

# OPTICAL DETERMINATION OF THE AN-CONTENT OF PLAGIOCLASES TWINNED BY CARLSBAD-LAW: A REVISED CHART

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ABSTRACT. The charts published earlier in this Journal (Tobi, 1963) are revised using data of Burri, Parker, and Wenk (1967).

## SUMMARY OF THE DETERMINATION METHOD

The method is applied to Carlsbad twins of plagioclase, in which the extinction angles  $X' \Delta$  (010) are measured in a section normal to (010). As the Carlsbad composition plane is often irregular, the Carlsbad twin individuals themselves should exhibit albite twinning in order to allow a more accurate determination of the position of the (010) plane (fig. 1).

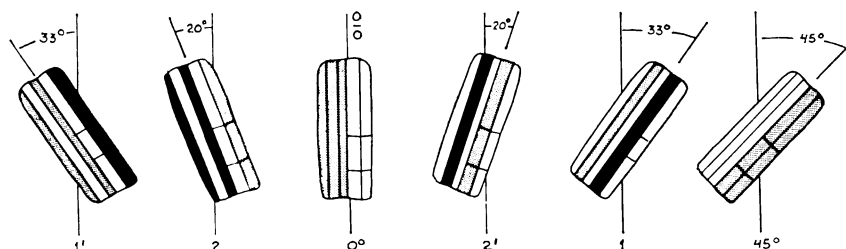


Fig. 1. Appearance of a Carlsbad twin—each individual with albite twin lamellae—on turning the stage with crossed nicols. The Carlsbad individual at the right is oriented normal to [100]. The symbol [100] is used here regardless of sign.

1-1': extinction positions of albite lamellae in Carlsbad individual at the right.

2-2': extinction positions of albite lamellae in Carlsbad individual at the left.

The albite lamellae "disappear" in the 0° and 45° positions of the stage, whereas the Carlsbad twin is visible in one or both these positions by a difference in brightness of the two individuals. In this particular case, the twins are also indicated by the (001) cleavage: the traces make an angle of 8° in the albite lamellae of the right Carlsbad individual and are invisible in the left individual.

Within each Carlsbad individual, the extinction angle  $X' \Delta$  (010) is best obtained by halving the angle between the two albite extinction positions. In this way, the effect of an eventual small tilt of (010) is largely compensated.

*We are not dealing with a Carlsbad twin if in a section normal to the composition plane:*

1. the lamellar twin does not show symmetrical extinction;
2. the elongation with regard to the composition plane is positive for one or more of the twin individuals;
3. one or more of the twin individuals remain almost dark on turning the stage.

*The negative criteria (2) and (3) do not apply if the An-content of the plagioclase is higher than about 70 percent An as will be indicated by extinction angles approaching 45°. In this case, the type of twinning can be ascertained only if one or more individuals are cut normal to [100] and thus show the (010) and (001) traces (figs. 1, 4).*

The two extinction angles of the Carlsbad twin are now plotted in the chart (figs. 2, 3), using the solid and the dashed curves for the higher

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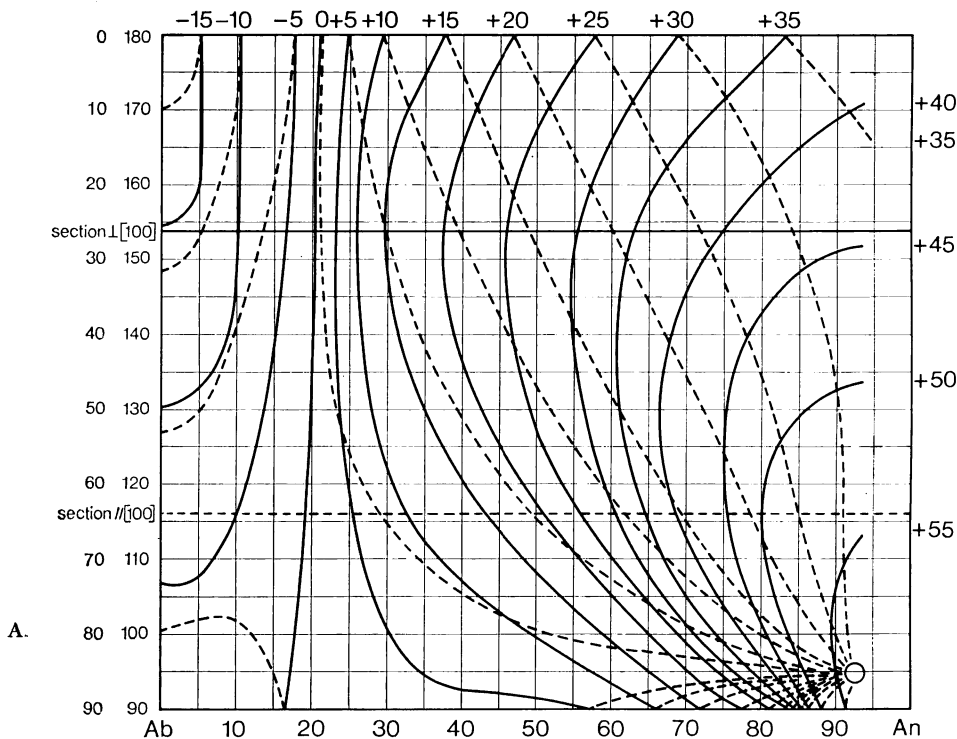


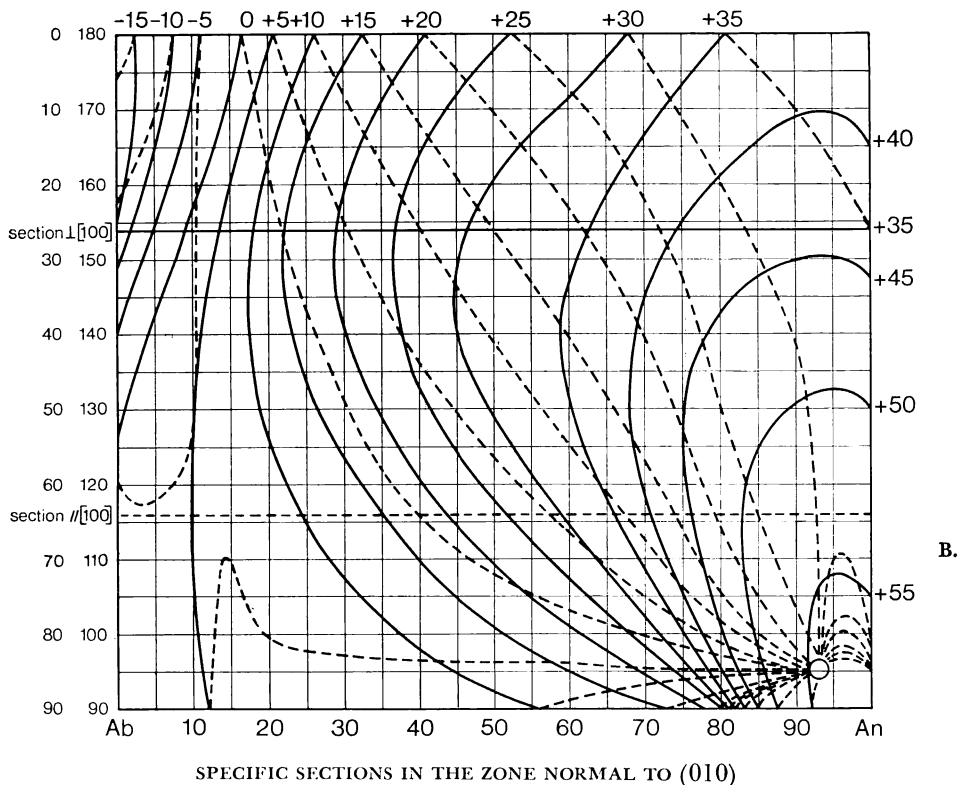
Fig. 2. Charts for determination of the An-content of "low" (A) and "high" (B) plagioclases with the aid of the extinction angles  $X' \Delta$  (010) in the zone normal to (010). Solid curves: larger extinction angle of Carlsbad twin, including section normal to [100] and maximum extinction angle. Dashed curves: smaller extinction angle of Carlsbad twin, including section parallel to [100]. See keys: figures 3 and 5.

and lower value, respectively. The intersection of the curves gives the An-content as indicated along the base of the chart. At 20 percent An, the extinction angles of "low" plagioclase remain about  $0^\circ$  in the whole zone normal to (010). Conventionally, the extinction angles as seen in the section normal to [100] are considered negative for albitic plagioclase, positive for intermediate and calcic plagioclase (fig. 4).<sup>1</sup> If such a section is not found, a choice between the two alternatives can often be made by taking the difference in refractive index between balsam or quartz and plagioclase into consideration.

*Strictly speaking, the extinction angle signs as given in the charts apply only to the individual with the larger extinction angle. However, this does not lead to ambiguity in using the chart.*

*For high plagioclase with An-contents below 25 percent An the extinction angles may deviate from the rules given above. Here a section normal to [100] should be present for a correct determination.*

<sup>1</sup> It will be seen that this rule applies for both albite twin individuals, that is, for the positive as well as the negative side of [100]. Therefore, the symbol [100] is used here regardless of sign.



The ordinate of the charts gives the position of the section in the zone normal to (010). Usually this information is irrelevant for the determination procedure. However, the easily recognizable section normal to [100] can be represented by a horizontal line. It is well-known that the extinction angle in the section normal to [100] alone suffices to determine the An-content. To this end, special charts are in current usage. In the charts presented here, the two methods may be elegantly combined. If only an albite twin normal to [100] is present, the intersection of the corresponding solid extinction curve and the line “ $\perp$  [100]” indicates the An-content. If an adjoining Carlsbad individual is present, the dashed curve representing its extinction angle should pass through the same point, thus providing a cross check and eventually a means to discriminate between high and low plagioclase (fig. 3).

It is recalled that in highly calcic plagioclase the section  $\perp$  [100] may also serve to determine the plane (010), because the elongation with regard to this plane remains negative for the whole plagioclase range. Again, this section is used for determination of the sign of the extinction angle (fig. 4).

Some textbooks also mention the “maximum extinction angle method”. This method is not recommended here, but if it has to be applied,

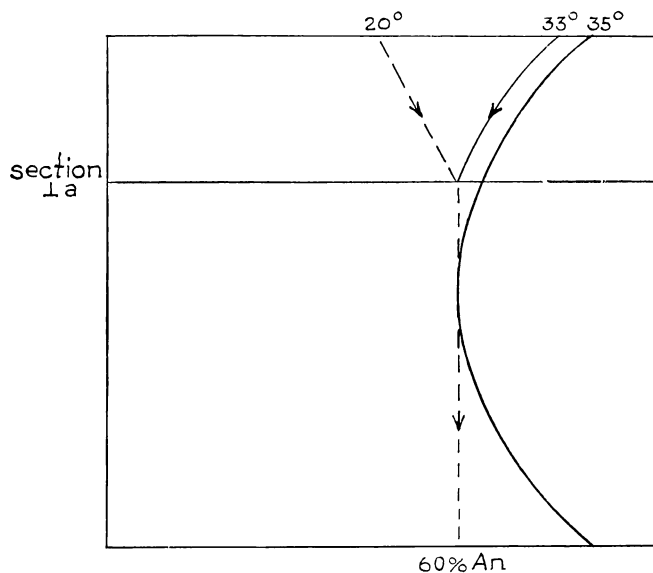


Fig. 3. Key to figure 2, drawn for the case of figure 1. The Carlsbad individual with extinction angle of  $33^\circ$  is oriented normal to  $[100]$ , so that the horizontal line representing that orientation must pass through the intersection of the extinction curves of the two individuals. The curve of the maximum extinction angle to occur with that An-content ( $35^\circ$ ) is also indicated. "Low" plagioclase.

the An-content can be found with the aid of the vertical tangent to the curve representing the maximum extinction angle (fig. 3).

The section parallel to  $[100]$  in the zone normal to  $(010)$  is also indicated in the charts. It should be used in conjunction with the dashed extinction curves. The distribution of these curves over the chart area is less favorable than in the neighborhood of the section normal to  $[100]$ . In volcanic rocks, the section may be recognized as longitudinal sections of plagioclase microlites elongated in the direction of  $[100]$ . It will be realized that this section does not coincide with  $(001)$ . If its extinction angles are used with  $(001)$  cleavage flakes, these should have albite-twin lamellae, so that a correction for tilt can be made by averaging the two extinction angles.

#### ZONED PLAGIOCLASE CRYSTALS

If a Carlsbad twin is zoned, the crystallographical orientation of each twin individual should remain the same for all zones. Thus, the pairs of extinction angle curves representing the various zones should all intersect on one horizontal line, denoting the orientation of the section. Especially if the twin is a synneusis twin, care should be taken that the adjoining crystal parts that are measured belong to the same zone. Once the orientation of the section is known, one extinction angle suffices to determine the An-content: another advantage of this type of chart (fig. 5).

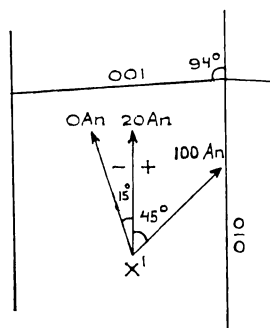


Fig. 4. Diagram of the extinction angles  $X' \Delta (010)$  of plagioclase in an albite twin cut normal to  $[100]$ . Between 0 percent and 20 percent An  $X'$  passes through the obtuse angle of  $(010)$  and  $(001)$ , and the extinction angle is called negative; above 20 percent An  $X'$  passes through the acute angle of  $(010)$  and  $(001)$ , and the extinction angle is called positive. The elongation of this section with regard to  $(010)$  is negative for the whole plagioclase range, providing a means to distinguish between the  $(010)$  and  $(001)$  composition planes in ambiguous cases. The symbol  $[100]$  is used regardless of sign.

#### "LOW" AND "HIGH" PLAGIOCLASE

The optical properties of plagioclases are not only influenced by their composition but also by their structural state. Burri, Parker, and Wenk (1967) divided their data into two groups: mean values of "plutonic" and mean values of "volcanic" plagioclases. This can be done because intermediate values are comparatively rare. The groups have also been called "low temperature" and "high temperature optics" (Tobi, 1963), or "plagioclase-O" and "plagioclase-D" (Bambauer, 1969, p. 716). In this paper, they are designated as "low" and "high" plagioclase, following Smith (1974). As a rule, low plagioclase is found in plutonic and metamorphic rocks, high plagioclase in volcanics. However, natural albite is generally low albite even when found in volcanic rocks. In hypabyssal rocks, both types may be found.

#### FURTHER COMMENTS ON THE PRESENTED CHARTS

For an explanation of the principles underlying the charts, for a comparison with other currently used Carlsbad charts, and for references up to 1963, the reader is referred to Tobi (1963). The new charts were calculated from data of Burri, Parker, and Wenk (1967) by the second author by means of a FORTRAN-IV program based on Burri (1950).

Although the charts are fully drawn for clarity, it will be seen that the upper right-hand parts are best suited for use of the Carlsbad angles, because the full-drawn and dashed curves there intersect at a large angle. The Carlsbad angles should not be used: (A) for volcanic plagioclase with An-content below about 25 percent An, (B) if their difference is more than about  $15^\circ$ . The most favorable sections are those in which one individual is cut normal to  $[100]$ , providing the possibility of a cross check.

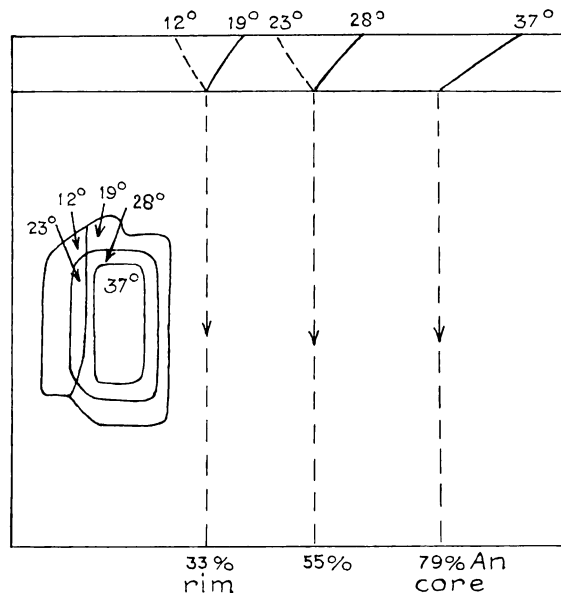


Fig. 5. Key to figure 2, drawn for the case of a zoned Carlsbad twin as indicated schematically in the inset. Once the orientation is known, a single extinction angle suffices to determine the An-content, as is the case with the core of our example. For clarity, the albite lamellae are omitted. "High" plagioclase.

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