Igneous petrology EOSC 321

Laboratory 4:

Intermediate and Felsic Volcanic Rocks. Pyroclastic Rocks

Duration: This lab is to be completed within the lab period. The results will be evaluated and returned to you in the following lab period.

Material Needed: a) Microscope, b) a Manual on Optical Mineralogy (i.e. Minerals in Thin Section by Perkins and Henke)

Introduction:
This lab introduces intermediate and felsic volcanic rocks ranging in composition from andesite to rhyolite. These magmas often fragment to form pyroclastic rocks, therefore we devote the second, minor part of the Lab (~ 30 mins) to look at these.

For classification of intermediate and felsic volcanics you should plot quartz, plagioclase and alkali feldspar modes in the "Volcanic" triangle (attached below). Classification of these rocks is difficult because viscous silicic magmas tend to solidify into glasses rather than crystallize. You can examine such glassy rocks in T/s's 302, 581 (pumices) and in T/s 765 (vitrophyric andesite). Later devitrification of these glasses produces fine-grained aggregates of felsic minerals. In the rocks where it is impossible to determine mineral abundances of phases in the groundmass, the rock classification must be based on phenocrysts. The IUGS recommends that rocks identified in such a manner be called PHENOTYPES (like “pheno-latite). If based on phenocrysts, the position of a rock on classification triangles will be biased to more mafic and basic rocks and usually erroneous for the rock as a whole.

In intermediate-silicic volcanics, plagioclase is usually the most abundant phenocryst phase and generally displays complex oscillatory zoning. Quartz is the next most common felsic mineral, whereas alkali feldspar is not common in calc-alkaline volcanic rocks and is restricted only to the alkaline series.

Clear (not zoned or twinned) low birefringent phenocrysts could be quartz or K feldspar. To identify them, you need to recall conoscopy (see additional 2 pages at the back of this Lab). In the conoscopic view, see the movement of the interference figure for the mineral. If isogyres move vertically or horizontally, the mineral is uniaxial and therefore is quartz. If isogyres rotate and change the curvatures, the mineral is biaxial and therefore is K feldspar or plagioclase. Observe Quartz phenocrysts in T/s 765.

In volcanic felsic rocks you can come across 2 varieties of K-Fsp: sanidine and anorthoclase. The latter is very rare. Sanidine may have simple Carlsbad twinning or may have no twinning at all. As a simple rule of thumb, you should call any volcanic K-Fsp sanidine.

Amphiboles in andesites are strongly pleochroic hornblendes frequently showing intense opaque reaction rims due to low-pressure instability. When reddish-brown, the amphiboles are termed oxyhornblende. They are also distinguished from hornblende by their higher birefringence and lower extinction angles. Oxyhornblende is not a distinct mineral species, but a hornblende in which a substantial amount of iron has been oxidized to the Fe^{3+} state and $(OH)^-$ is replaces by O_2^- to balance the charge. There is a continuous range of compositions and properties between members of the hornblende and oxyhornblende. Conventional hornblende can be converted to oxyhornblende by heating in an oxydizing environment, and the process may be reversed by heating in a reduced environment.

Make sure you see rhyolite with spherulitic textures (T/s 866) characteristic of felsic volcanics. Spherulites are spheroidal bodies in a rock composed of an aggregate of fibrous crystals of one or more minerals radiating from a nucleus, with glass or crystals in between. The most common occurrence of spherulitic texture is a radiating aggregate of acicular alkali feldspars with glass between them, though quartz or other mineral may also be present, resulting in the intergrowth texture. The colour variation in the spherulites is caused by variations in the density of fibres.

Make sure that you see the following minerals and textures in the Reference Collection for Intermediate-Felsic Volcanics:

- ❑ Oxyhornblende
- ❑ Sanidine, with or without simple twinning
- ❑ Conoscopic evidence for quartz
- ❑ Trachytic, vitrophiric, spherulitic, perlitic amd pumiceous (in the order of importance)

After you finished working with this collection, move to the collection of Pyroclastic rocks. Explanations on the origin of the pyroclastic rocks can be found after thin section descriptions, rather than in a separate Introduction.

In the third hour you will receive a thin section of an unknown volcanic rock for your independent examination. Write its petrographic description and give a rock name. Determination of the plagioclase composition is a necessary part of the petrographic description. Your petrographic report should be completed and handed to the TA by the end of the Lab.

Reference collection: Intermediate and Felsic Volcanic rocks

Thin Section: 1035
Sample: P 365
Rock Type: Feldspathic volcanic rock (Trachyte? Latite? Andesite?)
Location: ?

Thin Section Description:
Texture: Porphyritic. Texture of the groundmass is concertal, i.e. with notched or serrated boundaries between grains.

20% Phenocrysts:
12% Hornblende, strongly pleochroic from yellow to green-blue, zoned, euhedral, many grains are simply twinned, extinction angle 22º
8% Plagioclase, euhedral, zoned, N > N Balsam, An15, with simple Calsbad twinning, and polysynthetic twinning, severely altered to clay minerals and saussurite
1% Augite, euhedral, pale olive to colorless.
Few grains K-Fsp? Grains with no Calsbad or polysynthetic twinning

80% groundmass:
68% Fine-grained felsic mineral with $N<N_{Balsam}$. Could be either albite or K-Fsp. Tentatively identified as K feldspar (sanidine) as it lacks polysynthetic twinning.
10% Hornblende, in small green high-relief grains
1% Augite, in small colourless high-relief grains
1% Apatite
Opaque mineral

Secondary Minerals: Clay minerals and Saussurite after Plagioclase

Comment: Felsic Mineral in the groundmass cannot be identified with 100% certainty (Albite? K-Fsp?) and therefore we cannot assign a name to this rock. However, we know that quartz is absent and thus the rock should be classified as trachyte or latite or andesite, i.e. a fedspathic volcanic rock.

Thin Section: 1245
Sample: P 631
Rock Type: Andesite
Location: Mt. Shasta, Fort Ebbutt

Thin Section Description:
Texture: Porphyritic. Texture of the groundmass is hypohyalline, i.e. with a considerable amount of glass

20% Phenocrysts:
14% Plagioclase, euhedral, strongly zoned, N> N Balsam, cores An 55-68, rims An 45-56
6% Oxyhornblende, strongly pleochroic from yellow-brown to almost colourless, zoned, euhedral, extinction angle 4-6º, high 3-4 order interference colours, with reaction rims of an opaque mineral. Oxyhornblende is distinguished from hornblende by higher birefringence, lower extinction angles and darker brown colour.
0.5% Felsic mineral with $N < N_{Balsam}$, in euhedral grains with circular cracks around spherulitic aggregates. Most likely is a secondary zeolite after plagioclase. However, it may also be a primary K-Fsp.

80% Groundmass:
35% Plagioclase, euhedral laths, zoned, An45.
35% Glass, colourless, N< N Balsam, with incipient crystallization and therefore not completely isotropic.
10% An opaque dark-brown-reddish mineral in euhedral long grains – Ilmenite?

Secondary Minerals: Zeolite after Plagioclase

Thin Section: 1465
Sample: P 581
Rock Type: Dacite
Location: ?

Thin Section Description:
Texture: Porphyritic. The groundmass has a segregational texture, with rock patches of different mineralogy.

25% Phenocrysts:
21% Plagioclase, euhedral, severely zoned, An 33 in core, An 42 in rims. N core > N rim. Partly altered to sericite. Forms glomeroporphyric intergrowths and is present in fragments of broken larger grains.
2% Biotite in euhedral crystals partly replaced by chlorite and epidote.
2% Quartz, in smaller euhedral grains, sometime with uneven "domain" extinction.

The groundmass has segregational texture with patches enriched in biotite and quartz. These areas are comprised of larger euhedral biotite (50%) and larger grains of quartz (50%).
75% groundmass:
50% Quartz in equi-dimensional, anhedral interlocking grains
12% Plagioclase in subhedral twinned grains of larger microphenocrysts.
12% Biotite in euhedral grains.
Opaque mineral

Secondary Minerals: Sericite after Plagioclase
Chlorite after Bi, green
Epidote after Bi, yellow grains with strong pleochroism from yellow to green.

Comment: Bi-rich segregations in the groundmass may have resulted from the crystallization of volatile-enriched residual pockets of melt. The volatile enrichment of the magma in these areas is suggested by larger grains sizes of Bi and Qz (like in pegmatites) and by more abundant biotite – the only hydrous primary mineral of the rock.

Note also that plagioclase rims in the rock are more calcic than cores. Such reverse zoning is rather unusual for a magmatic rock,

Thin Section: 765
Sample: P 1580
Rock Type: Vitrophyric Andesite
Location: Mt. Lassen

Thin Section Description:
Texture: Vitrophyric vesicular. Phenocrysts are set in a glassy groundmass.

20% Phenocrysts.
12% Plagioclase, euhedral, severely zoned, $N > N_{Balsam}$, An_{29}. Several grains show an unusual patchy zoning. Inclusions of light-brown and grey glass are very common and give the plagioclase a "sieved" texture.
5% Biotite, euhedral
3% Quartz, clear, unzoned, un twinned grains with low birefringence. Conoscopy confirms its uniaxial character
1 grain of oxyhornblende with high birefringence
1 grain of euhedral pyroxene (Opx? Cpx?)

10% Glomeroporhyric intergrowths
The integrowths found in the thin section are:
Plag+ Plag; Bi +smaller Plag crystals nucleating on their rims;
Ol with Hb rims and smaller Plag crystals; Opaques + Plag + Bi + Hb

80% groundmass:
60% Colourless to grey glass with N< N Balsam, N~ 1.52
10% Round vesicles
4% Light brown glass associated with Plag phenocrysts
3% Hornblende in larger euhedral microphenocrysts
3% Plagioclase in euhedral grains.
0.5% Biotite, euhedral
0.5% Pyroxene, euhedral
Apatite

Thin Section	1006
Sample Number	P242
Rock Name:	Silicitized Trachyte
Location:	Chaffee, Colorado

Thin Section Description:

Texture: Vitrophyric. Phenocrysts are set in the glassy groundmass
Amygdaloidal, i.e. with vesicles filled with secondary minerals

9% Phenocrysts:

8% Sanidine in subhedral resorbed crystals. (-), 2V~ 20o. Distinguished from quartz by elongate grain habits, imperfect cleavage and N< N Balsam. Distinguished from albite by the lack of polysynthetic twinning. Some crystals are entirely replaced by an aggregate of secondary quartz.

1% Biotite, euhedral

few grains of a euhedral opaque mineral

91% Groundmass:

75% Glass, clear, with tiny unidentifiable crystallites marking flow textures. The glass has darker, almost black colour next to vesicles where it is more oxidized. Perlitic fractures.

10% Vesicles of elongate irregular shapes marking flow directions. The vesicles are filled with a fine-grained aggregate of secondary quartz.

5% Quartz of secondary origin filling out fractures and veins

Secondary Minerals: Fine-grained Quartz after Sanidine, glass and vesicles.

Thin Section	1553
Sample Number	P1487
Rock Name:	Quartz-rich Rhyolite
Location:	Keno Hill

Thin Section Description:
Texture: Aphyric, aphanitic.

5% Phenocrysts:
4% Quartz, euhedral grains with N > N Balsam. Can easily be identified by conoscopy as the only uniaxial felsic mineral.
1% Plagioclase with polysynthetic twinning, N< N_{Balsam}, An_9. Altered to secondary muscovite and carbonate. Has a "dusty" look due to development of fine clay (?) mineral grains.
0.5% Muscovite, in euhedral laths associated with an opaque mineral.

95% Groundmass:
65% Quartz, fine-grained interlocking grains
15% Muscovite, subhedral crystals. May well be of secondary origin
15% Alkali Feldspar (Sodic Plagioclase? Sanidine?), in larger subhedral grains, N< N_{Balsam}, Under one polar grains have a "dusty" look and stand out in the quartz matrix. Partly replaced by carbonate.

Secondary Minerals:
25% Secondary Muscovite replacing Plag phenocrysts and minerals in the groundmass. Cannot be easily distinguished from a primary muscovite present in the rock.
3% Carbonate. Anhedral crystals with pearl colour that show severe change in relief as one rotates the stage.

Comment: An alkali feldsar in the groundmass cannot be identified. However, this rock should be classified as "quartz-rich rhyolite" irrespectively of the type of the alkali feldspar in it.

Thin Section: 1448
Sample: P1254
Rock Type: Pheno-Andesite.
Location: South side Ben Nevis

Thin Section Description:
Texture: Porphyritic. Texture of the groundmass is concertal, i.e. with notched or serrated boundaries between grains

15% Phenocrysts:
10% Plagioclase, euhedral, strongly zoned, An_{32} in core, An_{20} in rims. Polysynthetic twinning. Some grains are almost completely seriticized, some grains are absolutely fresh.
5% Biotite, strongly pleochroic from yellow to dark-brown, euhedral to subhedral resorbed , surrounded by thin black rims of oxidation products. Partly replaced by green chlorite
Few grains of K-Fsp (?) – euhedral prismatic grains with no twinning, completely sericitized.

85% groundmass:
Fine-grained intergrowth of mostly unidentifiable felsic minerals. They include quartz, twinned plagioclase and K-Fsp with $N<N_{Balsam}$. Modal proportions of the minerals are unknown. Also present apatite and opaque mineral.

Secondary Minerals: Sericite (5%) after Plagioclase and Chlorite (1%) after Bi.

Comment: The rock is classified on the basis of phenocryst mineralogy, since it is impossible to determine a mineralogical mode of the groundmass. However, the rock name “andesite” is certainly biased toward basic composition and does not reflect the presence of Qz and K-Fsp in the groundmass. If we assume equal modes for Plag, Qz and K-Fsp in the groundmass, the rock should be classified as rhyolite.

Thin Section: 722 (2 thin sections)
Sample: P 514
Rock Type: Andesite
Location: Mt. Shasta

Thin Section Description:
Texture: Porphyritic with hypocrystalline vesicular groundmass with trachytic texture.

7% Phenocrysts:
5% Augite in euhedral grains. Often in glomeroporphyric intergrwoth
2% Plagioclase, euhedral, zoned, An 47
Few grains of hypersthene – Opx with the parallel extinction

93% groundmass:
55% Plagioclase microlites aligned in the direction of flow.
10% Vesicles, round
25% Light brown glass with N < N Balsam
3% Augite, euhedral microphenocrysts
2% Opaque mineral

Comment: The rock should be classified as basalt based on the composition of the plagioclase (labradorite) and as andesite based on colour index (less than 35% mafic minerals). Small proportion of dark minerals (~ 7%) and silicic glass ($N < N_{Balsam}$) show it is most likely andesite.

Thin Section: 302, 581
Sample: P 2067
Rock Type: Pumiceous Rhyolite
Location: Askja eruption 1880, Iceland

Thin Section Description:
Texture: Pumiceous - Frothy vesicular
Glassy (holohyaline)

Groundmass:
50% oval and irregularly shaped vesicles marking flow structures and flow turbulence
50% glass with N << N Balsam, clear in T/s 302 and grey-brown in T/s 581, contain tiny crystallites of opaque and light minerals.

Comment: The rock is classified as "rhyolite" based on the very low refractive index of the glass ($<< N_{Balsam}$) typical of acid and silicic glass.

Thin Section: 866
Sample: P 2441
Rock Type: Spherulitic rhyolite (?)
Location: Granite Creek

Thin Section Description:
Texture: Aphyric, aphanitic, spherulitic.

3% Phenocrysts:
2% Plagioclase, euhedral, An_{45}, with polysynthetic twinning, severely altered to sericite and clay minerals. Commonly present in nuclei of spherulites.
0.5% Muscovite, long euhedral laths
0.5% K-Fsp (Sanidine?) euhedral laths without polysynthetic twinning, with perthitic structures, altered almost completely to sericite and clay minerals
Few grains of an opaque mineral

97% groundmass:
92% Fine-grained intergrowth of felsic minerals. They include sanidine with $N<N_{Balsam}$ growing in feather-like microlites with undulose extinction; quartz, and yellow fibrous crystobalite. Perlitic fractures and textures are very pronounced. The cores in perlitic round structures are composed of yellow fine-grained crystobalite, whereas rims crystallised in less finer-grained quartz and sanidine.
5% Spherulites - spheroidal bodies composed of an aggregate of fibrous crystals of crystobalite (yellow), quartz and K-Fsp.

Secondary Minerals: Carbonate in the groundmass and around spherulites.

Comment: The rock name "rhyolite" is tentative since it is impossible to determine modes of minerals in the groundmass. The rhyolitic nature of this rock is suggested by: 1) the presence of spherulites typical only for silicic volcanic rocks; 2) the presence of crystobalite in characteristic yellow-grey fibrous radiating aggregates; 3). The presence of sanidine identified by $N<N_{Balsam}$.

Pyroclastic Rocks and Their Textures

Thin Section: KAS-3A Sample: Rock Type: Alkali Olivine basalt subglacial pillow. Location: Cinder Mountain (see picture)

Description:
Texture: Vitrophyric with felty plagioclase groundmass
40% plagioclase microphenocrysts
20% olivine phenocrysts—some skeletal
groundmass: felty plagioclase, some sections have olivine

Rock Explanation: This thin section belongs to a basic volcanic rock that erupted as subglacial pillows and hyaloclastites. In subglacial and subaqueous environs, pillows can fragment to form hyaloclastite. The glassy rinds of the pillows spill off into the surrounding water. Some hyaloclastites are comprised solely of this material. Other pillows include this material and fresh glass that is quenched and fragmented when liquid lava comes into contact with water. Because this process occurs in a water+energy environment often times hyaloclastites have crude bedding. Nearly all hyaloclastites have a palagonite matrix which holds them together. Usually this matrix is orange/yellow and forms as the hot pile of fragmental material stews in the water and the small shards of glass break down.

Look at the next thin section of the subglacial hyaloclastite: KAS-3B. Describe the section in terms of its components (these are basaltic in composition). What are they? What are their characteristics? What are their origins?
Hint: phenocrysts and bubble content/shape are important in deciphering the origin of these rocks.

Thin Section: MM 93-7
Sample:
Rock Type: (mixed?, partially mixed? mingled?) Dacite pumice
Location: Mt. Meager B.C.

Minerals present (differing amounts in differing sections):
Feldspar, Biotite, Hornblende, Quartz, Apatite
Vesicularity: 50-70%
Groundmass: Glassy stretched bubble walls. Stretching is due to flow of material and originally spherical vesicles become elongated tubes.

Note: Most of the feldspars have little bits of glass included within their framework. This is called sieve texture. The bits of glass come from an event in which the minerals become thermally unstable and partially melt and then are quenched before the new melt can recrystallize. This can happen because of decompression or increase in temperature of the system (e.g., the intrusion of a hotter liquid).

Rock Explanation: Oftentimes prior to eruption a more mafic magma will intrude and cause a magma chamber to become unstable—sometimes causing the eruption. The intruding magma can entirely mix (form a rock of new composition), partially mix, or mingle (behave as an immiscible liquid) with the host magma. The pumice from Mt. Meager MM 93-7 has undergone one of the processes. After reviewing the textures and mineralogy decide which process it has undergone.

Thin Section: MSS-RX
Rock name: Felsic tuff

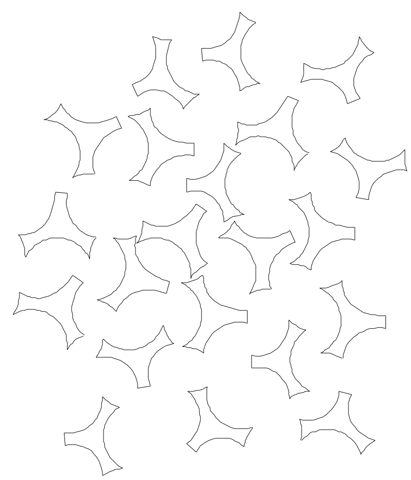
Rock Explanation: This tiff contains accretionary lapilli. They usually form in a suspended ash cloud. The particles can be brought together by electrostatic attraction or coalesce around rain falling through the ash cloud. After deposition some or all of the lapilli can become flattened and/or elongated due to overburden pressure. The dark circular rims are the edges of accretionary lapilli. These are called rim type lapilli because there is a coarser grained core surrounded by a finer grained rim. Core type lapilli do not have a finer grained rim.

Thin Section: WT-85-3 WT-85-4 WT-85-5 WT-85-6a WT-85-7 WT-85-9 Wt-85-10 Rock name: welded ash flow tuff

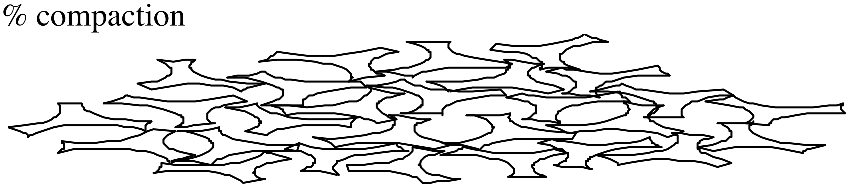
Rock Explanation: This tuff formed as a pyroclastic flow deposit. It is from a unique ash flow deposit—the Walcott tuff in Idaho. The hand samples from this tuff look to be lava flows. Some of them are even very similar to obsidian in character. However, if one looks close enough with a hand lens, small ash particles can be seen. These rocks are comprised of millions of tiny ash shards that have welded together because they were still above their glass transition when the pyroclastic flow came to rest. Most welded tuffs have distinct flattened pumice, or fiamme, which make them obvious in hand sample. (See other hand samples—fiamme are elongated aligned material different from the matrix).

In thin section it is obvious that these rocks are fragmental. Many glass shards are present in different stages of compaction. Originally, the glass shards were bubble walls. Hence, in a slightly welded deposit where very little compaction has occurred the shards will retain their shapes. These shapes will either be hollow circles (bubbles) or 120 degree Y shaped shards. The amount of compaction and welding can be surmised by looking at the deformation of these shards. The Y shapes will lessen or lose the angle in the Y and the bubbles will flatten. The flattening always occurs perpendicular to the principle stress direction (in this case the overburden of material is the stress).

Original Y shaped shards



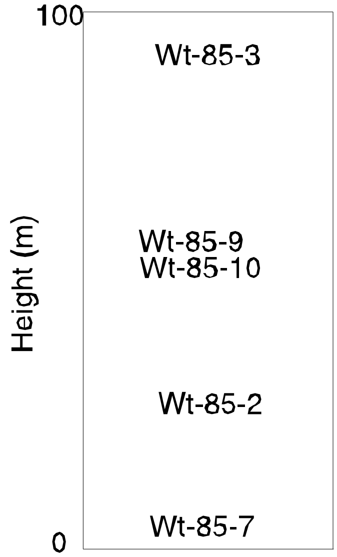
Shards after 75% compaction



Look at the suite of thin sections. Knowing what you know about welded pyroclastic deposits, put the sections into an idealized single cooling unit welding section. Briefly explain why you put each sample in its respective location.

Note: The numbers on the sections do not necessarily correspond with their stratigraphic position!

For example:



321 Microscope Basics - Conoscopic Mode

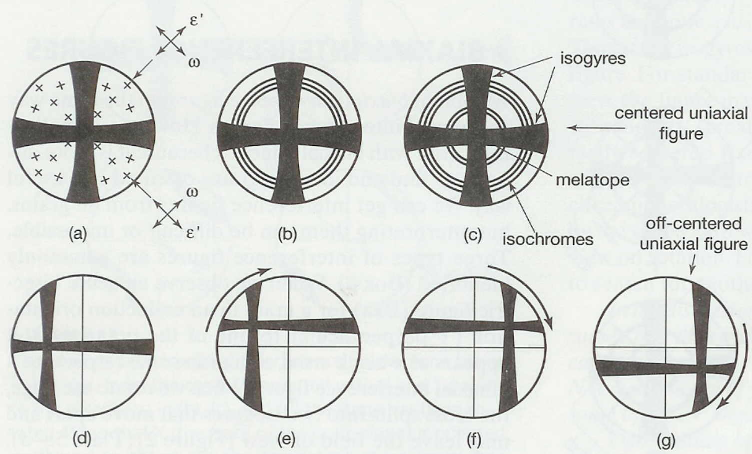
Getting Started:

1. Find a clear, unaltered and unfractured crystal. Focus on lowest power, refocus on medium power, and refocus again on highest power.
2. Try to rotate the table with a high power objective and make sure it is centered. If it is not, you will not see the conoscopic figure.
3. Put microscope into "conoscopic" viewing mode: crossed polars 'on/in', condensing lens 'up' and refocus, Bertrand lens 'on'.
4. If you work with the binocular "Leica" microscope, then you won't need to put the condensing lens up. Just switch the Bertrand lens "on".
5. …you should see an interference figure!

1. Uniaxial vs. Biaxial Minerals:

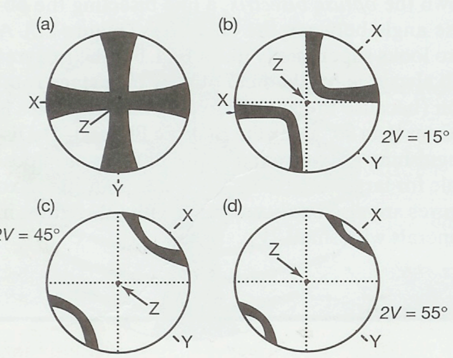
Determining whether or not a mineral is biaxial or unixial can be a valuable diagnostic property between two minerals that otherwise may look very similar, such as plagioclase (biaxial) vs. nepheline (uniaxial). The best interference figures (i.e., centered) are usually obtained from minerals that display the lowest interference colours, ideally one that *appears* to be isotropic or has very low 1st order dark grey interference colours (e.g., the optic axis, or c-axis, is essentially vertical when looking at the mineral in thin section). One way to distinguish between an off-centred uniaxial figure and an off-centered biaxial figure is that the uniaxial figure will only ever have straight isogyres, whereas the biaxial figure will have curved isogyres.

Uniaxial Interference Figure: A uniaxial mineral has ONE optic axis and will be a member of either the hexagonal or the tetragonal crystal systems. A uniaxial interference figure will look like those on the Figure below. However, very rarely one can find an ideal section of the mineral where isogyres cross in the center. Most times you see just one isogyre in the field of view. **If this isogyre moves vertically or horizontally without changing the slope as you rotate the table, you're looking at a uniaxial mineral.**



▶**FIGURE 19**
Uniaxial interference figures. In (a), (b), and (c) the figure is centered; in (d), (e), (f), and (g) it is off-center but the cross is visible. In (a), the small crosses show the vibration directions of ε' and ω; ε' always vibrates radially and ω vibrates perpendicular to ε'. In (b), one set of isochromes is shown, while in (c) there are two sets because of higher birefringence. (d) through (g) show how the melatope (the center of the cross) of an off-center figure precesses as the microscope stage is rotated.

Biaxial Interference Figure: A biaxial mineral has TWO optic axes and will be a member of the orthorhombic, monoclinic, or triclinic crystal systems. A biaxial interference figure will look like the Figure on the right. However, very rarely one can find an ideal section of the mineral with two isogyres. Most times you see just one isogyre in the field of view. **If this isogyre changes its slope and curvature, as you rotate the table, you're looking at a biaxial mineral.**

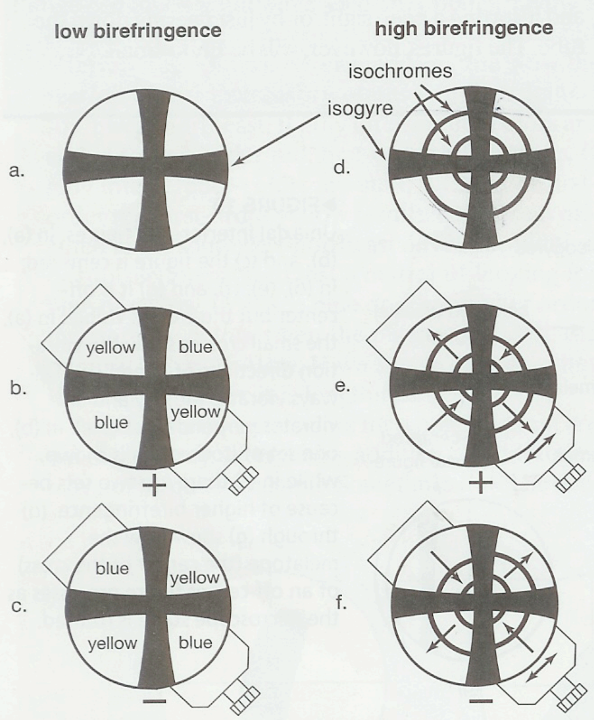


▶**FIGURE 21**
Biaxial acute bisectrix (Bxa) interference figures for a biaxial (+) crystal. In (a) the crystal is oriented with X and Y parallel to the polarizers; in (b), (c), and (d) the stage has been rotated 45° so that X (the trace of the optic plane) is oriented northwest-southeast and the isogyres are at maximum separation. The degree of separation is proportional to *2V*. Similar relationships apply to biaxial (−) crystals except that X and Z are interchanged. Compare these drawings with Plate 5a–h.

2. Determining Optic Sign

The optic sign of a mineral is another diagnostic property that can be obtained from an interference figure. Optically (+) minerals will have $n_\varepsilon > n_\omega$, or the extraordinary wavelength (ε) is *faster* than the ordinary wavelength (ω). To determine the optic sign of a mineral, obtain a good interference figure (preferably centred, although not necessary), and insert the accessory slot.

If the colours *add* ("blue") in the upper right quadrant, then the mineral is optically (+); if the colours *subtract* ("orange") in the upper right quadrant, then the mineral is optically (-). A good way to remember this is the acronym **BURP** (**B**lue-**U**pper-**R**ight-**P**ositive). The example on the right illustrates the optic sign using a uniaxial interference figure, however a biaxial mineral would have the same response to the accessory plate insertion.



▶FIGURE 20
Determining the sign of a uniaxial mineral. (a) A slightly off-center uniaxial interference figure showing no isochromes (low birefrigence). (b and c) When the accessory plate is inserted, yellow and blue colors seen in different quadrants allow us to determine whether the mineral is positive or negative. (d) A slightly off-centered uniaxial interference figure with isochromes (due to high birefrigence). (e and f) When a quartz wedge is inserted, many colors are visible, but the isochromes move in and out in different quadrants depending on optic sign.

plutonic (phaneritic):

Volcanic (aphanitic):

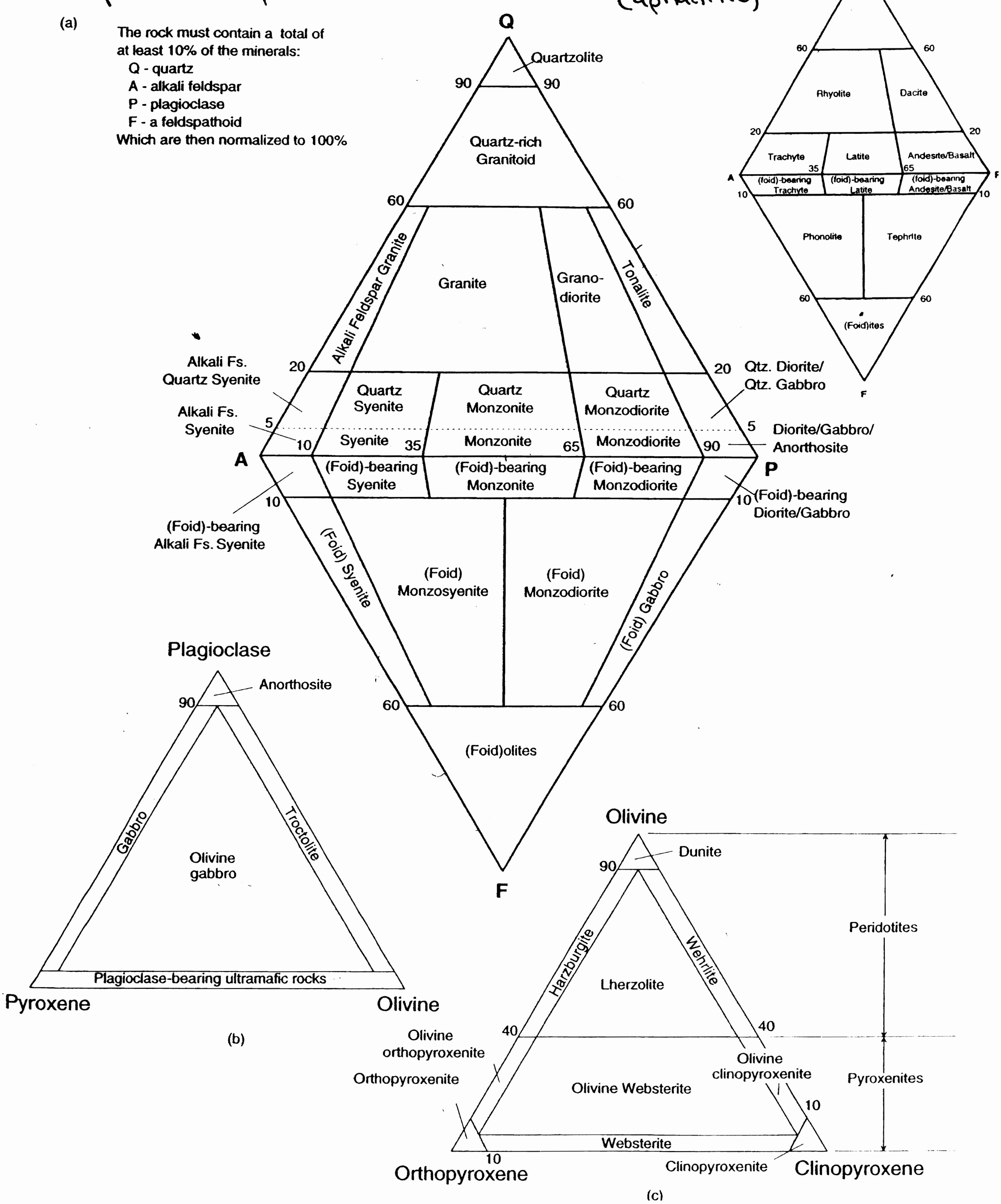


Figure 2–2 A classification of the phaneritic igneous rocks. **(a)** Phaneritic rocks with more than 10% (quartz + feldspar + feldspathoids). **(b)** Gabbroic rocks. **(c)** Ultramafic rocks. After IUGS (see references at the end of the chapter).

from Winter (2001)