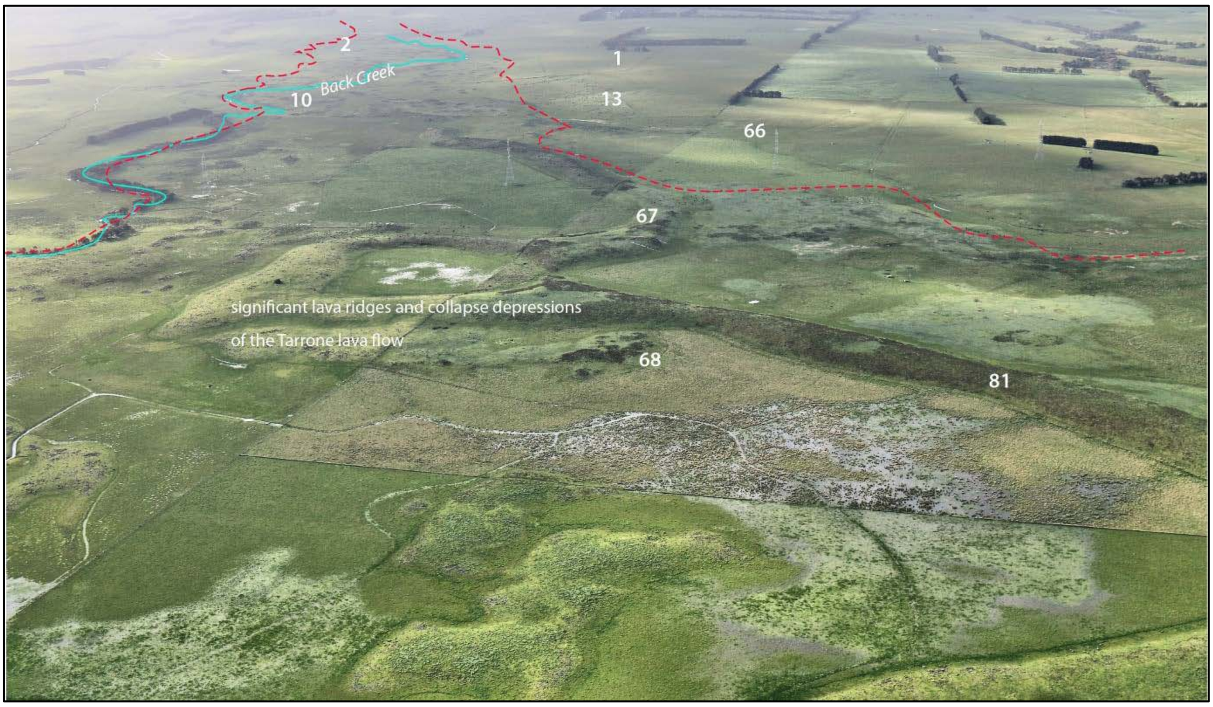

Figure 33. Complex lava and stream topography at Back Creek. (Photo: Neville Rosengren, Sept, 2017).

7.3.4 Sector 4: Riordans Road

This southern sector includes nine turbines and a met mast. The terrain is illustrated in Figure 25 and 26 on page 35 above and Figures 34 and 35 below. The lava ridges and depressions are well-defined and include a ridge at turbine 82 that is at the edge of an inlier of older lava.

Figure 34. Met mast location south of Riordans Road. (Photo: Neville Rosengren, Dec. 2017).

Figure 35. Turbine sites south of Riordans Road. (Photo: Neville Rosengren, Dec. 2017).

7.3.5 Sector 5: Landers Lane

This sector is between Woolsthorpe-Heywood Road and Riordans Road and includes 20 turbines within three kilometres west of Landers Lane and one turbine just east of Landers Lane. Along with sector 4 and sector 6 it comprises the core of the Mount Rouse - Port Fairy lava flows in the proposed wind farm area (Figures 36 to 39). The area is a broad, shallow valley on the alignment of the pre-volcanic Shaw River and represents an initial lava pathway following that valley and diverting the river. A defined and co-ordinated drainage system has developed with a main continuous channel linking elongate lava depressions. These contained an extensive wetland, now much reduced by artificial drainage and diversion channels. A variety of lava ridges and depressions occur with subdued relief and extensive broad flatter surfaces rather than narrow ridges. These surfaces will essentially retain their geomorphic character without significant loss of geoscience values with wind farm construction and operation.

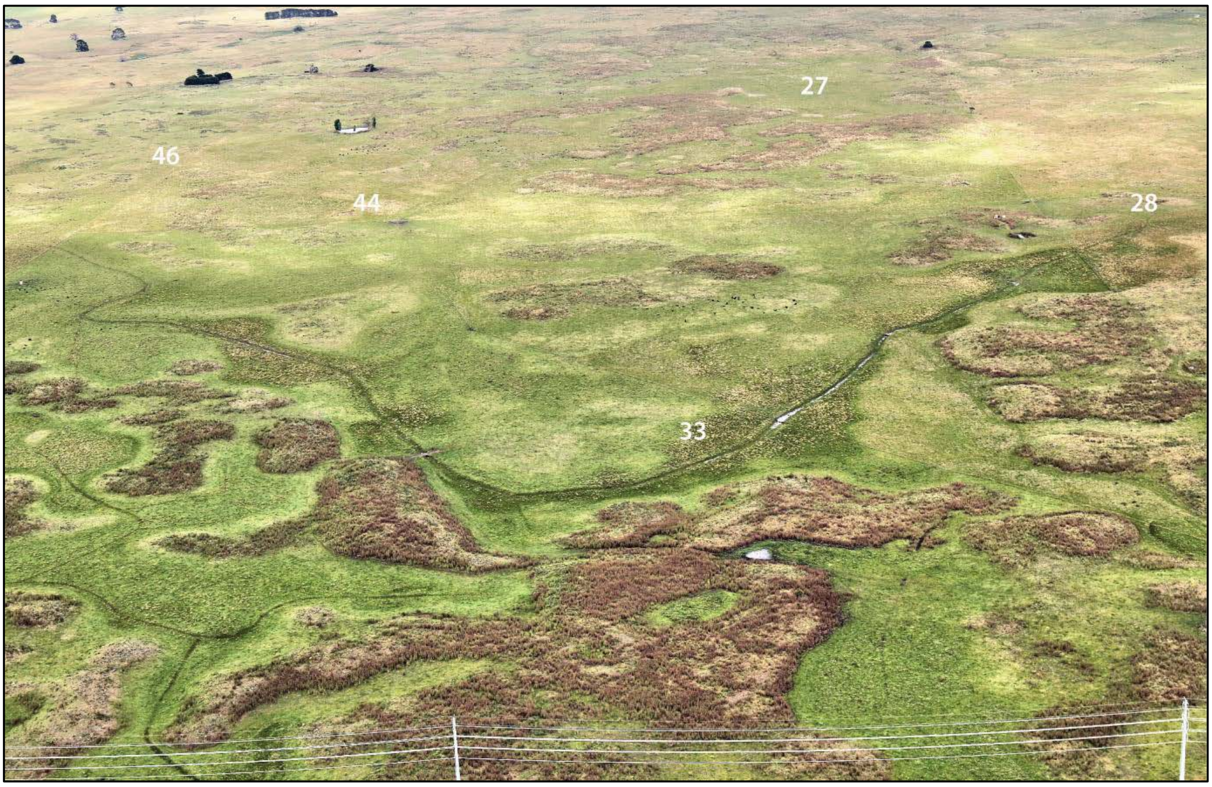

Figure 36. Broad drainage line (former wetland) and low ridges west of Landers Lane with five turbine locations. (Photo: Neville Rosengren, Dec. 2017).

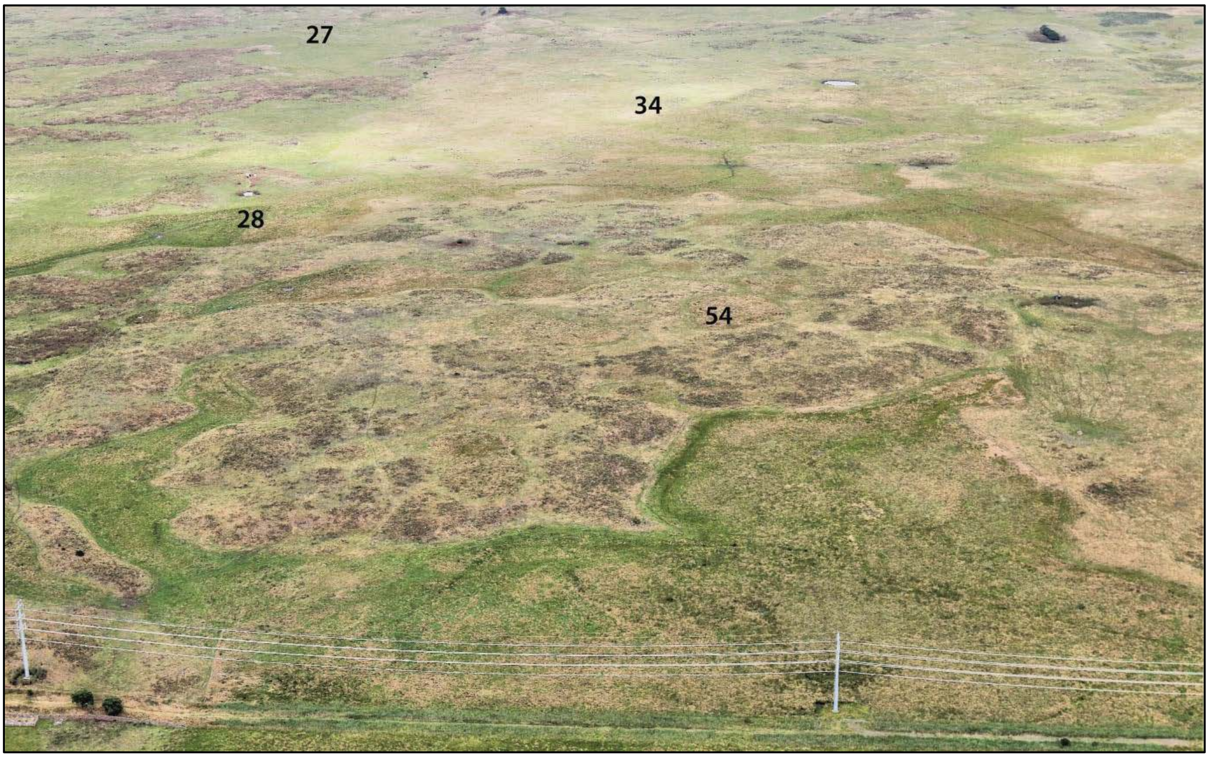

Figure 37. Broad low ridges west of Landers Lane showing four turbine locations. (Photo: Neville Rosengren, Dec. 2017).

Figure 38. Irregular low ridges west of Landers Lane showing turbine locations 35, 39. (Photo: Neville Rosengren, Dec. 2017).

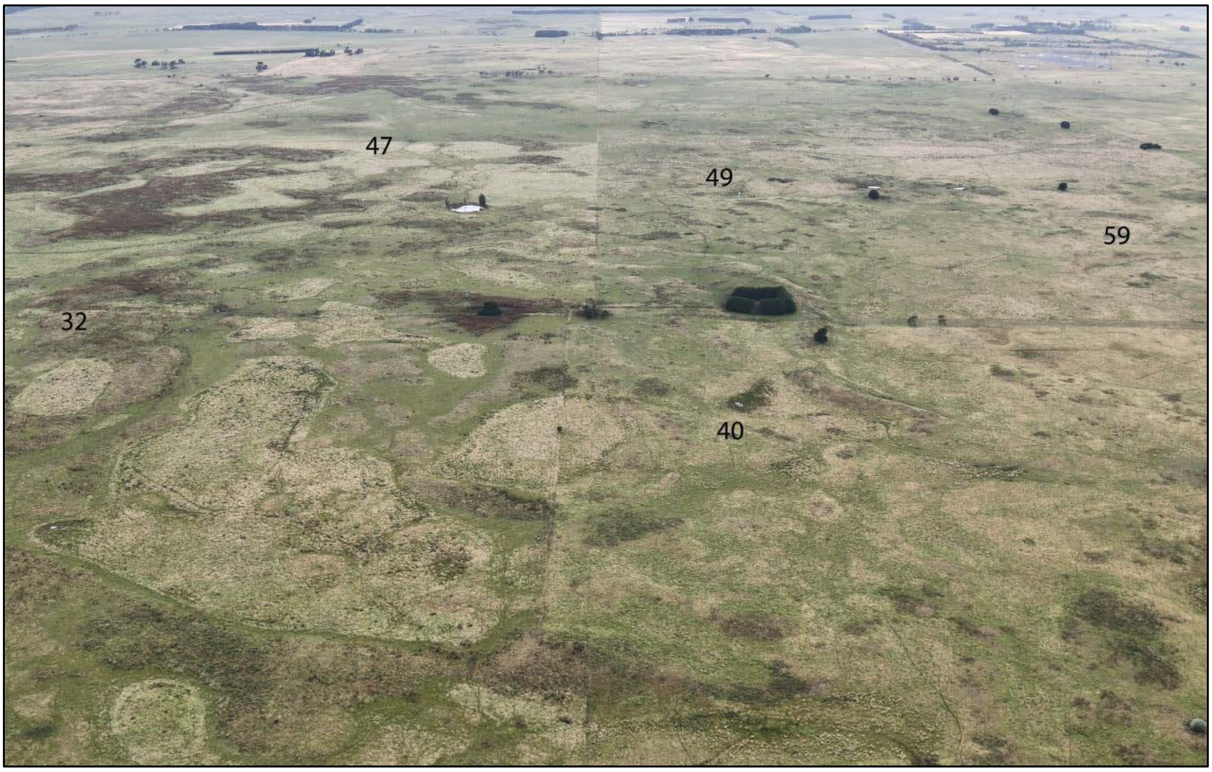

Figure 39. View to east across turbine sites 40, 47. 49, 59. (Photo: Neville Rosengren, Dec. 2017).

A widespread feature of this part of the lava flows are naturally occurring circular depressions from around 30-40 metres to less than sixty metres diameter (Figure 40). Some that contain open pools have been deepened for farm purposes. They are much smaller than the long elongate to irregular depressions that comprise the major relief of the main body of lava.

Figure 40. Naturally occurring small circular depressions (some deepened for farm use) near turbines 31,44, 46 59. (Photo: Neville Rosengren, Dec. 2017).

The planned turbine locations and cable and roadways will have a significant impact on the geoheritage values of this part of the Mount Rouse lava flows. However, because of the replication of similar sites across the sector that will not be impacted by the proposed wind farm infrastructure it is considered that no alteration to location of turbines is required.

7.3.6 Sector 6: Shaw River

This sector is bordered in the west and north by Shaw River, here a lateral stream to the main Mount Rouse - Port Fairy lava flows. The sector includes 19 turbines on the Mount Rouse - Port Fairy lava flows and one (turbine 69) on older lava. The landform is a broad low dome forming the western margin of the valley-form that characterises Sector 5 and sloping gently to the south west and east where drainage is to Shaw River lateral stream. Local relief on the lava is noticeably greater than most other areas in this study with large closed depressions (Figure 41) giving rise to many wetlands and complex flood drainage.

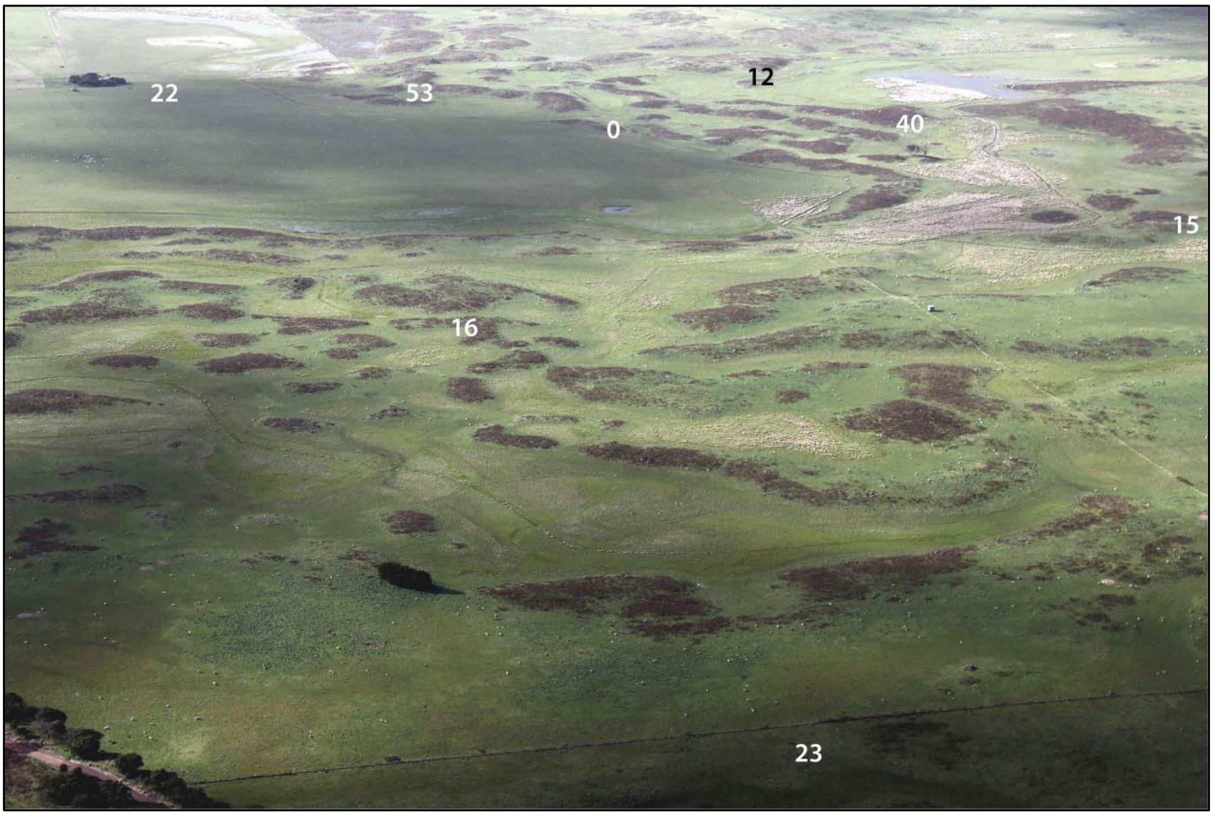

Figure 41. Northern part of sector 6 east of Old Dunmore Road. Note the many different sizes of wetland. (Photo: Neville Rosengren, Sept. 2017).

This sector is the most sensitive to disturbance and degrading of significant individual geoscience features in the present study area. The geomorphology of the area immediately south and east of Shaw River is significant for several reasons: (1) It is one of the largest contiguous areas of the Mount Rouse - Port Fairy lavas. (2) It includes a diverse range of landforms with greater relief than much of the southern lava flows. (3) It defines the course of Shaw River as a lateral stream on the west. (4) Despite the extensive artificial drainage, there are still substantial areas of active wetland in enclosed or contained depressions that have been little modified (Figure 42 and Figure 43).

Figure 42. Large depression west of extension of McGraths Road, the proposed site of turbine 68. (Photo: Neville Rosengren, Sept. 2017).

Figure 43. Steep ridges and multiple deep depressions, turbines 5, 6, 9. (Photo: Neville Rosengren, Sept. 2017).

For this site, a comprehensive Construction Environment Management Plan must be developed and enforced using the guidelines outlined in Section 7.4 below.

7.3.7 Sector 7.

Sector 7 is an area of older lavas and no features of geoscience significance were identified.

7.4 Recommendations to Minimize Impacts on Geoscience Significance

It is recommended that, in order to preclude and/or minimise damage to potential features of geoscience significance:

1. In developing final designs for location of wind farm infrastructure, the following procedures should be followed.

    (i) The number of towers and other structures built on narrow lava ridges should be kept to a minimum and where feasible be relocated to broader flat surfaces.

    (ii) Minimise reshaping and fill of all young lava surfaces.

(iii) Excess excavated rock should be removed from the site or used as fill for the immediate areas as needed.

(iv) Underground cabling across high and narrow lava ridges should be avoided where possible. Where ridges are crossed, reshaping should kept to a minimum and the geometry of the ridge should be maintained.

(v) Prior to any construction work, a high resolution topographic image (DTM) of the young lava surfaces should be prepared either from photogrammetry and/or LiDAR. This would give an invaluable benchmark to assist in future geological and hydrological studies of these surfaces.

(vi) Avoid/minimise alterations to stream channels.

(vii) Implement a construction environment management plan that conforms to the above requirements.

8 SUMMARY OF POTENTIAL GEOLOGICAL AND LANDFORM CONSTRAINTS

8.1 Overview

Constraints and hazards for a proposed wind farm are of two groups:

(a) General hazards (not specific to a wind farm) e.g. future volcanic eruptions:

(b) Specific hazards/constraints such as the capacity of 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. An overlay on these constraints is geoscience values.

An outline of geological and landform characteristics of the area that are relevant in a general sense and also in defining location of infrastructure is given below.

8.2 Lithology and Rock Structure

There is extensive rock outcrop over much of the proposed wind farm area. The main exposed hard rock units are all variants of basaltic lava derived from Mount Rouse. Areas without outcrop either are depressions in the Mount Rouse lavas backfilled with sediment and/or organic material or are older lavas with in situ regolith and soil cover. Borehole records show the Mount Rouse lavas are up to 40 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 Rouse lavas are comprised of numerous flow units and each may be from one metre to over five metres thick (Figure 44). 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. Closer to Mount Rouse (but unlikely in the present study area) some flow unit boundaries have a covering of scoria and fragmental basalt that is not strongly coherent or completely welded.

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

Figure 44. Four lava flow units of the Mount Rouse flow exposed in Tarone Quarry just south of the convergence of the Tarrone flow. (Photo from Boyce, 2013).

8.3 Volcanic activity

There are over 700 eruption points in the Newer Volcanic Province of Victoria spanning about seven million years; the NVP is considered an active volcanic province. A simple (and potentially very misleading) calculation indicates an average of 10,000 years between eruptions and as the youngest volcanoes appear to be over 30,000 years old, another eruption could be expected. The occurrence of mantle-derived CO2 at locations such as Mt. Gambier, Garvoc, Wangoom and the Daylesford region; and a thermal anomaly within the mantle beneath the Central Highlands subprovince (Wopfner & Thornton 1971; Chivas *et al*. 1987, 1983; Cartwright *et al*. 2002; Graeber *et al*. 2002; Aivazpourporgou *et al*. 2012) is direct evidence of continuing volcanic crustal processes. A new volcano would be produced with very little warning, with only minor seismic activity. Rapid magma ascent at velocities of tens of metres per second (Rutherford & Gardner 2000) means a magma originating at a depth of 80 km could reach the surface in as little as 2 hours (Boyce 2013). 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 the risk of future eruptions as between high and medium in an area south of Hamilton. In the event of renewed volcanic activity, three types or 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 Rouse and Mount Napier) following existing valleys, (c) scoria eruptions similar to Mount Rouse. 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.

Although the potential for future volcanic activity in the volcanic province south of Hamilton was assessed as high to medium by Joyce (2005), the eruption record of western Victorian volcanoes indicates it is unlikely that *past eruption points* including Mount Rouse 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.

8.4 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 sediments 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 (120 km southeast of Penshurst) rapid and substantial uplift of up to 200 metres has occurred over this time. Paine *et al.* (2004) also demonstrated substantial uplift in the region around Hamilton, but concluded that tectonism was short-lived and had occurred prior to the eruption of the lava flows in the Hamilton to Portland 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, there was moderate building 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 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 the basic assumption 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 (8.3 page 48 above), seismic risk is a continuing, but low background factor for this project.

8.5 Geomorphological (landform) constraints

Potential landform constraints in the proposed wind farm area include slope steepness, rapid changes of slope angle and aspect, areas of stream dissection, 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 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.

8.5.1 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).

8.5.2 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 the potential for soil erosion by water (sheet erosion) as low for most of the present study site with areas of moderate potential only occurring on the more deeply weathered lavas surrounding the Mount Rouse lavas. All the area was classed as having low susceptibility to gully erosion and wind erosion.

8.5.3 Surface drainage, soil drainage and waterlogging

Although Baxter and Robinson (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 does occur in depressions for parts of the year and is a constraint on vehicle movement and construction activities. Areas of waterlogged soil and peat will also have low load-bearing capacity.

8.5.4 Potential acid sulphate soils

The potential for acid sulphate soils is considered very low, as there is no geologically recent marine influence to have left saline sediments. The potential for saline groundwater or surface water providing suitable conditions for acid sulphate soils to have developed or have the potential to develop is also considered low.

8.5.5 Mass movement

Although 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. Large loose blocks on the crests and upper slopes of lava ridges have the potential to topple, roll or slide when disturbed by machinery. Ignition of surface and sub-surface peat deposits from wild fires will result in subsidence of the surface due to destruction of the peat by the fire. As peat deposits are localised and of restricted extent, the potential for this constraint developing in the proposed wind farm area is low.

8.6 Geoheritage

This report has addressed the geoheritage values of the proposed wind farm in earlier chapters.

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