Palaeomagnetic Secular Variation for Recent Normal and Reversed Epochs, from the Newer Volcanics of Victoria, Australia

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Summary

Palaeomagnetic studies were carried out on 46 sites in basalts from the Newer Volcanics of Victoria, which range in age from Recent to at least 4.5 My. After magnetic cleaning the 25 normal and 21 reversed sites show a marked improvement in precision compared with a previous investigation of 32 sites in which only NRM directions were considered, and give a palaeomagnetic pole at 86.6° S, 266.3° E with $A_{95} = 1.9°$. The small departure from the present south geographic pole is in the correct sense required by sea-floor spreading south of Australia. The between-site scattering of the mean directions and mean poles (VGPs), as a measure of secular variation, indicated no significant difference between the normal and reversed epochs. The overall values of the between-site angular standard deviation with respect to directions was 8.9°, and with respect to VGPs was 11.4°. The latter is significantly lower than expected on Cox's model, but not significantly different from results from New Zealand and the Western U.S.A., which have similar latitudes to the Newer Volcanics. Comparison of the angular dispersion due to directions with Creer's model suggests that the hemispherical asymmetry of the non-dipole field has persisted over the past few million years, and that the contribution of dipole wobble to the secular variation must have been small over the same period.

1. Introduction

(a) General

The palaeomagnetism of the Newer Volcanics of Victoria was first studied by Irving & Green (1957) and Green & Irving (1958). In an analysis of the NRM directions at 32 sites, these authors found 13 sites had normal polarity, 16 were reversed and 3 were of 'mixed polarity'. Because magnetic cleaning techniques have subsequently been developed, a more detailed investigation has now been undertaken with a view to providing information about palaeosecular variation over the past few million years.

McDougall, Allsopp & Chamalaun (1966) have carried out geochronological and polarity studies (with magnetic cleaning) at 11 of the 32 sites mentioned above. Employing the whole rock K–Ar dating method it was found that the Newer Volcanic

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activity started at least 4.5 My ago. Evidence based on C¹⁴ dating shows that the activity continued until 5000 years ago. Thus the Newer Volcanics were extruded during the Brunhes and Gauss Normal and Matuyama and Gilbert Reversed geomagnetic polarity epochs. The present collection from 48 sites includes practically all the sites collected by Irving & Green (1957). Since no geochronological work was done on the samples from the present collection, it was difficult to ascertain, except for the 11 sites from the previous collection, whether a particular polarity fell in a geomagnetic polarity epoch or an event.

(b) Palaeosecular variation

The palaeomagnetic study of a number of lava flows forming a geological sequence shows a certain dispersion of the directions of magnetization. This dispersion consists of within-site and between-site scatter. The within-site scattering, which is generally due to experimental errors or inhomogeneity of magnetization, can be averaged out by making a number of independent readings on an adequate number of samples. The random error due to tectonic movements and local displacements can be avoided to a great extent by careful choice of sites. Secondary components of magnetization may introduce additional errors, which may be eliminated by partially demagnetizing the specimen. The technique is referred to as 'magnetic cleaning'. If the age span of the lava sequence is sufficiently long, errors due to polar wander and continental drift must also be taken into account. After minimizing all these errors and assuming that the TRM of a lava flow provides a 'spot reading' of the palaeomagnetic field, the between-site scatter, as determined by a 'two-tier analysis' (Watson & Irving 1957; McElhinny 1967), is indicative of the magnitude of the Secular Variation (SV) over the time span sampled.

The study of the SV of the geomagnetic field during the historical past shows that it is dependent on the non-dipole field, which has an irregular distribution over the surface of the Earth. The non-dipole field is presumed to originate at the surface of the Earth’s core or just within it (Elsasser 1946). SV includes variations in the main field due to dipole oscillations and its wobble as well as changes in the magnitude and direction of the non-dipole field.

The palaeosecular variation due to the non-dipole field has been investigated by Hope (1957), Creer (1962), Chamalaun (1968), Cox (1969), Doell (1970), Wilson (1970), Brock (1970) and others. One of the major anomalous features on the non-dipole field is its hemispherical asymmetry, which may be due to the chance concentration of non-dipole foci in the Southern Hemisphere. A detailed investigation of the nature and the persistence of this asymmetry has a direct bearing on the magnetohydrodynamics of the Earth’s core. In this paper an attempt has been made to study the long term nature of the SV over the last few normal and reversed geomagnetic polarity epochs.

2. Location and geology

The Newer Volcanics of Victoria (S-E Australia) are alkaline olivine basalts ranging in age from Pliocene to Holocene. They are finely vesicular to vesicular, predominantly massive but also irregularly jointed and columnar to a lesser extent (Singleton & Joyce 1969). Edwards (1938) has recognized two iron oxide minerals, ilmenite and magnetite, and the latter is considered to be the main carrier of TRM in these basalts. The basalts form the continuous lava fields of the Werribee and Western District Plains, lying mainly on Cainozoic marine sediments but also overlapping northwards on to Palaeozoic basement (Singleton & Joyce) 1969. The Newer Volcanics crop out extensively over nearly 25 000 km² west of the meridian of Melbourne, lying approximately between Lat. 36°30’–38°25’ S and Long. 141°15’–145°5’ E (Fig. 1).
3. Experimental methods

From 48 widely-distributed sites, a total of 137 geographically oriented hand samples were collected, whose site locations are shown in Fig. 1. In six cases two sites collected from different terraces of a quarry might have been from the same flow. In other cases it is not known whether samples collected from quarries several kilometers apart were also in the same lava flow. An average of three samples were taken from each site, while at least two 2.2 cm cylindrical specimens were obtained from each sample. Directions and intensities of magnetizations were measured on both astatic and spinner magnetometers. Samples from two of the sites were discarded for palaeodirectional investigations, because they were highly weathered and had extremely low intensities of magnetization ($10^{-5}$ emu cm$^{-3}$), which were less by a factor 100 than the average NRM intensities. These samples also showed random directional changes on progressive partial demagnetization.

In order to determine the optimum alternating field (af) for magnetic cleaning, at least one pilot specimen from each site was step-wise demagnetized in alternating fields of 50, 100, 150, 200, 300, 400, 600 (and occasionally 800, 1200 and 1600) oersted peak field, using a biaxial tumbling af demagnetizer in field-free space (McElhinny 1966). An af of 200 Oe (peak value) was found to be most appropriate to remove the effects of the secondary components of magnetization in most cases but at sites 14 and 38, 50 and 600 oersteds respectively were used. The magnetic characteristics vary from site to site. For some sites the directions remained closely grouped and did not change much during partial demagnetization. The shapes of the demagnetizing
FIG. 2. Demagnetizing curves of normal and reversed polarity sites of Newer Volcanics. $J/J_0$ indicates the ratio between the intensity of magnetization after application of an alternating magnetic field $H$ and the intensity of NRM. Site numbers are marked on each curve.

curves (Fig. 2) are typical of TRM (Doell & Cox 1963). Some of the samples proved to be very stable and did not show any appreciable decrease in intensity even at relatively higher af. (1200 Oe). No bedding corrections were required at any site, as there has been no tectonic disturbance or tilting of the lavas.

4. Palaeomagnetic results

(a) Directions

The site-average directions of magnetization, after af treatment, given in Table 1 are believed to represent the palaeomagnetic field directions at the time of cooling of the lavas. The length of the vector resultant $R$ relative to $N$ is a measure of the scatter of magnetic vectors (Fisher 1953) and it is noteworthy that the within-site scatter of the cleaned samples is extremely low. The site-mean directions of magnetization before and after af treatment are illustrated in Fig. 3.
Table 1

Site-mean paleomagnetic results

(Mean site location is at 38° 3'S, 143° 5'E)

<table>
<thead>
<tr>
<th>Site No.</th>
<th>N</th>
<th>R</th>
<th>Decl.</th>
<th>Incl.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (NV8)</td>
<td>3</td>
<td>2.9978</td>
<td>4.9</td>
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<td>2</td>
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<td>3</td>
<td>3</td>
<td>2.9999</td>
<td>6.2</td>
<td>-59.2</td>
</tr>
<tr>
<td>5 (NV10)</td>
<td>3</td>
<td>2.9941</td>
<td>12.4</td>
<td>-56.7</td>
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<tr>
<td>6</td>
<td>3</td>
<td>2.9977</td>
<td>183.7</td>
<td>+58.5</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>2.9885</td>
<td>185.9</td>
<td>+56.9</td>
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<tr>
<td>8 (NV7)</td>
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<td>2.9954</td>
<td>2.4</td>
<td>-56.6</td>
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<tr>
<td>9</td>
<td>3</td>
<td>2.9950</td>
<td>1.6</td>
<td>-57.8</td>
</tr>
<tr>
<td>10 (NV4)</td>
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<td>357.9</td>
<td>-59.6</td>
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<td>2.9902</td>
<td>358.0</td>
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<td>14</td>
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<td>-73.6</td>
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<td>16</td>
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<td>2.9750</td>
<td>353.1</td>
<td>-65.6</td>
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<td>2.9</td>
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<td>3</td>
<td>2.9979</td>
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<tr>
<td>28 (NV27)</td>
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<td>2.9</td>
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<tr>
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<td>-55.5</td>
</tr>
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<td>3</td>
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<tr>
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<td>200.3</td>
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<tr>
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<td>2.9850</td>
<td>18.1</td>
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</tr>
<tr>
<td>36</td>
<td>3</td>
<td>2.9978</td>
<td>11.1</td>
<td>-54.5</td>
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<td>37</td>
<td>2</td>
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<td>-53.1</td>
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<td>39 (NV17)</td>
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<td>2.9958</td>
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<td>41 (NV2)</td>
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<td>+43.9</td>
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<td>45 (NV14)</td>
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<td>171.6</td>
<td>+49.1</td>
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<tr>
<td>46 (NV11)</td>
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<td>2.9938</td>
<td>165.4</td>
<td>+54.5</td>
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<tr>
<td>47 (NV13)</td>
<td>3</td>
<td>2.9946</td>
<td>171.4</td>
<td>+50.3</td>
</tr>
<tr>
<td>48</td>
<td>3</td>
<td>2.9817</td>
<td>354.9</td>
<td>-58.2</td>
</tr>
</tbody>
</table>

| Mean     | 46  | 45.4231 | 3.7  | -59.3  |
| Mean*    | 32  | —       | 3.4  | -59.8  |

N: number of samples.
R: length of vector sum of N unit vectors.
*: Due to Irving & Green (1957) and Green & Irving (1958), in which case
\( \alpha_{45} \) for directions was 4.8°, while in the present case it is 1.5°.

Site numbers with prefix NV refer to those collected by Irving & Green (Green & Irving 1958).
FIG. 3. Stereographic projection of (a) directions of NRM and (b) directions of remanent magnetization after magnetic cleaning in a field of 200 Oe. Open circles upper hemisphere and solid circles lower hemisphere. The plane of projection is horizontal.

The formation mean direction of magnetization \( (D = 3.7^\circ, I = -59.3^\circ) \) found by giving each of the 46 sites unit weight (Table 1) is very close to that given by Irving & Green (1957), who obtained a value \( D = 3.4^\circ, I = -59.8^\circ \), from 32 sites. The mean pole position lies within 0.5° from that found by Irving & Green (1957). The important difference, however, lies in the dispersion of the directions and poles. These are very much more tightly grouped as a result of the use of magnetic cleaning, and this has important implications regarding palaeosecular variation as will be discussed in the next section. The virtual geomagnetic poles (VGPs) for normal and

FIG. 4. Distribution of Virtual Geomagnetic Poles (VGPs) for normal and reversed sites of the New Volcanics. Cross, position of present geomagnetic pole; N and R 95 per cent confidence circles about the mean of normal and reversed VGPs; solid circle, normal polarity; open circle, reversed polarity.
reversed sites are plotted in Fig. 4. The mean pole in Table 2 lies $3.4^\circ$ away from the present geographic south pole along the line of longitude towards Victoria. The displacement of the pole is in the correct sense required by sea-floor spreading south of Australia, over the past few million years (Le Pichon & Heirtzler 1968).

(b) Intensities

The intensity histograms for normal and reversed samples, before and after af demagnetization, are given in Fig. 5.

![Histograms of frequency distribution of samples versus their remanent intensities](https://academic.oup.com/gji/article-abstract/24/3/255/629622)

**Fig. 5.** Histograms of frequency distribution of samples versus their remanent intensities (emu cm$^{-3}$) for normal and reversed magnetizations. The intensities of NRM as well as remanent intensities after magnetic cleaning are given. In the left half of the figure the logarithmic values of the intensities are plotted against the frequency of samples.
Both the arithmetic mean and log mean intensities of the specimen averaged for a particular treatment are plotted against the frequency of the samples. In the latter case the distribution approximates more nearly to a Gaussian distribution as has been found by Irving & Roy (1968).

When the means of the logs of normal and reversed intensities, averaged for a particular demagnetizing treatment, are plotted against the corresponding demagnetizing field, the curves shown in Fig. 6 are obtained. The error bars indicate the standard error of the mean. The curves show a number of features. Whereas the intensities of the normal samples decrease upon demagnetization, those of the reversed samples show a small increase at 50 Oe before decreasing. This difference in behaviour is that expected if a viscous component of magnetization in the direction of the present geomagnetic field is present (Irving & Roy 1968). However, the intensities of the reversed samples appear to be systematically higher than the normal ones. Between 50 and 200 Oe, the standard error bars do not overlap, so that they may be considered significantly different at the 67 per cent confidence level. However, application of Student's t test to the difference between the means at each demagnetizing field shows that they cannot be considered significantly different at the 95 per cent confidence level. The intensities of the two groups converge rapidly above 200 Oe (the usual cleaning field) and this confirms the observation of Irving & Roy (1968) that the average intensities of the normal and reversed lavas are probably the same.

5. Determination of palaeosecular variation

For a study of palaeosecular variation the quantities of main interest are the angular dispersion of site-mean directions and that of the site-mean VGPs, as deduced from their respective precision parameters. The total dispersion consists of the

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**Fig. 6.** The decrease of average remanent intensities (emu cm$^{-3}$), for normal and reversed magnetizations, on being progressively demagnetized in alternating magnetic fields. Bars indicate the standard errors of the means.
between-site and the within-site dispersions. The former is mainly due to the secular variation of the ancient geomagnetic field, while the latter is background noise due to orientation errors etc.

The data of site-mean directions and site-mean VGPs were subjected to a 'two-tier analysis' (Watson & Irving 1957; McElhinny 1967). In such an analysis, it is assumed that the within-site dispersion is the same at all sites, and a best estimate is then derived for the between-site (β) and within-site (ω) precision parameters. Cox (1969) and Doell (1970) have each made collections of eight samples per site, in order to average out within-site variations. This approach is necessary when the within-site and between-site variations are of comparable magnitude. However, in the particular case where the within-site scatter is an order of magnitude less than the between-site scatter, this is not necessary and fewer samples need be collected. This is the situation in the present investigation as indicated by Irving & Green's (1957) earlier work.

Table 2 shows the statistics for the average directions of magnetization and for the VGPs using the two-tier analysis. This shows that the within-site precision is always considerably greater than the between-site precision. The between-site angular dispersions obtained from the normal single-tier analysis (from Table 1) are $9.1^\circ$ for the site-mean directions and $11.8^\circ$ for the site VGPs. These reduce the $8.9^\circ$ and $11.4^\circ$ respectively with the use of the two tier analysis (Table 2). The relatively small 'corrections' occur because of the small within-site dispersion. In the present investigation therefore, it has not been found necessary to analyse more than three samples per site.

Although the between-site dispersion is a measure of the palaeosecular variation of the main field, nevertheless, it may also include small components due to continental drift, polar wandering and local palaeomagnetic anomalies. No allowance has been made for these possible errors, which are believed to be insignificant (Cox 1969). In all these calculations it has been assumed that the average field direction was that of an axial dipole. There appears to be no difference in angular dispersion between the normal and the reversed samples.

**Table 2**

Two-tier analyses

(a) Referred to mean directions:

<table>
<thead>
<tr>
<th>Polarity</th>
<th>N</th>
<th>B</th>
<th>$D_m$</th>
<th>$I_m$</th>
<th>$R$</th>
<th>$\alpha_{95}$</th>
<th>$\omega$</th>
<th>$\beta$</th>
<th>$\delta_\beta$</th>
<th>95% limits*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>72</td>
<td>25</td>
<td>$3.9^\circ$</td>
<td>$-60.0^\circ$</td>
<td>71</td>
<td>0557</td>
<td>1.9</td>
<td>603</td>
<td>98</td>
<td>8.2</td>
</tr>
<tr>
<td>Reversed</td>
<td>61</td>
<td>21</td>
<td>$176.1^\circ$</td>
<td>$+58.3^\circ$</td>
<td>60</td>
<td>0339</td>
<td>2.3</td>
<td>445</td>
<td>70</td>
<td>9.7</td>
</tr>
<tr>
<td>All</td>
<td>133</td>
<td>46</td>
<td>$3.9^\circ$</td>
<td>$-59.2^\circ$</td>
<td>131</td>
<td>0755</td>
<td>1.5</td>
<td>354</td>
<td>82</td>
<td>8.9</td>
</tr>
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</table>

(b) Referred to VGPs:

<table>
<thead>
<tr>
<th>Long.° E</th>
<th>Lat.° N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>72 25</td>
</tr>
<tr>
<td>Reversed</td>
<td>61 21</td>
</tr>
<tr>
<td>All</td>
<td>133 46</td>
</tr>
</tbody>
</table>

$N$: number of samples.

$B$: number of sites.

$R$: length of vector sum of $N$ unit vectors.

$\alpha_{95}$: 95 per cent confidence circle.

$\omega$: within-site precision parameter.

$\beta$: between-site precision parameter.

$\delta_\beta$: angular standard deviation due to between-site scattering = $8\lambda/\beta^*$.  

The variation in magnitude and direction of the non-dipole field with respect to the dipole field and the wobble of the dipole are considered to be the main causes of the angular dispersion of the geomagnetic field (Doell 1970). Since the dispersion of the VGPs produced by dipole wobble is invariant with respect to latitude (Cox 1962), it is advantageous to analyse VGPs rather than the directions, when comparing angular dispersion from different regions. The angular dispersion in excess of the component due to dipole wobble is then a minimum value for the dispersion produced by the non-dipole field at any locality (Doell 1970).

In Fig. 7 the angular dispersion of site-mean VGPs about the geographic pole for several localities described in earlier works (Cox & Doell 1964; Doell & Cox 1965; Cox 1969; Doell 1969) and modified by Doell (1970) are plotted against latitude. The 95 per cent confidence limits shown as error bars have been calculated according to the method of Cox (1969). An F-ratio test shows that the value of angular dispersion from Victoria (S-E Australia) is not significantly different from those obtained from the Western U.S.A. (Cox et al. 1964) and New Zealand (Cox 1969).

The between-site dispersion of the directions of magnetization can be compared with Creer's (1962) model curves for the angular dispersion due to the non-dipole field (see Creer's Fig. 5). Creer's analysis shows variation between the Northern and Southern Hemispheres due to the present stronger non-dipole contribution to the field in the Southern Hemisphere than in the Northern. The variations on Creer's model are shown in Fig. 8, together with Cox's (1970) model D curve. The angular dispersion calculated for the Newer Volcanics plots close to the expected position on Creer's Southern Hemisphere curve, and is significantly different from both the

![Figure 7](https://academic.oup.com/gji/article-abstract/24/3/255/629622/b56c256/25622)
Northern Hemisphere curve and Cox's model D. Two conclusions might be drawn. Firstly, the hemispherical asymmetry of the non-dipole field may be a more permanent feature of the geomagnetic field than was previously supposed. Secondly, the contribution of the dipole wobble to the secular variation must have been small over the past few million years. The latter is in accord with Brock's (1970) world-wide analysis of palaeosecular variation from palaeomagnetic data. However values from Hawaii, France and New Zealand for the Brunhes normal epoch plot on Cox's model D curve (Fig. 8), and this is not in accord with the Victoria results averaged over the last few epochs.

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References


**Appendix**

**Location of sampling sites**

Most of the samples were collected from quarries. The numbers refer to sites. The name of the map at 1:63,360 scale (unless stated otherwise) and the grid references are given in parentheses. The topographic maps used here are those prepared by the Australian Survey Corps. The K–Ar ages of some of the sites are due to McDougall et al. (1966).

1. Regal Quarry, Duke Street, Braybrook, Massive basalt sampled from the northern part and uppermost terrace of the quarry. (Melb. 289050 E, 341800 N).
2. Location nearly same as that for site 1. Irregularly jointed columnar basalt, sampled from a lower terrace 25 ft below site 1. (Melb.: 289055 E, 341800 N).
3. Location nearly the same as for 1 and 2. Irregularly jointed columnar basalt sampled 17m below 2. (Melb.: 289050 E, 341850 N).
4. Location nearly the same as for 3, and about 15 m above it. Weathered basalt. (Melb.: 289050 E, 341850 N).
5. Albion Reid Quarry, off Ballarat Road. Massive basalt sampled from the southern wall of the quarry. (Melb.: 285900 E, 341150 N). Two samples GA1020, GA1173 were dated; ages 2·55±0·15 and 2·74±0·20 My respectively.
6. Albion Reid Deer Park Quarry. Freshly worked olivine basalt sampled from the southern flank of the quarry. (Melb.: 277550 E, 340350 N).
8. Stanleys Quarries. Vesicular basalt sampled from the N-W flank of the upper terrace of the quarry. (Melb.: 288100 E, 337350 N).
12. Stanleys Quarries. Massive basalt sampled from the upper terrace on the eastern wall of the quarry. (Melb.: 288600 E, 336200 N).
14. Road-side exposure. Slightly weathered vesicular basalt sampled. This site was 5 km north of 13. (Lancefield: 266100 E, 391200 N).
15. Mount Macedon, road cutting near the transmission tower. Weathered basalt. (Lancefield: 262200 E, 388650 N).
16. Melbourne Hill. 5·5 km from Romsey on the left side of the road to Lancefield. Basalt sampled from an abandoned quarry. (Lancefield: 277600 E, 398800 N).
17. Consolidated Quarries Pty. Ltd Newport. Irregularly jointed vesicular basalt sampled from the upper terrace of middle one of the three pits of the quarry. (Melb.: 291500 E, 333200 N). Two samples GA1021, GA1115 were dated; ages 2·49±0·15 and 2·50±0·20 My respectively.
18. Location nearly the same as 17. Basalt sampled from the lower terrace of the western flank of the quarry. (Melb.: 291500 E, 333200 N).
19. Abandoned quarry on the right side of the road to Geelong, 20 km S-W of Werribee. Very vesicular basalt sampled from the S-E side of the quarry. (Geelong: 253200 E, 311900 N).
21. Location nearly the same as for 20. Massive basalt sampled from the upper terrace on the northern wall of the quarry. (Geelong: 237700 E, 296050 N).
22. Fyansford Quarry, Fyansford. Irregularly jointed basalt sampled from the southern flank of the upper terrace. (Geelong: 237600 E, 295500 N).
23. Fyansford Quarry, Fyansford. Irregularly jointed basalt sampled from a lower terrace S-E of site 22. (Geelong: 237650 E, 295500 N).
24. Abandoned quarry, 1 km S-W of the cement factory in Fyansford. Columnar basalt sampled from the western flank of the quarry. (Geelong: 237400 E, 295000 N).
25. Abandoned quarry, 10 km NW-W of 24. Basalt sampled from the southern side of the pit. (Geelong: 226900 E, 295800 N).
27. Armitage Quarry (abandoned), Armitage. Fractured basalt sampled from the southern flank. (Colac: 196200 E, 278500 N).
28. Coleman's Quarry. Irregularly jointed basalt sampled from the southern flank. (Penmure: 563200 E, 276200 N). Two samples GA1064, GA1172 were dated; age 0.57 ± 0.03 My.
29. Belfastshire Quarry (abandoned) located at about 2 km, on the left side of the road, along Port Fairy-Hamilton Rd. (Port Fairy: 515200 E, 268450 N).
32. Quarry near Hamilton on way to Penshurst. Basalt sampled from the eastern flank. (Penshurst: 501550 E, 342400 N). One sample GA1065 was dated; age 3.91 ± 0.15 My.
33. Barrett Quarry, Ararat. Basalt sampled from the western side of the pit. (Ballarat, 1:250,000: 585500 E, 393900 N). Two samples GA1066, GA1174 were dated; age 3.55 ± 0.10 My.
34. Abandoned quarry near Gorrin Creek, Ararat. Basalt sampled from the southern wall of the quarry. (Ballarat, 1:250,000: 594270 E, 394920 N).
36. Location nearly the same as 35. Basalt sampled from the upper terrace of the western flank. (Ballarat: 189700 E, 365300 N).
37. Disused quarry near Dunnstown. Slightly weathered basalt sampled from the western flank. (Ballarat: 203400 E, 360750 N). One sample GA1023 was dated; age 2.53 ± 0.07 My.
38. Quarry (working) at Dunnstown. Massive basalt sampled from the northern side of the quarry. (Ballarat: 204800 E, 361600 N). One sample GA2095 was dated; age 3.90 ± 0.10 My.
40. Location nearly the same as 39. Basalt sampled from the northern side of the upper terrace. (Ballan: 248100 E, 341800 N).
41. Abandoned Quarry in the back yard of a meat factory (Gilbertson Pty. Ltd, Melbourne. Disjointed basalt sampled from the eastern side of the pit. (Melb.: 290900 E, 334700 N).
42. Quarry on the right side of the Geelong-Werribee Road, about 5 km NE-E of Werribee. Basalt sampled from the eastern flank of the quarry. (Melb.: 265100 E, 320600 N).
43. Merri Creek Quarry (abandoned). Columnar irregularly jointed basalt sampled from the southern wall near the bottom of the pit. (Melb.: 302400 E, 341500 N). Two samples GA1061, GA1171 were dated; age $2.20 \pm 0.07$ My.

44. Quarry (abandoned) near Yarra river in Alphington. Samples collected from the S-E side of the pit. (Ringwood, 1:50,000, 306900 E, 341300 N). Three samples GA1017, GA1060, GA1116 were dated; age $0.81 \pm 0.03$ My.

45. Stone quarry (abandoned) at the end of Station Street. Massive basalt sampled from the western side of the pit. (Ringwood, 1:50,000, 306500 E, 343300 N).

46. Albion Reid Fowlers Quarry, North Essenden. Basalt sampled from the N-W wall of the quarry. (Sunbury: 291800 E, 345700 N). Two samples GA1018, GA1062 were dated; age $4.50 \pm 0.15$ My.

47. Galli Quarry, Epping. Very vesicular basalt sampled from the N-W flank (Yan Yean: 304850 E, 354200 N).

48. McGrath’s Quarry, Duke Street, Braybrook. Massive basalt sampled from the eastern side of the pit. (Melb.: 289200 E, 341500 N). One sample GA1019 was dated; age $2.63 \pm 0.15$ My.