PLAG. COMPOSITION.

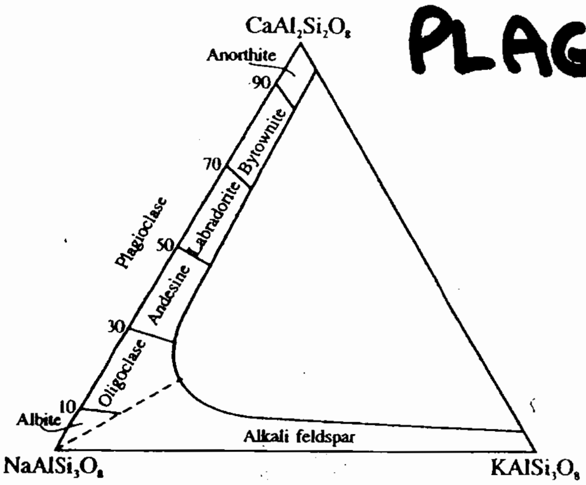

Figure 12.5 Composition range of common feldspars.

little K^+ is included in plagioclase, the composition is often described in terms of the percentage of the anorthite (An) end member, with the presumption that the remainder is dominantly albite (Ab) so that An + Ab = 100. The composition of plagioclase with 35 mole percent Ca^{2+} and 65 mole percent Na^+ is An_{35}, for example. The plagioclase feldspars are conventionally separated into six different named composition ranges:

Albite	An_0–An_{10}
Oligoclase	An_{10}–An_{30}
Andesine	An_{30}–An_{50}
Labradorite	An_{50}–An_{70}
Bytownite	An_{70}–An_{90}
Anorthite	An_{90}–An_{100}

Determining Composition It is not possible in hand sample to determine composition, but plausible guesses can be made based on the rock type in which the plagioclase is found (Table 12.4). Several optical techniques have been developed to allow composition to be estimated to within a few percent anorthite. If knowledge of composition is important, optical techniques should be supplemented with chemical and/or X-ray techniques.

Grain Mount: The most accurate method depends on measurement of n_α, n_β, and n_γ and comparison with Figure 12.13. However, cleavage tends to control fragment orientation making it difficult to find grains in appropriate orientations. This difficulty is turned to an advantage with the **Tsuboi method,** which is used for plutonic plagioclase. To use the Tsuboi method, proceed as follows:

1. Prepare a grain mount of crushed plagioclase (Chapter 10).
2. By examination, select a fragment lying on either cleavage surface, it does not matter which.
3. Cross the polarizers and rotate the grain to extinction with the fast ray parallel to the lower polarizer vibration direction. Use the accessory plate to determine which ray is fast (Chapter 7).

Table 12.4 Plagioclase Composition in Common Igneous Rock Types

Rock Type	Plagioclase Composition
Felsic (granitic pegmatite/granite/rhyolite/ granodiorite/dacite/etc.)	Albite or oligoclase
Intermediate (andesite/diorite and related)	Andesine
Mafic (basalt/gabbro and related)	Labradorite

4. In plane light, compare the index of refraction n'_α with the index of refraction of the oil.
5. Repeat, using different immersion oils, until a match is obtained.
6. Use Figure 12.14 to determine the composition. If n'_α is measured to an accuracy of ±0.001, accuracy of ±1% An content is possible in the range An_{20} to An_{60}, and ±3% An outside of that range. The accuracy for volcanic rocks is probably no better than ±5% An. A significant complication is that plagioclase often is chemically zoned, so grains from a crushed sample of a single crystal may contain a range of compositions.

Thin Section: The **Michel Lévy** and **Carlsbad-albite** methods are used to determine the composition of plagioclase in thin section. They depend on the fact that optical orientation of plagioclase varies systematically with composition. Both methods involve measurement of extinction angles to the trace of the {010} composition plane of albite twin lamellae, and require selection of grains oriented so that the {010} crystallographic plane is vertical (i.e., the *b* crystal axis is horizontal).

The Michel Lévy method requires measurement of a half dozen or more grains in the sample to find a maximum value of the extinction angle between {010} and the trace of the fast ray vibration direction. A number of grains must be

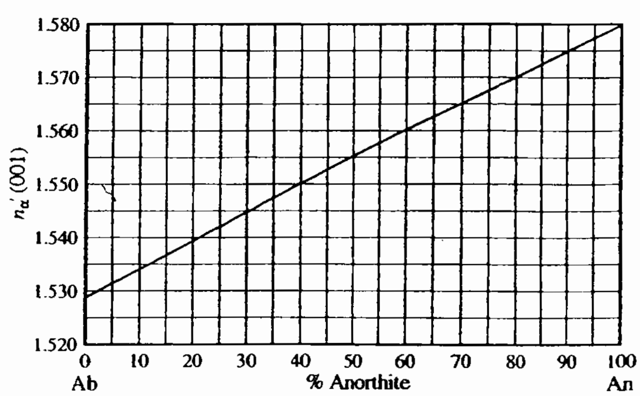

Figure 12.14 Index of refraction of the fast ray (n'_α) for plagioclase fragments lying on cleavages. The diagram is constructed for fragments on (001) cleavage surfaces but may also be used for fragments on (010) cleavage surfaces. After Morse (1968).

from Nesse (2000)

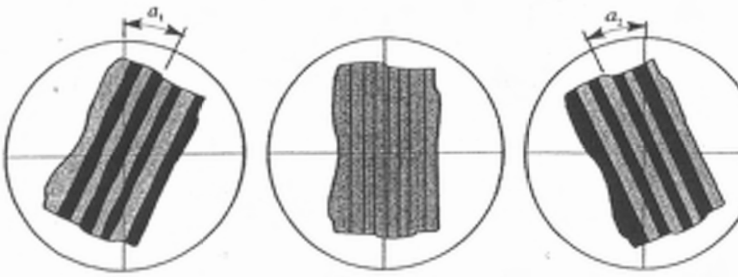

Figure 12.15 Michel Lévy method. Extinction angles a_1 and a_2 are measured to the fast ray vibration direction in their respective sets of albite twin lamellae. The two angles are averaged. A half dozen or more grains are measured and the largest average extinction angle is used to estimate the plagioclase composition from Figure 12.16.

measured because the extinction angle varies depending on grain orientation and it is necessary to find a grain in the correct orientation to yield the maximum extinction angle. To use the Michel Lévy method (Figure 12.15), proceed as follows:

1. Scan the slide to find a grain with the {010} composition plane between albite twin lamellae vertical. Usable grains have the following characteristics:
   - Composition planes between lamellae are crisp and sharp. If {010} is inclined significantly, the lamellae will be fuzzy and the position of the boundaries will shift laterally when focus is raised and lowered while viewed with the high-power objective.
   - All twin lamellae have essentially the same interference color between crossed polarizers when placed parallel to the N–S and in the 45° position. If the two sets of lamellae have different interference colors, either {010} is not vertical or the twins are pericline twins. If the grain is divided in half so lamellae on one side are all one color and lamellae on the other half are a different color, the boundary between the two sides is a Carlsbad twin and the Carlsbad–albite method should be used.
2. Between crossed polarizers, start with the composition plane between twin lamellae parallel to the N–S. Rotate clockwise to bring one set of lamellae to extinction and record the extinction angle a_1. Return the composition plane to N–S, then rotate counterclockwise to bring the other set of lamellae to extinction and record the extinction angle a_2. If the two extinction angles differ by 4° or less, calculate their average. If the two extinction angles differ by more than 4°, discard the readings and find a new grain to measure because {010} is not vertical. In most cases, the extinction angle between the trace of {010} and the fast ray vibration direction is less than 45°, but for calcic plagioclase, it may be larger. To identify the fast ray vibration direction within one set of lamellae, begin by rotating the grain to bring those lamellae to extinction. Then rotate 45° clockwise from the extinction position and insert the gypsum plate (slow NE–SW). If the retardations in the lamellae in question subtract (usually to produce first-order yellow) then the fast ray in those lamellae was correctly placed N–S at extinction. If the colors increase (usually to second-order blue) the slow ray was N–S in the extinction position, and rotation in the opposite direction is needed to bring the fast ray vibration direction in the set of lamellae N–S in the extinction position.
3. Repeat for a half dozen or more grains (more is better). Because only the maximum average extinction angle is useful, time can be saved by quickly moving on if the first angle measured on a grain is less than the largest average measurement taken on other grains.
4. The composition is determined from Figure 12.16. The maximum average extinction angle is plotted on the vertical axis; composition is plotted along the horizontal axis. Different curves are provided for high (volcanic) and low (plutonic) plagioclase. For angles less than about 18°, the curves indicate two possible compositions: one less than An_{20} (plutonic) or An_{12} (volcanic) and the other higher. The distinction between the two possibilities can be made based on indices of refraction and optic sign (Figure 12.13):

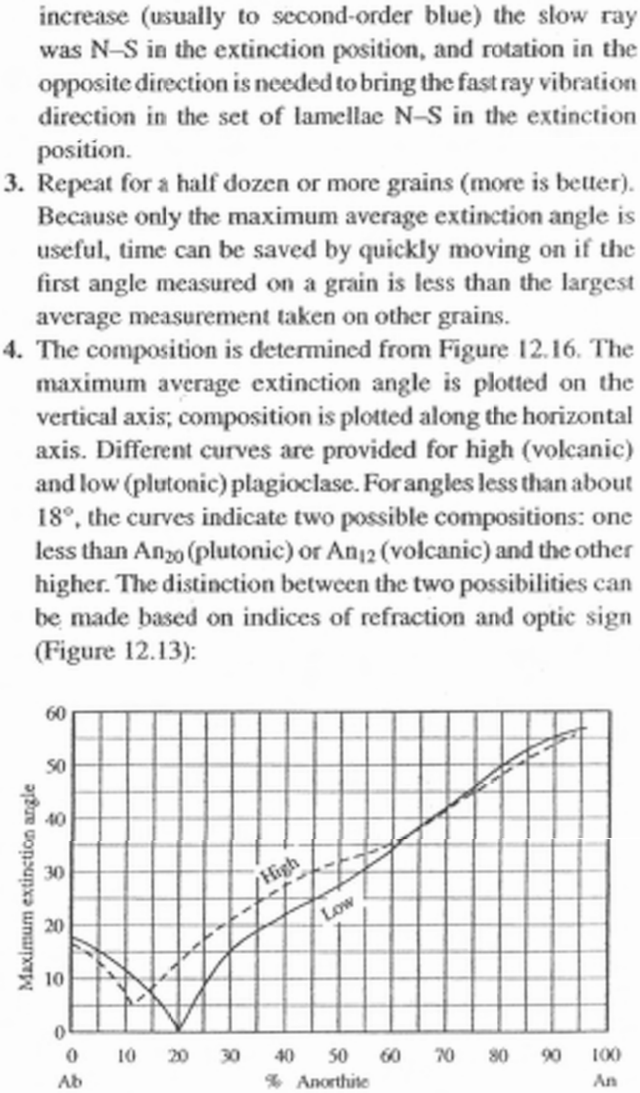

Figure 12.16 Diagram for use with the Michel Lévy method. The maximum extinction angle to albite twin lamellae in sections cut perpendicular to {010} is plotted on the vertical axis; composition is the horizontal axis. The dashed curve is for high (volcanic) plagioclase and the solid curve for low (plutonic) plagioclase. See text for additional discussion. Based on curves of Tobi and Kroll (1975).

An_0–An_{20}: Optically (+), $n_\alpha < 1.538$

An_{20}–An_{35}: Optically (−), $n_\alpha > 1.538$

Note that 1.538 is about the same as the index of refraction of many, but not all, commonly used thin section cements. Provided that the index of refraction of the cement is known to be about 1.538, the two possibilities can be distinguished by comparing n_α with n_{cement}. To do this, find a plagioclase grain with maximum birefringence whose edge is in contact with cement along a hole in the slide or along the edge. Rotate the stage to place the portion of the grain in contact with cement to an extinction position with the fast ray (n_α) vibration direction parallel to the vibration direction of the lower polarizer. Use the accessory plate to identify fast and slow ray vibration directions. Remove the upper polarizer and compare n_α with n_{cement} using the Becke line method.

Accuracy of the method for low plagioclase is roughly ±5% anorthite content up to about An_{60} and worse at higher An content. The accuracy is probably significantly worse with volcanic plagioclase.

The Carlsbad–albite method is closely related to the Michel Lévy method, but only one properly oriented grain is needed to obtain a composition. The procedure is as follows (Figure 12.17):

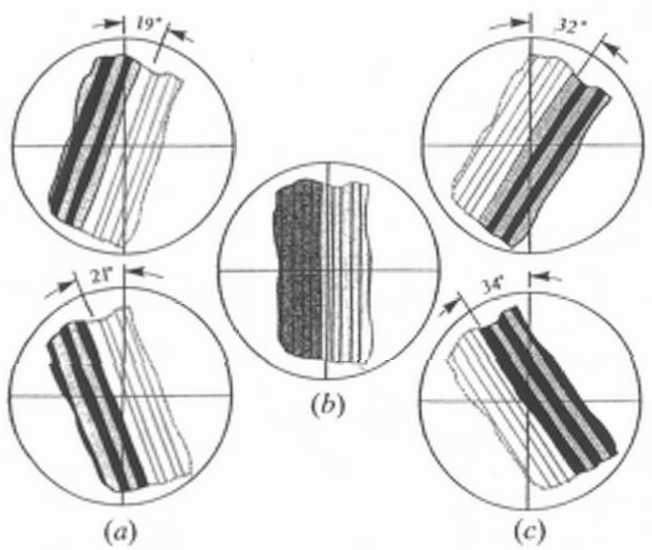

Figure 12.17 Carlsbad–albite method. (*a*) Grain with twin lamellae N–S between crossed polarizers. The two sides of the Carlsbad twin show different colors but the albite lamellae within each side are uniform. (*b*) Extinction angles measured to the fast ray vibration direction in the albite lamellae on the left side of the Carlsbad twin. The average extinction angle in this case is 20°. (*c*) Extinction angles measured to the fast ray vibration direction in the albite lamellae on the right side of the Carlsbad twin. The average extinction angle in this case is 33°. The composition of the plagioclase (An_{60}) is determined from Figure 12.18a.

1. Select a grain with both albite and Carlsbad twinning that is oriented with the {010} composition planes between albite twins vertical. Appropriately oriented grains have the following characteristics:
   - The albite twin lamellae are crisp and sharp indicating that {010} is vertical (see Michel Lévy method).
   - When the twin lamellae are placed in the N–S and 45° positions, the Carlsbad twin separates the grain into two segments with different interference colors, but the albite lamellae within each segment have essentially the same colors. The composition plane of the Carlsbad twin may be slightly irregular.
2. On the left half of the Carlsbad twin, measure the extinction angles from the albite twin lamellae to the fast ray vibration direction in each albite lamellae set as described in the Michel Lévy method. Average the two readings provided they differ by less than 4°. If they differ by more, discard the readings and find another grain.
3. On the right half of the Carlsbad twin, measure the extinction angles from the albite twin lamellae to the fast ray vibration direction in each albite lamellae set in the same manner and average the readings. The 4° rule still applies.
4. The composition is obtained from Figure 12.18a for low plagioclase and Figure 12.18b for high plagioclase. The solid lines are for the larger of the two average extinction angles found in steps 2 and 3; the dashed line is for the smaller. The point where the two curves intersect indicates the composition, which is read from the bottom of the diagram. The vertical axis indicates the inclination of the *c* axis to the stage of the microscope.

For extinction angles less than about 20°, there are two or three sets of curves, so the same set of readings may produce several intersections, indicating several possible compositions. For example, with high plagioclase, if the smaller average extinction angle is 10° and the larger is 15°, intersections can be found at An_1 (upper left), An_{29} (top at left center), and An_{66} (bottom at right center), but only one is correct. For relatively albite-rich compositions, the ambiguity is resolved in the same way described for the Michel Lévy method. For more calcic possibilities, additional grains can be measured to determine which is correct.