crystals (20 to 28 modal percent) ranging up to about 5 mm in size (Fig. 6.7f), and altered ferromagnesian and opaque grains (totalling less than 5 modal percent). The groundmass is typically microcrystalline and composed of aligned feldspar laths, though spherulites in some samples indicate formerly glassy groundmass. The massive porphyry is restricted to the southeastern part of the Complex where it is between 70 and 170 m thick. Volcanic breccias made almost exclusively of block-sized fragments of plagioclase porphyry immediately overlie the massive porphyry facies in upper Coombadjha Creek (GR363424 Coombadjha).

Pi Pi Ignimbrite

The Pi Pi Ignimbrite is a black, originally densely welded dacitic ignimbrite with a characteristically well-developed foliation of platy, grey relic pumice fragments (Figs. 6.7g,h). It is relatively crystal poor, having less than 25 modal percent crystal fragments (plagioclase and an altered ferromagnesian mineral; Figs. 6.6,6.8a) which are generally less than 2 mm in maximum dimension. Angular lapilli (less than 3 cm across) of volcanic rocktypes are sparsely distributed throughout the unit. Pumice fragments are commonly almost two-dimensional, ranging up to 25 cm in diameter, and in sections normal to the planar foliation, they have length to thickness ratios in excess of 30:1. The longer dimensions of prismatic plagioclase grains and of flattened devitrified matrix shards are parallel to the planar foliation defined by the relic pumice (Fig. 6.8a).

No mappable variations in original welding textures have been identified in the Pi Pi Ignimbrite, indicating that it constitutes a single simple cooling unit (*cf.* Smith, 1960a,b; Christiansen, 1979). With the exception of concentrations of angular volcanic lapilli near the base of the unit (e.g. GR350425, GR370425 Coombadjha), vertical sections display minimal internal textural variations and any flow unit boundaries are evidently masked by the consistently thorough welding. Only two exposures of lithic rich zones have been found higher in the ignimbrite (e.g. GR381495, GR284457 Coombadjha). The latter occurrence has clasts up to 15 cm across.

Thickness and distribution

The maximum reliable thickness of 300 to 320 m occurs along a southwest-northeast transect, from exposures around Pheasant Creek to lower Washpool Creek and upper Retreat Creek (Figs. 6.2,6.3). Inside the southeastern margin, very steep dips in the Pi Pi Ignimbrite imply apparently greater thicknesses (more than 500 m) but the sequence is probably repeated by faults. The Ignimbrite thins northward from 300 m in Retreat Creek to approximately 50 m in OBX Creek, a distance of 5.5 km, and lenses out completely within a further 2 km. Thickness variations over the southeastern sector of the Complex are marked, involving the full range from over 300 metres to zero, commonly within distances of less than 3 km (Fig. 6.3). These variations are a function of the relief of palaeo-landforms constructed by the underlying unit (Hianana Volcanics): Pi Pi Ignimbrite consistently thins on the flanks and pinches out at the crest of the thick pile of Hianana Volcanics (around GR378450 Coombadjha). Although the palaeo-topographic control on the distribution of Pi Pi Ignimbrite in the southeast is unmistakable, changes in its thickness are more systematic and gradual away from this area, and reflect comparatively subdued relief over the remainder of the Complex at the time of emplacement. In the northern and western parts of the Complex, beyond the limits of deposition of Hianana Volcanics, Pi Pi Ignimbrite directly overlies Pheasant Creek Volcanics, with no sign of angular discordance.

Pumice foliation

The pumice lapilli foliation is in general a reliable indicator of bedding, being parallel to the outcrop pattern of the boundaries of the unit. However there are local anomalies where the attitude of the foliation changes over short distances and is not consistent with the nearest contact surfaces (e.g. near GR373446, GR368448, GR317447 Coombadjha). The extreme length to thickness ratios of the pumice indicates that the shape is the result of stretching in addition to flattening by elimination of pore space (*cf.* Smith, 1960a; Ross and Smith, 1961; Ratté and Steven, 1967; Schmincke and Swanson, 1967). On uncommon exposures of surfaces parallel to the foliation plane, pumice fragments are ellipses, the longer axes of which define a lineation (e.g. 075°-255° at GR354506

Washpool). These features are probably the result of rheomorphism, that is, secondary mass flowage of the pyroclastic flow deposit during welding, immediately following emplacement (Ratté and Steven, 1967; Wolff and Wright, 1981). Also, most examples of foliations that deviate from bedding-parallel attitudes occur in the southeastern sector of the Complex, where the Pi Pi Ignimbrite overlies and thins onto the Hianana Volcanics which had significant positive constructional relief. Thus, it is likely that the Pi Pi Ignimbrite in this area was deposited on slopes, a circumstance considered important in the initiation of secondary mass flowage (Wolff and Wright, 1981).

Assessment of the possible role of primary flow processes in producing these features (*cf*. Schmincke and Swanson, 1967; Chapin and Lowell, 1979) requires systematic mapping of flowage structures and of pumice lineations, ideally with reference to a known source. The paucity of suitable exposures in the Pi Pi Ignimbrite precludes such an evaluation. However, there are no examples of imbricate pumices, and although two-dimensional platy pumice is ubiquitous, other flowage structures are restricted in occurrence and generally uncommon. It is concluded that stretching of pumice in the Pi Pi Ignimbrite was induced by generally slight but widespread rheomorphism, although the effects were locally more exaggerated where the Ignimbrite was emplaced on slopes.

Babepercy Volcanics

The Babepercy Volcanics consist of two rocktypes: bedded volcaniclastic rocks, and fine grained silicic porphyry. Both facies are quartz-bearing, pervasively altered and mainly confined to an area of less than 2 km^2 in upper Babepercy Creek (Fig. 6.2). Other isolated outcrops of similar lithologies nearby in the southwestern part of the Complex are included in this unit, increasing the extent to 4 km^2. In the best exposures (around GR308450 Coombadjha) the unit is about 100 m thick, half of which is silicic porphyry that overlies the bedded volcaniclastic rocks.

Silicic porphyry

The silicic porphyry is very sparsely porphyritic with less than

Figure 6.8: a. Photomicrograph of the Pi Pi Ignimbrite, showing plagioclase crystal fragments (f) and relic pumice (p) set in a matrix of poorly preserved welded shards. R55443, plane polarised light.

b. Photomicrograph of a bedded volcaniclastic sample of the Babepercy Volcanics. Most fragments are relic feldspar or lithic (l) clasts. R55447, plane polarised light.

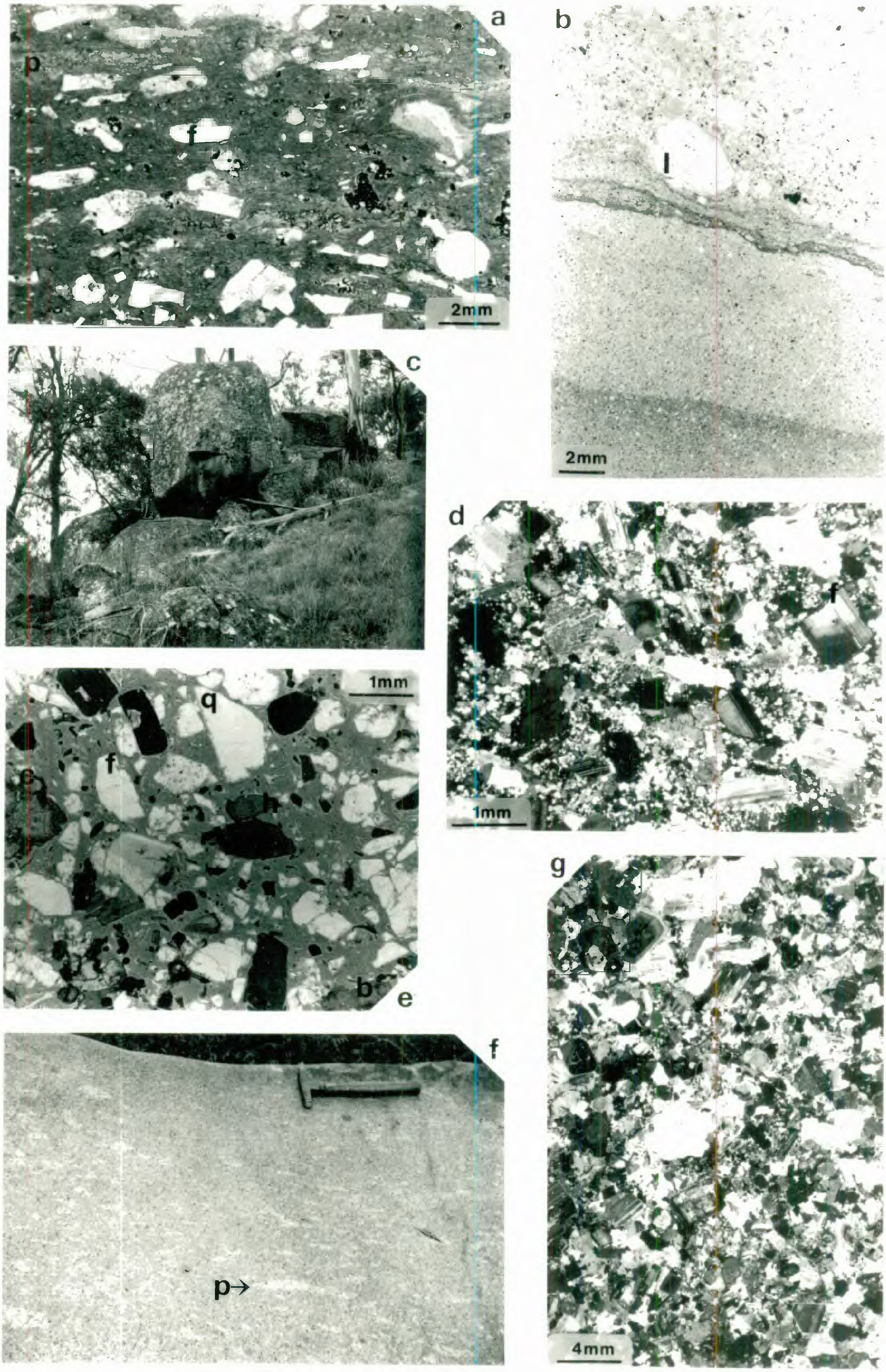
c. Outcrop of the Normal facies ignimbrite of the Dundee Rhyodacite. Hammer 33 cm. GR28245545 Washpool.

d. Photomicrograph of the Normal facies ignimbrite of the Dundee Rhyodacite. The matrix consists of a microcrystalline mosaic of quartz and feldspar. Note the truncated zoning of the plagioclase fragment (f). R55467, crossed nicols.

e. Photomicrograph of a sample from near the base of the Normal facies ignimbrite of the Dundee Rhyodacite. Crystal fragments of quartz (q), plagioclase (f), hornblende (h), biotite (b) and clinopyroxene (c) are set in a matrix containing welded devitrified shards. R55487, plane polarised light.

f. Boulder of the Normal facies ignimbrite of the Dundee Rhyodacite with comparatively conspicuous lensoid relic pumice (p). GR39454915 Coombadjha. Hammer 33 cm.

g. Photomicrograph of the Moonta Gully Adamellite. R55554, crossed nicols.


a
p
f
2mm
b
l
2mm
c
d
f
1mm
1mm
q
f
h
b
e
f
p→
g
4mm

about 5 modal percent phenocrysts of quartz and indeterminate feldspar set in a structureless, microcrystalline, presumably felsic groundmass. Pervasive recrystallisation and alteration have obliterated details of the primary texture and mineralogy, quartz crystals being the only exception. The alteration minerals are very fine grained, and include sericite, pyrite and other sulphides, quartz, and traces of prehnite. Most exposures display closely spaced joints or more irregular fractures, and appear to be massive though faint flow banding is recognisable in places.

Bedded volcaniclastic rocks

The principal components of the volcaniclastic rocks evident in outcrop are angular to subangular, pale and dark, very fine grained, dense (non-vesicular) lithic clasts and angular crystal fragments (quartz and altered feldspar). The pale lithic clasts are texturally similar to the silicic porphyry. As for the silicic porphyry, thin-section examination has not been rewarding and alteration is extreme.

Stratified intervals in the least altered exposures comprise equal, thin and very thin, laterally continuous and uniform beds. The grain size of these layers is generally finer than about 2 mm (Fig. 6.8b). Most have diffuse contacts and many appear to be well sorted and internally massive, or else show slight grading. Medium and thick beds of poorly sorted, lithic rich microbreccias and breccias are interbedded with the finer grained sequences.

Dundee Rhyodacite

The youngest unit of the Coombadjha Volcanic Complex is a blue crystal-rich ignimbrite which forms blocky-jointed outcrops and weathers into rounded tors (Fig. 6.8c). It is very similar in texture, modal mineralogy and chemical composition to the Dundee Rhyodacite (Flood *et al.*, 1977; Figs. 6.4,6.9, Tables 6.1,8.1), which is the name given to widespread crystal-rich ignimbrite overlying older volcanics west of the Complex from around Tenterfield in the northeast to Dundee in the southwest (Fig. 6.1). Regional geological maps (Pogson and Hitchins, 1973; Brunker and Chesnut, 1976) show a narrow strip of Dundee Rhyodacite

(Dundee Adamellite-Porphyrite) adjacent to the Demon Fault in the Coombadjha area; however it is in fact more extensive to the east (*cf.* Fig. 6.1). The Timbarra mass (Wilkinson *et al.*, 1964) on the western side of the Demon Fault is continuous southwards into the western part of the Coombadjha Volcanic Complex offset by the Fault from the main eastern part. Hence the blue ignimbrite of the Complex is here tentatively correlated with the Dundee Rhyodacite. It is acknowledged that the principal basis for this correlation, and for grouping the other masses of this rocktype (e.g. Wilkinson *et al.*, 1964), is lithological similarity.

Distribution and thickness variation

The Dundee Rhyodacite covers some 180 km² in the centre of the Coombadjha Volcanic Complex east of the Demon Fault. It forms a layer in excess of 500 m thick in the middle of the area (Figs. 6.2,6.3). Only thinner remnants are preserved above the older volcanic units closer to the margins of the Complex. Along the southeastern margin, it is intruded by the ring pluton of adamellite. In the north, the Dundee Rhyodacite unconformably overlies the ?Devonian-Carboniferous rocks and evidently originally extended beyond the present confines of the Complex. Its extent northeast from this area has not been established.

Throughout much of the Complex, the Dundee Rhyodacite directly overlies the Pi Pi Ignimbrite. However in parts of the southeastern sector it overlies the Hianana Volcanics where the Pi Pi Ignimbrite is missing, and in the north where both of these older units lense out, the Dundee Rhyodacite is underlain by Pheasant Creek Volcanics. Variation in the lateral extent of the older volcanic units is largely responsible for the apparently unconformable relationships between them and the Dundee Rhyodacite. Evidence of prior deformation of the older sequence is limited to the vicinity of pre-Dundee faults inferred from geological cross-sections (e.g. the Sugarloaf and Hianana faults, Fig. 6.2). Local angular discordance elsewhere at the base of the Dundee Rhyodacite may in part be attributable to primary dips in the underlying volcanics. The hiatus preceding eruption of the Dundee Rhyodacite was probably no more prolonged than those separating the emplacement of each of the older units. The general paucity of epiclastic units and particularly their absence immediately below the Dundee Rhyodacite support this conclusion.

Facies of the Dundee Rhyodacite

Good exposures of the lower levels of the Dundee Rhyodacite at many sites in the Complex have enabled internal subdivision into two mappable parts, each of which can be related to eruption stages and processes operating during emplacement (discussed in detail in Chapter 8). The lower and volumetrically subordinate Basal facies consists of four lithologies: ignimbrite, porphyritic dacite lava, bedded tuff and breccia. This facies occurs mainly in the north of the Complex where its aggregate thickness ranges from several to more than about 50 m. The upper 'Normal' facies is homogeneous, blue, crystal-rich ignimbrite which constitutes the bulk of the Dundee Rhyodacite in the Coombadjha Volcanic Complex. Only the Normal facies is described in detail below, and the Dundee Rhyodacite is undifferentiated on Figures 6.2 and 6.3.

Petrography of the Normal facies

Fresh crystal fragments (plagioclase + biotite + quartz + hornblende + pyroxene + magnetite ± K-feldspar) constitute more than 50 modal percent of the Normal facies ignimbrite (Figs. 6.8d,6.9). Equigranular clusters of fine and medium grained pyroxene + plagioclase ± hornblende ± biotite are ubiquitous but sparsely distributed, accounting for less than 2 percent of modes of most samples. At least one or two larger (up to about 10 cm) inclusions with the same mineralogy and texture are commonly evident in most exposures of the Dundee Rhyodacite. Flood *et al.* (1977) studied identical aggregates in the Dundee mass of the ignimbrite and concluded that they either represent refractory assemblages remaining after magma formation by partial melting, or are early formed crystal cumulates. Rock fragments of other types are mainly porphyritic felsic volcanics but are minor and only locally conspicuous. The ignimbrite matrix is totally devitrified and typically completely recrystallised to a microcrystalline mosaic of quartz and feldspar (Fig. 6.8d). Relic welded shards are preserved in many samples from near the base of the Normal facies (Fig. 6.8e).

Pumice fragments and flow units of the Normal facies

Former pumice fragments in the Normal facies appear as aligned, protruding, paler lenses on weathered surfaces, ranging up to about 30 cm across (Fig. 6.8f). They are more difficult to identify on fresh surfaces since the textures which distinguish them from the host ignimbrite are subtle: crystals in the pumice are euhedral, sparser and larger. The groundmass of the pumice and the matrix of the host ignimbrite are indistinguishable in handspecimen. Very little is known of the internal structure of the Normal facies of the Dundee Rhyodacite because it has not been possible to systematically map pumice foliations as has been done for all other ignimbrites of the Complex, including the ignimbrite of the Basal facies, due to the difficulty of detecting pumice in undisturbed outcrops.

No mappable discontinuities corresponding to either flow unit or cooling unit boundaries have been found in the thick (500 to 600 m) sections of the Normal facies in central parts of the Complex. The only conspicuous variation occurs within about three metres of the base, where there is a slightly finer grained, darker, more crystal-rich zone with pronounced alignment of crystal fragments and lacking in pumice. This is interpreted to be the basal shear layer of the Normal facies ignimbrite (Layer 2a, *cf.* Sparks *et al.*, 1973).

Moonta Gully Adamellite

All volcanic units of the Coombadjha Volcanic Complex are intruded by the Moonta Gully Adamellite, a ring pluton about 1 km wide separating the volcanics from the surrounding ?Devonian-Carboniferous rocks (Fig. 6.2).

Contacts

The map traces of the inner and outer contacts of the intrusion across areas of considerable relief show that both are near vertical. On the scale of single outcrops, the contacts are also steep or vertical, sharp and planar (e.g. with the volcanics GR357403 Coombadjha; with the ?Devonian-Carboniferous rocks GR406468 Coombadjha, GR394513 and GR376542 Washpool). Narrow (less than 1 m) dykes of adamellite extend from the intrusion into adjacent ?Devonian-Carboniferous rocks but have not been detected in the volcanics near the contacts.

Extent

For most of its extent the ring pluton forms a single wall of adamellite between the volcanics and the ?Devonian-Carboniferous rocks. However, in lower Coombadjha Creek and gullies immediately to the north, screens of volcanics and of the ?Devonian-Carboniferous rocks separate narrow, more dyke-like bands of adamellite. The continuity of the intrusion is interrupted for a 2 km arc along the southeastern edge of the Complex, and it is missing from the southwestern sector where the Triassic(?) Dandahra Creek Granite intrudes the Complex. Continuous outcrop of the intrusion also terminates south of Malara Creek. Farther northwest, the adamellite is exposed in several isolated patches that are probably connected subsurface, in which case the level of erosion in this area evidently coincides with the original roof of the pluton.

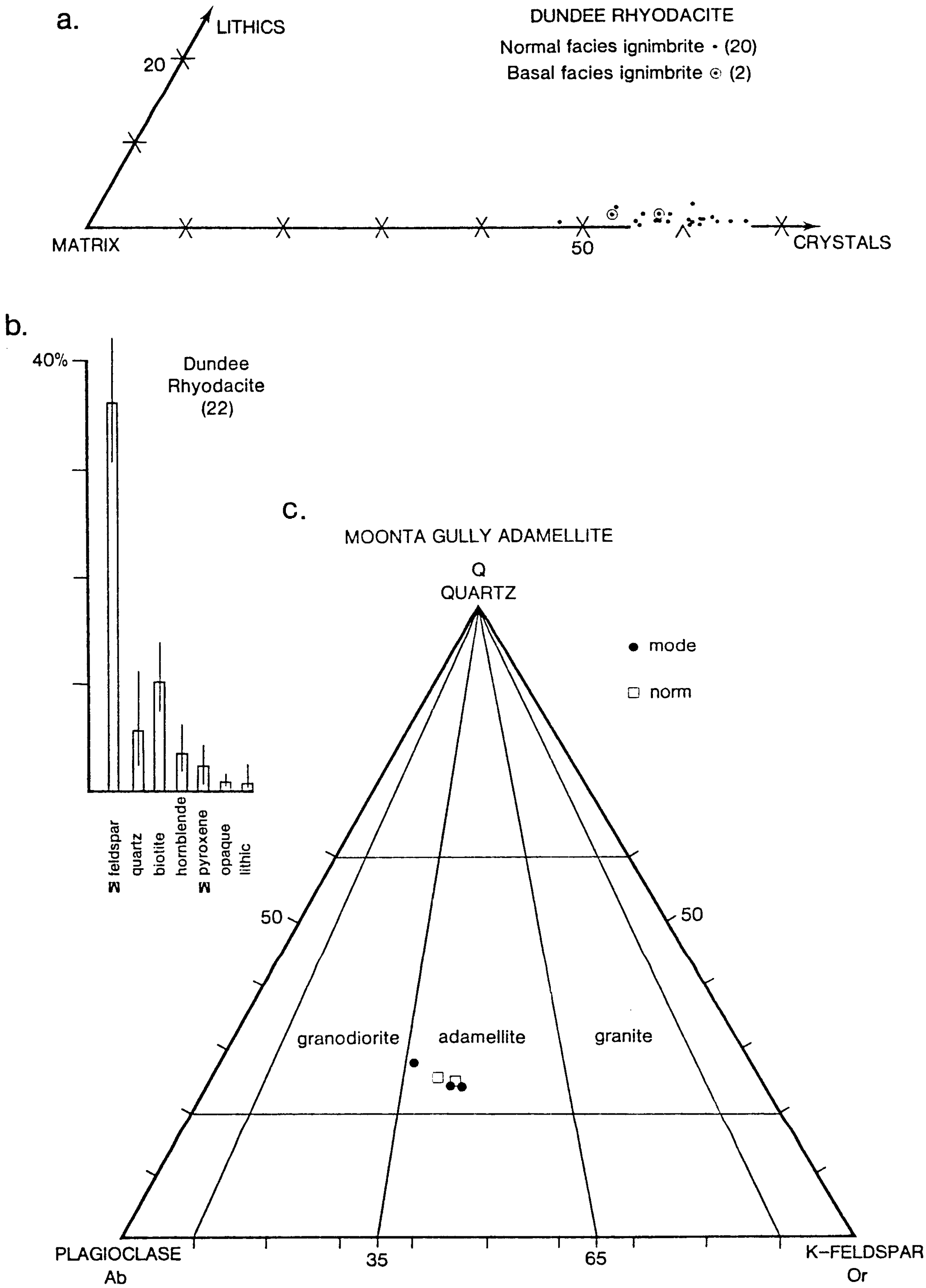
Petrography

The Moonta Gully Adamellite typically outcrops as massive grey boulders or bluffs. It is medium grained and composed principally of quartz, plagioclase, K-feldspar, brown biotite and green hornblende, with accessory sphene, apatite, zircon and an opaque mineral (Figs. 6.8g,6.9). Some thin-sections contain trace amounts of pyroxene partly replaced by hornblende. Feldspars and ferromagnesian minerals are commonly slightly affected by alteration to combinations of sericite, chlorite, calcite and epidote. The adamellite is porphyritic though it also displays equigranular and seriate textures. Zoned euhedral plagioclase is the main phenocryst phase of the porphyritic variants.

In most outcrops there are scattered, small (less than 20 cm), dark grey, fine to medium grained, equigranular, biotite-rich microgranitoid enclaves (*cf*. Vernon, 1983) with smooth and irregular outlines. At one exceptional locality (GR292622 Washpool), these enclaves are abundant and range up to 50 cm across. Metasedimentary and metavolcanic xenoliths occur near the intrusive contacts with the ?Devonian-Carboniferous

Figure 6.9: a,b. Modal data for the Dundee Rhyodacite (Normal facies only) of the Coombadjha Volcanic Complex. On the triangular diagram, 'lithics' includes equigranular aggregates and 'matrix' refers to recrystallised, formerly pumiceous components. The histogram gives the average (wide bar) and range (line) in modal percent of the different crystal fragment types. The feldspar is mainly plagioclase. In most samples, clinopyroxene is more abundant than orthopyroxene. The opaque mineral is principally magnetite. See Appendix B.

c. Modal quartz, orthoclase and plagioclase of the Moonta Gully Adamellite in relation to the subdivisions of Streckeisen (1976), retaining 'adamellite' for granitoids with subequal amounts of plagioclase and K-feldspar. See Appendix B. Normative *Q*, *Or*, *Ab* also shown for the two analysed samples, Table 6.1.


a.
LITHICS
20
MATRIX
50
CRYSTALS
DUNDEE RHYODACITE
Normal facies ignimbrite • (20)
Basal facies ignimbrite ⊙ (2)
b.
40%
Dundee
Rhyodacite
(22)
Σ feldspar
quartz
biotite
hornblende
Σ pyroxene
opaque
lithic
c.
MOONTA GULLY ADAMELLITE
Q
QUARTZ
• mode
□ norm
50
50
granodiorite
adamellite
granite
PLAGIOCLASE
Ab
35
65
K-FELDSPAR
Or

rocks (e.g. GR406468 Coombadjha) and the volcanics (e.g. GR357403 Coombadjha) respectively.

A granitoid pluton petrographically similar to the Moonta Gully Adamellite intrudes the base of the Dundee Rhyodacite and the older volcanics in a branch of OBX Creek in the north of the Complex (around GR300559 Washpool; Fig. 6.2). Disseminated sulphides (mainly pyrite) and quartz-chlorite veins are locally abundant in this intrusion and ferromagnesian minerals in the host are commonly extensively altered to chlorite-dominated assemblages.

Granitoid plutons of the Coombadjha area

Deeply incised creeks draining westward to the Timbarra River in the north of the Complex expose small granitoid intrusions which do not appear to be related to the formation of the Coombadjha Volcanic Complex. They may instead be members of a younger (Early Triassic) intrusive suite (the Leucoadamellite suite, Shaw and Flood, 1981) that occurs in the region, as is the Dandahra Creek Granite along the southwestern margin of the Complex, and the Billyrimba Leucoadamellite west of the Demon Fault System. Very little remains of the northern periphery of the displaced segment of the Complex west of the Demon Fault System (McPhie and Fergusson, 1983; Appendix A), as there the volcanics form a thin roof zone to the Bungulla Porphyritic Adamellite, a member of the Moonbi Plutonic Suite of Permian or Triassic age (Shaw and Flood, 1981).

A northeasterly trending set of vertical, fine grained, porphyritic flow banded silicic dykes near what remains of the western margin (around GR228749 Sandy Flat) intrudes both the Dundee Rhyodacite and the adjacent Bungulla Porphyritic Adamellite and hence post-dates the formation of the Complex.

STRUCTURE OF THE COOMBADJHA VOLCANIC COMPLEX

On a regional scale the Late Permian volcanic and sedimentary cover of the New England Tableland is generally only gently deformed (Leitch, 1974; Korsch, 1977) and is affected mainly by younger intrusions and later movements on faults. Hence the present configuration of the

Coombadjha Volcanic Complex can be reliably attributed to primary constructional processes and deformation attendant on the volcanic activity, and is not an artefact of regional tectonism. There are local qualifications relevant to this assumption: the Complex is intruded by younger plutons and is truncated by the Demon Fault System, both of which may have locally modified pre-existing volcanic structures. In addition, originally horizontal bedding cannot be universally assumed: primary dips of lava bodies and in pyroclastic airfall and surge sequences are known to be significant (e.g. Heiken, 1971; Crowe and Fisher, 1973; Korringa, 1973; Wright *et al.*., 1980; Wohletz and Sheridan, 1983) and may be important in some pyroclastic flows (ignimbrite veneer deposits of low-aspect ratio ignimbrites; Walker, Wilson and Froggatt, 1981; Walker, 1983). Bedding data from units comprising lava and related pyroclastic deposits (e.g. Hianana Volcanics in the southeast sector; Babepercy Volcanics in the southwest) probably include a substantial component of initial dip. However most of the structural information is based on measurement of foliations of flattened pumice fragments in welded ignimbrites, and the traces of ignimbrite unit boundaries, and thus should be largely free of interference by inherited primary dip.

The structure of the Coombadjha Volcanic Complex is described below in terms of the two most important features: the central, oval-shaped structural depression, and the faulted and intruded margin. There are also minor faults that locally complicate this arrangement.

The structural basin

Strikes of bedding in the volcanic units below the Dundee Rhyodacite curve through a 180° elliptical arc generally parallel to the outline of the Complex (Fig. 6.10). Bedding is near horizontal or else very gently dipping over much of the core of the Complex. Outward away from the central area, bedding consistently dips radially inward, progressively changing from moderate to steep and near vertical attitudes closer to the perimeter of the Complex. The structure so defined is that of an oval-shaped basin with a flat floor and steeply upturned (in the south and southeast) to moderately arched (in the northeast) rim.

Bedding data for the Dundee Rhyodacite are limited to measurements from the Basal facies which is mainly exposed in the north of the Complex. However structure contours constructed on the base of the Dundee Rhyodacite clearly define a similar basin morphology, essentially conformable with the structure defined by the underlying units (Fig. 6.11a,b). The Dundee Rhyodacite is preserved in the centre of the Complex because this area coincides with the centre of a structural depression. Remnants occur on, and locally beyond, the rim of the depression, indicating that the original extent was greater but has been subsequently reduced by erosion.

Relationships at the margin of the Coombadjha Volcanic Complex

The margin of the Complex changes in character from a ragged outline in the extreme north where the volcanics unconformably overlie the ?Devonian-Carboniferous rocks, to a smooth arc where it coincides with the near-vertical intrusive outer contact of the Moonta Gully Adamellite. The northernmost rim of the structural basin is in the form of an asymmetrical anticline in the volcanic units overlying the ?Devonian-Carboniferous rocks (Fig. 6.12, sections M,N,O). Within a kilometre farther south,the crest of the anticline is faulted (Fig. 6.12, sections L,K) and ruptured into segments with opposing steep dips. Within another kilometre southeast,the Moonta Gully Adamellite is exposed precisely along strike from the faulted arch at the basin rim (Fig. 6.12, sections J,H). The rest of the arcuate perimeter of the Complex is marked by an annulus of Moonta Gully Adamellite, clearly occupying the site of the faulted anticlinal crest which formerly encircled the entire structural basin (Fig. 6.13). Volcanics within the annular intrusion preserve only the inwardly dipping limb of the anticline and are downfaulted with respect to the surrounding ?Devonian-Carboniferous rocks. Where the intrusion is missing in the southeastern sector, the volcanics are in direct fault contact with the older sequence (Fig. 6.12, section F).

Minor faults

The southeastern quadrant of the Complex is structurally complicated by faults which are evidently unrelated to the marginal fractures. The best established example, informally named the Hianana fault, can be detected for only 3 km in a northwest-southeast direction, and involves

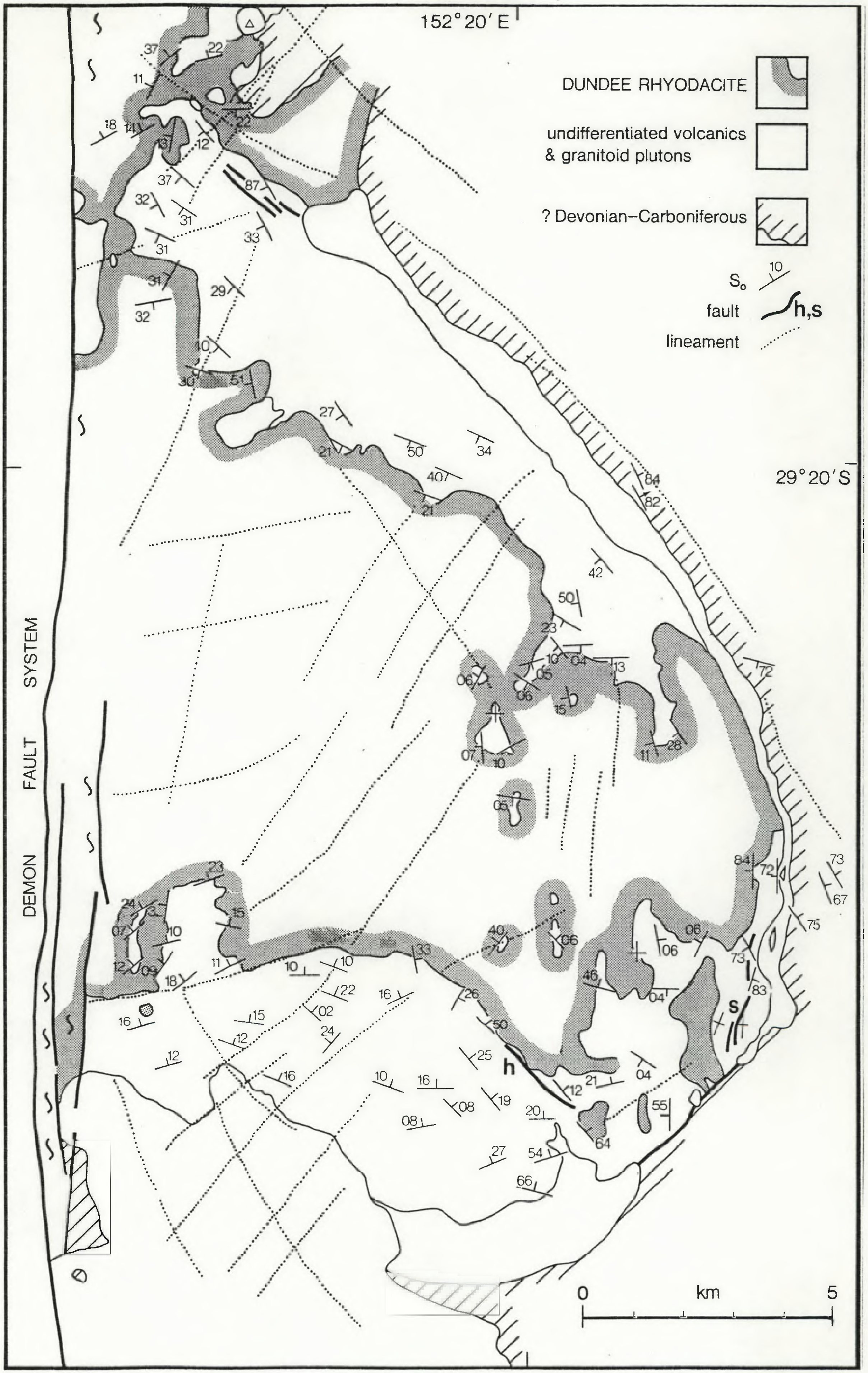


Figure 6.10: Map of the Coombadjha Volcanic Complex with most bedding readings, principal lineaments and faults shown. s, Sugarloaf faults; h, Hianana fault.

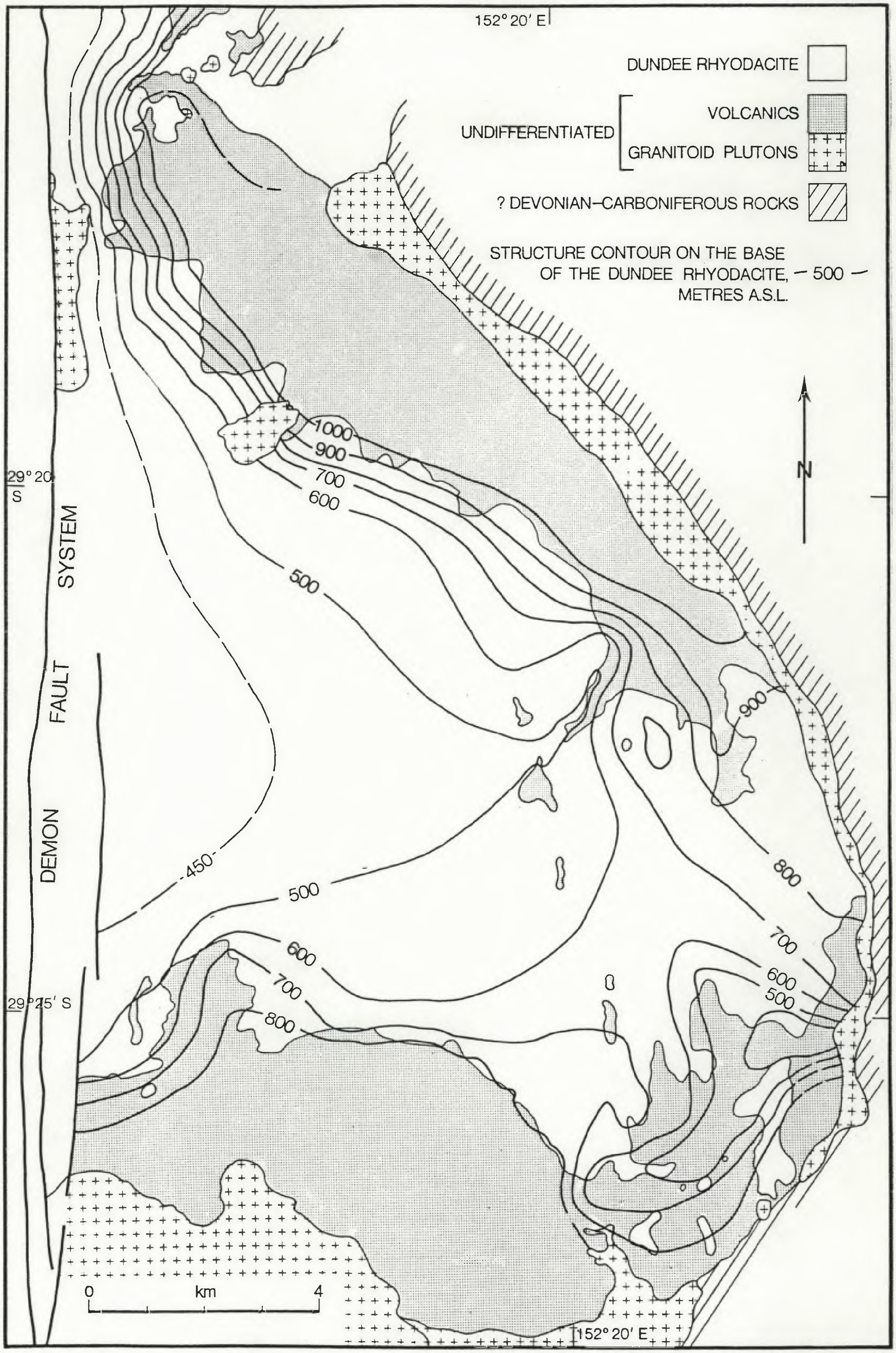


Figure 6.11: a. Structure contour map for the basal contact of the Dundee Rhyodacite of the Coombadjha Volcanic Complex.

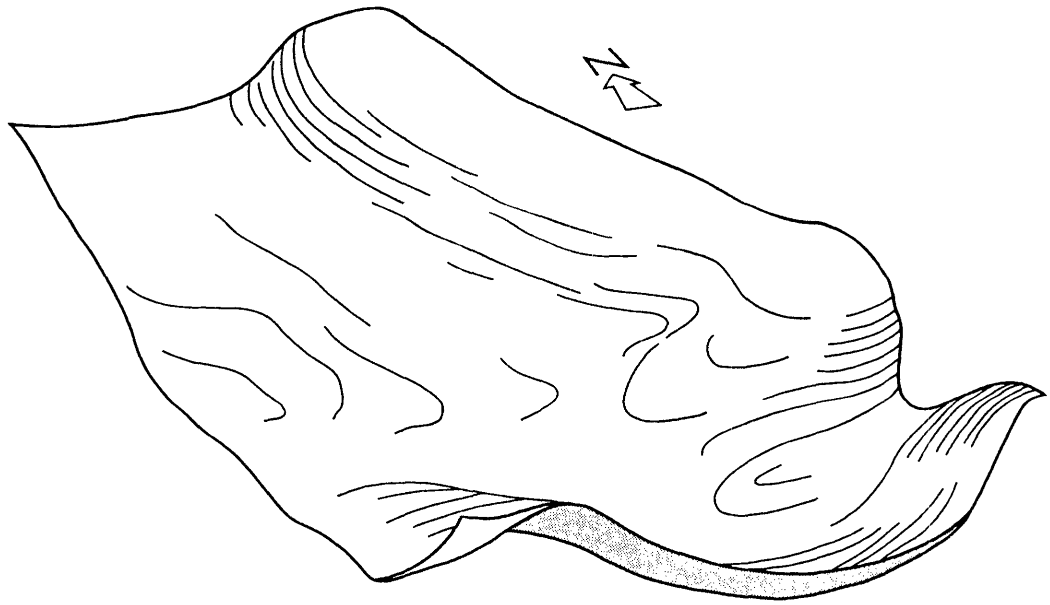


Figure 6.11: b. Sketch illustrating the shape of the basal contact of the Dundee Rhyodacite interpreted from the structure contour map (Figure 6.11a).

vertical separation of pre-Dundee Rhyodacite units of the order of 200 to 300 m (Figs. 6.10,6.12, sections C,D). The trace of the fault and the outcrop limit of the Dundee Rhyodacite are close and approximately parallel. Therefore, it is not possible to resolve whether the fault offsets (and postdates) the Dundee Rhyodacite, or else was originally covered by (and predates) the Dundee Rhyodacite which was later removed by erosion. Faults have been inferred in the volcanics close to the southeastern margin on either side of Coombadjha Creek,on the basis of repetition of units and marked changes in dip (Sugarloaf faults, Figs. 6.10,6.12, sections G,E). The location of the Sugarloaf faults and the separation shown are poorly constrained. The interpretation presented on cross-sections implies they are older than the Dundee Rhyodacite and covered by it (Fig. 6.12, section E). Both the Hianana and Sugarloaf faults displace a narrow outer block of volcanics downward relative to the main central area. This consistency in sense of offset provides meagre support for assuming a similar age and hence that the Hianana fault predates the Dundee Rhyodacite.

Lineaments

The overall shape of the Complex is reflected in lineament patterns evident from aerial photographs (Fig. 6.10). Lineaments within and adjacent to the ring pluton are approximately parallel to but not necessarily coincident with its contacts. The northeastern perimeter of the Complex is particularly well delineated, and is parallel to the northwest-southeast structural grain of the surrounding ?Devonian-Carboniferous rocks. The core of the Complex covered by Dundee Rhyodacite has fewer and more continuous lineaments than the adjacent older volcanic units. The most common directions (southeasterly and northeasterly) are parallel to the major and minor axes of the approximately elliptical shape of the Complex. An exceptional area of 4 km^2 just east of Washpool Creek displays a strong, regularly spaced north-south lineament set and is apparently a large-scale expression of jointing in the ignimbrite. Lineaments in older volcanic units surrounding the Dundee Rhyodacite are of a wide range of orientations but many are radial from the core of the Complex.

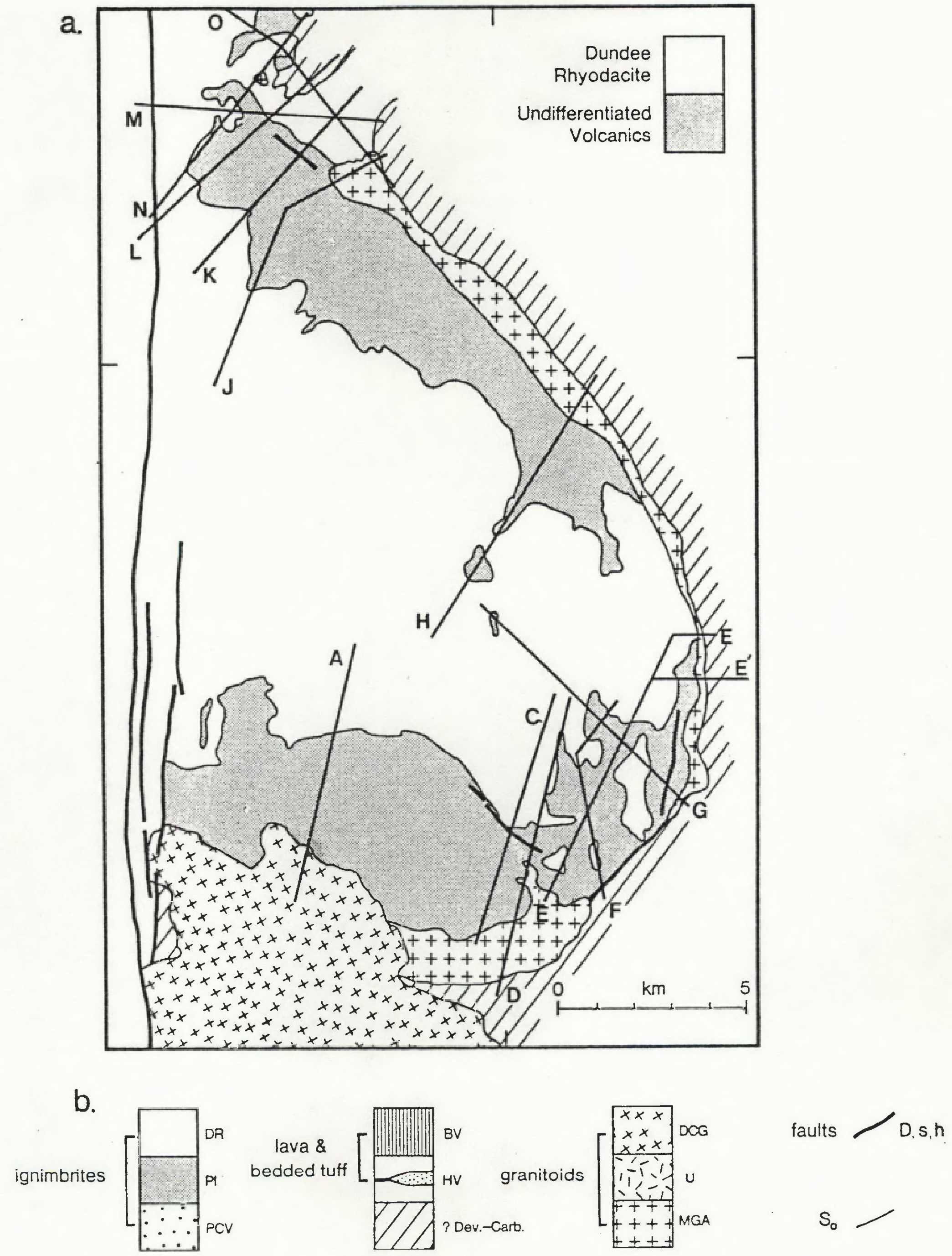


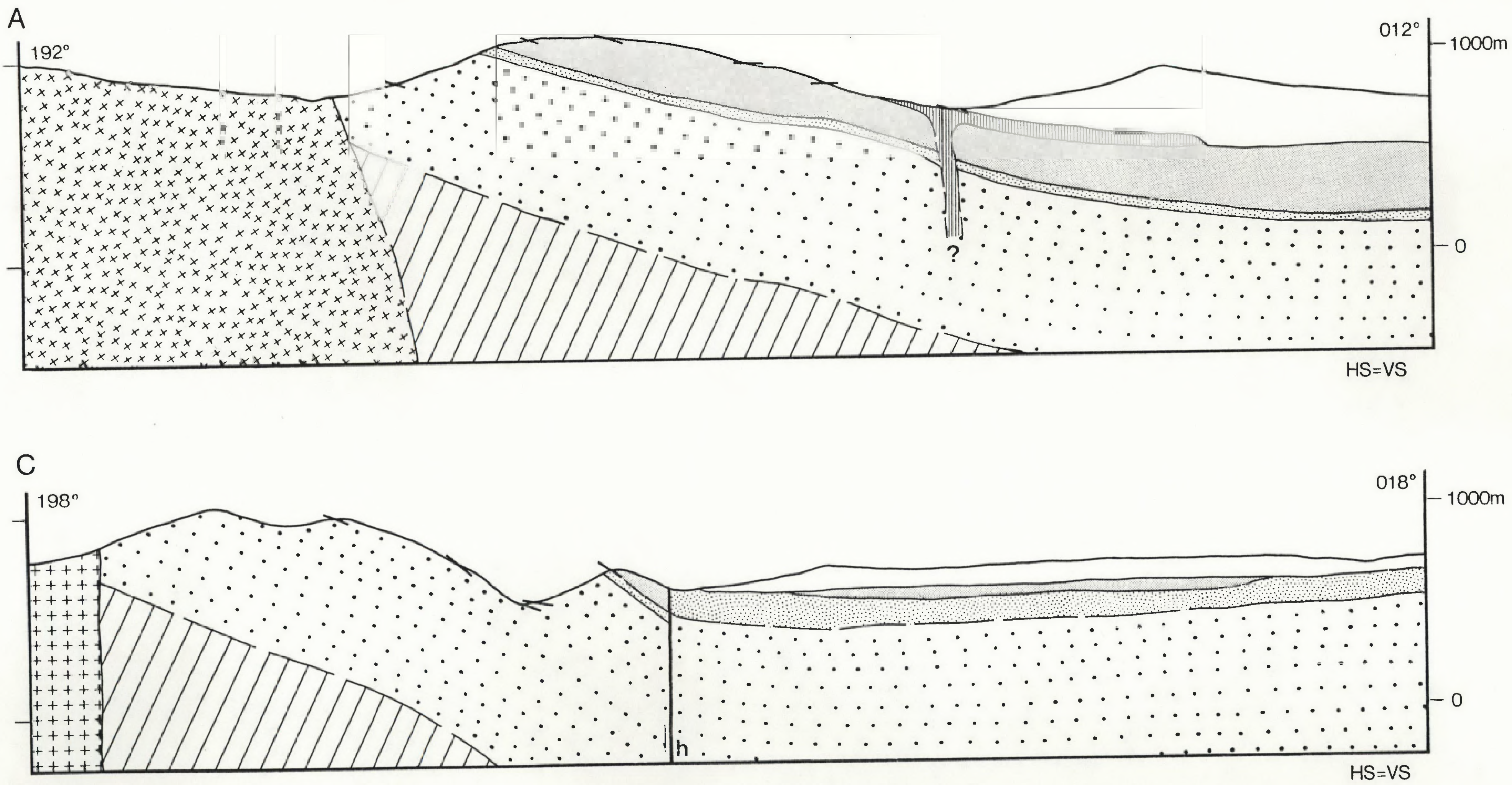
Figure 6.12: Vertical cross-sections through the Coombadjha Volcanic Complex.

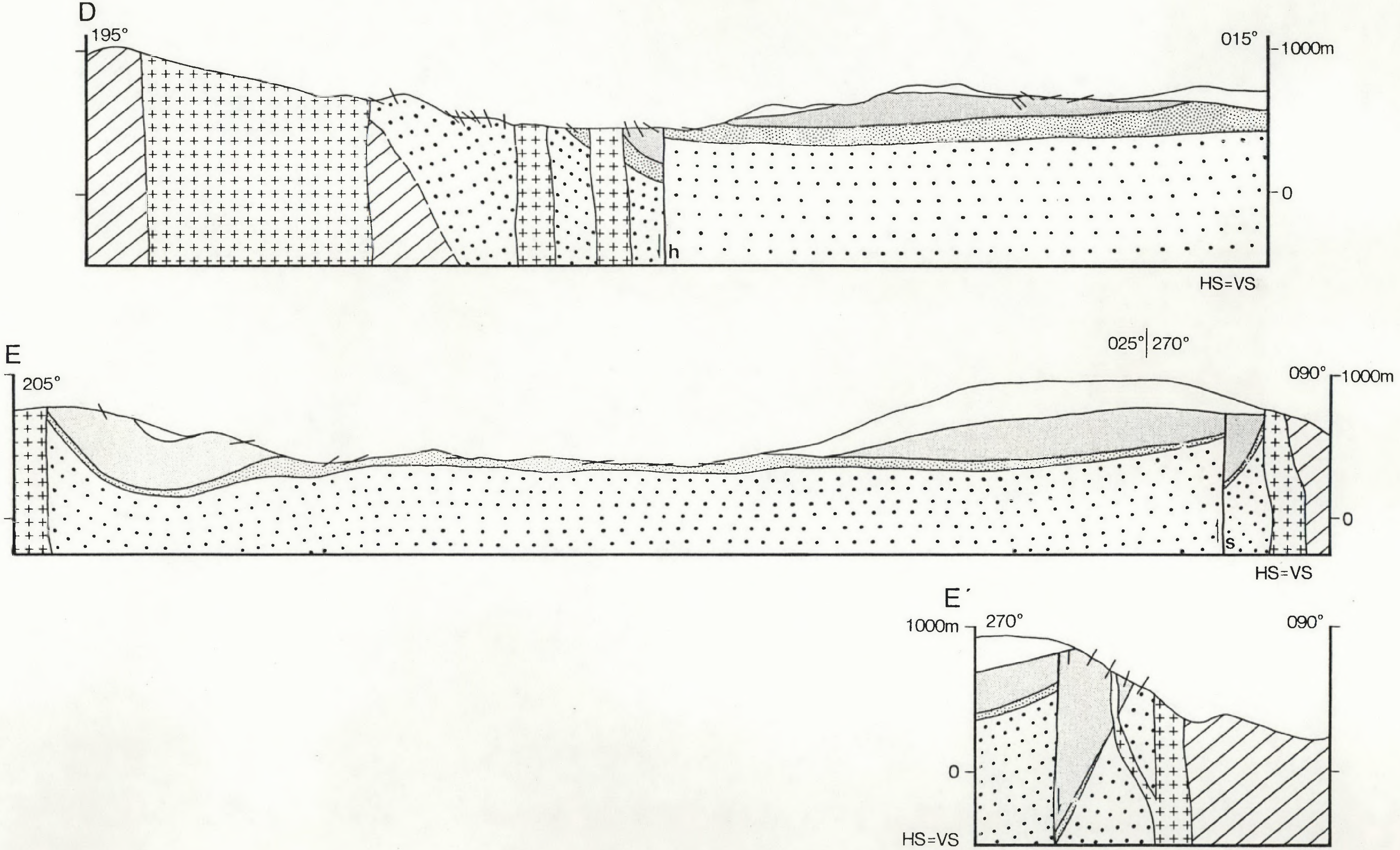
a. Map indicating the position and orientation of each cross-section.

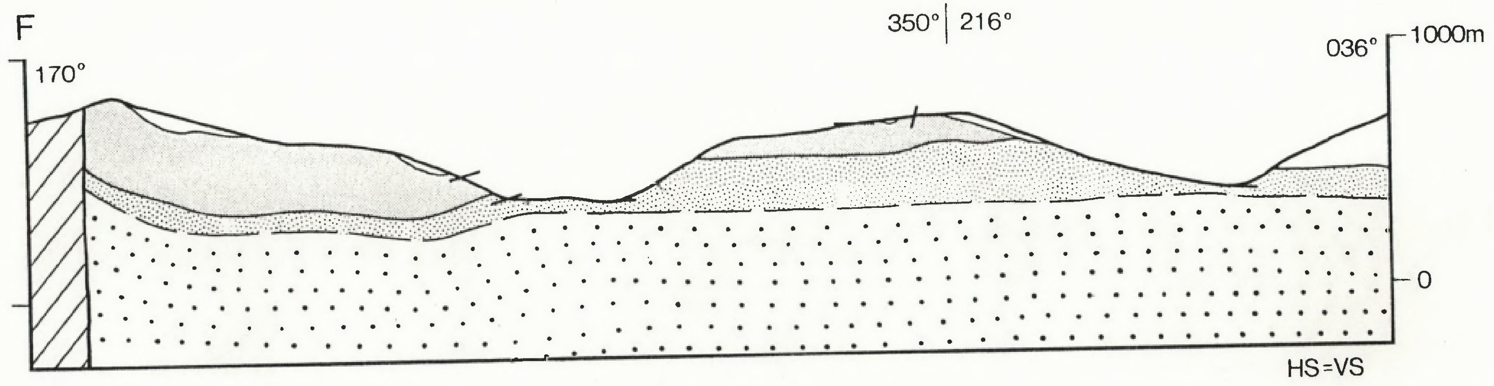
b. Key to symbols used on the cross-sections.

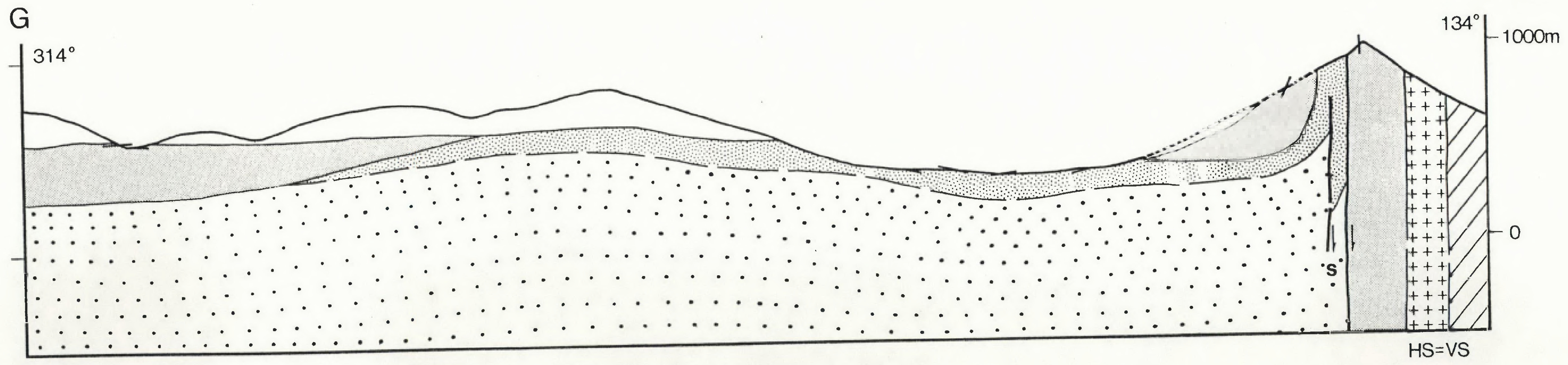
D, Demon Fault System; s, Sugarloaf faults; h, Hianana fault.

Poorly-constrained boundaries are shown by broken lines. Rock unit names are abbreviated to initials on the key.

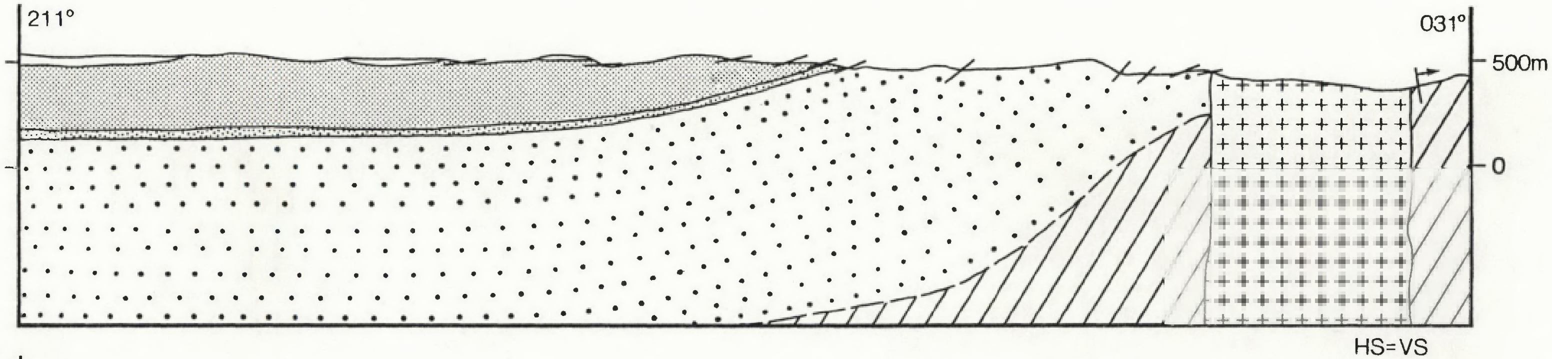

A
192°
012°
1000m
0
?
HS=VS
C
198°
018°
1000m
0
h
HS=VS


D
195°
015°
1000m
0
h
HS=VS
E
205°
025° | 270°
090°
1000m
0
s
HS=VS
E´
1000m
270°
090°
0
HS=VS

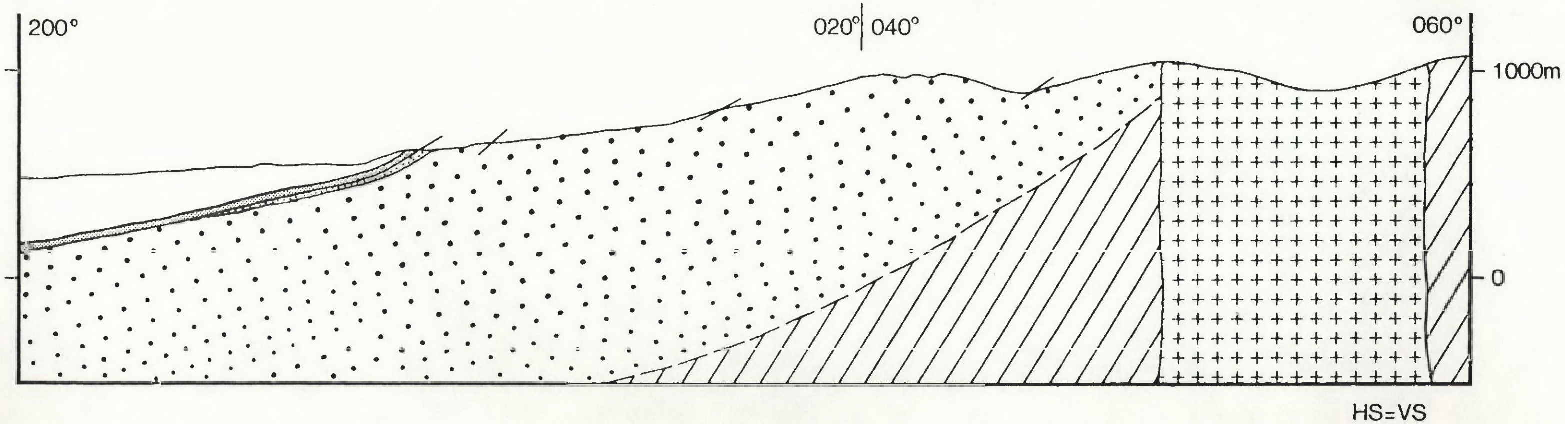

F
170°
350° | 216°
036°
1000m
0
HS=VS

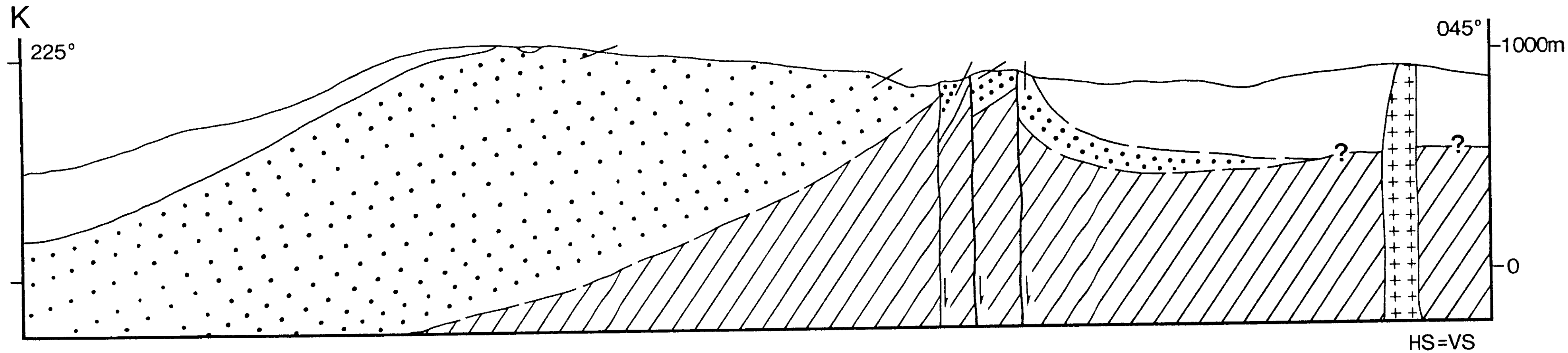

G
314°
134°
1000m
0
S
HS=VS

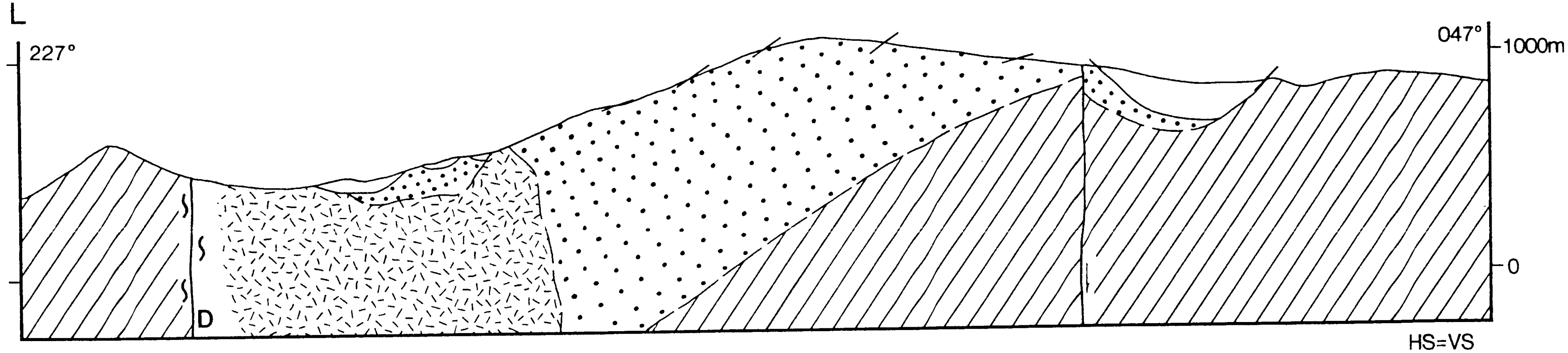
H



J




K
225°
045°
1000m
0
?
?
HS=VS


L
227°
047°
1000m
0
D
HS=VS

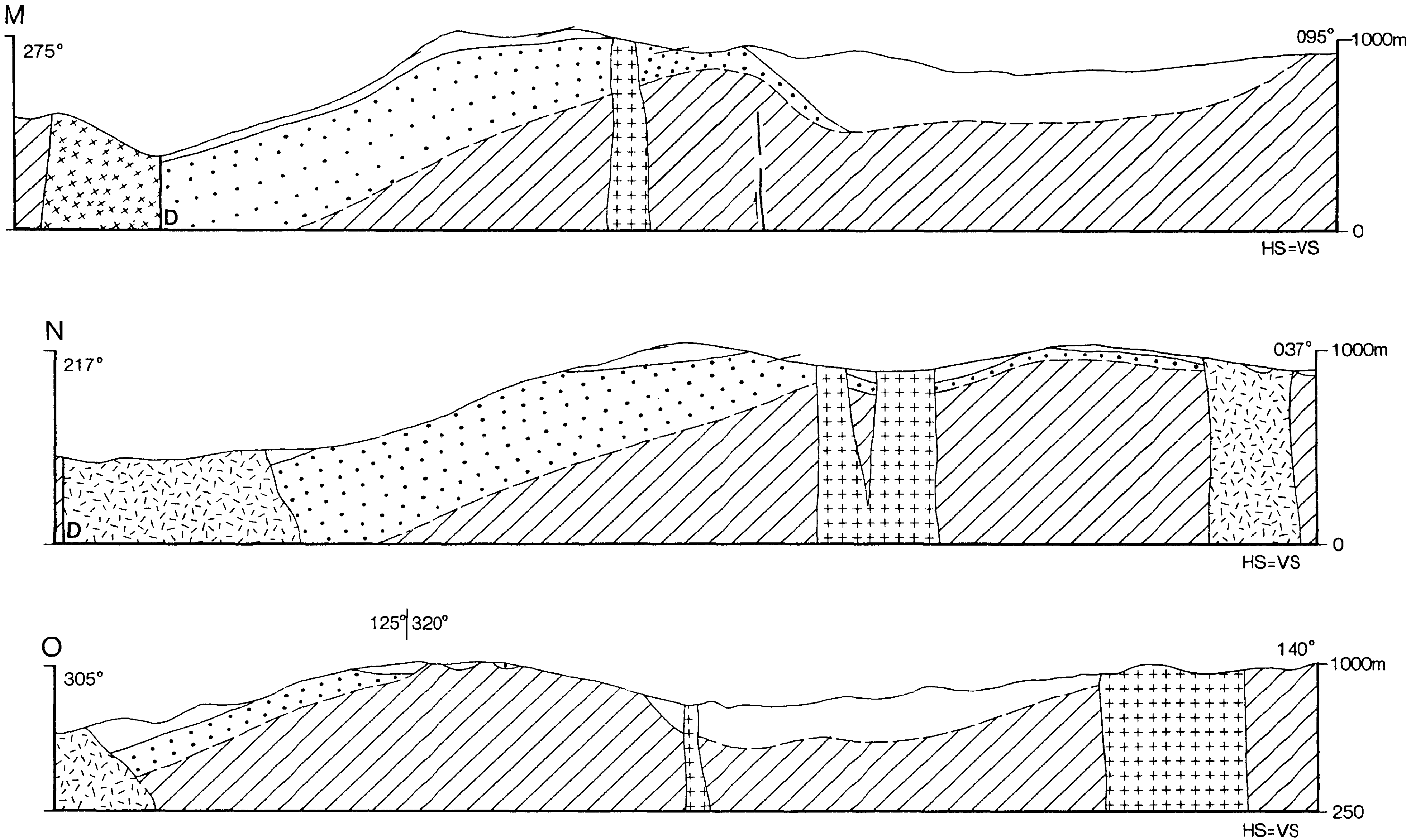

M
275°
D
095°
1000m
0
HS=VS
N
217°
D
037°
1000m
0
HS=VS
125°|320°
O
305°
140°
1000m
250
HS=VS

Figure 6.13: Structural development of the Coombadjha cauldron margin interpreted from three cross-sections (J,K,L, Figure 6.12). Initial collapse is considered to postdate emplacement of existing volcanic units within the Complex.

Section J. Cauldron bounded by the ring pluton.

a. Collapse along the marginal fault(s) after emplacement of about 600 m of Dundee Rhyodacite ignimbrite.

b. Intrusion of the ring pluton controlled by the cauldron margin fault(s). The pluton reached as high as, or higher than, the existing Dundee Rhyodacite layer. An additional thickness (v?) of Dundee Rhyodacite (or other volcanic rocks) is inferred from the magnitude of subsidence. Intracaldera ponding is shown but part of the implied erupted volume may have been distributed elsewhere by outflow. The ring fault still exists along parts of the southeastern margin of the Coombadjha Volcanic Complex (*cf.* section J,a.).

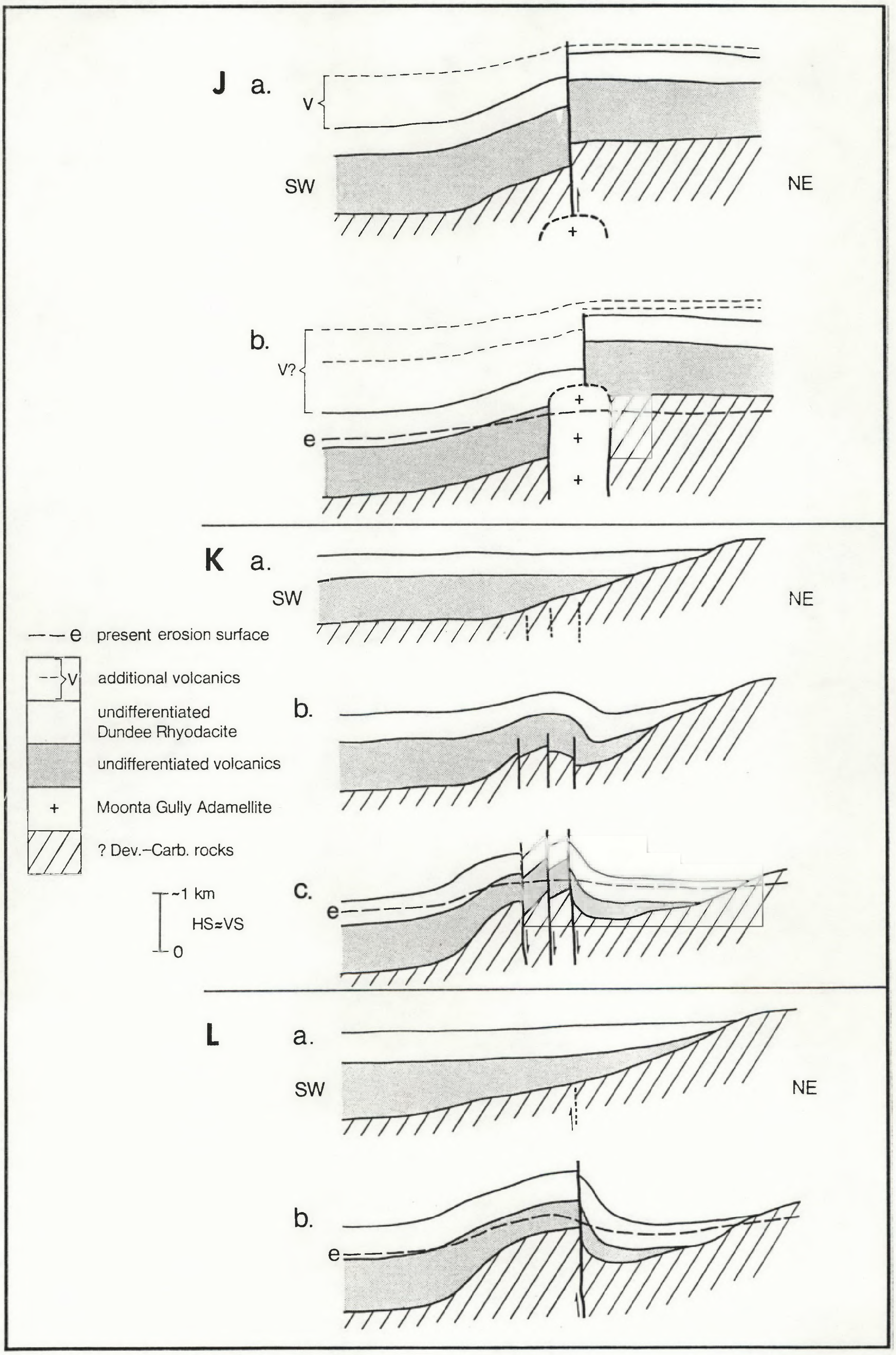
Section K. Faulted anticlinal cauldron margin.

a. Volcanic units thin onto the flanks of a palaeohill of ?Devonian-Carboniferous rocks,with the Dundee Rhyodacite overlapping the older volcanics.

b,c. Sagging of the cauldron block (b) and rupture of the volcanic pile (c) at the margin. As for section J, these stages may have been accompanied by, or have followed, emplacement of additional Dundee Rhyodacite (or other volcanics) to that shown.

Section L. Faulted marginal arch.

Evidently the ?Devonian-Carboniferous palaeohill influenced the geometry of the cauldron margin by locally inhibiting collapse. The reduction in disruption of the volcanics may have rendered the cauldron margin a less favourable site for later intrusion. The configuration of section L possibly represents an arrested stage in the cauldron margin development, exemplified most fully by section J.


J a.
V
SW
NE
b.
V?
e
K a.
SW
NE
b.
c.
e
L a.
SW
NE
b.
e
e present erosion surface
V additional volcanics
undifferentiated Dundee Rhyodacite
undifferentiated volcanics
Moonta Gully Adamellite
? Dev.–Carb. rocks
~1 km
HS≈VS
0

The Dandahra Creek Granite has a strong northeast-southwest joint-controlled lineament pattern which locally extends into the immediately adjacent volcanics of the southwestern sector of the Complex. The meridional Demon Fault also has a recognisable imprint on the Complex. Within one to two kilometres east of the trace of the Fault, north-south trends are prominent in the volcanics, especially near the southern end.

The structural significance of individual lineaments is only clear in a few instances where faults have been inferred on the basis of other data (disturbance of bedding attitudes and stratigraphy). Joint control can also be demonstrated locally. Some lineaments coincide with narrow (a few metres across) zones of pervasive shearing which lie entirely within one of the mappable units (e.g. GR336477 Coombadjha), or traverse units without detectable offset (e.g. south for 1.5 km from GR380428 Coombadjha).

VOLCANIC HISTORY OF THE COOMBADJHA CAULDRON

The volcanic stratigraphy and structure of the Coombadjha Volcanic Complex are the record of the formation of a large scale volcanic cauldron for which there are numerous Cainozoic analogues (e.g. Williams, 1941; Smith *et al.*, 1961; Ratté and Steven, 1967; Smith and Bailey, 1968; Elston *et al.*, 1976; Lipman, 1975,1976; Christiansen *et al.*, 1977; Elston, 1978,1984; Christiansen, 1979; Heiken and Goff, 1983). The term "cauldron" was used by Smith and Bailey (1968, p.616) in reference to "volcanic subsidence structures regardless of shape or size, depth of erosion, or connection with surface volcanism". This definition is entirely appropriate for the Late Permian Coombadjha cauldron as reconstructed from existing remnants preserved in the Coombadjha Volcanic Complex.

The evolution of the Coombadjha cauldron is discussed below in terms of three stages:

I the construction of a thick pile of texturally diverse volcanics contributed from at least four, probably geographically separate and genetically unrelated sources;

II inundation of the site by voluminous crystal-rich ignimbrite, possibly erupted from vent(s) situated close to incipient ring fractures along which centripetal collapse subsequently occurred, forming a trap for the products of later eruptions;

III emplacement of an intrusion, compositionally similar to the cauldron-forming ignimbrite, along much of the perimeter of the central subsided area.

I. Pre-collapse volcanism and palaeogeography

In this section, the style of eruption, mode of emplacement and source locations of each of the four units below the Dundee Rhyodacite are described. Changes in the local palaeogeography during construction of the pre-Dundee Rhyodacite volcanic pile are then outlined, in order to constrain the setting for the cauldron-forming eruptions that followed (Stage II).

Pheasant Creek Volcanics

The three ignimbrite types of the Pheasant Creek Volcanics are sufficiently distinctive in texture and petrography to infer the involvement of different source areas. The typical abundance (less than 3 percent) and maximum size (less than 3 to 4 cm) of dense lithic clasts in these ignimbrites are consistent with outflow from sources several kilometres distant (*cf.* Kuno *et al.*, 1964; Yokoyama, 1974; Sparks, 1975; Wright and Walker, 1977). The grade of breccias possibly related to the ignimbrites gives a similar result, as the ground breccias of some ignimbrites have dense clasts 20 to 30 cm across at distances greater than 10 km from the source (e.g. Yokoyama, 1974; Walker, Self and Froggatt, 1981). Actual positions of sources are unknown but were most likely to have been north, west or southwest of the Coombadjha cauldron (*cf.* Brunker and Chesnut, 1976). The single exposure of coherent silicic lava and lava breccia found in the south of the Complex is the only sign of a vent site within the present area of outcrop of the Pheasant Creek Volcanics. The northern occurrence of lava breccia implies that there was another source of lava within a few to several kilometres, presumably to the north, but it was subsequently destroyed by later events. The possibility of a relationship between the lava sources and the sources of ignimbrites exists but cannot be further explored on the basis of present data. Similarly, there is no positive evidence for vent structures concealed beneath younger units in more central parts of the Complex, but the possibility is acknowledged.

The diverse ignimbrites and breccias of the Pheasant Creek Volcanics probably accumulated with little interruption, even though a number of separate eruptions were involved, because the sequence includes only very minor amounts of clearly epiclastic deposits.

Hianana Volcanics

The volcaniclastic facies of the Hianana Volcanics is considered to be of primary pyroclastic origin in view of the juvenile character of the volcanic derived components, the presence of bed forms diagnostic of emplacement by pyroclastic surges and airfall, the subaerial setting and the absence of features indicative of subaqueous deposition. The volume, extent, thickness and depositional structures of the bedded tuffs in the Coombadjha Creek area are consistent with the interpretation that this part of the sequence is the remnant of a tuff ring constructed by base surges generated by explosive hydrovolcanic eruptions (*cf.* Moore, 1967; Fisher and Waters, 1970; Crowe and Fisher, 1973; Schmincke *et al.*, 1973; Fisher, 1977,1979; Kienle *et al.*, 1980; Wohletz and Sheridan, 1983). The thinner, more distal northern and western representatives of the volcaniclastic facies lack bed forms diagnostic of surge emplacement and may be ash-fall tuffs analogous to the widespread blankets of airfall ash that settle from ash clouds accompanying hydrovolcanic eruptions (*cf.* Moore, 1967; Fisher and Waters, 1970; Waters and Fisher, 1971; Walker and Croasdale, 1972; Sheridan and Updike, 1975; Self *et al.*, 1980; Sheridan and Wohletz, 1981,1983a; Walker, 1984). Arguments in support of this model for the volcaniclastic facies are presented in Chapter 7.

The massive porphyry of the Hianana Volcanics was emplaced as a lava flow as it forms a conformable layer and contributed fragmental debris to breccias. The Hianana lava has a high aspect ratio typical of moderately silicic, subaerial flows (*cf.* Walker, 1973b; Hulme, 1974) and is largely confined to the same area as that covered by the tuff ring. This coincidence and the petrographic similarity of the lava and the pyroclastic components of the bedded tuffs, suggest that both were supplied by a common magma source which was erupted explosively on initial contact with ground water, but at a later stage, changed to effusive discharge. Their source vent(s) may have been in the vicinity of the southeastern Coombadjha Creek exposures. The base surge deposits produced by the explosive activity owe their preservation to subsequent burial by the lava, so the actual original crater or craters are now hidden.

Pi Pi Ignimbrite

The present distribution of the Pi Pi Ignimbrite is a remnant of a larger sheet that extended beyond the margins of the Complex. There is no evidence to suggest that its source lies within the area presently exposed,nor are there systematic internal changes indicating the source direction. Palaeotopographic control of the thickness of Pi Pi Ignimbrite renders this parameter an ineffective indicator of outflow distance. Units of this thickness have been reported at localities tens of kilometres from known sources in the Tertiary ignimbrite fields of the western United States (e.g. Rainier Mesa and Ammonia Tanks Members of Timber Mountain Tuff; Byers *et al.*, 1976) and Quaternary sheets in New Zealand (e.g. Whakamaru Ignimbrite; Blank, 1965; Briggs, 1976). Thickness variations at best reflect the influence of palaeotopography on local distribution, in this case suggesting impoundment along a southwest-northeast axis coincident with the existing position of Washpool Creek.

Lithic fragments in general are less than 3 cm across and sparsely distributed, only constraining possible outflow distances to less than a few tens of kilometres (*cf.* Kuno *et al.*, 1964; Yokoyama, 1974; Sparks, 1975). The data of Yokoyama (1974) for dense clasts in segregation structures suggest that the only known example in the Pi Pi Ignimbrite (GR284457 Coombadjha) may have been formed at outflow distances as great as about 20 km, consistent with the range allowed by the lithic clast sizes in the rest of the unit. Thus, Pi Pi Ignimbrite is considered to be a vagrant outflow sheet from a remote source (caldera?) located at least several kilometres, but perhaps as far as tens of kilometres away, possibly to the southwest within areas shown on regional geological maps as undifferentiated Late Permian volcanics (Brunker and Chesnut, 1976).

Babepercy Volcanics

The silicic porphyry of the Babepercy Volcanics is most probably extrusive as it conformably overlies compositionally similar (quartz-bearing) volcaniclastic rocks. The fine grain size of the porphyry and the presence of flow banding are consistent with this conclusion. Whether the bedded volcaniclastic rocks are in part or predominantly of epiclastic origin remains unresolved. The volcanogenic character of the components and their angularity suggest that initial fragmentation involved volcanic processes (*cf.* Cas, 1983), and that any subsequent modification by epiclastic reworking was minimal. The intimate association with petrographically similar silicic lava, and the subaerial setting in existence at the time of deposition, support this inference.

Analogy with Cainozoic silicic lava flows and domes indicates that the two rocktypes of the Babepercy Volcanics are likely to be genetically related. Examples such as Comb Peak, Nevada (Christiansen and Lipman, 1966), Tarawera, New Zealand (Cole, 1970), Santiaguito, Guatemala (Rose, 1973; Rose *et al.*, 1977), Sugarloaf Mountain, Arizona (Sheridan and Updike, 1975), La Primavera, Mexico (Clough *et al.*, 1982), Little Glass Mountain, California (Fink, 1983), and Hahei, Coromandel, New Zealand (Moore, 1983) demonstrate that subaerial extrusion of silicic lava flows or domes is commonly preceded by explosive degassing of the magma producing more widespread, relatively small volume aprons of pyroclastic debris. Erosion and redeposition operate during spells between eruptions, locally transforming the primary deposits into immature volcaniclastic sediments. Explosive activity may persist during emergence and growth of domes (Smith, 1973; Newhall and Melson, 1983), and the advance of lava flows, and need not be centred on the source vent (Rose *et al.*, 1977). Auto-brecciation and gravitational collapse of unstable lava piles also contribute to the accumulating clastic envelope. Single extrusions of silicic lava are restricted in lateral extent, and commonly terminate within a couple of kilometres from the source vent (Walker, 1973b). Hence coherent lava ultimately overrides only the more proximal parts of the fragmental apron.

Representatives of both these types of eruption (explosive activity followed by lava extrusion) are recognisable in the Babepercy Volcanics, with the implication that present exposures are within a few kilometres of, or even overlying the source vent of the lava (Fig. 6.12, section A). The pervasive alteration of the unit is consistent with this inference and attributable to elevated hydrothermal and fumarolic activity associated with near-vent environments (*cf.* Moore, 1983). No further refinement is justified, since little-modified Cainozoic silicic lava flow and dome complexes can be substantially more extensive (up to a few hundred square kilometres) and more voluminous than single flows. The Haroharo Volcanic Complex, New Zealand (Nairn, 1982) and lava piles bordering the Mogollon Plateau Volcanic Ring Complex, New Mexico (Rhodes, 1976a) are appropriate examples. The possibility remains that the Babepercy Volcanics are erosional remnants of the peripheral reaches of such a lava pile, erupted from vents originally located beyond the southwestern margin of Complex and subsequently destroyed.

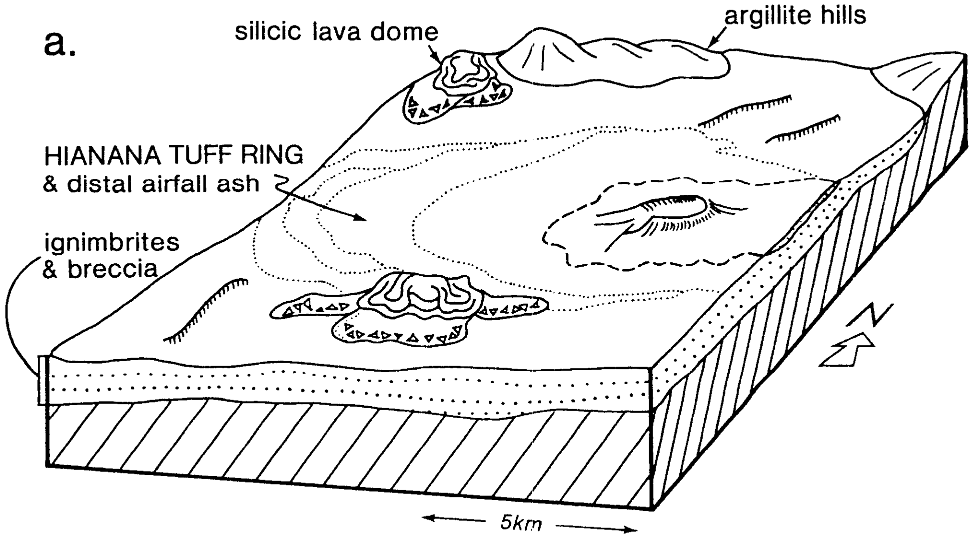
Pre-collapse palaeogeography

The deepest levels of exposure within the Complex do not reach the base of the volcanics, so the pre-volcanic palaeogeography and the concealed record of volcanic activity are largely matters for speculation. Only in a small area in the extreme north of the Complex can original relationships between the volcanics and the ?Devonian-Carboniferous sequence be observed. Here microbreccia and crystal-rich ignimbrite of the Pheasant Creek Volcanics onlap the flanks of a palaeohill made of ?Devonian-Carboniferous argillite. Hence for most of the area the history begins with the inundation of the Coombadjha locality by the ignimbrites of the Pheasant Creek Volcanics, registering eruptions from distant (at least several kilometres), simultaneously active but geographically separate vents. These ignimbrites would have transformed the Permian Coombadjha landscape to an area featuring the flat-lying upper surfaces typical of outflow sheets (Smith, 1960a; Ross and Smith, 1961), interrupted by isolated lava mounds with constructional relief and by residual hills made of older rocks. Small volumes of fault-scarp talus and other coarse slump debris, possibly including lahar deposits from distal sources, accumulated locally during spells between emplacement of ignimbrites.

Formation of the Hianana tuff ring seems to have heralded the earliest major departure from the initially ignimbrite-dominated sequence. The change in style of volcanic activity was dramatic: hydrovolcanic explosions generated base surges which built an apron of bedded tephra around a crater within, or else very close to, the southeastern edge of the Coombadjha area. A thinner and finer grained mantle of airfall deposits extended several kilometres farther across the older ignimbrite plain (**Fig.** 6.14a). Ash-fall tuffs may have been distributed around the source in all directions but the present day record is limited to the northwestern sector. The hill of ?Devonian-Carboniferous rocks that existed in the northern part of the area during inundation by Pheasant Creek ignimbrites was beyond the range of the Hianana tuff ring activity and remained largely unaffected.

Extrusion of coherent porphyritic lava some time after the explosive phase had ceased buried and preserved the proximal parts of the tuff ring. The distinctive style of volcanic activity displayed by the Hianana Volcanics was accompanied by a similarly marked difference in composition of the juvenile ejecta. The Pheasant Creek ignimbrites are predominantly quartz-bearing rhyolites whereas the Hianana Volcanics are plagioclase-rich and dacitic.

Construction of the Hianana tuff ring may have been a geologically rapid event, perhaps measurable in weeks or months (*cf.* Walker and Croasdale, 1972; Kienle *et al.*, 1980), and the eruption of the lava would not have added more than a few to several years to the duration of the event (*cf.* Walker, 1982; Newhall and Melson, 1983). Together the tuff ring and lava flow formed a prominent topographic feature at the time the Coombadjha area was again flooded by pyroclastic flows (Pi Pi Ignimbrite) sourced from elsewhere. The highest points on the Hianana edifice in fact remained emergent above the Ignimbrite. The Pi Pi



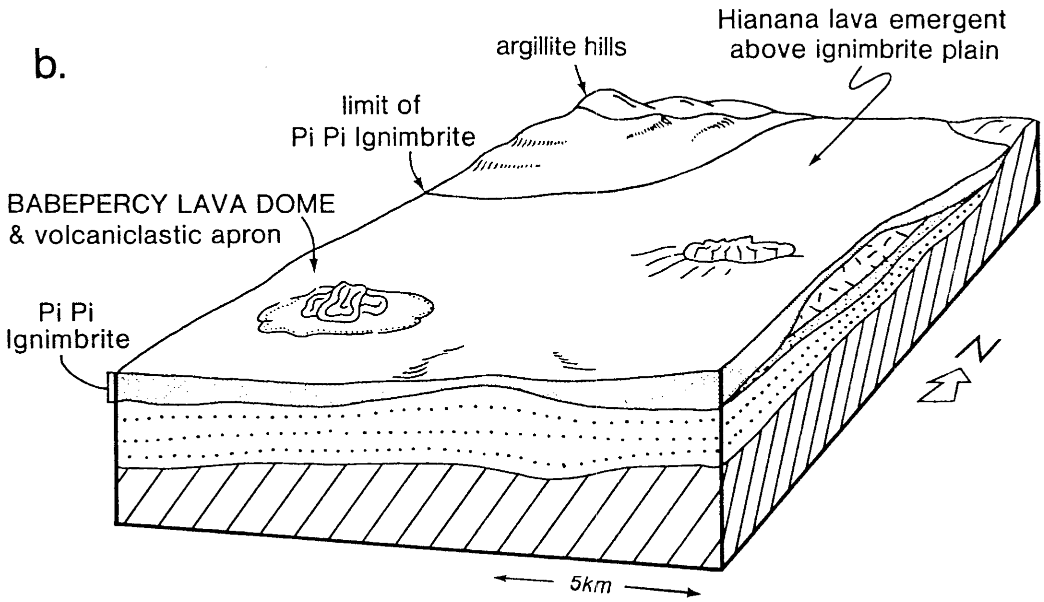


Figure 6.14 a: Reconstruction of the palaeogeography of the Coombadjha area soon after the formation of the Hianana tuff ring but prior to extrusion of the Hianana lava.

b: Reconstruction of the palaeogeography of the Coombadjha area after extrusion of the Babepercy lava.

Ignimbrite also thins toward the north and none has been found overlying the Pheasant Creek Volcanics where the latter onlap the flanks of the palaeohill made of ?Devonian-Carboniferous argillite. The northward reduction in thickness of the Pi Pi Ignimbrite apparently reflects the persistent control exerted by what remained of this palaeohill of older rocks.

The Pi Pi Ignimbrite is mineralogically and texturally very similar to the least common of the three Pheasant Creek ignimbrite types (3). Perhaps one of the sources previously active on a smaller scale reached the peak of eruptive output after the local and relatively shortlived Hianana episode. Alternately, Pi Pi Ignimbrite may be the product of eruptions which were temporally and spatially independent of the Pheasant Creek ignimbrite sources.

The Babepercy Volcanics are a comparatively small volume accumulation of pyroclastics and lava indicating proximity to an eruptive site located near the southwestern perimeter of the Coombadjha area. The Babepercy edifice was built on the level surface of Pi Pi Ignimbrite which elsewhere remained intact and exposed (Fig. 6.14b).

II. Eruption of the Dundee Rhyodacite and cauldron collapse

The emplacement of the Dundee Rhyodacite in the Coombadjha area led to profound changes in the configuration of the volcanic pile, in particular, the inception of the structural basin still in existence in the Coombadjha Volcanic Complex.

Eruption of the Dundee Rhyodacite

The earliest record of Dundee eruptions occurs mainly in the north where a thin interval of ignimbrite, lava and related volcaniclastic deposits exist below the Normal facies. Sustained ignimbrite production followed the opening fluctuations in eruptive style. There are no signs of interruptions to this protracted eruption of pyroclastic flows now preserved within the Normal facies Dundee Rhyodacite in the Coombadjha Volcanic Complex. Flow units within the Dundee Rhyodacite are not obvious but their presence seems probable by analogy with thick, similarly situated Cainozoic ignimbrites of the western United States (e.g. Byers *et al.*, 1976). Unit boundaries have presumably been masked by welding, devitrification and recrystallisation. Ratté and Steven (1967, p.H42) described a densely welded, crystal-rich cauldron-fill ignimbrite, the Snowshoe Mountain Quartz Latite, Colorado, which is more than 1300 to 2000 m thick and largely devoid of mappable breaks. The exposed thickness of the Dundee Rhyodacite also lacks mappable welding zonation, and must therefore represent only the lower part of an even thicker simple (or compound) cooling unit, the emplacement of which was essentially continuous.

Cauldron subsidence

There is no evidence for the existence of any topographic or structural depression prior to the emplacement of the Dundee Rhyodacite: the older volcanic units are equally affected by the subsidence and show no signs that either their distribution or their internal facies was controlled by a topographic basin. Neither have any epiclastic intervals, such as lacustrine sedimentary rocks, been identified within or above the pre-Dundee Rhyodacite volcanic units which would indicate the impounded drainage typical of present-day (e.g. Lake Taupo and Lake Rotorua, New Zealand) and Quaternary calderas (e.g. La Primavera, Mexico, Mahood, 1980; Clough *et al.*, 1981; Long Valley, California, Bailey *et al.*, 1976; Yellowstone, Wyoming, Christiansen and Blank, 1972; Cerro Galan, Argentina, Francis and Baker, 1978; Francis *et al.*, 1978).

The precise timing of the initial subsidence cannot be resolved as most bedding data collected from the Normal facies of the Dundee Rhyodacite are limited to positions near its base. However, early subsidence is unlikely because there is no indication of unconformable relationships within the lower parts of the Dundee Rhyodacite, or between it and the older volcanic units, at least where exposed near the margins of the

Complex (*cf.* Ratté and Steven, 1967). Neither have any collapse breccias symptomatic of the temporary existence of a steep-walled caldera been discovered intercalated within the Dundee Rhyodacite (*cf.* Ratté and Steven, 1967; Lipman *et al.*, 1973; Lipman, 1976; Deal *et al.*, 1978). The rims of collapse calderas are typically 3 to 5 km farther out from the ring faults that encircle the area of subsidence (Lipman, 1976; Heiken and Goff, 1983; Elston, 1984). Because the Coombadjha Volcanic Complex is bounded by the cauldron ring fault, it could be argued that all available exposures were originally beyond the limits reached by collapse breccias derived from a caldera scarp. However several examples of Tertiary caldera collapse breccias extend across ring faults into the subsided cauldron block sequence (e.g. Lipman, 1976). Consequently, the absence of breccias within the Dundee Rhyodacite layer is significant, and major subsidence is inferred to postdate the emplacement of most, if not all, the 600 m of Dundee Rhyodacite that still exists in the Complex.

Mechanism and magnitude of cauldron subsidence

Relationships mapped along the northeastern margin of the Complex indicate that subsidence began with formation of a shallow downwarp encircled by an arch or inward-facing monocline. Later collapse of the enclosed area proceeded along near vertical, arcuate faults which ruptured the crest of the arch. Deformation was narrowly confined to the perimeter of the depression and there is little sign of disruption of the central subsided block.

The present elevation of the base of the Dundee Rhyodacite on remnants of the arch around the northeastern perimeter is approximately 1000 m, compared with about 400 m, estimated from the structure contour map (Fig. 6.11a) at the deepest part of the basin. Thus, the preserved thickness of Dundee Rhyodacite ignimbrite implies subsidence of the order of 600 m, provided the pre-collapse elevations were similar. However, far greater total subsidence of the Coombadjha cauldron floor relative to the surrounding ?Devonian-Carboniferous rocks must have occurred. The volcanics below the Dundee Rhyodacite in the Complex are more than 1500 m thick along much of its northeastern and southern perimeter (see cross-sections, Fig. 6.12, Fig. 6.3), and elsewhere over 1000 m thick. With the exception of the extreme north of the area, no trace of either the Dundee Rhyodacite nor of any other of the volcanic units exists outside the Complex above the adjacent ?Devonian-Carboniferous rocks. Subsidence in excess of the aggregate thickness of volcanics within the Complex, in most places some 2100 m and at least 1500 m, is indicated by this geometry (Fig. 6.15).

Source vents for the Dundee Rhyodacite

Models for cauldron evolution based on Tertiary examples in the western United States and elsewhere repeatedly infer a relationship between pre-collapse ring fracture zones and the eruptive sites of cauldron-forming ignimbrites, a relationship supported by the common coincidence of younger, post-collapse vents with the margins of the sunken cauldron floor (e.g. Ross and Smith, 1961; Smith *et al.*, 1961; Ratté and Steven, 1967; Smith and Bailey, 1968; Rhodes and Smith, 1972; Steven *et al.*, 1974; Lipman, 1975; Bailey *et al.*, 1976; Elston *et al.*, 1976; Rhodes, 1976b; Christiansen *et al.*, 1977; Deal *et al.*, 1978; Elston, 1978,1984; Christiansen, 1979; Francis *et al.*, 1983; Heiken and Goff, 1983). Vents in such a location would invariably be destroyed or else significantly modified by subsequent collapse, thus accounting for the paucity of confirmed vents for ignimbrites that characterises even the youthful and well-exposed caldera terrains of the western United States (Luedke and Burbank, 1968; Ekren and Byers, 1976).

By analogy, the vents for the Dundee Rhyodacite are inferred to have been located around the periphery of the Coombadjha cauldron, at or beyond the site now occupied by the ring pluton. There are no other intrusions, or similar structures within the area of outcrop of the older volcanics which could possibly be interpreted as a Dundee Rhyodacite vent. Also, most of the core of the Complex is covered by a texturally uniform sheet of the Dundee Rhyodacite which is lacking in signs of the presence of source vents or equivalent remnants thereof. An identical configuration exists between the Tertiary Snowshoe Mountain Quartz Latite and the Creede caldera, Colorado (Ratté and Steven, 1967; Steven *et al.*, 1974; Lipman, 1975). Ratté and Steven (1967, p.H42) concluded that source vents were coincident with ring fractures but were unable to discern eruptive

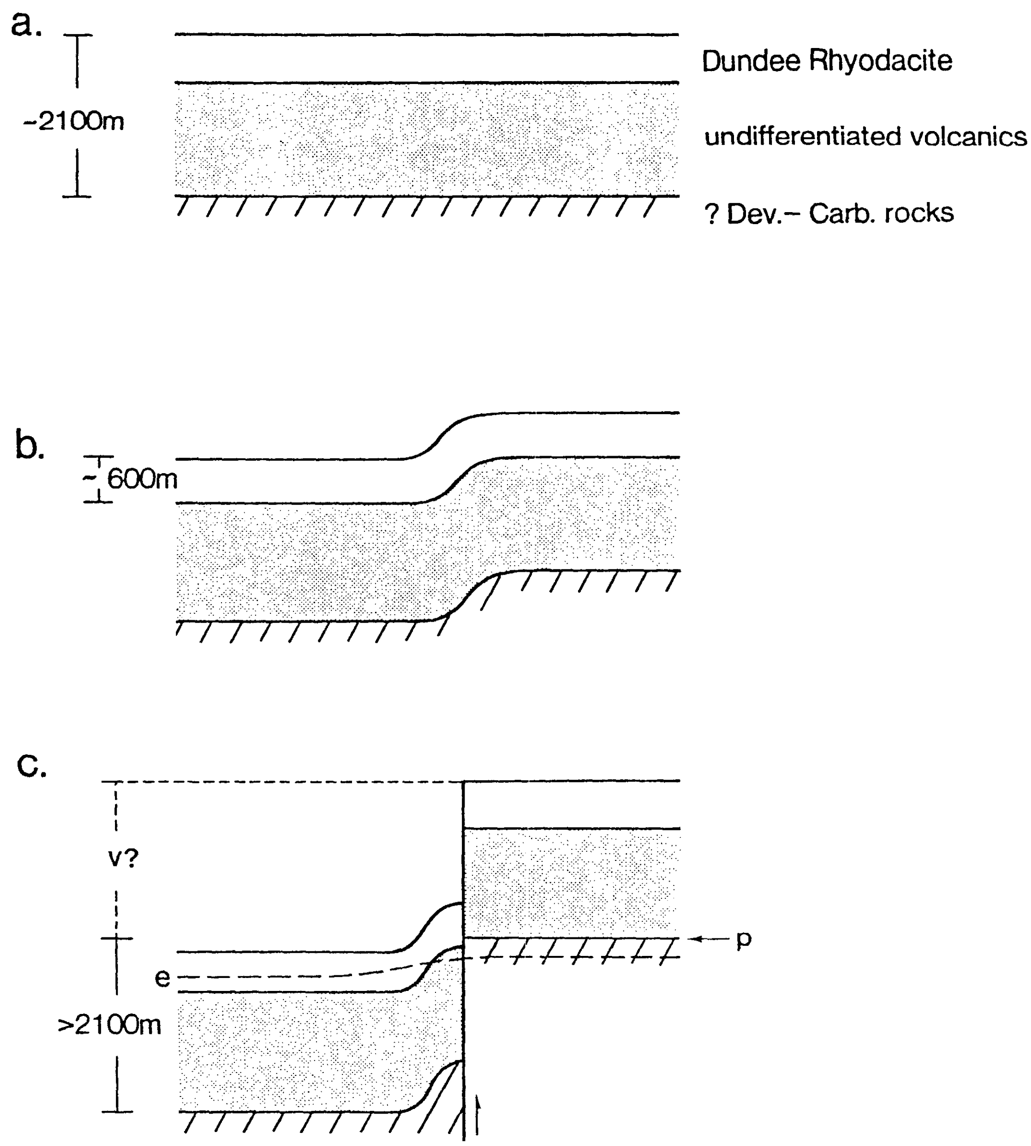


Figure 6.15: Schematic illustration of relationships at the margins of the Coombadjha cauldron which indicate subsidence of at least 1500 m and possibly more than 2100 m.

a. Pre-collapse, the layer of volcanics was approximately 2100 m thick, of which about 600 m was Dundee Rhyodacite.

b,c. Sagging of the centre of the cauldron (b) and faulting of the margins (c) resulted in subsidence of as much as 2100 m.

e, present day erosion surface; p, the ring pluton rose to this level, or higher.

v?, additional intracaldera Dundee Rhyodacite or other volcanics.

sites with any greater precision.

Attempts to apply textural criteria for source vent proximity, such as identification of co-ignimbrite lag breccias or lithic-rich "transitional" flow units (Wright and Walker, 1977,1981; Wright *et al.*, 1981; Druitt and Sparks, 1982) have been unrewarding in the case of the Dundee Rhyodacite in the Coombadjha Volcanic Complex. The present limits of the Dundee Rhyodacite layer are generally more than some 2 km from the nearest contacts of the ring pluton, part of the southeastern perimeter being the main exception. No textural variation has been detected in the Dundee Rhyodacite which correlates with proximity to the margins of the existing layer, even where it is intruded by the ring pluton in the southeast. Such textural homogeneity may be inherited from the mode of eruption and style of emplacement of the Dundee Rhyodacite pyroclastic flows (and of other intracaldera ignimbrites), and is not necessarily a consequence of remoteness from source. This possibility is explored in detail in Chapter 8.

Post-collapse volcanism

The existing thickness of the Dundee Rhyodacite accounts for only a third of the total subsidence of the core of the Coombadjha cauldron. The evidence for a much greater amount of collapse implies continued draining of the magma supply, although the level of exposure of the Coombadjha Volcanic Complex is so deep that the ultimate thickness of Dundee Rhyodacite and any other volcanics remain matters for speculation. Perhaps ignimbrite eruptions persisted in concert with progressive collapse, ponding the deposits to exaggerated intracaldera thicknesses but also allowing inundation of accessible parts of the surrounding terrain. In numerous Cainozoic examples, cauldron-forming ignimbrite eruptions were followed by lava-dominated intracaldera volcanic activity (e.g. Ratté and Steven, 1967; Smith and Bailey, 1968; Christiansen and Blank, 1972; Lipman, 1975; Bailey *et al.*, 1976; Byers *et al.*, 1976; Rhodes, 1976a,b; Deal *et al.*, 1978; Francis *et al.*, 1978; Lipman *et al.*, 1978; Christiansen, 1979; Mahood, 1980; Heiken and Goff, 1983; Hildreth *et al.*, 1984). Such a stage is postulated for the post-Dundee Rhyodacite Coombadjha cauldron.

III. Intrusion of the ring pluton along the Coombadjha cauldron margin

The Moonta Gully Adamellite now separates the subsided core of the Complex from the surrounding ?Devonian-Carboniferous rocks but is itself not affected by faults. It is exposed at the highest elevations of the Complex from the south anticlockwise around to the northeast, and is just being unroofed in the north. The shape and location of the pluton suggest that it was controlled by the arcuate margin of the ancient cauldron. Emplacement of the ring pluton is the final magmatic event recognisable in the history of the Coombadjha Volcanic Complex.

The Moonta Gully Adamellite and the Dundee Rhyodacite are compositionally and mineralogically similar. The formation of the Coombadjha cauldron is bracketed by emplacement of these same two rock units : subsidence followed eruption of the Dundee Rhyodacite but had ceased prior to intrusion of the Moonta Gully Adamellite. A co-magmatic relationship between the Dundee Rhyodacite ignimbrite and the Moonta Gully Adamellite is consistent with the field evidence and the available chemical data on the two rock types (Fig. 6.4, Table 6.1). The Moonta Gully Adamellite may be the product of a magma similar to that which had supplied the Dundee Rhyodacite eruptions at the inception of the cauldron, and which subsequently intruded its earliest eruptive products (*cf.* Smith *et al.*, 1961; Smith and Bailey, 1968; Lipman, 1976; Lipman *et al.*, 1978; Francis *et al.*, 1983; Heiken and Goff, 1983). From among the diverse intracaldera fill and ring fracture volcanics of the mid-Tertiary cauldrons of New Mexico, Rhodes (1976b) and Elston (1984) have distinguished crystal-rich "cauldron lavas". These are commonly erupted from sites at the margins of the cauldrons, and are chemically and mineralogically similar to possibly genetically related cauldron-forming ignimbrites. Following their model, the Moonta Gully Adamellite could be the intrusive representative of "cauldron lavas" of the Coombadjha cauldron, which may have been the dominant product of post-collapse volcanic activity.

Final emplacement of the ring pluton exploited the arcuate active fault zone encircling the sunken cauldron floor. The level in the volcanic pile reached by the ring pluton corroborates other evidence for the prior existence of a substantial thickness (at least 1 to 2 km) of cover rocks, since removed by erosion.

SUMMARY AND DISCUSSION

The stratigraphy and structure of the Coombadjha Volcanic Complex chronicle the evolution of a Late Permian proximal continental volcanic pile, which culminated in major eruptions of ignimbrite and attendant cauldron collapse. Prior to subsidence, the Coombadjha area received ignimbrites erupted from sources at least several kilometres distant. The Coombadjha site was beyond the range of the most proximal deposits which form from ignimbrite eruptions involving eruption column collapse, such as co-ignimbrite lag breccias and exceptionally coarse and lithic-rich "transitional" flow units (Wright and Walker, 1977,1981; Wright *et al.*, 1981; Druitt and Sparks, 1982; Wilson and Walker, 1982). Neither was the Coombadjha area affected by any subsidence events which these ignimbrite eruptions may have provoked at their sources. Local vents did exist (the Hianana and Babepercy centres) but were active on a much smaller scale, and indicate only minor interruptions to the steady accumulation of outflow ignimbrites. The paucity of epiclastic intervals throughout the sequence reflects both the rapidity with which volcanic units were emplaced, and the accessibility and comparative proximity of the Coombadjha area to active centres.

The Coombadjha area underwent a radical transformation on the inception of a major episode of essentially continuous eruptions which produced an ignimbrite (the Dundee Rhyodacite) more voluminous than any of those that had previously inundated the region. The magma supply feeding the Dundee Rhyodacite pyroclastic flows evidently underlay the Coombadjha area and its depletion eventually resulted in sagging then wholesale collapse intact of a fault-bounded oval to form the Coombadjha cauldron. Cumulative subsidence of the cauldron floor of more than 2 km relative to the surrounding terrain can be reliably inferred, and correlated with the eruption of Dundee Rhyodacite ignimbrite. Only part of the total eruptive record associated with cauldron formation still exists in the Coombadjha Volcanic Complex and the thickness of Dundee Rhyodacite ignimbrite in the pile at the cessation of eruptions is unknown.

Although much of the original near-surface record is lost, the closing stages of the evolution of the Coombadjha cauldron are adequately displayed. Magma was intruded along the formerly active and structurally weakened ring fault zone. This magma may initially have fed small-scale, post-collapse "cauldron lava" eruptions, although its ultimate cooling and crystallization terminated both subsidence and volcanism in the Coombadjha cauldron. Broad compositional affinity of the Moonta Gully Adamellite with the Dundee Rhyodacite ignimbrite, in addition to the field constraints on their close spatial and temporal relationships, suggest they originated from a common magma.

Character of the Coombadjha cauldron cycle

The ring pluton constitutes the only sign of post-collapse magmatic activity having occurred in the Coombadjha cauldron, although its emplacement was not a resurgent stage as envisaged by Smith and Bailey (1968; Stage V). There is no evidence for structural doming of the cauldron floor and neither are there substantial plutons related to the Coombadjha Volcanic Complex within the cauldron margin. Smith and Bailey (1968, p.654) concluded that ring intrusions related to cauldron-forming ignimbrite eruptions would be compositionally similar to the ignimbrites, and distinguishable from those ring intrusions which are emplaced after resurgence has occurred. The complete absence of evidence for structural resurgence of the Coombadjha cauldron is in accord with the genetic link between the cauldron-forming Dundee Rhyodacite ignimbrite and the encircling Moonta Gully Adamellite, inferred in view of their context and compositional affinity.

Elston (1984) has suggested refinements to the model of cauldron evolution of Smith and Bailey (1968), allowing for more complicated and diverse intrusive and extrusive igneous activity during the post-collapse stage. Structural resurgence is but one possible manifestation of continued magmatism following subsidence. The Coombadjha cauldron cycle seems to match this scheme in having three principal stages of development finishing with post-collapse igneous activity which did not involve structural doming of the cauldron floor.

Smith and Bailey (1968, p.646,651) proposed that cauldrons with central blocks having anomalously high thickness: diameter ratios, or which were extensively ruptured during collapse, would be less likely to respond to magma resurgence in the manner they outlined. Subsidence in the Coombadjha cauldron did little to disturb the coherence of the central block, so the second condition can be discounted. The known thickness of volcanics forming the upper part of the Coombadjha cauldron block is not exceptional but there is no data to constrain their total thickness. The possibility that the Coombadjha cauldron had a thickness: diameter ratio which prevented a resurgent response late in its history remains. Alternatively, the voluminous eruption of the cauldron-forming ignimbrite may have depleted the magma supply to such an extent that its capacity to sustain another major stage of volatile-driven explosive eruption was permanently retarded.

Duration of the Coombadjha cauldron cycle

The Coombadjha cauldron formed in response to a well-defined sequence of eruption and collapse, constituting a Late Permian example of a single caldera cycle (Christiansen, 1979) which did not proceed to a resurgent stage. Exhaustively dated Tertiary and Quaternary cauldron complexes and calderas (e.g. Valles Caldera, Doell *et al.*, 1968; Smith and Bailey, 1968; Heiken and Goff, 1983; Yellowstone Caldera, Christiansen and Blank, 1972; Long Valley Caldera, Bailey *et al.*, 1976; Timber Mountain-Oasis Valley Caldera Complex, Byers *et al.*, 1976; Christiansen *et al.*, 1977; calderas of the San Juan Volcanic Field, Steven *et al.*, 1974; Lipman, 1975,1976, Lipman *et al.*, 1976,1978; Slack and Lipman, 1979; calderas of the Mogollan Plateau Volcanic Field, Elston *et al.*, 1976; Rhodes, 1976b; Elston, 1984; Sierra La Primavera Volcanic Centre, Mahood, 1980; Rotorua Caldera, Taupo Volcanic Centre, Haroharo Caldera, Nathan, 1976; Nairn, 1982) demonstrate that single evolutionary cycles require no more than hundreds of thousands of years, and more complicated cycles are complete within 1 to 2 million years (Smith and Bailey, 1966, 1968; Christiansen, 1979; McKee, 1979; Smith, 1979). Related intrusive events follow closely or may continue for up to several million years (Lipman *et al.*, 1978; McKee, 1979; Francis *et al.*, 1983). By analogy the Coombadjha cauldron cycle was probably a similarly short-lived though dramatically catastrophic Late Permian event. The volcanic prelude to the Coombadjha cauldron provides no evidence of significant temporal breaks but includes ignimbrites probably themselves symptomatic of caldera cycles elsewhere. Even so, an interval of several million years would adequately accommodate the time required for the accumulation of the pre-collapse units.