Morphology of Recent Havey Quarry Elbaites

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Introduction

Maine has been known for many years as a source of world-class tourmaline specimens. Early specimens were recovered mostly as a by-product of mining for feldspar and sometimes mica. Later, specimen miners specifically targeted tourmaline and other gems, especially beryls. This mining was intermittent and often not profitable, but occasional major finds keep miners interested and dreaming about the big pocket that lies just a foot or so into the quarry wall. In recent years, Mount Mica Mine has produced a large number of tourmalines, and most recently, the Havey Quarry is doing the same. This study documents the morphology of typical crystals from a number of pockets encountered in 2013-2015.

Quarry Location and History

Materials and Methods

A total of 18 crystals were available for study from 10 different pockets, as shown in the following table.

Pocket	Year	Number of crystals
(First crystal found)		1
Unknown	2014	2
Silver Dollar		2
Heath		1
World Series		5
Ice Cream Sundae		1
Boxing Day		1
10/18/14	2014	2
7/5/14	2014	1
Corner Pocket	2014	2

Crystals were measured on a Stoe Two-circle Optical Goniometer with the c-axis parallel to the main (horizontal) axis of rotation. Because crystal faces in general were not highly perfect, and because high precision is not required to identify faces that belong to well-established forms, pairs of angles that fixed the locations of the faces (analogous to latitude and longitude on a globe) were generally recorded only to the nearest degree. Measurements were converted to approximate Miller indices using a FORTRAN implementation by Richards of formulas in Dana's System, 7th edition, Volume 1. Crystals were drawn using the SHAPE crystal drawing program.

About half of the crystals provided were too large to mount on the goniometer. All of these could be related to crystals that were measured, and their morphology could be determined by this visual comparison. Rare additional forms encountered on a few crystals were determined using zonal relationships.

Because of unusual and somewhat paradoxical results from the goniometric study (see below), some additional and much smaller crystals from some of the same pockets and with similar morphology were obtained and used for single crystal x-ray study. Using specialized techniques (John….) this approach was able to determine the polarity and resolve other ambiguities in the identity of specific faces, thus finalizing the determination of the morphology of these crystals.

Results and Discussion

Hemihedry and the ambiguity of orientation in tourmaline

Tourmaline crystallizes in symmetry class 3m (space group R3m1). This symmetry is reduced in comparison to the maximum (holohedral) symmetry for the trigonal subsystem of the hexagonal system, which is $\bar{3}$ 2/m. As a consequence, most forms in the holohedral class are represented in the class 3m by two or more conjugate forms with fewer faces, often half as many. Thus the general form {hkl} is a scalenohedron with 12 faces in the holohedral class, but "decays" under symmetry 3m into two ditrigonal pyramids, one on the top and one on the bottom. The hexagonal prism {100} becomes two trigonal prisms, {100} and {010}, which are rotated 60° relative to each other about the c axis. The pinacoid {001} becomes two pedions, {001} and {00$\bar{1}$}. These conjugate forms share the exact same shape, but their orientations relative to the crystal axes are different. How, then, can one decide which conjugate form is present, if only one is seen? The challenge is to tie the measured crystal correctly to its crystallographic axes.

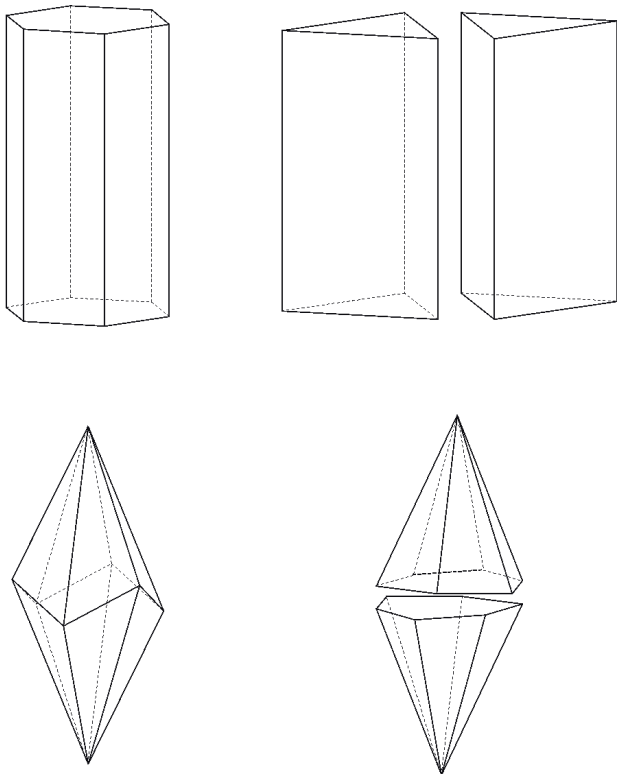

Figure 1. Representative forms in the classes $\bar{3}$2/m and 3m.

In calcite, there is a similar but less extreme problem in distinguishing between two possible orientations of many forms, referred to as positive and negative. The rhombohedra {101} and {011} appear identical, but differ from each other by 60° in their positions relative to the crystal axes. But calcite has a perfect cleavage, which can always be produced on a study crystal, and it is known to have the form {101}, not {011}, which allows the crystal to be placed in proper relationship to the symmetry axes. In fact, {101} is among the most common forms of calcite, but {011} is very rare. Unfortunately, tourmaline lacks a cleavage that might be used for obtaining such an orientation.

Tourmaline does provide some assistance, however. Because it is hemihedral, the top and bottom ends have different properties, and these can be used to tell the ends apart experimentally. However, these experiments are tricky to do reliably, even in a mineralogical laboratory. Morphological studies by experts have developed some generalizations, which then are usually assumed in other studies. These include the notion that the positive (antilogous) termination is steeper and tends to have more faces than the negative (analogous) end; the assumption that if only one trigonal prism is present, it is {100}, not {010}, or if both are present, {100} is the larger one; and the assumption that forms tend to conform to the "Rhombohedral Rule", which states that forms {hkl} for which 2h+k+l=N=3n, n being any integer, are more likely to occur than other forms. Thus, e.g., {101} is likely to occur (N=3), but {011} is not (N=2). In general, with conjugate forms, one will obey the Rhombohedral Rule and the other will not.

Sextants and the paradox of face locations in Havey specimens

During goniometric observations, the hexagonal prism {110} was apparent as bright signals 60° apart around the prism. In accordance with goniometric practice, the phi or "longitude" orientations of all faces of all forms measured were adjusted by addition of a constant so that one of the hexagonal prism faces was at 0° and the others were at approximately 60°, 120°, 180°, 240°, and 300° ("approximate" because of small measurement error). Signals were also often obtained corresponding to faces of {100} or {010}; these were intermediate in position between the {110} faces, but there were only three of these at 120° to each other corresponding to the three faces of a single trigonal prism. Given the choice of the additive constant, these could be approximately at 30°, 150°, and 270° or at 90°, 210°, and 330°. The first set of angles correspond to the faces of {100} and the second set of faces correspond to {010}. The constant was chosen to correspond to{100}, following the conventions mentioned above, thus fixing the phi angles of all faces.

When the measurements were processed, the faces on the terminations were consistently found to belong to forms that are not considered common and do not obey the Rhombohedral Rule, whereas their conjugate forms, which were not observed, do fit the rule and are considered common. The conjugate forms would have been obtained if the trigonal prism were assumed to be {010}, which however is not considered common and some writers state flatly does not occur on tourmaline.

As shown in Figure 2, the terminal faces fall in alternate 60° sectors (sextants) from the prism faces, but if the commonly expected equivalents were present instead, they would fall into the same sextants. But the measurements are consistent from crystal to crystal. For these crystals, then, the conventional assumptions about the trigonal prism and the common termination forms cannot both be right (though one of them is). The need to determine which conventional assumption is correct led us to perform the x-ray studies described below.

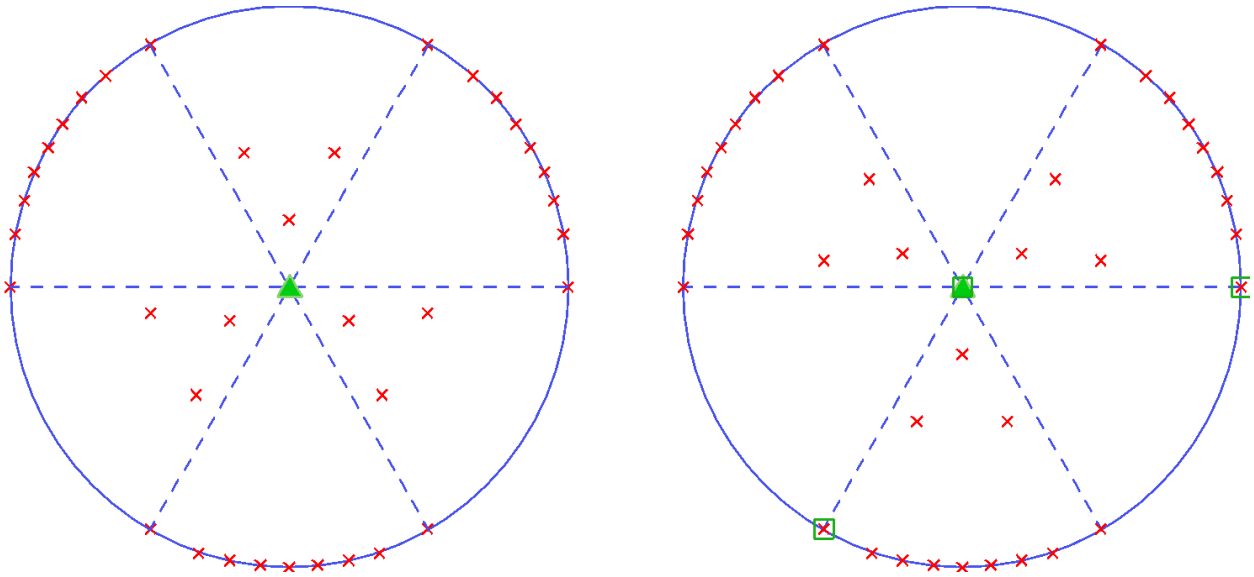

Figure 2. Stereographic projection of an observed crystal (Corner Pocket) and a hypothetical crystal composed of forms suggested by conventional expectations.

In general, differences in habit of the samples examined were not primarily due to the presence of different sets of forms on different crystals. Rather, habit differences were due to:

- the relative size of the faces of different forms,
- the relative size of faces within a particular form, including missing faces,
- the elongation of the crystal (and since no crystals were doubly terminated, this may reflect where the crystals broke off more than systematic differences in crystal length from pocket to pocket),
- other distortions such as flattening or strength of striations on prism faces.

Forms present

Table 2 lists the forms observed on the study crystals. No attempt was made to measure all the secondary signals present in the prism zones of all crystals, so no frequency is listed for them. Rho and phi angles are computed, not observed.

Table 2. Forms observed on study crystals.

Form letter	Miller indices	rho	phi	Number of crystals
c	001	0°0.0’	----	5
m	100	90°0.0’	30°0.00’	18
a	110	90°0.0’	0°0.00’	18
σ	210	90°0.0’	10°53.60’	16
	720	90°0.0’	17°47.02’	
	510	90°0.0’	21°3.10’	
	810	90°0.0’	24°10.95’	
e’	102	14°56.45’	30°0.00’	1

⊗	011	27°16.48’	-30°0.00’	14
o’	201	45°53.75’	30°0.00’	8
t’	121	53°45.18’	-10°53.60’	13

Prism morphology

Typical prisms are strongly striated, and have a rounded triangle shape, as if the triangle was an over-inflated two-dimensional balloon (Fig. 3). This shape results from the combination of the hexagonal prism a{110}, the trigonal prism m{100}, and a number of ditrigonal prisms {hk0} with h>k, together with the absence of the trigonal prism {010} and ditrigonal prisms {hk0} with k>h. There are many more ditrigonal prisms than are listed in Table 2. In fact, there is often a nearly continuous band of goniometer signals from one hexagonal prism face to the next, indicating a nearly continuously curved prism surface. The next 60° sector lacks any signals in the prism zone, and so on in alternating fashion around the entire 360°.

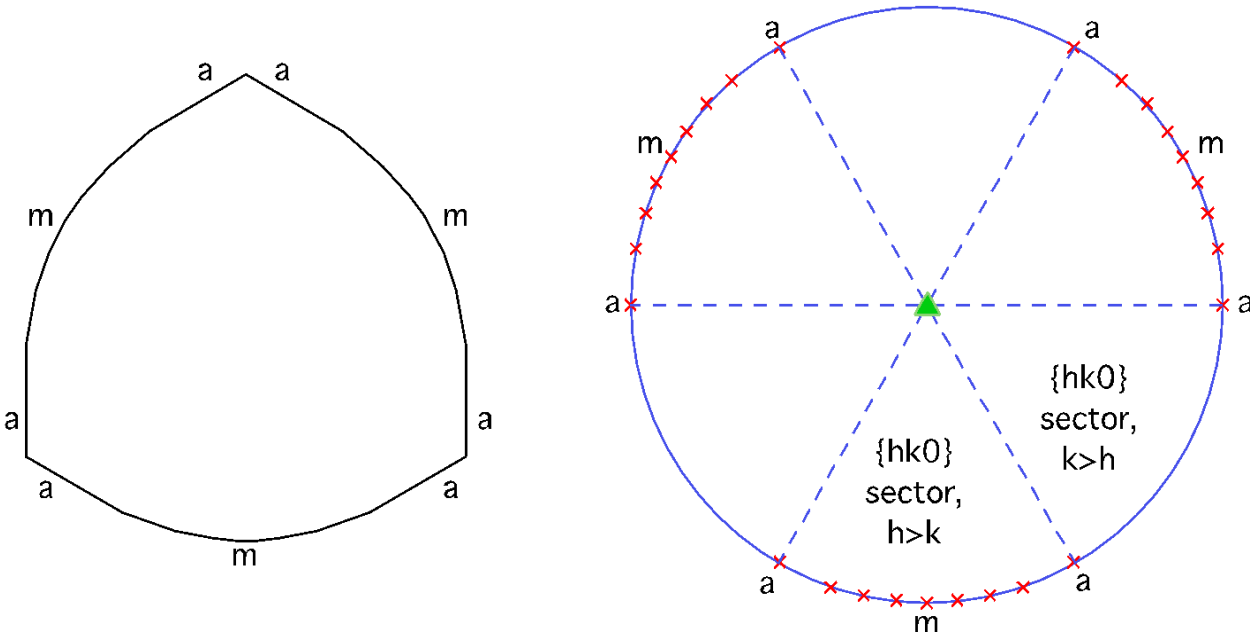

Figure 3. Cross section of a typical prism and stereogram showing the alternating sectors with and without prism faces.

Terminations

Most crystals have terminations that are combinations of {011} and {121}, sometimes modified by smaller faces of {201}. When {011} dominates, the termination is relatively blunt. When {121} dominates or {011} is absent, the termination is quite pointed. When {201} is present, it sometimes appears as very narrow “line” faces beveling edges of pairs of faces of {121} which lie above {100}. In other crystals, faces of {201} are broader and more nearly equidimensional.

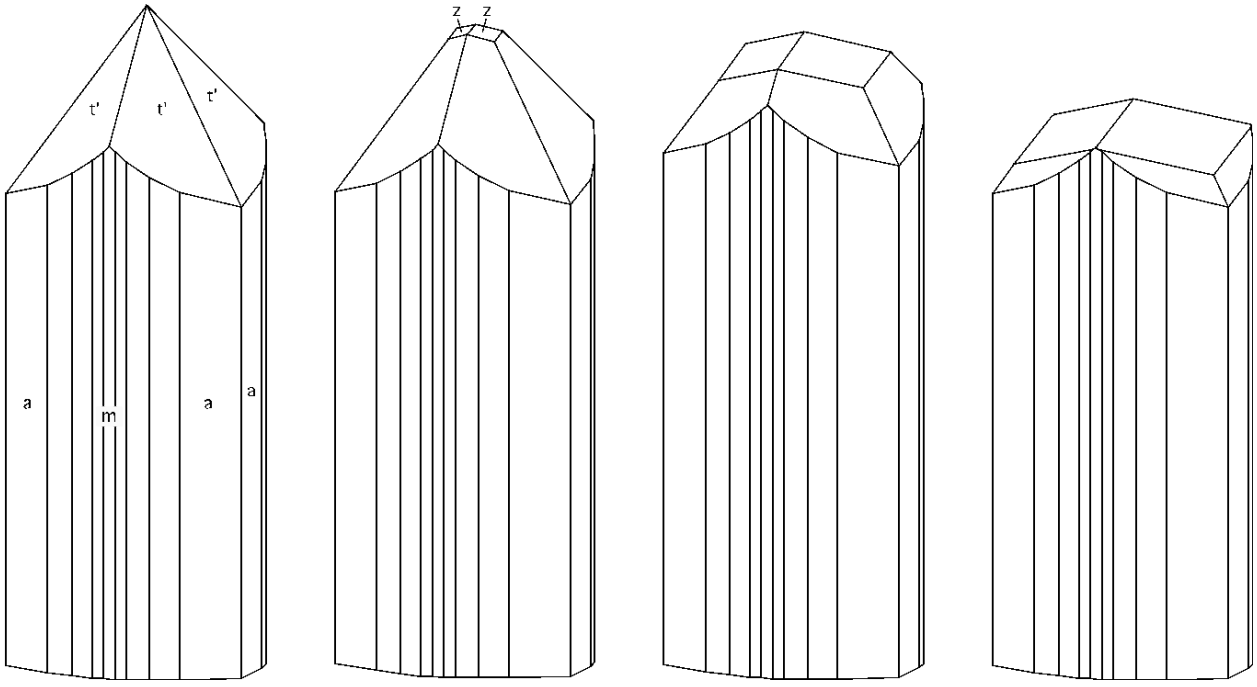

Figure 4. Crystals showing varying balance between faces of t'{121} and z{011}. From left to right, crystals are from the Silver Dollar, Corner, Boxing Day, and 10/18/2014 Pockets.

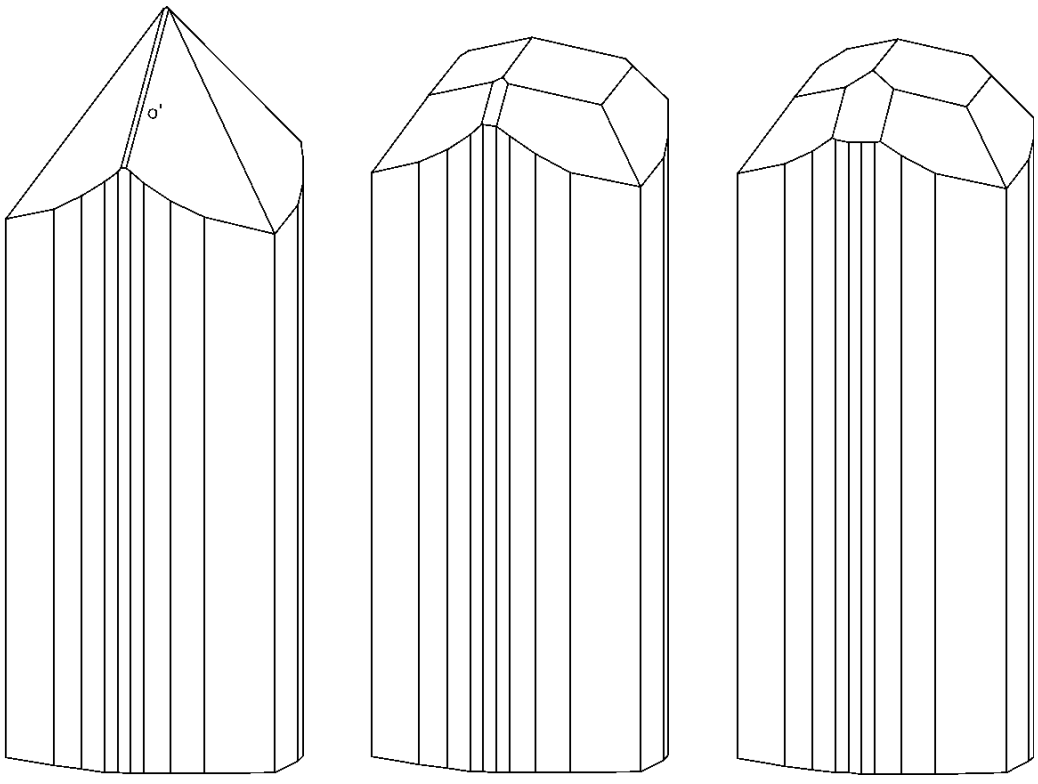

Figure 5. Crystals showing differing degrees of development of o'{201} From left to right, crystals are from the 7/5/2014 and Ice Cream Sunday Pockets and the first crystal found.

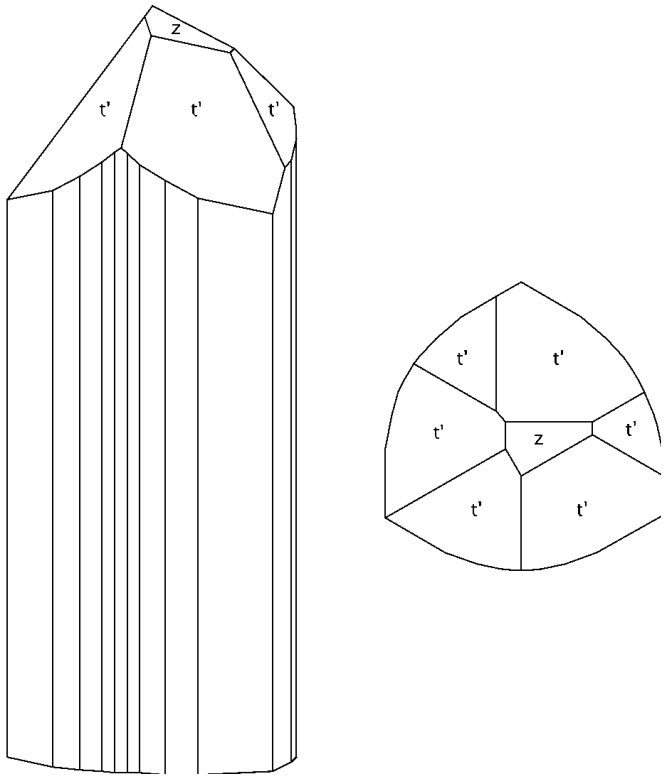

Figure 6. Crystal showing distortion of form due to different sized faces of t'{121} and missing faces of z{011}

The crystals from the World Series pocket are rather different. All five show the pedion {001}, the only crystals to do so. Four of the five also have {201} as a major face, and all lack the ditrigonal pyramid {121}. One of the four has one face of {011} beveling an edge of {201}. The fifth crystal has a large pedion face and balanced development of {012} and {101}. Its relatively flat morphology and large pedion compared to other crystals from the same pocket suggest that it might be the termination of the negative end of a crystal. However, its color is also different from the other crystals from the same pocket, so it might represent a different episode of growth.

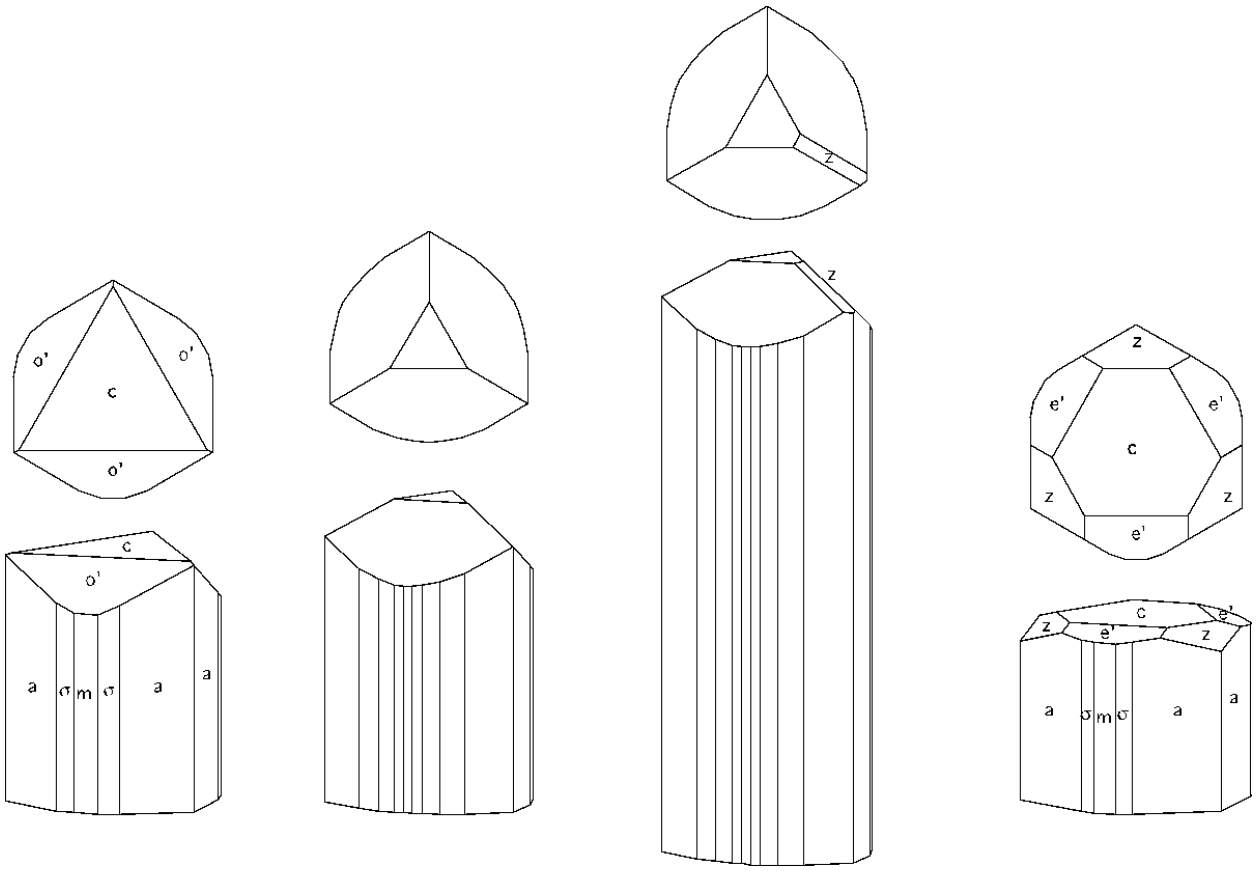

Figure 7. Crystals from the World Series Pocket, showing different morphologies than crystals from the other pockets.

X-ray study

Conclusions

Literature

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