The Greenmantle Farm Mineral Occurrence

Greenmantle Farm on the Essonville Line in Wilberforce, Ontario is an extremely special place.

Imagine being the first person to see Niagara Falls or the Grand Canyon. More specifically, imagine being the first to see any beautiful landscape before it was altered by human presence.

A family tours a calcite cave at Greenmantle Farms.

Mark and Sandra Bramham are the proud owners of an extraordinary piece of property. They are the keepers of what is arguably a globally significant mineral occurrence. On their property is the most notable occurrence of a mineral that has been found in perhaps only three other places in the world. The mineral fluorrichterite was not discovered until recently and not officially recognized as a separate mineral species until 1996. It is very rare. The minerals apatite, hornblende, tremolite, actinolite, orthoclase and quartz also occur on their property.

A Special Opportunity

What is truly special about the Bramham's mineral occurrence is that it has never been touched. The site in itself is a rarity, but it has also been preserved in an undisturbed state. It is as the owners found it. When the Bramham's bought the property 30 years ago, the previous owners made no mention of the mineral occurrences. There is also evidence that the site has not even been touched by native North Americans. This adds up to an exceptional opportunity for those wishing to view the site.

The Bramham's have a deep feeling of reverence and appreciation for what occurs on their property. They see themselves as the stewards of an extraordinary occurrence within the Haliburton landscape. Mark and Sandra are also retired teachers giving them a unique viewpoint. As educators, they not only want to preserve the site as an example of such occurrences, but also wish to share the beauty of the site with others.

Their property is also regarded as an opportunity to reveal the mystery and the science of the Earth's history as portrayed by the rocks and minerals that occur there. For those of us not familiar with the particulars of geology and mineralogy, much is revealed by what can be directly witnessed on their property. In the future, universities may conduct detailed research on the geological history of this occurrence taking advantage of the uncompromised state of the site.

The Bramham's thank all in advance for removing *nothing* from the site but photographs, and hopefully a deeper understanding of geology and its relevance to the living world.

Fluorrichterite exposed in calcite.

Setting The Stage

The Earth's crust in Haliburton County is part of **the Canadian or Precambrian Shield.** The Canadian Shield is the oldest foundation of the North American continent ranging in age from about 2.5 to 0.9 billion years. Mountain ranges such as the Rocky Mountains and the Appalachians are younger having been added on to the outside edges of this older core of the continent.

Haliburton County belongs to a part of the Precambrian Shield called the Grenville Province. All the rocks that make up this portion of the shield have their own complex histories. However, they evolved all together as a unit of the Earth's crust sharing some common historical points. This defines a geological "province". The Grenville Province was welded onto the older, pre-existing rocks of the Precambrian Shield between 0.9 and 1.2 billion years ago. It was at this time the rocks of the Wilberforce area as we see them today were born.

This collision of the Grenville Province with the older Superior Province was just like pushing a wad of Play-Doh against a wall, but over a long period of time. The Superior Province was the wall and the Grenville Province was the Play-Doh. Some of the Grenville Province material went up, and some of the material went down. The rocks that were deformed upward during the collision probably created mountains like the Himalayas. These rocks have long been weathered and eroded away over the last billion years or so.

On the other hand, the rocks that were deformed downward during the collision **were buried to a depth of about 10 to 15 kilometres.** The pressures and temperatures created by this depth of burial caused changes to the original material. Think of baking a cake. Certain ingredients are mixed together, then put into the oven at a certain temperature and pressure for a certain length of time. When the cake comes out of the oven, it has a new texture (hopefully!) and brand new substances have been created from the original ingredients. These rocks here are not really any different. Certain elements and molecules were buried to a great depth and subjected to certain temperatures and pressures for a period of time. When the rock "came out of the oven" just over 1 billion years ago, it contained new substances (minerals) and had a different texture than it had previously.

The process described above is called **metamorphism**, and these rocks are called **metamorphic rocks**. *"Meta"* means "after", and *"morph"* means "shape". So, a metamorphic rock is an "after-shape" rock. Time, pressure and heat have changed these rocks from their original form and mineral content.

It is also believed that these rocks have been put in the oven more than once. In other words, these rocks have undergone multiple periods of metamorphism. Each time, the texture and mineral content may have changed.

Weathering and erosion removed a lot of rock over the last billion years to allow these once deeply buried rocks to come to the surface. An important point to always remember while on the Precambrian Shield is that the minerals and textures that we see in outcrop are the result of a long tortured history that includes great pressures and temperatures.

So, the rocks of the Wilberforce area are about **1.1 billion years old**. This age means that the rocks took on their present texture and mineral content during the collision of the Grenville Province. The actual history of these rocks, however, would have begun long before this age. The story of the rocks is now frozen in the textures and minerals for us to ponder, reflect upon and interpret. The mineral species in the rocks and the way the minerals have grown together help reveal some of the events that have resulted in the kinds of rocks we see today at the surface in outcrops.

Rocks or Minerals?

To understand how the minerals of interest at this site were created, we need to understand how the rock in which they occur was created. It comes down to this; if the rock is the team, the minerals are the players and the geological history is the game. To understand what the players are doing, you need to understand what game the whole team is playing.

Rocks are combinations of minerals just like salads are a combination of ingredients. Rocks are most often a combination of many different mineral species. Minerals are like the ingredients in salads. A tossed salad is made up of iceberg lettuce, tomatoes and carrots, etc. A Caesar salad is made up of romaine lettuce, parmesan cheese and garlic, etc. Each is a different type of salad because of the different ingredients. It’s the same for rocks; different combinations of minerals make up different types of rocks.

The upshot of the above is that the origin of one mineral species within the rock cannot be defined without understanding the origin of the rock that it occurs in. In other words, explaining how the rock was created explains the history of most if not all the minerals that make up the rock.

Specific Geology

The origin of the rocks found on the Bramham’s property is the topic of somewhat of a controversy. There are two main schools of thought on how the rocks formed.

The longest held belief is that the rocks on the Bramham’s property are metasedimentary rocks. A “metasedimentary” rock is one that was originally a sedimentary rock that has been metamorphosed. That is, the original rock was changed by heat, pressure and time. It is generally thought that these rocks were originally sediments laid down on the bottom of an ancient ocean floor initially forming sedimentary rock known as limestone. Limestone is mostly made up of a mineral called calcite.

It is then thought that the parent limestone was buried during the collision of the Grenville Province. This burial elevated the pressure and temperature, both increasing with the depth of burial. As an intermediate step, the temperature and pressure would have metamorphosed the limestone into a rock type called marble.

However, metamorphic rocks formed by burial metamorphism usually exhibit a layering of the minerals in response to the pressure under which they formed. The calcite-rich rocks on the Bramham's property generally do not exhibit this metamorphic layering. This may be because, at some point, the temperature may have reached the melting point of the calcite that made up the marble. Once this temperature was reached, the calcite melted. Just like an Etch-A-Sketch being shaken to erase an image, the metamorphic marble melted and lost any texture gained through the metamorphic processes. Upon crystallization from the melt, the newly hardened rock took on the homogeneous, non-layered texture of an igneous rock. And it was upon crystallization that the present minerals of particular interest were formed from the original ingredients of the sedimentary limestone. These new minerals include the fluorrichterite, apatite, orthoclase, hornblende, tremolite and actinolite.

That is one theory.

The second theory is possibly a simpler one to grasp. It is thought by some that the igneous-looking rock comprised mostly of calcite that bears the fluorrichterite and apatite is originally an igneous rock, and not the result of metamorphic processes. During or perhaps after the stresses and strains of the Grenville Province collision, igneous melts were able to intrude into the rock above. The molten material then crystallized, forming rock with an igneous texture. On its way, the molten igneous fluid may have partially melted minerals and incorporated other elements into the melt to help create the interesting mix of minerals observed today.

Igneous rocks that are made up of greater than 50% carbonate minerals (calcite, dolomite) are known as carbonatites. Globally, carbonatites are quite rare. However, there appears to be some compelling evidence for this second theory.

Carbonatite lavas have been observed to give off high quantities of fluorine gas. If the carbonate-rich rock on the Brahmham's property were a carbonatite, this could help explain the presence of the fluorrichterite with incorporates fluorine in its structure. Carbonatites are also often found side by side with a quartz-poor rock called syenite. The rocks adjacent the calcite-rich rocks on the Brahmham's property have indeed been identified as syenites.

However, because of multiple periods of metamorphism, it is very difficult to sort out what these rocks were originally. The rocks in the Haliburton/Bancroft area of the type found on the Bramham's property are the subject of ongoing research and debate.

Minerals of Interest

Regardless of what the rock's origin is, it is clear that most of the minerals of interest were crystallized from a melt. That is, the apatite, fluorrichterite, orthoclase, quartz, hornblende, actinolite and tremolite all formed from a molten mixture of minerals. Evidence for this is directly related to the reason for these minerals' appeal.

A sample of tremolite crystals.

Crystal Sense

All minerals occur as crystals. The word "crystal" is inherently tied to the definition of a "mineral". This requires some explanation.

If a substance is truly a mineral, the atoms and molecules are bonded together in ordered arrangements that are repeated in all dimensions. The patterned design taken on by a collection of molecules is decided by the particular chemistry of each type of molecule. Patterned molecular arrangements are referred to as crystalline structures. Each mineral species has its own patterned molecular arrangement. This crystalline structure defines each mineral and dictates that minerals are crystalline substances. Each growth of a mineral is therefore a crystal by definition, regardless of the shape of the crystal.

However, the symmetry of each mineral's patterned crystalline architecture is seldom expressed outwardly in a shape that we can see and touch. Why? Most often, this is because many individual crystals grow simultaneously and compete for space. There is often not the "elbow room" required for the expression of the geometric shapes that we most often associate with "crystals". Because of this competition for space, most crystals have completely irregular shapes. However, they are still crystals.

An example of this lack of space to grow is the crystallization of the light coloured calcite that forms the host of the apatite and fluorrichterite. The calcite comprised the vast majority of the melt. Upon cooling, all the calcite crystallized almost simultaneously. Billions of calcite crystals formed more or less at the same time, all fighting for space. There was no opportunity for the outward symmetry and geometry of each calcite crystal to be expressed. This is why the calcite found on the Bramham's property does not show any crystal shape. Crystals that show no crystal shape are referred to as being *anhedral*.

Why then, do the fluorrichterite crystals show distinct crystal shapes while occurring within the calcite that does not show any crystal shape? (Crystals that show crystal shape are referred to as being *euhedral*.) There are basically three different ways that solidifying crystals can be given the "elbow room" to grow into a shape that reflects the crystalline structure of the minerals. One way is to grow into an open space. This can occur when minerals crystallize in an open fracture or cavity.

A cluster of quartz crystals.

A second way is for the growing crystal to actually fight for elbow room as it grows. Garnet, for example, often grows in the solid state during the process of metamorphism. As heat and pressure are applied, garnet grows from the appropriate mineral and molecular ingredients that are available within the parent rock. As a new garnet crystal grows, it is able to push its way outward into the surrounding material and express its inherent geometric shape.

In the case of the fluorrichterite and the apatite, the answer lies with the order in which the minerals crystallize from the molten mixture of minerals. If a crystal grows surrounded by still molten material, the growing crystal will be allowed to grow unhindered and express its true crystal geometry. Surrounded by liquid, newly emerging solid crystals have the elbow room to grow unobstructed.

Why do different minerals crystallize at different times? This occurs because each mineral species as a molten liquid has its own temperature at which it will solidify from the liquid state, exactly like water and alcohol freeze at different temperatures.

So, minerals that crystallize early on in the cooling of a melt are more likely to show a geometric crystal shape because they are allowed to grow within the yet to crystallize liquid. The apatite occurring in well formed hexagonal prisms also crystallized prior to the surrounding calcite.

Crystal Size and Rate of Cooling

The minerals that have crystallized from igneous parent materials at Greenmantle Farm display another geological concept that is of note. In general, the size of crystals in rock can vary from several metres in length down to being so small that they are indistinguishable, even under a microscope. The crystal size of most of the mineral species crystallized from molten material on the Bramham's property (calcite, fluorrichterite, apatite, hornblende, orthoclase) is relatively large. The reasons for this further reveal the geological history of the property.

One of the parameters that control the size of crystals is how quickly or how slowly the igneous melt cools down. In the case of the calcite intrusions on the Bramham's property, the rate of cooling was relatively slow. A slow rate of cooling is what would be expected for molten material that was buried kilometres down within the Earth's crust. The heat of the Earth's internal fire keeps all rock at depth much hotter than temperatures found on the surface. The entire system was hot, so, once the calcite-rich magma was in place, it lost heat very gradually to the surrounding host rock.

Eventually, the temperature of the melt did drop to a point where minerals began to crystallize. The extremely slow drop in temperature allowed a couple of things to happen. First, it allowed the molecules of each constituent mineral to form within the melt while still in the liquid state. As the temperature dropped further, the molecules then had the opportunity to connect and begin the growth of solid crystals. Because this all happened very slowly (perhaps over hundreds of thousands of years), the molecules were able to become organized in an ordered arrangement.

Once the crystals started to grow and the slow steady cooling continued, more of the same molecules added on to the growing crystals in a gradual, undisturbed manner that extended on the pattern of the original crystals. As this continued, the crystals increased in size.

This enlargement of the crystals would have continued as the temperature dropped until all the appropriate molecules within the melt were used up. As discussed earlier, the calcite was the last to crystallize at the lowest temperature. The calcite also crystallized slowly into large crystals.

The result of all this is what we see today; an assemblage of minerals that are occurring as relatively large, coarse-grained crystals. This is courtesy of, and evidence of, the slow cooling of the magma from which the minerals crystallized.

The most extreme opposite example of how rate of cooling controls crystal size is the creation of glass. Manufactured glass is derived from what is basically a molten mixture of minerals. Obsidian is a natural version of glass forming from lava. The formation of glass involves a relatively rapid cooling and solidification. By solidifying quickly, the atoms and molecules in the melt don't have the opportunity to organize themselves in any ordered arrangement. The result is a solid, but by definition, the material is not crystalline because of the lack of any patterned molecular arrangement. So, in the case of glass, crystals aren't just small: they don't get the chance to form at all.

Recent Geological History and Today's Landscape

The landscape at Greenmantle Farm and the rest of the Precambrian Shield is a result of the interaction of two sets of parameters. One is the character of the bedrock itself. The second is the particular set of forces that have weathered and eroded the bedrock. How these two factors have intertwined through the millennia has given rise to the details of landscape we see today.

Over the last billion years or so, the rock that is now on the surface throughout most of the Precambrian Shield has been brought up from a great depth of burial. The actions of weathering and erosion have removed approximately 10 kilometres of overlying rock to expose the rocks we presently see in outcrop.

Between about 78,000 and 8,000 years ago, it is thought that most of Canada was covered in up to three kilometres of ice. This is known as the Wisconsin glaciation. Because this glacier occurred on a large continuous scale spanning the breadth of the North American continent, this type of glaciation is known as continental glaciation. Modern evidence of this is the continental glacier that covers most of Greenland today. The glacial ice is about three kilometres thick above the underlying bedrock.

Three kilometres of ice weighs a lot. However, it is not just the weight of the glaciers that altered the landscape. The continental glacier did not just lay stagnant on top of the landscape. It also moved across the landscape. In the Wilberforce area, the motion was in a north to south direction. The movement of the glacier, in combination with the great mass of the ice, was not only able to break up or weather a lot of rock. The glaciers also had the ability to remove or erode the broken rock.

The combined action of weathering and erosion made the glaciers the most significant factor in wearing down bedrock across almost all of Canada. The glaciers were able to crush, scrape, scour and remove underlying bedrock as it moved along. In combination with the bedrock, the North American continental glaciers determined the character of the present day landscape. Over the last million years alone it is thought that there have been four periods of glaciation.

This begs an obvious question. After repeated advances of the continental glacier ripping and scraping across the land, why then was the landscape not flattened to a featureless plain? Indeed, the landscape is not featureless. On the Bramham's property, there are cliffs, valleys and changes in elevation of close to 100 metres. What would cause so much topographical variation within such a limited area? The answer lies in the particulars of the bedrock's character.

The main reason prompting variation is the simple fact that the bedrock itself is not uniform. That is, natural variations in the bedrock guarantee that the rock is stronger and more resistant to weathering and erosion in some areas and more vulnerable in others.

Possibly the most important features in the Haliburton area that have imparted weakness to the bedrock are faults. A fault is where the Earth's crust has failed and relative motion occurred between the rock on either side of the plane of failure. Faulting occurs when rock is at a low enough temperature to undergo brittle failure in response to stresses. In contrast, rock that is very hot will be pliable and will undergo plastic deformation, or folding, in response to stresses. So, the faulting on the Precambrian Shield for the most part occurred when the rock was at a lower temperature, and was therefore more brittle. This also suggests that the faulting occurred when the rock was closer to the Earth's surface and hence, much more recently in the area's geological history.

The initial brittle failure of the rock may have been caused by simple contraction as the rock cooled down. Once the rock fractured, stresses remaining from the Grenville Province collision would have prompted the shifting of the rock along the plane of failure. Two blocks of the Earth's crust grinding against each other represents the unleashing of a lot of energy. The rock along the two opposing rock faces would be subjected to a lot of violence; cracking, grinding, crushing and pulverizing….or worse!

As a result, the rock along many fault lines has lost all strength and competence. In many cases, the rock is broken and jumbled having little integrity compared to the surrounding rock outside of the fault zone. Enter the glaciers … stage north.

The glaciers showed no mercy. As they ripped and scraped across the landscape, the weakest rock would have been more susceptible to the glacial movement. As the faults became exposed at the Earth's surface, the weak, broken rock along the fault zones was picked upon. The glaciers were able to preferentially dig deep into the less competent rock along the faults.

Much of the topographic variation throughout Haliburton County can be attributed to this interplay between the glaciers and the weak rock found along fault zones. The cliffs seen throughout the County are the result of the glaciers removing fractured, faulted rock leaving behind the stronger, unbroken material.

The Bramham's property is probably criss-crossed by faults. The lower areas would be where the faults occurred and the higher areas are found between the faults. The glaciers were able to dig out the lower areas along the faults. The areas of higher elevation represent the more competent rock between the faults. The hilly topography of Greenmantle Farm is therefore a direct result of the interaction between the faults and the glaciers.

Streams: Now You See It, Now You Don't

Small streams that flow across the Bramham's property perform some amazing disappearing acts. Some streams have what appear to be a good steady flow and then completely disappear over a couple of metres. Where do they go?

It is the belief of the author and the Bramham's that the disappearance of the streams marks the location of faults that may criss-cross the property.

The flow of water on the Earth's surface is controlled by topography, precipitation and by the level of groundwater saturation, or the water table. With all other parameters held constant, the particulars of ground water flow have a great effect on surface waters. If the ground is not saturated with water, surface water will percolate downwards to fill the available open space leaving the surface dry. In other words, the ground gets first dibs on the water, courtesy of the fundamental force of gravity.

So, why do the streams flow along the surface then suddenly disappear? For the most part, the metamorphic and igneous rock has very little open space, probably about 0.1%. There is little opportunity for the rock to accept any water. Streams will flow along for great distances not losing any appreciable water to percolation.

But what if the underlying rock is cracked and broken up? What if the rock has actually been shifted or jumbled by some mechanical action, such as a fault, a glacier, or both? The action of faulting alone creates open space. The further action of the glaciers disturbs the broken, faulted rock. So, along a fault, one would expect there to long, narrow zones of open space in the rock.

Further more, if open space introduced by faulting and glaciation exists within marble, then the action of water itself has probably helped increase the amount of open space. The marble found on the Bramham's property is composed of calcite which is quite water-soluble compared to most other minerals. Once water finds its way into open spaces within the marble, the calcite will begin to dissolve and get carried off in solution with the water. This action increases the open space, which in turn, can accept more water. This ongoing dissolving of the calcite combines with the results of the faulting and glaciers to create zones of open space in the bedrock. All of the above have an effect on surface water flows.

So, the story of the disappearing streams goes something like this: a stream flows along above well sealed rock with little open space. The water stays on the surface because downward percolation is not possible. At some point, the surface flow encounters a fault in the underlying rock, where there will be open space to accept the surface water. Because of gravity, the water will quickly choose to occupy the open space along the fault. As a result, the water percolates downward and disappears from the surface. The disappearance is mysterious because the reason is completely hidden.

The explanation for the disappearing streams on the Bramham's property highlights that a complete understanding of landscape dynamics begins with knowledge of the underlying geology.

Mmm….Calcium!!

With an abundance of calcium carbonate (calcite) on the Bramham's property, it is not surprising that the area hosts a number of calcium-loving plants. Plants that tend to be restricted to calcareous soils are known as being "calciphile" which means calcium-loving.

Calcium is an essential nutrient that plays an important role in determining the physical and chemical characteristics of soil. Calcium is also required for the elongation and division of cells in plants. Adequate calcium helps delay the physical deterioration of leaves associated with aging and slows down or prevents leaf and fruit fall.

Calcium and specifically calcium carbonate also helps control soil acidity. When calcium levels in the soil are low, acidic soil conditions may result from the acids formed by the decay of vegetation. This can cause the solubility of manganese and aluminum to increase making the soil toxic to some plants.

This all adds up to some plant species not growing very well, if at all, without a good supply of calcium in the soil.

Many fern species are calciphile. One fern species present in abundance on the Bramham's property is maidenhair fern. It is a known calcium-loving plant often growing on limestone terrains. (Limestone is also predominately comprised of calcite)

Another plant found on the property that prefers calcareous soils is wild leek. This plant, also known as ramps, is a member of the onion family. Both the leaves and the root are edible. The plant has a strong flavour that lies somewhere between onions and garlic. It is enjoyed as a flavouring for many foods and, when eaten raw, has an odour that stays with you for days.

Mark and Sandra have suggested that the extent of the calcite-rich rock bodies on their property can be traced using the presence of these calciphile plants. This is not a far-fetched idea. Plants have been used as an exploration tool to locate the presence of certain rocks and minerals for decades if not centuries.

A group of wild leek.

The response of plants to the abundance of calcium on the Bramham's property serves as a pointed example of how the living world is dependent on the non-living aspects of the landscape.

Mineral Occurrence Descriptions

Fluorrichterite

This location demonstrates that the soil cover in this immediate area is quite thin, perhaps no more than a metre thick or less. The fluorrichterite has been exposed by the action of a seasonal stream. The stream appears to only flow during the spring melt. Over the years the stream has been able to scour away the thin layer of soil. At this location, the fluorrichterite is occurring in an outcrop of coarse-grained calcite that has a non-layered, igneous texure.

The fluorrichterite crystals are showing the typical diamond-shaped cross sections and double terminations in many cases. Crystals range from 1 cm to 10 cm in length. Colour ranges from almost black, dark grey to a dark dull green.

The action of the stream water here demonstrates that the calcite is very water soluble compared to most other minerals. This explains why the stream bed contains loose crystals. The calcite was weathered out by the water leaving the much more resistant fluorrichterite crystals intact.

Tremolite, Actinolite, Hornblende (Oh My!!)

These three minerals, plus fluorrichterite and others, belong to a mineral subgroup of the silicates known as amphiboles. The bedrock on the Bramham's property includes fairly extensive areas that are predominated by these minerals.

The amphiboles have their own defining molecular structural template as do other groups such as the pyroxenes and feldspars. For each amphibole mineral species, there is an idealized elemental composition. However, within the amphibole mineral structure, there is lots of opportunity for the substitution of certain elements with others, without changing the structural template. That is, many kinds of atoms (elements) can substitute for each other in the structural locations within the minerals' molecules. Because of this, there is a fair amount of variability in the composition of amphibole group minerals. Hornblende at least is known as the "garbage can" of the mineral kingdom.

A relationship exists between the three minerals listed in this description. For the mineral species tremolite, actinolite and hornblende, there are idealized compositional and structural versions. But because of the elemental substitution that can occur in this group of minerals, a continuous spectrum of elemental compositions can exist between two or more similar minerals. Therefore, the species compositions of tremolite, actinolite and hornblende act as compositional bookends and a range of compositions can exist in between. In other words, a crystal in one part of the property might be pure actinolite; 50 metres away, the composition of crystals may have changed slightly and have a composition somewhere between actinolite and tremolite. At another location the composition of the amphibole crystals may lie somewhere between hornblende and tremolite.

It is also suspected that there may be a compositional transition between the fluorrichterite and these other amphibole group minerals. The presence of fluorrichterite may be the result of slight compositional differences such as the presence of fluorine, and temperature of crystallization.

This range in composition between two or more similar minerals is known as a solid solution series. The defining “bookend” mineral species at each end of the spectrum is known as an “end member”. This variation is controlled by temperature, pressure and the availability of elemental ingredients. As discussed earlier, the crystallization of minerals is controlled by all of these factors. The minerals found on the Bramham’s property are the end result of these conditions.

The tremolite, actinolite and hornblende found on the Bramham’s property shows typical amphibole characteristics of moderately high hardness and two cleavages. The tremolite and actinolite are occurring in masses of coarse crystals with some euhdral expression when occurring with calcite. Colour ranges from beige to dark grey to black depending on compositional variation. The hornblende is typically dark green to black and, again, is euhdral when occurring with calcite. Hornblende is found in quite large crystals in some locations.

Apatite

Apatite is also occurring within the coarse-grained calcite of igneous texture. Crystals have formed in the typical hexagonal prisms and exhibit a bright green colour. The crystals are fractured and mostly cloudy with some good terminations. Apatite can substitute either fluorine, chlorine or the hydroxyl ion into its structure. The apatite found in surrounding occurrences such as the Bear Lake Diggings has been determined to be fluorapatite. This suggests, along with the fluorrichterite, that there was a certain quantity of fluorine introduced to the system at some point within the geological history of this area.

Orthoclase

Orthoclase is a member of the potassium feldspar family. The notable occurrences of orthoclase at Greenmantle Farm include blocky white crystals with well formed crystal habit. These crystals occur along what appear to be open fractures in the bedrock. The orthoclase crystals are lining the walls of these narrow, linear open-spaced structures along with calcite and hornblende. Upon closer examination, the true nature of this occurrence becomes evident.

Large orthoclase crystals.

At the edges of these open crevasses, the surrounding host rock and the minerals within the narrow structures meet and form sharp, well-defined boundaries. This suggests that these narrow, linear structures were dykes intruded as molten mixtures of minerals. Within these structures, coarse-grained calcite can be found weathering out around the other, more resistant minerals. It appears that the dykes once had a core of calcite that has probably been dissolved out by groundwater. The open spaced centre of these dyke structures is therefore courtesy of the solubility of calcite.

The orthoclase and hornblende are found at the outside edges of the dykes in contact with the host rock. It is assumed that calcite occupied the central open space of the structures. This ordered arrangement of minerals in a dyke or intrusion is called “zoning” because the minerals occupy well defined zones within the intrusion. How is it that the mineral species took on this ordered arrangement within the dykes?

Zoning occurs because each mineral species has its own temperature at which it will solidify from the liquid state, exactly like water and alcohol freeze at different temperatures. The hornblende and the orthoclase both crystallize at higher temperatures than calcite. This means that the hornblende and the orthoclase would have crystallized first as the dyke began to cool down. So, why are the hornblende and the orthoclase occurring at the margins and the calcite in the centre of the dykes?

The areas within the dyke that would cool first would have been the margins up against the cooler host rock. As hornblende or orthoclase began to crystallize from the melt at the cooler margins, it would have displaced the still molten calcite to the centre. As the liquid calcite was shoved to the centre, any other solid crystals forming in the centre of the dyke would also get displaced to the margins. The centre of the dyke would eventually be filled with molten calcite that cooled and solidified at a later time and at a lower temperature.

This also explains why the orthoclase and, to some degree, the hornblende exhibit well formed crystal shape. They crystallized prior to the surrounding calcite which remained in the liquid state long after the other minerals had crystallized.

It also appears that these dyke structures occur along the margins of the larger, calcite-rich bodies that occupy much of the Bramham's property. The dykes may have invaded fractures that opened up as a result of the main calcite intrusion cooling and contracting. The margins of the larger calcite intrusive bodies would have cooled and solidified first being up against the cooler host rock in the solid state. This explains why the dykes are found at the margins of the larger calcite intrusions.

Fractures opening up at the margins of the larger calcite rich intrusion would have then been invaded by molten material. This material probably came from a greater depth; it would have been under higher pressure and hot enough to still be in the molten state. This second intrusion of molten material invaded the fractures alleviating some of the pressure. Upon cooling, the molten material crystallized forming the mixture of minerals observed in the dykes today, including the orthoclase.

<u>Thanks</u>

Thank you for reading this report. If you have visited the Bramham's property, you are now aware of its special character. If you have not visited Greenmantle Farm, please take advantage of this once in a lifetime opportunity. As you can see from this report and their website (www.mineraltours.net), there is a lot happening. Recent and ancient geological histories have combined to create a landscape that reveals the complexity of geological processes.

The mineralogical marvel of this site has been preserved by the Bramham's with the help of all visitors to the property. It is hoped that what has occurred here has been made more comprehensible by maintaining this undisturbed state. It is also the Bramham's hope that the connection between the underlying geology and the living world has been brought to light through visits to the site.

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