# CHAPTER 4

## PETROGRAPHY OF THE THOLEIITIC ROCKS

Detailed mineralogical and chemical data, presented in Chapters 5 and 6, suggest that two distinct tholeiitic series have developed more or less contemporaneously within the southern portion of the Shield. One of these is transitional to alkaline in gross characteristics, lacking Ca-poor pyroxene even as a groundmass phase. In contrast pigeonite is a ubiquitous phenocryst and groundmass phase in members of the other series and hypersthene phenocrysts are not uncommon. The two series are designated the low-Si series and the high-Si series respectively, although they are both clearly tholeiitic in overall character.

### 4.1 NOMENCLATURE

It is difficult to erect a meaningful classification scheme for the rapidly cooled members of volcanic series. For example, the following difficulties arise in any purely petrographic classification:

1) Fine grainsize often precludes identification of critical groundmass phases such as pigeonite or alkali feldspar and estimation of their abundances.

2) Rapid cooling may result in the preservation of early crystallized phases which are metastable with respect to C.I.P.W. normative parameters *e.g.* many olivine-bearing tholeiites are quartz normative.

3) It is not possible to asses the intrinsic modal significance of glass, especially if the latter is K-rich.

4) The composition of some modal phases, _e.g._ plagioclase, is dependent upon the P-T conditions operative during crystallization (_e.g._ _see_ Duggan and Wilkinson, 1973).

Because of these constraints volcanic rocks have in recent years been classified primarily on the basis of whole rock chemistries, utilising C.I.P.W. norms and chemical parameters such as Na/K and Mg/Fe ratios and levels of silica saturation.

Nomenclature of alkaline series varying in their degree of undersaturation has become more systematic, particularly with respect to the members of mildly undersaturated sodic and potassic series, and their more undersaturated equivalents (_e.g._ _see_ Coombs and Wilkinson, 1969). In contrast, the principles of nomenclature of tholeiitic series are by no means as well established and unfortunately terms such as tholeiite, tholeiitic basalt, tholeiitic andesite, basaltic andesite and ferrobasalt, although frequently applied, have rarely been specifically defined. For example, rocks which would be accepted by many petrologists as tholeiitic andesites and which are chemically similar (with 48-52% $SiO_2$, 0-5% _qz_, 100_an_/_ab_ + _an_ = 40-50) have been variously termed "tholeiite" (Thingmuli; Carmichael, 1964), "ferrobasalt" (Galapagos; McBirney and Williams, 1969), and "andesine normative lava" (Thompson, 1972b).

Confusion in terminology for the tholeiitic series is due in part to the variable parameters adopted to discriminate between basalt and andesite resulting in the unsystematic use of the term basaltic andesite, widely applied to the more mafic members of many calc-alkaline assemblages.

The Thingmuli tholeiitic sequence was subdivided by Carmichael

(1964) into olivine tholeiite, tholeiite, basaltic andesite, andesite (icelandite) and rhyolite, the term icelandite being introduced for the first time to distinguish the Thingmuli andesites from calc-alkaline andesites. However the Thingmuli "icelandites" are significantly more silicic than most typical calc-alkaline andesites, being more akin to dacites (59-65% $SiO_2$; 15-25% qz; 100an/ab + an = 33-20; e.g. Wilkinson, 1971). Recent usage tends to equate icelandite with tholeiitic dacite (=inninmorite; Bailey *et al.*, 1924; see Tilley *et al.*, 1968; Wilkinson and Duggan, 1973).

McBirney and Williams (1969) extended the name icelandite to cover a variety of differentiated volcanics in the Galapagos Islands with $SiO_2$ ranging from approximately 49-60% and used a change in trend from predominant iron enrichment to alkali enrichment as a criterion for distinguishing "icelandites" from more basic eruptives. Irvine and Baragar (1971) stressed the iron-rich nature of the original icelandites as defined by Carmichael (1964) and define icelandite as "a very iron-rich variant of andesite or dacite". They use the term tholeiitic andesite to cover both the basaltic andesites and icelandites of Carmichael (1964) and their use of the term icelandite is based on parameters that are over-restrictive. Joplin (1971) discarded the terms "basaltic andesite" and "tholeiitic andesite" and in their place adopted the term "basaltic icelandite". The approaches of McBirney and Williams (1969) and Joplin (1971) have unnecessarily broadened the scope of the term "icelandite" beyond its original definition. Furthermore, rejection of the term "tholeiitic andesite" does not appear warranted in view of its clear compositional connotations, widespread use and acceptance. In this thesis it will be retained but its compositional limits will be defined more rigourously than previously. Thus the terminology of Irvine and Barager (1971) is adopted in part but the term "icelandite" is expanded beyond the definition of these authors and simplified to include tholeiitic volcanics that are essentially analogous to the dacites in calc-alkaline suites.

Some tholeiitic series contain members which, although relatively low in $SiO_2$ contents (46-52% $SiO_2$) and levels of silica saturation (ol normative or 0-5% qz), have a normative plagioclase in the andesine range and apparently lack Ca-poor pyroxene. They are found in the Snake River area, Idaho, U.S.A. (Thompson, 1972b), the Parana Basin in South America (Leterrier *et al.*, 1972), and Feather River in California (Hietenan, 1972). The rocks of the Tweed low-Si series are in many respects compositionally similar to these types.

In the classification scheme adopted herein, the tholeiitic rocks have been subdivided on the basis of Thornton-Tuttle Differentiation Index* (D.I. = qz + or + ab + ne + lc; Thornton and Tuttle, 1960) and an/ab+an ratios into tholeiite, tholeiitic andesite, icelandite (= tholeiitic dacite), tholeiitic rhyodacite and tholeiitic rhyolite (Fig. 4.1). Using these parameters, the classification provides a close parallel with the scheme for alkaline eruptives proposed by Coombs and Wilkinson (1969). The recognition of two distinct tholeiitic series (a low-Si and high-Si series; see Chapters 5 and 6) invites further subdivision of the tholeiitic andesites

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* The terms "Differentiation Index" and "evolved" used throughout this thesis imply no genetic connotations and thus do not in any way presuppose an origin by fractional crystallization processes.

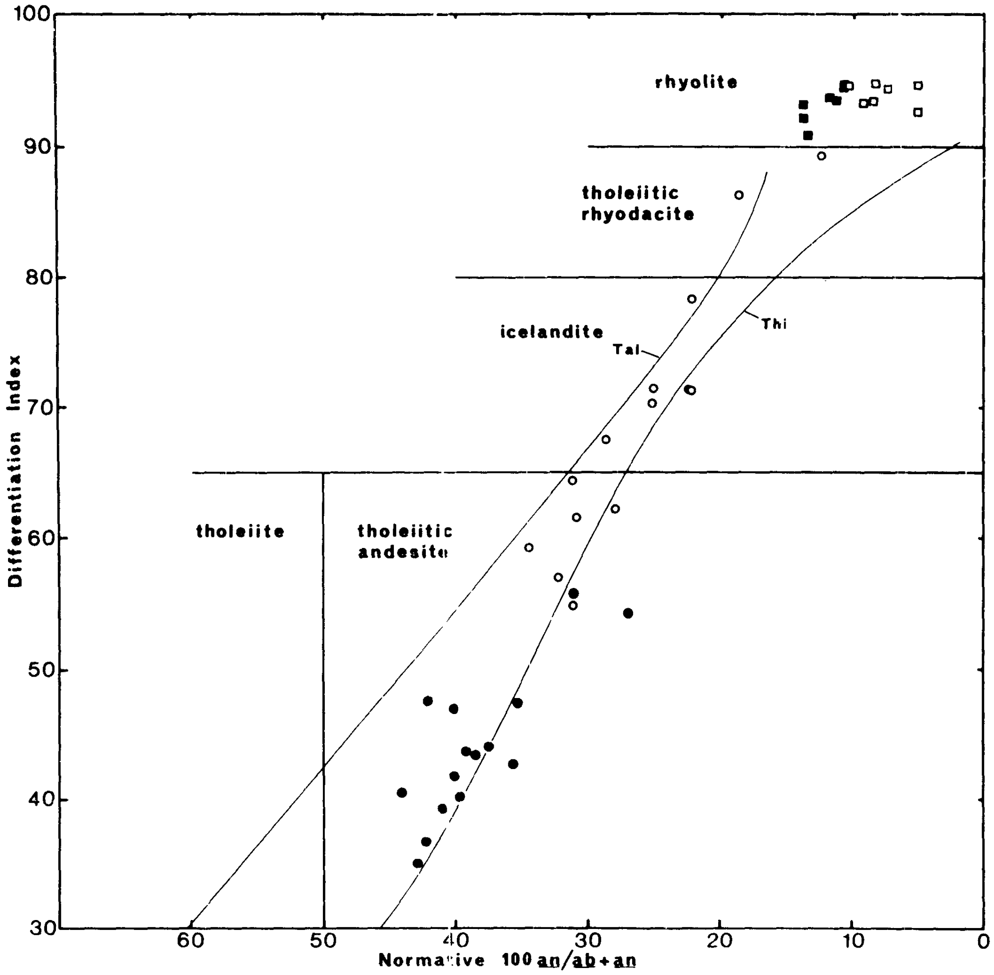



Fig. 4.1: Plot of Differentiation Index against normative plagioclase composition for analysed rocks from the southern portion of the Tweed Shield (Tables 6.1-6.3) illustrating the classification scheme adopted herein. Filled circles, members of the low-Si series; open circles, members of the high-Si series; filled squares, rhyolitic pitchstones; open squares, microcrystalline rhyolites. Generalized trends for the Thingmuli, Iceland (Thi; Carmichael, 1964) and Talasea, New Britain (Tal; Lowder and Carmichael, 1970) volcanic series are shown for comparison.

into low-Si and high-Si types based on the respective pyroxene assemblages and qz contents.

Ideally any igneous rock classification utilising modal plagioclase should embody the plagioclase compositions. As discussed above, this is impractical for rapidly cooled volcanics. If the an/ab+an ratio is used as an alternative parameter its validity should be critically assessed. Two principal factors may be responsible for divergences between modal and normative plagioclase compositions. $Al_2O_3$ contained in modal pyroxene calculates as an in the norm and thereby increases the an/ab+an ratio but the effect will be quite small. For example, 20 wt% modal clino-pyroxene containing 2.8% $Al_2O_3$ (about average for the more mafic Tweed rocks) will contribute an additional 1.5% an to the normative anorthite component. On the other hand, about 6 wt% residual glass containing 3.0% $Na_2O$ will make a similar contribution to ab, thereby tending to eliminate the effects of $Al_2O_3$ in clinopyroxene. Consequently correspondence between normative and modal plagioclase is enhanced.

In the more salic members of the series tholeiite-rhyolite, an/ab+an ratios become rather less important as a classification parameter because an contents decrease to low values and the proportion of low melting components (ab,or,qz) increases markedly. Consequently D.I. is an especially useful parameter for these rocks because it indicates the degree to which a liquid has acquired a low melting composition in "Petrogeny's Residua System". A chemical parameter is essential in the classification of these rocks because glass may be an essential, even major component.

## 4.2 PETROGRAPHY

In the following account, a brief outline of the distribution of the various rock types precedes discussion of their petrography merely for ease of presentation. For the same reason, salient features of the mineralogy are discussed under headings for the various mineral groups. However detailed discussion of the mineralogy of these rocks is deferred until Chapter 5.

### 4.2.1 Low-Si Tholeiitic Andesites

Low-Si tholeiitic andesites comprise the greater part of the Lismore and Blue Knob Basalts. Individual flows are usually relatively thin (< 20 m) and display a thin weathered vesicular zone at the top, less commonly at the base. Although the central portion of flows is massive and usually fresh in outcrop deuteric groundmass alteration tends to be common over the entire thickness of each flow.

#### Petrography

Low-Si andesites are characterized by the absence of Ca-poor pyroxenes, either as phenocryst or groundmass phases, and exhibit a wide range of textural types. Porphyritic varieties contain phenocrysts of plagioclase, less commonly olivine. The groundmass is composed of olivine granules, clinopyroxene (which may have a distinctly pink tint), plagioclase laths, ilmenite, intersertal glass and chlorophaeite. Strictly aphyric varieties are also common. Groundmass textures of both porphyritic and aphyric types vary from intersertal to sub-ophitic. Some of the more common textural types are illustrated in Plates 1 and 2. Modal data on representative

EXPLANATION OF PLATE 1

1. Olivine-rich tholeiitic andesite 28046 (Table 6.1, No. 1). Phenocrysts of olivine (ol) in a groundmass of plagioclase laths, olivine, clinopyroxene, ilmenite and residual glass. Plane polarized light, x 20 magnification.

2. Low-Si tholeiitic andesite 28048 (Table 6.1, No. 3). Phenocrysts of olivine (ol) and plagioclase (pl) in a groundmass of plagioclase laths, minor olivine, subophitic clinopyroxene, ilmenite and a little glass. Plane polarized light, x 20 magnification.

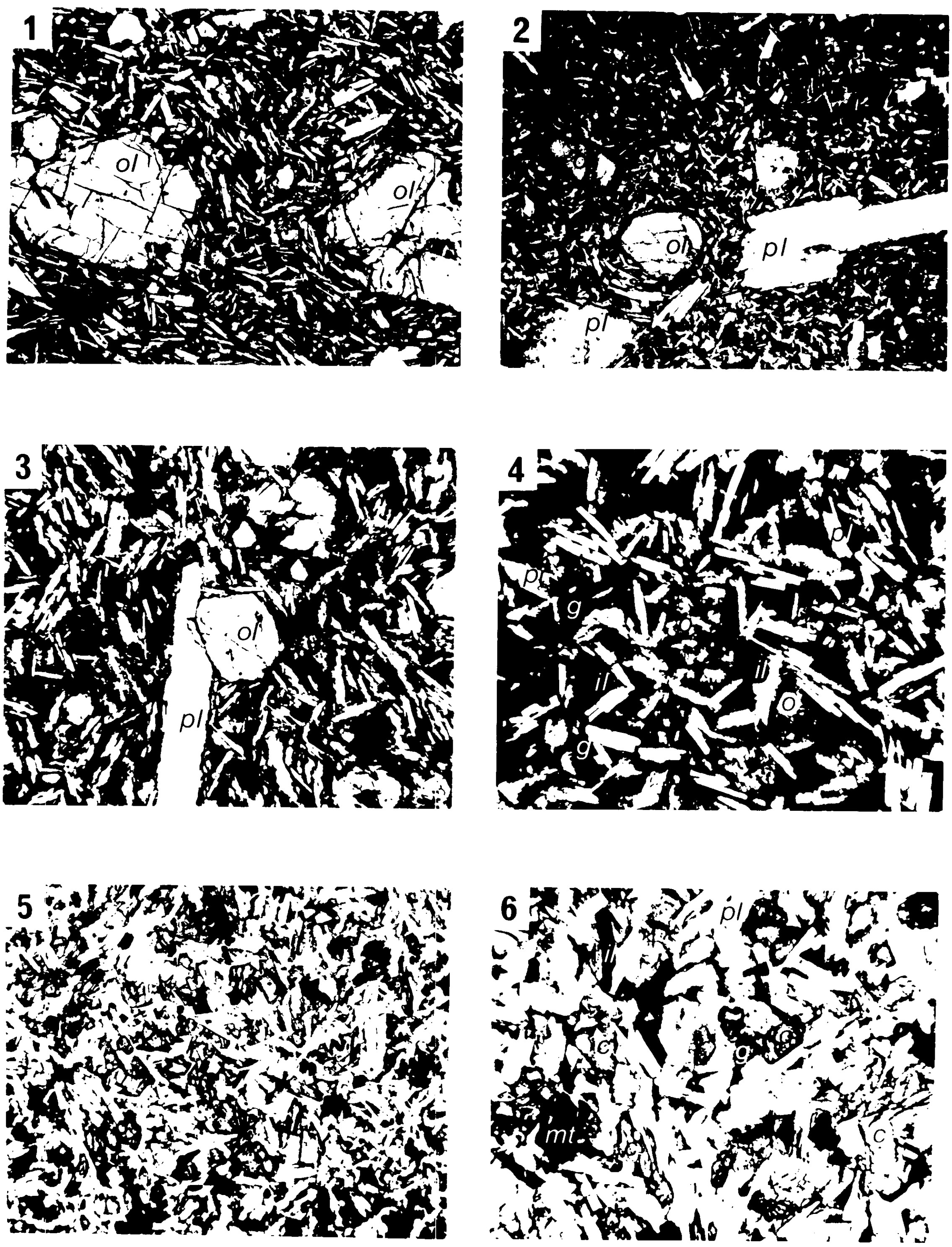
3. Low-Si tholeiitic andesite 28049 (Table 6.1, No. 4). Microphenocrysts of olivine (ol) and plagioclase (pl) in a groundmass of plagioclase, clinopyroxene, ilmenite and residual glass. Plane polarized light, x 50 magnification.

4. Low-Si tholeiitic andesite 28050 (Table 6.1, No. 5). An aphyric rock containing plagioclase laths (pl), olivine (o) and ilmenite granules (il) in an iron-rich vitric base (g). Plane polarized light, x 50 magnification.

5. Low-Si tholeiitic andesite 28051 (Table 6.1, No. 6). An aphyric rock consisting of plagioclase laths, olivine, subophitic clinopyroxene, ilmenite, magnetite and minor intersertal glass. Plane polarized light, x 20 magnification.

6. As for No 5. Symbols: o, olivine; pl, plagioclase, c, clinopyroxene; mt, magnetite; il, ilmenite; g, glass. Plane polarized light, x 50 magnification.

# Plate 1



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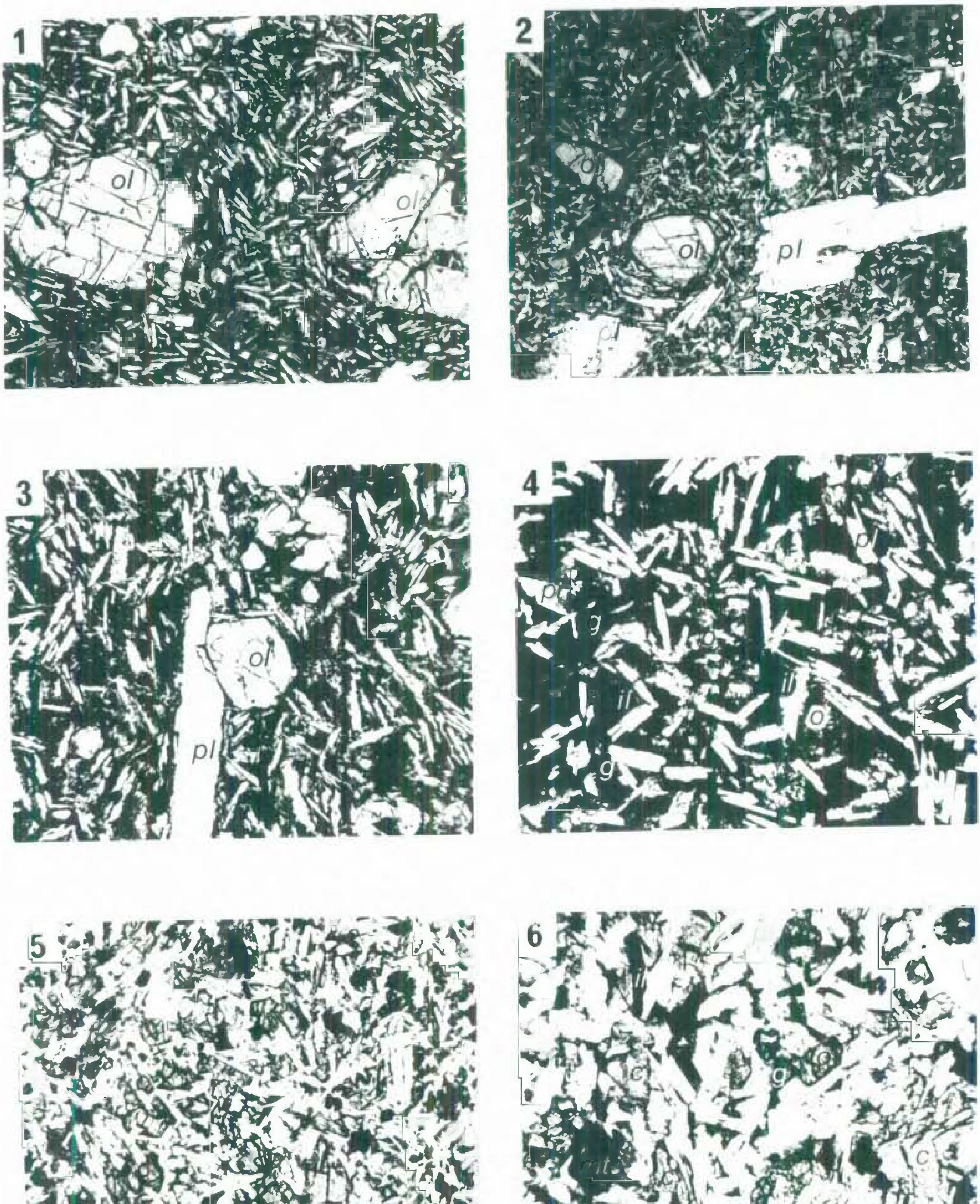


EXPLANATION OF PLATE 2

1. Low-Si tholeiitic andesite 28055 (Table 6.1, No. 10). Microphenocrysts of plagioclase (pl) and clinopyroxene (c) in a groundmass of plagioclase, magnetite and an iron-rich vitric base. Microphenocrysts of olivine occur elsewhere in the rock. Plane polarized light, x 20 magnification.

2. Low-Si tholeiitic andesite 27291 (Table 6.1, No 15). An aphyric rock consisting of plagioclase laths (pl), olivine (o), clinopyroxene (c), magnetite, acicular apatite and abundant residual glass (g). Plane polarized light, x 40 magnification.

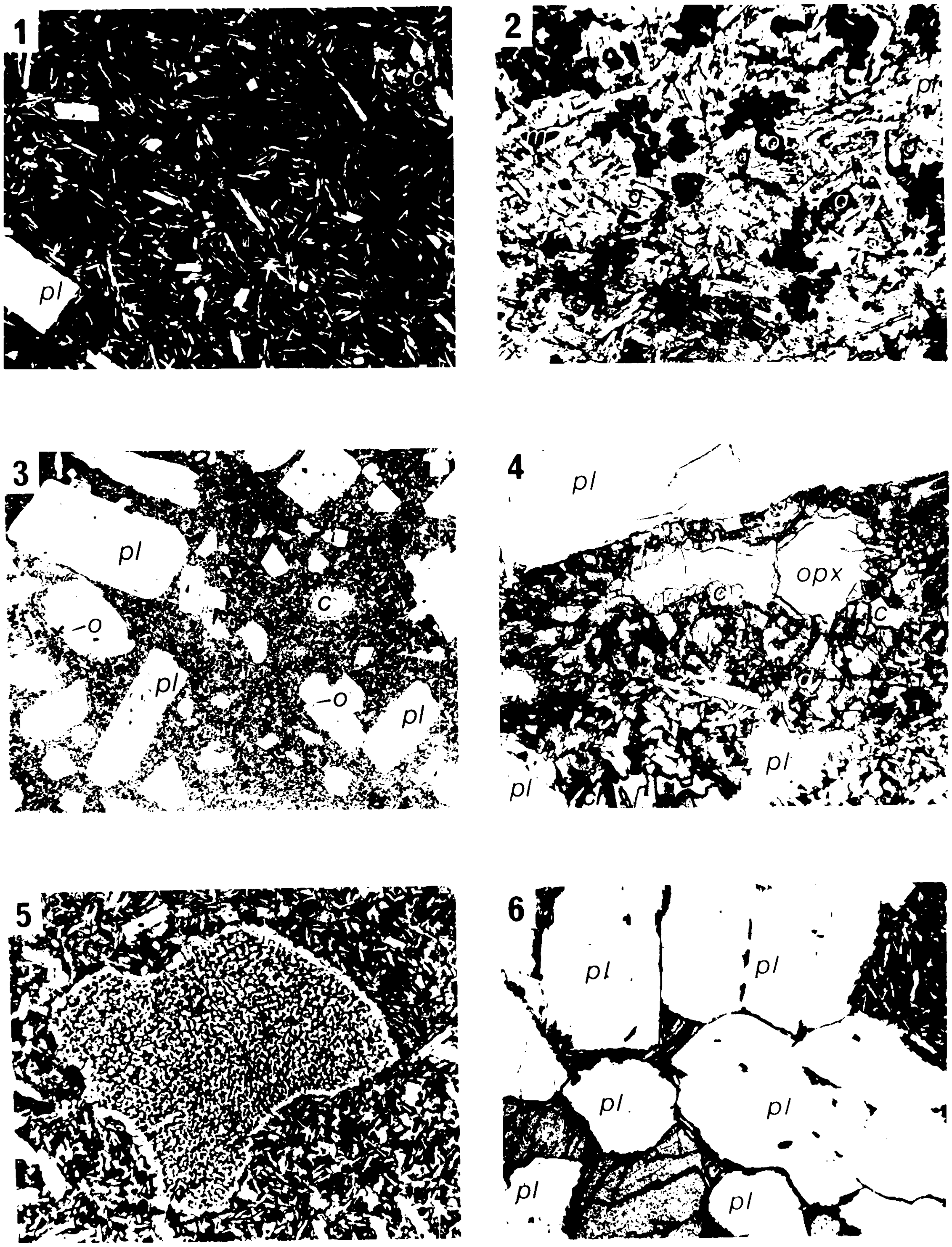
3. High-Al tholeiitic andesite 27290 (Table 6.1, No. 14). Megacrysts of plagioclase (pl) containing inclusions of Al-rich orthopyroxene (o), occasional Al-rich clinopyroxene megacrysts (c) in a groundmass of plagioclase, olivine, clinopyroxene, ilmenite and residual glass. Plain light, x 2 magnification.

4. Reaction corona of clinopyroxene (c) and iddingsite (id; pseudomorphing olivine) surrounding Al-rich orthopyroxene (opx) adjacent to a plagioclase megacryst (pl) in high-Al tholeiitic andesite 27290. The groundmass contains some interstitial chlorophaeite (ch). Plane polarized light, x 40 magnification.

5. Sieved plagioclase megacryst in low-Si tholeiitic andesite 28310. The glassy clear mantle has a similar composition to the groundmass plagioclase ($\sim An_{50}$). Plane polarized light, x 20 magnification.

6. Plagioclase-olivine cumulate in low-Si tholeiitic andesite 28060 (Table 6.1, No. 13). Plane polarized light, x 20 magnification.

# Plate 2



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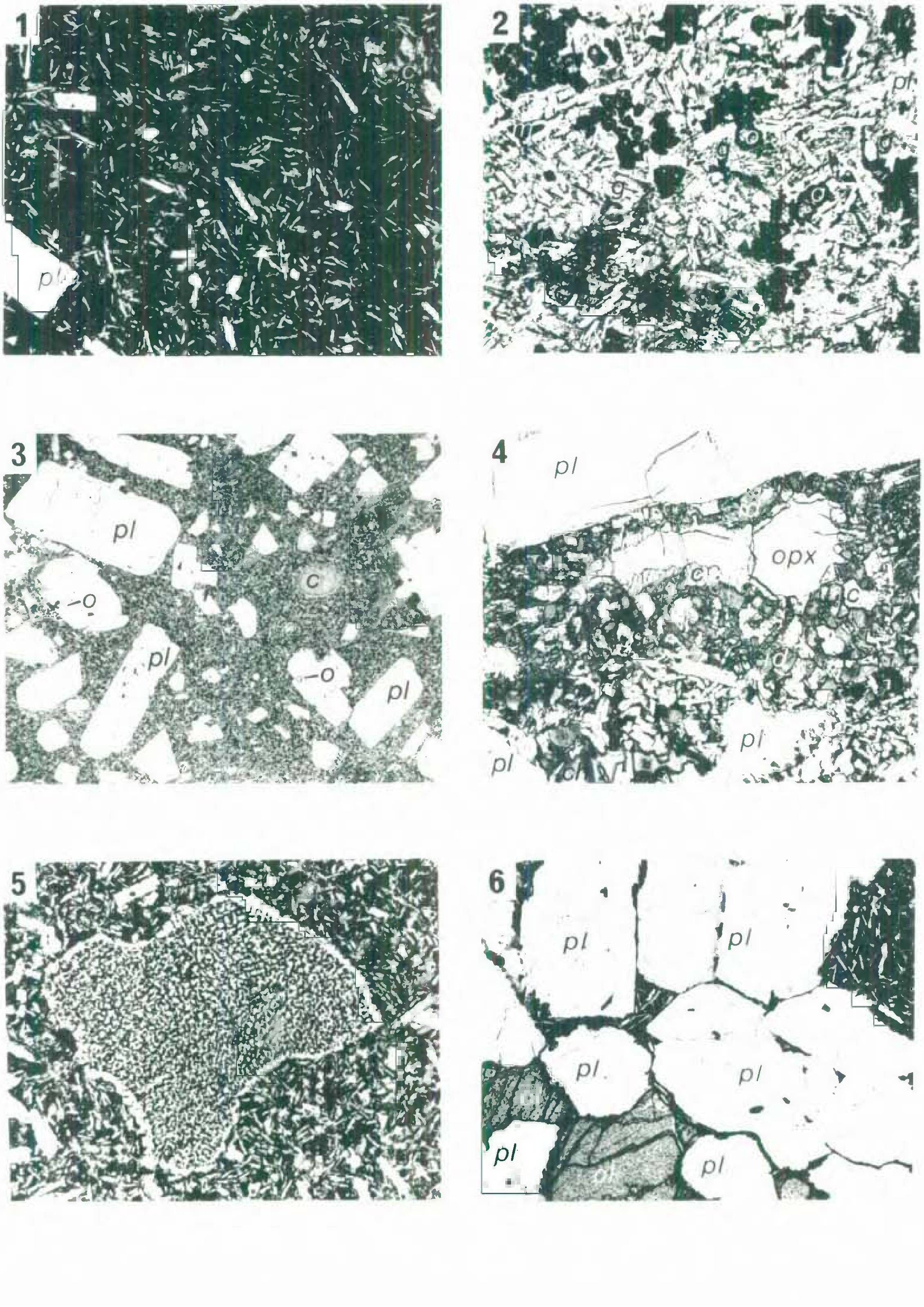


analysed specimens are set down in Table 4.1.

*Olivine:* Microprobe data indicate that olivine compositions are to some extent a function of the size of individual crystals. For example, the larger phenocrysts ($Fo_{80-70}$) up to 2 mm in diameter display normal zoning to less Mg-rich compositions (~$Fo_{60}$); smaller olivine phenocrysts (<0.5 mm) are zoned from $Fo_{70}$ (core) to $Fo_{55}$ (margins) and groundmass olivines are even more iron-rich (~$Fo_{30}$). The olivines display no evidence of reaction with liquid to yield Ca-poor pyroxene.

*Pyroxenes:* Microprobe data indicate that groundmass pyroxenes vary little in composition particularly within individual specimens (Fig. 5.4). Although the compositions of the analysed pyroxenes all fall within the range $Ca_{35}Mg_{50}Fe_{15}$ to $Ca_{43}Mg_{30}Fe_{27}$ atom %, neither Ca,Mg nor Fe in pyroxenes in individual specimens varies by more than 5 atom %. The crystals, which may be small, ragged and elongate or larger (up to 1 mm) and subophitic, often exhibit a decidedly pink tint, particularly those pyroxenes in the more mafic members of the series.

*Plagioclase:* Plagioclase phenocrysts are usually sodic labrodorites zoned to calcic andesine; exceptionally they may be as calcic an $An_{65}$. In some rocks an early generation of plagioclase phenocrysts has an unzoned relatively sodic andesine core mantled by a narrow rim of labrodite. The inner zone is often partly sieved and partially resorbed. The genesis and petrogenetic significance of these phenocrysts will be discussed in more detail in Chapter 5. Groundmass feldspar varies from calcic to sodic andesine. The presence of alkali feldspar has only been confirmed in

Table 4.1

MODAL ANALYSES OF SOME ROCKS OF THE LOW-Si SERIES

| Rock Type | | Low-Si tholeiitic andesite | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Specimen No. | | 28046 | 28048 | 28049 | 28050 | 28051 | 28055 | 27291 |
| Olivine | Phenocrysts | 13.8 | 5.2 | 4.7 | - | - | 1.1 | - |
| | Groundmass | 5.9 | 2.2 | 1.6 | 7.2 | 10.3 | 1.0 | 5.8 |
| Clinopyroxene | Phenocrysts | - | - | - | - | - | 8.9 | - |
| | Groundmass | 21.1 | 18.3 | 12.2 | - | 22.0 | - | 9.7 |
| Plagioclase | Phenocrysts | - | 14.8 | 13.1 | - | 0.8 | 10.2 | 1.2 |
| | Groundmass | 48.2 | 34.0 | 23.2 | 34.2 | 49.3 | 26.0 | 52.5 |
| Ilmenite | | 3.7 | 6.3 | 8.0 | 6.5 | 7.5 | - | - |
| Magnetite | | - | - | tr | | | 6.8 | 8.0 |
| Indeterminable groundmass | | - | 15.7 | 29.4 | 49.6 | - | 43.7 | - |
| Residual glass | | 5.3 | - | - | - | 5.3 | - | 22.1 |
| Chlorophaeite | | 5.0 | 4.5 | 8.7 | 2.5 | 4.4 | 1.7 | 1.7 |
| Apatite | | - | - | - | - | 0.4* | - | - |

For key to localities see Table 6.1.

one specimen (28051) by microprobe analysis as a (very rare) groundmass constituent but probably occurs rather more commonly in the groundmass of these lavas.

*Iron-Titanium Oxides:* Ilmenite occurs as small anhedral grains in the groundmass of most low-Si tholeiitic andesites. Microprobe data (Chapter 5) indicate that the ilmenites have a relatively low $R_2O_3$ component (<8 mol %).

*Residual Glass:* Brownish to pink residual glass usually comprises about 5 % of the groundmass component where it is intersertal to plagioclase laths. Microprobe analyses of the glasses indicate that they are rhyolitic in chemistry (Chapter 5). The glass is often associated with chlorophaeite which varies from pale green and isotropic to brown and fibrous, with a low birefringence. The latter variant is associated with more extensive deuteric alteration and weathering but the former, presumably $Fe^{2+}$-rich, is characteristic of particularly fresh rocks.

<u>Minor Variants of the Low-Si Series</u>

A minor but distinctive variety of low-Si tholeiitic andesite contains small laths of plagioclase ($An_{55-45}$) and granules of olivine ($Fo_{60}$) and opaques in an iron-rich vitric base (Plate 1, No.4). Olivine microphenocrysts ($Fo_{70-60}$) may also be present. The iron-rich residuum is similar in appearance to that in tholeiites from the Inverell area (Wilkinson and Duggan, 1972) where pyroxene occurs as feathery quench crystals together with plagioclase microlites, opaque oxide granules, and glass.

Additional variants of the low-Si tholeiitic andesites include more evolved types containing a sodic groundmass plagioclase, Fe-rich olivine, titanomagnetite and increased amounts of glass. Two types have been recognised. In the first type (28055; Plate 2, No 1) microphenocrysts of augite (average $Ca_{41}Mg_{37}Fe_{22}$), plagioclase ($An_{50-40}$), rare olivine ($Fo_{50}$) and titanomagnetite are set in a groundmass of andesine and opaque-charged residuum. The second type (27291; Plate 1, Nos 5 and 6) consists of granules of Fe-rich olivine ($Fo_{30}$), plagioclase ($An_{45}$) and subophitic pale pink clinopyroxene ($Ca_{32}Mg_{33}Fe_{20}$) titanomagnetite, together with about 20% of colourless Fe-poor rhyolitic glass.

### 4.2.2 High-Si Tholeiitic Andesite

High-Si tholeiitic andesites, the most basic variants of the high-Si series, are characterized by the presence of Ca-poor pyroxene(s), either pigeonite or hypersthene or both.

Flows of high-Si tholeiitic andesite occur sporadically throughout the Lismore Basalt but are extremely rare or absent from the Blue Knob Basalt. They comprise only a small proportion (~5%) of the total volcanic pile.

#### Petrography

High-Si tholeiitic andesites are quite variable petrographically and range from aphyric to porphyritic types carrying phenocrysts of plagioclase, augite, pigeonite, hypersthene, ilmenite and sometimes olivine.

Aphyric variants are fine-grained and consist essentially of plagioclase laths (up to 0.03 x 0.01 mm), augite and pigeonite prisms, ilmenite and abundant pink residual glass (Plate 3, Nos 1 and 2). Hypersthene is absent. The groundmass of the porphyritic types is essentially identical in appearance to the aphyric types.

Modal data on selected porphyritic representatives are set down in Table 4.2 but it must be appreciated that the groundmasses of these rocks are too fine-grained to permit accurate measurements of all phases. Furthermore augite and pigeonite are not readily distinguishable during a point count analysis. However reconnaissance microprobe surveys indicate the augite and pigeonite very often are approximately equal in abundance. Some textural features are illustrated in Plates 3 and 4.

*Olivine:* Olivine occurs only as a phenocryst phase. Where preserved these are relatively Mg-rich ($Fo_{80}$-$Fo_{60}$) and invariably mantled by a reaction rim of pigeonite. More commonly, olivine is pseudomorphed by bowlingite, itself surrounded by pigeonite.

*Pyroxenes:* Augite and pigeonite form microphenocrysts (up to 1.0 x 0.6 mm) which often form glomeroporphyritic aggregates. Intergrowths of plagioclase and augite also occur. Orthopyroxene microphenocrysts are small (up to 0.5 mm), prismatic and invariably mantled by pigeonite (Plate 3, No.6).

Augite commonly occurs as two distinct generations. The first generation consists of ferroaugite (average $Ca_{39}Mg_{23}Fe_{38}$) followed by a more Mg-rich augite (average $Ca_{38}Mg_{44}Fe_{18}$). Pigeonite is the dominant groundmass pyroxene with subordinate augite. Groundmass granules are prismatic and average 0.1 mm in length.

*Plagioclase:* Plagioclase phenocrysts commonly occur in two generations similar to their occurrence in some low-Si tholeiitic andesites. These phenocrysts will be interpreted as products of crystallization under differing pressure regimes (Chapter 5).

Table 4.2

MODAL ANALYSES OF SOME ROCKS OF THE HIGH-Si SERIES

| | High-Si tholeiitic andesite | | | | Icelandite | | Rhyodacite |
|---|---|---|---|---|---|---|---|
| | 28061 | 28062 | 28065 | 28520 | 28067 | 28072 | 28073 |
| Olivine | 0.9 | 1.8[a] | 0.2 | 2.6 | 0.9 | 0.4 | - |
| Clinopyroxene[b] | 0.8 | 3.9 | 1.3 | 6.0 | 1.8 | 0.3 | - |
| Orthopyroxene | 0.2 | 1.0 | 0.2 | 0.4 | 0.1 | 0.1 | 1.6 |
| Plagioclase sieved | 2.0 | - | 0.5 | 1.5 | 5.4 | 2.0 | - |
| Plagioclase unsieved | 4.9 | 11.6 | 3.8 | 16.0 | 2.2 | 1.4 | 8.4 |
| Ilmenite | 0.3 | 0.7 | 0.1 | 1.5 | 0.4 | 0.1 | 0.1 |
| Groundmass | 90.9 | 81.1 | 93.9 | 71.6 | 89.2 | 95.7 | 89.9 |

[a] Pseudomorphed by bowlingite.

[b] Includes augite and pigeonite.

For key to localities see Table 6.2.

Plagioclase belonging to the first generation consist of an essentially unzoned andesine core mantled by a rim of more calcic andesine or sodic labrodorite. In some rocks the core approaches potassic oligoclase or Ca-rich anorthoclase in composition. It is commonly partially resorbed and always sieved to varying degrees. The narrow more calcic mantle is glassy clear and free of inclusions.

The second generation plagioclase phenocrysts are euhedral, free from resorption and sieving and exhibit minor but consistent zoning (from $An_{60-50}$ to $An_{50-45}$). Groundmass plagioclase has a limited compositional range which overlaps that of phenocrysts and may extend to slightly more calcic compositions. However in one specimen (28065) the phenocrysts ($An_{65-58}$) coexist with more sodic groundmass plagioclase ($An_{57}$-$An_{30}$).

*Iron-Titanium Oxides:* Ilmenite is usually the only Fe-Ti oxide. It varies from phenocrysts up to 2.0 x 1.0 mm to groundmass granules.

*Residual Glass:* This is quite variable in appearance and abundance, varying from colourless with abundant Fe-Ti oxide inclusions to deep grey brown and inclusion-free. The groundmass glass is characteristically fresh and deuteric alteration minimal.

4.2.3 Icelandites

Icelandites are comparatively rare in this part of the Tweed Shield, being confined to sporadic flows within the Lismore Basalt. Two small flows of icelandite near Stoney Shute Trig station, 7 km west of Nimbin, have problematical field relations, but their circular outcrop pattern and localised occurrence suggest that they may be plug-like bodies.

Large blocks of icelandite (up to 2 m in diameter) in pumice

EXPLANATION OF PLATE 3

1. High-Si tholeiitic andesite 28063 (Table 6.2, No. 10). Rare microphenocrysts of plagioclase in a groundmass of plagioclase, augite, pigeonite, ilmenite and residual glass. Plane polarized light, x 40 magnification.

2. High-Si tholeiitic andesite 28064 (Table 6.2, No. 4). An aphyric rock consisting of plagioclase laths, augite, pigeonite, ilmenite and residual glass. Plane polarized light, x 40 magnification.

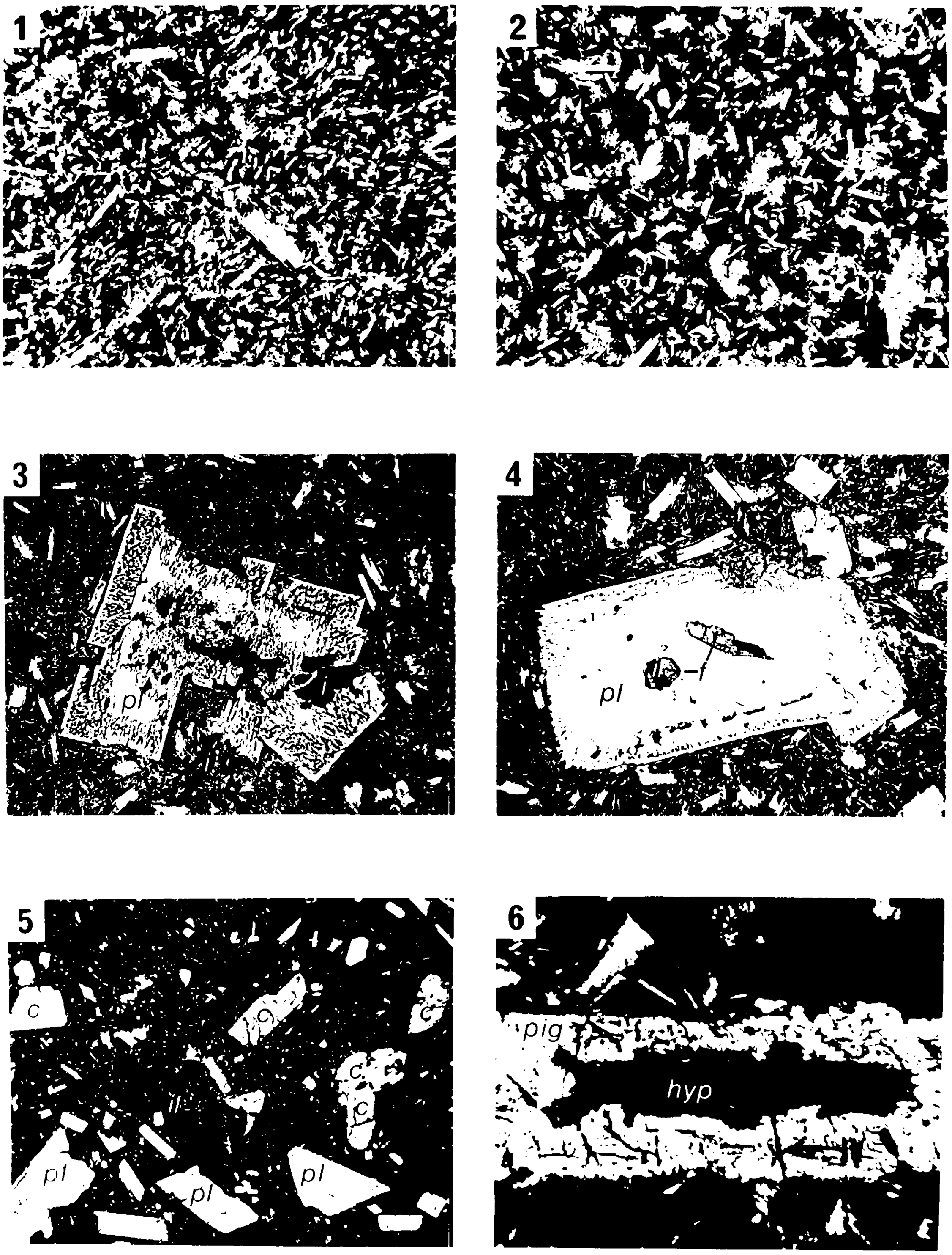
3. Sieved plagioclase phenocryst (pl) in high-Si tholeiitic andesite 28061 (Table 6.2, No. 1). Note the remnant core of unzoned sodic plagioclase ($\sim An_{35}$), the glassy mantle of more calcic plagioclase ($\sim An_{50}$) and the inclusion of ilmenite (i). Plane polarized light, x 20 magnification.

4. Sieved plagioclase phenocryst (pl) containing inclusions of ferroaugite (f) and ilmenite (il) in high-Si tholeiitic andesite 28061. Plane polarized light, x 40 magnification.

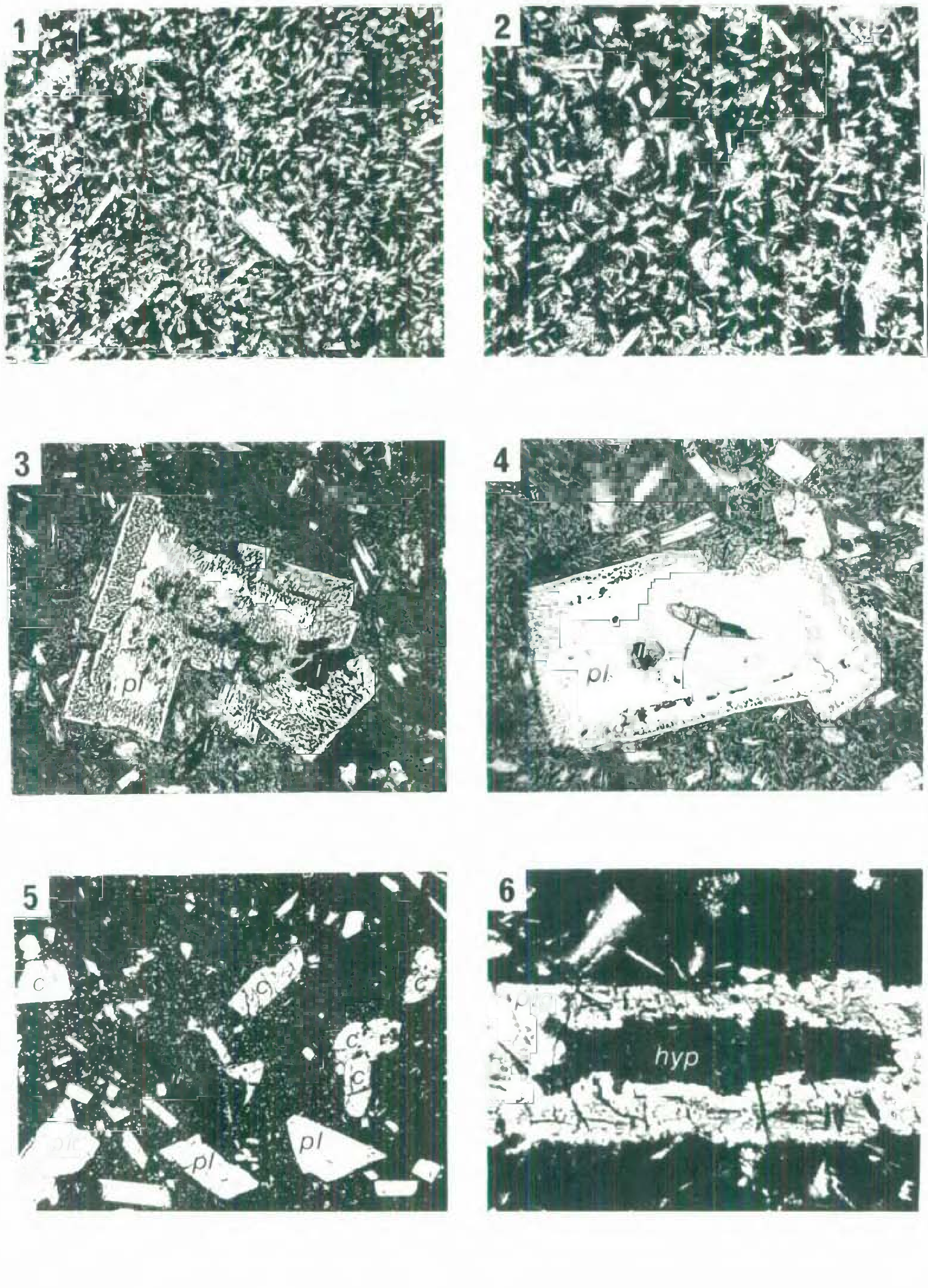
5. Common textural variant of the high-Si tholeiitic andesites. Phenocrysts of clinopyroxene (c), plagioclase (pl) and ilmenite (il) in a fine grained groundmass of the same minerals and residual glass. High-Si tholeiitic andesite 28062 (Table 6.2, No. 2). Plane polarized light, x 20 magnification.

6. Hypersthene (hyp) mantled by pigeonite (pig) in high-Si tholeiitic andesite 28062. Note the irregular interface between the two phases. Crossed polars, x 80 magnification.

# Plate 3



# Plate 3



agglomerate in the Nimbin Rhyolite (28072) are transitional toward tholeiitic rhyodacite.

Petrography

In most respects the icelandites are similar petrographically to the high-Si tholeiitic andesites. Porphyritic types contain phenocrysts of fayalitic olivine, ferroaugite, pigeonite, hypersthene, plagioclase and ilmenite in a groundmass of pyroxene, plagioclase, ilmenite and abundant pink or brown residual rhyolitic glass. Pigeonite and augite, but not hypersthene, have been identified among the groundmass pyroxenes. Principal textural features of the icelandites are illustrated in Plate 4 (Nos 1-4).

In contrast to the tholeiitic andesites, olivine phenocrysts in the icelandites are quite Mg-poor ($Fo_{34}$-$Fo_{17}$). No reaction relation with Ca-poor pyroxene and liquid is evident, but resorption and partial alteration to iddingsite are common.

Plagioclase, pyroxenes and ilmenite resemble analogous phases in the tholeiitic andesites, both in habit and occurrence. However their compositional ranges reflect the more evolved nature of their host rocks. Residual glass is more abundant than in the tholeiitic andesites, comprising up to 40 vol. % of the groundmass.

One rare variety of icelandite (28070) contains small phenocrysts of plagioclase and pigeonite in a groundmass of plagioclase, augite, pigeonite, ilmenite, minor magnetite and abundant residual glass. The latter is colourless and heavily studded with opaque oxide granules.

4.2.4 Tholeiitic Rhyodacites

Although they are rare members of the high-Si series the rhyodacites

EXPLANATION OF PLATE 4

1. Icelandite 28070 (Table 6.2, No. 10). Aphyric variant consisting of plagioclase laths, pyroxene and ilmenite granules and abundant residual glass (g). Plane polarized light, x 40 magnification.

2. Glomeroporphyritic aggregate of sieved plagioclase (pl) and ferroaugite in icelandite 28067 (Table 6.2, No. 8). Plane polarized light, x 20 magnification.

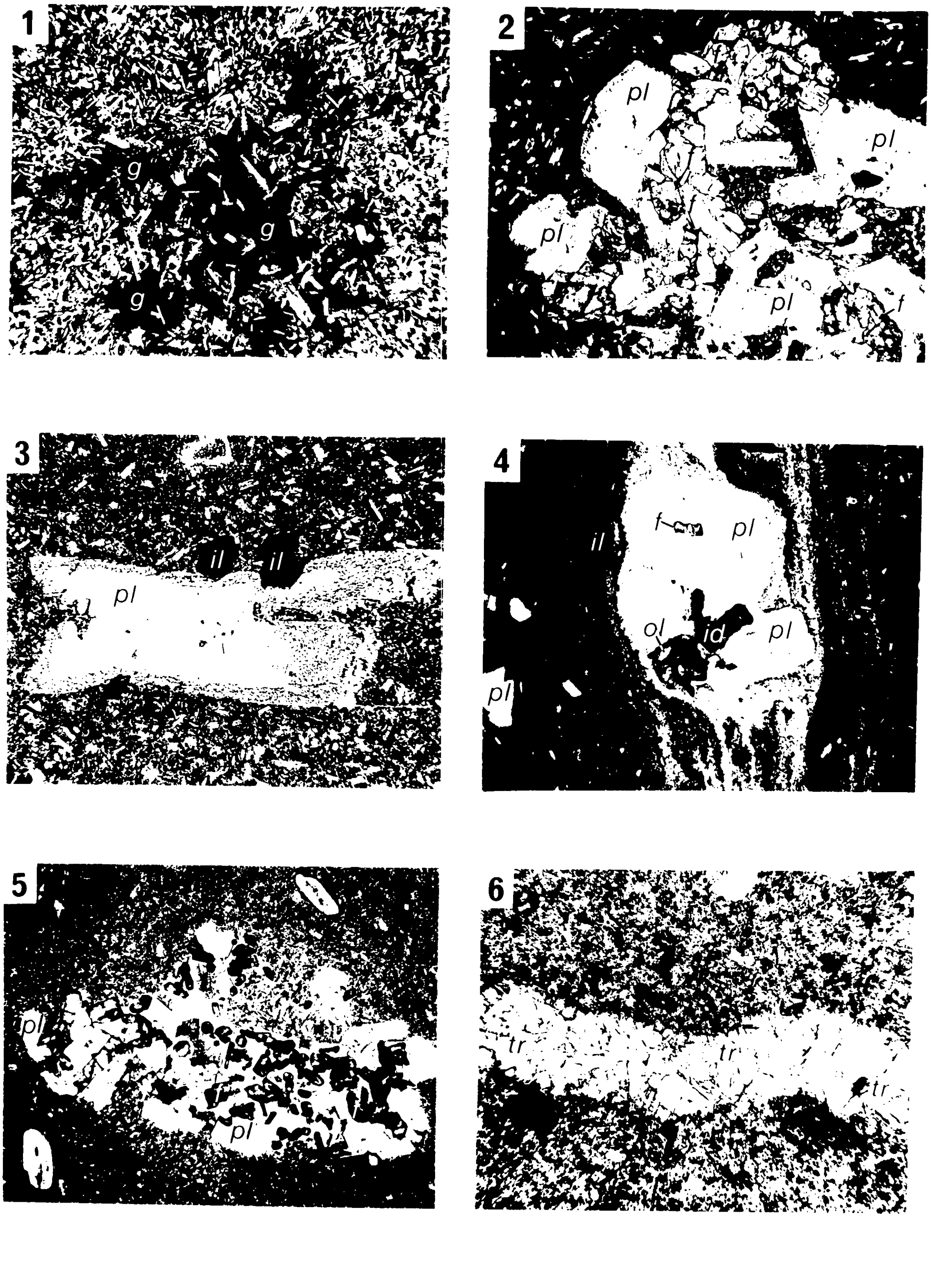
3. Sieved plagioclase phenocryst (pl) and microphenocrysts of ilmenite (il) in a fine grained groundmass of plagioclase, pyroxene, ilmenite and glass. Icelandite 28067. Plane polarized light, x 40 magnification.

4. Aggregate of sieved plagioclase (pl), and olivine (ol) partially pseudomorphed by iddingsite (id), in a fine grained glass-rich groundmass. Icelandite 28072 (Table 6.2, No. 12). Plane polarized light, x 20 magnification.

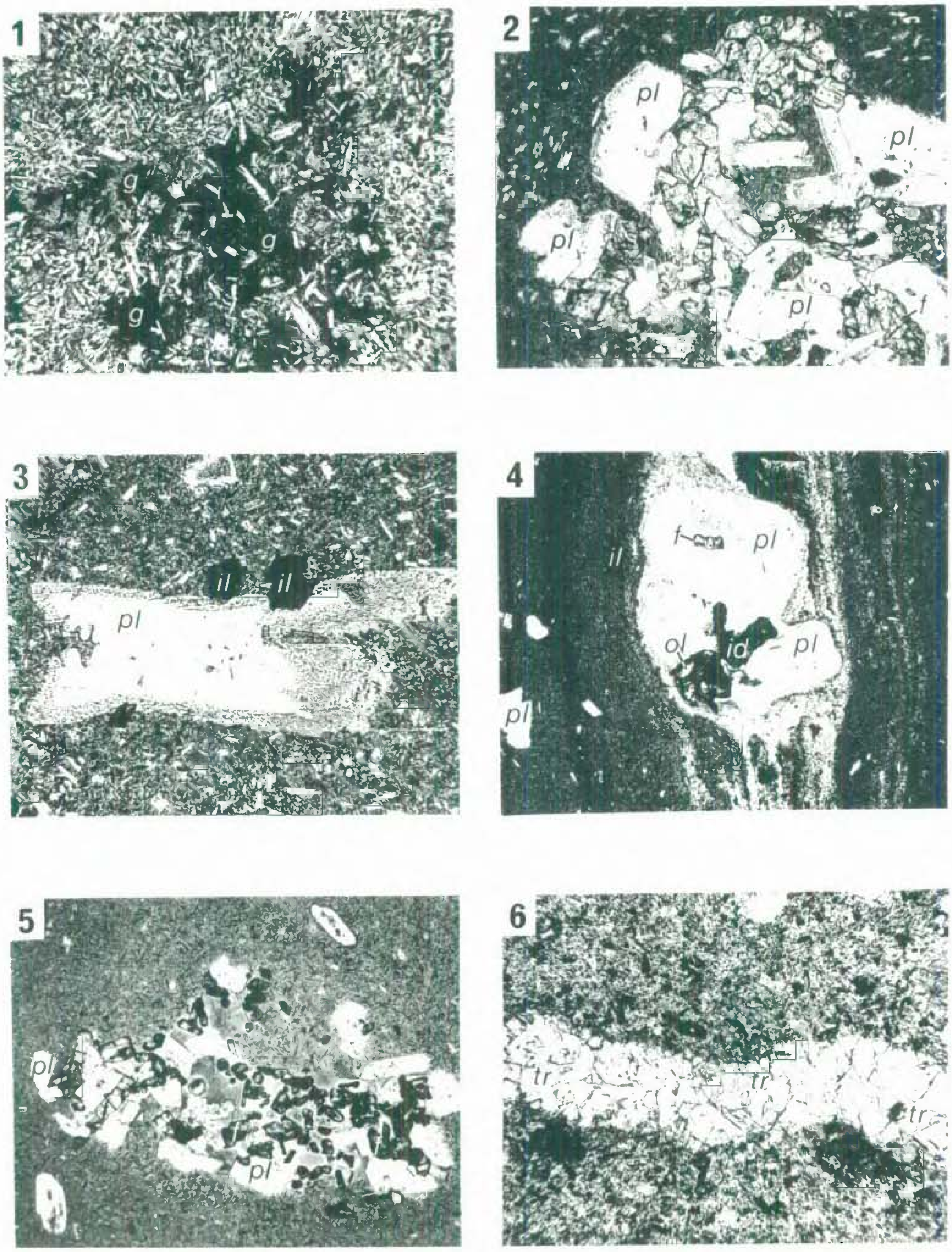
5. Aggregate of plagioclase (pl) and ferrohypersthene (f) crystals enclosing patches of crystal-free glass in rhyodacite 28073 (Table 6.2, No. 13). Plane polarized light, x 20 magnification.

6. Vein of tridymite (tr) in devitrified rhyodacite 28653. The surrounding groundmass consists predominantly of sanidine, oligoclase and cristobalite. Plane polarized light, x 40 magnification.

# Plate 4



# Plate 4



are petrographically distinct rocks linking the icelandites and the ferro-hypersthene-bearing rhyolitic pitchstones. Only two occurrences of tholeiitic rhyodacite have been discovered. One is a small flat-lying extrusive some 50 m thick and about 1 km in diameter capping a small hill on the Koonorigan Range, 3 km east-south-east of Nimbin. Although most of the flow is devitrified, it still retains a glassy basal selvage.

The second occurs on the Lismore-Dunoon road, 4 km north of Lismore, where it intrudes a relatively thick flow of tholeiitic andesite. Outcrop is extremely poor but persistent vertical flow banding suggests it may be a dyke about 100 m wide.

Petrography

When preserved as a glassy selvage, the extrusive rock is black and sub-vitreous. In thin section, microphenocrysts of ferrohyperstene ($Fe_{54}$-$Fe_{61}$) up to 0.5 mm in length, andesine (~$An_{38}$; up to 1 mm) and ilmenite occur in a groundmass of residual glass containing abundant microlites of euhedral plagioclase, alkali feldspar and clinopyroxene. Phenocrysts often form aggregates enclosing patches of pale brown glass almost entirely free of crystalline material (Plate 4, No.5). A modal analysis of this rock is listed in Table 4.2. Devitrified portions of the flow are grey in colour. Original ferrohypersthenes have altered completely to low birefringent fibrous material and opaques. The groundmass is composed predominantly of microcrystalline cristobalite and sanidine with a little quartz. Tridymite occurs partly filling lenticular cavities in the devitrified rhyodacite.

The rhyodacite from the Lismore-Dunoon Road contains several phenocryst species which almost certainly represent a disequilibrium assemblage. Thus phenocrysts of Mg-rich olivine ($Fo_{74}$ zoned to $Fo_{52}$) and ferroaugite ($Ca_{35}Mg_{21}Fe_{44}$) occur in a groundmass containing minute crystals of Fe-rich olivine ($Fo_{23}$) and subcalcic augite ($Ca_{27}Mg_{53}Fe_{20}$); phenocrysts of andesine ($Ab_{61}An_{34}Or_{5}$) and anorthoclase ($Ab_{69}An_{14}Or_{17}$) coexist with more calcic groundmass andesine ($Ab_{51}An_{46}Or_{3}$) and Ca-rich anorthoclase ($Ab_{69}An_{46}Or_{12}$). All feldspar phenocrysts display some evidence of sieving and resorption.

Apart from atypically high Fe, Mg and Na the chemistry of this rock is essentially rhyolitic in character and this, assessed in conjunction with the compositions of its unusual phenocrysts, suggests a rhyolitic liquid mixed with a small proportion of somewhat more basic partly crystallized magma. The intruded flow of tholeiitic andesite is usually thick (about 25 m) and it is conceivable that partly crystallized portions of this flow were caught up by the later rhyolitic intrusive.

### 4.2.5 Rhyolites and Rhyolitic Pitchstones

The Georgica Rhyolite Member and the bulk of the Nimbin Rhyolite are composed of thick flows of rhyolite, some of which attain a thickness of 200 m. These eruptives are laterally persistent over considerable distances. The groundmass of the rhyolite is largely devitrified to a micro-crystalline K-feldspar-silica assemblage but glassy basal selvages (rhyolitic pitchstones) up to 10 m thick are often locally preserved. Several centres of rhyolitic eruption have been recognized. These include Doughboy Mountain (317458) and Mount Tarawyra (315439) near Doon Doon, Nimbin Rocks (201344), The Tower (7.5 km south-west of Nimbin; 135298) and a small plug in Coopers Creek, 2.5 km north of Peach Mountain (362385).

Most rhyolites are porphyritic. However aphyric varieties do occur and are particularly common in the Whian Whian State Forest area. Modal analyses of rhyolites and rhyolitic pitchstones are listed in Table 4.3.

Petrography

*Rhyolitic Pitchstones:* The chilled basal selvages to the larger rhyolite flows are often completely devoid of any devitrification. Porphyritic types contain abundant rounded and embayed phenocrysts of quartz and sanidine, less abundant oligoclase, minor ilmenite, and commonly ferrohyperthene. The sanidines (up to 5 mm in diameter) are relatively potassic ($Ab_{30}An_2Or_{68}$) and often possess a somewhat more sodic margin (up to $Ab_{49}An_3Or_{48}$). Plagioclase phenocrysts ($\sim An_{25}$) are virtually unzoned. Resorption of quartz and feldspar is relatively common (Plate 5, Nos 1 and 2) and in sanidine phenocrysts this may produce a "brain structure" of residual sanidine and glassy corrosion canals.

Pleochroic ferrohypersthene ($Fe_{66-74}$), where present, forms prismatic crystals up to 0.5 mm in length, usually closely associated with ilmenite microphenocrysts. In some flows the original ferromagnesian phases (presumably orthopyroxene) have been completely pseudomorphed by an unidentified colourless low birefringent fibrous material.

Zircon is a common accessory. Very rare grains of allanite are present in some specimens (Plate 5, No.3).

Glass varies from brown through pale brown to colourless and may show well developed flow banding (Plate 5, No.4). Colourless glasses contain

Table 4.3

MODAL ANALYSES OF SOME RHYOLITIC ROCKS

| | Rhyolitic pitchstone | | | | | | Microcrystalline rhyolite | |
|---|---|---|---|---|---|---|---|---|
| | 28075 | 28076 | 28077 | 28078 | 28079 | 28251 | 28084 | 28088 |
| Quartz | 1.3 | 3.9 | - | 6.0 | 12.0 | - | 3.2 | 2.7 |
| Sanidine | 1.3 | 8.8 | - | 9.0 | 6.5 | - | 6.3 | 2.1 |
| Plagioclase | 0.6 | 0.8 | 0.4 | 2.0 | 3.5 | 0.2 | 0.9 | 0.5 |
| Orthopyroxene | 0.6 | 1.0 | 0.3 | - | - | 0.1 | - | - |
| Ilmenite | 0.1 | 0.2 | 0.1 | 0.2 | 0.2 | tr | 0.1 | tr |
| Groundmass | 95.8 | 85.2 | 99.2 | 82.7 | 77.1 | 99.7 | 89.5 | 94.7 |
| Other[a] | 0.3 | 0.1 | - | 0.1 | 0.7 | - | 0.1 | - |

[a] Includes accessory minerals (e.g. allanite,zircon) and fibrous material pseudomorphing ferromagnesian minerals.

For key to localities see Table 6.3.

EXPLANATION OF PLATE 5

1. Rhyolitic pitchstone 28076 (Table 6.3, No. 2). Resorbed and fractured phenocrysts of sanidine (san) and quartz (qtz) occur in a vitric base. Plane polarized light, x 20 magnification.

2. As for No. 1. Crossed polars.

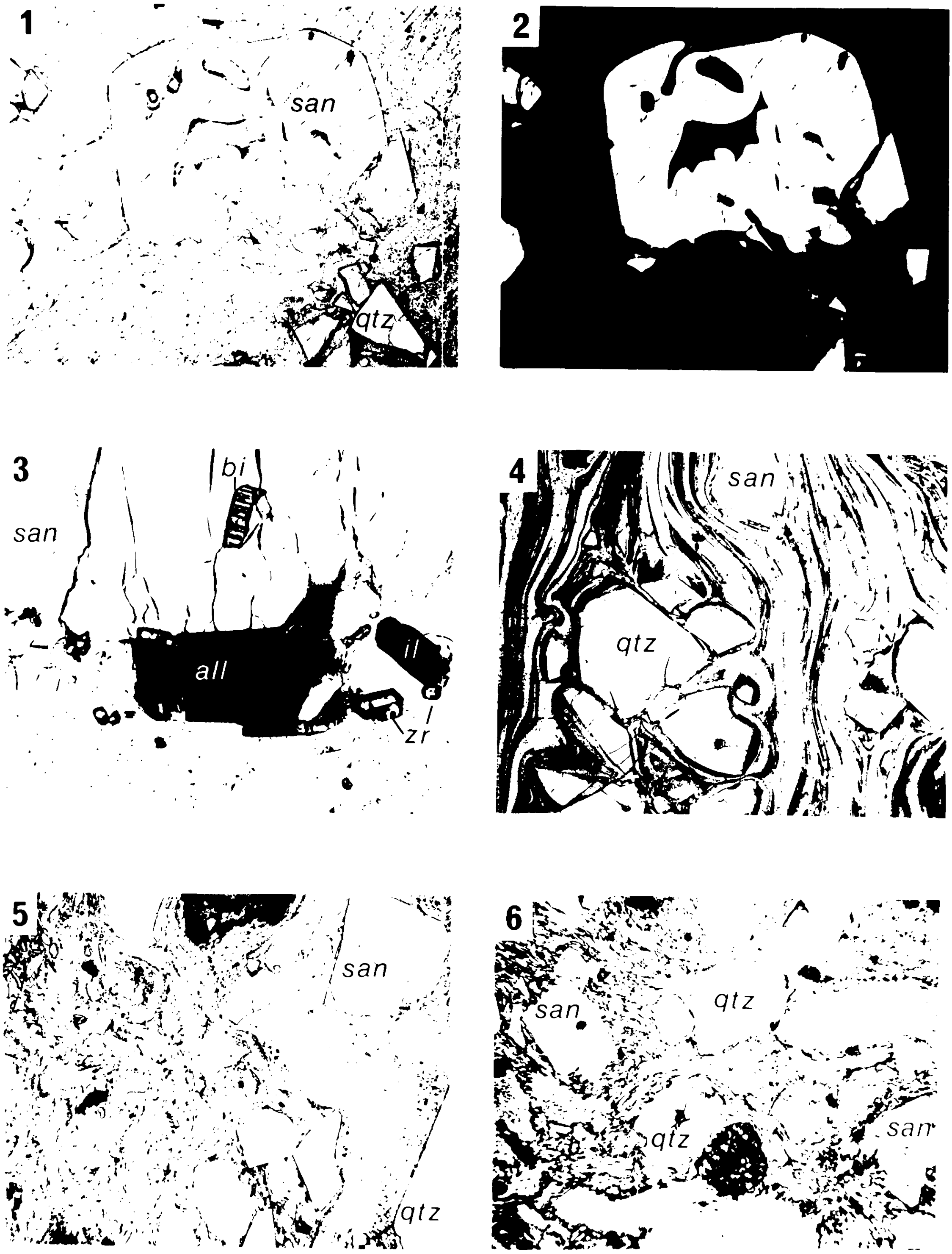
3. Assemblage of accessory minerals, allanite (all), biotite (bi), ilmenite (il) and zircon (zr) included or partially included in a sanidine phenocryst. Rhyolitic pitchstone 28078 (Table 6.3, No. 4). Plane polarized light, x 80 magnification.

4. Rhyolitic pitchstone 28079 (Table 6.3, No. 5). Fractured phenocrysts of quartz (qtz) and sanidine (san) in a flow-banded vitric base. Plane polarized light, x 20 magnification.

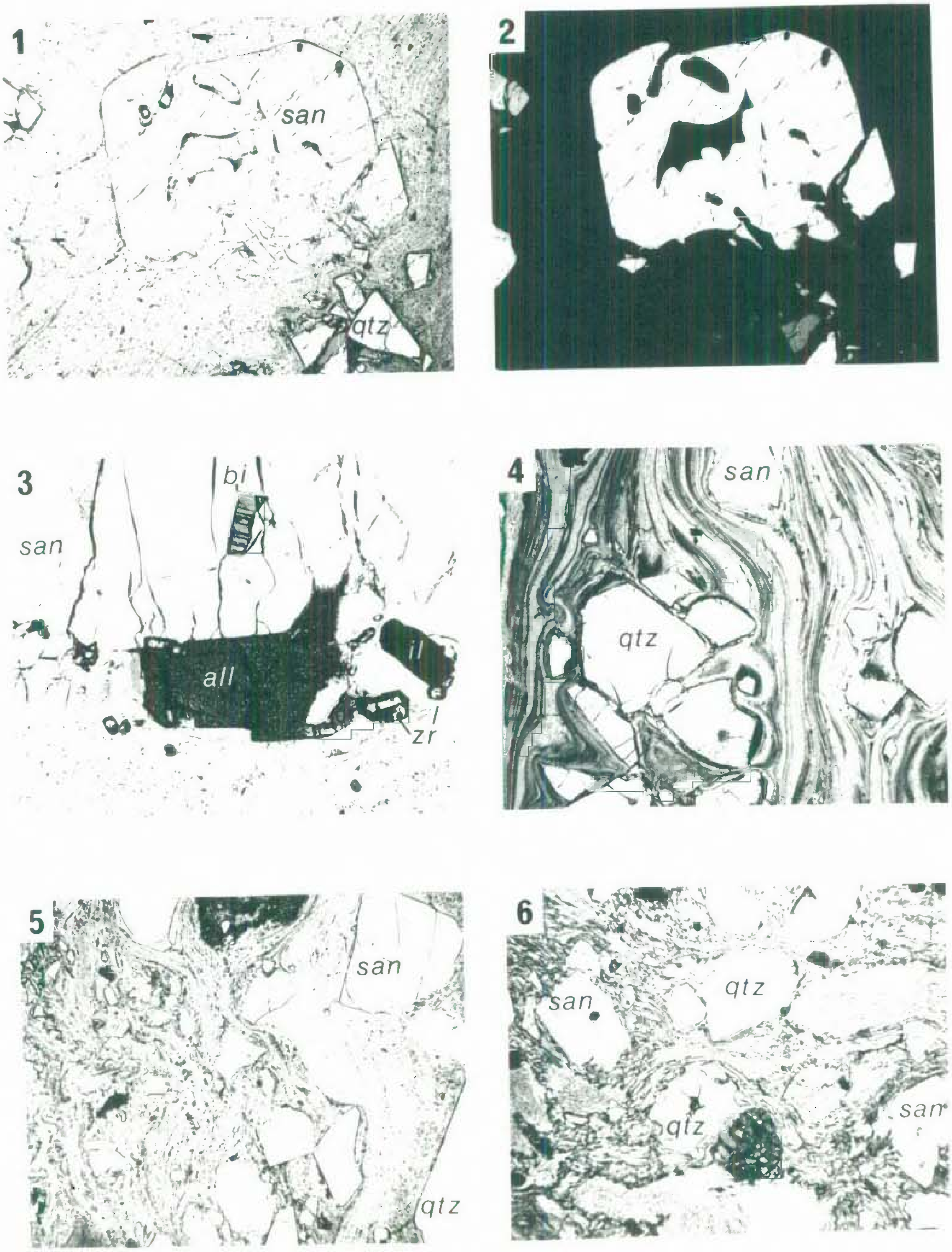
5. Rhyolitic pitchstone 28079. Areas of flow-banded groundmass containing fractured quartz and feldspar phenocrysts (left) and almost unbanded groundmass in which the quartz and feldspar phenocrysts remain unfractured (right). Plane polarized light, x 20 magnification.

6. Welded rhyolitic tuff 28127. Fragmented quartz (qtz) and sanidine (san) phenocrysts occur in a welded base of glass shards and pumice fragments. Plane polarized light, x 20 magnification.

# Plate 5



# Plate 5



a variety of crystallite forms such as trichites, margarites, longulites and globulites. Several trichites often radiate from a common point to from stellate clusters. The high reflectivity of the globulites in polished sections suggests they are an opaque oxide. Trichites and margarites have high relief and are probably pyroxene while longulites usually have much lower relief and are probably feldspars.

Some rhyolitic pitchstones possess alternating layers of banded and unbanded glass, characterized by highly fractured quartz and feldspar phenocrysts (Plate 5, No.5) and more or less unfractured quartz and feldspar respectively.

Every gradation exists from strongly porphyritic types to varieties composed of essentially 100% glass. In the near aphyric types plagioclase was generally the first felsic phase to crystallize, followed soon afterwards by quartz and sanidine as the phenocryst content increased.

*Microcrystalline Rhyolites:* Rhyolites have a similar phenocryst assemblage to the vitric types except that the ferromagnesian assemblage is now always completely altered. The fine-grained groundmass consists of a microcrystalline assemblage of alkali feldspar, silica minerals and a little biotite. X-ray diffraction studies have enabled interpretation of the somewhat complex assemblage of silica minerals developed in the various textural types.

Three principal groundmass textural types may be distinguished. In the first, small oval-shaped optically continuous patches of quartz (~0.5 mm diameter) contain numerous inclusions of sanidine, biotite and hematite. These are scattered through darker pinkish brown material consisting mainly of sanidine and cristobalite with some ragged biotite and hematite granules (Plate 6, Nos. 2-4). The second type is characterized by numerous closely packed microspherulites of cristobalite and sanidine with the characteristic "maltese cross" appearance under crossed nicols (Plate 6, Nos. 5 and 6). These textures are interpreted as products of divitrification of groundmass glass subsequent to solidification. The variety of microlites observed in vitric types commonly persist through devitrification. In addition, alkali feldspar microlites up to 0.1 mm in length commonly develop throughout the groundmass. A third variant, especially characteristic of rhyolite plugs, consists simply of a microcrystalline aggregate of quartz and sanidine devoid of the textural features previously noted (Plate 6, No.1). This probably represents primary crystallization of the groundmass brought about by slower cooling. It is notable that biotite is more abundantly developed in this type than in those described above. Tridymite may occur in any of these textural variants, usually in narrow cavities parallel to flow banding.

#### 4.2.6 Pyroclastic Rocks

Throughout the Nimbin Rhyolite a wide variety of tuffaceous and agglomeratic pyroclastics up to 20 m in thickness occur as discontinuous horizons separating rhyolitic flows. A coarse rhyolitic agglomerate comprises the bulk of the Homeleigh Agglomerate which does however also contain blocks of alkaline eruptives, including mugearite, benmoreite and trachyte. Every gradation exists from lapilli tuffs with fragments up to a maximum 2 mm in diameter through to agglomerates with numerous blocks exceeding 1 m in diameter.

EXPLANATION OF PLATE 6

1. Microcrystalline rhyolite 28086 (Table 6.3, No 14), consisting of quartz (clear), sanidine (cloudy) and a few flakes of biotite. Plane polarized light, x 40 magnification.

2. Flow banded microcrystalline rhyolite 28085 (Table 6.3, No 13) containing ovoid areas rich in quartz and turbid areas of sanidine and cristobalite. Some tridymite occurs in cavities parallel to the flow banding. Plane polarized light, x 40 magnification.

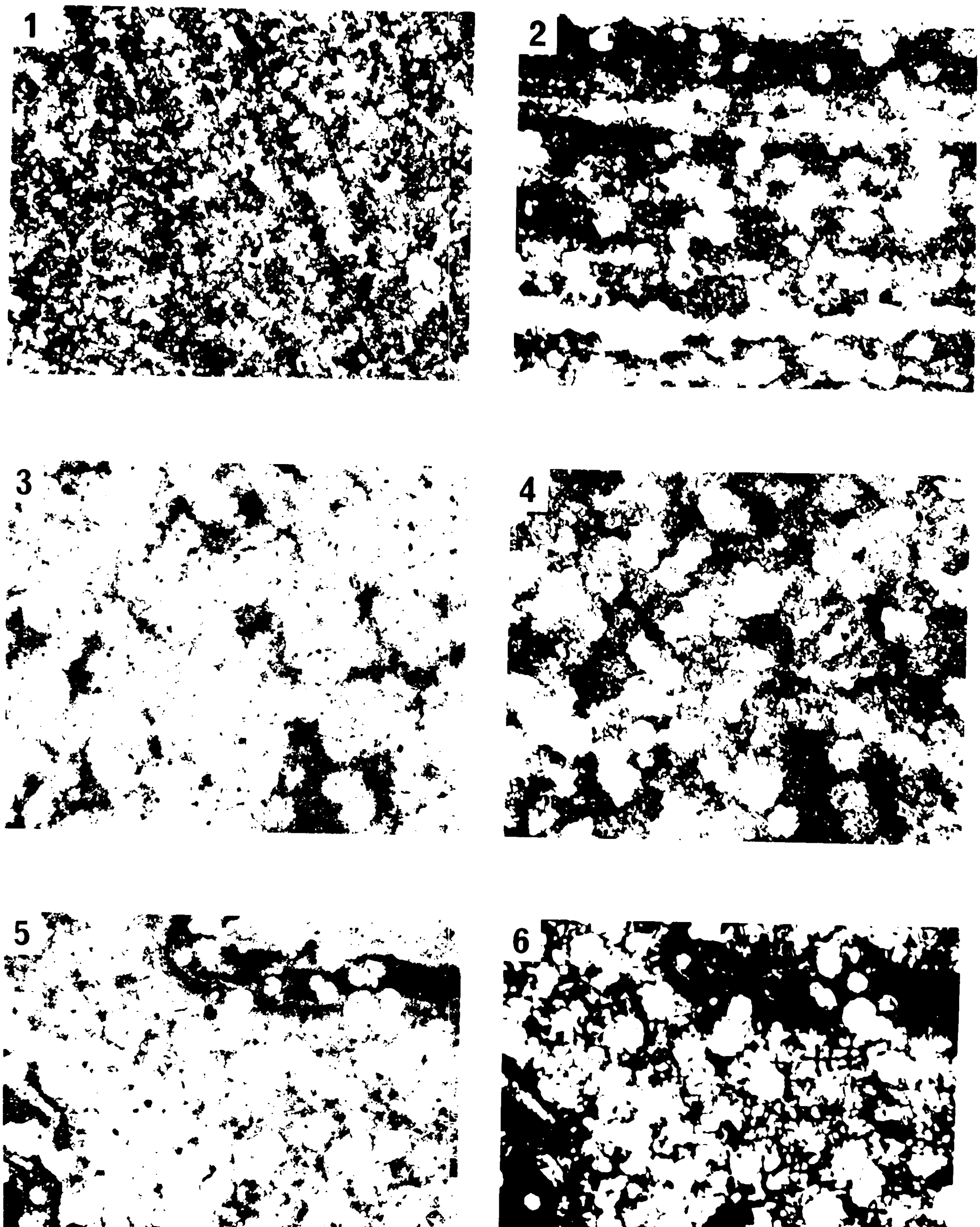
3. Microcrystalline rhyolite 28465. Light coloured areas are rich in quartz and sanidine with a little biotite. Turbid areas contain some cristobalite. Plane polarized light, x 40 magnification.

4. As for No 3. Crossed polars.

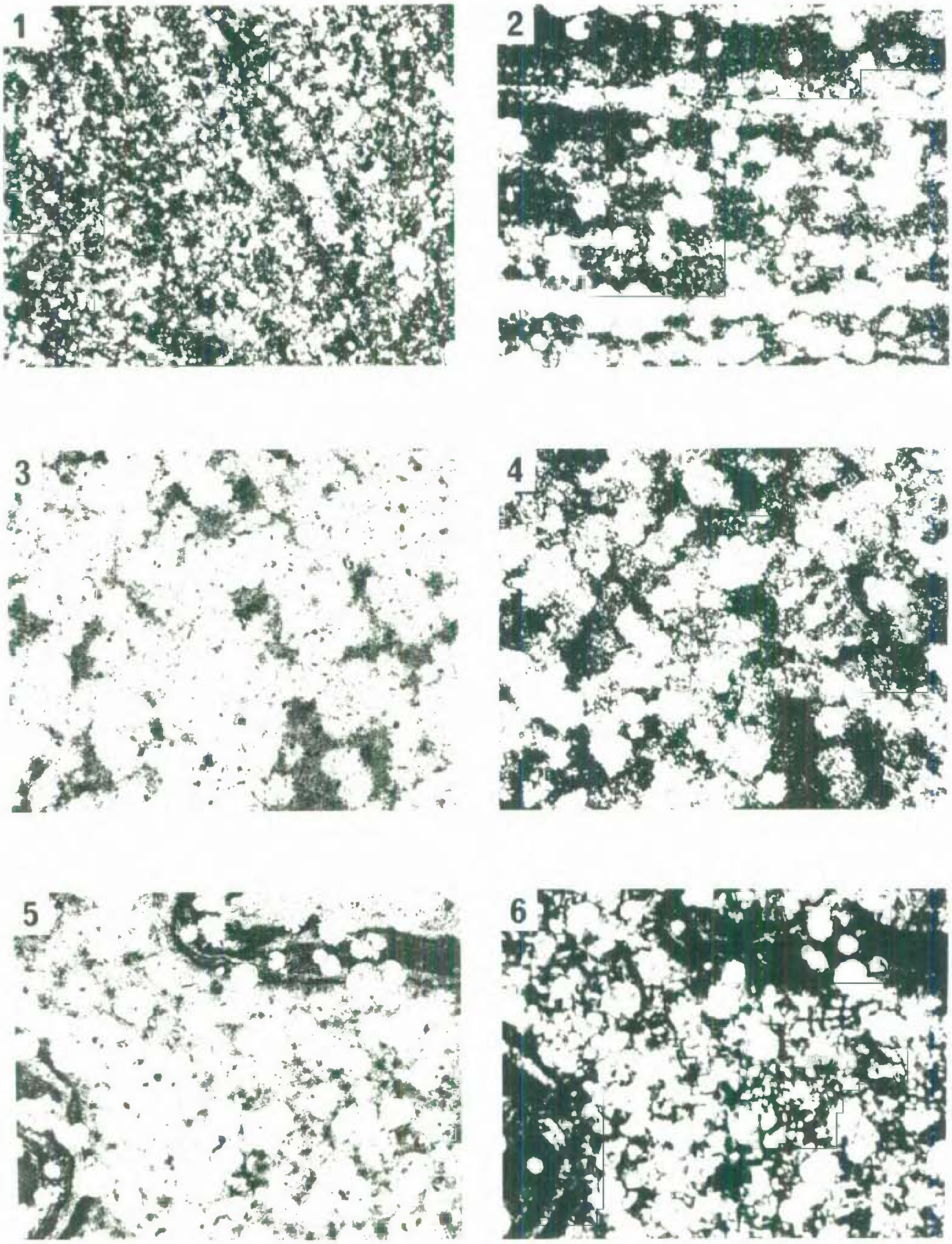
5. Flow-banded microcrystalline rhyolite 28160 containing ovoid patches of quartz and turbid areas of sanidine, cristobalite and quartz. Biotite flakes occur throughout the rock. Plane polarized light, x 40 magnification.

6. As for No 5. Crossed polars. Note the "maltese cross" appearance produced by the radiating chalcedonic quartz.

# Plate 6



# Plate 6



Pyroclastic horizons within the Nimbin Rhyolite consist predominantly of blocks of pumice, rhyolitic pitchstone and less commonly highly altered fragments of basaltic and andesitic rocks, apparently of tholeiitic affinity. The abundance of pumice fragments renders many of the pyroclastics very friable and consequently prone to rapid weathering.

Petrography

In thin section, the matrix consists of broken crystals of quartz, sanidine and plagioclase, and abundant glassy pumice fragments and glass shards which sometimes show evidence of compaction and welding (e.g. 28130; Plate 5, No.6).

Occasional pumice tuff and pumice agglomerate horizons consist entirely of pumice fragments. Minimal post-depositional compaction is indicated by the tendency for gas bubbles in the pumice fragments retain their original spherical shapes.