# Origin of Tourmaline in the Setters Formation, Maryland: Evidence from Major and Trace Element, Boron Isotope, and Rare Earth Element Characteristics

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## ABSTRACT

The occurrence of tourmaline within the Setters Formation of the Glenarm Series in the Maryland Piedmont is poorly understood. Very little research has been conducted to elucidate the origins of the tourmaline. The focus of this study has been to provide geochemical and petrologic evidence to gain a more thorough understanding of the conditions under which the tourmaline of the Setters Formation developed. Tourmaline can form in a wide variety of geologic settings. Natural tourmaline has a $\delta^{11}B$ range from -30‰ to +40‰, and individual samples fall within sub-ranges that may be indicative of the boron source reservoir. Studies of tourmaline are growing in popularity as petrological tools due to several unique chemical and physical characteristics that have implications for its use as a single-crystal indicator of numerous geologic processes and conditions.

Major element chemistry of tourmaline collected as part of this study from the Setters formation along the margin of the Woodstock Dome is consistent with the dravite-schorl solid-solution series. This solid-solution is expected of tourmaline developed during prograde metamorphism within a metapelitic host rock. Single collector LA-ICP-MS analysis was performed in situ to acquire boron isotopic measurements for tourmaline concentrates. Tourmaline from the Setters Formation is isotopically heavy with a $\delta^{11}B$ range of -21.13 to +9.58‰ (with an accuracy of $<\pm 10.72$‰). This range of $\delta^{11}B$ is consistent with expected values for tourmaline development during prograde metamorphism. LA-ICP-MS in situ measurements of trace elements in tourmaline provided a range of $\Sigma$REE (0.31-24.97ppm), where the relatively wide range may reflect distinct growth horizons within the evolution of the tourmalines. The REE measurements display a distinct concave upward pattern with slight LREE enrichment, slight HREE depletion and a positive Eu anomaly.

## BACKGROUND

### *GEOLOGIC SETTING*

#### *PIEDMONT PROVINCE*

The Piedmont Province formed because of continental rifting that produced the Iapetus Ocean approximately 600 million years ago (Southworth et al., 2007). Between 440 and 265 million years ago, the Iapetus Ocean was closed by three mountain building events: the Taconic, Acadian, and Alleghenian Orogenies. The eastern Piedmont was metamorphosed during the three orogenic events that joined the Iapetus Ocean basin sediment, a volcanic island chain, and a portion of continental crust (Southworth et al., 2007).

The Maryland Piedmont comprises the Chopawamsic, Bel Air-Rising Sun, Baltimore, Potomac, and Westminster terranes (Gates et al., 1991). The Baltimore terrane is characterized by dome forming anticlines and intermittent granitoid intrusions. A Baltimore Gneiss core surrounded by a thin shell of Setters Formation generally characterizes the domes in the Baltimore terrane.

*SETTERS FORMATION*

The Setters Formation is a 0-750 ft thick, Cambro-Ordovician, metasedimentary unit that comprises interbedded massive quartzite and schist. Because the Setters breaks easily along the schist foliation plane to form flagstone slabs, the rock has been historically quarried for construction material. Setters Formation is the basal member of the Glenarm Series. The three members of the Glenarm Series, from base to top, are: the Setters Formation, the Cockeysville Marble and the Wissahickon Schist (Hopson, 1964).

Three lithological members of the Setters Formation were originally described in 1929 by Knopf and Jonas (in Hopson, 1964): 1) a lower mica schist member, 2) a middle quartzite member, and 3) an upper mica gneiss member.

The lower member is predominantly composed of medium-grained feldspathic schist, with quartzite beds interstratified locally. The Middle member is characterized by "dirty" quartzitic rocks interstratified with thin layers of mica schist. Tourmaline is readily present within the mica schist foliations of the middle member. The upper member is again feldspathic schist, but finer-grained than the lower member, and is interbedded with quartzite to form a gneissic texture. The quartzite beds of the Setters do not contain any evidence of cross-bedding, channeling, or other sedimentary features, which would indicate a high-energy depositional environment. However, there are fine laminations preserved in the quartzite beds.

The Setters Formation unconformably overlies the Precambrian Baltimore Gneiss (Hopson, 1964). In the past there has been debate over the presence of an unconformity between the Setters and the Baltimore Gneiss, some of the strongest arguments for the presence of an unconformity include:

- Rocks of the Glenarm Series have relict sedimentary structures, but the Baltimore Gneiss does not preserve any sedimentary structures due to extensive metamorphism (Hopson, 1964).
- Radiogenic dating demonstrated that the Baltimore Gneiss has undergone two crystallization periods, with the oldest aging to about 1000-1100 m.y. (Aleinikoff et al., 2000). The Glenarm deposits would have to be older than 1100 m.y. for there to be conformable strata.
- Gneissic basement rocks that experienced crystallization about 1000 m.y. ago are present throughout the central and southern Appalachians (Aleinikoff et al., 2000), demonstrating the widespread presence of the basement rock.

Metamorphic grade of the Setters Formation increases along a northeastern trend; the Setters Formation is observed to be garnet grade in outcrops near Granite, MD and increases to staurolite grade near Hunt Valley, MD. Tourmaline is a common accessory mineral in the Setters Formation, constituting up to ~10 modal% of the schist layers and <1 modal% of the quartzite layers. The tourmaline is present as subhedral to euhedral black crystals within the micaeous matrix. Tourmaline grain size varies from <1cm long and mm-scale diameter, up to ~10cm long and ~1.5cm in diameter. Within schist layers, tourmaline distribution is nearly homogeneous, with the c-axes of individual grains parallel to the plane of foliation.

The interbedded quartzite and schist of the Setters Formations represent metamorphosed sand and mud layers, respectively. A mix of sandstone, siltstone and shale are the likely precursors for the all three members of the Setters Formation.

The Setters Formation metasediments likely represent deposition on a relatively shallow stable continental platform (Fisher et al., 1979). Distinct lack of planar laminated bedding, with lack of high-energy indicators, suggests that the sediments, which formed the Setters Formation, were deposited in a lacustrine or shallow marine environment. The transition from Setters quartzose rocks to the marble of the Cockeysville, followed by the schist of the Wissahickon, is an indication that the Glenarm Series may represent a transgressional sequence.

The repetition of the micaceous layers interstratified with quartzite is a strong indicator of cyclical geologic event. If the interstratified quartzose beds and micaceous laminations are representative of a change in sedimentation, this may be an indicator that the influx of sediments changed episodically. This may be a result of terrestrial and/or tectonic processes. If submarine volcanism was present in the area during the period of deposition, the micaceous layers could be a representation of volcanogenic mineralization. If terrestrial volcanism was present in the area during the period of deposition, the micaceous layers could be a representation of volcanic ash sediments.

Metamorphic differentiation may have been an important mechanism in the production of interstratified layers of the Setters. If the beds of sediment were generally homogeneous during deposition, metamorphic differentiation could have concentrated micaceous mineralization along planes of weakness at bedding boundaries. If the micaceous laminations are representative of clay sediments interstratified with quartzose sediments, the clay minerals may have served to compound the effects of mineralization along bed boundaries during metamorphic differentiation.

## *TOURMALINE*

### *MINERALOGY*

Tourmaline does not have a single chemical composition, rather it is the name given to a supergroup of borosilicate minerals (boron-bearing ring silicates) with the generalized formula $XY_3Z_6[T_6O_{18}][BO_3]_3V_3W$. There are currently 21 approved species of tourmaline (Henry & Dutrow, 2012). **Table 1** lists a selection of the minerals included in the tourmaline supergroup and their major element chemistry. The complexity of tourmaline structure allows for the incorporation of mono-, di-, tri- and tetravalent cations, as well as mono- and divalent anions. Tourmaline is a veritable garbage-can mineral because of the wide range of cations and anions accepted by its structure, having the flexibility to incorporate nearly half of the elements on the periodic table including trace elements and REEs (Marschall & Jiang, 2011).

**Table 1.** End-member compositions of IMA-accepted tourmaline species (Hawthorne and Dirlam 2011)

| General Formula | $(X)$ | $(Y_3)$ | $(Z_6)$ | $T_6O_{18}$ | $(BO_3)_3$ | $(V_3)$ | $(W)$ |
|---|---|---|---|---|---|---|---|
| **Alkali Group** | | | | | | | |
| Dravite | Na | $Mg_3$ | $Al_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | (OH) |
| Schorl | Na | $Fe_3^{2+}$ | $Al_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | (OH) |
| Chromium-dravite | Na | $Mg_3$ | $Cr_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | (OH) |
| Vanadium-dravite | Na | $Mg_3$ | $V_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | (OH) |
| Fluor-dravite | Na | $Mg_3$ | $Al_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | F |
| Fluor-schorl | Na | $Fe_3^{2+}$ | $Al_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | F |
| Elbaite | Na | $Li_{1.5}Al_{1.5}$ | $Al_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | (OH) |
| Povondraite | Na | $Fe_3^{3+}$ | $Mg_2Fe_4^{3+}$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | O |
| Chromo-alumino-povondraite | Na | $Cr_3$ | $Mg_2Al_4$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | O |
| Fluor-buergerite | Na | $Fe_3^{3+}$ | $Al_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $O_3$ | F |
| Olenite | Na | $Al_3$ | $Al_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $O_3$ | (OH) |
| **Calcic Group** | | | | | | | |
| Fluor-uvite | Ca | $Mg_3$ | $MgAl_5$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | F |
| Feruvite | Ca | $Fe_3^{2+}$ | $MgAl_5$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | (OH) |
| Uvite | Ca | $Mg_3$ | $MgAl_5$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | (OH) |
| Fluor-liddicoatite | Ca | $Li_2Al$ | $Al_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | F |
| **Vacancy Group** | | | | | | | |
| Foitite | □ | $Fe_2^{2+}Al$ | $Al_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | (OH) |
| Magnesio-foitite | □ | $Mg_2Al$ | $Al_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | (OH) |
| Rossmanite | □ | $LiAl_2$ | $Al_6$ | $Si_6O_{18}$ | $(BO_3)_3$ | $(OH)_3$ | (OH) |

Tourmaline has seven structural components, as illustrated in **figure 1**:

1. One 9-coordinated *X*-site which is typically occupied by Na or Ca, but can be vacant
2. Three octahedral coordinated *Y*-sites
3. Six octahedral coordinated *Z*-sites which are typically occupied by Al
4. Six tetrahedral coordinated *T*-sites which are predominantly occupied by Si, but can incorporate Al or B
5. Three triangular coordinated sites entirely occupied by B
6. Three anion filled *V*-sites
7. One anion filled *W*-site

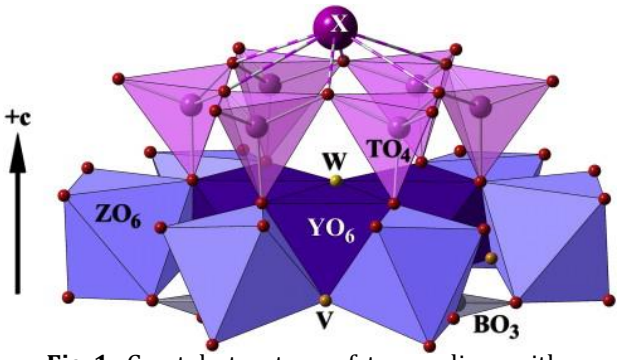


**Fig 1.** Crystal structure of tourmaline, with the seven structural components labeled (from Henry and Dutrow, 2012)

A six-member ring is composed of the corner-sharing tetrahedral sites, with all tetrahedra pointing in the same direction. The uniform directionality of the tetrahedral corners is significant because it defines the positive (antilogous) and negative (analogous) poles along the crystallographic c-axis and results in a polar character in the mineral (Dutrow & Henry, 2011). **Figure 2** depicts the growth sectors of tourmaline as related to the crystal habit. Polarity of the mineral structure contributes to the hemimorphic character of tourmaline, whereby morphological differences develop at each end of the c-axis. Tourmaline can

exhibit unique physical properties related to the polar and hemimorphic character, including (Hawthorne & Dirlam, 2011):

- Pyramidal faces forming more steeply at the antilogous pole
- Antilogous pole having highly reflective faces and analogous pole having matte faces
- Faster crystal growth in the antilogous direction than in the analogous direction
- Pyroelectricity, where crystals gain a charge when heated
- Piezoelectricity, where crystals gain a change when mechanically stressed

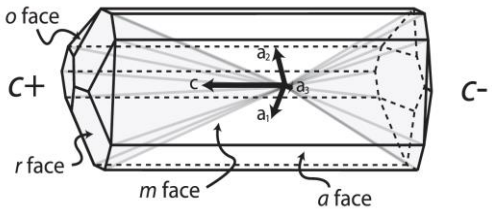


**Fig. 2.** A visual representation of the orientations of tourmaline growth sectors and growth faces with respect to the c-axis (van Hinsberg & Schumacher, 2007)

Dietrich (1985) discussed the pyroelectric and piezoelectric nature of tourmaline, suggesting that these characteristics result from the net polarization of the atom arrangement. Thanks to the pyroelectric and piezoelectric character of tourmaline, it played an important role in scientific advances throughout the 18th and 19th centuries (Henry & Dutrow, 2011). These scientific advances include aiding Benjamin Franklin in developing his theory of positive and negative electricity. Properties of tourmaline were also used by John Wilcke in his early attempt to develop a "grand unifying theory" linking heat, electricity and magnetism (Dietrich, 1985). In more recent history, tourmaline is being investigated for its potential use in a multitude of petrologic methods.

As a result of its highly refractory nature, tourmaline is grouped with rutile and zircon among the ultrastable minerals in sedimentary environments through transport, diagenesis and metamorphism (van Hinsberg et al., 2011a). Being highly resistant to chemical and mechanical weathering means that tourmaline has a great potential for use as an indicator mineral, even after host rock has be subjected to weathering processes.

Tourmaline is able to form under a wide range of P-T conditions: temperatures ranging from <150 °C to >900 °C and pressures ranging from <6 MPa to >6 GPa (Henry & Dutrow, 2012). Additionally, tourmaline chemistry allows it to equilibrate with a wide variety of fluid compositions. These two characteristics make tourmaline a stable mineral under most crustal conditions.

Furthermore, tourmaline exhibits very slow intracrystalline diffusion of major and trace elements, even at relatively high temperatures (van Hinsberg et al., 2011b). Slow intracrystalline diffusion, coupled with the hemimorphic character of tourmaline, give rise to multiple petrologic measurement techniques.

*COMPOSITIONAL CONTROLS*

Henry and Guidotti (1985) identified distinct compositional ranges of tourmaline associated with different rock types; the compositional ranges in **figure 3** are defined as follows:

1. Li-rich granitoid pegmatites and aplites
2. Li-poor granitoids and their associated pegmatites and aplites
3. Fe^(3+)-rich quartz-tourmaline rocks (hydrothermally altered granites)
4. Metapelites and metapsammites coexisting with an Al-saturating phase
5. Metapelites and metapsammites not coexisting with an Al-saturating phase
6. Fe^(3+)-rich quartz-tourmaline rocks, calc-silicate rocks, and metapelites
7. Low-Ca metaultramafics and Cr, V-rich metasediments
8. Metacarbonates and meta-pyroxenites

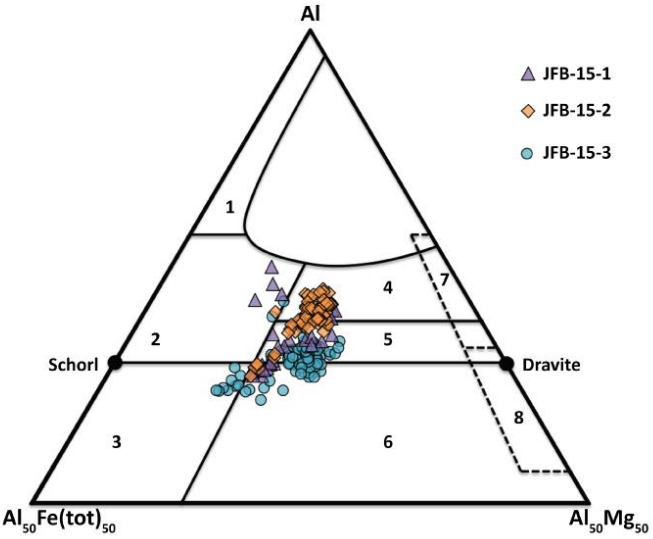


**Fig. 3.** Al-Fe(total)-Mg diagram (molar proportions) for Setters tourmalines plot as an intermediate along the Schorl-Dravite solid-solution series. Zones 1-8 represent host rock types, as defined by Henry and Guidotti (1985).

The data used to compile the host rock relationship to tourmaline species by Henry and Guidotti (1985) was from a limited region in NW Maine, and therefore is used as a model rather than a tool for determining absolute classifications. Compiling additional tourmaline species data for known rock types will provide further evidence of the efficacy of the Henry and Guidotti (1985) model.

It has been proposed that by classifying the chemical composition of tourmaline through chemical analysis by spectroscopic means, the rock type associated with the tourmaline grain can be determined (Henry & Guidotti, 1985; Slack & Trumbull, 2011).

*GEOTHERMOMETRY*

Traditional geothermobarometry relies on diffusion and cation exchange between multiple mineral phases, but tourmaline has been proposed as a single-mineral geothermometer (Henry & Dutrow 1996; van Hinsberg & Schumacher 2007).

Tourmaline commonly exhibits optical and/or chemical zoning; Ca, Ti, and K will be incorporated more readily the c- sector of tourmaline than in the c+ sector (Hawthorne & Dirlam, 2011; Marks et al., 2013; Marschall & Jiang, 2011; Slack & Trumbull, 2011). In **figure 2** the c+, and c- sectors are illustrated to demonstrate their orientation in an elongate tourmaline crystal. The cation partitioning rate along the c-axis is driven by the peak crystallization temperature (Henry & Dutrow, 1992, 1996; van Hinsberg &

Schumacher, 2007). Two geothermometers have been proposed for tourmaline by using the Ca and Ti concentrations in adjacent sectors (Henry & Dutrow, 1992, 1996; van Hinsberg & Schumacher, 2007).

### *BORON ISOTOPES*

Ethier and Campbell (1977) describe tourmaline as being the most important repository of boron in metamorphic settings. There are strong indications that the boron isotopic composition of tourmaline can be used to understand geologic processes that produced the fluids from which tourmaline crystallized.

## PROBLEM & HYPOTHESIS

Petrogenesis of the Setters Formation has not been thoroughly studied and the origin of the tourmaline phase is not well understood. Analysis of tourmaline from the Setters Formation has provided petrogenetic information that has provided insights into regional geologic history. Chemical analysis of the Setters Formation tourmaline has been used to test the following hypotheses:

1. Tourmaline in the amphibolite-grade metasediments of the Setters Formation exhibits a compositional range along the schorl-dravite solid-solution series, being consistent with previously studied psammites and metapsammites (fields 4 and 5 of figure 1; Henry and Guidotti 1985).
2. Using Ca- and Ti- geothermometers, intersector partitioning of trace elements in tourmaline will record crystallization temperatures consistent with amphibolite grade metamorphism.
3. Chondrite-normalized REE patterns for tourmaline in the Setters Formation reflects distinct REE patterns associated with metasedimentary host rock.
4. Measurements of boron isotopes in tourmaline from the Setters Formation compared to reference materials to determine the boron to be isotopically heavy associated with a seawater source ($\delta 11B$ (‰)>0).

Growing interest in the capacity of tourmaline to record vast amounts of geologic information would suggest that analysis of this phase in the Setters Formation can provide insights into the series of geologic processes experienced in the region. Synthesizing tourmaline analysis with the available information from existing geologic studies of the region, a clearer understanding of the origin of the tourmaline in the Setters Formation can be developed. Of particular interest in the investigation into the provenance of the tourmaline phase is the source of boron. Probable geologic processes that would have influenced the formation of tourmaline in the Setters Formation include:

- Intermittent volcanism resulted in boron-rich volcanic ash forming thin layers interbedded with quartzo-feldspathic sediments.
- Boron from seawater was adsorbed into thin layers of pelagic sediments interbedded with quartzo-feldspathic sediments.
- Boron was present in the quartzo-feldspathic sediments and was concentrated along with micaceous minerals into thin schist layers by metamorphic differentiation.

- Cyclic transgressive-regressive periods resulted in the formation of evaporitic tourmaline.
- Boron was concentrated in the sediments from entrained seawater and was concentrated at the schist layers, where pelagic sediments were present, through metamorphic differentiation.
- Boron-rich hydrothermal fluids, possibly related to granite intrusions, fluxed through the Setters and led to the formation of tourmaline along planes of weakness at boundaries between quartzite beds.

## METHODS

### *SAMPLE COLLECTION*

Setters Formation samples were collected from three sites located along the western limb of the Woodstock Dome. Potential Setters Formation sample sites were identified using online interactive ArcGIS maps that include overlain geologic maps, **figure 4** (Schmidt, 2015). These geologic overlays provided a useful guide in targeting the focus of my search for sample collection locations. Three locations were selected for sample collection, indicated by red arrows in **figure 4**, the details of which are summarized in **table 2**.

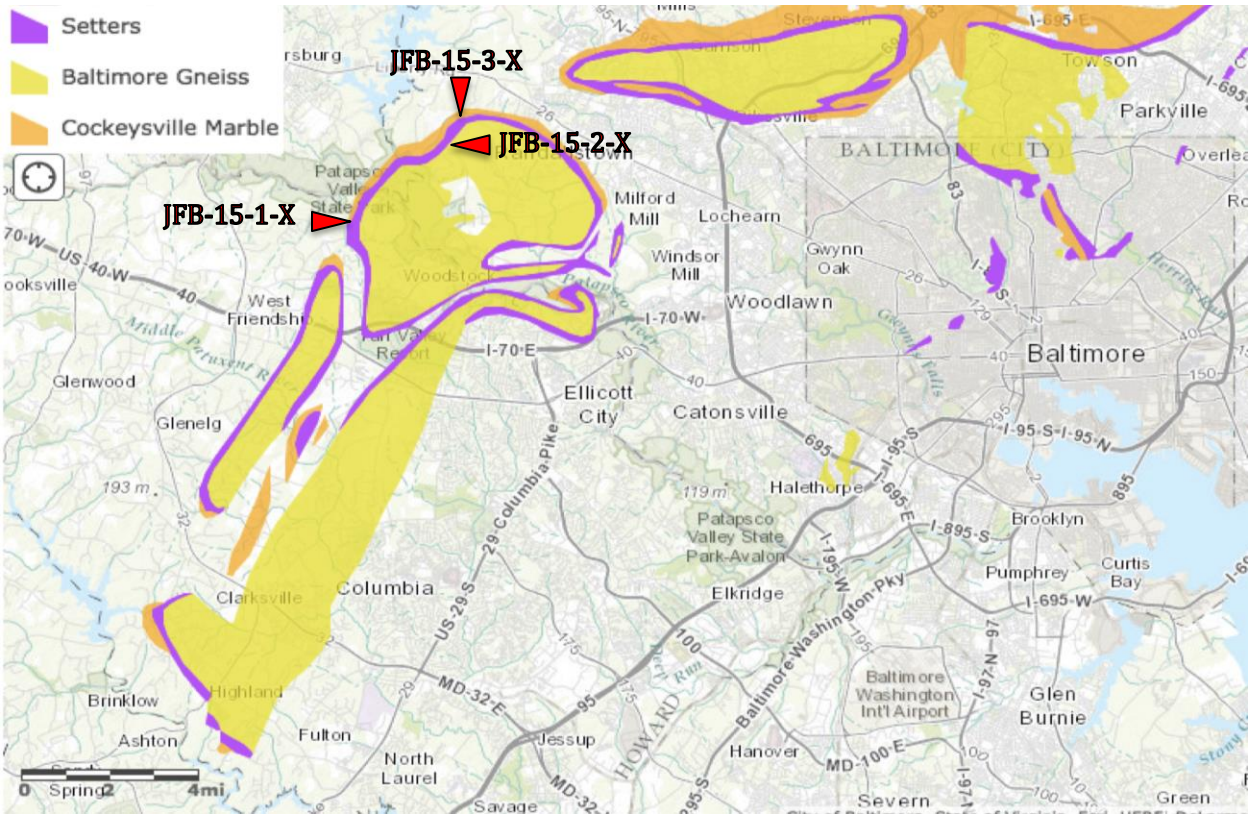


**Fig. 4.** Road map indicating sample collection sites and potential outcropping locations for Setters Formation, Baltimore Gneiss, and the Cockeysville Marble in the Maryland Piedmont (Schmidt 2015). Red arrows indicate sample ing locations.

The lithology of samples collected from sites 1 and 3 are from the middle quartzite member of the Setters Formation. The lithology of samples collected from site 2, coupled with

structural clues, indicates that this location is represents a contact of the lower schist and middle quartzite members of the Setters Formation. Tourmaline size varied between sample locations, an example of the large crystals found at site 3 can be seen in **figure 5**.

**Table 2.** Samples descriptions and field site locations

| Site | Lithology | Description | Location | Coordinates | Notes |
|---|---|---|---|---|---|
| JFB-15-1 | Middle Quartzite Member | Tourmaline phase is fine-grained (<1cm elongate crystals); micaceous phases fine-grained; host rock displays minor weathering | Marriotsville Rd & Driver Rd (North end of Vinci Quarry) | N39°21.003' W76°53.924' | Abandoned Quarry |
| JFB-15-2 | Middle Quartzite Member | Tourmaline phase is medium-grained (~1cm elongate crystals); micaceous phases medium/fine-grained; host rock appears moderately weathered | Marriotsville Rd, East side of road (N end of Bluegrass Quarry) | N39°22.392' W76°51.837' | Abandoned Quarry |
| JFB-15-3 | Middle Quartzite Member | Tourmaline phase is more coarsely grained (>1cm elongate crystals) than samples JFB-15-1-X and JFB-15-2-X; micaceous phases coarse-grained; host rocks appears highly weathered; pegmatite lenses observed | Marriotsville Rd, West side of road (N end of Bluegrass Quarry) | N39°22.417' W76°51.770' | Abandoned Quarry |

## *SAMPLE PREPARATION*

In the laboratory, tourmaline gains were removed from the host rock. The individual tourmaline grains were examined using a binocular microscope to select grains for subsequent analysis. Similarly, USGS tourmaline reference materials were sorted using reflected-light microscope to select tourmaline grains for use as calibration standards.

The isolated tourmaline grains were then washed in Milli-Q purified water to remove residual dirt and dust using the sonicator, and allowed to air-dry. Tourmaline grains from each sample from individual samples were aligned on a glass plate covered with

**Fig. 5.** An example of tourmaline (black crystal) occurring within the schist foliations of the middle quartzite member at site 3.

double-sided tape for mounting in one-inch epoxy plugs. A binocular microscope was used to ensure each sample epoxy plug contains gains oriented in the mount with the c-axis parallel and perpendicular to the surface of the epoxy plugs. Additionally, the four reference materials acquired from USGS were mounted in two, half-inch epoxy plugs.

Following orientation of the tourmaline grains on the double-sided tape, epoxy molds were positioned around the grains and epoxy was poured into the mold and allowed to cure over night. When the epoxy was fully cured, the epoxy plugs were carefully removed from the glass base with a razor blade. Dry sandpaper was used to remove excess epoxy from the exterior of the plugs to ensure proper fit into the laser ablation sample mount. To expose the tourmaline samples and reference materials for analysis, the surface of the epoxy plugs was polished through wet sanding and use of diamond grit polish.

Whole-rock mounts were created for the Setters quartzite from site 3 and Setters schist from site 2. These samples were cut into small pieces, approximately 0.75 inches cubed, and mounted in 1-inch diameter epoxy plugs. Samples were oriented with the bedding planes perpendicular to the face of the epoxy mounts.

Polishing of the whole-rock mounts was performed using the autopolisher with progressively finer grit polishing plates. The polishing plates used were: 15-micron, 9-micron, 6-micron, and 3-micron grit. The mounts sat on the polishing plates for ten minutes per plate, and were washed with soap and rinsed in a sonicator bath between each polishing stage.

### *EPMA*

The electron probe microanalyzer (EPMA) was utilized to analyze tourmaline from the Setters Formation. EMPA was used for detailed qualitative imaging and mapping, as well as quantitative analysis of major- and minor-element compositions. A JEOL 8900 EPMA was used for this study and is housed in the AIMLab (Advanced Imaging and Microscopy Laboratory). Backscatter electron (BSE) imaging provided insights into the petrologic textures of tourmaline crystals. The textural information included the presence and distribution of mineral and fluid inclusions within tourmaline grains. Additional textural clues highlighted by BSE imaging included the style of zoning present.

Energy dispersive x-ray spectroscopy (EDS) was performed to identify mineralogy of the samples. EDS analysis was used primarily for assessment of potential targets for quantitative analysis of tourmaline composition, and for subsequent analysis by LA-ICP-MS. Determination of mineral inclusion species and distributions was useful in mapping analysis targets and gaining a better understanding of the environment in which the tourmaline formed.

Wavelength dispersive x-ray spectroscopy (WDS) was used for element mapping and determination of tourmaline compositions. WDS maps clarified the variation in major element chemistry relative to intracrystalline zoning. WDS transects across tourmaline grains provided compositional measurements and quantitative indications of chemical zoning within single crystals.

Instrument parameters and standards used for EMPA analyses are defined in **tables 3-5**.

**Table 3.** EMPA Counting Times

| Element | Peaks/Background Seconds (s) |
|---|---|
| B | 60/30 |
| Fe | 40/5 |
| Na, K, Mn | 30/5 |
| Si, Ca, Mg, Al, Ti | 20/5 |
| F, Cl, Cr | 60/10 |
| Zn | 90/10 |

**Table 4.** EPMA Settings

| Accelerating Voltage Kilovolts (kV) | Cup Current Nanoamps (nA) | Beam Diameter Microns (μm) |
|---|---|---|
| 15 | 20 | 5 |

**Table 5.** EPMA Standards

| Standard Name | Element |
|---|---|
| Tourmaline [species: buergerite] (San Luis Potosi, Mexico) | Na, Fe, Al, Si, B, F |
| Rhodonite (Broken Hill, Australia) | Mn |
| Garnet-12442 (locality unknown) | Ca, Mg |
| Scapolite [species: meionite] (Brazil) | Cl |
| Chromite (Bushveld, South Africa) | Cr |
| Zn metal (Alfa Aesar) | Zn |
| Microcline (locality unknown) | K |

## *LA-ICP-MS*

In situ analysis of tourmaline grains was performed by laser ablation inductively coupled plasma mass spectroscopy (LA-ICP-MS) using the Element 2 single collector ICP-MS with a solid state Nd:YAG laser ablation system. Two separate analytical techniques were performed using LA-ICP-MS: 1) trace element and REE abundances were analyzed, and 2) boron isotope compositions were determined by assessing $^{11}B/^{10}B$ ratios calculated directly from the measured counts per second (cps).

For trace element and REE analysis, internal standardization of tourmaline targets was performed assuming 30 wt% $Al_2O_3$. This approximation for alumina content in tourmaline was estimated based on the composition results from EMPA analysis. Analysis of USGS reference material BHVO-2G (basalt glass) and NIST610 (trace elements in glass) bracketed sample analysis for use as external calibration standards.

For assessment of boron isotope measurements, a method for in situ analysis of boron ratios was developed. Natural tourmaline standards were acquired from John Slack at the USGS. The details of the natural tourmaline standards are outlined in **table 6**. Natural standards were useful in assessing the efficacy of the LA-ICP-MS technique for boron ratio determination because these materials have been previously analyzed for boron isotope values by thermal ionization mass spectrometry (TIMS) (Palmer & Slack, 1989).

Boron isotope values, $\delta^{11}B$, for tourmaline were calculated from the measured $^{11}B/^{10}B$ ratios using the equation:

$$\delta^{11}B(‰)_{\text{measured}} = \left[\frac{(^{11}B/^{10}B)_{\text{sample}}}{(^{11}B/^{10}B)_{\text{standard}}} - 1\right] \times 1000‰ \text{ (Yavuz et al., 2011)}$$

All values were then normalized to NIST 951 for reporting using the calculation:

$$\delta^{11}\mathrm{B}(‰)_{\mathrm{sample}} = \delta^{11}\mathrm{B}(‰)_{\mathrm{measured}} + \delta^{11}\mathrm{B}(‰)_{\mathrm{standard}}$$

Where the $\delta^{11}$B values for the standard was set equal to the literature value.

**Table 6.** Descriptions of USGS tourmaline reference material source locations, rock types, ages, and boron isotope information (Palmer & Slack 1989)

| Standard | Location | $\delta^{11}$B (TIMS) | Rock Type/age | Notes |
|---|---|---|---|---|
| EZ-272 | Elizabeth Mine, VT | -14.17±0.23 | Amphibolite, Devonian | Med-grained (~2mm), Euhedral crystals within sulfide |
| EB-67-90 | Gouverneur area, New York | +10.47±0.36 | Amphibolite, Late Proterozoic | Med/fine-grained (~mm), black/dark color |
| JS-79N-1 | Bleikvassi mine, Nordland, Norway | -12±0.24 | Amphibolite, Late Proterozoic | Fine-grained (<mm), green-yellow color |
| JS-82A-3 | Pinnacles Area, Broken Hill Deposit, Australia | -20.83±0.37 | Granulite, Mid Proterozoic | Very fine-grained (<mm), black/dark color |

## RESULTS

### *MINERAL PHASE IDENTIFICATION*

Through EDS analysis of whole-rock samples of the lower schist and middle quartzite members of the Setters Formation divulged the differences in mineral assemblages between the two lithological units. Point counting was not performed to assess the modal proportions of the mineral assemblages.

Investigating a characteristic sample of the lower schist member revealed the following mineral assemblage: quartz, muscovite, biotite (Mg-poor; Fe/Mg ~75%), potassium feldspar (k-spar), aluminosilicate (i.e., kyanite or sillimanite), monazite, zircon, rutile, magnetite, and ilmenite. It is important to note that no tourmaline was found in this sample prepared from the lower schist member.

Analysis of a sample from the middle quartzite member revealed the following mineral assemblage: quartz, k-spar, muscovite, aluminosilicate (i.e., kyanite or sillimanite), monazite, zircon, rutile, magnetite, ilmenite and tourmaline. Monazite, zircon and rutile were more abundant in the middle quartzite member than in the lower schist member. Tourmaline was found to be present in the foliations dominated by muscovite and aluminosilicate. Furthermore, k-spar lenses commonly surround tourmaline crystals.

EDS analysis of individual tourmaline grains established that the crystals contain a complex assemblage of mineral and fluid inclusions. The observed mineral inclusions present in tourmaline include: zircon, ilmenite, rutile, monazite, and quartz.

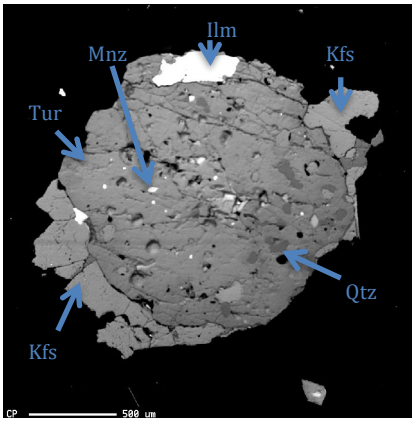


**Fig. 6.** BSE image of a tourmaline grain from sample JFB-15-1-1. Tourmaline [Tur] is observed with intergrowths of quartz [Qtz], and inclusions of ilmenite [Ilm], monazite [Mnz], and k-feldspar [Kfs].

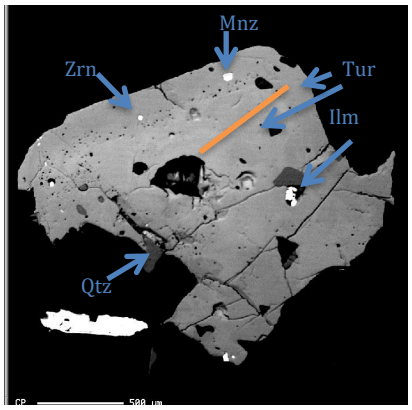


**Fig. 7.** BSE image of a tourmaline grain from sample JFB-15-2-1. Tourmaline [Tur] is observed with inclusions of quartz [Qtz], ilmenite [Ilm], monazite [Mnz], and zircon [Zrn]. Core-rim zoning is evident. A WDS traverse path is indicated by the orange line.

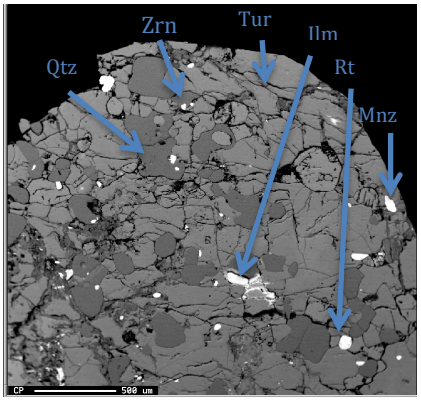


**Fig. 8.** BSE image of a tourmaline grain from sample JFB-15-3-3. Tourmaline [Tur] is observed with intergrowths of quartz [Qtz] and inclusions of ilmenite [Ilm], monazite [Mnz], and rutile [Rt].

## *TOURMALINE MAPPING AND ZONING*

There is vast variability in the distribution and abundance of inclusions between grains. **Figures 6-8** depict some examples of the variability in crystal habit, size, zoning and distribution of inclusions. In some grains of tourmaline, particularly those from sample sites 1 and 3, there is no obvious order to the distribution of mineral and fluid inclusions. Conversely, select grains from sample site 2 appear to show a more systematic distribution of inclusions.

BSE imaging and X-ray mapping exposed complex zoning patterns. Crystals are highly zoned with patchy convolute zoning; some tourmaline crystals display oscillatory zoning as well.

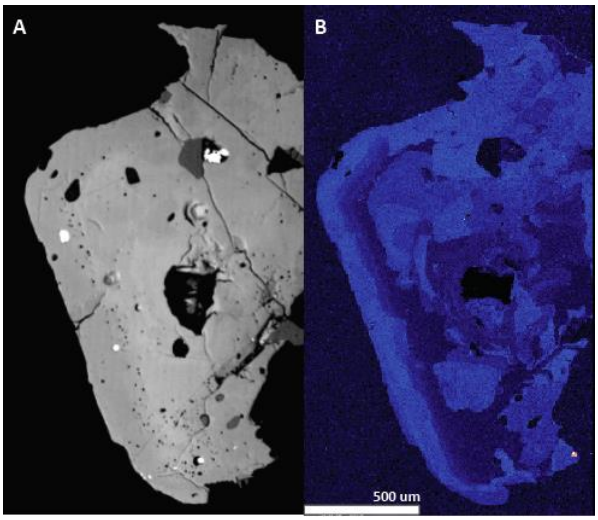


**Fig. 9.** Single tourmaline grain from the Setters Formation displays characteristics of zoning in:
A) BSE image showing distinct rim and core zones.
B) WDS map depicting complex Ca-zoning (Ca content increases from dark to light blue).

An example of the more ordered inclusion scheme is depicted in the BSE image in **figure 9A**, where the core of the tourmaline is relatively inclusion-poor, the rim is relatively mineral inclusion-rich and fluid inclusions are concentrated at the boundary between the core and rim. Changes in major element chemistry, which influenced the core-rim fractionation, may be related to unique growth horizons resulting from prograde metamorphism.

WDS mapping of the same tourmaline mentioned above exposed complex chemical zoning of Ca (see **figure 9B**). Zoning patterns discovered through BSE were exposed to be more complex through WDS, with a more Ca-rich rim and patchy patterned convolute zoned core. Zoning within the core of the grain may reflect multiple growth phases during the early stages of prograde metamorphism. The more homogeneous rim reflects late-stage crystal growth.

*TOURMALINE SPECIATION*

Major element analysis of Setters Formation tourmaline was used to calculate mineral formulae and assign tourmaline species. Mineral formula determination, from EPMA data (see **Appendix B**), was performed by the 31-anion method using the Excel plug-in developed by Selway and Xiong (2002). The results of mineral formula calculations determined that the Setters Overall, the tourmaline species was determined to be an intermediate between schorl (Fe/Mg > 1) and dravite (Fe/Mg < 1); with ~75% schorl and ~24% dravite (see **Appendix C**).

Compositional data was plotted on the modified AFM developed by Henry and Guidotti (1985), **figure 3**, with compositional zones assigned based on host-rock type. Setters Formation tourmaline compositions plot primarily within zones 4 and 5, metapelite and metapsammite associated tourmaline. Plotting within these compositional zones is consistent with the occurrence of tourmaline along the metapelitic foliations that express the boundaries between quartzite beds.

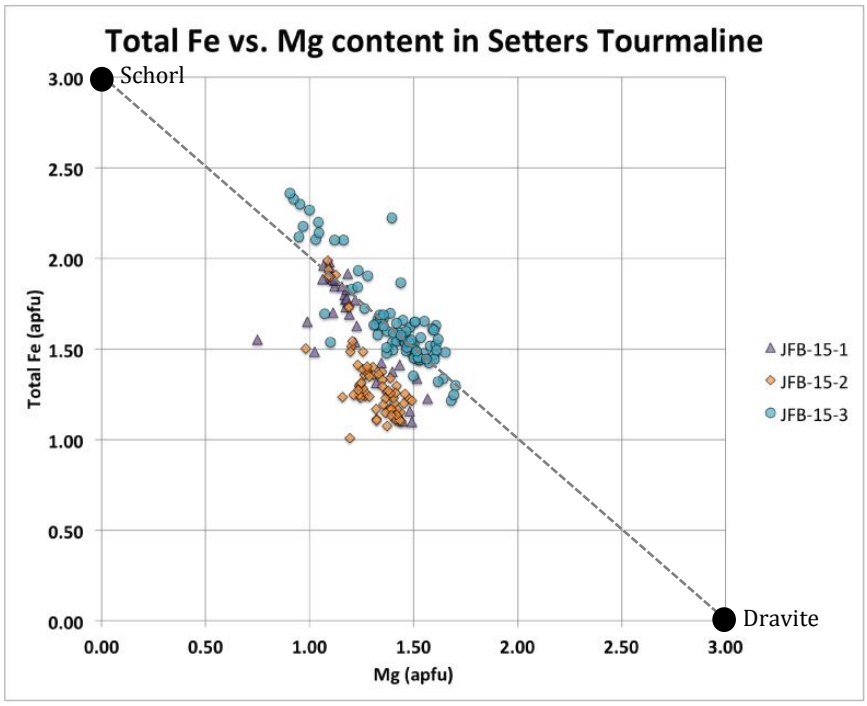


**Fig. 10.** X-site Fe vs. Mg plotted based on amount per formula unit (apfu) calculated from WDS measurements.

Henry and Dutrow (2012) indicated that tourmaline formed under low-temperature evaporitic conditions will follow a povondraite to dravite trend, having a higher proportion of $Fe^{3+}$ in hypersaline environments. Tourmaline from the Setters Formation does not follow this povodraite to dravite trend, rather the Fe/Mg ratios for all samples fall in the intermediate range between schorl and dravite (see **figure 10**). The average values for Fe/Mg ratios were determined based on sample site, with average values of: 1) 1.40 ± 0.37 for samples collect at site JFB-15-1, 2) 1.03 ± 0.26 for samples collected at site JFB-15-2, and 3) 1.22 ± 0.42 for samples collected at site JFB-15-3.

WDS traverses across tourmaline grains were performed in order to evaluate the degree of elemental partitioning. An example of such a traverse is indicated in **figure 7**, the results of which are presented in **figures 11** and **12**. Element partitioning is evident in this grain based on the variation of oxide abundances from core to rim; FeO, $TiO_2$ and CaO content decreases as MgO and $Na_2O$ content increases.

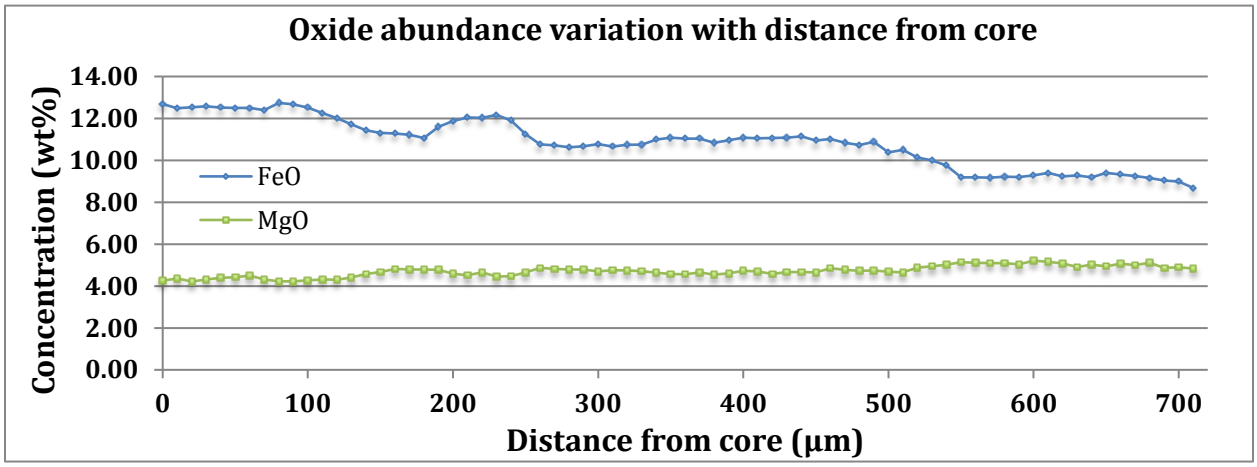


**Fig. 11.** WDS traverse data for partitioning of FeO and MgO in a tourmaline cross-section from JFB-15-2-1

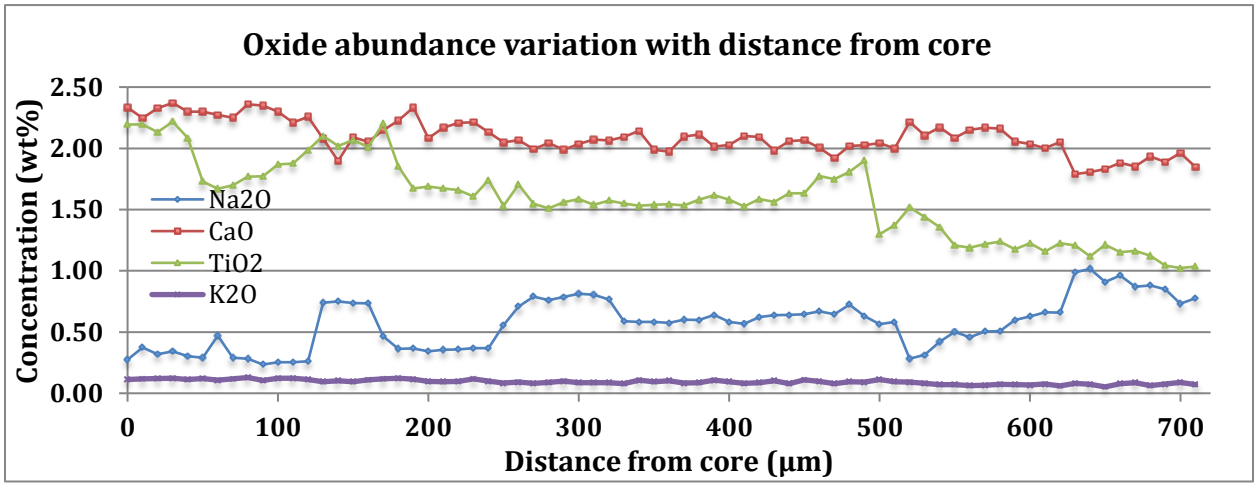


**Fig. 12.** WDS traverse data for partitioning of $Na_2O$, CaO, $TiO_2$, and $K_2O$ in a tourmaline cross-section from JFB-15-2-1

## *GEOTHERMOMETRY*

Setters Formation tourmaline was assessed to identify the presence of hourglass zoning in order to utilize the geothermometric technique developed by van Hinsberg et al. (2007). This technique relies on the partitioning of Ti and Ca/Na along the c-axis of a tourmaline crystal. Due to the hemimorphic nature of tourmaline, the $c^+$ and $c^-$ sectors of the crystal will incorporate cations at different rates. As temperature increases, the incorporation of cations approaches homogeneity across the two sectors (see **figure 13**). As a result of the slow intracrystalline diffusion exhibited by tourmaline, the temperature record will be

locked into individual crystals even as temperature conditions change and thus prograde or retrograde temperature conditions may be determined.

No hourglass zoning was identified in tourmaline from the Setters Formation. With a lack of hourglass zoning, the geothermometric determinations could not be performed with any confidence.

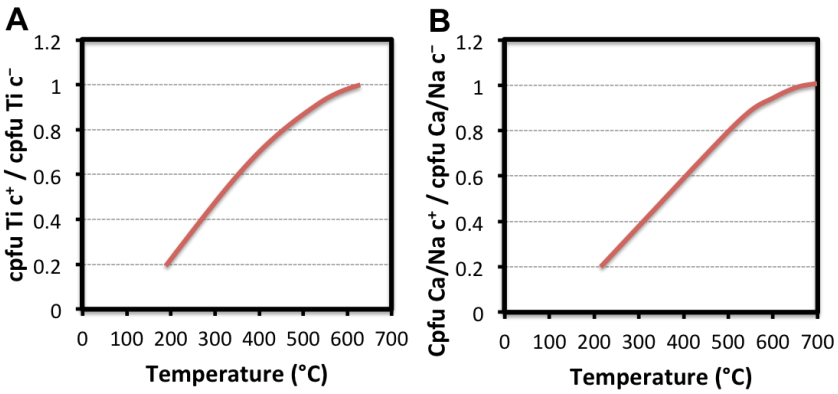


**Fig. 13.** Elemental partitioning within tourmaline as a function of crystallization temperature as calibrated by van Hinsberg et al. (2006) for A) Ti distribution, and B) Ca/Na distribution.

## *Trace Element and REE Patterns*

Trace element tends (**figure 14**) represent the average of all LA-ICP-MS analyses performed for each sample site, these averages are the product of analyzing: 13 spots across 4 tourmaline grains from site JFB-15-1, 68 spots across 14 tourmaline grains from site JFB-15-2, and 35 spots across 15 tourmaline grains from site JFB-15-3. Average trace element trends at all sample sites are similar for the lighter trace elements measured. However, samples from JFB-15-3 display elevated levels of the heavier trace elements relative to sites JFB-15-1 and JFB-15-2.

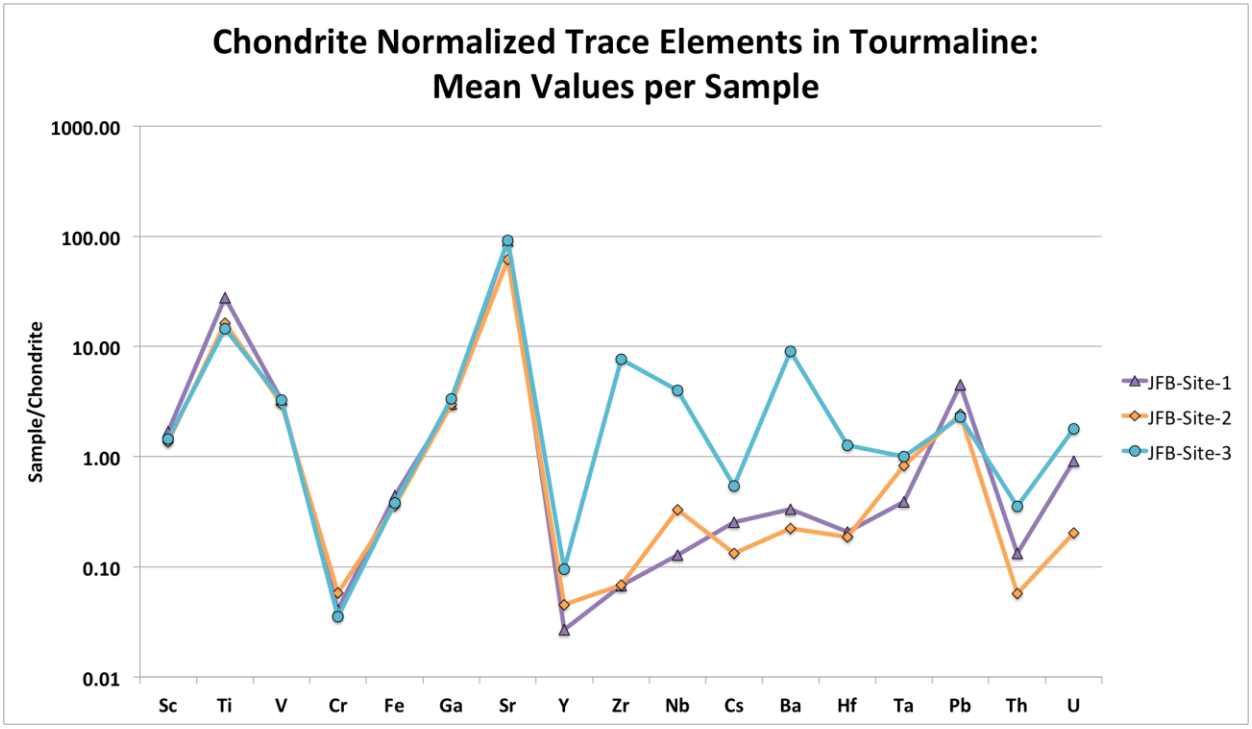


**Fig. 14.** Average chondrite normalized trace element concentration in tourmaline per sample site.

REE tends (**figure 15**) represent the average of all LA-ICP-MS analyses performed for each sample site, these averages are the product of analyzing: 13 spots across 4 tourmaline grains from site JFB-15-1, 68 spots across 14 tourmaline grains from site JFB-15-2, and 35 spots across 15 tourmaline grains from site JFB-15-3. The trend at all three samples locations is similar, with a slight enrichment of LREE, strong positive Eu-anomaly, and slight depletion of HREE.

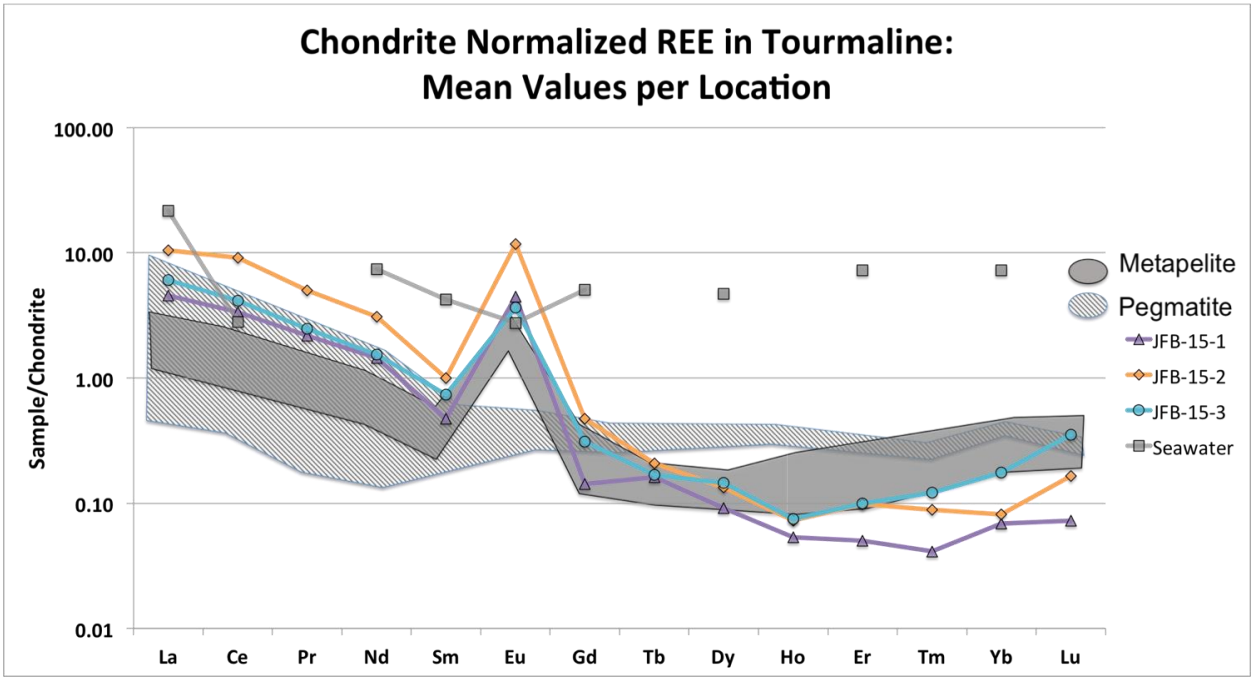


**Fig. 15**. Average chondrite normalized REE trends for tourmaline in Setters Formation plotted per sample location, with published data from tourmalines in metapelites (Hazarika et al., 2015) and pegmatites (Marks et al., 2013), and REE in seawater (Goldstein & Jacobsen, 1988).

REE trends of Setters Formation tourmaline more closely reflect the trends of previously published samples of tourmaline in metapelitic rock (Hazarika et al., 2015). The positive Eu anomaly present in Setters Formation tourmaline differentiates the data from previously published samples of tourmaline in pegmatitic rock (Marks et al., 2013). REE trends of Setters Formation tourmaline do not match the REE trends for seawater samples (Goldstein & Jacobsen, 1988).

## *Boron Isotopes*

The isotopes $^{10}B$ and $^{11}B$ were analyzed via LA-ICP-MS. Boron isotope ratios, $^{11}B/^{10}B$, were determined using the following equation:

$$^{11}B/_{^{10}B} = \frac{Mean\,[^{11}B]_{signal} - Mean\,[^{11}B]_{background}}{Mean\,[^{10}B]_{signal} - Mean\,[^{10}B]_{background}}$$

where mean signal and background measurements, in counts per second (cps), were determined qualitatively by evaluating the plots of cps versus analysis run time (see **figure 16**).

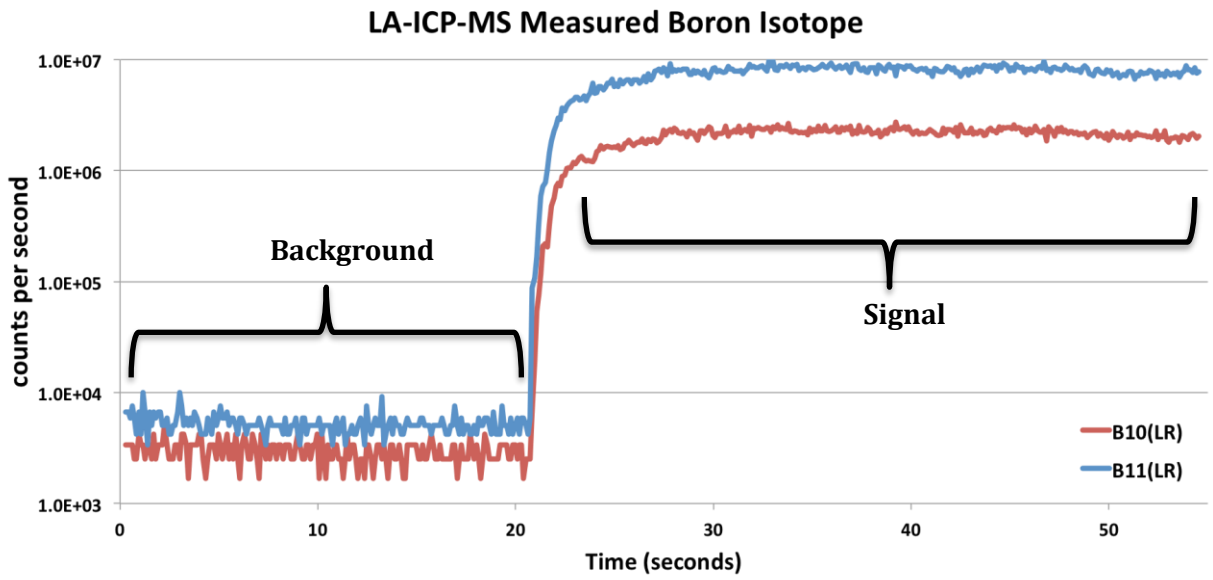


**Fig. 16**. Example of LA-ICP-MS analysis of boron in tourmaline, with boron-10 and -11 represented in red and blue, respectively.

Accuracy of boron isotopic measurements for Setters tourmaline was assessed using natural tourmaline standards. Accepted values for tourmaline standards were determined using TIMS (see **table 6**; Palmer & Slack, 1989). LA-ICP-MS measured values for standards are within one standard deviation of a 1:1 trend, as represented in **figure 17**.

$\delta^{11}B$ values determined for tourmaline from the Setters Formation were compared to well defined major geologic reservoirs for boron.

In **figure** 18, $\delta^{11}B$ values for tourmaline from the Setters Formation were compared to defined ranges for $\delta^{11}B$ in pegmatitic and metasedimentary environments, as well as $\delta^{11}B$ values for modern seawater (Marschall & Jiang, 2011). The average $\delta^{11}B$ value for Setters tourmaline was determined to be -7.94 ±8.00‰. There is a large degree of variability in $\delta^{11}B$ values between, and within, sample collection sites.

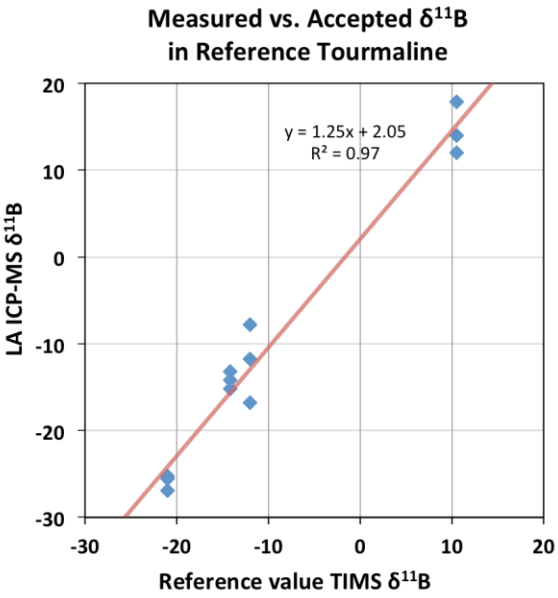


**Fig. 17**. Accepted values for tourmaline standards were determined using TIMS (Palmer & Slack, 1989). LA-ICP-MS measured values for standards are within one standard deviation of a 1:1 trend.

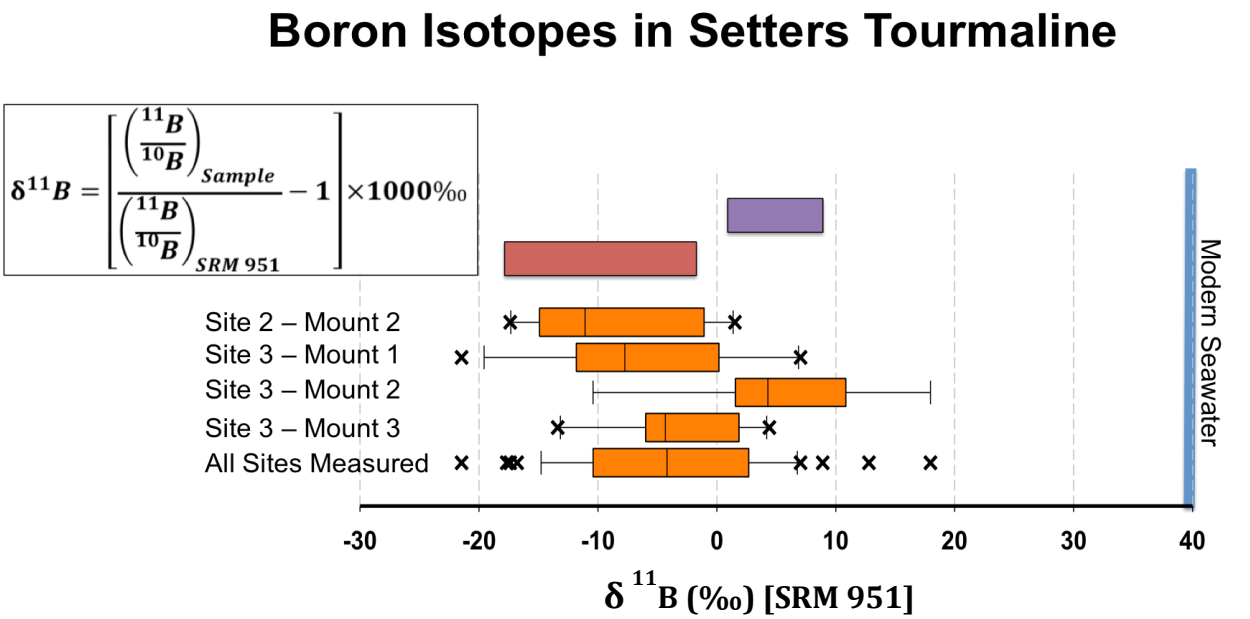


**Fig. 18**. Boron isotope ratio measurements for tourmaline collected in situ using LA-ICP-MS. The blue line indicated the $\delta^{11}B$ value for modern seawater, the purple field indicates the range of $\delta^{11}B$ values for tourmaline hosted in pegmatites, and the red field indicates the range of $\delta^{11}B$ values for tourmaline hosted in metasediments (from Marschall & Jiang, 2011). Orange fields indicate measurements on Setters tourmaline.

Warren (2016) indicates that $\delta^{11}B$ signatures are diagnostic of geological origins; examples of these diagnostic signatures are: 1) marine evaporites are generally around +10‰, 2) mafic volcanic related tourmaline are near -2‰, 3) tourmaline formed from sediments at continental margins are near -15‰, and 4) tourmaline from nonmarine evaporites are around -20‰.

## DISCUSSION

The aim of this senior thesis research has been to address some of the major questions pertaining to the origin of tourmaline in the Setters Formation. First, major and trace element compositions have been analyzed to examine the influence of host-rock environment on the chemistry of Setters Formation tourmaline.

Analysis of Setters tourmaline indicates that distinct compositional variations exist on a local scale. These distinct variations are reflected in the major- and minor-element, and REE data. Correlations between major-element composition and REE abundances appear to be present: JFB-15-2 has the highest Al content and the highest REE abundance of the three sites sampled.

If the source of boron in the Setters Formation tourmaline is seawater, there must have been some fractionation that resulted in the isotopically lighter boron in tourmaline relative to seawater. Background research indicates that this fractionation may be the result of isotopically lighter boron being more susceptible to adsorption on the surface of pelitic sediments that formed the schist layers (Hemming & Hanson, 1992).

Two previous undergraduate research projects studying tourmaline in the Setters Formation were conducted at Towson University (Cook et al., 2004; Watt et al. 2002). These studies indicated that the chemical variability of tourmaline in Setters Formation likely represents multistage crystal growth and investigated the compositions of fluid inclusions.

Geochemical analyses of Setters tourmaline yielded results that are consistent with the minerals being the product of prograde metamorphism of the metapelitic host rock based on tourmaline speciation from major element compositions from previous publications (Henry & Guidotti 1985).

Major and trace element analyses reveal complex crystal zoning, which is verified by X-ray mapping techniques. This complex zoning is a likely indicator of multistage crystal growth resulting from prograde metamorphism. Additionally, data from each of the three sample locations tends to fall in distinct groups (see **figure 3** & **10**). The stratigraphic relationship between the three locations cannot be directly determined with the observations made during this study. However, the following assumed stratigraphic order can be approximated by evaluating the changes in lithology: site 2, site 1, site 3 (from bottom to top). If this approximation is correct, a systematic compositional relationship is revealed; Al-content decreases from bottom to top of the stratigraphic column.

Trace element and REE trends in Setters tourmaline are consistent across all sample locations selected for this study.

Boron isotopic measurements performed in situ using nonconventional methods yielded promising results for Setters tourmaline. The $\delta^{11}B$ values determined using single collector LA-ICP-MS have been performed with and accuracy that is adequate considering the natural range of $\delta^{11}B$ values in tourmaline ranges from approximately -30‰ to +40‰ (Marschall & Jiang, 2011). Exploring the boron isotopic measurements indicates a metasedimentary or pegmatitic origin for Setters tourmaline.

From the signatures identified by Warren (2016), $\delta^{11}B$ values for tourmaline from the Setters Formation most closely reflects the signatures for continental margin sediments and mafic volcanics. It is possible that the schist foliations in the middle quartzite member of the Setters Formation represent volcanic ash sediments emplaced by a series of volcanic events. The combination of continental margin sediments and volcanic ash may account for the variability of $\delta^{11}B$ values determined for Setters Formation tourmaline.

## *AREAS OF UNCERTAINTY*

### *SAMPLE COLLECTION*

Due to the sampling techniques used, the relationship between compositional variation and schist horizons can not be directly made. However, variation in composition may be present on a meter-scale based on observations of change in mineral (i.e., tourmaline and muscovite) size and abundance between individual beds in the quartzite member of the Setters Formation. Additionally, changes in quartzite bed thicknesses were observed in the field; bed sizes can vary from <1cm to >5cm in thickness.

### *Tourmaline Speciation*

Uncertainty for major element determinations is due to counting statistics and has been calculated using the following equation:

$$1\sigma = \frac{\sqrt{N}}{N} \times 100\% = \frac{1}{\sqrt{N}} \times 100\% \text{ (Goldstein et al., 1992)}$$

Using the tourmaline mineral formula spreadsheet (Selway & Xiong, 2002) to evaluate the species of tourmaline from EPMA data relies on simplifying assumptions. First, the calculations assume 31-anions are present, which are not directly measured by WDS. Next, site assignment of cations is performed by assuming ideal coordination in structural sites.

### *Trace Elements and REE*

Trace element and REE abundances were calculated assuming 30 wt% $Al_2O_3$, which is a generous assumption. More precise calculations of trace element and REE abundances could have been determined through the use of EPMA data for exact $Al_2O_3$ content.

Due to the nature of the natural samples, LA-ICP-MS measurements of tourmaline were vulnerable to the introduction of error by ablating mineral inclusions within the crystals. Ablating a zircon or monazite inclusion would easily distort the trace element and REE measurements.

Additional uncertainty in LA-ICP-MS was introduced by the limits of the Element 2 instrument. Low concentrations of trace elements and REE could not be measured in some samples because they fell below the instrumental detection limit.

### *Boron Isotopes*

Boron isotope ratios were used rather than absolute concentrations because they reduce the uncertainty associated with matrix variation between samples and standards. Obtaining accurate and precise analyses of boron isotopes can be very problematic. Difficulties arise when performing LA-ICP-MS analyses due to the drastic effects of matrix-dependencies (Farber et al., 2015; Hazarika et al., 2015; Mikova et al., 2014; Palmer & Slack, 1986). To minimize the uncertainty associated with measurement inaccuracies, tourmaline reference materials selected for use as standards have been previously studied and $\delta^{11}B$ values have been confidently determined (Palmer and Slack 1986; Mikova et al. 2014).

Uncertainty for boron isotope measurements is introduced via instrumental limitations; for δ11B, the Element 2 single collector LA-ICP-MS has a precision of ±5‰. The limitation of boron measurements using plasma spectroscopy is due in part to the fractionation associated with the high volatility of boron. Because boron is a light element, measurement inaccuracies can result from the high relative mass difference between $^{10}B$ and $^{11}B$ (Mikova et al., 2014). The boron concentration of NIST610 is 400ppb and the boron concentration of tourmaline is ~10 wt% as $B_2O_3$ (~3 wt% B), there is also high potential for measurement uncertainties to result from boron isotope fractionation variation as a function of the sample matrix.

After overcoming the initial ionization potential, $^{40}Ar^{4+}$ may occur due to the overabundance of Ar in the plasma; this quadruply charged Ar could produce an

interference signal for $^{10}B$ (Mikova et al. 2014). However, due to the low rate of $^{40}Ar^{4+}$ occurrence in the plasma, running boron analyses of boron isotopes in medium or low resolution will make this interference signal negligible.

## *FUTURE POSSIBILITIES*

### *BORON ISOTOPES*

Further boron isotope investigations would be useful in clarifying the results and better assess the precision of the values determined for Setters Formation tourmaline. Reanalyzing the same targets previously analyzed would be one method for assessing the precision of the determined values. By comparing multiple runs of analysis for the same set of targets would provide a means to understand the potential variation in measurements. In addition to analyzing the same set of targets, performing analysis using a method of bracketing, where each Setters Formation target is bracketed by a the same tourmaline standard (standard → sample → standard → sample → …). By bracketing in this manner, variation between standards due to instrumental drift or interferences can be used to eliminate or validate sample measurements.

### *GEOCHRONOLOGY*

Distinct core-to-rim zoning of tourmaline can be useful in understanding multistage crystal growth. Due to the chemical flexibility of tourmaline, the minerals can readily incorporate elements used for radiometric dating. The chemistry, slow rate of intracrystalline diffusion and distinct growth horizons combine to make tourmaline a strong candidate for geochronologic measurements (Marschall and Jiang, 2011). Performing geochronologic measurements on Setters Formation tourmaline may provide useful information to better constrain the ages of deformation for the region.

## CONCLUSIONS

Compositional ranges of tourmaline from the Setters Formation are consistent with previously studied pelites and metapelites (fields 4 and 5 of figure 1; Henry and Guidotti 1985) as determined by EMPA analysis.

Crystallization temperature for tourmaline from the Setters Formation could not be determined using Ca- and Ti- geothermometers due to the lack of hourglass zoned crystals in the samples analyzed during this study.

By assessing LA-ICP-MS data for Setters Formation tourmaline, chondrite-normalized REE patterns for tourmaline in the Setters Formation reflects distinct REE patterns associated with metasedimentary host.

A procedure for measuring $\delta^{11}B$ values using LA-ICP-MS was developed during this study. The measurements of boron isotopes in tourmaline from the Setters Formation compared to reference materials determine the boron to be isotopically light ($\delta^{11}B$ (‰)<0) and possibly formed from fluid derived from continental margin sediments and mafic volcanic ash.

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## APPENDIX A

**I pledge on my honor that I have not given or received any unauthorized assistance or plagiarized on this assignment.**

**_____ Date: _____**

## APPENDIX B

**Table 7.** WDS data for JFB-15-1-1.

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 12.96 | 8.71 | 0.19 | 1.12 | 2.15 | 0.01 | 6.23 | 0.00 | 29.64 | 0.04 | 0.08 | 35.26 | 1.25 | 0.02 | 97.58 |
| 13 | 12.71 | 10.82 | 0.16 | 0.18 | 2.46 | 0.05 | 4.81 | 0.00 | 28.32 | 0.09 | 0.10 | 35.58 | 2.03 | 0.01 | 97.25 |
| 16 | 11.79 | 12.56 | 0.17 | 0.07 | 2.21 | 0.03 | 4.35 | 0.02 | 25.11 | 0.10 | 0.14 | 33.11 | 2.63 | 0.02 | 92.23 |
| 17 | 9.69 | 9.93 | 0.00 | 0.37 | 2.64 | 0.02 | 2.69 | 0.00 | 26.25 | 0.28 | 0.11 | 32.11 | 2.22 | 0.00 | 86.32 |
| 18 | 12.42 | 12.94 | 0.11 | 0.11 | 2.54 | 0.00 | 4.02 | 0.00 | 25.26 | 0.10 | 0.10 | 32.84 | 2.53 | 0.03 | 92.95 |
| 19 | 13.09 | 12.30 | 0.17 | 0.12 | 2.87 | 0.05 | 4.75 | 0.00 | 27.08 | 0.16 | 0.13 | 34.96 | 2.35 | 0.01 | 97.96 |
| 20 | 12.88 | 9.36 | 0.26 | 0.62 | 2.43 | 0.01 | 5.97 | 0.01 | 28.97 | 0.07 | 0.08 | 35.11 | 1.20 | 0.00 | 96.86 |
| 21 | 11.95 | 7.83 | 0.25 | 1.10 | 1.95 | 0.00 | 5.76 | 0.01 | 30.74 | 0.13 | 0.08 | 35.12 | 1.23 | 0.02 | 96.06 |
| 22 | 12.13 | 7.84 | 0.11 | 1.12 | 1.97 | 0.04 | 5.98 | 0.00 | 31.14 | 0.09 | 0.06 | 35.03 | 1.18 | 0.02 | 96.65 |
| 23 | 12.51 | 8.25 | 0.27 | 0.93 | 2.06 | 0.05 | 5.93 | 0.00 | 30.50 | 0.01 | 0.08 | 35.43 | 1.29 | 0.01 | 97.20 |
| 24 | 12.58 | 12.13 | 0.12 | 0.09 | 2.64 | 0.04 | 4.60 | 0.00 | 26.97 | 0.14 | 0.13 | 35.30 | 3.01 | 0.02 | 97.72 |
| 25 | 12.99 | 12.25 | 0.07 | 0.10 | 2.68 | 0.04 | 4.54 | 0.00 | 26.53 | 0.07 | 0.11 | 35.04 | 2.64 | 0.01 | 97.05 |
| 26 | 12.61 | 13.07 | 0.09 | 0.09 | 2.98 | 0.04 | 4.45 | 0.01 | 27.23 | 0.10 | 0.12 | 35.75 | 2.66 | 0.03 | 99.19 |
| 27 | 11.67 | 13.12 | 0.14 | 0.09 | 2.90 | 0.02 | 4.39 | 0.00 | 26.51 | 0.11 | 0.12 | 35.48 | 2.55 | 0.03 | 97.07 |
| 28 | 12.84 | 12.59 | 0.15 | 0.09 | 2.86 | 0.00 | 4.58 | 0.00 | 26.96 | 0.15 | 0.11 | 35.40 | 2.53 | 0.03 | 98.23 |
| 29 | 9.85 | 10.01 | 0.02 | 0.17 | 2.50 | 0.04 | 5.31 | 0.01 | 28.38 | 0.26 | 0.11 | 35.40 | 2.10 | 0.03 | 94.18 |
| 30 | 13.06 | 9.75 | 0.10 | 0.32 | 2.48 | 0.00 | 5.55 | 0.00 | 29.08 | 0.08 | 0.08 | 35.83 | 1.38 | 0.00 | 97.65 |
| 31 | 11.53 | 11.48 | 0.06 | 0.71 | 2.15 | 0.02 | 4.85 | 0.00 | 28.48 | 0.03 | 0.17 | 35.38 | 2.00 | 0.04 | 96.87 |
| 32 | 11.74 | 13.34 | 0.00 | 0.09 | 3.04 | 0.02 | 4.35 | 0.01 | 26.81 | 0.04 | 0.11 | 35.66 | 2.56 | 0.02 | 97.79 |
| 33 | 8.81 | 12.29 | 0.18 | 0.14 | 2.95 | 0.02 | 4.52 | 0.02 | 30.54 | 0.07 | 0.09 | 35.58 | 1.65 | 0.02 | 96.80 |
| 35 | 8.45 | 9.90 | 0.00 | 1.07 | 1.97 | 0.05 | 3.83 | 0.02 | 30.69 | 0.21 | 0.15 | 31.18 | 1.46 | 0.00 | 88.96 |
| 36 | 18.13 | 9.56 | 0.33 | 0.93 | 2.11 | 0.05 | 5.39 | 0.01 | 31.09 | 0.34 | 0.12 | 35.89 | 1.59 | 0.03 | 105.43 |
| 39 | 13.86 | 9.98 | 0.10 | 0.35 | 1.20 | 0.03 | 3.15 | 0.01 | 33.21 | 0.20 | 0.06 | 16.18 | 1.65 | 0.03 | 79.96 |
| 40 | 10.99 | 11.91 | 0.19 | 0.06 | 2.65 | 0.03 | 4.71 | 0.00 | 28.64 | 0.18 | 0.08 | 35.62 | 1.39 | 0.03 | 96.39 |
| 41 | 14.03 | 10.09 | 0.08 | 0.32 | 2.58 | 0.03 | 5.74 | 0.00 | 28.90 | 0.05 | 0.09 | 36.05 | 1.63 | 0.02 | 99.57 |
| 43 | 12.93 | 12.82 | 0.03 | 0.11 | 2.88 | 0.01 | 4.64 | 0.00 | 26.97 | 0.17 | 0.11 | 35.39 | 2.53 | 0.04 | 98.62 |
| 44 | 13.13 | 12.48 | 0.11 | 0.08 | 2.66 | 0.02 | 4.63 | 0.01 | 27.14 | 0.08 | 0.10 | 35.57 | 2.47 | 0.03 | 98.46 |
| 45 | 10.28 | 10.99 | 0.13 | 1.09 | 2.09 | 0.04 | 3.70 | 0.02 | 34.12 | 0.19 | 0.09 | 27.52 | 1.93 | 0.02 | 92.15 |
| 46 | 13.31 | 13.71 | 0.12 | 0.09 | 2.83 | 0.03 | 4.18 | 0.01 | 26.55 | 0.03 | 0.13 | 35.35 | 2.70 | 0.02 | 99.00 |

(**Table 7.** Continued)

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 48 | 13.32 | 13.24 | 0.00 | 0.10 | 2.71 | 0.06 | 4.38 | 0.01 | 26.82 | 0.17 | 0.12 | 35.60 | 2.63 | 0.01 | 99.14 |
| 49 | 12.91 | 13.63 | 0.25 | 0.07 | 2.97 | 0.05 | 4.29 | 0.00 | 26.29 | 0.12 | 0.13 | 35.41 | 2.70 | 0.03 | 98.74 |
| 50 | 11.88 | 12.90 | 0.02 | 0.06 | 2.73 | 0.05 | 4.53 | 0.00 | 26.58 | 0.10 | 0.12 | 35.51 | 2.59 | 0.04 | 97.09 |
| **mean** | **12.28** | **11.31** | **0.12** | **0.37** | **2.49** | **0.03** | **4.71** | **0.01** | **28.36** | **0.12** | **0.11** | **34.21** | **2.07** | **0.02** | **96.16** |
| **1σ** | **1.71** | **1.77** | **0.09** | **0.39** | **0.41** | **0.02** | **0.80** | **0.01** | **2.18** | **0.08** | **0.02** | **3.66** | **0.57** | **0.01** | **4.41** |

**Table 8.** WDS data for JFB-15-2-1.

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | 13.61 | 8.84 | 0.09 | 0.77 | 2.07 | 0.02 | 5.06 | 0.00 | 31.37 | 0.09 | 0.08 | 35.05 | 1.09 | 0.07 | 98.17 |
| 52 | 13.30 | 9.58 | 0.18 | 0.64 | 2.18 | 0.02 | 5.18 | 0.00 | 30.19 | 0.10 | 0.08 | 35.10 | 1.26 | 0.02 | 97.76 |
| 53 | 12.19 | 13.19 | 0.11 | 0.11 | 2.74 | 0.00 | 4.36 | 0.00 | 26.60 | 0.13 | 0.11 | 34.96 | 2.36 | 0.03 | 96.83 |
| 54 | 13.21 | 13.37 | 0.15 | 0.30 | 2.52 | 0.02 | 4.22 | 0.00 | 26.62 | 0.27 | 0.12 | 34.79 | 2.45 | 0.03 | 98.01 |
| 55 | 13.24 | 13.21 | 0.28 | 0.32 | 2.48 | 0.01 | 4.29 | 0.01 | 26.91 | 0.23 | 0.12 | 35.06 | 2.54 | 0.02 | 98.61 |
| 56 | 12.43 | 13.18 | 0.09 | 0.44 | 2.41 | 0.01 | 4.24 | 0.01 | 26.89 | 0.03 | 0.12 | 34.88 | 2.46 | 0.02 | 97.16 |
| 57 | 12.51 | 12.14 | 0.00 | 0.24 | 2.43 | 0.02 | 4.65 | 0.01 | 27.28 | 0.21 | 0.12 | 35.24 | 2.52 | 0.02 | 97.38 |
| 58 | 13.88 | 13.69 | 0.35 | 0.10 | 2.80 | 0.00 | 4.20 | 0.01 | 25.96 | 0.14 | 0.11 | 35.08 | 2.32 | 0.00 | 98.50 |
| 59 | 12.63 | 11.98 | 0.00 | 0.15 | 2.59 | 0.02 | 4.62 | 0.00 | 27.45 | 0.00 | 0.10 | 35.05 | 2.03 | 0.01 | 96.64 |
| 60 | 12.79 | 9.54 | 0.00 | 0.45 | 2.17 | 0.00 | 4.98 | 0.01 | 30.03 | 0.19 | 0.06 | 35.17 | 1.21 | 0.01 | 96.60 |
| 61 | 13.08 | 9.12 | 0.08 | 0.71 | 2.11 | 0.02 | 4.90 | 0.01 | 30.73 | 0.00 | 0.05 | 34.94 | 1.18 | 0.00 | 96.89 |
| 62 | 8.72 | 9.36 | 0.02 | 0.86 | 1.60 | 0.03 | 3.43 | 0.00 | 25.73 | 0.00 | 0.07 | 31.73 | 1.37 | 0.01 | 82.93 |
| 63 | 13.40 | 9.63 | 0.15 | 0.28 | 2.29 | 0.01 | 5.03 | 0.00 | 29.21 | 0.08 | 0.10 | 35.52 | 1.45 | 0.02 | 97.10 |
| 64 | 12.75 | 9.77 | 0.00 | 0.28 | 2.29 | 0.02 | 5.05 | 0.00 | 29.31 | 0.24 | 0.09 | 35.51 | 1.49 | 0.01 | 96.81 |
| 65 | 12.02 | 9.76 | 0.24 | 0.50 | 2.22 | 0.02 | 4.94 | 0.01 | 29.73 | 0.12 | 0.08 | 35.21 | 1.19 | 0.02 | 95.95 |
| 66 | 12.90 | 10.45 | 0.04 | 0.33 | 2.33 | 0.02 | 4.96 | 0.00 | 29.14 | 0.07 | 0.09 | 35.51 | 1.45 | 0.01 | 97.28 |
| 67 | 12.46 | 9.89 | 0.30 | 0.49 | 2.20 | 0.00 | 5.17 | 0.00 | 29.55 | 0.00 | 0.07 | 35.52 | 1.31 | 0.01 | 96.84 |
| 68 | 13.71 | 10.07 | 0.33 | 0.52 | 2.35 | 0.01 | 4.92 | 0.00 | 30.09 | 0.04 | 0.08 | 35.83 | 1.14 | 0.00 | 98.96 |
| 69 | 12.70 | 9.88 | 0.00 | 0.47 | 2.26 | 0.02 | 5.04 | 0.01 | 29.74 | 0.08 | 0.07 | 35.35 | 1.21 | 0.00 | 96.83 |
| 70 | 12.86 | 8.90 | 0.22 | 0.80 | 1.97 | 0.02 | 5.04 | 0.01 | 31.16 | 0.15 | 0.07 | 34.84 | 1.03 | 0.03 | 96.97 |
| 71 | 12.10 | 9.64 | 0.09 | 0.50 | 2.27 | 0.01 | 5.30 | 0.00 | 29.39 | 0.04 | 0.05 | 35.25 | 1.25 | 0.00 | 95.85 |
| 72 | 12.44 | 8.59 | 0.22 | 0.83 | 1.93 | 0.02 | 4.86 | 0.00 | 30.93 | 0.14 | 0.06 | 34.26 | 1.06 | 0.04 | 95.31 |
| 73 | 11.39 | 8.78 | 0.26 | 0.85 | 2.02 | 0.01 | 4.90 | 0.00 | 31.16 | 0.00 | 0.09 | 34.61 | 1.10 | 0.04 | 95.10 |

(**Table 8.** Continued)

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 74 | 11.81 | 9.02 | 0.16 | 0.79 | 2.06 | 0.02 | 4.97 | 0.00 | 30.65 | 0.10 | 0.08 | 34.89 | 1.15 | 0.03 | 95.66 |
| 75 | 12.01 | 9.17 | 0.22 | 0.76 | 2.11 | 0.00 | 4.90 | 0.01 | 30.52 | 0.05 | 0.08 | 35.09 | 1.14 | 0.02 | 95.99 |
| 76 | 12.55 | 9.03 | 0.20 | 0.85 | 1.86 | 0.03 | 4.82 | 0.00 | 30.23 | 0.20 | 0.06 | 34.06 | 1.14 | 0.04 | 95.00 |
| 77 | 10.13 | 8.95 | 0.01 | 0.92 | 2.16 | 0.03 | 4.70 | 0.05 | 31.62 | 0.15 | 0.14 | 35.94 | 1.08 | 0.02 | 95.88 |
| 78 | 12.24 | 9.31 | 0.30 | 0.79 | 2.06 | 0.01 | 4.97 | 0.00 | 30.78 | 0.22 | 0.07 | 35.12 | 1.11 | 0.03 | 96.88 |
| 79 | 11.57 | 9.53 | 0.09 | 0.60 | 2.24 | 0.03 | 5.10 | 0.00 | 30.24 | 0.18 | 0.06 | 35.21 | 1.21 | 0.03 | 96.07 |
| 80 | 12.19 | 8.82 | 0.09 | 0.80 | 1.95 | 0.00 | 4.81 | 0.01 | 31.47 | 0.09 | 0.07 | 34.74 | 1.04 | 0.02 | 96.06 |
| 81 | 12.97 | 9.05 | 0.09 | 0.91 | 1.94 | 0.03 | 4.92 | 0.00 | 31.18 | 0.03 | 0.08 | 35.12 | 1.03 | 0.01 | 97.31 |
| 82 | 12.40 | 10.63 | 0.15 | 0.71 | 2.10 | 0.04 | 4.73 | 0.00 | 29.17 | 0.19 | 0.16 | 35.07 | 1.70 | 0.03 | 97.01 |
| 83 | 13.14 | 10.42 | 0.15 | 0.81 | 2.13 | 0.02 | 4.71 | 0.01 | 29.41 | 0.03 | 0.08 | 34.98 | 1.48 | 0.03 | 97.32 |
| 85 | 13.04 | 10.68 | 0.12 | 0.79 | 2.03 | 0.01 | 4.68 | 0.00 | 28.57 | 0.06 | 0.10 | 34.57 | 1.78 | 0.02 | 96.38 |
| 88 | 11.99 | 8.83 | 0.08 | 0.77 | 2.00 | 0.03 | 4.86 | 0.01 | 29.70 | 0.06 | 0.08 | 30.71 | 1.01 | 0.00 | 90.08 |
| 89 | 12.26 | 8.66 | 0.00 | 0.77 | 2.04 | 0.01 | 5.03 | 0.01 | 29.72 | 0.18 | 0.07 | 30.29 | 1.06 | 0.02 | 90.13 |
| 90 | 13.94 | 8.71 | 0.04 | 0.76 | 2.00 | 0.01 | 4.96 | 0.00 | 29.79 | 0.00 | 0.07 | 31.08 | 1.01 | 0.05 | 92.39 |
| **mean** | **12.50** | **10.09** | **0.13** | **0.59** | **2.19** | **0.02** | **4.80** | **0.01** | **29.41** | **0.11** | **0.09** | **34.63** | **1.44** | **0.02** | **95.96** |
| **1σ** | **0.98** | **1.53** | **0.10** | **0.25** | **0.24** | **0.01** | **0.36** | **0.01** | **1.64** | **0.08** | **0.03** | **1.36** | **0.50** | **0.02** | **2.92** |

**Table 9.** WDS data for JFB-15-2-2.

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91 | 12.06 | 8.75 | 0.20 | 0.76 | 2.24 | 0.01 | 5.92 | 0.00 | 30.29 | 0.15 | 0.06 | 35.48 | 1.22 | 0.02 | 97.07 |
| 92 | 12.71 | 7.96 | 0.16 | 1.07 | 1.90 | 0.01 | 5.69 | 0.01 | 31.80 | 0.06 | 0.06 | 35.13 | 1.09 | 0.07 | 97.66 |
| 93 | 13.05 | 8.18 | 0.15 | 0.90 | 1.98 | 0.03 | 5.72 | 0.00 | 31.02 | 0.26 | 0.08 | 34.95 | 1.06 | 0.03 | 97.34 |
| 94 | 12.79 | 8.67 | 0.00 | 0.77 | 2.09 | 0.05 | 5.66 | 0.00 | 28.30 | 0.18 | 0.07 | 35.07 | 1.22 | 0.04 | 94.91 |
| 95 | 7.38 | 6.91 | 0.09 | 1.30 | 1.60 | 0.05 | 4.59 | 0.01 | 35.27 | 0.05 | 0.08 | 30.34 | 0.95 | 0.01 | 88.57 |
| 96 | 13.81 | 8.62 | 0.27 | 0.60 | 2.19 | 0.03 | 5.94 | 0.00 | 30.03 | 0.27 | 0.07 | 35.39 | 1.23 | 0.04 | 98.37 |
| 97 | 12.96 | 8.93 | 0.19 | 0.72 | 2.15 | 0.05 | 5.52 | 0.00 | 30.41 | 0.07 | 0.06 | 35.35 | 1.29 | 0.02 | 97.63 |
| 98 | 8.49 | 8.45 | 0.04 | 0.91 | 1.84 | 0.04 | 4.93 | 0.01 | 31.30 | 0.11 | 0.08 | 32.59 | 1.08 | 0.01 | 89.85 |
| 99 | 13.14 | 8.24 | 0.17 | 1.05 | 1.88 | 0.02 | 5.52 | 0.00 | 30.96 | 0.07 | 0.10 | 34.60 | 1.07 | 0.03 | 96.79 |
| 101 | 12.43 | 8.01 | 0.03 | 1.01 | 1.86 | 0.04 | 5.66 | 0.01 | 31.26 | 0.07 | 0.07 | 34.92 | 0.98 | 0.04 | 96.37 |
| 102 | 12.42 | 9.18 | 0.32 | 0.82 | 2.06 | 0.05 | 5.63 | 0.01 | 30.18 | 0.16 | 0.07 | 35.02 | 1.33 | 0.00 | 97.11 |
| 103 | 10.05 | 8.29 | 0.15 | 0.58 | 2.17 | 0.04 | 5.52 | 0.00 | 30.49 | 0.00 | 0.07 | 35.77 | 1.16 | 0.00 | 94.22 |

(**Table 9.** Continued)

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 105 | 12.61 | 8.56 | 0.12 | 0.82 | 2.09 | 0.05 | 5.82 | 0.00 | 30.32 | 0.15 | 0.06 | 35.59 | 1.23 | 0.00 | 97.37 |
| 106 | 12.58 | 8.25 | 0.00 | 0.82 | 2.06 | 0.02 | 5.62 | 0.00 | 30.29 | 0.03 | 0.07 | 35.14 | 1.19 | 0.02 | 96.10 |
| 108 | 12.17 | 7.85 | 0.04 | 1.06 | 1.93 | 0.03 | 5.76 | 0.00 | 31.36 | 0.15 | 0.06 | 35.02 | 0.98 | 0.02 | 96.40 |
| 109 | 10.37 | 7.62 | 0.03 | 1.73 | 1.84 | 0.03 | 5.46 | 0.00 | 31.90 | 0.03 | 0.07 | 34.17 | 0.96 | 0.03 | 94.24 |
| 110 | 12.60 | 7.92 | 0.25 | 0.93 | 1.96 | 0.05 | 5.65 | 0.00 | 31.22 | 0.11 | 0.05 | 35.16 | 0.97 | 0.05 | 96.82 |
| 111 | 12.57 | 7.90 | 0.35 | 1.05 | 1.86 | 0.05 | 5.73 | 0.00 | 31.31 | 0.14 | 0.08 | 35.10 | 1.02 | 0.02 | 97.04 |
| 112 | 12.95 | 8.50 | 0.00 | 0.90 | 2.04 | 0.02 | 5.59 | 0.00 | 30.25 | 0.12 | 0.07 | 35.22 | 1.22 | 0.00 | 96.89 |
| 113 | 12.23 | 8.92 | 0.07 | 0.74 | 2.09 | 0.05 | 5.44 | 0.00 | 29.92 | 0.00 | 0.07 | 35.40 | 1.27 | 0.01 | 96.19 |
| 114 | 13.14 | 8.43 | 0.36 | 0.88 | 1.97 | 0.03 | 5.37 | 0.00 | 30.66 | 0.18 | 0.13 | 34.90 | 1.25 | 0.01 | 97.17 |
| 115 | 12.77 | 9.12 | 0.18 | 0.33 | 2.32 | 0.05 | 5.35 | 0.00 | 29.73 | 0.13 | 0.07 | 35.44 | 1.42 | 0.02 | 96.86 |
| 116 | 12.84 | 8.72 | 0.23 | 0.35 | 2.24 | 0.00 | 5.58 | 0.00 | 29.86 | 0.15 | 0.08 | 35.70 | 1.33 | 0.02 | 97.00 |
| 117 | 12.51 | 8.91 | 0.04 | 0.87 | 2.03 | 0.04 | 5.52 | 0.00 | 30.35 | 0.15 | 0.10 | 35.36 | 1.26 | 0.01 | 97.14 |
| 119 | 11.64 | 8.83 | 0.03 | 0.77 | 2.05 | 0.04 | 5.57 | 0.00 | 29.81 | 0.29 | 0.07 | 34.93 | 1.30 | 0.03 | 95.33 |
| 120 | 13.33 | 8.10 | 0.08 | 1.04 | 1.91 | 0.02 | 5.67 | 0.00 | 31.36 | 0.12 | 0.07 | 35.00 | 1.04 | 0.03 | 97.73 |
| 121 | 12.20 | 8.64 | 0.09 | 0.78 | 2.00 | 0.01 | 5.38 | 0.00 | 30.41 | 0.13 | 0.05 | 34.84 | 1.17 | 0.04 | 95.69 |
| 122 | 11.38 | 8.11 | 0.28 | 1.06 | 1.81 | 0.03 | 5.42 | 0.00 | 30.79 | 0.20 | 0.07 | 33.70 | 1.09 | 0.05 | 93.89 |
| 123 | 10.09 | 7.93 | 0.08 | 1.14 | 1.83 | 0.04 | 5.29 | 0.01 | 32.48 | 0.10 | 0.08 | 34.34 | 1.06 | 0.03 | 94.46 |
| 124 | 9.95 | 7.81 | 0.16 | 1.09 | 1.88 | 0.05 | 5.24 | 0.00 | 31.74 | 0.32 | 0.11 | 34.37 | 0.92 | 0.03 | 93.59 |
| 125 | 6.92 | 4.79 | 0.08 | 0.77 | 1.28 | 0.00 | 3.42 | 0.02 | 27.19 | 0.14 | 5.47 | 41.86 | 0.62 | 0.02 | 92.54 |
| 126 | 12.46 | 8.85 | 0.05 | 0.79 | 2.10 | 0.02 | 5.49 | 0.00 | 30.04 | 0.05 | 0.08 | 35.13 | 1.26 | 0.00 | 96.30 |
| 127 | 11.62 | 9.09 | 0.10 | 0.80 | 2.22 | 0.04 | 5.53 | 0.01 | 30.45 | 0.01 | 0.07 | 35.61 | 1.25 | 0.03 | 96.77 |
| 128 | 9.90 | 7.99 | 0.13 | 1.12 | 1.73 | 0.02 | 5.07 | 0.01 | 31.35 | 0.26 | 0.06 | 32.70 | 0.99 | 0.01 | 91.28 |
| 129 | 12.45 | 8.02 | 0.00 | 1.05 | 1.98 | 0.01 | 5.35 | 0.08 | 31.06 | 0.21 | 0.14 | 33.96 | 1.03 | 0.02 | 95.36 |
| 130 | 12.47 | 8.05 | 0.00 | 1.03 | 1.91 | 0.04 | 5.55 | 0.00 | 31.22 | 0.06 | 0.08 | 34.90 | 1.03 | 0.05 | 96.40 |
| **mean** | **11.81** | **8.25** | **0.12** | **0.90** | **1.97** | **0.03** | **5.45** | **0.01** | **30.73** | **0.13** | **0.23** | **34.95** | **1.13** | **0.02** | **95.68** |
| **1σ** | **1.63** | **0.77** | **0.10** | **0.25** | **0.20** | **0.02** | **0.43** | **0.01** | **1.25** | **0.08** | **0.90** | **1.58** | **0.16** | **0.02** | **2.23** |

**Table 10.** WDS data for JFB-15-3-1.

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131 | 12.93 | 10.31 | 0.00 | 0.31 | 2.35 | 0.03 | 5.88 | 0.00 | 28.07 | 0.11 | 0.17 | 35.59 | 1.31 | 0.03 | 97.07 |
| 132 | 12.36 | 10.27 | 0.11 | 0.32 | 2.34 | 0.01 | 5.90 | 0.01 | 27.94 | 0.05 | 0.17 | 35.42 | 1.29 | 0.00 | 96.15 |

(**Table 10.** Continued)

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 133 | 12.09 | 9.66 | 0.00 | 0.30 | 2.45 | 0.02 | 6.02 | 0.00 | 28.75 | 0.07 | 0.19 | 36.46 | 1.25 | 0.00 | 97.24 |
| 134 | 13.06 | 11.41 | 0.16 | 0.31 | 2.40 | 0.03 | 5.17 | 0.00 | 27.57 | 0.09 | 0.15 | 35.64 | 1.44 | 0.03 | 97.39 |
| 139 | 12.14 | 9.87 | 0.19 | 0.34 | 2.32 | 0.04 | 6.13 | 0.00 | 27.97 | 0.20 | 0.16 | 35.17 | 1.05 | 0.02 | 95.51 |
| 140 | 12.92 | 10.12 | 0.09 | 0.49 | 2.31 | 0.00 | 6.18 | 0.00 | 27.82 | 0.11 | 0.17 | 34.69 | 1.08 | 0.02 | 95.95 |
| 144 | 11.02 | 10.07 | 0.28 | 0.60 | 2.15 | 0.01 | 5.88 | 0.00 | 25.73 | 0.07 | 0.17 | 34.05 | 1.04 | 0.02 | 90.99 |
| 145 | 11.07 | 9.98 | 0.23 | 0.58 | 2.37 | 0.00 | 6.20 | 0.00 | 26.49 | 0.20 | 0.17 | 35.60 | 1.08 | 0.03 | 93.90 |
| 146 | 6.44 | 6.01 | 0.19 | 0.43 | 1.24 | 0.02 | 3.64 | 0.01 | 16.72 | 0.16 | 0.09 | 58.90 | 0.68 | 0.00 | 94.44 |
| 147 | 9.17 | 9.91 | 0.10 | 0.57 | 2.25 | 0.03 | 5.86 | 0.01 | 27.41 | 0.10 | 0.17 | 34.85 | 1.06 | 0.03 | 91.48 |
| 149 | 11.20 | 9.40 | 0.00 | 0.71 | 2.14 | 0.03 | 6.48 | 0.00 | 28.47 | 0.02 | 0.18 | 35.63 | 0.91 | 0.04 | 95.21 |
| 150 | 10.57 | 8.59 | 0.10 | 1.19 | 1.75 | 0.05 | 6.66 | 0.00 | 29.65 | 0.04 | 0.15 | 35.28 | 0.78 | 0.01 | 94.77 |
| 151 | 12.35 | 9.39 | 0.00 | 0.52 | 2.17 | 0.02 | 6.45 | 0.02 | 28.88 | 0.23 | 0.17 | 36.09 | 0.97 | 0.00 | 97.25 |
| 153 | 12.81 | 10.64 | 0.29 | 0.33 | 2.31 | 0.04 | 5.85 | 0.00 | 27.96 | 0.20 | 0.17 | 35.40 | 1.20 | 0.02 | 97.10 |
| 154 | 12.07 | 11.46 | 0.06 | 0.29 | 2.42 | 0.03 | 5.61 | 0.00 | 27.75 | 0.00 | 0.15 | 34.75 | 1.38 | 0.03 | 95.98 |
| 155 | 12.49 | 10.87 | 0.02 | 0.30 | 2.27 | 0.00 | 5.67 | 0.00 | 27.96 | 0.03 | 0.16 | 35.12 | 1.36 | 0.01 | 96.27 |
| 156 | 12.73 | 11.55 | 0.06 | 0.24 | 2.34 | 0.01 | 5.16 | 0.00 | 27.71 | 0.00 | 0.12 | 35.29 | 1.25 | 0.01 | 96.43 |
| 157 | 13.08 | 11.44 | 0.41 | 0.29 | 2.44 | 0.05 | 5.20 | 0.01 | 27.14 | 0.24 | 0.14 | 34.79 | 1.24 | 0.01 | 96.30 |
| 159 | 11.51 | 10.52 | 0.12 | 0.29 | 2.35 | 0.02 | 5.36 | 0.00 | 27.77 | 0.10 | 0.14 | 34.54 | 1.26 | 0.04 | 93.98 |
| 160 | 12.42 | 10.66 | 0.06 | 0.35 | 2.48 | 0.03 | 5.50 | 0.00 | 27.86 | 0.10 | 0.15 | 34.90 | 1.25 | 0.00 | 95.70 |
| 161 | 11.45 | 9.14 | 0.06 | 0.76 | 2.08 | 0.04 | 6.70 | 0.00 | 28.85 | 0.17 | 0.19 | 35.33 | 0.90 | 0.03 | 95.68 |
| 162 | 10.51 | 10.42 | 0.24 | 0.41 | 2.47 | 0.05 | 4.92 | 0.00 | 26.75 | 0.11 | 0.16 | 33.35 | 1.18 | 0.01 | 90.47 |
| 163 | 11.29 | 9.58 | 0.29 | 0.45 | 2.13 | 0.03 | 6.00 | 0.02 | 26.39 | 0.11 | 0.16 | 32.31 | 1.05 | 0.01 | 89.70 |
| 164 | 11.03 | 10.65 | 0.00 | 0.41 | 2.29 | 0.02 | 5.85 | 0.01 | 28.09 | 0.00 | 0.16 | 35.43 | 1.21 | 0.03 | 95.17 |
| 165 | 11.92 | 10.66 | 0.19 | 0.35 | 2.35 | 0.02 | 5.81 | 0.00 | 28.00 | 0.15 | 0.17 | 35.46 | 1.18 | 0.03 | 96.23 |
| 170 | 10.96 | 8.62 | 0.12 | 1.27 | 1.76 | 0.00 | 6.57 | 0.01 | 28.60 | 0.17 | 0.14 | 34.66 | 0.80 | 0.03 | 93.63 |
| **mean** | **11.60** | **10.05** | **0.13** | **0.48** | **2.23** | **0.03** | **5.79** | **0.00** | **27.40** | **0.11** | **0.16** | **35.95** | **1.12** | **0.02** | **95.00** |
| **1σ** | **1.42** | **1.15** | **0.11** | **0.26** | **0.27** | **0.02** | **0.65** | **0.01** | **2.33** | **0.07** | **0.02** | **4.75** | **0.20** | **0.01** | **2.17** |

**Table 11.** WDS data for JFB-15-3-2.

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 171 | 11.78 | 11.94 | 0.31 | 1.28 | 1.78 | 0.04 | 4.92 | 0.01 | 28.80 | 0.00 | 0.17 | 34.40 | 1.01 | 0.05 | 96.35 |
| 173 | 11.31 | 12.64 | 0.23 | 1.46 | 1.53 | 0.04 | 4.66 | 0.00 | 28.55 | 0.07 | 0.17 | 34.28 | 0.97 | 0.03 | 95.85 |

(**Table 11.** Continued)

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 175 | 11.59 | 10.71 | 0.30 | 2.06 | 1.45 | 0.01 | 5.48 | 0.04 | 27.18 | 0.11 | 0.15 | 31.31 | 0.88 | 0.01 | 91.13 |
| 176 | 12.77 | 11.15 | 0.18 | 0.23 | 2.34 | 0.01 | 5.37 | 0.01 | 27.71 | 0.06 | 0.15 | 35.61 | 1.42 | 0.02 | 96.95 |
| 179 | 14.66 | 12.15 | 0.00 | 1.53 | 1.08 | 0.04 | 4.28 | 0.02 | 21.92 | 0.26 | 0.14 | 26.09 | 0.94 | 0.04 | 83.14 |
| 180 | 11.97 | 10.70 | 0.27 | 1.92 | 1.44 | 0.03 | 5.67 | 0.00 | 29.20 | 0.04 | 0.14 | 34.10 | 0.82 | 0.00 | 96.18 |
| 181 | 12.80 | 10.54 | 0.15 | 1.46 | 1.83 | 0.02 | 6.25 | 0.02 | 27.95 | 0.08 | 0.07 | 34.68 | 0.91 | 0.02 | 96.71 |
| 182 | 12.07 | 14.34 | 0.00 | 0.50 | 2.46 | 0.01 | 4.46 | 0.03 | 25.80 | 0.23 | 0.17 | 34.77 | 1.62 | 0.03 | 96.46 |
| 183 | 13.30 | 14.83 | 0.10 | 0.24 | 2.37 | 0.06 | 3.94 | 0.00 | 25.79 | 0.12 | 0.13 | 34.34 | 1.69 | 0.00 | 96.87 |
| 184 | 12.24 | 15.28 | 0.00 | 0.20 | 2.52 | 0.01 | 3.77 | 0.01 | 25.41 | 0.00 | 0.14 | 34.42 | 1.72 | 0.01 | 95.73 |
| 185 | 12.45 | 15.45 | 0.00 | 0.17 | 2.71 | 0.03 | 3.59 | 0.00 | 25.56 | 0.13 | 0.12 | 34.13 | 1.74 | 0.02 | 96.12 |
| 186 | 11.98 | 15.63 | 0.01 | 0.11 | 2.54 | 0.03 | 3.47 | 0.01 | 25.19 | 0.06 | 0.12 | 34.39 | 1.74 | 0.01 | 95.28 |
| 187 | 12.71 | 14.36 | 0.00 | 0.19 | 2.36 | 0.02 | 3.93 | 0.00 | 26.37 | 0.19 | 0.14 | 34.90 | 1.45 | 0.02 | 96.64 |
| 188 | 12.18 | 14.95 | 0.02 | 0.16 | 2.50 | 0.04 | 3.73 | 0.01 | 26.12 | 0.00 | 0.14 | 35.28 | 1.53 | 0.01 | 96.65 |
| 189 | 12.81 | 15.88 | 0.20 | 0.11 | 2.41 | 0.06 | 3.42 | 0.00 | 25.38 | 0.06 | 0.10 | 34.55 | 1.58 | 0.02 | 96.49 |
| 190 | 12.68 | 14.52 | 0.15 | 0.11 | 2.46 | 0.03 | 3.65 | 0.02 | 26.99 | 0.04 | 0.11 | 35.19 | 0.92 | 0.03 | 96.83 |
| 191 | 10.89 | 10.44 | 0.27 | 1.96 | 1.40 | 0.02 | 5.93 | 0.00 | 29.08 | 0.16 | 0.11 | 34.68 | 0.93 | 0.01 | 95.78 |
| 192 | 10.19 | 11.18 | 0.18 | 1.47 | 1.74 | 0.01 | 5.74 | 0.00 | 27.81 | 0.11 | 0.14 | 34.61 | 0.95 | 0.04 | 94.10 |
| 193 | 9.21 | 11.76 | 0.00 | 1.51 | 1.66 | 0.03 | 5.40 | 0.00 | 27.86 | 0.25 | 0.17 | 34.74 | 1.01 | 0.02 | 93.63 |
| 194 | 10.71 | 14.61 | 0.00 | 0.16 | 2.44 | 0.02 | 3.99 | 0.00 | 25.68 | 0.07 | 0.12 | 35.04 | 1.71 | 0.01 | 94.54 |
| 197 | 10.25 | 14.11 | 0.03 | 0.20 | 2.47 | 0.00 | 4.22 | 0.00 | 24.84 | 0.25 | 0.16 | 34.62 | 1.79 | 0.02 | 92.95 |
| 198 | 13.17 | 11.72 | 0.03 | 0.22 | 2.46 | 0.02 | 4.16 | 0.03 | 31.30 | 0.03 | 0.11 | 32.76 | 1.42 | 0.01 | 97.42 |
| 199 | 10.41 | 13.15 | 0.00 | 0.31 | 2.36 | 0.04 | 4.72 | 0.00 | 25.19 | 0.00 | 0.14 | 35.22 | 1.74 | 0.04 | 93.31 |
| 200 | 11.07 | 11.30 | 0.19 | 0.73 | 2.10 | 0.02 | 5.48 | 0.01 | 26.51 | 0.09 | 0.13 | 35.28 | 1.36 | 0.00 | 94.19 |
| 201 | 12.26 | 10.72 | 0.37 | 2.01 | 1.38 | 0.01 | 5.76 | 0.00 | 28.66 | 0.14 | 0.15 | 34.40 | 0.95 | 0.06 | 96.71 |
| 202 | 13.14 | 10.51 | 0.22 | 1.95 | 1.44 | 0.01 | 5.80 | 0.01 | 28.72 | 0.04 | 0.13 | 33.79 | 0.92 | 0.02 | 96.62 |
| 203 | 13.08 | 10.49 | 0.25 | 0.26 | 2.33 | 0.02 | 5.78 | 0.01 | 28.03 | 0.16 | 0.15 | 35.77 | 1.49 | 0.02 | 97.73 |
| 204 | 12.30 | 12.62 | 0.30 | 1.32 | 1.63 | 0.00 | 4.73 | 0.01 | 28.08 | 0.05 | 0.24 | 34.09 | 1.06 | 0.00 | 96.32 |
| 205 | 12.36 | 11.52 | 0.13 | 2.01 | 1.38 | 0.01 | 5.19 | 0.00 | 28.91 | 0.03 | 0.15 | 33.90 | 0.86 | 0.04 | 96.42 |
| 206 | 12.55 | 11.69 | 0.17 | 1.92 | 1.45 | 0.01 | 5.20 | 0.01 | 28.88 | 0.24 | 0.14 | 34.03 | 0.93 | 0.02 | 97.16 |
| 207 | 13.38 | 11.43 | 0.34 | 0.23 | 2.36 | 0.04 | 5.13 | 0.00 | 27.86 | 0.06 | 0.13 | 35.56 | 1.52 | 0.01 | 97.92 |
| 208 | 11.34 | 10.46 | 0.14 | 1.87 | 1.52 | 0.05 | 5.50 | 0.03 | 29.32 | 0.14 | 0.26 | 34.43 | 0.95 | 0.02 | 95.96 |
| 209 | 10.83 | 10.61 | 0.15 | 2.00 | 1.46 | 0.04 | 5.53 | 0.00 | 30.32 | 0.07 | 0.14 | 35.51 | 0.87 | 0.04 | 97.50 |

(**Table 11.** Continued)

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 210 | 13.53 | 10.69 | 0.21 | 2.10 | 1.35 | 0.05 | 5.69 | 0.01 | 29.33 | 0.22 | 0.12 | 33.86 | 0.91 | 0.03 | 98.02 |
| **mean** | **12.06** | **12.47** | **0.14** | **1.00** | **1.96** | **0.03** | **4.84** | **0.01** | **27.36** | **0.10** | **0.14** | **34.26** | **1.24** | **0.02** | **95.58** |
| **1σ** | **1.15** | **1.85** | **0.12** | **0.80** | **0.49** | **0.02** | **0.85** | **0.01** | **1.90** | **0.08** | **0.03** | **1.67** | **0.35** | **0.01** | **2.68** |

**Table 12.** WDS data for JFB-15-3-3.

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 211 | 13.29 | 13.24 | 0.21 | 0.25 | 2.43 | 0.02 | 4.99 | 0.00 | 26.73 | 0.00 | 0.12 | 35.54 | 1.60 | 0.00 | 98.34 |
| 212 | 12.20 | 11.17 | 0.10 | 0.28 | 2.38 | 0.03 | 5.63 | 0.00 | 27.50 | 0.04 | 0.11 | 35.84 | 1.59 | 0.02 | 96.86 |
| 213 | 12.26 | 11.49 | 0.03 | 0.31 | 2.21 | 0.04 | 5.17 | 0.00 | 27.02 | 0.08 | 0.12 | 34.43 | 1.62 | 0.02 | 94.79 |
| 216 | 13.49 | 10.55 | 0.00 | 0.45 | 2.23 | 0.01 | 5.84 | 0.01 | 27.79 | 0.14 | 0.12 | 35.45 | 1.48 | 0.03 | 97.60 |
| 217 | 10.62 | 10.31 | 0.20 | 1.95 | 1.36 | 0.04 | 5.10 | 0.00 | 27.16 | 0.06 | 0.11 | 31.66 | 0.92 | 0.02 | 89.43 |
| 218 | 11.86 | 11.03 | 0.12 | 0.68 | 2.09 | 0.02 | 5.73 | 0.00 | 27.78 | 0.21 | 0.14 | 35.78 | 1.47 | 0.04 | 96.89 |
| 219 | 12.98 | 10.21 | 0.03 | 2.06 | 1.38 | 0.02 | 6.00 | 0.00 | 29.41 | 0.17 | 0.14 | 34.48 | 0.91 | 0.02 | 97.78 |
| 220 | 13.35 | 10.09 | 0.38 | 2.13 | 1.31 | 0.04 | 6.02 | 0.00 | 29.57 | 0.08 | 0.13 | 34.31 | 0.87 | 0.02 | 98.13 |
| 221 | 11.90 | 10.31 | 0.29 | 2.06 | 1.42 | 0.01 | 6.06 | 0.00 | 29.33 | 0.00 | 0.13 | 34.14 | 0.93 | 0.02 | 96.49 |
| 222 | 11.77 | 11.55 | 0.08 | 1.62 | 1.94 | 0.05 | 6.39 | 0.00 | 28.15 | 0.17 | 0.12 | 35.29 | 1.00 | 0.04 | 98.12 |
| 223 | 11.21 | 11.34 | 0.04 | 1.60 | 1.76 | 0.06 | 5.97 | 0.01 | 27.62 | 0.10 | 0.14 | 34.01 | 1.00 | 0.02 | 94.88 |
| 224 | 8.45 | 10.39 | 0.01 | 1.58 | 1.60 | 0.05 | 5.29 | 0.02 | 30.72 | 0.21 | 0.23 | 32.62 | 0.87 | 0.00 | 92.04 |
| 225 | 11.77 | 11.27 | 0.30 | 1.61 | 1.77 | 0.02 | 6.23 | 0.00 | 27.95 | 0.17 | 0.14 | 34.86 | 0.97 | 0.02 | 96.99 |
| 226 | 10.69 | 11.33 | 0.11 | 1.56 | 1.83 | 0.06 | 6.33 | 0.00 | 28.98 | 0.11 | 0.13 | 34.64 | 1.04 | 0.01 | 96.79 |
| 228 | 12.96 | 10.06 | 0.08 | 1.99 | 1.36 | 0.05 | 5.92 | 0.01 | 29.21 | 0.05 | 0.15 | 33.84 | 0.85 | 0.00 | 96.49 |
| 229 | 10.66 | 10.15 | 0.00 | 2.00 | 1.31 | 0.05 | 5.90 | 0.01 | 29.80 | 0.21 | 0.13 | 34.06 | 0.90 | 0.01 | 95.18 |
| 230 | 12.43 | 10.16 | 0.17 | 1.94 | 1.42 | 0.04 | 5.97 | 0.00 | 29.45 | 0.06 | 0.12 | 34.20 | 0.88 | 0.04 | 96.81 |
| 231 | 12.54 | 10.46 | 0.16 | 1.63 | 1.70 | 0.03 | 6.32 | 0.00 | 28.33 | 0.04 | 0.15 | 34.87 | 1.04 | 0.03 | 97.22 |
| 234 | 11.82 | 10.96 | 0.14 | 1.79 | 1.53 | 0.04 | 6.04 | 0.00 | 28.59 | 0.14 | 0.16 | 34.83 | 0.96 | 0.01 | 96.94 |
| 235 | 13.16 | 11.22 | 0.00 | 0.66 | 2.18 | 0.02 | 5.76 | 0.01 | 27.57 | 0.17 | 0.13 | 35.60 | 1.47 | 0.01 | 97.95 |
| 236 | 6.65 | 9.10 | 0.13 | 1.06 | 1.66 | 0.00 | 3.65 | 0.06 | 27.57 | 0.07 | 0.18 | 27.23 | 1.21 | 0.02 | 78.50 |
| 237 | 12.76 | 10.62 | 0.13 | 0.47 | 2.33 | 0.02 | 5.80 | 0.00 | 28.06 | 0.15 | 0.12 | 35.70 | 1.50 | 0.05 | 97.65 |
| 238 | 11.53 | 10.84 | 0.14 | 2.09 | 1.38 | 0.04 | 5.55 | 0.02 | 29.30 | 0.10 | 0.15 | 33.28 | 0.91 | 0.03 | 95.30 |
| 239 | 2.09 | 3.68 | 0.08 | 3.11 | 0.15 | 0.00 | 2.30 | 0.05 | 46.06 | 0.23 | 0.54 | 20.31 | 0.16 | 0.01 | 78.74 |
| 240 | 12.86 | 10.80 | 0.26 | 2.07 | 1.34 | 0.05 | 5.81 | 0.01 | 29.20 | 0.09 | 0.15 | 34.47 | 0.95 | 0.02 | 97.96 |

(**Table 12.** Continued)

| Line | $B_2O_3$ | FeO | F | CaO | $Na_2O$ | MnO | MgO | Cl | $Al_2O_3$ | ZnO | $K_2O$ | $SiO_2$ | $TiO_2$ | $Cr_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 241 | 13.13 | 10.20 | 0.37 | 2.15 | 1.43 | 0.02 | 6.20 | 0.01 | 29.57 | 0.16 | 0.13 | 34.62 | 0.87 | 0.03 | 98.72 |
| 242 | 9.40 | 11.34 | 0.15 | 1.01 | 2.14 | 0.00 | 5.30 | 0.00 | 28.00 | 0.12 | 0.14 | 35.11 | 1.21 | 0.01 | 93.90 |
| 244 | 10.71 | 10.84 | 0.33 | 2.08 | 1.46 | 0.03 | 5.85 | 0.01 | 29.87 | 0.24 | 0.15 | 33.64 | 0.94 | 0.02 | 96.01 |
| 246 | 11.76 | 12.98 | 0.19 | 0.76 | 2.39 | 0.01 | 5.61 | 0.00 | 26.57 | 0.11 | 0.13 | 35.28 | 1.39 | 0.01 | 97.10 |
| 247 | 11.61 | 11.45 | 0.22 | 1.01 | 2.44 | 0.03 | 6.67 | 0.00 | 28.67 | 0.22 | 0.12 | 37.32 | 1.11 | 0.00 | 100.79 |
| 248 | 13.04 | 11.46 | 0.12 | 0.82 | 2.04 | 0.00 | 5.86 | 0.00 | 27.27 | 0.21 | 0.15 | 35.01 | 1.42 | 0.04 | 97.40 |
| 250 | 12.97 | 10.35 | 0.18 | 2.06 | 1.33 | 0.02 | 5.90 | 0.01 | 29.37 | 0.01 | 0.11 | 33.97 | 0.86 | 0.02 | 97.06 |
| **mean** | **11.50** | **10.65** | **0.15** | **1.46** | **1.73** | **0.03** | **5.66** | **0.01** | **29.00** | **0.12** | **0.15** | **33.95** | **1.09** | **0.02** | **95.46** |
| **1σ** | **2.28** | **1.51** | **0.11** | **0.72** | **0.49** | **0.02** | **0.82** | **0.01** | **3.28** | **0.07** | **0.07** | **2.99** | **0.31** | **0.01** | **4.87** |

## APPENDIX C

**Table 13.** Calculated mineral formulae for JFB-15-1-1.

| Line | | 11 | 13 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 5.94 | 6.05 | 6.04 | 6.00 | 6.00 | 6.02 | 5.99 | 5.91 | 5.87 | 5.94 | 6.03 | 6.06 | 6.03 | 6.07 | 5.87 |
| | **Al** | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.09 | 0.13 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.13 |
| | **B** | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 5.83 | 5.67 | 5.40 | 5.79 | 5.44 | 5.49 | 5.82 | 6.00 | 6.00 | 5.96 | 5.43 | 5.41 | 5.42 | 5.35 | 6.00 |
| | **Mg** | 0.17 | 0.33 | 0.60 | 0.22 | 0.56 | 0.51 | 0.18 | 0.00 | 0.00 | 0.05 | 0.57 | 0.59 | 0.58 | 0.65 | 0.00 |
| **Y:** | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| | **Ti** | 0.16 | 0.26 | 0.36 | 0.31 | 0.35 | 0.30 | 0.15 | 0.16 | 0.15 | 0.16 | 0.39 | 0.34 | 0.34 | 0.33 | 0.15 |
| | **Cr** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Mg** | 1.39 | 0.89 | 0.58 | 0.53 | 0.54 | 0.71 | 1.34 | 1.45 | 1.49 | 1.44 | 0.60 | 0.58 | 0.54 | 0.47 | 1.49 |
| | **Mn** | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 |
| | **$Fe^{2+}$** | 1.23 | 1.54 | 1.92 | 1.55 | 1.98 | 1.77 | 1.34 | 1.10 | 1.10 | 1.16 | 1.73 | 1.77 | 1.85 | 1.88 | 1.10 |
| | **Zn** | 0.01 | 0.01 | 0.01 | 0.04 | 0.01 | 0.02 | 0.01 | 0.02 | 0.01 | 0.00 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |
| | **Li*** | 0.21 | 0.29 | 0.12 | 0.56 | 0.12 | 0.19 | 0.17 | 0.28 | 0.23 | 0.24 | 0.25 | 0.29 | 0.26 | 0.31 | 0.23 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.20 | 0.03 | 0.01 | 0.08 | 0.02 | 0.02 | 0.11 | 0.20 | 0.20 | 0.17 | 0.02 | 0.02 | 0.02 | 0.02 | 0.20 |
| | **Na** | 0.70 | 0.81 | 0.78 | 0.96 | 0.90 | 0.96 | 0.80 | 0.64 | 0.64 | 0.67 | 0.87 | 0.90 | 0.97 | 0.96 | 0.64 |
| | **K** | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.03 | 0.02 | 0.03 | 0.03 | 0.01 |
| | **r** | 0.08 | 0.13 | 0.17 | 0.00 | 0.05 | 0.00 | 0.07 | 0.15 | 0.15 | 0.15 | 0.08 | 0.06 | 0.00 | 0.00 | 0.15 |
| | **OH** | 3.90 | 3.91 | 3.90 | 4.00 | 3.94 | 3.91 | 3.86 | 3.87 | 3.94 | 3.86 | 3.94 | 3.96 | 3.95 | 3.92 | 3.94 |
| | **F** | 0.10 | 0.09 | 0.10 | 0.00 | 0.06 | 0.09 | 0.14 | 0.13 | 0.06 | 0.14 | 0.06 | 0.04 | 0.05 | 0.08 | 0.06 |
| | **Cl** | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Dravite | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Dravite | Dravite | Dravite | Schorl | Schorl | Schorl | Schorl | Dravite |

(**Table 13.** Continued.)

| Line | | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 35 | 36 | 39 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 5.87 | 5.94 | 6.03 | 6.06 | 6.03 | 6.07 | 6.05 | 6.02 | 6.05 | 6.00 | 6.06 | 5.88 | 5.59 | 5.89 | 3.66 |
| | **Al** | 0.13 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.12 | 0.41 | 0.11 | 2.34 |
| | **B** | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 6.00 | 5.96 | 5.43 | 5.41 | 5.42 | 5.35 | 5.43 | 5.69 | 5.78 | 5.68 | 5.37 | 5.83 | 6.00 | 5.91 | 6.00 |
| | **Mg** | 0.00 | 0.05 | 0.57 | 0.59 | 0.58 | 0.65 | 0.57 | 0.31 | 0.22 | 0.32 | 0.63 | 0.17 | 0.00 | 0.10 | 0.00 |
| **Y:** | **Al** | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.51 |
| | **Ti** | 0.15 | 0.16 | 0.39 | 0.34 | 0.34 | 0.33 | 0.32 | 0.27 | 0.18 | 0.26 | 0.33 | 0.21 | 0.20 | 0.20 | 0.28 |
| | **Cr** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| | **Mg** | 1.49 | 1.44 | 0.60 | 0.58 | 0.54 | 0.47 | 0.59 | 1.04 | 1.18 | 0.91 | 0.47 | 0.94 | 1.02 | 1.23 | 1.06 |
| | **Mn** | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 |
| | **$Fe^{2+}$** | 1.10 | 1.16 | 1.73 | 1.77 | 1.85 | 1.88 | 1.80 | 1.42 | 1.38 | 1.63 | 1.89 | 1.70 | 1.49 | 1.31 | 1.89 |
| | **Zn** | 0.01 | 0.00 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.01 | 0.00 | 0.01 | 0.01 | 0.03 | 0.04 | 0.03 |
| | **Li*** | 0.23 | 0.24 | 0.25 | 0.29 | 0.26 | 0.31 | 0.26 | 0.23 | 0.26 | 0.20 | 0.30 | 0.14 | 0.19 | 0.21 | 0.00 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.78 |
| **X:** | **Ca** | 0.20 | 0.17 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.06 | 0.13 | 0.02 | 0.02 | 0.21 | 0.16 | 0.08 |
| | **Na** | 0.64 | 0.67 | 0.87 | 0.90 | 0.97 | 0.96 | 0.95 | 0.82 | 0.81 | 0.71 | 1.00 | 0.95 | 0.68 | 0.67 | 0.52 |
| | **K** | 0.01 | 0.02 | 0.03 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.04 | 0.03 | 0.02 | 0.03 | 0.03 | 0.02 |
| | **r** | 0.15 | 0.15 | 0.08 | 0.06 | 0.00 | 0.00 | 0.02 | 0.12 | 0.11 | 0.13 | 0.00 | 0.01 | 0.08 | 0.14 | 0.37 |
| | **OH** | 3.94 | 3.86 | 3.94 | 3.96 | 3.95 | 3.92 | 3.92 | 3.99 | 3.95 | 3.97 | 4.00 | 3.90 | 4.00 | 3.83 | 3.92 |
| | **F** | 0.06 | 0.14 | 0.06 | 0.04 | 0.05 | 0.08 | 0.08 | 0.01 | 0.05 | 0.03 | 0.00 | 0.10 | 0.00 | 0.17 | 0.07 |
| | **Cl** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 |
| **Mineral Name** | | Dravite | Dravite | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl |

(**Table 13.** Continued.)

| Line | | 40 | 41 | 43 | 44 | 45 | 46 | 48 | 49 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 6.05 | 6.04 | 6.03 | 6.06 | 4.94 | 6.05 | 6.06 | 6.06 | 6.08 |
| | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 1.06 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **B** | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 5.73 | 5.70 | 5.42 | 5.45 | 6.00 | 5.36 | 5.38 | 5.30 | 5.36 |
| | **Mg** | 0.27 | 0.30 | 0.58 | 0.55 | 0.00 | 0.64 | 0.62 | 0.70 | 0.64 |
| **Y:** | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Ti** | 0.18 | 0.21 | 0.33 | 0.32 | 0.26 | 0.35 | 0.34 | 0.35 | 0.33 |
| | **Cr** | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| | **Mg** | 0.92 | 1.14 | 0.60 | 0.63 | 0.99 | 0.42 | 0.49 | 0.40 | 0.51 |
| | **Mn** | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| | **$Fe^{2+}$** | 1.69 | 1.41 | 1.83 | 1.78 | 1.65 | 1.96 | 1.89 | 1.95 | 1.85 |
| | **Zn** | 0.02 | 0.01 | 0.02 | 0.01 | 0.03 | 0.00 | 0.02 | 0.02 | 0.01 |
| | **Li*** | 0.18 | 0.23 | 0.22 | 0.26 | 0.00 | 0.26 | 0.26 | 0.28 | 0.28 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.10 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.01 | 0.06 | 0.02 | 0.01 | 0.21 | 0.02 | 0.02 | 0.01 | 0.01 |
| | **Na** | 0.87 | 0.84 | 0.95 | 0.88 | 0.73 | 0.94 | 0.90 | 0.99 | 0.90 |
| | **K** | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 |
| | **r** | 0.10 | 0.09 | 0.00 | 0.08 | 0.04 | 0.02 | 0.06 | 0.00 | 0.06 |
| | **OH** | 3.90 | 3.96 | 3.98 | 3.94 | 3.92 | 3.94 | 4.00 | 3.87 | 3.99 |
| | **F** | 0.10 | 0.04 | 0.02 | 0.06 | 0.07 | 0.06 | 0.00 | 0.13 | 0.01 |
| | **Cl** | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl |

**Table 14.** Calculated mineral formulae for JFB-15-2-1.

| Line | | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 5.89 | 5.94 | 6.05 | 6.03 | 6.03 | 6.02 | 6.03 | 6.09 | 6.05 | 5.99 | 5.92 | 6.08 | 6.05 | 6.03 | 6.00 |
| | **Al** | 0.11 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 |
| **B** | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 6.00 | 5.97 | 5.42 | 5.44 | 5.45 | 5.47 | 5.50 | 5.31 | 5.58 | 6.00 | 6.00 | 5.81 | 5.86 | 5.87 | 5.97 |
| | **Mg** | 0.00 | 0.04 | 0.58 | 0.56 | 0.55 | 0.53 | 0.50 | 0.69 | 0.42 | 0.00 | 0.00 | 0.19 | 0.14 | 0.14 | 0.03 |
| **Y:** | **Al** | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Ti** | 0.14 | 0.16 | 0.31 | 0.32 | 0.33 | 0.32 | 0.32 | 0.30 | 0.26 | 0.16 | 0.15 | 0.20 | 0.19 | 0.19 | 0.15 |
| | **Cr** | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Mg** | 1.27 | 1.27 | 0.55 | 0.53 | 0.55 | 0.57 | 0.69 | 0.40 | 0.77 | 1.26 | 1.24 | 0.79 | 1.14 | 1.14 | 1.23 |
| | **Mn** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| | **$Fe^{2+}$** | 1.24 | 1.36 | 1.91 | 1.94 | 1.90 | 1.90 | 1.74 | 1.99 | 1.73 | 1.36 | 1.29 | 1.50 | 1.37 | 1.39 | 1.39 |
| | **Zn** | 0.01 | 0.01 | 0.02 | 0.04 | 0.03 | 0.00 | 0.03 | 0.02 | 0.00 | 0.02 | 0.00 | 0.00 | 0.01 | 0.03 | 0.02 |
| | **Li*** | 0.24 | 0.20 | 0.22 | 0.18 | 0.19 | 0.20 | 0.21 | 0.29 | 0.24 | 0.19 | 0.25 | 0.50 | 0.30 | 0.25 | 0.21 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.14 | 0.12 | 0.02 | 0.06 | 0.06 | 0.08 | 0.04 | 0.02 | 0.03 | 0.08 | 0.13 | 0.18 | 0.05 | 0.05 | 0.09 |
| | **Na** | 0.68 | 0.72 | 0.92 | 0.85 | 0.83 | 0.81 | 0.81 | 0.94 | 0.87 | 0.72 | 0.69 | 0.59 | 0.76 | 0.76 | 0.73 |
| | **K** | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 |
| | **r** | 0.17 | 0.15 | 0.04 | 0.07 | 0.09 | 0.09 | 0.12 | 0.02 | 0.08 | 0.19 | 0.17 | 0.21 | 0.17 | 0.17 | 0.16 |
| **OH** | | 3.95 | 3.90 | 3.94 | 3.92 | 3.85 | 3.95 | 4.00 | 3.81 | 4.00 | 4.00 | 3.96 | 3.99 | 3.92 | 4.00 | 3.87 |
| **F** | | 0.05 | 0.10 | 0.06 | 0.08 | 0.15 | 0.05 | 0.00 | 0.19 | 0.00 | 0.00 | 0.04 | 0.01 | 0.08 | 0.00 | 0.13 |
| **Cl** | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Dravite | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl |

(**Table 14.** Continued.)

| Line | | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 6.03 | 6.02 | 6.01 | 6.00 | 5.89 | 6.01 | 5.87 | 5.87 | 5.92 | 5.95 | 5.89 | 5.94 | 5.92 | 5.95 | 5.88 |
| | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.00 | 0.13 | 0.13 | 0.08 | 0.05 | 0.11 | 0.06 | 0.08 | 0.05 | 0.12 |
| | **B** | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 5.83 | 5.90 | 5.95 | 5.95 | 6.00 | 5.91 | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 | 5.98 | 6.00 |
| | **Mg** | 0.17 | 0.10 | 0.05 | 0.05 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 |
| **Y:** | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.12 | 0.11 | 0.05 | 0.04 | 0.06 | 0.10 | 0.04 | 0.00 | 0.15 |
| | **Ti** | 0.19 | 0.17 | 0.14 | 0.15 | 0.13 | 0.16 | 0.14 | 0.14 | 0.15 | 0.15 | 0.15 | 0.13 | 0.14 | 0.15 | 0.13 |
| | **Cr** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Mg** | 1.09 | 1.21 | 1.18 | 1.23 | 1.27 | 1.25 | 1.24 | 1.24 | 1.26 | 1.24 | 1.24 | 1.16 | 1.25 | 1.26 | 1.21 |
| | **Mn** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 |
| | **$Fe^{2+}$** | 1.48 | 1.40 | 1.41 | 1.40 | 1.26 | 1.38 | 1.23 | 1.25 | 1.28 | 1.30 | 1.31 | 1.24 | 1.31 | 1.35 | 1.25 |
| | **Zn** | 0.01 | 0.00 | 0.01 | 0.01 | 0.02 | 0.01 | 0.02 | 0.00 | 0.01 | 0.01 | 0.03 | 0.02 | 0.03 | 0.02 | 0.01 |
| | **Li*** | 0.23 | 0.23 | 0.26 | 0.20 | 0.21 | 0.21 | 0.24 | 0.26 | 0.25 | 0.27 | 0.21 | 0.35 | 0.23 | 0.21 | 0.24 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.06 | 0.09 | 0.09 | 0.09 | 0.15 | 0.09 | 0.15 | 0.16 | 0.14 | 0.14 | 0.16 | 0.16 | 0.14 | 0.11 | 0.15 |
| | **Na** | 0.77 | 0.72 | 0.76 | 0.74 | 0.65 | 0.75 | 0.64 | 0.66 | 0.68 | 0.69 | 0.62 | 0.69 | 0.67 | 0.74 | 0.64 |
| | **K** | 0.02 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.01 | 0.03 | 0.02 | 0.01 | 0.02 |
| | **r** | 0.16 | 0.18 | 0.13 | 0.16 | 0.19 | 0.15 | 0.19 | 0.16 | 0.16 | 0.15 | 0.21 | 0.12 | 0.17 | 0.14 | 0.20 |
| | **OH** | 3.98 | 3.84 | 3.83 | 4.00 | 3.88 | 3.95 | 3.88 | 3.86 | 3.92 | 3.88 | 3.89 | 3.98 | 3.84 | 3.95 | 3.95 |
| | **F** | 0.02 | 0.16 | 0.17 | 0.00 | 0.12 | 0.05 | 0.12 | 0.14 | 0.08 | 0.12 | 0.11 | 0.01 | 0.16 | 0.05 | 0.05 |
| | **Cl** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Schorl | Schorl | Schorl | Schorl | Dravite | Schorl | Dravite | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl |

(**Table 14.** Continued.)

| Line | | 81 | 82 | 83 | 85 | 88 | 89 | 90 |
|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 5.91 | 5.97 | 5.97 | 5.97 | 5.65 | 5.60 | 5.68 |
| | **Al** | 0.09 | 0.03 | 0.03 | 0.03 | 0.35 | 0.40 | 0.32 |
| | **B** | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 6.00 | 5.82 | 5.88 | 5.79 | 6.00 | 6.00 | 6.00 |
| | **Mg** | 0.00 | 0.18 | 0.12 | 0.21 | 0.00 | 0.00 | 0.00 |
| **Y:** | **Al** | 0.10 | 0.00 | 0.00 | 0.00 | 0.09 | 0.08 | 0.09 |
| | **Ti** | 0.13 | 0.22 | 0.19 | 0.23 | 0.14 | 0.15 | 0.14 |
| | **Cr** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| | **Mg** | 1.23 | 1.02 | 1.07 | 1.00 | 1.33 | 1.39 | 1.35 |
| | **Mn** | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **$Fe^{2+}$** | 1.27 | 1.51 | 1.49 | 1.54 | 1.36 | 1.34 | 1.33 |
| | **Zn** | 0.00 | 0.02 | 0.00 | 0.01 | 0.01 | 0.03 | 0.00 |
| | **Li*** | 0.25 | 0.22 | 0.24 | 0.22 | 0.06 | 0.02 | 0.08 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.16 | 0.13 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| | **Na** | 0.63 | 0.69 | 0.70 | 0.68 | 0.71 | 0.73 | 0.71 |
| | **K** | 0.02 | 0.04 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| | **r** | 0.19 | 0.14 | 0.13 | 0.15 | 0.12 | 0.10 | 0.13 |
| | **OH** | 3.95 | 3.92 | 3.92 | 3.93 | 3.95 | 4.00 | 3.98 |
| | **F** | 0.05 | 0.08 | 0.08 | 0.07 | 0.05 | 0.00 | 0.02 |
| | **Cl** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Schorl | Schorl | Schorl | Schorl | Schorl | Dravite | Dravite |

**Table 15.** Calculated mineral formulae for JFB-15-2-2.

| Line | | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 101 | 102 | 103 | 105 | 106 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 5.95 | 5.85 | 5.89 | 6.06 | 5.29 | 5.97 | 5.94 | 5.71 | 5.87 | 5.88 | 5.92 | 6.00 | 5.96 | 5.95 |
| | **Al** | 0.06 | 0.15 | 0.11 | 0.00 | 0.71 | 0.03 | 0.06 | 0.29 | 0.13 | 0.12 | 0.08 | 0.00 | 0.04 | 0.05 |
| **B** | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 5.93 | 6.00 | 6.00 | 5.76 | 6.00 | 5.93 | 5.97 | 6.00 | 6.00 | 6.00 | 5.93 | 6.00 | 5.95 | 6.00 |
| | **Mg** | 0.08 | 0.00 | 0.00 | 0.24 | 0.00 | 0.07 | 0.03 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.05 | 0.00 |
| **Y:** | **Al** | 0.00 | 0.09 | 0.05 | 0.00 | 0.54 | 0.00 | 0.00 | 0.17 | 0.06 | 0.09 | 0.00 | 0.03 | 0.00 | 0.00 |
| | **Ti** | 0.15 | 0.14 | 0.13 | 0.16 | 0.12 | 0.16 | 0.16 | 0.14 | 0.14 | 0.12 | 0.17 | 0.15 | 0.16 | 0.15 |
| | **Cr** | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Mg** | 1.40 | 1.41 | 1.44 | 1.22 | 1.19 | 1.42 | 1.35 | 1.29 | 1.40 | 1.42 | 1.34 | 1.38 | 1.41 | 1.42 |
| | **Mn** | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 |
| | **$Fe^{2+}$** | 1.23 | 1.11 | 1.15 | 1.25 | 1.01 | 1.22 | 1.26 | 1.24 | 1.17 | 1.13 | 1.30 | 1.16 | 1.20 | 1.17 |
| | **Zn** | 0.02 | 0.01 | 0.03 | 0.02 | 0.01 | 0.03 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.00 | 0.02 | 0.00 |
| | **Li*** | 0.19 | 0.23 | 0.19 | 0.33 | 0.12 | 0.16 | 0.21 | 0.15 | 0.23 | 0.22 | 0.17 | 0.27 | 0.21 | 0.25 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.14 | 0.19 | 0.16 | 0.14 | 0.24 | 0.11 | 0.13 | 0.17 | 0.19 | 0.18 | 0.15 | 0.10 | 0.15 | 0.15 |
| | **Na** | 0.73 | 0.61 | 0.65 | 0.70 | 0.54 | 0.72 | 0.70 | 0.63 | 0.62 | 0.61 | 0.68 | 0.71 | 0.68 | 0.68 |
| | **K** | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 |
| | **r** | 0.12 | 0.18 | 0.17 | 0.14 | 0.20 | 0.16 | 0.16 | 0.19 | 0.17 | 0.19 | 0.16 | 0.17 | 0.16 | 0.16 |
| **OH** | | 3.90 | 3.92 | 3.92 | 4.00 | 3.95 | 3.86 | 3.90 | 3.98 | 3.91 | 3.98 | 3.83 | 3.92 | 3.94 | 4.00 |
| **F** | | 0.10 | 0.08 | 0.08 | 0.00 | 0.05 | 0.14 | 0.10 | 0.02 | 0.09 | 0.01 | 0.17 | 0.08 | 0.07 | 0.00 |
| **Cl** | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Dravite | Dravite | Dravite | Schorl | Dravite | Dravite | Dravite | Dravite | Dravite | Dravite | Dravite | Dravite | Dravite | Dravite |

(**Table 15.** Continued.)

| Line | | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 119 | 120 | 121 | 122 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 5.88 | 5.76 | 5.91 | 5.89 | 5.95 | 5.99 | 5.91 | 6.00 | 6.02 | 5.94 | 5.95 | 5.87 | 5.93 | 5.81 |
| | **Al** | 0.12 | 0.24 | 0.09 | 0.11 | 0.05 | 0.01 | 0.09 | 0.00 | 0.00 | 0.06 | 0.05 | 0.13 | 0.07 | 0.19 |
| **B** | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 6.00 | 6.00 | 6.00 | 6.00 | 5.97 | 5.96 | 6.00 | 5.94 | 5.94 | 5.96 | 5.93 | 6.00 | 6.00 | 6.00 |
| | **Mg** | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.04 | 0.00 | 0.07 | 0.06 | 0.04 | 0.07 | 0.00 | 0.00 | 0.00 |
| **Y:** | **Al** | 0.08 | 0.09 | 0.09 | 0.08 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.03 | 0.07 |
| | **Ti** | 0.12 | 0.12 | 0.12 | 0.13 | 0.16 | 0.16 | 0.16 | 0.18 | 0.17 | 0.16 | 0.17 | 0.13 | 0.15 | 0.14 |
| | **Cr** | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| | **Mg** | 1.44 | 1.37 | 1.42 | 1.43 | 1.38 | 1.33 | 1.36 | 1.29 | 1.34 | 1.34 | 1.35 | 1.42 | 1.36 | 1.39 |
| | **Mn** | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 |
| | **$Fe^{2+}$** | 1.10 | 1.07 | 1.11 | 1.11 | 1.20 | 1.26 | 1.19 | 1.29 | 1.23 | 1.25 | 1.26 | 1.14 | 1.23 | 1.17 |
| | **Zn** | 0.02 | 0.00 | 0.01 | 0.02 | 0.02 | 0.00 | 0.02 | 0.02 | 0.02 | 0.02 | 0.04 | 0.02 | 0.02 | 0.03 |
| | **Li*** | 0.23 | 0.33 | 0.23 | 0.23 | 0.25 | 0.24 | 0.24 | 0.21 | 0.24 | 0.22 | 0.19 | 0.22 | 0.21 | 0.19 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.19 | 0.31 | 0.17 | 0.19 | 0.16 | 0.13 | 0.16 | 0.06 | 0.06 | 0.16 | 0.14 | 0.19 | 0.14 | 0.20 |
| | **Na** | 0.63 | 0.60 | 0.64 | 0.61 | 0.67 | 0.69 | 0.65 | 0.76 | 0.73 | 0.66 | 0.68 | 0.62 | 0.66 | 0.61 |
| | **K** | 0.01 | 0.02 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 |
| | **r** | 0.17 | 0.07 | 0.19 | 0.19 | 0.15 | 0.17 | 0.17 | 0.16 | 0.19 | 0.16 | 0.17 | 0.18 | 0.19 | 0.18 |
| **OH** | | 3.98 | 3.99 | 3.86 | 3.82 | 4.00 | 3.96 | 3.81 | 3.90 | 3.88 | 3.98 | 3.99 | 3.96 | 3.95 | 3.84 |
| **F** | | 0.02 | 0.01 | 0.14 | 0.18 | 0.00 | 0.04 | 0.19 | 0.10 | 0.12 | 0.02 | 0.01 | 0.04 | 0.05 | 0.15 |
| **Cl** | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Dravite | Dravite | Dravite | Dravite | Dravite | Dravite | Dravite | Schorl | Dravite | Dravite | Dravite | Dravite | Dravite | Dravite |

(**Table 15.** Continued.)

| Line | | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 |
|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 5.76 | 5.82 | 6.61 | 5.96 | 5.95 | 5.72 | 5.82 | 5.88 |
| | **Al** | 0.24 | 0.18 | 0.00 | 0.04 | 0.05 | 0.28 | 0.19 | 0.12 |
| **B** | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 6.00 | 6.00 | 5.06 | 5.96 | 5.95 | 6.00 | 6.00 | 6.00 |
| | **Mg** | 0.00 | 0.00 | 0.81 | 0.04 | 0.05 | 0.00 | 0.00 | 0.00 |
| **Y:** | **Al** | 0.18 | 0.15 | 0.00 | 0.00 | 0.00 | 0.17 | 0.08 | 0.08 |
| | **Ti** | 0.13 | 0.12 | 0.07 | 0.16 | 0.16 | 0.13 | 0.13 | 0.13 |
| | **Cr** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| | **Mg** | 1.32 | 1.32 | 0.00 | 1.35 | 1.32 | 1.32 | 1.37 | 1.39 |
| | **Mn** | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 |
| | **$Fe^{2+}$** | 1.11 | 1.11 | 0.63 | 1.26 | 1.27 | 1.17 | 1.15 | 1.13 |
| | **Zn** | 0.01 | 0.04 | 0.02 | 0.01 | 0.00 | 0.03 | 0.03 | 0.01 |
| | **Li*** | 0.23 | 0.25 | 2.41 | 0.23 | 0.24 | 0.17 | 0.24 | 0.24 |
| | **∑Y** | 3.00 | 3.00 | 3.14 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.21 | 0.20 | 0.13 | 0.14 | 0.14 | 0.21 | 0.19 | 0.19 |
| | **Na** | 0.59 | 0.62 | 0.39 | 0.69 | 0.72 | 0.59 | 0.66 | 0.63 |
| | **K** | 0.02 | 0.02 | 1.10 | 0.02 | 0.02 | 0.01 | 0.03 | 0.02 |
| | **r** | 0.18 | 0.16 | 0.00 | 0.15 | 0.12 | 0.19 | 0.12 | 0.17 |
| **OH** | | 3.96 | 3.91 | 3.95 | 3.97 | 3.95 | 3.92 | 3.98 | 4.00 |
| **F** | | 0.04 | 0.09 | 0.04 | 0.03 | 0.05 | 0.08 | 0.00 | 0.00 |
| **Cl** | | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 |
| **Mineral Name** | | Dravite | Dravite | Elbaite | Dravite | Dravite | Dravite | Dravite | Dravite |

**Table 16.** Calculated mineral formulae for JFB-15-3-1.

| Line | | 131 | 132 | 133 | 134 | 139 | 140 | 144 | 145 | 146 | 147 | 149 | 150 | 151 | 153 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 6.07 | 6.07 | 6.10 | 6.10 | 6.06 | 6.03 | 6.13 | 6.16 | 8.11 | 6.08 | 6.06 | 5.97 | 6.07 | 6.07 |
| | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 |
| **B** | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 5.65 | 5.65 | 5.67 | 5.56 | 5.68 | 5.69 | 5.46 | 5.40 | 2.71 | 5.63 | 5.71 | 5.89 | 5.73 | 5.65 |
| | **Mg** | 0.35 | 0.36 | 0.33 | 0.44 | 0.32 | 0.31 | 0.54 | 0.60 | 0.75 | 0.37 | 0.29 | 0.11 | 0.28 | 0.35 |
| **Y:** | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Ti** | 0.17 | 0.17 | 0.16 | 0.19 | 0.14 | 0.14 | 0.14 | 0.14 | 0.07 | 0.14 | 0.12 | 0.10 | 0.12 | 0.15 |
| | **Cr** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| | **Mg** | 1.14 | 1.15 | 1.17 | 0.88 | 1.26 | 1.29 | 1.04 | 1.00 | 0.00 | 1.16 | 1.35 | 1.57 | 1.34 | 1.14 |
| | **Mn** | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 |
| | **$Fe^{2+}$** | 1.47 | 1.47 | 1.35 | 1.63 | 1.42 | 1.47 | 1.52 | 1.45 | 0.69 | 1.45 | 1.34 | 1.22 | 1.32 | 1.53 |
| | **Zn** | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.03 | 0.02 | 0.01 | 0.00 | 0.01 | 0.03 | 0.03 |
| | **Li*** | 0.20 | 0.20 | 0.31 | 0.28 | 0.15 | 0.08 | 0.29 | 0.38 | 4.76 | 0.24 | 0.18 | 0.10 | 0.18 | 0.15 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 5.54 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.06 | 0.06 | 0.05 | 0.06 | 0.06 | 0.09 | 0.12 | 0.11 | 0.06 | 0.11 | 0.13 | 0.22 | 0.09 | 0.06 |
| | **Na** | 0.78 | 0.78 | 0.79 | 0.80 | 0.77 | 0.78 | 0.75 | 0.80 | 0.33 | 0.76 | 0.71 | 0.57 | 0.71 | 0.77 |
| | **K** | 0.04 | 0.04 | 0.04 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | 0.02 | 0.04 | 0.04 | 0.03 | 0.04 | 0.04 |
| | **r** | 0.13 | 0.12 | 0.11 | 0.11 | 0.13 | 0.09 | 0.10 | 0.06 | 0.59 | 0.09 | 0.13 | 0.18 | 0.16 | 0.13 |
| **OH** | | 4.00 | 3.94 | 4.00 | 3.91 | 3.90 | 3.95 | 3.84 | 3.87 | 3.92 | 3.94 | 4.00 | 3.94 | 4.00 | 3.84 |
| **F** | | 0.00 | 0.06 | 0.00 | 0.09 | 0.11 | 0.05 | 0.16 | 0.13 | 0.08 | 0.06 | 0.00 | 0.06 | 0.00 | 0.16 |
| **Cl** | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| **Mineral Name** | | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Rossmanite | Schorl | Dravite | Dravite | Dravite | Schorl |

(**Table 16.** Continued.)

| Line | | 154 | 155 | 156 | 157 | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 170 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 6.02 | 6.05 | 6.09 | 6.08 | 6.04 | 6.04 | 6.01 | 6.03 | 5.97 | 6.06 | 6.07 | 5.99 |
| | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.01 |
| **B** | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 5.66 | 5.67 | 5.63 | 5.59 | 5.72 | 5.69 | 5.79 | 5.70 | 5.72 | 5.66 | 5.65 | 5.82 |
| | **Mg** | 0.34 | 0.33 | 0.37 | 0.41 | 0.28 | 0.31 | 0.22 | 0.30 | 0.28 | 0.34 | 0.35 | 0.18 |
| **Y:** | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Ti** | 0.18 | 0.18 | 0.16 | 0.16 | 0.17 | 0.16 | 0.12 | 0.16 | 0.15 | 0.16 | 0.15 | 0.10 |
| | **Cr** | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Mg** | 1.11 | 1.13 | 0.96 | 0.94 | 1.12 | 1.10 | 1.48 | 1.03 | 1.37 | 1.15 | 1.13 | 1.51 |
| | **Mn** | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| | **$Fe^{2+}$** | 1.66 | 1.57 | 1.67 | 1.67 | 1.54 | 1.54 | 1.30 | 1.58 | 1.48 | 1.52 | 1.53 | 1.25 |
| | **Zn** | 0.00 | 0.00 | 0.00 | 0.03 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.00 | 0.02 | 0.02 |
| | **Li*** | 0.04 | 0.12 | 0.21 | 0.19 | 0.15 | 0.17 | 0.07 | 0.21 | 0.00 | 0.16 | 0.17 | 0.11 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.02 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.05 | 0.06 | 0.04 | 0.06 | 0.06 | 0.07 | 0.14 | 0.08 | 0.09 | 0.08 | 0.07 | 0.24 |
| | **Na** | 0.81 | 0.76 | 0.78 | 0.83 | 0.80 | 0.83 | 0.69 | 0.87 | 0.76 | 0.76 | 0.78 | 0.59 |
| | **K** | 0.03 | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.03 |
| | **r** | 0.10 | 0.15 | 0.15 | 0.09 | 0.12 | 0.07 | 0.14 | 0.02 | 0.11 | 0.13 | 0.12 | 0.15 |
| **OH** | | 3.97 | 3.99 | 3.97 | 3.77 | 3.93 | 3.97 | 3.97 | 3.86 | 3.83 | 4.00 | 3.90 | 3.93 |
| **F** | | 0.04 | 0.01 | 0.04 | 0.23 | 0.06 | 0.03 | 0.03 | 0.14 | 0.17 | 0.00 | 0.10 | 0.07 |
| **Cl** | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Dravite | Schorl | Schorl | Schorl | Schorl | Dravite |

**Table 17.** Calculated mineral formulae for JFB-15-3-2.

| Line | | 171 | 173 | 175 | 176 | 179 | 180 | 181 | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 5.93 | 5.94 | 5.77 | 6.10 | 5.71 | 5.87 | 5.99 | 6.09 | 6.09 | 6.11 | 6.07 | 6.13 | 6.12 | 6.15 | 6.14 |
| | **Al** | 0.07 | 0.06 | 0.23 | 0.00 | 0.29 | 0.13 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **B** | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 5.78 | 5.77 | 5.67 | 5.59 | 5.37 | 5.79 | 5.67 | 5.33 | 5.39 | 5.32 | 5.36 | 5.29 | 5.45 | 5.36 | 5.32 |
| | **Mg** | 0.22 | 0.23 | 0.34 | 0.41 | 0.63 | 0.21 | 0.33 | 0.68 | 0.61 | 0.69 | 0.64 | 0.71 | 0.55 | 0.64 | 0.68 |
| **Y:** | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Ti** | 0.13 | 0.13 | 0.12 | 0.18 | 0.15 | 0.11 | 0.12 | 0.21 | 0.23 | 0.23 | 0.23 | 0.23 | 0.19 | 0.20 | 0.21 |
| | **Cr** | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Mg** | 1.05 | 0.97 | 1.17 | 0.96 | 0.76 | 1.25 | 1.28 | 0.49 | 0.43 | 0.31 | 0.31 | 0.21 | 0.48 | 0.33 | 0.22 |
| | **Mn** | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 |
| | **$Fe^{2+}$** | 1.72 | 1.83 | 1.65 | 1.60 | 2.22 | 1.54 | 1.52 | 2.10 | 2.20 | 2.27 | 2.30 | 2.33 | 2.11 | 2.18 | 2.36 |
| | **Zn** | 0.00 | 0.01 | 0.02 | 0.01 | 0.04 | 0.01 | 0.01 | 0.03 | 0.02 | 0.00 | 0.02 | 0.01 | 0.02 | 0.00 | 0.01 |
| | **Li*** | 0.09 | 0.06 | 0.04 | 0.25 | 0.00 | 0.10 | 0.07 | 0.16 | 0.12 | 0.19 | 0.13 | 0.21 | 0.20 | 0.28 | 0.19 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.20 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.24 | 0.27 | 0.41 | 0.04 | 0.36 | 0.35 | 0.27 | 0.09 | 0.05 | 0.04 | 0.03 | 0.02 | 0.04 | 0.03 | 0.02 |
| | **Na** | 0.59 | 0.52 | 0.52 | 0.78 | 0.46 | 0.48 | 0.61 | 0.83 | 0.82 | 0.87 | 0.94 | 0.88 | 0.80 | 0.84 | 0.83 |
| | **K** | 0.04 | 0.04 | 0.03 | 0.03 | 0.04 | 0.03 | 0.02 | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 |
| | **r** | 0.13 | 0.18 | 0.04 | 0.15 | 0.15 | 0.13 | 0.10 | 0.04 | 0.11 | 0.06 | 0.01 | 0.08 | 0.13 | 0.10 | 0.13 |
| **OH** | | 3.83 | 3.87 | 3.81 | 3.90 | 3.99 | 3.85 | 3.91 | 3.99 | 3.94 | 4.00 | 4.00 | 3.99 | 4.00 | 3.99 | 3.89 |
| **F** | | 0.17 | 0.13 | 0.18 | 0.10 | 0.00 | 0.15 | 0.08 | 0.00 | 0.05 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.11 |
| **Cl** | | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl |

(**Table 17.** Continued.)

| Line | | 190 | 191 | 192 | 193 | 194 | 197 | 198 | 199 | 200 | 201 | 202 | 203 | 204 | 205 | 206 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 6.14 | 5.91 | 6.00 | 6.00 | 6.15 | 6.16 | 5.66 | 6.19 | 6.13 | 5.91 | 5.87 | 6.08 | 5.95 | 5.87 | 5.87 |
| | **Al** | 0.00 | 0.09 | 0.01 | 0.00 | 0.00 | 0.00 | 0.34 | 0.00 | 0.00 | 0.09 | 0.13 | 0.00 | 0.05 | 0.13 | 0.13 |
| **B** | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 5.55 | 5.75 | 5.67 | 5.66 | 5.31 | 5.21 | 6.00 | 5.22 | 5.43 | 5.72 | 5.75 | 5.62 | 5.73 | 5.77 | 5.74 |
| | **Mg** | 0.45 | 0.25 | 0.33 | 0.34 | 0.69 | 0.79 | 0.00 | 0.78 | 0.57 | 0.28 | 0.25 | 0.39 | 0.27 | 0.23 | 0.26 |
| **Y:** | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Ti** | 0.12 | 0.12 | 0.12 | 0.13 | 0.23 | 0.24 | 0.18 | 0.23 | 0.18 | 0.12 | 0.12 | 0.19 | 0.14 | 0.11 | 0.12 |
| | **Cr** | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 |
| | **Mg** | 0.50 | 1.26 | 1.15 | 1.05 | 0.35 | 0.33 | 1.07 | 0.45 | 0.85 | 1.19 | 1.25 | 1.08 | 0.96 | 1.11 | 1.08 |
| | **Mn** | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **$Fe^{2+}$** | 2.12 | 1.49 | 1.62 | 1.70 | 2.14 | 2.10 | 1.69 | 1.93 | 1.64 | 1.54 | 1.53 | 1.49 | 1.84 | 1.67 | 1.69 |
| | **Zn** | 0.01 | 0.02 | 0.01 | 0.03 | 0.01 | 0.03 | 0.00 | 0.00 | 0.01 | 0.02 | 0.01 | 0.02 | 0.01 | 0.00 | 0.03 |
| | **Li*** | 0.25 | 0.11 | 0.08 | 0.08 | 0.27 | 0.30 | 0.00 | 0.38 | 0.32 | 0.12 | 0.09 | 0.21 | 0.05 | 0.11 | 0.08 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.02 | 0.36 | 0.27 | 0.28 | 0.03 | 0.04 | 0.04 | 0.06 | 0.14 | 0.37 | 0.36 | 0.05 | 0.25 | 0.37 | 0.35 |
| | **Na** | 0.83 | 0.46 | 0.59 | 0.56 | 0.83 | 0.85 | 0.82 | 0.80 | 0.71 | 0.46 | 0.49 | 0.77 | 0.55 | 0.46 | 0.49 |
| | **K** | 0.02 | 0.03 | 0.03 | 0.04 | 0.03 | 0.04 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.05 | 0.03 | 0.03 |
| | **r** | 0.12 | 0.15 | 0.11 | 0.13 | 0.11 | 0.08 | 0.11 | 0.11 | 0.13 | 0.14 | 0.13 | 0.15 | 0.15 | 0.13 | 0.13 |
| **OH** | | 3.91 | 3.85 | 3.90 | 4.00 | 4.00 | 3.98 | 3.97 | 4.00 | 3.89 | 3.80 | 3.88 | 3.87 | 3.83 | 3.93 | 3.91 |
| **F** | | 0.08 | 0.15 | 0.10 | 0.00 | 0.00 | 0.02 | 0.02 | 0.00 | 0.10 | 0.20 | 0.12 | 0.13 | 0.17 | 0.07 | 0.09 |
| **Cl** | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl |

(**Table 17.** Continued.)

| Line | | 207 | 208 | 209 | 210 |
|---|---|---|---|---|---|
| **T:** | **Si** | 6.08 | 5.88 | 5.90 | 5.82 |
| | **Al** | 0.00 | 0.12 | 0.10 | 0.18 |
| **B** | | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 5.61 | 5.79 | 5.85 | 5.77 |
| | **Mg** | 0.39 | 0.21 | 0.16 | 0.23 |
| **Y:** | **Al** | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Ti** | 0.20 | 0.12 | 0.11 | 0.12 |
| | **Cr** | 0.00 | 0.00 | 0.01 | 0.00 |
| | **Mg** | 0.92 | 1.19 | 1.22 | 1.23 |
| | **Mn** | 0.01 | 0.01 | 0.01 | 0.01 |
| | **$Fe^{2+}$** | 1.63 | 1.50 | 1.48 | 1.54 |
| | **Zn** | 0.01 | 0.02 | 0.01 | 0.03 |
| | **Li*** | 0.23 | 0.17 | 0.18 | 0.08 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.04 | 0.34 | 0.36 | 0.39 |
| | **Na** | 0.78 | 0.50 | 0.47 | 0.45 |
| | **K** | 0.03 | 0.06 | 0.03 | 0.03 |
| | **r** | 0.15 | 0.10 | 0.15 | 0.14 |
| **OH** | | 3.82 | 3.92 | 3.92 | 3.88 |
| **F** | | 0.18 | 0.08 | 0.08 | 0.12 |
| **Cl** | | 0.00 | 0.01 | 0.00 | 0.00 |
| **Mineral Name** | | Schorl | Schorl | Schorl | Schorl |

**Table 18.** Calculated mineral formulae for JFB-15-3-3.

| Line | | 211 | 212 | 213 | 216 | 217 | 218 | 219 | 220 | 221 | 222 | 223 | 224 | 225 | 226 | 228 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 6.11 | 6.10 | 6.05 | 6.07 | 5.84 | 6.08 | 5.87 | 5.85 | 5.84 | 5.96 | 5.93 | 5.67 | 5.97 | 5.87 | 5.85 |
| | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.16 | 0.00 | 0.13 | 0.15 | 0.16 | 0.04 | 0.07 | 0.34 | 0.03 | 0.13 | 0.15 |
| **B** | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 5.41 | 5.52 | 5.60 | 5.60 | 5.74 | 5.56 | 5.77 | 5.79 | 5.76 | 5.57 | 5.61 | 5.95 | 5.61 | 5.65 | 5.80 |
| | **Mg** | 0.59 | 0.48 | 0.40 | 0.40 | 0.26 | 0.44 | 0.23 | 0.21 | 0.24 | 0.43 | 0.39 | 0.05 | 0.39 | 0.35 | 0.20 |
| **Y:** | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Ti** | 0.21 | 0.20 | 0.21 | 0.19 | 0.13 | 0.19 | 0.12 | 0.11 | 0.12 | 0.13 | 0.13 | 0.11 | 0.13 | 0.13 | 0.11 |
| | **Cr** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Mg** | 0.69 | 0.95 | 0.95 | 1.10 | 1.14 | 1.01 | 1.29 | 1.32 | 1.30 | 1.18 | 1.16 | 1.32 | 1.20 | 1.25 | 1.33 |
| | **Mn** | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 |
| | **$Fe^{2+}$** | 1.90 | 1.59 | 1.69 | 1.51 | 1.59 | 1.57 | 1.45 | 1.44 | 1.48 | 1.63 | 1.65 | 1.51 | 1.61 | 1.61 | 1.45 |
| | **Zn** | 0.00 | 0.01 | 0.01 | 0.02 | 0.01 | 0.03 | 0.02 | 0.01 | 0.00 | 0.02 | 0.01 | 0.03 | 0.02 | 0.01 | 0.01 |
| | **Li*** | 0.19 | 0.25 | 0.13 | 0.18 | 0.12 | 0.20 | 0.11 | 0.11 | 0.10 | 0.03 | 0.03 | 0.02 | 0.04 | 0.00 | 0.10 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.01 | 3.00 |
| **X:** | **Ca** | 0.05 | 0.05 | 0.06 | 0.08 | 0.39 | 0.12 | 0.38 | 0.39 | 0.38 | 0.29 | 0.30 | 0.29 | 0.30 | 0.28 | 0.37 |
| | **Na** | 0.81 | 0.79 | 0.75 | 0.74 | 0.49 | 0.69 | 0.46 | 0.43 | 0.47 | 0.63 | 0.59 | 0.54 | 0.59 | 0.60 | 0.46 |
| | **K** | 0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.05 | 0.03 | 0.03 | 0.03 |
| | **r** | 0.12 | 0.14 | 0.16 | 0.15 | 0.10 | 0.16 | 0.14 | 0.15 | 0.12 | 0.05 | 0.08 | 0.12 | 0.09 | 0.09 | 0.14 |
| **OH** | | 3.89 | 3.94 | 3.98 | 4.00 | 3.89 | 3.94 | 3.98 | 3.80 | 3.84 | 3.96 | 3.97 | 3.99 | 3.83 | 3.94 | 3.95 |
| **F** | | 0.11 | 0.06 | 0.02 | 0.00 | 0.12 | 0.07 | 0.02 | 0.20 | 0.16 | 0.04 | 0.02 | 0.01 | 0.17 | 0.06 | 0.05 |
| **Cl** | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl |

(**Table 18.** Continued.)

| Line | | 229 | 230 | 231 | 234 | 235 | 236 | 237 | 238 | 239 | 240 | 241 | 242 | 244 | 246 | 247 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **T:** | **Si** | 5.82 | 5.86 | 5.96 | 5.94 | 6.07 | 5.50 | 6.06 | 5.78 | 3.75 | 5.88 | 5.86 | 6.02 | 5.75 | 6.07 | 6.07 |
| | **Al** | 0.18 | 0.14 | 0.04 | 0.06 | 0.00 | 0.50 | 0.00 | 0.22 | 2.25 | 0.12 | 0.14 | 0.00 | 0.25 | 0.00 | 0.00 |
| **B** | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Z:** | **Al** | 5.82 | 5.80 | 5.66 | 5.69 | 5.54 | 6.00 | 5.61 | 5.77 | 6.00 | 5.74 | 5.75 | 5.66 | 5.77 | 5.38 | 5.49 |
| | **Mg** | 0.18 | 0.20 | 0.34 | 0.31 | 0.46 | 0.00 | 0.39 | 0.23 | 0.00 | 0.26 | 0.25 | 0.34 | 0.23 | 0.62 | 0.51 |
| **Y:** | **Al** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 1.76 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Ti** | 0.12 | 0.11 | 0.13 | 0.12 | 0.19 | 0.18 | 0.19 | 0.12 | 0.02 | 0.12 | 0.11 | 0.16 | 0.12 | 0.18 | 0.14 |
| | **Cr** | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **Mg** | 1.33 | 1.32 | 1.27 | 1.22 | 1.00 | 1.10 | 1.08 | 1.21 | 0.63 | 1.22 | 1.31 | 1.02 | 1.26 | 0.82 | 1.11 |
| | **Mn** | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| | **$Fe^{2+}$** | 1.45 | 1.45 | 1.50 | 1.56 | 1.60 | 1.54 | 1.51 | 1.57 | 0.57 | 1.54 | 1.44 | 1.63 | 1.55 | 1.87 | 1.56 |
| | **Zn** | 0.03 | 0.01 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 | 0.03 | 0.01 | 0.02 | 0.02 | 0.03 | 0.01 | 0.03 |
| | **Li*** | 0.07 | 0.09 | 0.09 | 0.07 | 0.18 | 0.10 | 0.20 | 0.07 | 0.00 | 0.10 | 0.11 | 0.18 | 0.04 | 0.12 | 0.17 |
| | **∑Y** | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.02 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| **X:** | **Ca** | 0.37 | 0.36 | 0.30 | 0.33 | 0.12 | 0.23 | 0.09 | 0.39 | 0.62 | 0.38 | 0.39 | 0.19 | 0.38 | 0.14 | 0.18 |
| | **Na** | 0.43 | 0.47 | 0.56 | 0.51 | 0.72 | 0.65 | 0.77 | 0.47 | 0.06 | 0.45 | 0.47 | 0.71 | 0.48 | 0.80 | 0.77 |
| | **K** | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.05 | 0.03 | 0.03 | 0.13 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 |
| | **r** | 0.17 | 0.15 | 0.11 | 0.13 | 0.13 | 0.08 | 0.12 | 0.11 | 0.20 | 0.14 | 0.11 | 0.07 | 0.10 | 0.04 | 0.03 |
| **OH** | | 4.00 | 3.91 | 3.91 | 3.93 | 4.00 | 3.90 | 3.93 | 3.92 | 3.94 | 3.86 | 3.80 | 3.92 | 3.82 | 3.90 | 3.89 |
| **F** | | 0.00 | 0.09 | 0.09 | 0.07 | 0.00 | 0.08 | 0.07 | 0.08 | 0.05 | 0.14 | 0.20 | 0.08 | 0.18 | 0.10 | 0.11 |
| **Cl** | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.01 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Mineral Name** | | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl | Liddicoatite | Schorl | Schorl | Schorl | Schorl | Schorl | Schorl |

(**Table 18.** Continued.)

| Line | | 248 | 250 |
|---|---|---|---|
| **T:** | **Si** | 6.04 | 5.84 |
| | **Al** | 0.00 | 0.16 |
| **B** | | 3 | 3 |
| **Z:** | **Al** | 5.54 | 5.79 |
| | **Mg** | 0.46 | 0.21 |
| **Y:** | **Al** | 0.00 | 0.00 |
| | **Ti** | 0.18 | 0.11 |
| | **Cr** | 0.01 | 0.00 |
| | **Mg** | 1.05 | 1.31 |
| | **Mn** | 0.00 | 0.00 |
| | **$Fe^{2+}$** | 1.65 | 1.49 |
| | **Zn** | 0.03 | 0.00 |
| | **Li*** | 0.08 | 0.09 |
| | **∑Y** | 3.00 | 3.00 |
| **X:** | **Ca** | 0.15 | 0.38 |
| | **Na** | 0.68 | 0.45 |
| | **K** | 0.03 | 0.02 |
| | **r** | 0.13 | 0.15 |
| **OH** | | 3.93 | 3.90 |
| **F** | | 0.07 | 0.10 |
| **Cl** | | 0.00 | 0.00 |
| **Mineral Name** | | Schorl | Schorl |

## APPENDIX D

**Table 19.** Average chondrite normalized trace element measurements from LA-ICP-MS analysis of Setters Formation tourmaline.

| Sample | Grain | Sc 45 | Ti 49 | V 51 | Cr 53 | Fe 57 | Ga 71 | Sr 88 | Y 89 | Zr 90 | Nb 93 | Cs 133 | Ba 137 | Hf 179 | Ta 181 | Pb 206 | Th 232 | U 238 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JFB-15-1-1 | 1 | 1.62 | 28.23 | 3.26 | 0.03 | 0.46 | 3.25 | 82.52 | 0.03 | 0.04 | 0.06 | bdl | 0.30 | 0.23 | 0.16 | 4.41 | 0.31 | 0.55 |
| | 2 | 1.65 | 24.72 | 3.29 | 0.04 | 0.39 | 3.06 | 78.58 | 0.01 | | 0.12 | 0.25 | 0.37 | 0.09 | 0.19 | 3.98 | 0.02 | 1.48 |
| | 3 | 1.62 | 29.36 | 3.39 | 0.04 | 0.47 | 2.98 | 99.77 | 0.04 | 0.09 | 0.23 | bdl | 0.48 | 0.05 | 0.85 | 3.90 | 0.09 | 0.34 |
| | 4 | 1.82 | 28.86 | 3.08 | 0.04 | 0.45 | 2.78 | 102.41 | 0.03 | 0.08 | 0.10 | bdl | 0.19 | 0.45 | 0.35 | 5.61 | 0.12 | 1.26 |
| JFB-15-2-1 | 1 | 1.10 | 14.10 | 3.71 | 0.12 | 0.37 | 3.54 | 21.33 | 0.00 | 0.00 | 0.00 | 0.19 | 0.14 | 0.11 | 0.25 | 1.05 | 0.05 | 0.28 |
| | 2 | 1.55 | 29.95 | 3.68 | 0.06 | 0.53 | 2.98 | 211.04 | 0.02 | 0.00 | 0.58 | 0.02 | 0.50 | 0.29 | 1.66 | 7.21 | 0.03 | 0.29 |
| | 3 | 1.50 | 17.45 | 3.26 | 0.04 | 0.41 | 2.90 | 74.18 | 0.05 | 0.03 | 0.26 | 0.50 | 0.33 | 0.07 | 1.08 | 3.06 | 0.12 | 1.10 |
| | 4 | 1.43 | 12.28 | 2.72 | 0.05 | 0.30 | 2.90 | 22.11 | 0.05 | 0.04 | 0.41 | bdl | 0.14 | 0.30 | 1.12 | 1.03 | 0.07 | 0.07 |
| | 5 | 1.42 | 14.78 | 2.71 | 0.04 | 0.31 | 2.69 | 46.84 | 0.05 | 0.07 | 0.31 | 0.17 | 0.18 | 0.20 | 0.95 | 0.92 | 0.04 | 0.02 |
| | 6 | 1.65 | 19.90 | 3.21 | 0.06 | 0.41 | 2.64 | 110.06 | 0.04 | 0.08 | 0.41 | 0.14 | 0.30 | 0.41 | 0.89 | 1.81 | 0.04 | 0.12 |
| | 7 | 1.45 | 18.67 | 3.48 | 0.08 | 0.42 | 3.17 | 84.52 | 0.01 | 0.32 | 0.19 | bdl | 0.18 | 0.40 | 1.18 | 4.03 | 0.03 | 0.41 |
| | 8 | 1.71 | 21.00 | 3.43 | 0.05 | 0.45 | 2.76 | 94.43 | 0.05 | 0.10 | 0.22 | 0.10 | 0.42 | 0.38 | 0.37 | 1.41 | 0.02 | 0.09 |
| | 9 | 1.54 | 10.56 | 3.01 | 0.06 | 0.29 | 3.42 | 22.76 | 0.04 | 0.06 | 0.58 | 0.11 | 0.11 | 0.18 | 0.88 | 1.04 | 0.03 | 0.13 |
| | 10 | 1.52 | 14.99 | 2.96 | 0.04 | 0.35 | 2.93 | 51.75 | 0.05 | 0.07 | 0.25 | 0.08 | 0.17 | 0.16 | 0.35 | 2.25 | 0.08 | 0.06 |
| JFB-15-2-2 | 1 | 1.08 | 11.52 | 2.47 | 0.05 | 0.28 | 3.06 | 17.87 | 0.06 | 0.04 | 0.35 | bdl | bdl | 0.07 | 0.70 | 1.62 | 0.00 | 0.00 |
| | 2 | 1.03 | 13.01 | 2.42 | 0.06 | 0.29 | 2.86 | 20.96 | 0.09 | 0.07 | 0.34 | 0.06 | 0.11 | 0.00 | 1.00 | 2.20 | 0.17 | 0.14 |
| | 3 | 1.09 | 16.49 | 2.57 | 0.05 | 0.33 | 2.74 | 57.59 | 0.04 | 0.04 | 0.30 | 0.06 | 0.20 | 0.04 | 0.66 | 4.46 | 0.06 | 0.00 |
| | 4 | 0.95 | 13.34 | 2.53 | 0.06 | 0.30 | 2.93 | 18.00 | 0.07 | 0.05 | 0.39 | 0.03 | 0.10 | 0.00 | 0.44 | 1.82 | 0.05 | 0.12 |
| JFB-15-3-1 | 1 | 1.16 | 16.62 | 2.65 | 0.03 | 0.40 | 3.77 | 72.89 | 0.10 | 0.39 | 0.07 | 0.00 | 0.23 | 0.00 | 0.07 | 2.98 | 1.28 | 3.04 |
| | 2 | 1.10 | 13.83 | 1.92 | 0.02 | 0.35 | 3.09 | 78.30 | 0.05 | 0.14 | bdl | 0.06 | 0.29 | 0.16 | 0.06 | 2.84 | 0.46 | 0.70 |
| | 3 | 1.13 | 14.02 | 2.72 | 0.04 | 0.36 | 3.78 | 63.25 | 0.02 | 0.00 | 0.12 | 0.08 | 0.27 | 0.17 | 0.09 | 2.48 | 0.07 | 0.04 |
| | 4 | 1.27 | 11.53 | 2.45 | 0.02 | 0.30 | 3.78 | 60.57 | 0.03 | bdl | bdl | 0.04 | 0.36 | 0.26 | 0.00 | 2.13 | 0.03 | 0.00 |
| | 5 | 1.13 | 15.38 | 2.58 | 0.03 | 0.40 | 3.92 | 84.36 | 0.19 | 65.92 | 0.06 | 0.06 | 0.41 | 16.16 | 0.23 | 3.14 | bdl | 13.98 |
| | 6 | 0.93 | 13.68 | 2.40 | 0.04 | 0.33 | 3.06 | 68.27 | 0.01 | bdl | 0.03 | 0.03 | 0.22 | 0.00 | bdl | 2.85 | 0.00 | 0.00 |
| | 7 | 1.12 | 14.33 | 2.56 | 0.03 | 0.33 | 3.47 | 65.59 | 0.01 | bdl | bdl | bdl | 0.15 | 0.00 | 0.00 | 2.65 | 0.00 | 0.00 |

bdl= below detection limit

(**Table 19.** Continued.)

| Sample | Grain | Sc 45 | Ti 49 | V 51 | Cr 53 | Fe 57 | Ga 71 | Sr 88 | Y 89 | Zr 90 | Nb 93 | Cs 133 | Ba 137 | Hf 179 | Ta 181 | Pb 206 | Th 232 | U 238 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JFB-15-3-2 | 1 | 1.38 | 10.51 | 3.86 | 0.04 | 0.37 | 2.59 | 78.70 | 0.14 | 0.09 | bdl | 0.06 | 0.47 | 0.15 | 0.11 | 0.94 | 0.02 | 0.11 |
| | 2 | 3.22 | 17.07 | 5.04 | 0.05 | 0.32 | 3.29 | 113.44 | 0.08 | 0.17 | 5.83 | 4.49 | 122.16 | 1.16 | 4.30 | 2.00 | 0.03 | 0.21 |
| | 3 | 1.76 | 17.90 | 4.78 | 0.04 | 0.51 | 2.41 | 154.70 | 0.05 | 0.21 | 0.11 | bdl | 0.31 | 0.17 | 0.12 | 2.95 | 0.10 | 0.76 |
| | 4 | 1.84 | 16.49 | 5.08 | 0.04 | 0.44 | 2.66 | 138.81 | 0.12 | bdl | bdl | 0.03 | 0.38 | 0.16 | 0.06 | 2.36 | 0.12 | 0.27 |
| | 5 | 1.24 | 11.14 | 4.11 | 0.03 | 0.38 | 3.08 | 58.68 | 0.17 | 1.65 | bdl | bdl | bdl | 0.53 | 0.06 | 1.00 | 0.00 | 0.00 |
| JFB-15-3-3 | 1 | | 16.91 | 3.01 | 0.04 | 0.41 | 3.42 | 150.53 | 0.25 | bdl | bdl | bdl | 0.23 | 0.08 | 0.00 | 2.68 | 0.00 | 0.08 |
| | 2 | 1.44 | 15.44 | 2.98 | 0.04 | 0.39 | 3.57 | 131.89 | 0.10 | bdl | 25.48 | bdl | 0.28 | 0.00 | 8.89 | 2.29 | 2.82 | 7.52 |
| | 3 | 1.38 | 11.92 | 3.08 | 0.02 | 0.41 | 4.13 | 58.25 | 0.11 | 0.10 | 0.20 | bdl | 0.43 | 0.00 | 0.00 | 1.05 | 0.00 | 0.05 |

**Table 20.** Standard deviations of chondrite normalized trace element measurements from LA-ICP-MS analysis of Setters tourmaline.

| Sample | Grain | Sc 45 | Ti 49 | V 51 | Cr 53 | Fe 57 | Ga 71 | Sr 88 | Y 89 | Zr 90 | Nb 93 | Cs 133 | Ba 137 | Hf 179 | Ta 181 | Pb 206 | Th 232 | U 238 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JFB-15-1-1 | 1 | 0.18 | 7.91 | 0.80 | 0.02 | 0.12 | 0.69 | 48.69 | 0.02 | 0.03 | 0.06 | | 0.05 | 0.09 | 0.16 | 2.67 | 0.17 | 0.71 |
| | 2 | 0.20 | 8.58 | 0.23 | 0.00 | 0.09 | 0.30 | 49.25 | 0.01 | | 0.17 | | 0.23 | 0.08 | 0.33 | 2.74 | 0.03 | 0.60 |
| | 3 | 0.15 | 2.58 | 0.08 | 0.01 | 0.03 | 0.03 | 15.65 | | 0.04 | 0.24 | | 0.18 | 0.09 | 1.04 | 2.06 | 0.10 | 0.45 |
| | 4 | 0.57 | 8.91 | 0.29 | 0.00 | 0.10 | 0.17 | 51.44 | 0.02 | 0.05 | 0.03 | | 0.17 | 0.55 | 0.32 | 2.50 | 0.15 | 1.44 |
| JFB-15-2-1 | 1 | 0.01 | 0.61 | 0.36 | 0.08 | 0.03 | 0.19 | 3.76 | 0.00 | 0.00 | 0.00 | | | 0.16 | 0.00 | 0.53 | 0.07 | 0.00 |
| | 2 | 0.27 | 7.98 | 0.11 | 0.01 | 0.09 | 0.26 | 94.20 | 0.01 | | 0.60 | 0.03 | 0.18 | 0.35 | 1.21 | 3.54 | 0.10 | 0.66 |
| | 3 | 0.06 | 0.41 | 0.11 | 0.01 | 0.01 | 0.10 | 3.68 | 0.01 | | 0.10 | | 0.05 | 0.12 | 0.92 | 0.19 | 0.14 | 0.96 |
| | 4 | 0.09 | 0.70 | 0.14 | 0.01 | 0.02 | 0.17 | 1.36 | 0.02 | 0.01 | 0.15 | | 0.05 | 0.44 | 0.76 | 0.18 | 0.11 | 0.11 |
| | 5 | 0.28 | 4.29 | 0.51 | 0.01 | 0.06 | 0.62 | 38.33 | 0.02 | 0.02 | 0.16 | | 0.15 | 0.26 | 0.66 | 0.29 | 0.09 | 0.07 |
| | 6 | 0.17 | 5.46 | 0.15 | 0.01 | 0.04 | 0.25 | 55.12 | 0.02 | 0.05 | 0.25 | | 0.15 | 0.56 | 0.40 | 0.61 | 0.09 | 0.35 |
| | 7 | 0.10 | 5.85 | 0.08 | 0.01 | 0.07 | 0.48 | 85.49 | 0.00 | 0.36 | 0.08 | | 0.09 | 0.56 | 1.10 | 4.00 | 0.06 | 0.20 |
| | 8 | 0.09 | 0.70 | 0.15 | 0.00 | 0.01 | 0.08 | 38.60 | 0.01 | 0.02 | 0.00 | | 0.46 | 0.47 | 0.14 | 0.55 | 0.03 | 0.08 |
| | 9 | 0.06 | 0.48 | 0.14 | 0.03 | 0.01 | 0.27 | 1.06 | 0.06 | 0.01 | | | | 0.23 | 1.07 | 0.06 | 0.04 | 0.18 |
| | 10 | 0.04 | 1.77 | 0.23 | 0.01 | 0.02 | 0.21 | 25.01 | 0.04 | 0.05 | 0.04 | | 0.03 | 0.11 | 0.34 | 1.07 | 0.10 | |

(**Table 20.** Continued.)

| Sample | Grain | Sc 45 | Ti 49 | V 51 | Cr 53 | Fe 57 | Ga 71 | Sr 88 | Y 89 | Zr 90 | Nb 93 | Cs 133 | Ba 137 | Hf 179 | Ta 181 | Pb 206 | Th 232 | U 238 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JFB-15-2-2 | 1 | 0.03 | 0.08 | 0.06 | 0.00 | 0.00 | 0.11 | 0.08 | 0.02 | 0.01 | 0.06 | | | 0.11 | | 0.06 | 0.00 | 0.00 |
| | 2 | 0.05 | 2.10 | 0.15 | 0.03 | 0.02 | 0.07 | 6.05 | 0.06 | 0.04 | 0.13 | | 0.02 | 0.00 | 0.57 | 0.82 | 0.16 | 0.24 |
| | 3 | 0.13 | 5.56 | 0.09 | 0.00 | 0.04 | 0.33 | 72.16 | 0.01 | 0.01 | 0.11 | 0.02 | 0.08 | 0.07 | 0.23 | 4.45 | 0.09 | 0.00 |
| | 4 | 0.02 | 1.57 | 0.09 | 0.01 | 0.02 | 0.13 | 4.29 | 0.05 | 0.02 | 0.08 | | 0.04 | 0.00 | 0.13 | 0.37 | 0.08 | 0.21 |
| JFB-15-3-1 | 1 | 0.13 | 0.19 | 0.05 | 0.01 | 0.01 | 0.01 | 11.86 | 0.14 | | | | 0.15 | | 0.10 | 0.68 | 1.81 | 3.99 |
| | 2 | 0.02 | 1.27 | 0.24 | 0.01 | 0.01 | 0.37 | 8.35 | 0.03 | | | 0.08 | 0.03 | 0.22 | 0.08 | 0.28 | 0.66 | 0.98 |
| | 3 | 0.05 | 1.72 | 0.19 | 0.00 | 0.03 | 0.16 | 1.86 | | | | | | 0.08 | 0.08 | 0.29 | 0.13 | 0.08 |
| | 4 | 0.10 | 0.88 | 0.03 | 0.02 | 0.03 | 0.05 | 4.97 | 0.00 | | | | 0.18 | 0.37 | 0.00 | 0.13 | 0.04 | 0.00 |
| | 5 | 0.13 | 0.47 | 0.13 | 0.01 | 0.05 | 0.03 | 4.89 | 0.06 | | 0.03 | | | 22.86 | | 0.13 | | 19.43 |
| | 6 | 0.04 | 0.36 | 0.14 | 0.00 | 0.01 | 0.08 | 3.29 | 0.01 | | | 0.02 | 0.03 | 0.00 | | 0.06 | 0.00 | 0.00 |
| | 7 | 0.23 | 0.24 | 0.16 | 0.00 | 0.01 | 0.39 | 0.67 | | | | | | 0.00 | 0.00 | 0.18 | 0.00 | 0.00 |
| JFB-15-3-2 | 1 | 0.05 | 1.73 | 0.23 | 0.00 | 0.05 | 0.06 | 54.34 | 0.07 | | | | 0.35 | 0.07 | 0.15 | 0.34 | 0.03 | 0.15 |
| | 2 | 2.34 | 2.11 | 0.30 | 0.02 | 0.13 | 1.40 | 98.81 | | | 9.81 | | 210.63 | 1.92 | 7.09 | 1.69 | 0.05 | 0.27 |
| | 3 | 0.01 | 6.71 | 1.23 | 0.01 | 0.04 | 0.06 | 37.40 | 0.04 | | 0.10 | | | 0.08 | 0.00 | 0.95 | 0.15 | 1.07 |
| | 4 | 0.27 | 6.64 | 0.55 | 0.01 | 0.10 | 0.32 | 84.42 | | | | | 0.08 | 0.22 | 0.08 | 1.13 | 0.17 | 0.07 |
| | 5 | 0.04 | 0.54 | 0.27 | 0.02 | 0.02 | 0.19 | 14.88 | 0.04 | | | | | 0.59 | 0.08 | 0.05 | 0.00 | 0.00 |
| JFB-15-3-3 | 1 | | 5.58 | 0.41 | 0.01 | 0.03 | 0.69 | 91.38 | | | | | 0.05 | 0.07 | 0.00 | 1.65 | 0.00 | 0.13 |
| | 2 | 0.10 | 2.86 | 0.21 | 0.02 | 0.03 | 0.15 | 44.89 | 0.05 | | | | | 0.00 | 15.39 | 0.68 | 4.30 | 11.93 |
| | 3 | 0.26 | 1.22 | 0.36 | 0.01 | 0.03 | 0.14 | 25.04 | | | | | | 0.00 | 0.00 | 0.44 | 0.00 | 0.09 |

## APPENDIX E

**Table 21.** Average chondrite normalized REE measurements from LA-ICP-MS analysis of Setters Formation tourmaline.

| Sample | Grain | La 139 | Ce 140 | Pr 141 | Nd 146 | Sm 147 | Eu 151 | Gd 157 | Tb 159 | Dy 163 | Ho 165 | Er 167 | Tm 169 | Yb 173 | Lu 175 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JFB-15-1-1 | 1 | 5.17 | 2.86 | 2.62 | 1.59 | 0.53 | 3.80 | 0.21 | 0.27 | 0.03 | 0.05 | 0.00 | 0.10 | 0.07 | 0.10 |
| | 2 | 5.73 | 3.71 | 2.57 | 1.35 | 0.44 | 5.53 | 0.07 | 0.14 | 0.07 | 0.02 | 0.06 | 0.07 | 0.07 | 0.05 |
| | 3 | 5.71 | 5.43 | 2.59 | 1.97 | 0.80 | 5.29 | 0.16 | 0.09 | 0.22 | 0.12 | 0.14 | 0.00 | 0.07 | 0.03 |
| | 4 | 1.62 | 1.37 | 0.96 | 0.84 | 0.13 | 3.18 | 0.14 | 0.14 | 0.05 | 0.02 | 0.00 | 0.00 | 0.07 | 0.11 |
| JFB-15-2-1 | 1 | 8.89 | 10.29 | 5.02 | 3.60 | 0.30 | 10.16 | 0.43 | 0.05 | 0.17 | 0.10 | 0.05 | 0.00 | 0.18 | 0.00 |
| | 2 | 6.29 | 6.48 | 3.72 | 1.88 | 0.60 | 9.42 | 0.34 | 0.14 | 0.02 | 0.07 | 0.37 | 0.09 | 0.06 | 0.07 |
| | 3 | 3.33 | 3.02 | 1.69 | 0.96 | 0.00 | 8.43 | 0.43 | 0.04 | 0.00 | 0.02 | 0.12 | 0.12 | 0.04 | 0.13 |
| | 4 | 12.92 | 11.37 | 6.51 | 4.02 | 1.30 | 12.80 | 0.65 | 0.27 | 0.12 | 0.06 | 0.10 | 0.15 | 0.13 | 0.26 |
| | 5 | 11.46 | 10.31 | 5.63 | 3.59 | 1.38 | 12.44 | 0.44 | 0.30 | 0.12 | 0.10 | 0.08 | 0.06 | 0.11 | 0.29 |
| | 6 | 9.77 | 8.65 | 4.99 | 2.94 | 0.99 | 13.59 | 0.27 | 0.15 | 0.13 | 0.08 | 0.04 | 0.07 | 0.17 | 0.29 |
| | 7 | 4.46 | 4.58 | 2.12 | 1.21 | 0.42 | 6.91 | 0.22 | 0.15 | 0.15 | 0.02 | 0.03 | 0.07 | 0.09 | 0.05 |
| | 8 | 9.75 | 8.95 | 4.16 | 2.43 | 1.16 | 16.67 | 0.45 | 0.10 | 0.13 | 0.04 | 0.14 | 0.04 | 0.03 | 0.11 |
| | 9 | 15.69 | 12.48 | 7.01 | 5.23 | 0.90 | 10.98 | 0.17 | 0.18 | 0.13 | 0.14 | 0.11 | 0.06 | 0.11 | 0.13 |
| | 10 | 5.42 | 4.80 | 2.49 | 1.53 | 0.77 | 7.94 | 0.22 | 0.20 | 0.04 | 0.14 | 0.08 | 0.12 | 0.08 | 0.14 |
| JFB-15-2-2 | 1 | 23.03 | 17.72 | 10.64 | 5.94 | 2.03 | 17.92 | 1.09 | 0.26 | 0.34 | 0.17 | 0.03 | 0.04 | 0.08 | 0.14 |
| | 2 | 13.95 | 11.24 | 6.14 | 4.25 | 1.43 | 14.17 | 0.83 | 0.42 | 0.27 | 0.04 | 0.07 | 0.21 | 0.03 | 0.26 |
| | 3 | 8.20 | 6.55 | 4.11 | 2.20 | 0.93 | 10.10 | 0.28 | 0.29 | 0.09 | 0.00 | 0.06 | 0.04 | 0.00 | 0.39 |
| | 4 | 13.40 | 11.63 | 6.31 | 3.44 | 1.76 | 13.97 | 0.84 | 0.37 | 0.18 | 0.04 | 0.11 | 0.18 | 0.03 | 0.06 |
| JFB-15-3-1 | 1 | 1.49 | 1.26 | 0.91 | 0.54 | 0.60 | 2.24 | 0.06 | 0.18 | 0.08 | 0.05 | 0.16 | 0.18 | 0.07 | 0.32 |
| | 2 | 2.93 | 1.94 | 1.19 | 0.83 | 0.70 | 3.87 | 0.19 | 0.11 | 0.03 | 0.00 | 0.06 | 0.14 | 0.10 | 0.07 |
| | 3 | 2.62 | 1.99 | 1.25 | 0.69 | 0.29 | 3.50 | 0.03 | 0.03 | 0.06 | 0.02 | 0.02 | 0.02 | 0.00 | 0.08 |
| | 4 | 4.74 | 3.24 | 2.22 | 1.28 | 0.70 | 4.58 | 0.13 | 0.03 | 0.05 | 0.02 | 0.03 | 0.00 | 0.03 | 0.08 |
| | 5 | 2.52 | 1.95 | 1.10 | 0.54 | 0.61 | 3.03 | 0.28 | 0.14 | 0.24 | 0.05 | 0.24 | 0.24 | 0.51 | 0.17 |
| | 6 | 1.75 | 1.30 | 0.59 | 0.46 | 0.09 | 3.42 | 0.05 | 0.04 | 0.00 | 0.00 | 0.05 | 0.03 | 0.00 | 0.12 |
| | 7 | 1.93 | 1.38 | 0.61 | 0.63 | 0.73 | 2.70 | 0.16 | 0.02 | 0.05 | 0.00 | 0.00 | 0.09 | 0.00 | 0.07 |

bdl= below detection limit

(**Table 21.** Continued.)

| Sample | Grain | La 139 | Ce 140 | Pr 141 | Nd 146 | Sm 147 | Eu 151 | Gd 157 | Tb 159 | Dy 163 | Ho 165 | Er 167 | Tm 169 | Yb 173 | Lu 175 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JFB-15-3-2 | 1 | 25.93 | 16.14 | 10.49 | 6.18 | 1.35 | 5.90 | 1.03 | 0.54 | 0.30 | 0.11 | 0.15 | 0.20 | 0.21 | 0.63 |
| | 2 | 8.26 | 5.39 | 2.93 | 1.83 | 0.72 | 3.04 | 0.61 | 0.14 | 0.12 | 0.14 | 0.07 | 0.18 | 0.27 | 0.66 |
| | 3 | 1.29 | 0.95 | 0.50 | 0.34 | 0.33 | 1.77 | 0.18 | 0.02 | 0.07 | 0.05 | 0.21 | 0.06 | 0.12 | 0.46 |
| | 4 | 6.83 | 4.19 | 2.43 | 1.68 | 1.06 | 4.62 | 0.64 | 0.40 | 0.15 | 0.16 | 0.09 | 0.18 | 0.21 | 0.59 |
| | 5 | 15.17 | 10.45 | 5.94 | 4.02 | 1.85 | 6.26 | 0.35 | 0.31 | 0.28 | 0.16 | 0.22 | 0.07 | 0.21 | 0.60 |
| JFB-15-3-3 | 1 | 4.36 | 3.36 | 2.16 | 1.25 | 0.72 | 2.97 | 0.11 | 0.22 | 0.33 | 0.10 | 0.05 | 0.15 | 0.35 | 0.38 |
| | 2 | 4.36 | 2.79 | 1.54 | 1.13 | 0.28 | 3.04 | 0.30 | 0.10 | 0.12 | 0.09 | 0.02 | 0.15 | 0.22 | 0.67 |
| | 3 | 6.92 | 5.57 | 3.12 | 1.78 | 1.05 | 3.73 | 0.54 | 0.25 | 0.31 | 0.18 | 0.14 | 0.11 | 0.32 | 0.38 |

**Table 22.** Standard deviations of chondrite normalized REE measurements from LA-ICP-MS analysis of Setters tourmaline.

| Sample | Grain | La 139 | Ce 140 | Pr 141 | Nd 146 | Sm 147 | Eu 151 | Gd 157 | Tb 159 | Dy 163 | Ho 165 | Er 167 | Tm 169 | Yb 173 | Lu 175 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JFB-15-1-1 | 1 | 6.22 | 4.22 | 3.12 | 1.98 | 0.56 | 3.07 | 0.13 | 0.21 | 0.06 | 0.09 | 0.00 | 0.08 | 0.00 | 0.17 |
| | 2 | 9.16 | 5.84 | 4.20 | 2.11 | 0.77 | 4.92 | 0.10 | 0.20 | 0.04 | 0.04 | 0.09 | 0.07 | 0.06 | 0.06 |
| | 3 | 4.65 | 4.65 | 2.34 | 1.60 | 0.47 | 3.10 | 0.08 | 0.13 | 0.05 | 0.11 | 0.15 | 0.00 | 0.11 | 0.05 |
| | 4 | 1.69 | 1.36 | 0.92 | 0.69 | 0.19 | 3.61 | 0.16 | 0.13 | 0.03 | 0.02 | 0.00 | 0.00 | 0.09 | 0.10 |
| JFB-15-2-1 | 1 | 1.29 | 1.35 | 1.12 | 0.71 | 0.14 | 1.33 | 0.26 | 0.07 | 0.08 | 0.05 | 0.07 | 0.00 | 0.09 | 0.00 |
| | 2 | 5.12 | 5.38 | 2.95 | 1.86 | 0.52 | 5.56 | 0.25 | 0.17 | 0.03 | 0.05 | 0.94 | 0.13 | 0.14 | 0.10 |
| | 3 | 0.71 | 0.46 | 0.77 | 0.28 | 0.00 | 1.20 | 0.24 | 0.06 | 0.00 | 0.03 | 0.13 | 0.17 | 0.07 | 0.00 |
| | 4 | 2.65 | 2.45 | 1.56 | 0.49 | 0.44 | 1.60 | 0.29 | 0.19 | 0.11 | 0.06 | 0.15 | 0.11 | 0.13 | 0.18 |
| | 5 | 3.29 | 2.96 | 1.66 | 1.01 | 0.47 | 3.35 | 0.20 | 0.20 | 0.09 | 0.06 | 0.09 | 0.08 | 0.15 | 0.18 |
| | 6 | 3.53 | 3.23 | 1.96 | 1.12 | 0.58 | 3.30 | 0.20 | 0.08 | 0.08 | 0.05 | 0.07 | 0.07 | 0.19 | 0.23 |
| | 7 | 4.56 | 4.89 | 2.26 | 1.18 | 0.39 | 4.47 | 0.17 | 0.15 | 0.04 | 0.02 | 0.03 | 0.06 | 0.08 | 0.04 |
| | 8 | 1.66 | 1.27 | 0.84 | 0.49 | 0.42 | 1.34 | 0.03 | 0.07 | 0.04 | 0.04 | 0.13 | 0.04 | 0.04 | 0.04 |
| | 9 | 2.13 | 3.02 | 0.32 | 1.02 | 0.79 | 4.39 | 0.24 | 0.16 | | 0.12 | 0.03 | 0.09 | 0.16 | |
| | 10 | 3.01 | 2.60 | 1.38 | 0.93 | 0.25 | 2.08 | 0.16 | 0.05 | 0.03 | 0.15 | 0.08 | 0.08 | 0.09 | 0.03 |

(**Table 21.** Continued.)

| Sample | Grain | La 139 | Ce 140 | Pr 141 | Nd 146 | Sm 147 | Eu 151 | Gd 157 | Tb 159 | Dy 163 | Ho 165 | Er 167 | Tm 169 | Yb 173 | Lu 175 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JFB-15-2-2 | 1 | 0.11 | 0.19 | 1.17 | 1.09 | 0.15 | 2.08 | 0.13 | 0.10 | 0.10 | 0.18 | 0.04 | 0.06 | | 0.07 |
| | 2 | 6.60 | 5.57 | 3.69 | 2.08 | 0.22 | 3.60 | 0.52 | 0.30 | 0.20 | | 0.07 | 0.18 | 0.05 | 0.06 |
| | 3 | 8.36 | 6.49 | 4.18 | 1.97 | 1.10 | 4.08 | 0.30 | 0.29 | 0.10 | 0.00 | 0.00 | 0.04 | 0.00 | 0.29 |
| | 4 | 5.67 | 5.89 | 3.08 | 1.67 | 1.56 | 2.43 | | 0.28 | 0.15 | 0.04 | 0.13 | 0.18 | 0.05 | 0.05 |
| JFB-15-3-1 | 1 | 0.35 | 0.38 | 0.44 | 0.53 | 0.48 | 0.27 | 0.01 | 0.20 | 0.12 | 0.08 | | 0.26 | 0.09 | 0.26 |
| | 2 | 0.31 | 0.11 | 0.03 | 0.55 | 0.16 | 0.29 | 0.04 | 0.09 | | 0.00 | 0.03 | 0.20 | 0.15 | 0.00 |
| | 3 | 1.61 | 1.06 | 0.63 | 0.43 | 0.10 | 1.07 | | 0.06 | | 0.02 | 0.03 | 0.04 | 0.00 | |
| | 4 | 0.24 | 0.49 | 0.34 | 0.43 | 0.30 | 0.52 | 0.10 | 0.04 | 0.02 | 0.02 | 0.04 | 0.00 | 0.05 | 0.12 |
| | 5 | 1.41 | 1.08 | 0.52 | 0.25 | 0.16 | 0.18 | 0.31 | 0.01 | 0.11 | 0.02 | 0.21 | 0.25 | 0.05 | 0.14 |
| | 6 | 0.38 | 0.04 | 0.02 | 0.12 | 0.12 | 0.27 | 0.01 | 0.06 | | 0.00 | 0.07 | 0.05 | 0.00 | 0.17 |
| | 7 | 0.83 | 0.34 | 0.13 | 0.07 | 0.02 | 0.47 | | 0.03 | 0.04 | | 0.00 | 0.12 | 0.00 | 0.09 |
| JFB-15-3-2 | 1 | 7.07 | 2.66 | 1.99 | 1.06 | 0.58 | 0.10 | 0.42 | 0.24 | 0.27 | | 0.09 | 0.29 | 0.15 | |
| | 2 | 12.82 | 8.50 | 4.46 | 3.05 | 0.74 | 2.40 | 0.74 | 0.12 | 0.20 | 0.11 | 0.06 | 0.13 | 0.24 | 0.35 |
| | 3 | 0.69 | 0.17 | 0.06 | 0.22 | 0.46 | 1.11 | 0.18 | 0.03 | 0.06 | 0.07 | 0.16 | 0.09 | 0.16 | 0.45 |
| | 4 | 7.57 | 4.67 | 2.92 | 1.76 | 1.26 | 2.26 | 0.82 | 0.50 | 0.21 | 0.07 | 0.06 | 0.17 | 0.22 | 0.08 |
| | 5 | 3.41 | 2.03 | 2.11 | 0.46 | 1.02 | 0.25 | 0.07 | 0.05 | 0.07 | 0.04 | 0.31 | 0.10 | 0.05 | 0.33 |
| JFB-15-3-3 | 1 | 5.74 | 4.22 | 2.68 | 1.78 | 1.25 | 2.31 | | 0.38 | 0.47 | 0.07 | 0.06 | 0.15 | 0.28 | 0.11 |
| | 2 | 3.89 | 2.38 | 1.77 | 0.82 | 0.16 | 1.06 | 0.37 | 0.13 | 0.18 | 0.05 | 0.03 | 0.15 | 0.07 | 0.13 |
| | 3 | 3.53 | 3.36 | 1.93 | 1.12 | 0.89 | 2.46 | | 0.22 | 0.34 | 0.21 | 0.24 | 0.06 | 0.23 | 0.27 |

## APPENDIX F

**Table 22.** Boron isotope data from Setters Formation tourmaline.

| Sample | Grain | $\delta^{11}B$ Reference | $^{11}B/^{10}B$ Measured | $^{11}B/^{10}B$ Average | $\delta^{11}B$ [JS79N-1] | $\delta^{11}B$ [NIST 951] |
|---|---|---|---|---|---|---|
| **EZ272** | | **-14.17** | 3.64 | 3.68 | -19.84 | **-34.01** |
| **EZ272** | | | 3.71 | | | |
| **JS82A-3** | | **-20.83** | 3.72 | 3.70 | -13.50 | **-27.67** |
| **JS82A-3** | | | 3.69 | | | |
| **JS79N-1** | | **-12** | 3.72 | 3.74 | -3.68 | **-17.85** |
| **JS79N-1** | | | 3.76 | | | |
| **EB67-90** | | **10.47** | 3.79 | 3.79 | 10.51 | **-3.66** |
| **EB67-90** | | | 3.79 | | | |
| **JFB-15-3-2** | #5 | | 3.75 | | 0.68 | **-13.49** |
| **JFB-15-3-2** | #5 | | 3.79 | | 11.32 | **-2.85** |
| **JFB-15-3-2** | #5 | | 3.78 | | 6.88 | **-7.29** |
| **JFB-15-3-2** | #5 | | 3.73 | | -6.10 | **-20.27** |
| **JFB-15-3-2** | #5 | | 3.78 | | 6.38 | **-7.79** |
| **JFB-15-3-2** | #5 | | 3.76 | | 3.39 | **-10.78** |
| **JFB-15-3-2** | #5 | | 3.73 | | -6.67 | **-20.84** |
| **JFB-15-3-2** | #5 | | 3.81 | | 15.88 | **1.71** |
| **JFB-15-3-2** | #5 | | 3.78 | | 8.09 | **-6.08** |
| **JFB-15-3-2** | #5 | | 3.73 | | -6.96 | **-21.13** |
| **EZ272** | | **-14.17** | 3.68 | 3.71 | -9.92 | **-14.17** |
| **EZ272** | | | 3.75 | | | |
| **JS82A-3** | | **-20.83** | 3.69 | 3.69 | -15.74 | **-29.91** |
| **JS82A-3** | | | 3.69 | | | |
| **JS79N-1*** | | **-12** | 3.75 | 3.75 | 0.00 | **-14.17** |
| **JS79N-1*** | | | 3.75 | | | |
| **EB67-90** | | **10.47** | 3.83 | 3.83 | 21.07 | **6.90** |
| **EB67-90** | | | 3.83 | | | |
| **JFB-15-3-2** | #1 | | 3.75 | | -1.84 | **-16.01** |
| **JFB-15-3-2** | #1 | | 3.73 | | -5.02 | **-19.19** |
| **JFB-15-3-2** | #1 | | 3.74 | | -2.44 | **-16.61** |
| **JFB-15-3-2** | #1 | | 3.76 | | 0.78 | **-13.39** |
| **JFB-15-3-2** | #1 | | 3.77 | | 5.41 | **-8.76** |
| **JFB-15-3-2** | #1 | | 3.78 | | 7.04 | **-7.13** |
| **JFB-15-3-2** | #1 | | 3.73 | | -4.61 | **-18.78** |
| **JFB-15-3-2** | #1 | | 3.78 | | 8.65 | **-5.52** |
| **JFB-15-3-2** | #1 | | 3.77 | | 5.92 | **-8.25** |
| **JFB-15-3-2** | #1 | | 3.73 | | -4.98 | **-19.15** |
| **JFB-15-3-2** | #1 | | 3.82 | | 16.88 | **2.71** |

*This measurement of standard JS79N-1 was used for normalization calculations

(**Table 22.** Continued.)

| Sample | Grain | $\delta^{11}B$ Reference | $^{11}B/^{10}B$ Measured | $^{11}B/^{10}B$ Average | $\delta^{11}B$ [JS79N-1] | $\delta^{11}B$ [NIST 951] |
|---|---|---|---|---|---|---|
| **EZ272** | | **-14.17** | 3.72 | 3.72 | -8.41 | -22.58 |
| **EZ272** | | | 3.72 | | | |
| **JS82A-3** | | **-20.83** | 3.70 | 3.69 | -16.30 | -30.47 |
| **JS82A-3** | | | 3.68 | | | |
| **JS79N-1** | | **-12** | 3.72 | 3.70 | -13.23 | -27.40 |
| **JS79N-1** | | | 3.69 | | | |
| **EB67-90** | | **10.47** | 3.79 | 3.82 | 19.02 | 4.85 |
| **EB67-90** | | | 3.85 | | | |
| **JFB-15-3-2** | #3 | | 3.75 | | -1.81 | -15.98 |
| **JFB-15-3-2** | #3 | | 3.77 | | 3.85 | -10.32 |
| **JFB-15-3-2** | #3 | | 3.80 | | 14.07 | -0.10 |
| **JFB-15-3-2** | #3 | | 3.79 | | 9.45 | -4.72 |
| **JFB-15-3-2** | #3 | | 3.84 | | 23.75 | 9.58 |
| **JFB-15-3-2** | #3 | | 3.84 | | 22.28 | 8.11 |
| **JFB-15-3-2** | #3 | | 3.80 | | 13.91 | -0.26 |
| **JFB-15-2-2** | #1 | | 3.79 | | 11.42 | -2.75 |
| **JFB-15-2-2** | #1 | | 3.77 | | 5.90 | -8.27 |
| **JFB-15-2-2** | #1 | | 3.78 | | 6.53 | -7.64 |
| **JFB-15-2-2** | #1 | | 3.79 | | 10.84 | -3.33 |
| **JFB-15-2-2** | #1 | | 3.77 | | 4.21 | -9.96 |
| **JFB-15-2-2** | #2 | | 3.79 | | 11.07 | -3.10 |
| **JFB-15-2-2** | #2 | | 3.79 | | 10.19 | -3.98 |
| **JFB-15-2-2** | #2 | | 3.82 | | 17.32 | 3.15 |
| **JFB-15-2-2** | #2 | | 3.79 | | 8.91 | -5.26 |
| **EZ272** | | **-14.17** | 3.74 | 3.74 | -3.51 | -17.68 |
| **EZ272** | | | 3.74 | | | |
| **JS82A-3** | | **-20.83** | 3.67 | 3.70 | -14.93 | -29.10 |
| **JS82A-3** | | | 3.72 | | | |
| **JS79N-1** | | **-12** | 3.70 | 3.71 | -11.55 | -25.72 |
| **JS79N-1** | | | 3.72 | | | |
| **EB67-90** | | **10.47** | 3.82 | 3.83 | 20.18 | 6.01 |
| **EB67-90** | | | 3.84 | | | |