Chapter five

Field and laboratory methods

SYNOPSIS: Field methods applied at the Warrumbungle Complex are described, as is the interpretation of volcanic landforms from 1:50 000 scale aerial photographs of the shield. Various procedures for the reconstruction of original shield dimensions, and techniques for the extraction of diatom frustules (for the reconstruction of past environmental conditions from consolidated sediment) are described, or references are given where these are adequately dealt with elsewhere. The aim of the various techniques is the reconstruction of pre-volcanic landforms and volcanic morphology at cessation of activity, as well as post-volcanic landscape evolution.

5.1 General introduction

The description of the volcanic landforms identified in this study follows the more traditional classification of volcanic features which have been discussed in Chapter 3. Classification of volcanic features from aerial photographs is therefore based on the conclusions made in Chapter 3 and those definitions that appear in Table 1.1. Where these criteria were found to be insufficient, identification was supplemented with the categorisation of a number of features including presumed origin, shape and physical characteristics (particularly jointing structures and degree of erosion). These supplementary elements were particularly useful in separating lava domes from highly viscous lava flows, and crater remnants from residual erosional forms.

Topographic, geomorphic and morphological surveying was carried out over most of the shield (Figure 1.2) with the purpose of interpreting landforms from aerial photographs and ground truthing. Landform analyses, derived largely from aerial photographs and contour maps, were carried out for a number of reasons: to establish volcanic flow boundaries; to map the distribution and geographic associations of volcanic landforms, their morphology and drainage; and to locate sites of local erosion and deposition with the aim of determining stratigraphy and morphology. Exceptions occur in areas of extremely rugged terrain, and private property where access was denied. In these areas, the data obtained (lithological contacts, minor landforms) are largely extracted from aerial photographs and could not be verified in the field. In accessible areas the boundaries, morphology and stratigraphy of volcanic landforms were delineated, along with associated post-volcanic landforms, lacustrine and volcanigenic deposits. Much of this information was obtained from 1:50 000 scale aerial photographs (Land Information Centre 1979, 1992), the topographic maps listed in Section 1.3, the 1:250 000 Gilgandra geological map sheet (Geological Survey of New South Wales 1968), with further geological information extracted from maps produced by Hockley (undated) and the Coonabarabran Shire Council (1987). Interpretations derived from these sources was then confirmed by field observations.

5.2 The identification of volcanic landforms from aerial photographs

Among the methods of investigation that have directly and indirectly increased the capacity of geomorphology as a research tool, both in the laboratory and field settings, is the mapping of geomorphological features. An important technique that has improved geomorphological methods is the application of aerial survey methods (the applications and limitations of which are discussed in Appendix D). The interpretation of images taken from aircraft or satellites has made observations, and the study of the origin and relationships between landforms, more reliable. Among the many features of the natural landscape are a great variety of recurrent topographic shapes (landforms) of variable sizes which may be readily recognised and classified. These landforms may reflect the origin and composition of the materials they are constructed from, as well as the history of past weathering and erosion processes that have acted on them. Generally, larger topographic forms can be separated into smaller forms. Frequently these smaller forms may be used as diagnostic elements of identification for the interpretation of larger units. Commonly, smaller landforms are units of the landscape that:

1. contain a definite geomorphic framework with repetitive geological associations;
2. possess recurrent and typical ranges of geotechnical, hydrological, pedalogical and biological properties; and

3. have characteristic topographic, drainage, soil and ecological qualities.

In the Warrumbungle Complex it is possible to recognise distinct patterns from the study of aerial photographs which correspond to different volcanic flows or, more probably, groups of flows that are related. Fieldwork was used in this study to interpret flow relationships observed from aerial photographs. Aerial photographs were preferred for this study over satellite images for several reasons, including cost, availability and resolution especially since the ability to study micro-relief is severely limited by the resolution of images taken from orbital altitudes.

The aerial photographs used in this study consist of a series of 23 partially overlapping images covering the following areas:

Tenandra NSW 4072 Run 2 numbers 47, 49, 51, 53.

Coonabarabran NSW 3708 Run 2 number 167.

Coonabarabran NSW 3708 Run 3 number 126.

Tenandra NSW 4072 Run 3 numbers 1, 3, 5.

Tenandra NSW 4069 Run 4 numbers 262, 265, 267.

Coonabarabran NSW 3708 Run 4 numbers 114, 120.

Coonabarabran NSW 3708 Run 5 number 73.

Tenandra NSW 4069 Run 5 numbers 216, 218, 220, 222.

Coonabarabran NSW 3708 Run 6 numbers 62, 63, 65, 67 (Land Information Centre 1979, 1992).

The patterns observed in this coverage are reflected by the relative proportion of soil and rock and the density and height of tree growth (which are related to soil/rock ratios; Section 4.3.1). Alternatively, patterns and textures evident in aerial photographs may be associated with distinct landform elements (Section 4.4.3.1). The combined factors give an indication of lithology and morphology: where tree growth is tall and dense, the development of a soil profile or colluvium is indicated, suggesting the absence of exposed domes or flows. Other flow patterns may be revealed by their morphology. This includes relief, the form and sharpness of flow margins (for example, terracing), and the degree of dissection and drainage patterns (especially knickpoints).

Thus landscape analysis through aerial photographic interpretation was applied in the following manner:

1. landforms in the Warrumbungle Complex were identified and divided into major constitutional elements of the landscape. These elements included topography or type of landform, drainage, and erosional and depositional features; and
2. the size of different elements was studied, along with details of shape, pattern, texture, organisation and inter-relationships.

Within this analysis, the identification of volcanic landforms in this project is concerned with:

1. *static geomorphology* where emphasis is placed on actual landforms. Studies of static geomorphology are seldom purely descriptive. Studies of this type are basically a classification of relief and may encompass parameters such as slope gradient, degree of dissection and relief amplitude. No inference is made about causative processes in the past or the future;
2. *dynamic geomorphology* which is concerned with the processes and the short-term changes in landforms. Emphasis is placed on the active process of weathering, erosion, sedimentation and transportation over a non-geological time frame. Dynamic geomorphology emphasises the slow but continuous development of the landscape under the influence of everyday processes; and
3. *genetic geomorphology* which is concerned with the long-term development of relief. This aspect of geomorphic investigation requires extrapolation into the past (and, in some cases, the future). It is obvious that slow and almost imperceptible changes occur in the landscape over geological time. The synthesis of landform evolution

requires elements of dynamic geomorphology, as well as modern aspects of geomorphology such as climatic and structural geomorphology.

These three elements of geomorphology are used to produce an integrated account of the geomorphic evolution of the Warrumbungle Complex which considers individual landforms, the processes that contribute to their form, and the long-term development of the landscape.

5.3 Identification and morphology of crater-like features

A surprising aspect in the landscape of the Warrumbungle Complex is the preservation of four previously unrecognised crater-like features, hereafter called craters (more precisely, crater remnants). These landforms were identified from the investigation of aerial photographs and field morphology, and were subsequently named after the nearest significant landform feature. They are presented here as Milchomi, Salters Spring, Wheoh and Caraghnan Craters. Classification of the new features is based on similarities in morphology to the previously identified Crater Bluff (Hockley undated; Plate 3.1) and comparable morphological features arising from other Australian volcanic activity (for example, the Atherton craters, Queensland; and the craters and maars of the Newer Volcanics, Victoria). These new features also conform to the definition derived from discussion in Section 3.6.2. A fifth feature, the Hungerford Swamp Depression, exhibits crater-like morphology but does not conform to the classification model in Section 3.6.2. Another new landform (Black Mountain) is reported in this study and has been interpreted as a crater-fill lava, based on Ollier's (1967) interpretation of Mount Holden, Newer Volcanics, Victoria. The Black Mountain crater-fill differs in morphology from the new crater remnants, the details of which are reported in Section 6.4.2.6.

Calculations of morphometric parameters of crater remnants are based on those used by Hasenaka and Carmichael (1985) and Hasenaka (1994) where appropriate. However, when measuring landform dimensions in ancient landscapes, consideration must be given to the rate of erosional retreat, especially when crater walls are steep or composed of layered ash deposits. If this is the case, then the crater may become enlarged to several times the vent diameter (Twidale and Campbell 1993; Section 3.6.2).

Unlike similar methods applied on remnants of Quaternary cinder cones (Hasenaka and Carmichael 1985), the crater remnants preserved in the Warrumbungle Complex are highly eroded. This has several implications. Because conical shape is assumed in calculating volume, the deviation of the actual shape from conical will cause the greatest error. Deviations may include disintegrated shape caused by erosion, elongated shape caused by inclined basement surfaces or uneven deposition of airfall deposits, and convex or concave profiles. As such, estimates may be either above or below the true volume, but should lie within the same order of magnitude. The dimensions of crater remnants (and their associated flows) were obtained from 1:50 000 topographic maps. These dimensions include minimum vent height (H), crater diameter (W_{cr}) and cone basal diameter (W_{co}). Cone slope was not measured because they were obscured by spoil or partially buried by volcanic material (Figure 5.1). H is the difference in elevation between the summit of the crater rim and the base of the cone. W_{cr} and W_{co} are defined as the mean of the maximum and minimum values of the cone and crater widths. If the ratio between H and W_{cr} (D) varies greatly, this will give an estimate of the relative rate of change of the dimensions of the cone. However, this will only be an accurate measure if major erosional processes such as long-term denudation; landslides or partial burial from other eruptions have not modified the shape of the volcanic cone. The basal elevation of the cone is taken to be the mean of the highest and lowest basal values. The basement is the Pilliga Sandstone or underlying, older volcanic material. All craters and their associated features were clearly visible on the relevant topographic maps and aerial photographs. Once these values were established, the volumes of symmetrically truncated cones were calculated.

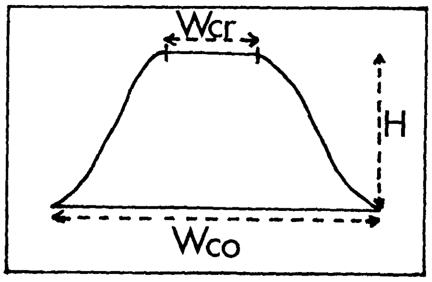

Figure 5.1: Schematic diagram representing the parameters used to estimate the current size of crater remnants. *Source*: Hasenaka and Carmichael 1985.

5.4 Calculations of remnant lava flow dimensions

The flow boundaries of the lavas preserved in the Warrumbungle Complex, delineated from aerial photograph interpretation and ground truthing, were drawn onto the Tenandra, Bugaldie, Binnaway, Gilgandra, Tooraweenah and Coonabarabran 1:50 000 contour maps from information extracted from 1:50 000 aerial photographs and field observations. In some cases, it is possible to trace a flow to its source vent based on field relations and aerial photograph interpretation. The average flow thickness (m), width (m) and distance (km) from the source vent were calculated from the contour maps and field measurements. Thickness measurements were made at equal intervals along the flow margins, and then averaged. When the thickness was less than the distance between contour intervals, the distance between the contour intervals was divided into 5 m divisions in order to provide a reasonable estimate of thickness. Flow width is presented as the maximum width of each eroded flow in the mapped sequence. Estimates of width have not been made for those flows mapped which have their boundaries partially obscured by overlying flows, as it is impossible to determine the location of their margins. Flow distance is the distance from the designated source vent to the end of the flow. Flow distance is not straight and has been calculated by measuring the distance along the centre of the flow. Note that the measurement of the length of flows may be limited if the end of the flow is obscured by the presence of overlying or adjacent flows and may also be underestimated because of the accumulation of colluvium at the foot of flow margins and later alluvial deposits surrounding the lava flows. Flows may also be discontinuous as a result of erosion, and their length may therefore be underestimated. Thus, measurements may record minimum flow distances from their source.

Flow area (km^2) and volume (km^3) were calculated using PLANIMETER, a computer program designed to calculated area and volume from mapped data. For the basal flows that have been delineated and appear to have their boundaries partially obscured by overlying flows, the extent of the boundary has not been extrapolated from existing boundaries for the reasons outlined above. The flow volume is the measured volume that the flow remnants fill in km^3. Volumes of lava flows whose margins were clearly observable from aerial photographs (scale 1:50 000) were calculated by determining their thickness from the nearest contour interval (20 m; see above). The volume of each flow unit was then calculated from its average thickness and area. The volume of lava flows hidden by subsequent flows was not estimated and lava thickness may be underestimated because of alluvial and colluvial deposition at flow margins. Generally, volumes will provide underestimates of flow volumes because of the above mentioned factors, but they at least give worthwhile minimum figures for flow volumes.

5.5 The morphology of the sub-volcanic basement

5.5.1 The updoming of pre-volcanic topography

Large terrestrial volcanoes are often underlain by a dome in the bedrock due to intrusive activity which probably inflates the basement under the centre of eruption, since it is unlikely that volcanoes could consistently erupt on pre-existing domes (Wellman 1986, Ollier 1988). The directional properties of sedimentary rocks (palaeocurrent direction) is especially useful for determining the direction of initial dip or palaeoslope of a rock unit in order to determine the regional and localised effects of volcanism.

In general, every clastic structure that has directional properties (palaeocurrent) will show a preferred rather than random transport direction (Potter and Pettijohn 1963). The variability of the palaeocurrent directions can usually be assessed with a preliminary sample of several outcrops, and then comparisons with previously published studies can be made. If similar directions are observed, then these can be added and a widespread coverage obtained. While palaeocurrent studies usually involve vector mean and variance analysis (using methods such as the F-test), this study required only measures of dip and direction of dip which would vary from regional average palaeocurrent direction if the sedimentary basement was disturbed by the emplacement of igneous materials. Therefore, statistical analysis is not warranted here because of the small sample size and the fact that crossbedding is not the primary concern of the measurements.

In the Warrumbungle Complex, both Triassic (Purlawaugh Beds) and Jurassic (Pilliga Sandstone) sediments outcrop in association with mid-Miocene igneous intrusions where erosion has removed overlying volcanic material. By determining the extent of the effects of the Warrumbungle intrusion on the essentially flat-lying Pilliga Sandstone and Purlawaugh Beds, it is possible to determine the original height of the Warrumbungle Complex summit above local base level by taking into account the possible effects of updoming. For this reason, the amount and direction of tectonic disturbance was measured wherever sedimentary material was found in close association with volcanic rock. Further measurements were made away from major intrusive bodies to provide a regional base level which may indicate general trends in regional and local updoming.

Therefore, a total of 98 dip and dip direction measurements were made from 29 localities in and around the Warrumbungle Complex. These *in situ* measurements were made using a compass-clinometer. The number of dip and directional measurements required to determine the average dip and direction of dip for each outcrop of basement sediment depended on the variance of directional data within each particular directional structure. The measurements made in this study found that directional variance was in the order of 10 to 30°. The more variable the structure, the more measurements that are required to obtain a reliable mean.

5.5.2 The sub-volcanic surface

A map of the sub-volcanic surface was compiled from field observations, aerial photographs, contour maps, existing geological maps, and scattered information in the literature. This was undertaken in order to establish the nature of the pre-volcanic topography and its influence on subsequent morphology. The fieldwork, based on Galloway's (1967) method of determining sub-volcanic contours, consisted of mapping the extent of igneous outcrop and fixing the altitude of the base of the volcanics by contour map. The reliability of the map varies and depends on the frequency of igneous outcrop and the clarity of contact between the volcanic and sub-volcanic surface. In some areas, the quality of the data does not encourage extrapolating form lines, although it was possible to draw form lines at most 20 m contour intervals which were then used to interpret the generalised nature of the pre-volcanic surface.

The biggest problem in preparing the map was to identify the true base of the volcanics. Generally, the sub-volcanic contact was obscured by rubble or thin soil which extended up to 1.5 m below the outcrop boundary. For example, on the western slopes of Mount Exmouth and in the north of the shield, it was virtually impossible to establish the true contact due to thick debris loads. The best exposures were found at the bases of cliffs, where debris had stabilised, whereas contacts in creek beds and valley bottoms were obscured by slump material. Where lavas rest directly on the sedimentary rock, the contact was marked by a horizontal shelf cut into the softer underlying rock.

Further information about the nature of the sub-volcanic surface was determined by plotting the position and altitude of summits without volcanic cover, and using analogies from the present land surface immediately to the north of the volcanic pile. The resultant map shows remarkable similarities to the morphology of analogies used, showing mesa-like hills separated by steep cliffs and broad valleys. Using these methods, fixing the altitude of the sub-volcanic surface with an accuracy sufficient for the present purpose was relatively straight forward once the true contact was established.

5.6 Drainage reconstructions

Longitudinal river profiles were constructed to analyse river gradient regimes to search for evidence of drainage diversion and drainage alteration caused by the emplacement of the various elements of the Warrumbungle Complex. Profiles constructed from 1:50 000 topographic maps were considered to produce enough detail to reveal points of interest that have bearing on the geomorphic development of streams and their tributaries. Long-river profiles may be diagnostic of the processes of valley development. For example, knickpoints revealed in a long profile may reflect lithological control on valley development and rates of stream incision (Hack 1957). In other localities, interpretations of drainage alteration were made from aerial photographs and field surveys, where morphological evidence of diversion/alteration was evident through processes of dome emplacement and relief inversion (Section 3.8.1).

5.7 Reconstruction of volcanic features

The reconstruction of volcanic features from topographic maps and aerial photographs has largely been based on the extrapolation of slope angles, of crater slope angles and slope angles of lava flows. As a comparison, field measurements of mapped data were made to estimate the reliability of reconstruction techniques, as well as to supplement reconstructions. While the most valuable indication of the constructional form of the original shield lies in the preservation of remnant planeze surfaces (Section 3.8.2), the Warrumbungle Complex is deeply dissected and does not contain any well preserved planeze surfaces. However, assuming that the more distinctive slope surfaces preserved in the Warrumbungle Complex are representative of the old volcanic surface, they should exhibit a fairly consistent decreasing slope outwards (for example, Plate 5.1). Furthermore, they should be directed towards a central focal point. In addition, they should be in reasonable conformity with angles of dip of lavas and pyroclastics radiating from the centre of the shield. To test the validity of these map and photographic reconstructions, comparative gradients of residual mountain and skeletal stages of shield dissection were made in the field. Appropriate slopes were identified from aerial photographs and located on topographic maps. The absolute elevation was then graphed against horizontal distance. Elevations were taken from the topographic maps that gave approximations of true constructional surfaces, with allowances made for irregularities along the slope profile. Slope profiles were extrapolated across a distance comparable to 1/8 of the present average shield radius (four kilometres), towards the supposed shield centre to determine whether the form and elevation of the original shield foci could be obtained. This distance, upon experimentation, was found to be the most reliable since larger radii produced too broad an interpretation of the original shield elevation and the location of the focus. However, due to the ovoid shape of the shield, such reconstructions will be associated with a small error since they do not conform to the geometry of true cones. These field measurements are expected to differ slightly from planeze surface approximations as planeze surface approximations reflect the angle of dip of the higher constructional surfaces which represent major shield forming flows.

Plate 5.1: An example of a partially preserved planeze surface in the Warrumbungle Complex. Mount Exmouth (1206 m), composed of interbedded trachyte and basalt lavas and pyroclastics, decreases in altitude away from the shield centre to an elevation of 400 m. Dissection of the original planeze surface is evident where the headward retreat of streams has cut into the interfluve surface, reducing the height of the original surface (for example, Section 3.8). *Photo*: A. Timmers.

With regard to the use of idealised planeze surface for the reconstruction of the Warrumbungle Complex, it has been observed that the streams draining the flanks have evolved by eroding headward into the interfluve surface. The result is that the planeze surface will be preserved until the headward erosion alters the planeze surface into a thin ridge. As such, the planeze will represent a constructional surface until the ridge is breached, whereupon it will suffer a loss in elevation. This translates into shallower slope angles measured in the field. In the field, three to five slope measurements were made per slope depending on the degree of slope preservation, in order to compare reconstructions with actual field conditions.

These reconstructions have several limitations. Minor erosion and resultant undulations in surface elevations cannot be detected or compensated at on such a scale. It is also assumed that the original shield surface had a consistent radial slope, although some convexity or concavity of the shield's focal surface would be expected. Such a surface is preserved on the less eroded Hawaiian shields, but it is felt that any variation in slope with resulting decrease or increase in elevation of the Warrumbungle Complex shield focus is compensated for by the radial limit of accuracy in the values calculated.

There are other problems associated with these reconstructions. It is important to consider that the cumulative effect of continuous or discontinuous processes in a given geological interval, may have resulted in significant changes in landforms. However, these changes may be masked by the progressive effects of the various geomorphological processes that are normally slow and imperceptible over such a time scale. Differential rates of erosion within the complex will reduce the reliability of reconstructions. In addition, the extent of updoming of the Pilliga Sandstone, if any, needs to be taken into account (Section 5.5.1).

Estimates of the original area and volume of erupted materials have been made from reconstructions made on the principles outlined above. The difference between past and present shield volume and area can then give an indication of the amount of erosion that has taken place since cessation of activity.

5.8 Diatom and pollen sampling for palaeoenvironmental analysis

The selection of methods for palaeoecological analysis in this study was designed to render the most accurate and extensive palaeoenvironmental information from compositionally variable clastic material integrated in the diatomite deposit at Wandiallabah Creek. As palaeoenvironmental analysis is a subsidiary aspect of this study, the methods used in diatom analysis are described at length in Appendix E rather than the main thesis. Laboratory techniques and treatment of the data were adapted from the more standardised diatom frustule extraction processes discussed in the literature. The principal aim of diatom analysis is the reconstruction of depositional environmental conditions coincident with volcanic activity. Subsidiary evidence from pollen analysis was also used in this study to support palaeoecological interpretations. The palaeolimnological applications of diatoms has been discussed in Appendix B.

5.8.1 Site selection

Site selection has been discussed in Section 4.4.3.7.

5.8.2 Bulk sample preparation

The site was logged before sample collection. For logging, a one metre wide column was established which contained the most continuous vertical column of diatomite. Each side of the column was bound by a tape measure pegged at the base and top of the outcrop. Logging involved the description of texture, contacts, particle size, sedimentary structures and fossils within the sample column. Significant geomorphic features outside the column such as channel scour, leaf imprints and root casts were also noted.

After logging, lump samples were cut from the outcrop using a portable quick cut saw. This involved cutting two vertical slashes into the face of the deposit, and then joining them with horizontal cuts at intervals of approximately 0.5 m. These horizontal cuts were positioned so as to preserve major stratigraphic features and contacts. The lump samples of diatomite were then prised out using a cold chisel and lump hammer and carefully laid on the ground in sequence. These lumps were placed back in their cuts one at a time where their height above an arbitrary datum was determined, with their actual heights determined trigonometrically in the laboratory. The lumps were carefully labeled and placed in large plastic bags to avoid contamination. Each bag was labeled A to K and their stratigraphic sequence recorded in a notebook.

5.9 Data presentation

5.9.1 Geomorphic data

The study of landforms, their structure and development, requires the need to graphically display the findings of an investigation and the character of the landforms investigated. As such, the results of these analyses were compiled in a series of maps, cross-sections, annotated aerial photographs and diagrams to extract information on landscape development in terms of the origin (genesis), form (morphology) and composition (stratigraphy) of the Warrumbungle Complex. From these data, an account of the evolution of the shield could be made within a joint chronological and geomorphic framework.

5.9.2 Fossil diatom diagram construction

In the preparation of this diagram, all diatom taxa recorded were included in the sum from which the percentage representivity of each taxon was expressed. However, taxa from which no potential information could be drawn were excluded from discussion. Such exclusion was beneficial for two reasons: it helped eliminate species which, when analysed, contributed little to the discussion, and helped ensure that the inclusion of species transported from elsewhere would not be considered. The fossil diatom diagram is presented in the standard manner (Battarbee 1986).