THE GEOLOGY AND GEOCHEMISTRY OF THE GUNUNG PANI GOLD PROSPECT, NORTH SULAWESI, INDONESIA

by

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III. GEOLOGY OF THE PANI VOLCANIC COMPLEX AND RELATED ROCKS

3.1 Introduction

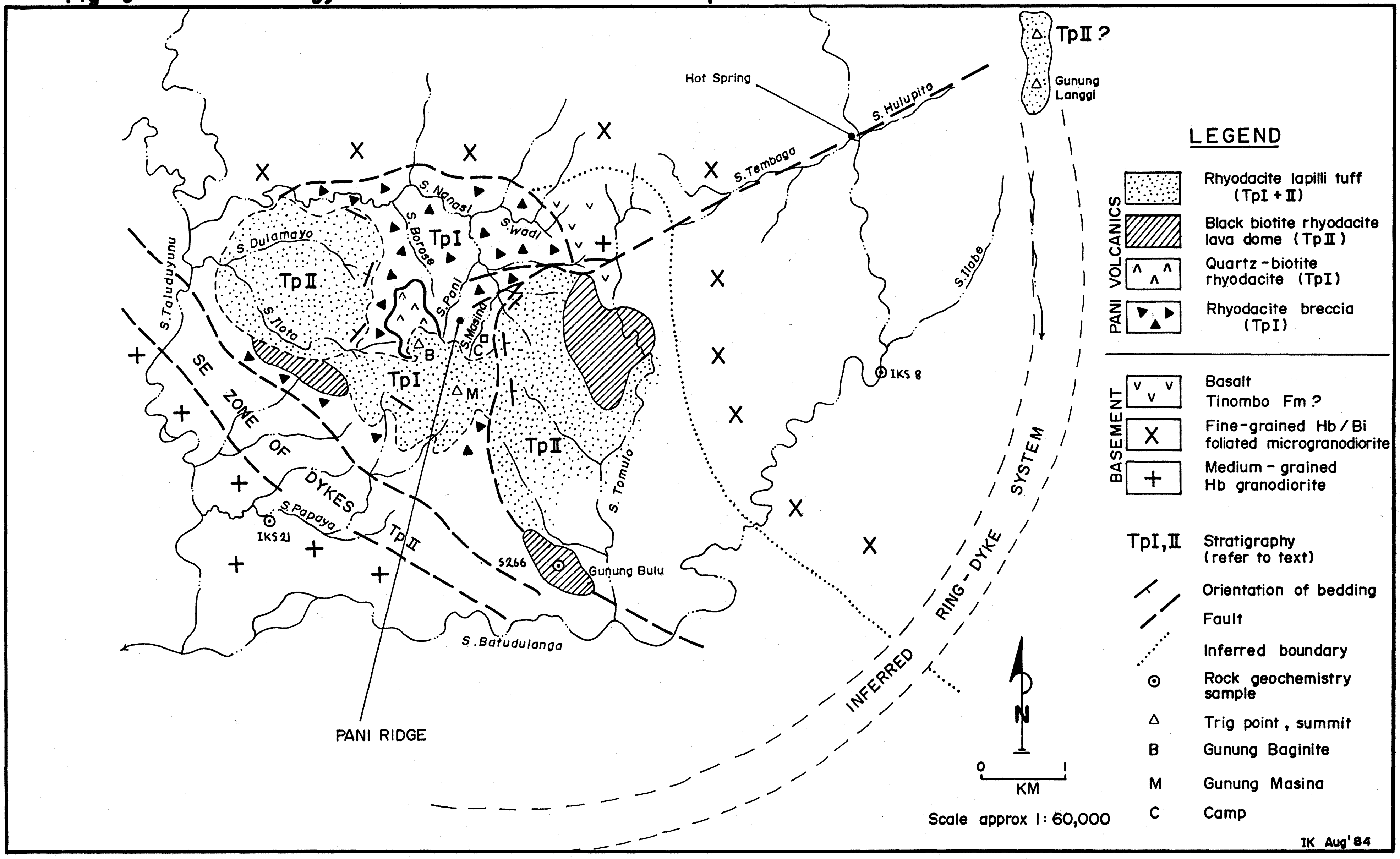
The Pani Volcanic Complex (Fig. 5) consists of non-welded pyroclastics, breccias and massive or flow banded lava-like rhyodacites, essentially confined to a partly circular structure of about 3.5km diameter, within older granodiorite basement. The adjacent basement is extensively intruded by rhyodacite dykes and porphyritic microgranites. These rocks comprise more than 50% of the area within a 20km radius of the Pani Volcanic Complex. On the SW margin of the volcanic structure a dense dyke swarm appears structurally controlled mainly in an ESE direction.

It has been concluded from these broad relationships that the Pani Volcanic Complex represents a deeply eroded remnant of an acid volcanic centre. The Pani Complex has at least one other major counterpart in the area, which reinforces this conclusion (the Tabulo ring-dyke Complex). Description of rocks from the Tabulo structure are referred to in the following sections.

3.2 Lithology

Mineralogically the Pani Complex igneous rocks are remarkably similar, although they comprise a wide range of textural types, from massive porphyritic rhyodacites to lapilli tuffs, agglomerates and volcanic breccia.

Fig 5 Geology of the Pani Volcanic Complex



The majority of rocks comprising the Pani Volcanic Complex are buff or pale green porphyritic rhyodacites ($SiO_2 \geqslant 70\%$) or rhyolites, with 40-65% phenocrysts (1-3mm) of sodic plagioclase, quartz, biotite and sanidine, in order of decreasing abundance. Groundmass textures are siliceous and aphanitic. Accessory minerals are titaniferous magnetite, sphene, allanite, apatite and zircon. Hornblende as well as biotite occurs in less silicic rhyodacites with a lower quartz phenocryst content, but these lithologies are subordinate.

3.3 Stratigraphy and structure

To date the stratigraphy of the Pani Volcanic Complex is only understood in the broadest of terms, and essentially only two units are recognised (TpI and TpII) (T : Tertiary; p : Pani Volcanics; I : unit I).

However, these are genetic units defined upon gross mineralogy, as well as distribution, and are therefore independent of textural type, which includes fine pyroclastics, agglomerates, lavas and breccias. Intrusive equivalents are also correlated.

The term Pani Volcanics refers to the whole volcanic field, including subvolcanic equivalents (porphyritic microgranodiorites), and is not restricted to the Pani Volcanic Complex. A similar comment applies to the two subdivisions, TpI and TpII.

In the Pani Volcanic Complex (Fig. 5) the lowest portion stratigraphically consists of rhyodacitic volcanic breccia and agglomerate of unknown thickness filling the main structure of 3.5km in diameter. Up to 50% of this unit is composed of massive and flow banded quartz-biotite porphyritic rhyodacite, both as lavas and shallow intrusives. The intrusives are not restricted to the structure and may be as voluminous and widespread in the adjacent basement.

Subordinate to agglomerates and breccias are matrix-rich rhyodacitic lapilli tuffs composed predominantly of lithic clasts of quartz-biotite porphyritic rhyodacite, and very minor rhyodacitic crystal-ash tuffs. All of the pyroclastic units are non-welded.

This assemblage, mineralogically dominated by quartz-biotite porphyritic rhyodacite, is denoted as TpI.

Higher in the stratigraphic sequence rhyodacitic lapilli tuffs predominate over agglomerates or breccias.

There is a transitional change stratigraphically with increasing amounts of a distinctive lithology referred to as black-biotite porphyritic rhyodacite.

The sequence dominated by black-biotite porphyritic rhyodacite is denoted as TpII. The mineralogy of TpI and TpII lithology is described subsequently. The TpII lithology reflects a slight change in the mineralogy and chemistry of volcanic products which is accompanied by differentiation of the early volcanic structure into several overlapping subsiding centres, and extrusion of black-biotite rhyodacite lavas and domes within and on the margins of these structures (Fig. 5). Quartz-biotite porphyritic rhyodacite intrusives belonging to TpI lithology become less common in the upper parts of the non-welded pyroclastic sequence. In the subsidence structure east of Gunung Masina (Fig. 5), the centre is predominantly composed of black-biotite rhyodacite pyroclastics and lavas. This structure is bounded on the NW by a steep arcuate fault intruded by dykes, including hornblende-biotite porphyritic rhyodacites, which elsewhere are typical as ring-dykes. These hornblende bearing lithologies probably correlate to TpII lithology. The SE boundary of this structure has not been defined by mapping.

The circular structure NW of Gunung Baganite (Fig. 5) may also be mainly dominated by TpII lithology, but not enough information is available to be certain. The base of this sequence is exposed in a small creek draining into Sungai Nanasi and consists of 3m or more of buff, fine to medium-grained calcareous tuff, massive or laminar bedded, overlain by at least several metres of coarsely bedded lapilli tuff, composed of subrounded TpII lithology clasts with a calcareous matrix. These units are overlain after an area of no outcrop by more buff lapilli tuff containing accretionary lapilli, and dip at a shallow angle to the SW. The exact transition from the underlying TpI breccia-agglomerate assemblage is not exposed.

The lapilli tuff sequence in the centre of the early volcanic structure, including Gunung Baganite and Gunung Masina, is not well understood and may include pyroclastic components of both TpI and TpII volcanicity. A 120m thick homogeneous sequence of hydrothermally silicified non-welded pyroclastics capping Gunung Baganite are subhorizontal, coarse bedded and graded and contain accretionary lapilli. Clasts are subrounded to angular, average lapilli size and are composed mainly of TpI lithology. On nearby Gunung Masina similar pyroclastics seem to occur but are highly weathered. The steep exposed flanks of Gunung Baganite consist mainly of rhyodacitic breccia, followed outward by buff lapilli tuffs with accretionary lapilli textures. The limited structural evidence suggests resurgent doming about Gunung Baganite, which occupies the centre of the breccia filled structure. The flanking lithologies are however structurally complex and apart from general interpretations it is not clear what they represent structurally or stratigraphically.

The northern edge of the Pani Volcanic Complex (Fig. 5) is reasonably well defined by the mapped limits of rhyodacitic breccia and agglomerate but the precise confining structure has not been observed due to very intensive dyke intrusion.

The rhyodacite breccia filled volcanic structure is intersected, or lies on a major N60E fault zone (Tembaga Line) connecting it with a similar lithological pyroclastic deposit (?) (an outlier or vent) restricted to the summit of Gunung Langgi, 10km away. The 'Tembaga Line' is intruded by large porphyritic rhyodacite dykes up to 30m wide correlated to TpI lithology, and also localises active hot springs in Sungai Batudulanga (Fig. 5).

The summit of Gunung Langgi forms part of an arcuate morphological feature composed of a chain of high ridges extending S and SW, which present an impressive topographical wall to the coastal lowland. The Pani Volcanic Complex lies near the centre of this circular feature. The topographic feature has not been investigated, but could represent a ring-dyke system. Morphologically at least it is analogous to the Tabulo structure.

Apart from the Tembaga Line, major controlling structures for the Pani Volcanic Complex are probably oriented ESE (Fig. 5). The drainage and morphology strongly expresses lineaments at N30E and N150E which are known on a regional scale from 1:250,000 SLAR imagery and affect the central part of the north arm of Sulawesi.

3.4 Geology of the Gunung Pani Prospect (Plate 2)

The Gunung Pani Prospect is located in the centre of the Pani Volcanic Complex. The prospect is physiographically dominated by Gunung Baganite and Gunung Masina, elevation 780m and 750m respectively, which rise several hundred metres above deeply incised valleys in rugged topography. Gold is widely dispersed in the surrounding drainage, but the distribution suggests most is shed from the Pani ridge and the flanks of Gunung Baganite as well as along the Tembaga Line.

3.4.1 Pani Ridge

Pani ridge from surface mapping and drill core is found to be composed of pyroclastics that grade from lapilli tuffs to agglomerates, intercalated flow banded rhyodacite, lavas, breccias and silicified rhyodacitic intrusives (?).

Relative proportions of the above listed components are difficult to estimate, but possibly up to 50% of the geology can be considered to be composed of lapilli tuffs, agglomerates and breccias whilst the remainder consists of intrusives and lavas in unknown proportion. Silicified rhyodacite bodies could make up 30% of the ridge between drillholes 2 and 7. These rocks are characteristic of the prospect and are related to gold mineralisation.

From the geometry of surface outcrop and drilling the silicified rhyodacites are difficult to interpret and may be irregular intrusive bodies or in part conformable lava-like bodies. It is believed that the silicified rhyodacites are not zones of preferential silicification within a complex sequence. They are texturally uniform and exhibit clear contacts, with parallel flow banding.

Rhyodacitic wallrocks may be composed of flow banded lavas, pyroclastics or breccias. Wall rocks are much softer, rarely silicified, typically grey but often showing iron staining, adjacent to the silicified bodies.

Ferruginised (oxidised pyrite) fractures and veining, and minor quartz-adularia vuggy fracturing, is common in wall rocks, typically extending a few metres from contacts. Locally rich gold mineralisation occurs in these ferruginised fractures.

Intercalated pyroclastics on Pani ridge in outcrop and drillhole commonly exhibit mass flow textures due to gravity slumping (section 3.5.4, 5) and mud-flow type (lahar). Pyroclastics on the summit of Gunung Baganite, possibly Gunung Masina, and on the road directly east of Gunung Masina, are distinguished by lack of such features, but instead are coarsely graded or laminar bedded and characteristically containing accretionary lapilli. In finer tuffs scour and fill sedimentary structures occur.

The pyroclastic and lava sequence on Pani ridge is complex, dips at high angles and may in part be chaotic. Even general features such as overall dip and strike are not well known. Dips in drillholes vary from subhorizontal to subvertical, commonly the latter.

3.4.2 Baganite

Gunung Baganite is a steep sided mass of relatively homogeneous rhyodacite, capped by 120m of lapilli tuff with low dips. Drilling indicates a single rhyodacite unit below the lapilli tuff of at least 200m in vertical dimension.

The porphyritic rhyodacite differs from the siliceous rhyodacite bodies on Pani ridge in scale, coarser grainsize, and massive rather than flow banded structure. The upper part near the contact with the lapilli tuff is moderately to strongly silicified and locally quartz-veined and stockwork veined.

The contact is almost certainly intrusive.

The flanks of Gunung Baganite are composed mainly of rhyodacitic breccia. Clear contacts to adjacent geology have not been observed; instead silicification and quartz veining decrease and a mixed assemblage of flow banded rhyodacite and breccia, in some cases subvertical, becomes dominant over largely uniform and coarse-grained porphyritic rhyodacite.

These relationships suggest the Baganite porphyritic rhyodacite may be dome-like intrusive with a flat roof.

3.5 Petrography of Unit I (TpI)

3.5.1 General

Quartz biotite porphyritic rhyodacites typify TpI stratigraphy and form the centre of the Pani Volcanic Complex, including the prospect area. This lithology is of special interest since, where silicified, it hosts the gold mineralisation and is therefore described in considerable detail.

Quartz biotite porphyritic rhyodacites encompass the following textural types:

1. intrusives (section 3.5.2)
2. lavas (section 3.5.3)
3. breccia (section 3.5.4)
4. non-welded pyroclastics (section 3.5.5)

All these lithologies share the same mineralogy, described subsequently.

3.5.1.1 Porphyritic textures

Porphyritic rhyodacites belonging to the Pani Volcanics generally, and in particular to TpI lithology (quartz-biotite rhyodacites), are characterised by a high phenocryst content (50%).

The phenocryst assemblage is characterised by glomeroporphyritic aggregates and composite crystals (Fig. 6) involving all the main mineral phases. Plagioclase, biotite and allanite inclusions occur in sanidine and quartz phenocrysts. Quartz has been found to enclose plagioclase and the reverse also occurs (Fig. 6). In addition quartz phenocrysts show multiple overgrowths each tending to produce euhedral bipyramidal crystals alternating with phases of resorption.

Bent (annealed?) plagioclase phenocrysts have been observed in thin section; without obvious recrystallisation or deformational lamellae. Instead these odd phenocrysts exhibit strong reaction with the surrounding groundmass and have indistinct boundaries.

3.5.1.2 Phenocryst mineralogy

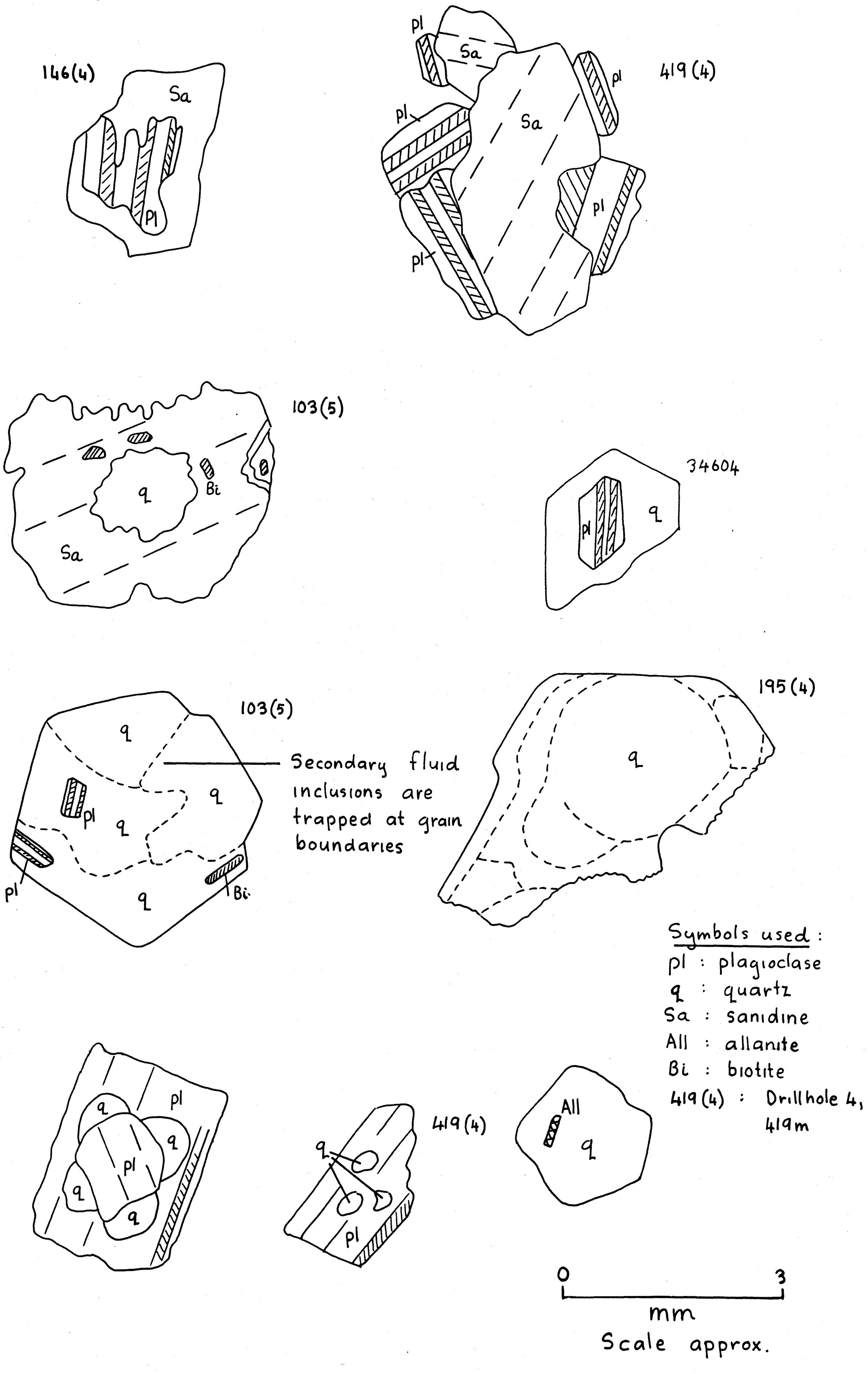
Sodic plagioclase (35%)

Subhedral, tabular plagioclase, typically 2-3mm in size, is the predominant phenocryst phase, exceeding quartz by a ratio of 2:1 to 3:1. Plagioclase is commonly glomeroporphyritic.

Unaltered plagioclase is strongly zoned and ranges in composition from andesine to possibly albite, and exhibits Carlsbad and Albite twins.

Plagioclase is commonly strongly alkali metasomatised, particularly in the prospect area, exhibiting loss of Albite twins and replacement by clear patches (usually albite).

Fig 6 : Composite phenocrysts from quartz-biotite porphyritic rhyodacites



Plagioclase phenocrysts from the prospect area are distinctive in containing irregular tubular dissolution cavities oriented along major crystallographic directions.

Quartz (5-10%)

Quartz phenocrysts, typically 3mm in size, but ranging from 1mm to 5mm, vary from euhedral bipyramidal Beta-quartz forms to highly resorbed and embayed irregular crystals. Large quartz phenocrysts show evidence of multiple growth stages and inclusions of biotite, allanite and zircon. In addition fluid inclusions are relatively common (Photo 4).

Biotite (5-10%)

Fresh biotite is rarely observed, usually being partly or completely replaced by chlorite and/or sericite.

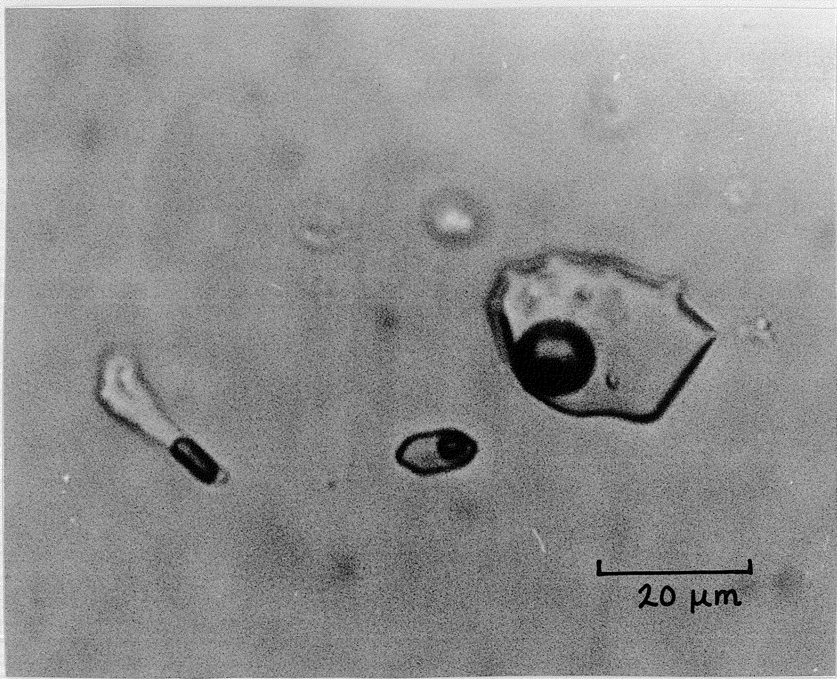
Biotite from all rhyodacite lithologies in the Pani Volcanic Complex is characteristically euhedral, as hexagonal plates 1-2mm in diameter.

Deformed, bent or kinked biotite is common. Biotite commonly contains needles of apatite and prisms of zircon and is commonly associated with opaque accessory and alteration minerals, magnetite and pyrite, as well as anatase and chlorite.

Sanidine (2-5%)

Sanidine occurs as large euhedral or resorbed phenocrysts up to 1cm (megacrysts).

Photoplate 4: Liquid-vapour fluid inclusions in quartz phenocrysts



Drillhole 4 (GPD4), 353m depth

Sanidine invariably contains smaller subhedral to euhedral inclusions of plagioclase, biotite and allanite aligned parallel to crystal margins, and may be partly mantled by large plagioclase crystals (Photo 5).

3.5.1.3 Accessory minerals

Early formed, non-metamict allanite occurs as long euhedral prisms included in quartz and sanidine phenocrysts. Allanite is strongly pleochroic, red-brown and yellow-green. Allanite has not been observed in the groundmass from rocks of the Pani Volcanic Complex. In similar, but hornblende-bearing rocks from the Tabulo Structure, allanite has been found as micro-phenocrysts in the groundmass (Photo 13c).

Sphene in quartz-biotite-porphyritic rhyodacites in the Pani Volcanic Complex is known only from distinctive diamond shaped pseudomorphs (Photo 14f), mainly composed of anatase, up to 1mm long in the groundmass, and has not been observed as inclusions. Sphene in these rocks is a late stage accessory mineral.

Apatite and zircon are ubiquitous accessories, occurring as small euhedral crystals in all phenocryst phases and groundmass. Apatite also is common as subhedral and euhedral microphenocrysts (0.5mm) in the groundmass.

Photoplate 5 : Sanidine megacryst

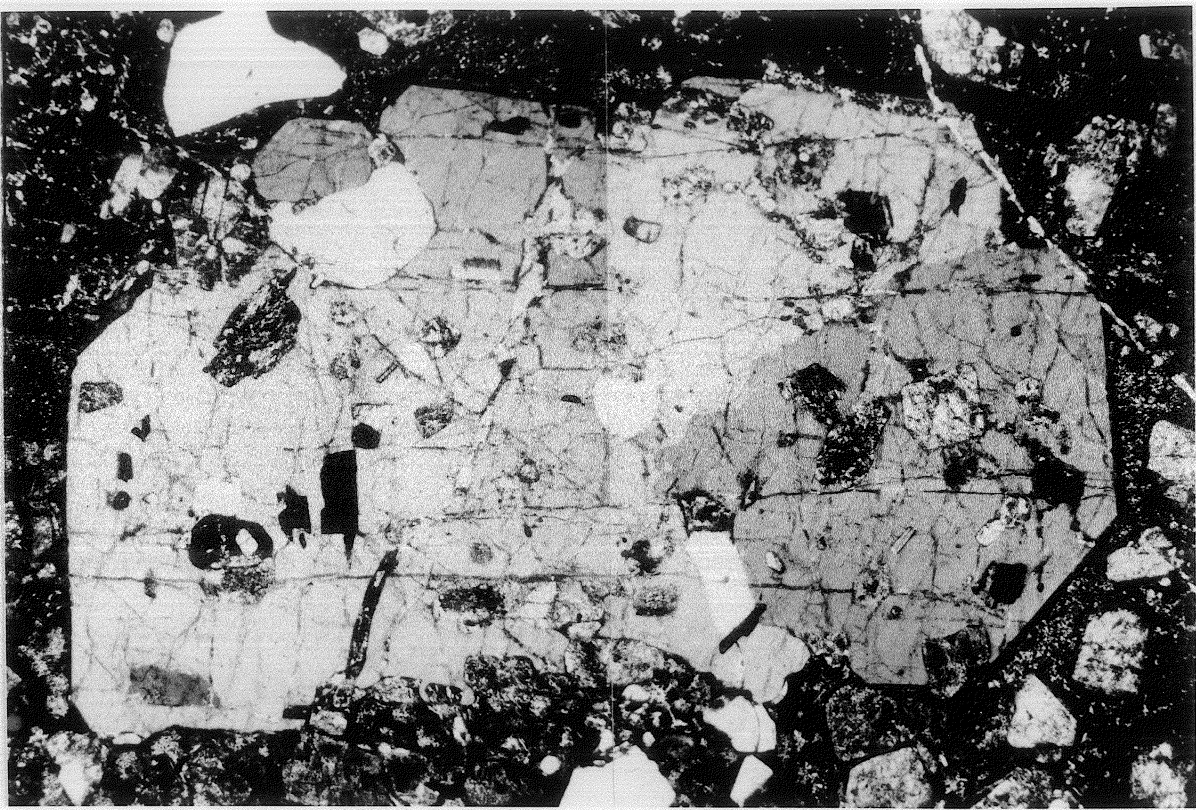
Sanidine megacryst with inclusions of plagioclase, biotite and allanite. Early formed crystals are oriented parallel to margins of the sanidine megacryst.

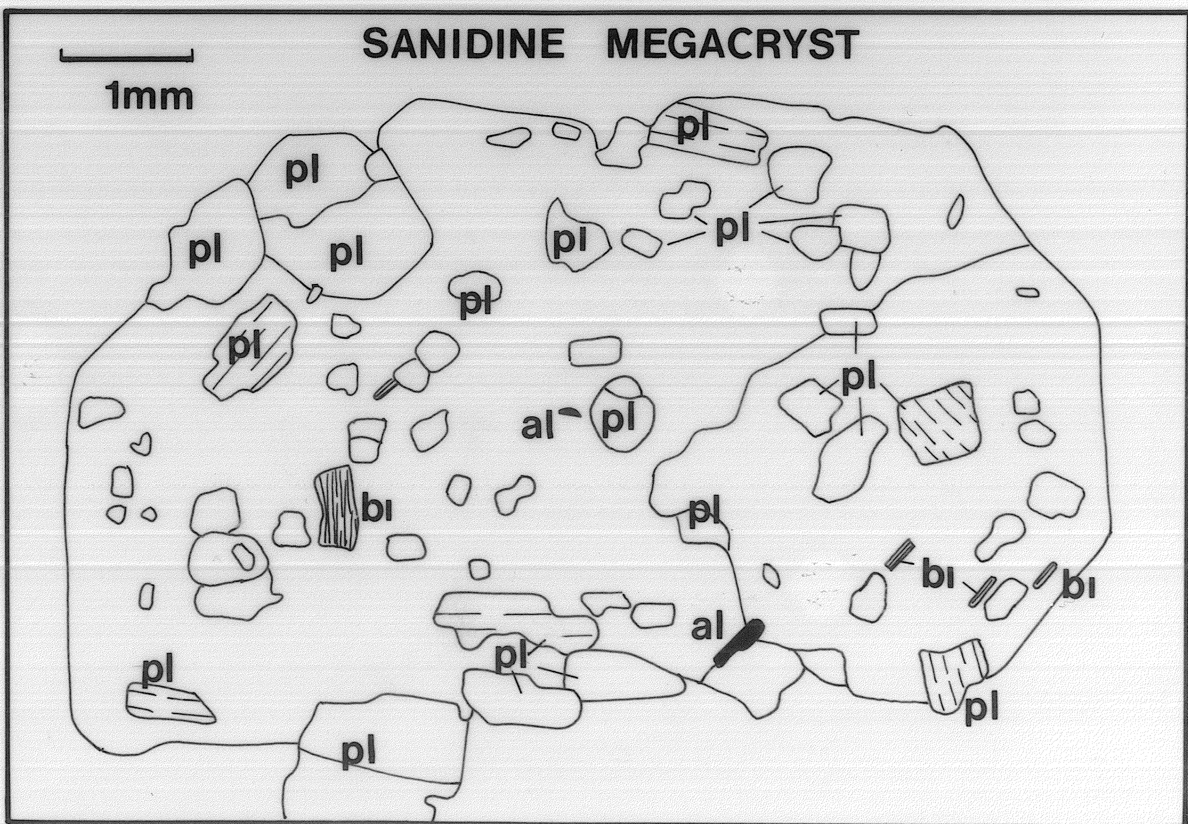
Drillhole 4, 143m. Gunung Baganite.

X-nicols.

Symbols

pl : plagioclase; al : allanite; bi : biotite





SANIDINE MEGACRYST
1mm
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Magnetite is a ubiquitous opaque accessory, usually as subhedral, corroded crystals (1mm). The corrosion of magnetite may be due to magmatic resorption suggesting that magnetite is an early formed accessory phase.

3.5.1.4 Groundmass

The groundmass of the porphyritic rhyodacites is typically cryptocrystalline, or microcrystalline (Photos 13e, 10d,e).

Cryptocrystalline groundmass texture may be heterogeneous or homogeneous depending upon the distribution and concentration of fine inclusions or alteration products. Rhyodacites which are extremely rich (>50%) in phenocrysts and with intense flow structures have a highly heterogenous, turbid groundmass (Photo 11e,f). The turbidity of the groundmass may be due to submicroscopic fluid cavities, and possibly phyllosilicate alteration products. In some examples the groundmass is completely opaque optically, but in unweathered hand specimen it is buff white, indicating an absence of microscopic opaque minerals such as iron oxides. The crystallinity of the groundmass may also vary between flow layers, with some zones tending to microcrystalline. The turbidity and heterogenity of the groundmass correlates to higher phenocryst density, intense flow layering and proximity to margins or contacts of the rhyodacitic units.

Homogeneous groundmass textures occur in rhyodacites with lower phenocryst content and less intense fluidal structure. Homogeneous textures range from cryptocrystalline to microcrystalline, and micro-granular in porphyritic microgranodiorites (Photo 13a, b,c, 10b). Crypto-microcrystalline textures may be 'felted' or 'mosaic'-like (Photo 10f).

Petrographically the massive or flow banded rhyodacites have some pyroclastic features, such as fragmented crystals and deformed biotite platelets. However, the nature of the groundmass, as well as frequent glomeroporphyritic textures, suggests a welded pyroclastic origin is unlikely. Biotite occurs as very small fabric elements (just resolvable) (Photo 10e), as well as ranging to phenocryst size, and therefore its occurrence in the groundmass is primary. The tiny biotites clearly show the structure of the otherwise cryptocrystalline groundmass, disposed in a strongly fluidal manner around larger phenocrysts. Such small primary crystals are thought unlikely to be preserved in a recrystallised, originally hyaline welded groundmass. In addition typical vitroclastic and eutaxitic fabrics or their pseudomorphs have not been observed either in outcrop or thin section. Furthermore field relationships do not suggest typical ash-flow units.

3.5.1.5 Mineral chemistry

Plagioclase

Compositions of plagioclase are given in Tables 1, 2a, 3a, 4 (Appendix 6), and show that plagioclase is invariably albitised.

The electron probe analyses of plagioclase occasionally contain minor amounts of Fe, Mg, Mn and Cl. This is likely contamination due to submicroscopic chlorite alteration (section 5.2.4), and possibly in the case of Cl to fluid filled dissolution cavities.

Proportionally higher Mg to Fe is probably spurious due to overlap between Na, Al and Mg in energy dispersive electron probe analysis.

Since the plagioclase is invariably strongly altered (Na-alkali metasomatised) corrections for impurities have not been made.

Biotite

Compositions of biotite (and hornblende) are given in Table 5 (Appendix 6) and indicate the ferromagnesian minerals are relatively titanium-rich.

Sanidine

Electron probe analyses (Table 6, Appendix 6) and XRD determinations (methods after Hutchinson 1974, p.182) independently give a composition for the sanidine megacrysts of 63% Or. The Ti shown in the analyses (Table 6, Appendix 6) is probably Ba ($TiK_{\alpha} \sim BaL_{\alpha_1}$) and may be significantly greater than weight percentage indicated for Ti.

Detailed determination of composition from the margin of crystals to the core indicates that despite a long growth history as indicated by the large crystal size and trapped inclusions, the sanidine is compositionally homogeneous, within the precision of the analysis. This is to be expected due to the high diffusivity of potassium in the feldspar lattice. However, in a few specimens a faint concentric zoning is discernible optically by very fine opaque inclusions, or in hand specimen.

K-feldspar corona texture (refer to section 3.5.2)

Electron probe analyses of typical corona texture (mantled phenocrysts) are given in Table 9 (Appendix 6) and indicate the corona is almost pure K-feldspar.

Groundmass

Examination of the groundmass by sodium cobaltinitrite staining and electron probe shows it to be composed of predominantly K-feldspar and quartz, and minor sodic plagioclase. Electron probe analyses (Tables 1, 2c, 8, Appendix 6) reveal up to 17% K_2O). The analyses of the groundmass usually show mixtures of alkali feldspar and quartz. Structural formulae shown are calculated on the basis of feldspar and are only meaningful where the composition approaches that of feldspar. XRD analyses often reveal sericite and chlorite and show the K-feldspar to have a monoclinic symmetry.

Magnetite

A small number of analyses (Table 7, Appendix 6) indicate magnetite has about 3% TiO_2).

3.5.1.6 Interpretation

The petrography suggests the following crystallisation sequence for the quartz-biotite porphyritic rhyodacites: Ca plagioclase → biotite → Na plagioclase → sanidine + biotite → quartz + sanidine.

Due to alteration it cannot be convincingly demonstrated, but it is possible that the small plagioclase euhedra enclosed in sanidine were essentially unzoned (Ca-plagioclase), but late stage plagioclase phenocrysts had strong zoning before albitisation.

Allanite is important as an early accessory phase, and apparently does not occur in the groundmass, while sphene is prominent as euhedral microphenocrysts in the groundmass and unknown as early inclusions. Apatite and zircon occur as early crystals included in all phenocryst phases; apatite also occurs as irregular microphenocrysts. Hornblende, which could be expected as an early phase and be trapped as inclusions or residual cores in biotite, is conspicuously absent.

In the Tabulo structure, in rocks slightly more intermediate in composition, hornblende co-exists with biotite phenocrysts and allanite occurs in the groundmass. Biotite is observed to replace resorbed hornblende, suggesting in this case hornblende precedes biotite crystallisation. The occurrence of hornblende typifies TpII lithology.

From the few electron probe analyses (Table 5, Appendix 6) the Fe/Fe+Mg ratio of early biotite inclusions and later biotite phenocrysts are comparable and in the order of 0.5. Co-existing hornblende and biotite in the Tabulo ring-dyke have similar Fe/Fe+Mg ratios.

One of the most striking characteristics of the quartz-biotite-sanidine porphyritic rhyodacites, and the Pani Volcanics generally, is the unusually high phenocryst abundance. Silicic volcanic rocks with comparable phenocryst abundances are only common as welded rhyolitic ash flow tuffs, and even in these rocks 50% or more phenocrysts are rare (Smith, 1979). Rhyolite flows and domes are characteristically phenocryst poor; typically with 5% small phenocrysts and glassy groundmasses.

Silicic magmas at advanced stages of crystallisation (with over 50% phenocrysts) may be considerably enriched in magmatic volatiles which lower viscosity and prevent consolidation. However extremely volatile enriched magmas are unlikely to reach the surface as passive flows, and instead erupt explosively. To extrude relatively volatile depleted silicic magmas with over 50% phenocrysts is unusual in nature as it requires high temperatures to overcome viscosity.

The composite phenocryst textures including glomeroporphyritic aggregates are interpreted as evidence for a long rest time in the magma chamber, and record changes in crystal-melt equilibrium and episodic disruption of partly consolidated magma by convective overturn or by influx of new magma.

Evidence for influx of new magma may include 'annealed' phenocrysts (section 3.5.1.1).

The accretion of euhedral crystals, enveloping earlier quartz and sanidine phenocrysts, suggests high temperature crystallisation or magmatic growth of the enclosing phase, which later may be subject to resorption. Conversely, irregular overgrowths, typically late stage mantles to phenocrysts, for example sodic rims on plagioclase, are not characteristic.

3.5.2 Rhyodacite intrusives

3.5.2.1 Lithology

Massive or indistinctly flow banded, buff or pale green porphyritic rhyodacites are generally intrusives, and occur extensively in the lower part of the Pani Volcanic Complex and adjacent basement.

Silicified rhyodacites, associated with mineralisation on Pani ridge and Baganite, are texturally and mineralogically similar; grey-white (or a distinctive red-brown when oxidised) and locally exhibit strong flow banding, open quartz veining and vuggy fracturing.

3.5.2.2 Texture

Flow banding

Although fluidal groundmass textures are ubiquitous in thin section, strong flow banding, visible in hand specimen is less common, restricted generally to contacts or more commonly found in thin (metres) rhyodacite dykes.

Flow banded rhyodacites exhibit strong flow alignment of biotite (Photo 10e) and alternating layers, of a few millimetres, that show finer and coarser groundmass crystallinity and sometimes slightly differing concentrations of phenocrysts and phenocryst size. In exceptionally phenocryst-rich fabrics (>50%), alignment of phenocrysts occurs, but generally fluidal textures do not involve major fabric elements, apart from biotite.

Contacts

Intrusive contacts between porphyritic rhyodacites and pyroclastics are commonly brecciated and appear transitional. Chilled margins of rhyodacites are not known in outcrop, and are unconvincing in thin section. Rare examples of silicified pyroclastics forming narrow contacts to porphyritic rhyodacites occur on Pani ridge.

In drillhole 7 (GPD 7) a number of thin, relatively fine-grained and strongly flow banded porphyritic rhyodacites intrude rhyodacite breccia or agglomerate. These rhyodacite units, especially near contacts, are characterised by densely packed porphyritic fabrics with 60% or more phenocrysts in a very strongly flow oriented, turbid, heterogenous groundmass. Near contacts sheared fabrics involving crystal fragments, impinging phenocrysts, brecciated phenocrysts streaked out along the flow direction and microscopic autobrecciated zones alternating with coherent flow layers are typical.

Explosive brecciation

The porphyritic rhyodacite intrusives exhibit various degrees of explosive brecciation (incipient to complete disruption), as distinct from flow autobrecciation. The brecciated zones usually occur on a small scale (cms).

Explosive brecciation (Photos 12f, 9 a,b) is characterised by disruption of the porphyritic rhyodacites into sharp angular fragments, accompanied by introduction of a siliceous fluidal matrix of fine lithic and crystal debris. Entrained in this matrix are well-rounded clasts of rhyodacite introduced from deeper levels, that can be distinguished by their coarser groundmass crystallinity.

Globular groundmass texture

Strong flow banding with a peculiar globular groundmass texture (Photo 10c) characterises the main rhyodacite intrusive body at Gunung Baganite over the last 20m or 30m to the lower contact at 328m in drillhole 4 (GPD4). The groundmass is strongly fluidal but is composed of 50% or more of small (0.25mm) quartz filled ovoid patches reminiscent of grains of rice enveloping the phenocrysts. The 'globules' have distinct boundaries.

Mantled phenocrysts

At the upper contact between porphyritic rhyodacite and lapilli tuff in drillhole 4 (GPD 4) (Plate 5) at Gunung Baganite, phenocrysts are mantled by cryptocrystalline or very finely radiating coronas of K-feldspar (Photos 13f, 10a), which resemble the high temperature spherulitic devitrification textures common in glassy rhyolitic rocks. The coronas are accentuated by a fine dusting of opaques concentrated on their outer margins. The development of the K-feldspar corona appears to be accompanied by depletion of K-feldspar in the associated groundmass, which is composed mainly of the albite and quartz (electron probe analysis).

Xenoliths

In thin section most common are xenoliths of a few millimetres length, composed of 'quartzite', foliated microgranodiorite and of metadolerite or amphibolite.

Near the contact with foliated microgranodiorite basement north of S. Nanasi, basement xenoliths up to a few centimetres long occur in intrusive rhyodacites.

Rounded cognate xenoliths of similar lithology (rhyodacite) or of pyroclastics have also been noted (Photo 12d). Xenoliths invariably comprise less than 1% of the host lithology.

Chert clasts and veinlets

Chert-like veinlets up to 1cm, of buff, homogeneous cryptocrystalline silica occur as early fracture fillings and as disrupted fragments entrained in porphyritic rhyodacite forming the Baganite rhyodacite dome. Similar, but rounded, silica clasts also occur as exotic components of explosively brecciated zones (Photo 9a,b).

3.5.2.3 Interpretation

A major problem is that without detailed mapping intrusive porphyritic rhyodacites are not readily distinguished from lavas. Only in the Baganite rhyodacite do groundmass textures show transitions to microgranitic textures; in general groundmass textures for the quartz biotite porphyritic rhyodacites are cryptocrystalline.

The K-feldspar corona texture is interpreted to be of similar origin to that observed in the glassy volcanic rocks, i.e. due to rapidly nucleating K-feldspar due to rapid cooling upon emplacement. The K_2O/Na_2O ratio in the residual melt is then lowered, explaining an associated sodic groundmass, which is peculiar to this contact. Elsewhere the porphyritic rhyodacites invariably have potassium-rich groundmass.

The globular groundmass texture is suggestive of an originally vesicular texture, which could mean that the base of the rhyodacite unit was exceptionally volatile-rich. Alternatively but probably less likely the 'globules' could be pseudomorphs after an original hyaline portion of the groundmass.

Xenoliths found in the rhyodacites are consistent with presently exposed basement rocks, with the possible exception of the 'quartzite'. This lithology may be part of the foliated microgranodiorite fabric, as metasedimentary origin is less likely.

Cryptocrystalline silica fragments and veinlets at Gunung Baganite are interpreted as evidence for formation of siliceous late stage volatiles during cooling and consolidation of large intrusive bodies and therefore a consequence of retrograde boiling. Exsolved silica-rich volatiles opened early fractures and produced explosive brecciation. Entrained angular disrupted chert fragments may be the result of continued viscous intrusion of the partly crystallised rhyodacite magma. Entrapment as fragments in explosively brecciated zones, suggests multiple intrusion and brecciation.

Siliceous rhyodacites are interpreted as relatively volatile enriched magmas, which have undergone deuteric alteration during cooling.

3.5.3 Rhyodacite lavas

3.5.3.1 Lithology

Buff-grey, strongly flow banded porphyritic rhyodacites intercalated with rhyodacitic breccias and thin (cms) zones of grey silty volcaniclastics (mudflows) are interpreted to be lava flows. However, they may be only one particular type of flow unit, identifiable due to field relationships.

Currently these rocks are only known from Pani ridge in the vicinity of the drillhole 1 and 2, where the NW hillslope has been stripped by local people working alluvial gold. This lithology is intersected in the drillholes.

Petrographically these rocks are similar to quartz-biotite porphyritic rhyodacites in general, but usually exhibit more intense flow layering, and highly heterogeneous and turbid groundmass fabrics.

3.5.3.2 Texture

Flow banding

Flow banding is very strong in the lava-like rhyodacites outcropping between drillhole 1 and 2, but unlike in typical glassy rhyolite lavas, it is not complexly contorted. Flow banding appears laminar, and individual layers are traceable for several metres, but may be tightly isoclinally folded.

Autobrecciation

Autobrecciation due to flow is relatively common, and occurs on all scales, from thin section texture to brecciated units in outcrop. Transitional relationships to coherent flow banded lava can be observed in outcrop. Rhyodacite breccias are described in section 3.5.4, and include autobreccia.

Contacts

Flow banded rhyodacites are intercalated with breccias and mudflow pyroclastics, which exhibit small scale sedimentary structures in thin section (Photo 12c) and in outcrop. Intercalated volcaniclastic units are invariably disrupted.

Cataclased flow layering (Photo 11d)

The intense flow banding is characterised by shearing and 'streaking-out' of fabric elements (phenocrysts).

In hand specimen thin, grey-cherty lensoid layers and laminae 1-2mm thick and 10-20mm long representing cataclased flow layers and brecciated phenocrysts are enclosed and alternate with non-deformed flow banded zones. This is an unusual texture, particularly as in some examples cataclased phenocrysts seem to be completely enclosed by fluidal, undeformed matrix.

Tuffisite dykes

Thin irregular veinlets, a few mms to 1cm, composed of small crystals of quartz and plagioclase in a grey siliceous aphanitic matrix are interpreted to be tuffisite dykes. They are ubiquitous to the strongly flow layered rhyodacite lava, and in some cases appear to originate from the cataclased flow layering. In hand specimen both features are similar. The tuffisite dykes intersect the flow layering at all angles.

Sedimentary dykes

As well as tuffisite dykes, distinctly sedimentary infillings also occur on fractures intersecting the rhyodacite lava. They are composed of soft grey silty tuffaceous material, known also in intercalated pyroclastic and breccia interbeds in the lava sequence (refer to section 3.5.4). The sedimentary infillings are up to a few centimetres wide and postdate the tuffisite dykes.

In thin section sedimentary injected material is strongly fluidal and oriented parallel to the fracture walls. It is distinguished from the tuffisite dykes which are akin to infillings produced by explosive brecciation by (1) lack of angular shattering of the invaded rock, and (2) because the introduced matrix is not strong recrystallised by silica.

3.5.3.3 Interpretation

On the basis of intercalated rhyodacitic breccias and disrupted mudflow pyroclastics the intensely flow layered rhyodacites on Pani ridge are interpreted as lava flows. However, these rocks are unusual, particularly in terms of the apparent laminar flow layering and intense shearing during emplacement resulting in cataclasis of phenocrysts and flow layers. These textures are not consistent with viscous glassy magmas, which are highly contorted due to gravitational creep and slumping, but instead suggest extreme compressional loading during emplacement.

The lavas are injected everywhere by tuffisite dykes and subsequently by sedimentary infillings. The latter are believed to be due to thixotropic injection of tuffaceous material into cooled and fractured lava, while the tuffisite dykes are due to degassing and release of volatiles before final consolidation.

The characteristics of these rhyodacite lavas are believed to be transitional to intrusive rocks. Similar sheared and cataclased fabrics are found in intrusive rhyodacites, e.g. in GPD 7.

3.5.4 Rhyodacitic volcanic breccia

Breccia formed by (1) pyroclastic eruptions (agglomerates); (2) autobrecciation of viscous magma; and (3) hydrothermal fragmentation are not readily separable in the Pani Volcanic Complex. The following description encompasses rocks that may owe their origin to one or all of the above processes.

3.5.4.1 Lithology

Rhyodacitic breccias are buff to pale green; heterolithic to the extent that the component clasts vary slightly in colour and degree of alteration, show different porphyritic textures and groundmass, and resistance to weathering.

Clasts are predominantly quartz-biotite porphyritic rhyodacites, but minor mineralogically similar, rhyodacite lapilli tuff clasts also occur. Basement xenoliths (granitoids or metabasalt) are generally rare. However, on the NE edge of the Pani Complex in Sungai Wadi volcanic breccias incorporate up to 50% of basaltic xenoliths.

3.5.4.2 Texture

Most breccias are unsorted, and composed of both angular and subrounded clasts in a tuffaceous, lithic-crystal rich matrix. The matrix commonly shows alignment and envelopes the clasts. Clasts are generally matrix supported. Clast size varies from lapilli (4mm) to cobble and boulder size (0.25m), and rarely exceeds 1 metre. Matrix content varies 15% to 50%, with generally finer clast size associated with higher matrix content (Photo 6d).

Pyroclastic brecciation (agglomerate)

In drillholes on Pani ridge lapilli tuffs are found to grade to coarse breccias (agglomerate), composed of unsorted, angular to subrounded clasts. Agglomerate may be distinguished from autobrecciated lavas or intrusives by greater heterogenity of component rhyodacite clasts. Breccia deposits on Pani ridge interbedded with lavas are characterised by occasional silicified rhyodacite clasts, ranging from less than 1cm up to several metres in length, which are comparable to the silicified rhyodacite intrusives.

Pyroclastic mass flow texture

Rhyodacitic breccias exposed on Pani ridge and in drillholes commonly exhibit fluidal groundmass fabrics and alignment of clasts, indicative of mass flow. In general, finer breccias are transitional to non-welded mass flow pyroclastic deposits, perhaps mud flows (lahars).

Autobrecciation

Some rhyodacitic breccias are clearly transitional to flow banded lavas or porphyritic rhyodacite intrusives (section 3.5.3.3). However, the auto-brecciation texture due to flow or intrusion cannot be readily distinguished from pyroclastic agglomerate textures, and interpretations depend on detailed field relationships.

Intraformational brecciation

Soft clay altered, fine grey 'silty' or 'ashy' waterlaid tuffs form small layers (tens of centimetres) of interformational breccia within the rhyodacite breccia and lava sequence on Pani ridge between drillholes 1 and 2. In thin section these fragments are composed of sharply angular quartz feldspar crystal detritus (<0.5mm) grading to cryptocrystalline size. Fine layering, grading or fluidal texture are often apparent, indicative of sedimentary reworking.

Hydrothermal brecciation

In S. Batudulanga rhyodacite breccia comparable in every respect to typical breccias from the Pani Volcanic Complex core occur in linear zones up to several hundred metres wide, intrusive into foliated microgranodiorite basement. These breccias as at the prospect are intensively intruded by flow banded rhyodacites.

Pebble dykes

Pebble dykes (cms to possibly metres width) are composed of subrounded to angular rhyodacite clasts in a tuffaceous matrix.

Contact brecciation

Margins of large porphyritic rhyodacite dykes intruded into the basement and possibly elsewhere may be brecciated. These breccias form zones one or two metres wide composed of subrounded rhyodacite clasts and incorporated basement clasts.

3.5.4.3 Interpretation

It is believed that a large proportion of the rhyodacite breccia in the centre of the Pani Volcanic Complex is of pyroclastic origin proximal to a vent. Part of the breccia assemblage on Pani ridge and near Baganite may be derived by collapse of rhyodacite lava domes, with concomittant small scale pyroclastic activity. The textures are consistent with autobrecciation, followed by gravity slumping of spalled rubble (mass flow textures). Incorporated in the debris may be minor pyroclastic components (ash falls) that form mudflow deposits.

The occurrence of relatively large silicified rhyodacite blocks in breccia may be consistent with a collapse origin from lava domes. The silicified rhyodacite representing volatile-rich magma fractions which may form flows or intrusions during the growth of the lava dome.

Pebble dykes are injected along fractures due to differentiation compaction between massive and fragmental lithologies or due to hydrothermal brecciation and transport of material by escaping volatiles. The explosive brecciation described previously (section 3.5.2) leads ultimately to pebble-dyking.

3.5.5 Rhyodacitic lapilli tuff (Photo 6d, 7a,b,c,d; 8a,b)

The lapilli tuff sequence is poorly differentiated but in general two main types occur; lapilli tuffs or agglomerates transitional to rhyodacitic volcanic breccia, and lapilli tuffs characterised by finer grainsize and sedimentary structures.

3.5.5.1 Lithology

Typically the lapilli tuffs are dark grey to buff or pale green, containing 20-50% subrounded clasts, 2mm to 2cm in a finer crystal/lithic matrix, which may be essentially debris derived from comminution of phenocryst-rich rhyodacite.

3.5.5.2 Texture

Sedimentary structures

The most common sedimentary structures found in the pyroclastic sequence are grading and coarse bedding. Grading may be normal or inverse. Fine pyroclastics may be laminar bedded, cross bedded and exhibit small scale scour and fill structures.

Graded and bedded sequence invariably have associated accretionary lapilli, which are either scattered or very poorly bedded.

Accretionary lapilli

A few percent of accretionary lapilli (Photos 7a, 12a, b), up to 5mm in diameter, occur in airfall pyroclastics of the Pani Complex where evidence of secondary reworking after deposition is minimal. The accretionary lapilli have nuclei of fine crystal or lithic debris and a shell composed of concentric layers of extremely fine volcanic detritus.

Scoria

The lapilli tuffs from Pani ridge contain rare clasts of vesicular scoria (Photo 12e) composed of highly fluidal porphyritic rhyodacite. Phenocryst content and matrix of the scoria is similar to typical quartz-biotite porphyritic rhyodacites.

Mass flow textures

Lapilli tuffs on Pani ridge exhibit oriented fabrics due to mass-flow (Photo 7d, 8b). This texture is similar to that described for rhyodacitic breccia (section 3.5.4.2).

3.5.5.3 Interpretation

All lapilli tuffs are non-welded airfall deposits. The nature and grainsize of the matrix components is consistent with their derivation by explosive fragmentation of pre-existing porphyritic rhyodacite lithology.

Normal and inverse bedded or coarsely graded bedded textures as well as accretionary lapilli are consistent with airfall deposition. Laminar bedding, cross bedding and scour and fill structures may be consistent to deposition as base surge deposits, rather than due to sedimentary reworking in a lacustrine environment.

Mass flow textures and intraformational breccias are due to slumping or mud flow and are characteristic of pyroclastics on Pani ridge.

Intraformational breccias represent disrupted finer-grained tops to pyroclastic airfall units, probably water saturated by rainfall and runoff upon deposition. Lithologically fine ash beds are similar to the sedimentary dykes (section 3.5.3.2).

For the accretionary lapilli an airborne origin by accretion of volcanic dust upon particles in a thunderstorm is likely. Possibly accretionary lapilli may be generated during base surge explosions.

The occurrence of vesiculated rhyodacite as scoria suggests that some phenocryst-rich silicic magma of the Pani Complex erupted as froth-like lava and tephra, as well as fluidal lavas and pyroclastics.

3.6 Petrography of Unit II (TpII)

3.6.1 General

Igneous rocks belonging to TpII are similar mineralogically to TpI, but have a higher ferromagnesian mineral content, and are characterised by the presence of hornblende. Volcanics have fewer quartz phenocrysts and generally have finer-grained porphyritic textures.

TpII rocks are characteristic of the Tabulo ring-dyke Complex, and are generally widespread as intrusions in the basement. In all cases these intrusions postdate TpI dykes.

TpII lithologies are almost never hydrothermally altered, and are characterised by fresh biotite, which is highly a distinctive black vitreous phase.

3.6.2 Black biotite porphyritic rhyodacite

3.6.2.1 Lithology

These rocks are buff, pale grey to purple-pink flow banded porphyritic rhyodacites, characterised by small phenocrysts 1mm(20-35%), less than 5% quartz, and 5-7% black vitreous biotite. Sanidine makes up less than 5% of the rock and occurs as 2-3mm long phenocrysts similar to that in the quartz-biotite rhyodacite.

The black biotite rhyodacites exhibit similar textures and lithological associations as the quartz-biotite porphyritic rhyodacites. Lavas and intrusives, agglomerates, breccias and lapilli tuffs comprise this lithology. Fine-grained, black biotite porphyritic rhyodacites show contorted flow banding unlike quartz-biotite rhyodacite lava, but similar to phenocryst-poor, hyaline rhyolite lavas.

3.6.6.2 Interpretation

Black biotite rhyodacites form lava domes a few hectares in area (Fig. 5), occur as small intrusives, and are an important component of concomitant lapilli tuffs. The lava domes have similar volcanic facies to the Baganite rhyodacite, and comprise a massive or flow banded core, surrounded by breccia which grades outward to fine-grained airfall pyroclastics. These features suggest similar volcanic processes and environment (section 3.7).

Hypabyssal equivalents (fine-grained porphyritic microgranodiorites) occur in the basement outside the Pani Complex but their frequency, size and distribution is poorly known.

3.6.3 Hornblende-biotite rhyodacite and microgranodiorite

3.6.3.1 Lithology

Buff to grey-green hornblende-biotite-porphyritic rhyodacites are characterised by 50% phenocrysts (2-3mm), mainly plagioclase, but including 10% ferromagnesian minerals, hornblende and biotite, and 5% quartz. Groundmass textures vary from aphanitic to microgranular. Strong flow orientation may occur in rhyodacites but is less marked or absent in related porphyritic microgranodiorites.

3.6.3.2 Texture

The microgranodiorites are porphyritic but have microcrystalline or granular groundmass textures transitional to those described for rhyodacites, reflecting crystallisation at deeper levels.

In some examples plagioclase phenocrysts are in contact with each other and closely intergrown with a granular groundmass fabric. This texture is transitional to an equigranular fabric.

3.6.3.3 Mineralogy

Hornblende-biotite rhyodacites and microgranodiorites are typically composed of 50% phenocrysts (2-3mm), plagioclase, Beta-quartz, biotite and hornblende.

Large phenocrysts of sanidine characteristic of quartz-biotite rhyodacites have not been observed in the microgranodiorites.

Biotite and hornblende occur in varying proportions and comprise up to 10% of the phenocryst mineralogy.

Hornblende phenocrysts in microgranodiorites of the Tabulo ring-dyke Complex are prismatic, euhedral to subhedral, average 1 x 3mm in size and are strongly pleochroic. Hornblende exhibits ragged overgrowths of biotite. Optically similar hornblende occurs in comparable rocks from the Pani Volcanic Complex. In the Tabulo ring-dyke structure hornblende is altered to sphene.

3.6.3.4 Interpretation

The hornblende-biotite rhyodacites and microgranodiorites are only known as intrusions, usually dykes. In the Pani Volcanic Complex they occur as ring-dykes along the northern margin of the structure and apparently fill a SE structural zone on the SW margin. Many of the intrusions on the SW margin are however shallow dipping inward towards the breccia filled centre and may be cone-sheets.

These rocks comprise also the Tabulo structure where they occur as large ring-dykes, and are common as intrusive bodies in the basement in Block E.

Sphene as an alteration product does not occur in TpI rhyodacites, perhaps due to the absence of hornblende. In contrast to TpII lithology, in quartz-biotite rhyodacites of TpI, sphene is a primary late stage accessory mineral.

3.7 Volcanic environment

The structure of the Pani Volcanic Complex (Fig. 5) and the Tabulo ring-dyke (Photoplate 2) is compatible with large scale silicic, caldera forming volcanic systems, such as are well documented in Western USA (e.g. Lipman, 1984), Kyushu, Japan (Aramaki, 1984) and the Taupo Volcanic Zone in New Zealand (Wilson et al., 1984).

Important components of these volcanic systems include voluminous ash flow pyroclastic units, large scale (10km) circular caldera collapse or subsidence structures and ring-dykes. Rhyolite lava domes, intrusives, breccias and non-welded ash-lapilli tuffs are typical intracaldera features and develop usually after major ash-flow magmatism (e.g. Elston, 1984). The Pani Volcanic Complex is interpreted in these terms, although major extracaldera pyroclastic deposits are currently unknown. An enclosing ring-dyke system is inferred (Fig. 5) from morphology and analogy to the Tabulo ring-dyke Complex. The ring-dyke is not a key element in the interpretation since the Pani Volcanic Complex appears most likely to be a central-vent type system, rather than a ring-fracture type, and may be analogous to the Japanese Late Quaternary calderas (Aramaki, 1984), which are funnel-shaped collapse structures. In the Taupo Volcanic Zone the lack of associated welded ash flow tuffs is attributed to the effects of surface water on eruption styles, i.e. phreato-magmatic eruptions (Wilson et al., 1984) and this can be postulated to be the case also for the Pani Volcanic Complex.

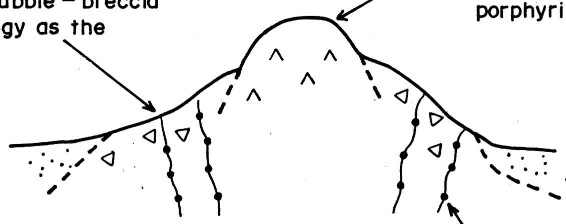
Eroded volcanic morphology and lithology at the prospect area, and in the Pani Volcanic Complex generally suggests the geology is interpretable in terms of volcanic domes and associated volcanic facies. Fig. 7 summarises general features of volcanic domes of the Pani Volcanic Complex with notes on processes.

The silicified rhyodacite bodies on Pani ridge can be interpreted as volatile-rich components of the

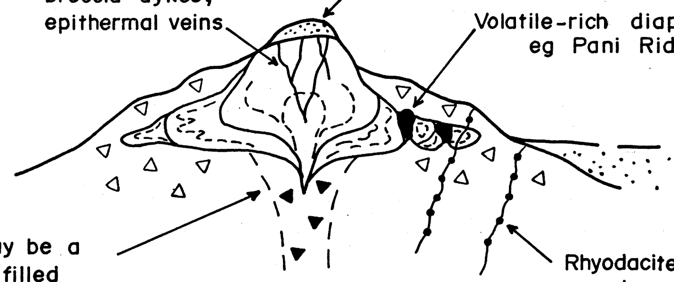
Fig 7 Volcanic domes from the Pani Volcanic Complex

A : GENERAL FEATURES OF AN ERODED VOLCANIC DOME

(eg Gunung Baginite , quartz - biotite rhyodacite dome ;
S.Tomulo , black - biotite rhyodacite dome)



B : POSSIBLE INTERNAL STRUCTURE OF AN ENDOGENIC SILICIC INTRUSIVE DOME , WITH NOTES ON PROCESSES.



NOTE

① The latest intrusion forms the core

② Earlier intrusions (or extrusions) spread laterally outward and are autobrecciated and incorporated into the rubble - mantle

③ The first magma erupted is the most volatile - rich, but in lava domes is generally covered by later more voluminous, passive flows.
Therefore chemical and volatile zonation in the magma chamber is inverted upon emplacemt of domes .

④ Volatile - rich 'lava', due to its lower specific gravity may rise diapirically through the partly consolidated lava - breccia assemblage .

⑤ Diapiric intrusions play an important role in the ductile deformation of the lava dome assemblage .
At Pani ridge lava flow layering may partly envelope volatile - rich silicic intrusions .

lava dome magma erupted as flows and possibly diapirically emplaced due to lower specific gravity. This is a speculative interpretation, but accords well with detailed mapping which indicates the silicified rhyodacite bodies exhibit characteristics of both flows and intrusives. Diapirism due to volatile-rich magma in rhyolite lava domes is described by Fink (1983). A consequence of diapiric emplacement may be deformation of the partly consolidated lava and breccia mantle to envelop the silicified rhyodacite bodies (Plate 2). Possibly shearing of phenocrysts and laminar flow structure of the enclosing lava can be attributed to this process.

The initial volatile-rich magma which preceded lava flows, breccias and endogenic dome emplacement at Gunung Baganite undoubtedly breached the surface explosively. Pyroclastics and breccias on Pani ridge contain clasts and blocks up to several metres diameter of silicified rhyodacite, attributable to collapse of former rhyodacite domes and hydrothermal brecciation. The breccia and pyroclastic assemblage which fills the main volcanic structure may have been resurgently domed upon final emplacement of the Baganite rhyodacite. It is presumed that the Baganite rhyodacite choked off the early vent and apart from dyke intrusion, largely terminated TpI volcanicity in the Pani Volcanic Complex.

The following volcanicity is characterised by TpII lithology and exhibits analogous volcanic facies and structures (domes and breccias) to the TpI assemblage, but lacks hydrothermal alteration.

The non-welded lapilli tuff sequence which accompanies the lava dome and breccia assemblage may have resulted from Plinian-type eruptions and has some characteristics indicative of a base-surge depositional facies.

Photoplate 6 : Pani Volcanics lithology.

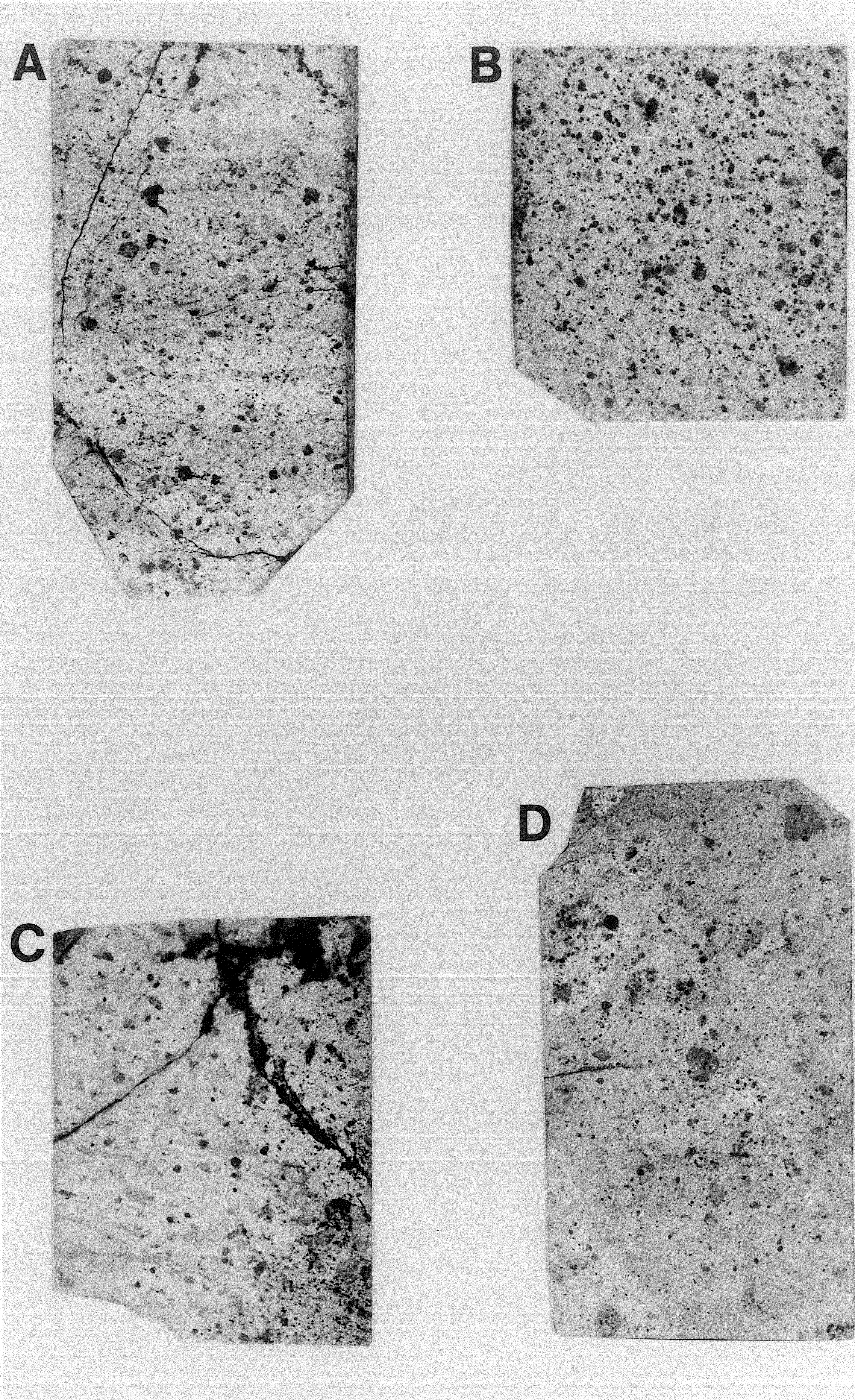
6a Silicified porphyritic rhyodacite, exhibiting strong flow banding.
Drill hole 3, 36m. Pani ridge.

6b Massive porphyritic rhyodacite; 50% or more phenocrysts. Typical of porphyritic rhyodacite comprising Gunung Baganite.
Groundmass is buff-white; plagioclase phenocrysts (35%) display strong alteration by chlorite.
No silicification.
Drillhole 6, 190m. Gunung Baganite.

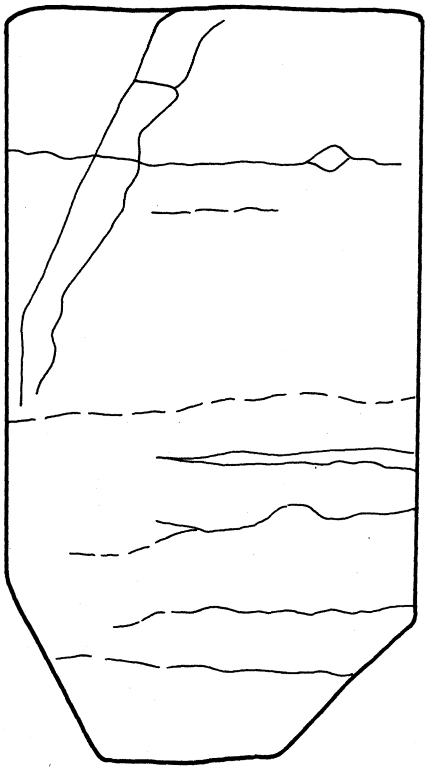
6c Buff-white porphyritic rhyodacite with a streaky texture due to cataclasis along flow layering.
On Pani ridge this lithology, due to frequent intercalation with autobreccia and rhyodacite pyroclastics is interpreted as a rhyodacite lava.
Silicification is related to cataclased zones.
Drillhole 6, 28m. Gunung Baganite.

6d Typical rhyodacitic pyroclastic from Pani ridge.
Composed of angular and subrounded porphyritic rhyodacite clasts in a crystal-lithic matrix.

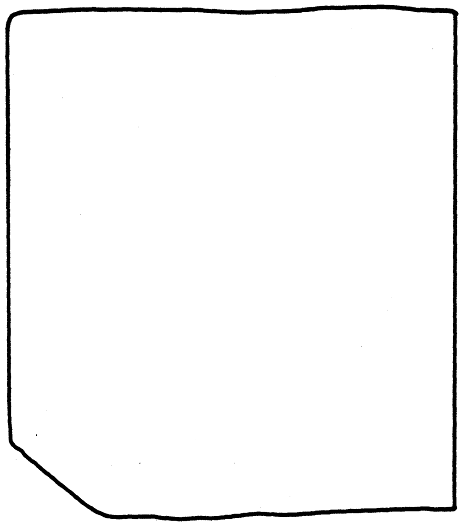
Photographs of HQ drill core. Actual size.


A
B
C
D

Photoplate 6 :

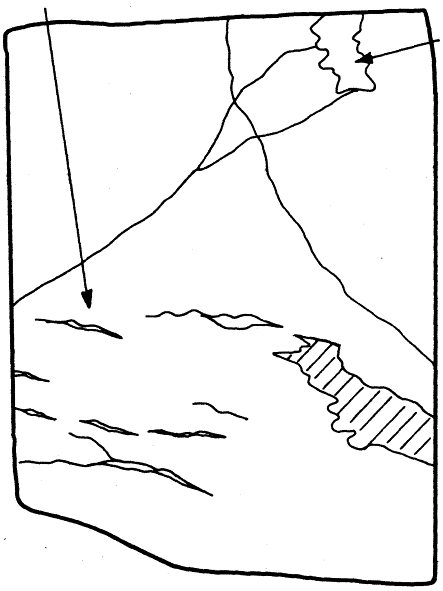


GPD3 36m



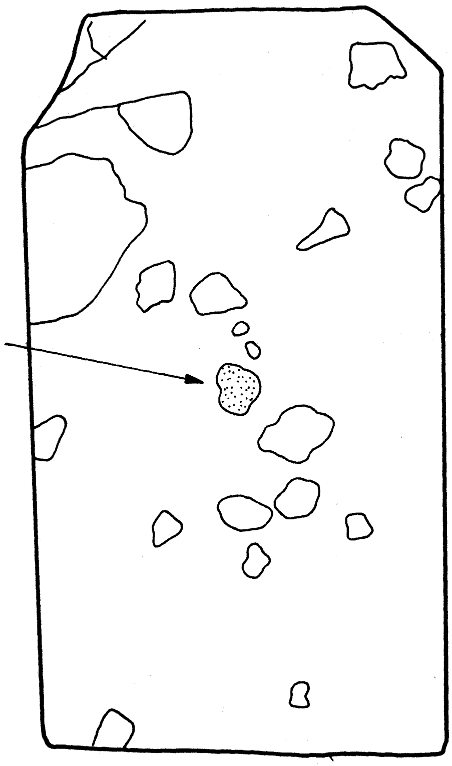
GPD6 190m

Massive porphyritic rhyodacite



GPD 6 28m

Rhyodacitic lapilli tuff, with a crystal-rich matrix.



GPD 2 227m

Photoplate 7 : Pani Volcanics lithology

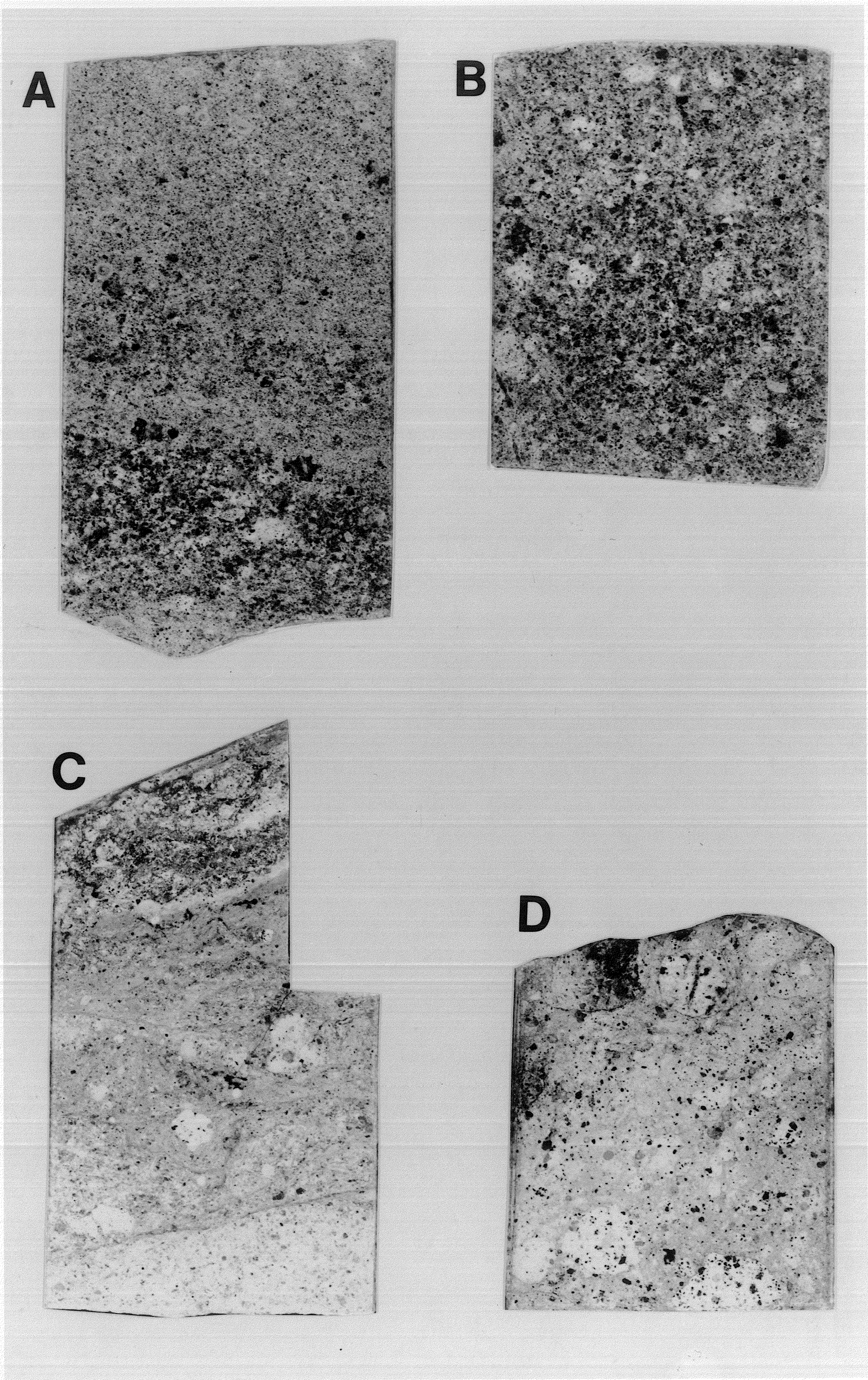
7a Rhyodacitic crystal-lithic tuff containing accretionary lapilli. The unit containing the accretionary lapilli is finer-grained and without sedimentary reworking. Note the accretionary lapilli are slightly flattened due to compaction. Drillhole 5, 78m. Gunung Baganite.

7b Typical rhyodacitic lapilli tuff, forming the summit of Gunung Baganite.
Drillhole 5, 72m. Gunung Baganite.

7c Small scale sedimentary structures marking the contact between airfall pyroclastic units. These structures are interpreted due to unconsolidated flow, referred to as 'mass flow' in the text. Drillhole 4, 69m. Gunung Baganite.

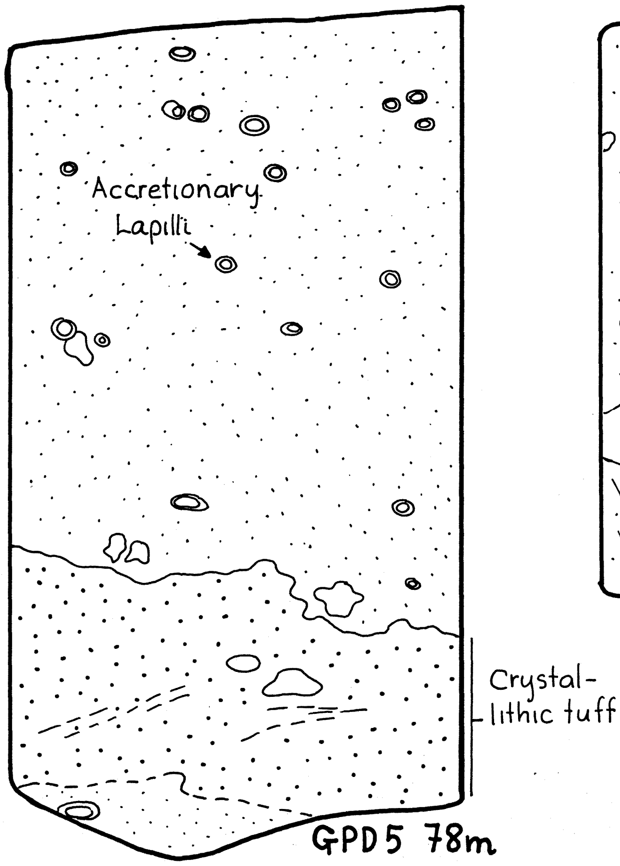
7d Rhyodacitic lapilli tuff, composed of subrounded porphyritic rhyodacite clasts in a tuffaceous, foliated matrix. The orientation of clasts and enveloping matrix is a 'mass flow' texture. Units of this type are typical to Pani ridge; they have high dips and are likely to be due to slumping and flow. Some may be interpreted as lahars.
Drillhole 3, 234m. Pani ridge.

Photographs of HQ drill core. Actual size.

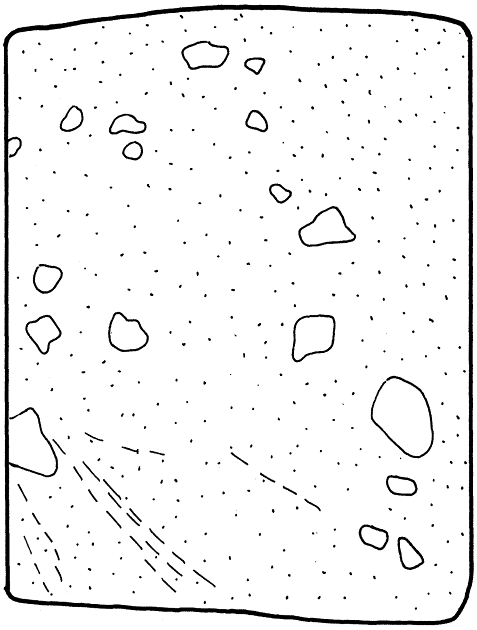


A
B
C
D

Photoplate 7 :

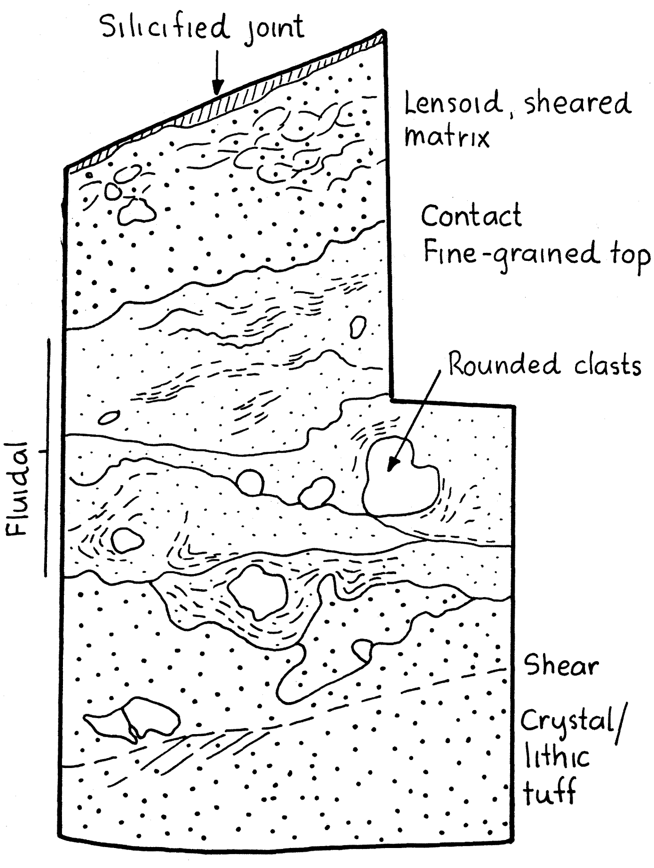


GPD5 78m



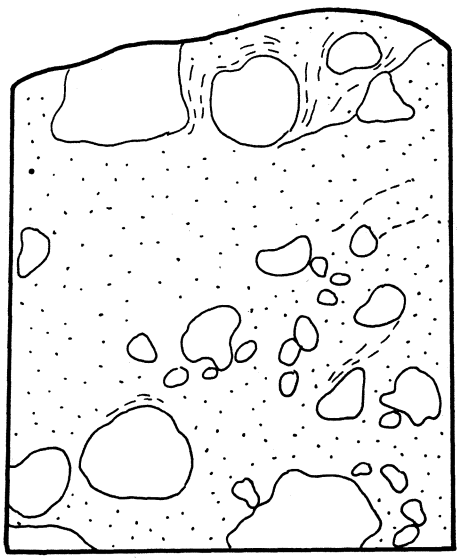
GPD5 72m

Buff-white, grey-green + dark grey angular to sub-rounded clasts in a lithic/crystal-rich matrix



GPD 4 69m

Buff-white, rounded clasts in a crystal/lithic tuffaceous, foliated matrix.



GPD 3 234m

Photoplate 8 : Pani Volcanics lithology

8a Intraformational breccia composed of fine silty rhyodacitic clasts.
Interpreted as thin ash beds marking the tops of pyroclastic units disrupted due to slumping.
Drillhole I, 105m. Pani ridge.

8b Rhyodacitic lapilli tuff with strong 'mass flow' texture (Refer to 7d).
Drillhole 2, 166m. Pani ridge.

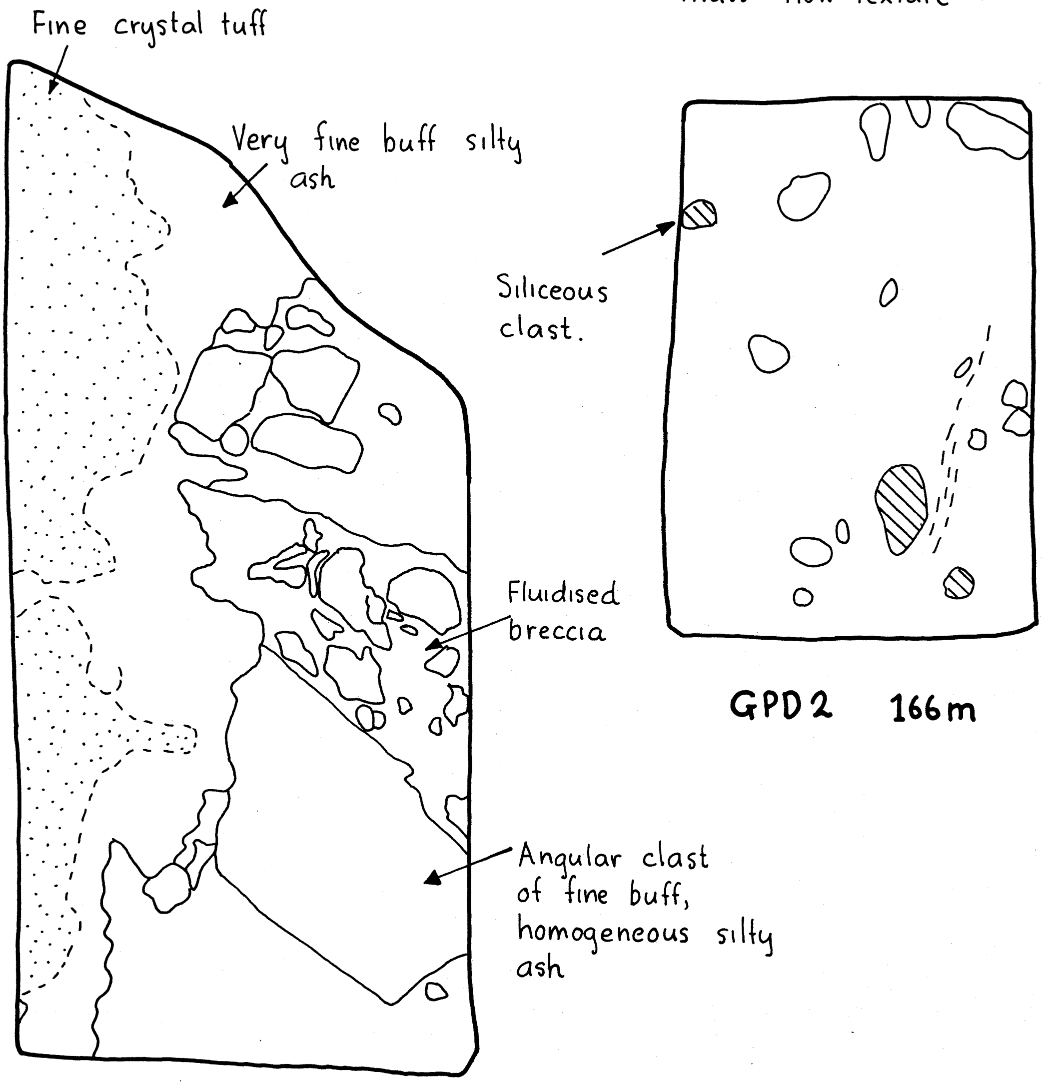
A

B

Photoplate 8 :

Disrupted lacustrine? volcaniclastics.

Lapilli tuff with mass-flow texture



GPD 1 105m

GPD 2 166m

Photoplate 9 : Pani Volcanics lithology.

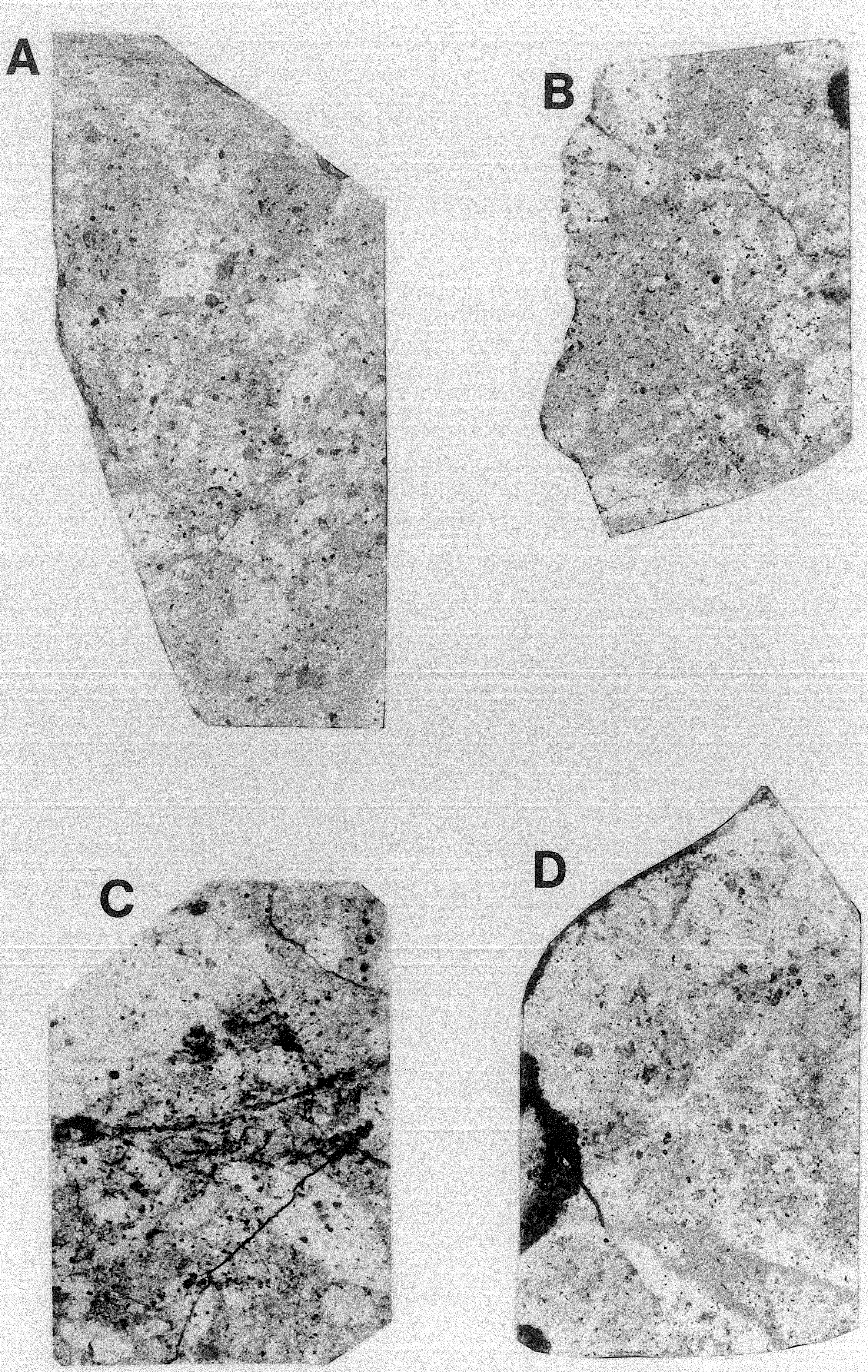
9a Rhyodacitic volcanic breccia, composed of angular and subrounded clasts in a crystal-rich tuffaceous matrix.
Drillhole 2, 193m. Pani ridge.

9b Explosive brecciated porphyritic rhyodacite. Angular fragments in a fluidal, siliceous matrix.
Drillhole 4, 160m. Gunung Baganite.

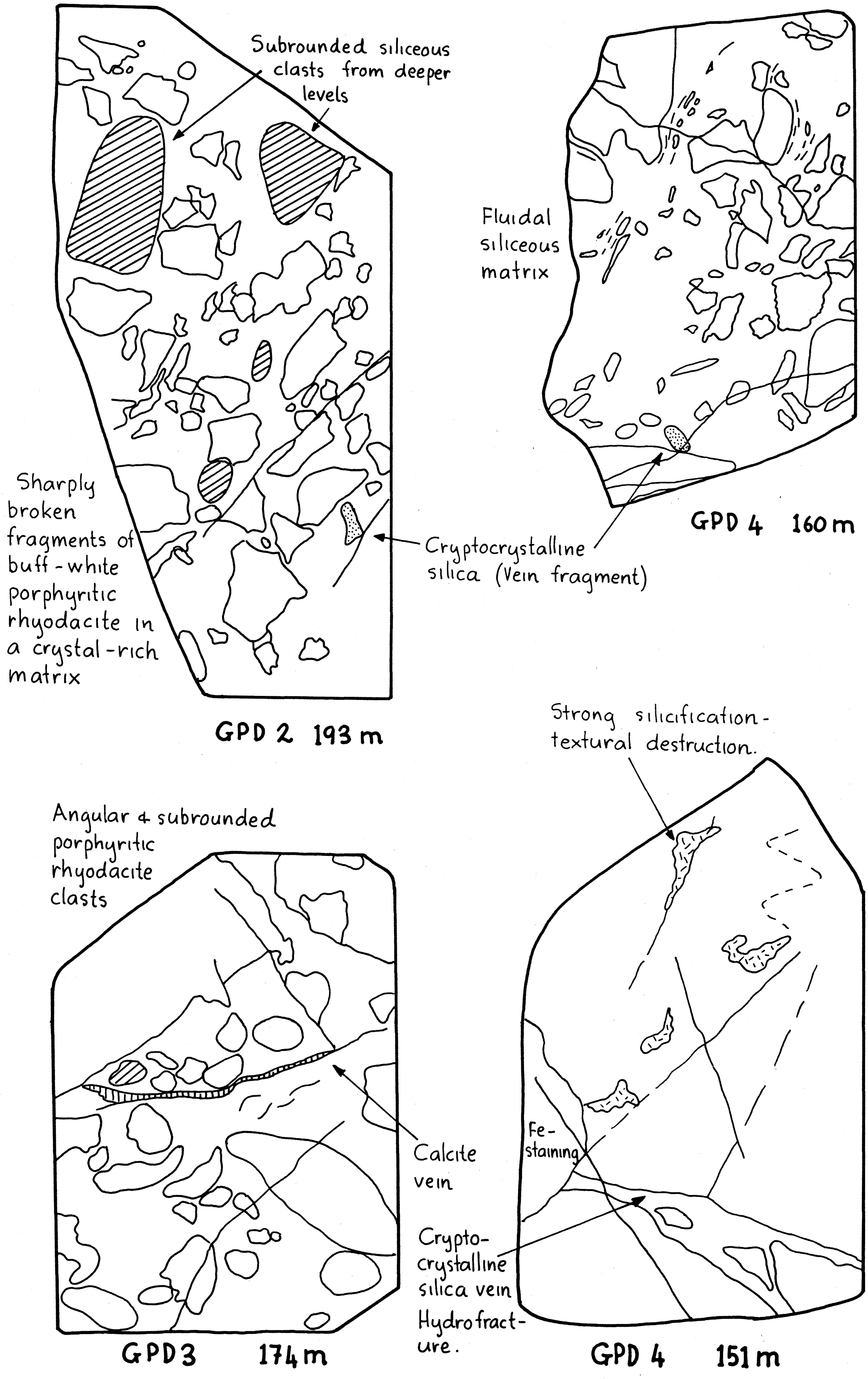
9c Rhyodacitic volcanic breccia, similar to 9a.
Drillhole 3, 174m. Pani ridge.

9d Silicified and hydrofractured porphyritic rhyodacite, typical of contact zone between lapilli tuff and porphyritic rhyodacite at Gunung Baganite. Fractures are filled with cryptocrystalline silica, but without entrained crystal or lithic material.
In examples 14a, b crypto-crystalline silica vein fragments form a minor component of the breccia.

Photographs of HQ drill core. Actual size.


A
B
C
D

Photoplate 9 :



Photoplate 10 : Pani Volcanics petrography

10a Plagioclase and quartz phenocrysts mantled by K-feldspar corona. Note the dense packed porphyritic texture.
Drillhole 4, 143m. Gunung Baganite.
X-nicols.

10b Microgranular groundmass texture.
Prismatic phenocryst of hornblende corroded at margins and replaced by biotite. Note zoned plagioclase phenocryst.
Sample 726. Tabulo ring-dyke Complex.
X-nicols.

10c Globular groundmass texture. Strongly flow oriented groundmass, characterised by ovoid patches of quartz.
Drillhole 4, 309m. Gunung Baganite.
Plain polarised light.

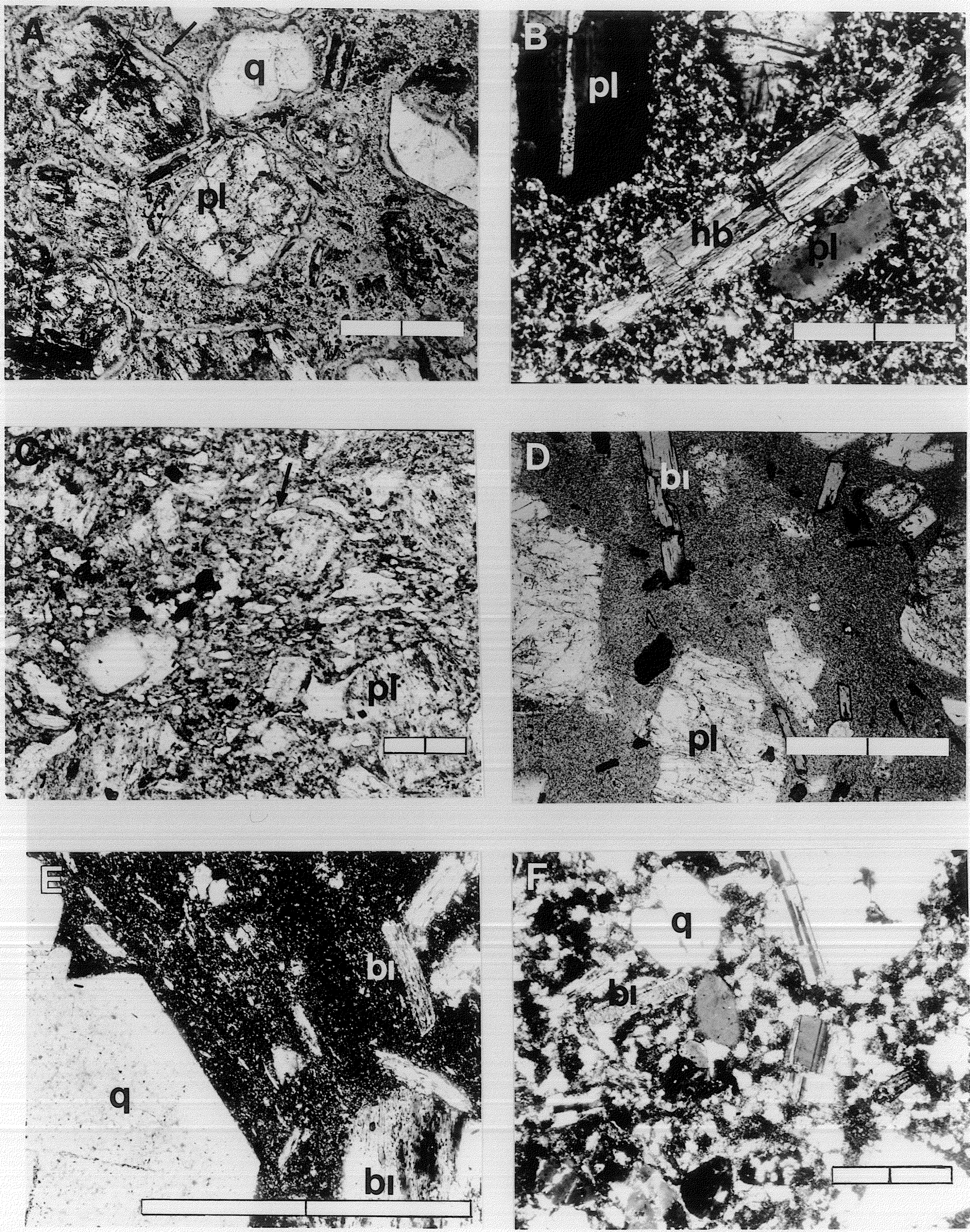
10d Fine microcrystalline groundmass texture.
Biotite and smaller plagioclase phenocrysts are flow oriented.
Sample 722. Tabulo ring-dyke Complex.
X-nicols.

10e Flow orientation of biotite crystallites in crypto-microcrystalline groundmass. Note euhedral quartz phenocryst.
Drillhole 1, 28m. Pani ridge.
X-nicols.

10f Mosaic-like groundmass texture in porphyritic rhyodacite.
Sample 30. Gunung Baganite.
X-nicols.

Symbols
pl : plagioclase; q : quartz; bi : biotite

Scale bar division is 1mm.


A
q
pl
B
pl
hb
pl
C
pl
D
bi
pl
E
bi
q
bi
F
q
bi

Photoplate 11 : Pani Volcanics petrography

11a Cataclasis along flow layering in a phenocryst-rich porphyritic rhyodacite. This is an autobreccia texture and is not due to later tectonic deformation.
Drillhole 4, 139m. Gunung Baganite.
Plain polarised light.

11b 11a X-nicols.

11c Fractured quartz phenocryst.
Deformed or broken quartz phenocrysts rarely show evidence of strain. Plagioclase phenocrysts exhibit mechanical twinning or ductile deformation instead of brittle fracture.
Drillhole 1, 135m. Pani ridge.
Plain polarised light.

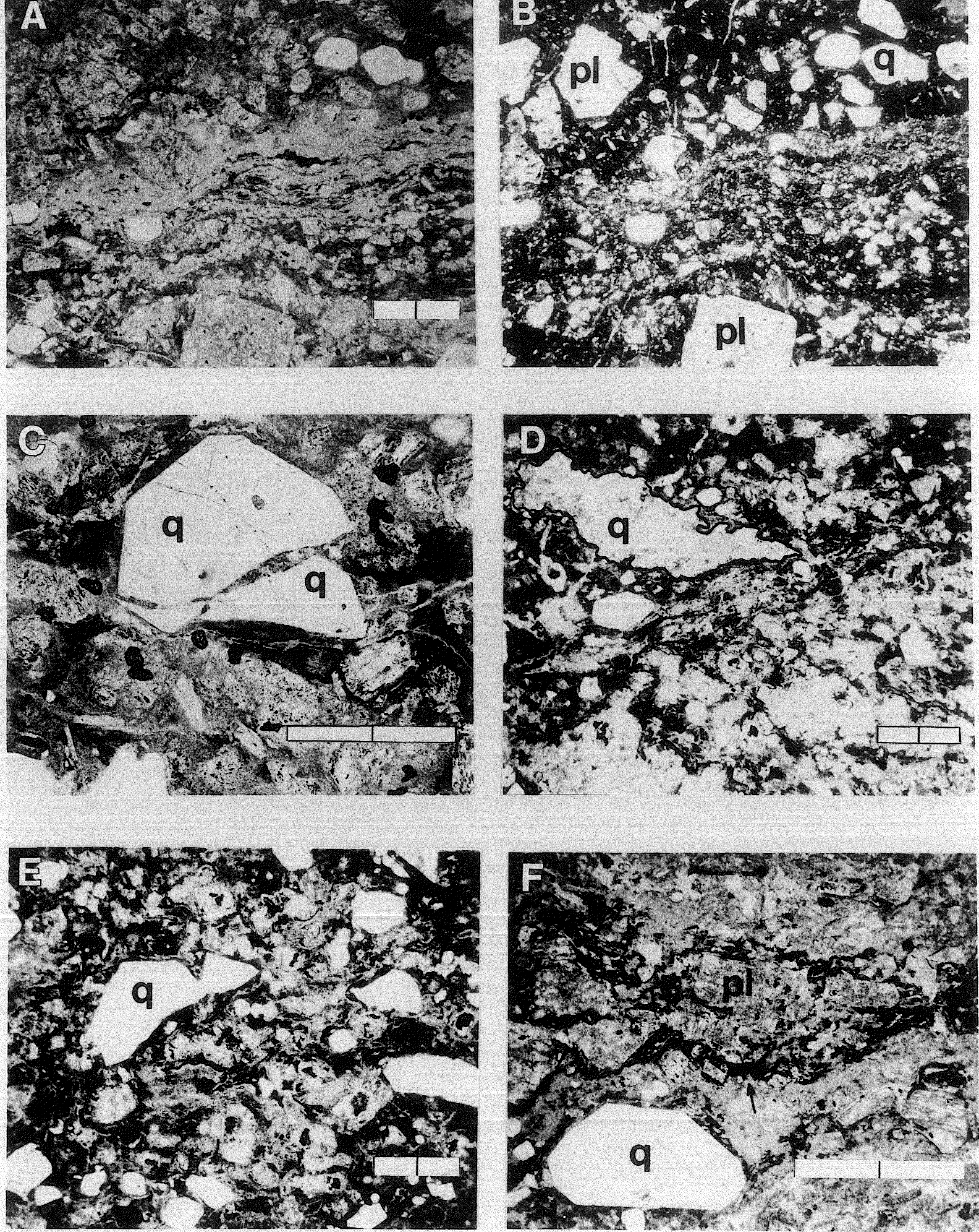
11d Sheared quartz phenocryst, drawn-out into an irregular lensoid shape along flow layering. Highly turbid, heterogeneous cryptocrystalline groundmass.
Drillhole 7, 79m. Pani ridge.
Plain polarised light.

11e Highly turbid, heterogeneous cryptocrystalline groundmass.
Drillhole 7, 79m. Pani ridge.
Plain polarised light.

11f Heterogeneous turbid groundmass.
Completely opaque layers (arrow).
Drillhole 6, 167m. Gunung Baganite.

Symbols
pl : plagioclase; q : quartz

Scale bar division is 1mm.



A
B
pl
q
pl
C
q
q
D
q
E
q
F
pl
q

Photoplate 12 : Pani Volcanics petrography

12a,b Accretionary lapilli in fine crystal/lithic rhyodacitic tuff. Note lapilli show concentric accretion, often around a crystal nucleus.
Sample 804. Sungai Nanasi.
Plain polarised light.

12c Contact between porphyritic rhyodacite and fine rhyodacitic tuff (upper).
Drillhole 7, 198m. Pani ridge.
X-nicols.

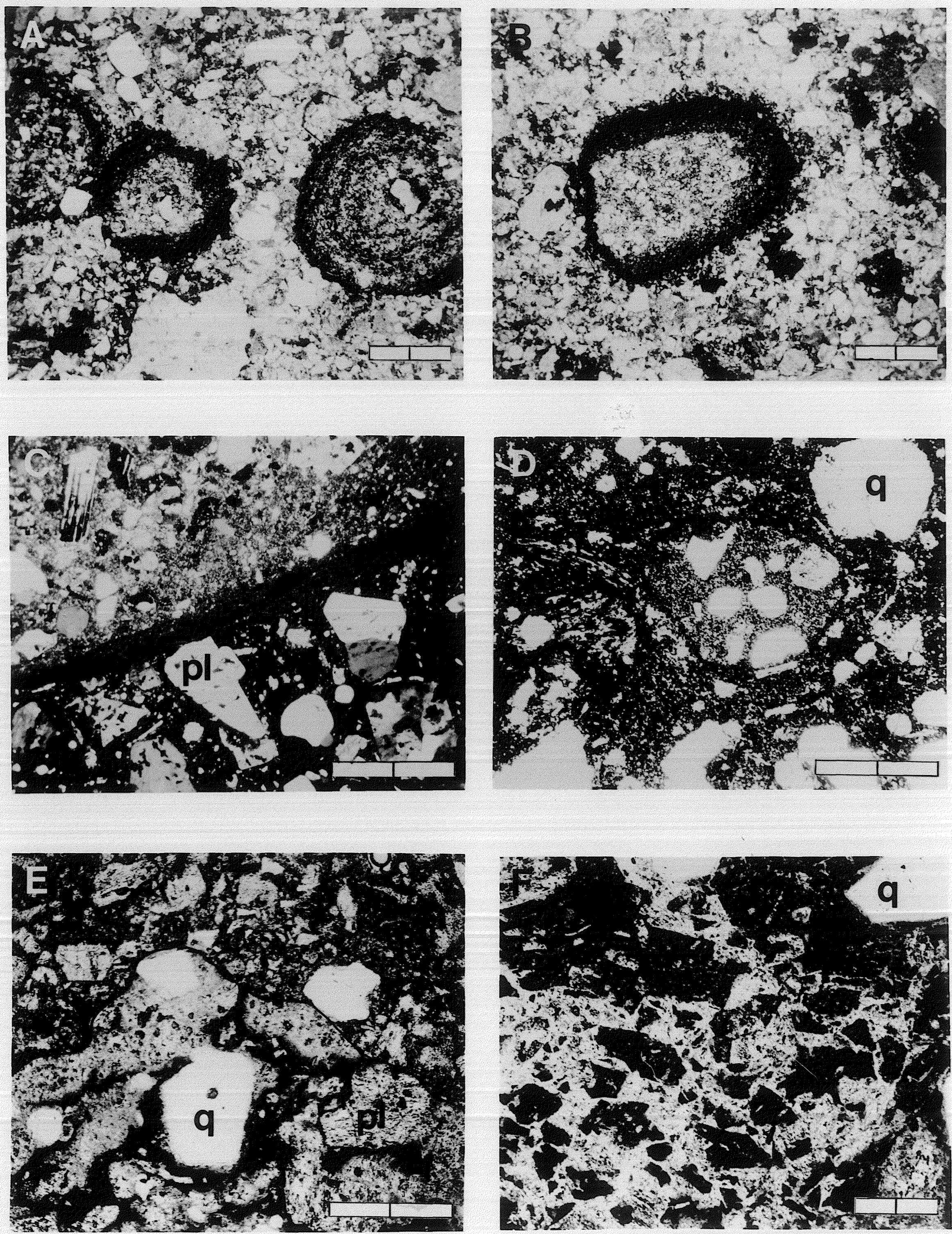
12d Lithic xenolith enclosed in fluidal porphyritic rhyodacite.
Drillhole 1, 12m. Pani ridge.
X-nicols.

12e Scoria clast within rhyodacitic crystal/lithic lapilli tuff. The scoria is phenocryst-rich with a cryptocrystalline matrix. It has a vesiculated texture.
Drillhole 1, 144m. Pani ridge.

12f Explosive brecciation of porphyritic rhyodacite. Note sharp angular fragments.
Drillhole 1, 164m. Pani ridge.

Symbols
pl : plagioclase; q : quartz

Scale bar division is 1mm.


A
B
C
pl
D
q
E
q
pl
F
q

Photoplate 13: Pani Volcanics petrography

13a Normal and oscillatory zoned euhedral plagioclase phenocryst (unidentified inclusion in core) in a microcrystalline granular groundmass. Hornblende/biotite microgranodiorite from the Tabulo ring-dyke Complex. Sample 726 (Location Photoplate 1). X-nicols.

13b Porphyritic biotite/hornblende microgranodiorite from the Pani Volcanic Complex. Sample 565 (Plate 2). X-nicols.

13c Hornblende/biotite microgranodiorite (Sample 726). Note allanite microphenocryst; hornblende with replacement rim of biotite and biotite phenocryst. Plain polarised light.

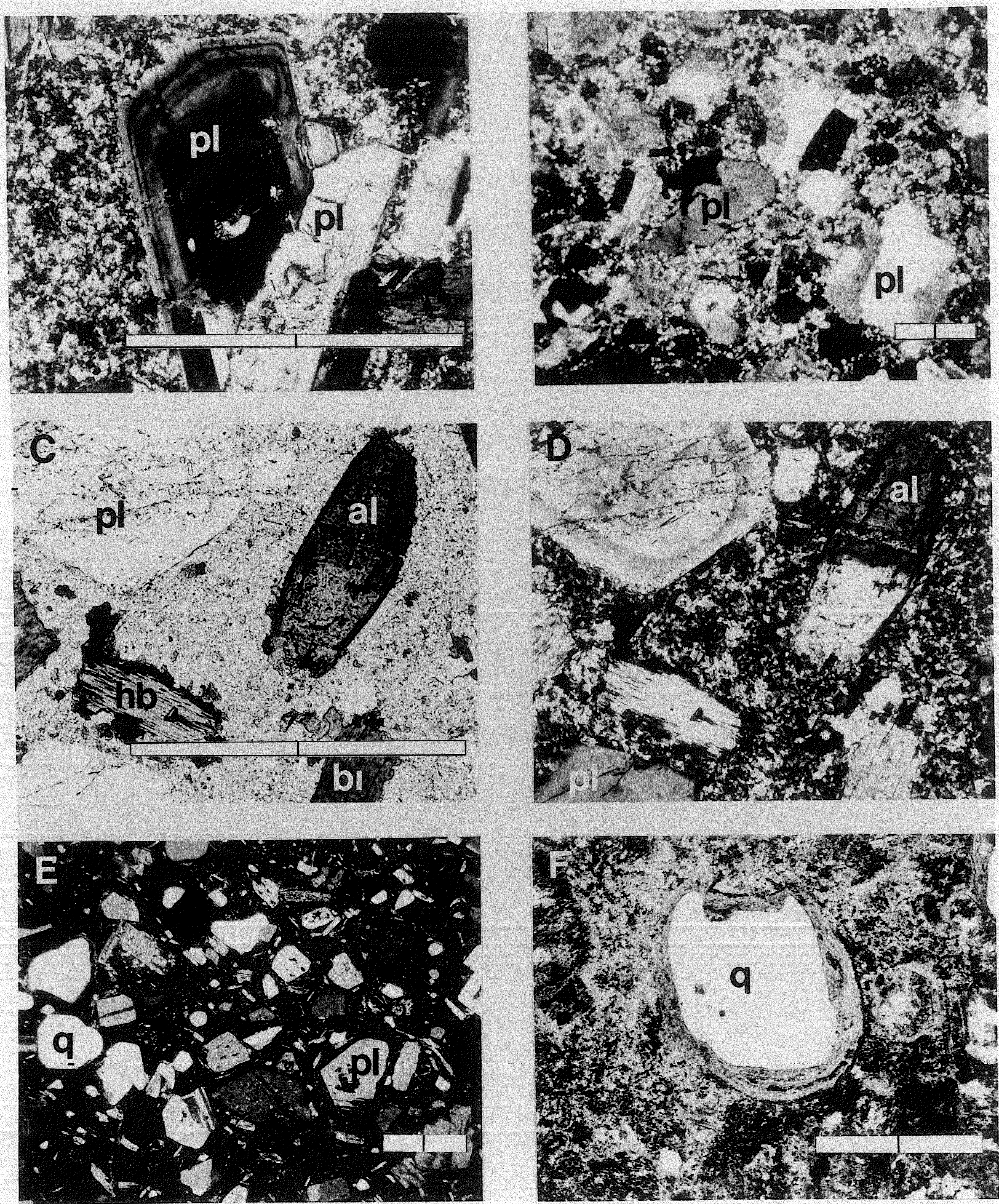
13d 13c x-nicols. Note zoning in plagioclase and microcrystalline-granular groundmass.

13e Typical porphyritic texture of rhyodacites from the Pani Complex. Note cryptocrystalline groundmass. Phenocrysts are quartz, plagioclase and biotite. Sample 34601. Pani ridge. X-nicols.

13f Mantled quartz phenocrysts in porphyritic rhyodacite. The corona is composed of cryptocrystalline K-feldspar. Drillhole 4, 141m. Gunung Baganite. X-nicols.

Symbols
pl : plagioclase; q : quartz; bi : biotite;
al : allanite

Scale bar division is 1mm.


A
pl
pl
B
pl
pl
C
pl
al
hb
bi
D
al
pl
E
q
pl
F
q