

Special Note: This is an old paper from my sophomore year. It is not peer reviewed in anyway, and I think it may even be a draft version. Expect some spelling errors and some misinformation. I posted this because it is difficult to find information comparing the two. Please don't copy my work and give credit where it is due.

Ben Huffman

The Skaergaard Complex in Comparison with the Stillwater Complex



Looking southwest across Skaergaard Bay (near bay) and Kangerlussuaq Bay. The ship is left of center and has dimensions of 66 m long, 12.8 m wide, with a draft of ~4 m, and a displacement of 2000 tons (Hollocher 2001).

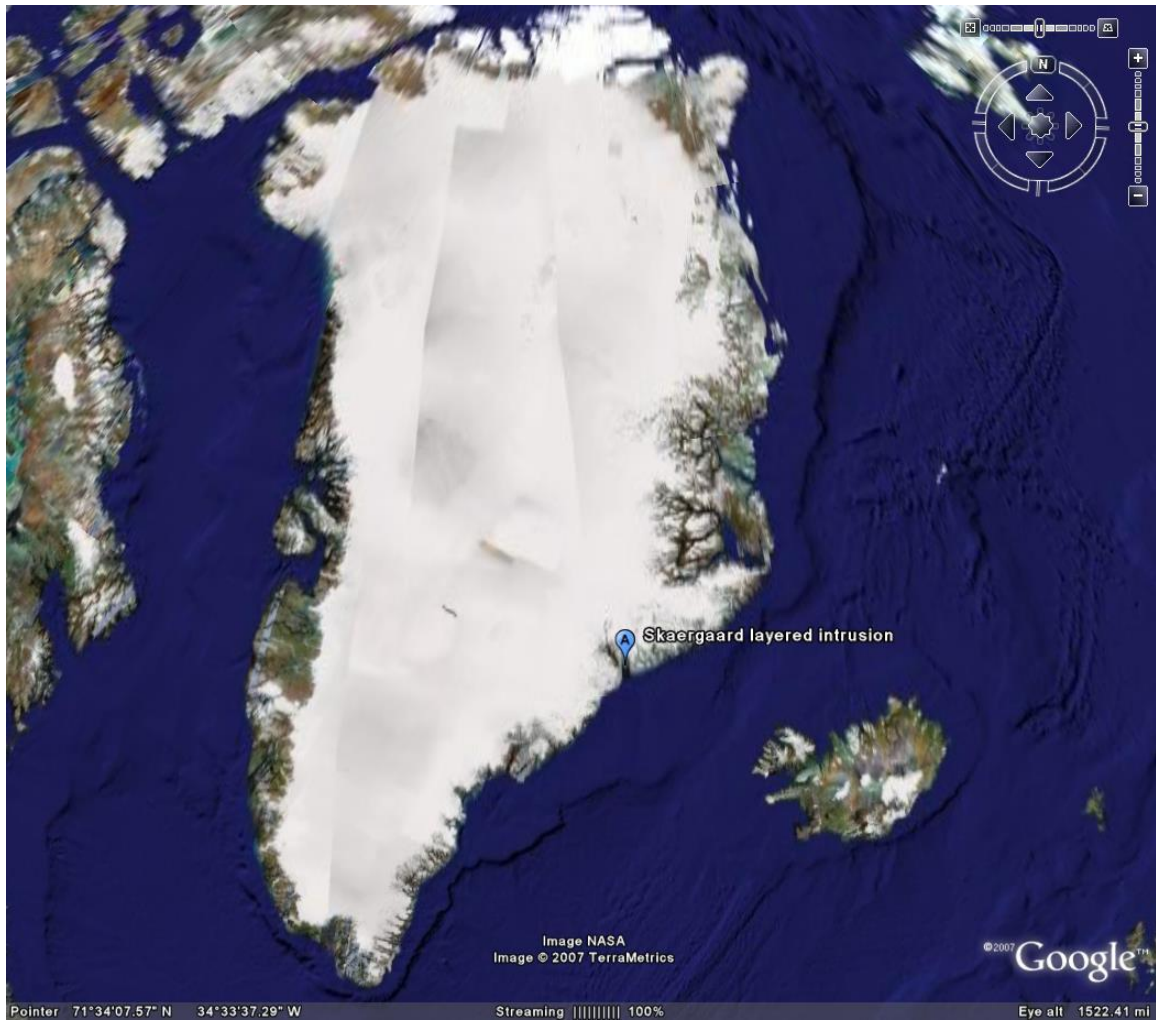


Figure 1 Location of Skaergaard Complex as viewed from GoogleEarth in 2007

Abstract

The Skaergaard Intrusion (Complex) is located in southeastern Greenland approximately at lat. $68^{\circ}S 10^{\circ}N$, long. $31^{\circ} 40^{\circ} W$. and is well known in geology as being one of the youngest testing locations for magmatic differentiation, crystallization, solidification processes, and the evolution of tholeiitic magma stored in crustal reservoirs. The Skaergaard Complex was made famous by Wager and his colleagues in the 1930s and has

become one of the most studied ultramafic complexes in the world. Wager's early work accounts for much of the base knowledge for recent discoveries. However, many of his early observations have been modified. The Skaergaard is one of the few places in the world that geologists can test their theories on magma differentiation. Recently mineral resources have added to interest in the Skaergaard. Like the Stillwater Complex, the Skaergaard has a large reserve of platinum group metals. Analysis of the two reveals similarities and discrepancies that can be drawn between the Skaergaard and Stillwater Complex. An examination of minerals common to Stillwater and Skaergaard yield little information to draw conclusions from, but it is important to recognize that more data could lead to new correlations.

History of the Skaergaard

“Skaergaard” is the international name that has been given to the area to describe the geological formation in eastern Greenland. The word “Skaergaard” is derived from the Scandinavian word “Skærgård”. Skærgård is loosely translated as a rocky coastline with many outlying islands where the sea meets a system of fjords (Andersen 2003).

Although the Skaergaard Complex has been studied heavily by many scientists, there is still a lot to learn about the complex because summers there are short and extensive ice fields cover much of the surface throughout the majority of the year. The working season is generally only a few months long. The rest of the time the average temperature is around -20° F, and snow and ice cover many of the outcrops, making hiking too hazardous for people to cover much area. There are no building materials other than rocks in this part of Greenland (Wager 1940). Any building material or fuel that is needed has to be imported so there is little support for scientists on extended missions to

studying the area. Until helicopters became common, the only way in or out was by ship. In most cases, people would leave from Iceland and hope that the weather would allow them to make it to shore. Often, icebergs would prevent the scientist from making it to shore for days (Andersen 2003).

Formation of the Skaergaard

The Skaergaard Complex formed approximately 55My ago in association with a hot-spot that is presently located beneath Iceland (Andersen 2003). The shape we see today is the same as it was 55My ago with the exception of some faulting. Recently it has been suggested that faults may be the controlling factor in the shape of the Skaergaard. Aerial photos seem to indicate that the margins of the magma chamber were controlled by faulting along what is now the edges of the intrusion.

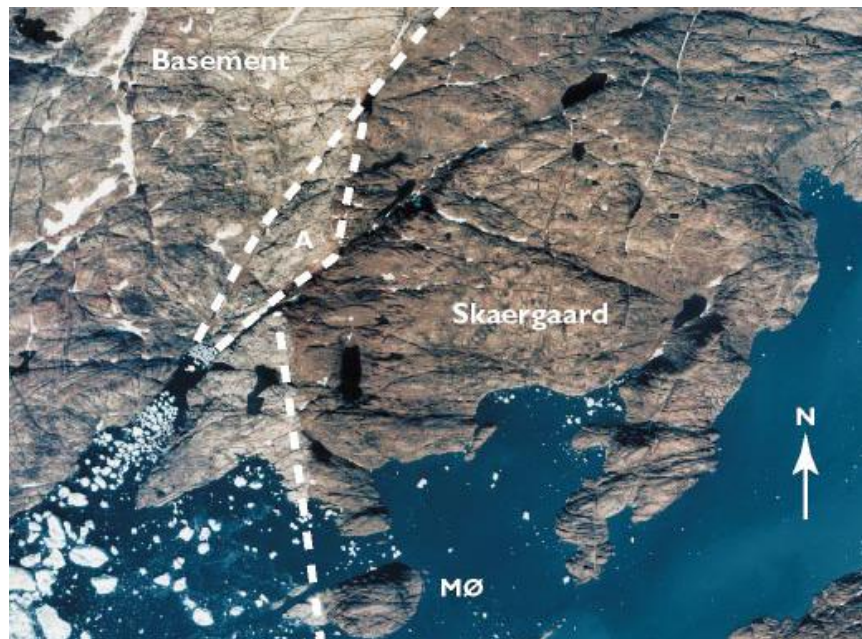


Figure 2
Aerial Photograph with color enhancement to show the edges of the Skaergaard (Nielsen 2004)

There is a distinctive change in rock type and age from the Skaergaard to the surrounding area. To the north of the Skaergaard, there are Archean Gneisses, and to the

south and east there are Eocene volcanic depots that are mostly basaltic in composition. At the surface the intrusion appears to be oval shaped with dimensions of approximately 11km by 8 km (Nielsen 2004).

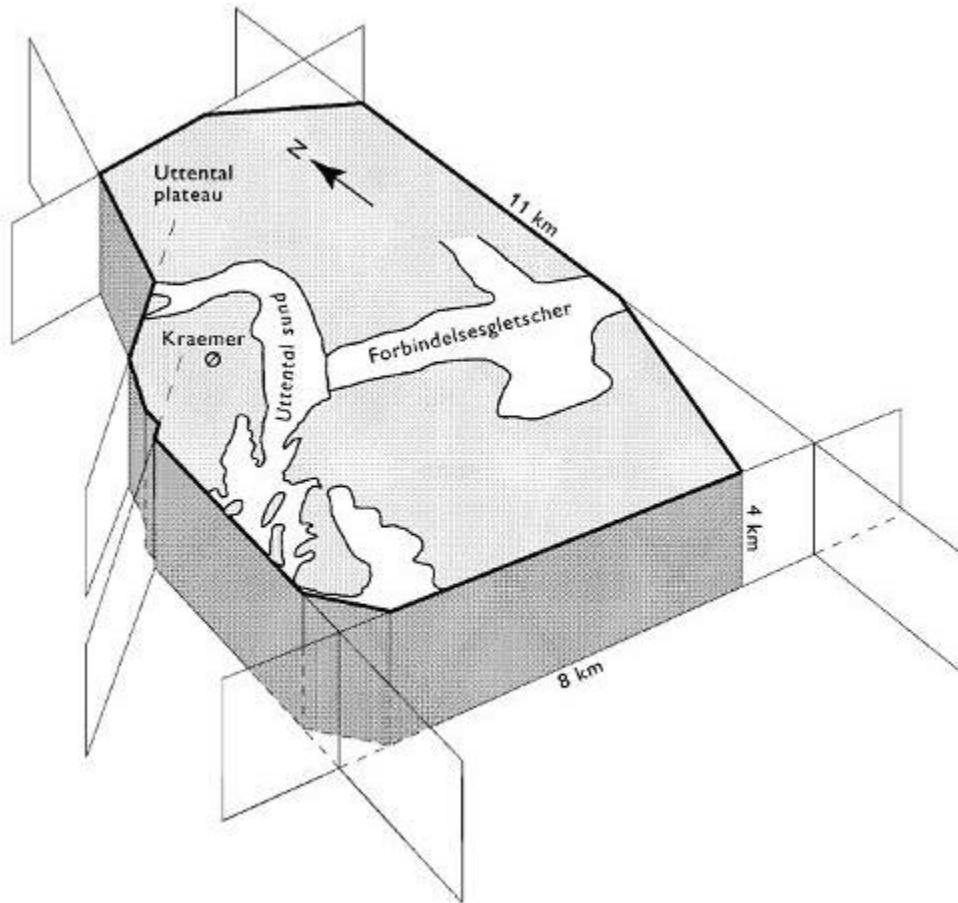


Figure 3
3D Cross-section showing the shape, size, and fault zones that border the Skaergaard (Nielsen 2004).

It is indicated that an intrusion of magma was able to uplift a large section of the overlying rock that had already been faulted in such a way that it could thrust upward and act like a lid for the magma chamber. The model for this process has been supported by gravity modeling of the Skaergaard [refer to figure 4] (Irvine 1992).

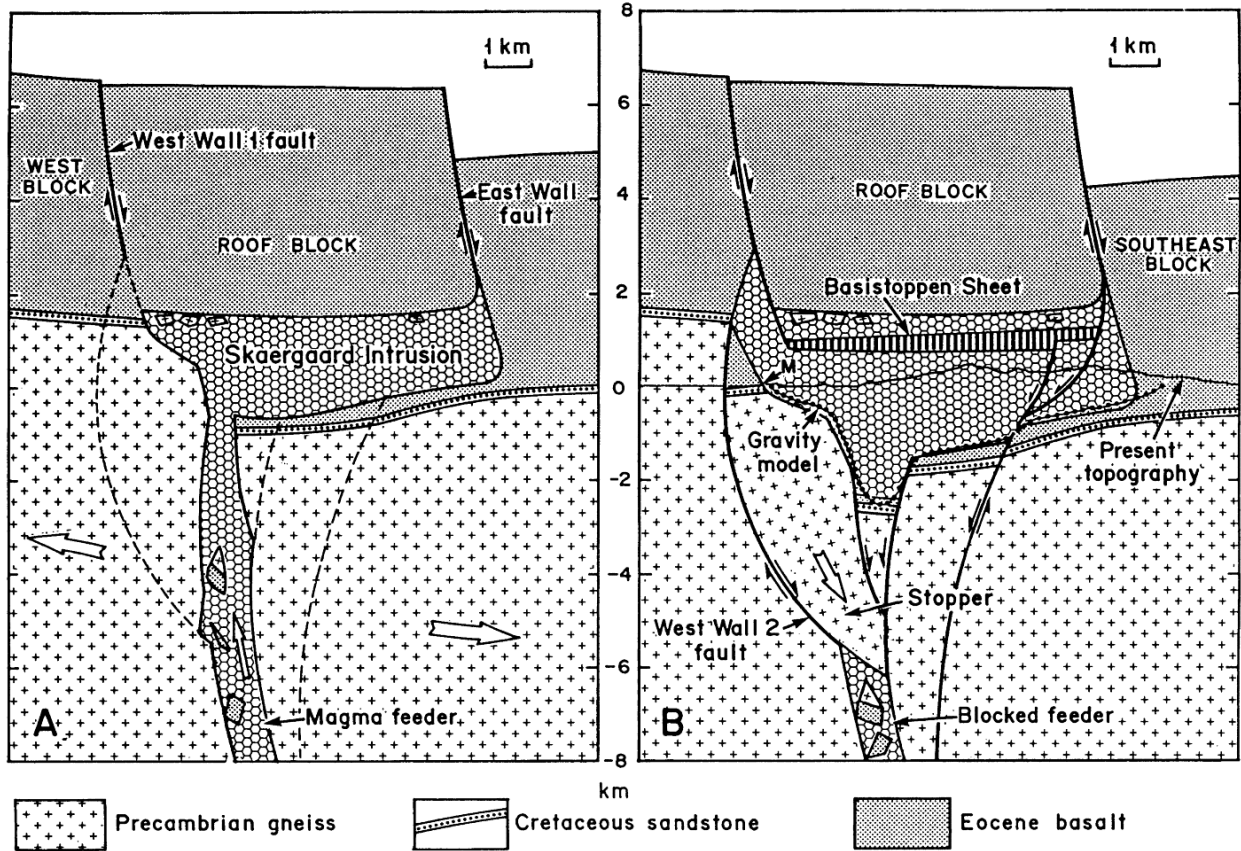


Figure 4 Formation processes model as indicated by gravity data and faults (Irvine 1992).

The unique scenario allowed for the ultramafic body to cool slowly below ground rather than erupting. Similar uplifting events have taken place at some super volcanoes. The Skaergaard may be thought of as a large volcano that was never given the opportunity to erupt, which left its magma chamber intact. The magma chamber was sealed as little as 2 kilometers below the surface. The uplift also caused the overlying rocks to be eroded away which has uncovered most of the Skaergaard Complex.

Layering in the Skaergaard

The Skaergaard is primarily made up of mafic and ultramafic rocks. These rocks are believed to have formed as a result of a mantle plume in a closed system, from a single injection of magma. This closed system allowed the magma body to cool slowly without turbation, which allowed differentiation to take place (McBirney 1979). The

result is a called “layered intrusion” which is defined as a plutonic complex that shows internal stratification and is believed to represent the crystalline products of fractional crystallization. The intrusions show concentrations of minerals, implying that mechanisms of mineral sorting operated during their crystallization. The resulting rocks indicate crystal sorting (McBirney 2003).

The Skaergaard is divided into three series: The Layered Series (LS), The Marginal Border Series (MBS), and the Upper Border Series (UBS). The Layered Series is subdivided into four zones. The unexposed zone is known as the hidden zone (HZ); The Lower Zone (LZ sub divisions a-c); the Middle Zone (MZ); and the Upper Zone (UZ sub division a-c). It is recognized that the Layered Series formed on the floor of the accumulation zone. Minerals were separated by gravity from the magma body as they cooled and became denser, causing them to sink to the bottom. The Marginal and Upper Border Series formed on the walls and roof. The banding in this area is much tighter because of the relatively high temperature contrast (McBirney 1979).

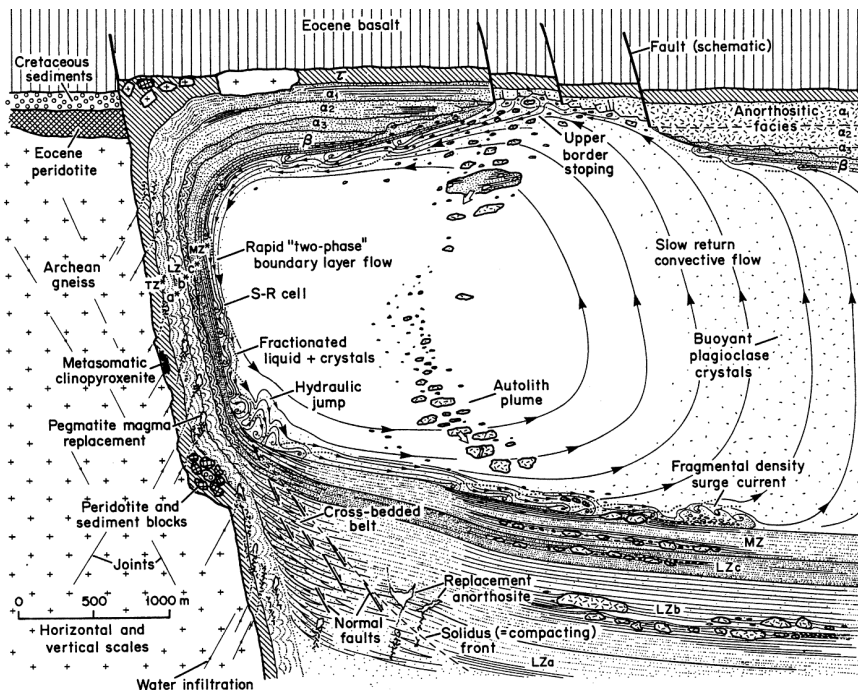


Figure 5

This diagram represents the cooling magma body and the resulting flow driven by density differences. Crystallization is seen taking place on the walls and floor of the magma chamber. Also modeled is the appearance of autoliths and xenoliths that brook from the roof and sank to the bottom of the chamber. (Irvine 1998)

There is no data describing the Hidden Zone of the intrusion because it is not exposed anywhere in the Skaergaard, and no drill cores have yet penetrated through the bottom of the intrusion. In the southern part of the intrusion there, is a small area of the roof exposed (McCallum I. S. 2003). The entire eastern margin of Greenland has subsided, causing the Skaergaard Complex to dip SSE, toward the sea, varying between 10 to 20 degrees (Nielsen 2004; McBiney & Creaser 2003). The shallow dip has helped expose more of the Skaergaard at the surface and has allowed scientists to examine everything from the Lower Zone to the Upper Border Series.

Maps and mineral analysis point to marginal cooling which means that correlations can be drawn between layers of minerals found on the bottom of the chamber with minerals near the top of the chamber (Refer to **Figure 6**). For example, the Lower Zone division “b” corresponds mineralogically to the Upper Border Series division “ α ”. Both of these layers contain Olivine, Plagioclase, and Augite. Some of the zones in the Skaergaard have a counterpart on the floor and roof, but there are a few that do not. The zones that do not have corresponding counterparts still have a similar mineral make up but contain variations in mineral ratios and compositions. The differences in composition are likely attributed to the change in pressure and temperature from the top of the chamber to the bottom of the chamber. An example of a zone without a counterpart can be seen in the Lower Zone sub division “c” which contains Plagioclase, Olivine, Augite, and Magnetite. There is near match in the Upper Border Series for that grouping of minerals. In the Upper Border series, Olivine seems to be replaced with Pigeonite which could indicate a slightly cooler environment during formation.

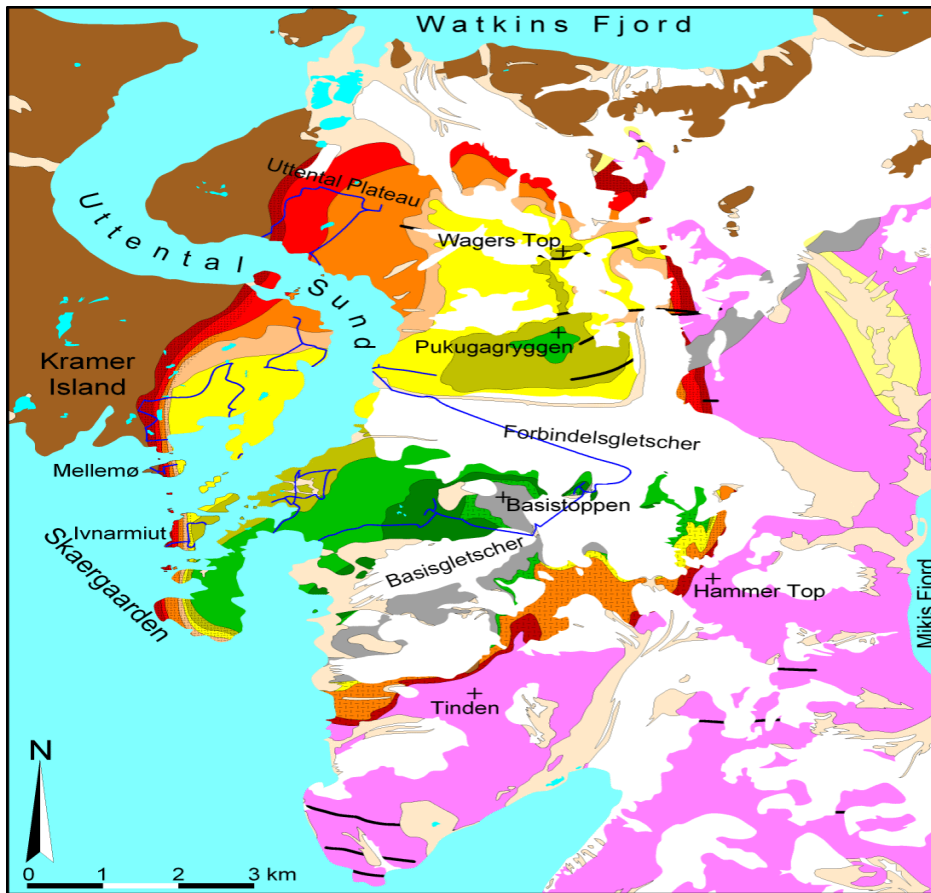
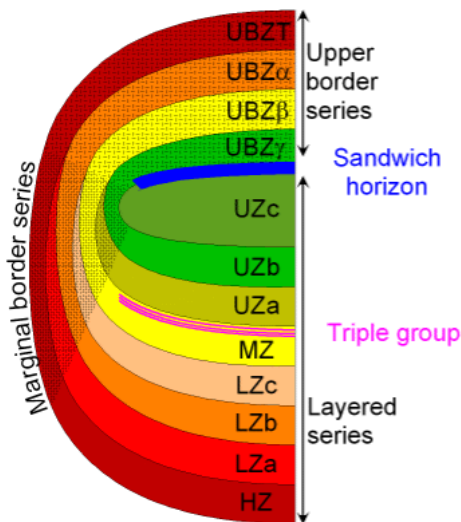


Figure 6: Geologic surface map with expected minerals to be found in those areas.
Modified (McBriney 1989)

Explanation of the geologic map units



Ice	
Holocene unconsolidated material	
Basistoppen sheet and feeder	
UBZT	Plag + Ol
UBZ α	Plag + Ol + Aug
UBZ β	Plag + Pig + Aug + Mt
UBZ γ	Plag + Ol + Fe-Aug + Mt + Ap
UZc	Plag + Ol + Fe-Bust + Mt + Ap
UZb	Plag + Ol + Fe-Aug + Mt + Ap
UZa	Plag + Ol + Fe-Aug + Mt
MZ	Plag + Pig + Aug + Mt
LZc	Plag + Ol + Aug + Mt
LZb	Plag + Ol + Aug
LZa	Plag + Ol
HZ	Plag + Ol
Eocene volcanics	
Cretaceous sediments	
Archean gneisses	

Modified after McBriney, 1989

Comparisons of the Skaergaard and Stillwater Complex

A comparison of the Stillwater Complex and the Skaergaard Complex reveals that the Stillwater Complex is significantly more complicated which could be expected because Stillwater is about 2.7 billion years older than the Skaergaard. The age, size, shape, and depth of formation are all significantly different when comparing the two. The Stillwater Complex is estimated to be about 2.7 billion years old. In comparison, the Skaergaard is only 55 million years old. The age difference is apparent not only in the weathering of the minerals but also in the physical structure of the complexes which is most easily viewed in cross section [Figure 7 & 8] (McCallum 2003).

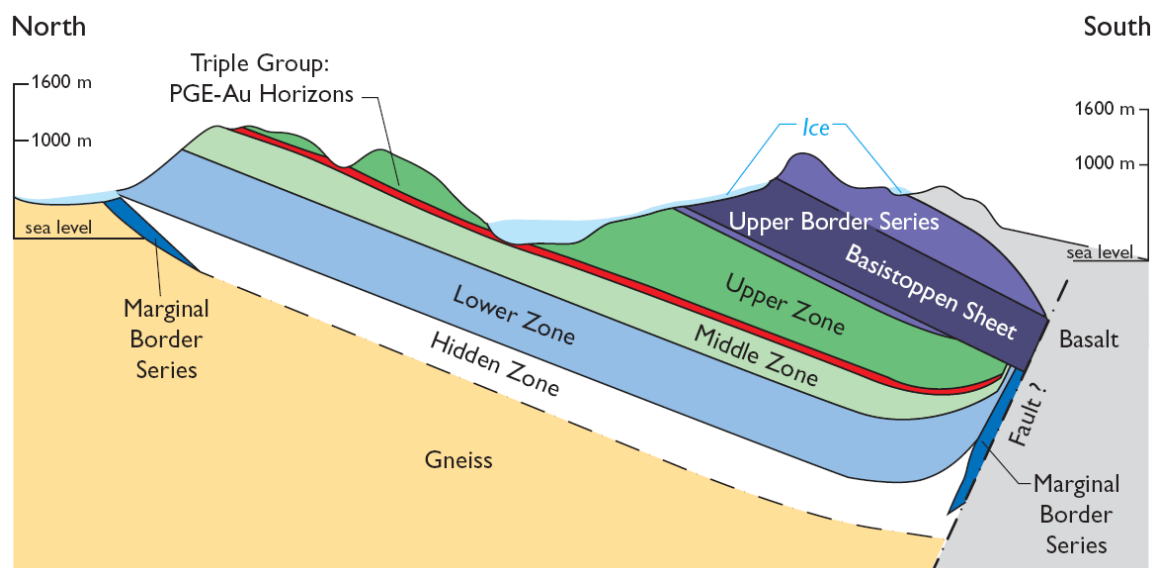


Figure 7 Simplified structural section of the Skaergaard Complex with the ore body portrayed in red (Nielsen 2006).

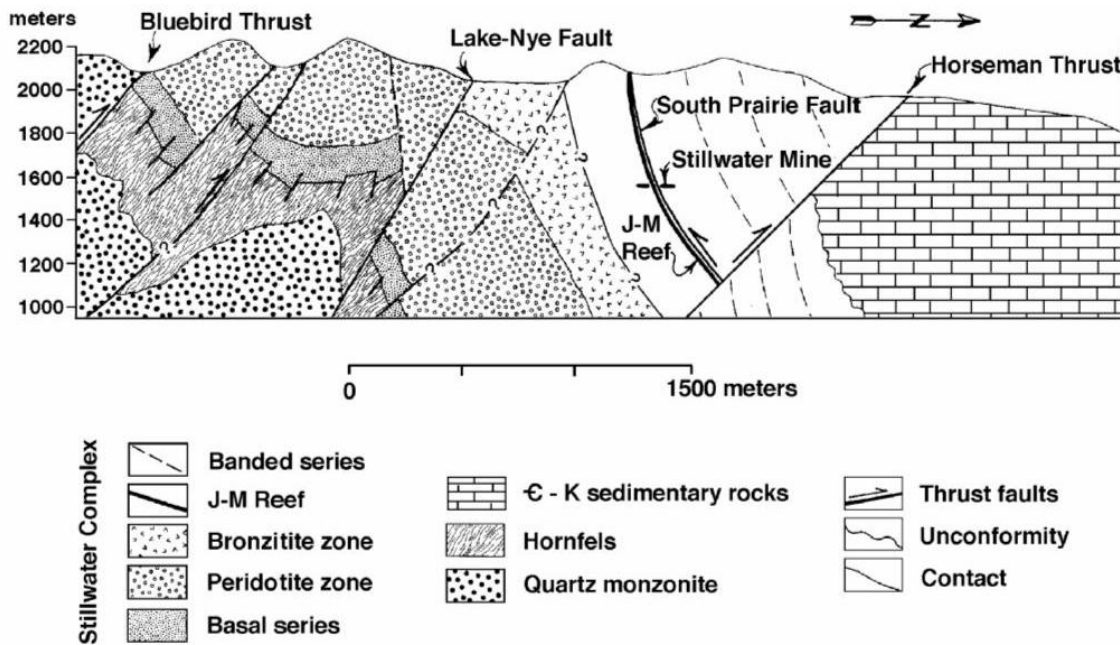


Figure 8 Simplified structural section of the Stillwater Complex [Mountain View] with the ore body labeled as J-M Reef (Turner 1985).

Although there has been significant faulting in both the Stillwater and Skaergaard Complexes, the main body of the Skaergaard is relatively untouched with only a few offsets near the edges. The shallow dip is easy to follow (Nielsen 2004). The Stillwater Complex is more challenging to follow because many of the beds dip at angles of at nearly 90 degrees, and in some cases can be overturned. There are numerous faults with offsets that make it impossible to follow some of the beds. In the Skaergaard there is no such level of complexity. Likewise, the explanation for formation of the Skaergaard is more simplistic in that it formed only a few kilometers below the surface, from a mantle plume. It is inferred that the magma chamber was filled in a single large event. It is indicated that Stillwater Complex formed at a greater depth, of up 10-15 Km and was uplifted in a series of events. A problem with comparing the two complexes is that only the final configuration can be seen. Originally the two may have been very similar with the exception of depth, but there is no accurate model of what the Stillwater Complex

magma chamber may have looked like 2.7 billion years ago. One of the main reasons for not having a model is because it would be incomplete because the upper layers of the magma chamber are missing. In the Skaergaard the entire magma body seems to be intact which includes the upper layers that are missing in the Stillwater Complex (McCallum 2003).

Mineralogically they share traits because they are both mafic/ultramafic intrusions and are made up of the same minerals, but even though they share those traits, the layers and mineral makeup don't seem to form an identical pattern that can be followed throughout both complexes. Matches in mineral composition are only consistent for one or two sequences of rock at a time. It has been suggested that the Stillwater Complex was subject to a number of injections of magma, but there is little evidence that that happened in Skaergaard. Multiple injections are important because they would add heat and new mantle material to the system allowing the process of crystallization to start repeatedly (Turner 1985). Even at points such as the platinum containing layers, the Triple Group in the Skaergaard and the JM Reef at Stillwater, the rock layers on either side share some traits but are not an exact match. However, data for the comparison was poor and should be revisited as more mineral data becomes available.

Mineral Resources of the Skaergaard and Stillwater Complex

Most of the easily minable resources in the world have already been exploited. With the ever increasing value of precious metals there has been a renewed interest in searching out new ore bodies. The search has been taken to areas that were considered too inhospitable, but are now feasible because of technology and prices. Stillwater Complex is the only platinum group producing mine in the United States. Throughout

the world there are only about five mines actively producing large amounts of platinum group metals (Infomine 2007).

As early as 1937 there was mineral exploration in the Skaergaard, and at the time, it was concluded that there were no minerals of economic value other than nepheline syenite which was used as an iron ore (Wager 1937). Although gold is mentioned in papers as early as 1957 no substantial finds were made until 1987 when gold anomalies were discovered near the triple group in the upper middle zone. The discovery led to comprehensive drilling that took place in 1989 and 1990. The data from those drilling expeditions lead to the discovery of not only a gold rich zone, but also a palladium rich zone which is about 20 meters below the gold zone (Andersen 2003). Throughout the 1990s and early 2000s research was conducted to determine just how much gold and palladium was in the Skaergaard, and how much of that is recoverable. By 2000 it was published that drill-core information indicated there was a potential for more than 60 million tons of ore (Minex 2000). The most recent data points to an even larger recoverable body of ore, on the magnitude of 150 million tons, and broadens the scope of focus metals adding titanium, iron, and vanadium (Nielsen 2006).

Proven ore reserves in the Stillwater Complex as of December 31, 2006 were only 4.8 million tons, but the Stillwater mine averages 1725 tons of ore removed per day with a capacity of 2000 tons per day. Working at capacity with the proven reserves there are at least 6.5 years of production left. The grade of the proven reserve is ~16.16g/t ounce per ton which contains ~ 76.5 million grams of palladium and platinum. Probable reserves are significantly higher at ~37.7 million tons at an average grade of ~15.3g/t (SWC editors 2006).

Although the ore grades are much lower for the Skaergaard Complex, it is likely that it will be a competitor in the market sometime in the future. Galahad Gold has finished a study based on a production of 35 thousand tons of ore per day. The expected lifetime of the mine at that rate would be 20-30 years. It would only produce a fraction of the platinum group metals that the Stillwater Complex is currently producing, but should be able to compensate with other metals. The planned method of retrieval is year round underground mining that will include everything from the Palladium/ Platinum to the Gold zone. The rocks between the zones have an average make up of 6.6% TiO₂, 1.3 kg/t V₂O₅ and 19% Fe₂O₃. The ore that is removed will be loaded aboard ships where it will be shipped to Iceland for processing (Nielsen 2006).

Zone	Estimated Ore Body Size	Gold (Au) Concentration	Palladium (Pd) Concentration	Platinum (Pt) Concentration
Gold	107M tons	1.68 g/t	0.59 g/t	0.05 g/t
Palladium	104M tons	0.11 g/t	1.91 g/t	0.16 g/t

Table 1: Estimated Reserve information for the Skaergaard. Created from data (Nielsen 2006)

It is likely that the Skaergaard will soon be mined for its precious metals. The price of gold has increased by approximately 30% this year alone and palladium has increased by more than 10% [refer to Figure 9]. This quick increase in price will likely continue as the mines that have previously been the worlds top produces exhaust their ore supply.

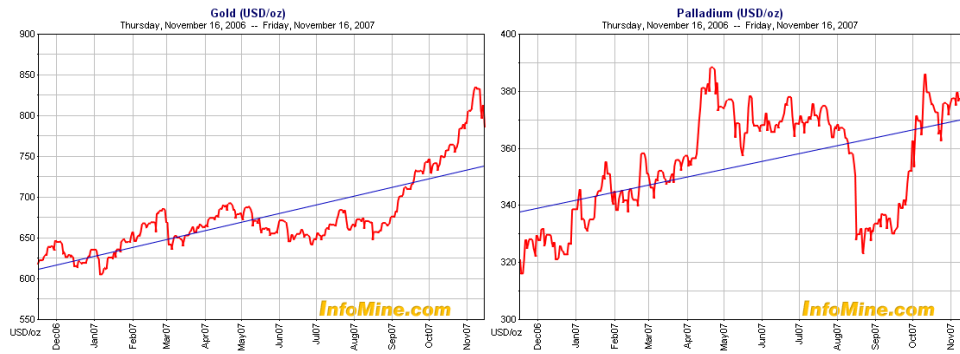


Figure 9 World market prices for Gold and Palladium in 2007

Conclusion

The Skaergaard has a rich history and a bright future for exploration. There is not strong evidence to suggest that the Stillwater Complex and Skaergaard Complex share similar history or formation circumstances, but analysis should be revisited in the future when more data is presented on a finer scale. Mining is almost certain to take place in the Skaergaard in the future as our resources dwindle.

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