

The Minerals of the Brandsnuten Manganese Deposit, Tokke, Norway

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ABSTRACT

Brandsnuten manganese deposit in western Telemark is interpreted as a synsedimentary deposit related to volcanic exhalations. It is embedded in an arkosic metasandstone of the Telemark suite and metamorphosed according to the Staurolite - Almandine subfacies of lower part of the amphibolite facies. Further alterations are attributed to retrograde metamorphism and hydrothermal activity.

The paragenesis consists of 18 identified manganese oxide-, silicate- and carbonate minerals. Rhodonite, braunite and spessartine are the most common minerals in the samples investigated from the deposit.

INTRODUCTION

The Brandsnuten manganese deposit is located in the mountainous area west of Dalen, Telemark county in southern Norway.

This paper summarises part of a M.Sc. thesis at the University of Oslo (van der Wel 1974). Apart from new contributions by Larsen (1978,1988) and Raade (1981) the current paper has not been extended with new studies.

The first notice of the Brandsnuten manganese deposit was by Scheerer (1845b) where it is mentioned that samples were received from local farmers "keen on prospecting for ore" and also by Vogt (1888). A discussion of its origin is given by Poulsen (1956). A field study in 1952 and 1953 by Dutch geologist was published by Westerveld (1961). An overview over mineral deposits in the area is given in Nordrum and van der Wel (1981).

Previous geological mapping has been carried out by Kollung (1964-1965) and Vokes and Vrålstad (1965). Details of the geological mapping of the area can be found in van der Wel (1979). Also, contributions in a more regional scale are found in Sigmond (1975 and 1978) and Dons and Jorde (1978).

GEOLOGICAL SETTING

Dahll (1861), Brøgger (1900), Reusch (1903), Werenskiold (1912) and Dons (1960,1962) discuss the western border of the Telemark suite at lake Byrtevatn. Brøgger (1900) recognised a major fault zone here separating the western granitic gneiss areas from the Telemark suite. According to Reusch (1903) the granitic gneiss area and the associated supracrustal rocks to the west of this fault zone, are older than the supracrustal rock of the Telemark suite. Vogt (1886) and Scheerer (1845a) observed younger granitic intrusions in the western gneiss area.

The following main units and events have been recognised by van der Wel (1974):

- Precambrian granitic to quartz dioritic gneisses and augengneisses of uncertain origin (basement).
- Precambrian supracrustal rocks deposited upon this basement belonging to the Telemark suite. The primary formation of the Brandsnuten manganese deposit is considered to occur at this time as a synsedimentary process.
- Intrusion of basic to intermediate sills and pegmatites. These may be related to the metamorphism of the supracrustal rocks according to the Staurolite - Almandine subfacies of lower part of the amphibolite facies (Turner and Verhoogen 1951). The supracrustals were in part strongly granitised.

- Precambrian porphyry granite intrusions.
- Faulting and hydrothermal activity most likely in several stages. Hydrothermal activity resulted in the deposition of sulphides, fluorite, etc (Foslie 1925, Dons 1963, Vokes and Vrålstad 1965, Nordrum and van der Wel 1981) and it also affected the Brandsnuten manganese deposit.

MINERALOGY

The Brandsnuten manganese deposit consists of a set of parallel and discontinuous lenses of about 2 kilometres in length within an arkosic metasandstone (fig 1). The dimensions of the lenses vary from centimetres to meter scale in width and up to possibly 10-12 meters in length at the site of exploration in the early 1950^{ies}.

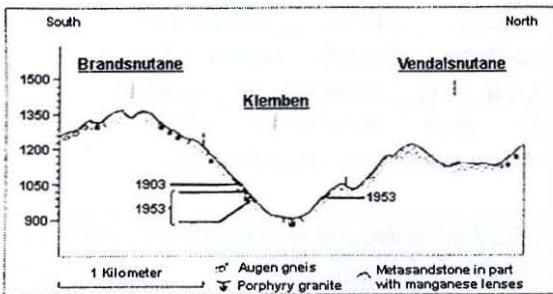


Fig 1: A profile parallel with the manganese horizon in the metasandstone. Roman numerals indicate where the analyses published by Westerveld (1961) were taken. The years indicate when the prospects were sampled

The lenses (Table 6) are composed of mixed manganese silicate and manganese oxide lenses. This paragenesis is called "gondite" by Roy (1964). The increased manganese content of the host rock near the lenses is indicated by the presence of rhodonite, manganese rich grossular - andradite and spessartine.

In a cross section the following zones have been recognised:

- Metasandstone with tiny bands of spessartine - titanite - ilmenite and of spessartine - secondary quartz. A modal analysis of the metasandstone

showed 46% quartz, 40% microcline, 8% spessartine, 4% plagioclase, 1% ilmenite and 1% titanite

- metasandstone with manganese rich grossular - andradite in lenses
- rhodonite with spessartine and braunite lenses in metasandstone
- quartz bands
- ore body with rhodonite, spessartine and braunite as the main minerals

Jacobsite

Jacobsite has only been observed in relatively small amounts. Westerveld (1961), however, mentions that it may constitute up to 30% of the ore.

Table 1: Jacobsite, X-ray diffraction pattern

hkl	d(obs)	I(obs)
111	4,91	4
220	3,29	4
-	2,85	1
-	2,75	1
311	2,57	5
222	2,46	3
-	2,29	1
-	2,24	1
400	2,13	4
422	1,736	3
511	1,636	4
440	1,504	5
531	1,439	2
620	1,344	2
533	1,299	4
622	1,282	3
444	1,229	3
711	1,193	2
642	1,138	3
731	1,109	4
751	-	-
800	1,065	3

Intensity scale: 1=very faint, 2=faint, 3=medium, 4=strong, 5=very strong

9cm Debye-Scheerer Camera

Under the ore microscope, in polished thin sections, it is easily recognised due to a well developed cleavage and a cream brownish hue in reflected light.

Most commonly the mineral occurs as isolated grains together with spessartine and rhodonite, less often it has been observed included in braunite. Hausmannite and hematite partly occur within jacobsite along cleavage planes and partly in a more irregular intergrowth.

Ideally the Mn/Fe ratio is 0,5. Chemical analyses with the electron microsonde show a Mn/Fe ratio of 1:1 for jacobsite from Brandsnuten. This indicates that manganese also substitutes for trivalent iron: $Mn^{+2}(Fe^{+3}, Mn^{+3})_2O_4$. The X-ray diffraction pattern is shown in table 1.

Hausmannite

In the studied samples hausmannite occurs in small amounts only. In the samples analysed for exploration purposes Westerveld (1961) states that hausmannite amounts to 20% of the ore minerals in a sample where the braunite content is 70%. It has only been observed in the manganese rich zone where no free quartz or feldspar occurs.

The mineral is most easily observed in polished thin sections under the microscope. It occurs intergrown with jacobsite, partly along its cleavage. Hausmannite has also been observed as isolated grains within spessartine and rhodonite grains, more seldom within braunite grains.

Manganese silicate minerals seem to replace hausmannite.

Pyrophanite

Pyrophanite has only been observed in a mineral separation fraction from the rhodonite – spessartine - braunite zone. It was identified by means of X-ray diffraction.

Ilmenite

Ilmenite occurs as an accessory mineral in the metasandstone. It has not been observed together with rhodonite and spessartine. Here pyrophanite seems to occur instead as its manganese rich equivalent.

Hematite

Hematite occurs as lamellae within jacobsite and rhodonite. In the metasandstone it has been observed as very thin lamellae within quartz and microcline.

Braunite

Braunite occurs as a homogeneous system of grains up to several millimetres in diameter, It is greyish black with a submetallic luster. The grains may show no sign of alteration or they may have been altered to rhodonite or spessartine along margins. Especially within brecciated parts the alteration to silica enriched phases is common.

Braunite replaces both jacobsite and hausmannite. It has not been observed directly in contact with quartz or microcline, since rhodonite and spessartine always seem to occur between the manganese oxides and quartz and microcline. The X-ray diffraction pattern is shown in table 2.

Table 2: Braunite, X-ray diffraction pattern

<i>hkl</i>	<i>d(obs)</i>	<i>I(obs)</i>
200,004	4,69	2
202,114	4,23	2
213	3,49	3
220	-	-
116	-	-
224	2,72	5
400,008	2,35	3
332,316	2,14	4
406,431	1,874	3
1.1.10	-	-
512,336	1,809	2
2.0.10	1,736	3
440,408	1,659	4
-	1,537	3
-	1,502	2-3
-	1,467	2-3
-	1,418	4
-	1,411	3-4
-	1,368	1-2
-	1,356	3
-	1,267	2

-	-	-
-	1,178	3
-	1,168	3
-	-	-
-	-	-
-	1,080	3
-	1,077	3-4
-	1,075	3
Intensity scale: 1=very faint, 2=faint, 3=medium, 4=strong, 5=very strong		
9cm Debye-Scheerer Camera		

Långbanite

Långbanite has only been found as strongly shiny black grains included in rhodonite. The type locality of the mineral is Långban in Sweden (Flink 1888). Långbanite is isochemical with braunite, most likely special conditions stabilise the långbanite structure.

It could be isolated for X-ray diffraction analysis and chemical analysis. From X-ray diffraction the cell dimensions have been calculated: $a=11,61$, and $c=11,07$. The cell volume is 1294 \AA^3 .

Pyrolusite

Pyrolusite occurs as a secondary mineral along fractures and cleavage planes. Occasionally it has been observed in veins together with rhodochrosite, indicating relationship to a hydrothermal phase.

Tephroite

Tephroite (Mn_2SiO_4) belongs to the olivine group, and represents the manganese end member in a continuous solid solution series with fayalite (Fe_2SiO_4). It is common in iron-manganese ore deposits and their associated skarns and metamorphosed manganese-rich sediments (Deer, Howie and Zussman 1972).

In van der Wel (1974) tephroite has only been identified in a mineral fraction after mineral separation of crushed rock.

Larsen (1978) identified tephroite in 1-2kg large amounts at the site of the main deposit. The colour is grey brown with a

wax like lustre. An analysis showed that the tephroite from Brandsnuten close to Mn_2SiO_4 in chemical composition (table 3). Larsen (1978) also gives the X-ray diffraction pattern.

Table 3: Tephroite analysis (Larsen 1978)

Wt-% of oxide		No of atoms based on 4 O		Mol-%	
SiO_2	29,0	Si	0,99		
FeO	2,2	Fe	0,06	Fe_2SiO_4	3
MnO	67,5	Mn	1,94	Mn_2SiO_4	96
MgO	0,4	Mg	0,02	Mg_2SiO_4	1
Total	99,1				

Garnet

Chemical analyses of garnets from the manganese ore and metasandstone near the ore show that their composition varies strongly. This is probably due to a primary variation in chemical composition of the sediment.

The following main garnet types have been recognised:

1. Spessartine

Spessartine is mainly confined to an environment characterised by rhodonite and braunite and the absence of quartz and feldspar.

Generally it is fine grained to medium grained, less usually it is developed as up to 3 mm large euhedral crystals. The colour varies from yellow to deep brownish-orange.

Spessartine occurs:

- as poikilitic and irregular intergrowth with rhodonite
- interstitially between braunite grains, replacing it. It occurs in part together with rhodonite in this position
- as graphic intergrowth replacing rhodonite along cleavage planes (fig 2)
- interstitially replacing rhodonite
- euhedral spessartine within rhodonite



Fig 2: Graphic intergrowth between spessartine (Sp) and rhodonite (R). The intergrowth is controlled by the rhodonite cleavage (crossed nikols).

Inclusions within spessartine consist of jacobsite, hausmannite and manganoan biotite. Veins with rhodochrosite, rhodonite and an oxide (pyrolusite?) occur across spessartine grains. Cell sizes range between 11,63-16,72 Å³ and densities between 4,05-4,17g/cm³. The X-ray diffraction pattern is shown in table 4.

Table 4: X-ray diffraction pattern for spessartine				
hkl	G2 *)		G5 *)	
	dÅ	I	dÅ	I
400, 420	2,92	4	2,919	s
420, 422	2,61	3-4	2,608	s+
332, 432	2,49	3	2,487	m
422, 521	2,38	4	2,382	m
431	2,29	3	2,287	m
521	2,13	3	2,132	m
440	2,07	2	2,063	w
611, 532	1,89	4	1,894	s
620	1,85	2-3	1,844	w
444	1,69	3	1,686	m
640, 800	1,62	4	1,62	s
721, 633	1,59	2-3	-	-
642	1,56	3-4	1,562	s+
800	1,46	3	-	-
Cell size	a= 11,67Å		a=11,67Å	

*) Guinier camera, sample from manganese lens Brandsnuten
Reflection intensity: 1=very faint, 2=faint, 3=medium, 4=strong, 5=very strong

1. Spandite

This garnet occurs within zones around manganese rich lenses where also quartz and feldspar are present together with rhodonite and piemontite.

Spandite is characterised by a high Ca and Fe³⁺ content and a low Al content. In thin section it has a stronger yellow hue than spessartine. In hand specimens it is yellow to brownish yellow.

2. Manganoan grossular - andradite

This garnet characterised by a varying content of Ca, Mn²⁺, Fe³⁺ and Al. It occurs within the metasandstone near the ore bearing horizon, in lenses and as scattered grains. Titanite, rhodonite, piemontite and epidote are frequently associated with this garnet, as are remnants of oxides within the garnet. It is often strongly poikilitic. The X-ray diffraction pattern is shown in table 5.

Table 5: X-ray diffraction pattern for manganoan grossular-andradite				
hkl	manganoan grossular - andradite *)		andradite **)	
	dÅ	I	dÅ	I
420	2,68	4	2,696	100
332	2,55	2	2,571	14
422	2,45	3-4	2,462	45
510	2,35	2-3	2,365	18
521	2,19	2-3	2,202	18
611	1,937	3	1,9564	25
620	1,895	2	1,9068	12
444	1,731	2	1,7406	10
640	1,665	3-4	1,6726	25
642	1,604	4	1,6112	60
800	1,500	2	1,5073	14
840	1,342	3	1,3483	14
842	1,310	3	1,3157	20
664	1,285	2-3	1,2856	14
10.4.0	1,114	3-4	1,1195	25
10.4.2	1,096	3-4	1,1008	16
880	1,061	3	1,0659	14

*) Guinier camera, sample from manganese rich metasandstone lens,
 Brandsnuten
 **) synthetic, ASTM-file
 Reflection intensity: 1=very faint, 2=faint, 3=medium, 4=strong, 5=very strong

Thin veins forming a network from the garnet into neighbouring minerals are interpreted as the result of hydrothermal activity.

The chemical composition of the garnets

The composition of approximately 40 garnets was analysed using the microprobes at the University of Oslo and Trondheim. Some of the results are shown in table 7. In this table analyses 7, 9, 23, 27 and 29 have been chosen in order to represent the main types of garnets found. Most of the analyses represent average values of several points across single grains. Calculations have been performed using "in house" software

programs at the Mineralogical Geological Museum, University of Oslo.

The following has been assumed when placing the cations into the different co-ordinations:

- Si is in tetrahedral co-ordination, if necessary this position is filled up with Al
- Al, Ti and Fe³⁺ are in octahedral co-ordination, if necessary this position is filled up with Mn³⁺
- Ca, Mn²⁺, Fe²⁺ and Mg are in cubic co-ordination

The full range of analyses are shown in the triangular diagram in fig 3 with the end members grossular, andradite and spessartine using co-ordination rules as defined above.

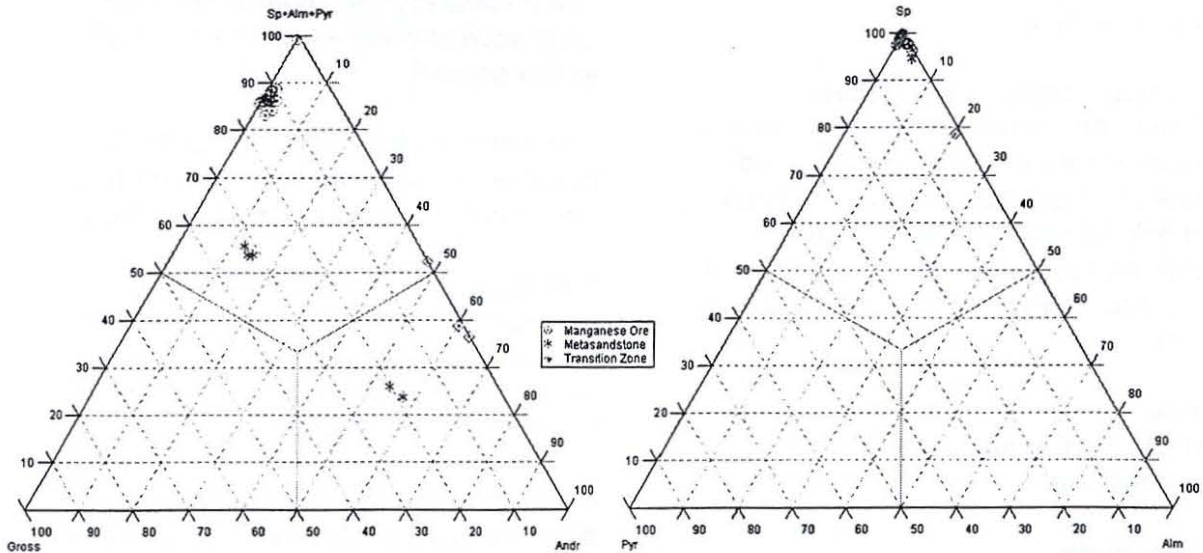


Fig 3: Microprobe analyses of garnets from the manganese ore proper, the transition zone (quartz and feldspar present) and the metasandstone. The left hand diagram (Grossularite-Pyralspite-Andradite) shows that there are distinct groups in terms of chemical composition. The garnets in the ore zone are all close to the pyralspite corner.. The garnets from the transition zone and the metasandstone have an increased Ca content and show a tendency for Al to be more dominant in the garnets of the metasandstone. The right hand diagram mainly shows that in terms of the elements Mg-Mn-Fe the manganese content is overwhelmingly dominant. This shows that the garnet from the ore zone is spessartine.

Piemontite

Mn²⁺ substitutes in substantial amounts for Ca. The mineral both occurs within the manganese zone and within the transition zone. Its colour varies from brownish black to yellow green, probably depending on the amount of manganese present. It occurs together with grossular – andradite (fig 4), rhodonite, oxides and titanite.

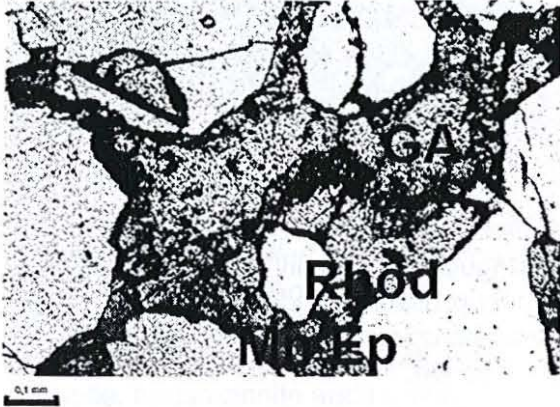


Fig 4: Piemontite (Pi) as an alteration product of grossular – andradite garnet (GA) in metasandstone. Rhodonite (Rhod) is also present (high relief). Transparent light.

Its chemical composition has been analysed with the microprobe. Due to a high content of rare earth elements and the lack of proper standards the analysis could only be semi quantitative. Apart from Si, Al, Fe, Mn, Mg and Ca, elements like Na, La, Er, Pr, Dy, Yb and Re are present.

Titanite

Occurs in small quantities within the metasandstone.

Johannsenite

Johannsenite is a manganese rich pyroxene. It occurs as a pale brown alteration product of rhodonite, most likely as a result of Ca - metasomatism.

The mineral occurs in zones resulting from hydrothermal activity together with

sulphides, native copper and fluorite along fissures.

According to Deer, Howie and Zussman (1972) johannsenite is formed as a product of metasomatism and on quartz and calcite veins related to acid and intermediate igneous rocks.

Rhodonite

Rhodonite is one of the most common minerals of the manganese zone. It is also found within the transition zone and within the metasandstone.

Rhodonite and several other manganese silicates fall into one series of so-called "pyroxenoids", whereas wollastonite, bustamite and other Ca-metasilicates define another series of pyroxenoids (Berman 1937, Deer, Howie and Zussman 1972).

Its colour varies from rose to red rose. The mineral is in part coarse crystalline, up to several centimetres, in part medium to fine grained.

It occurs in an intergranular position in braunite. As spessartine, rhodonite has been formed at the expense of braunite.

Included within rhodonite are the manganese oxides jacobsonite, hausmannite and braunite. The different types of intergrowth with spessartine have already been mentioned (fig 2).

In the zone of oxidation rhodonite is altered into secondary manganese oxides along cleavage planes.

The chemical composition of rhodonite is shown in fig 5. Here it is shown that some Ca and to a lesser extent also Mg and Fe substitute for Mn.

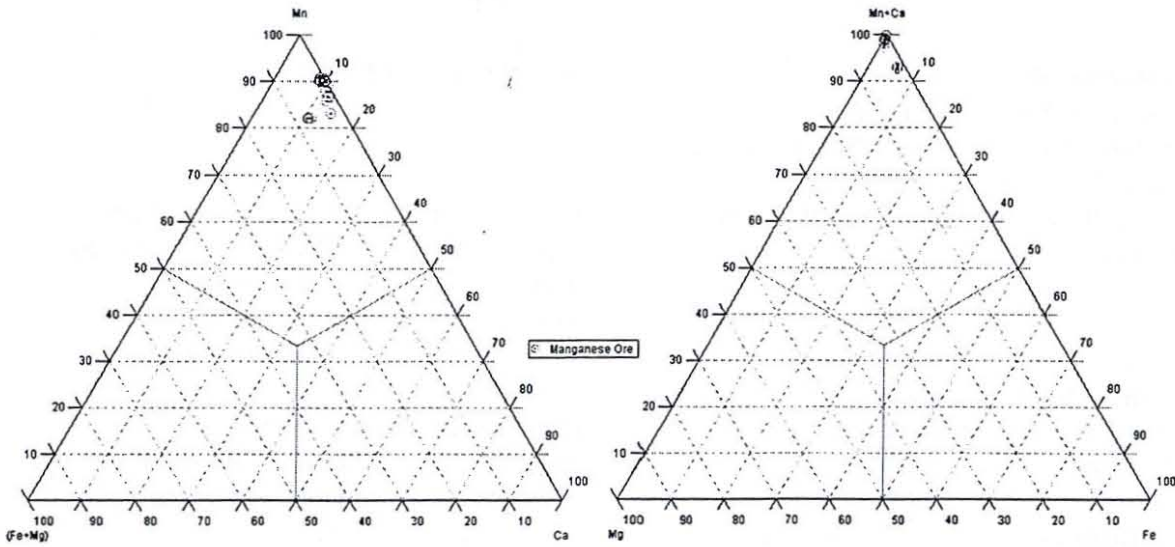


Fig 5: The relation between (Fe,Mg)-Ca-Mn and Mg-(Mn,Ca)-Fe in rhodonites from the manganese ore zone. The diagrams show that the Ca content is limited to approximately 15% and that the iron content is less than 10%.

Bustamite

Bustamite is also a pyroxenoid (see above). Raade (1981) has shown that the mineral occurs in large quantities as greyish aggregates with cleavage. An enrichment of quartz grains within bustamite along borders with rhodonite has been observed. Massive spessartine occurs within bustamite.

Manganoan biotite

Manganoan biotite occurs in an interstitial position between rhodonite and manganese oxides. It also occurs together with rhodochrosite and replaces braunite and rhodonite. In the transition zone it occurs together with garnet, titanite and ore. The mineral is yellowish brown in thin section, sometimes with a radial needle like structure.

Caryopilite and bannisterite

Caryopilite belongs to the kaolinite – serpentinite group, whereas bannisterite is related to stilpnomelane (Gaines et al 1997). Larsen (1988) reports a mixture of caryopilite and bannisterite as brown, flaky aggregates up to a few centimeters across. Microcline, rhodonite, spessartine and braunite occur together with these minerals.

Chlorite

Chlorite occurs within the transition zone.

Plagioclase

Occurs in small quantities within the metasandstone.

Microcline

One of the main constituents of the metasandstone.

Quartz

One of the main constituents of the metasandstone.

Rhodochrosite

Rhodochrosite is present in small quantities throughout the manganese deposit together with fluorite. It has only been observed in thin section. Generally it is fine crystalline. It is considered to have been formed during a hydrothermal phase.

Calcite

Calcite occurs within the metasandstone along tiny veins.

Apatite

Occurs in small quantities within the metasandstone.

Fluorite

As rhodochrosite it frequently occurs together with manganite, biotite and piemontite. It is widespread throughout the deposit, but only in very small amounts. It is colourless to violet in veins and in an interstitial position.

Pyrite

It occurs in very small amounts within rhodonite in the manganese zone, in part together with native copper and johannsenite.

Native Copper

Native copper occurs in very small amounts on veins, commonly together with rhodonite or johannsenite. It has also been observed scattered within rhodonite and spessartine.

CONCLUSION

The origin of the deposit is discussed by Westerveld (1961). He concludes that the mineral paragenesis is metamorphic. According to Westerveld this is supported by the granoblastic and poikiloblastic textures of the primary manganese silicates and oxides. Westerveld favours the formation as a low temperature manganese oxide deposit conformably to the layering of the arkose.

Three mechanisms are quoted by Westerveld:

1. Sedimentation of manganese oxides related to continental erosion
2. Accumulation of manganese oxides in a sedimentary basin related to volcanic exhalations
3. A subvolcanic origin and precipitation at low temperatures in veins parallel to the primary sedimentary layering (the preferred model according to Westerveld)

In the current study a synsedimentary deposition of manganese is preferred. Manganese is possibly related to volcanic exhalations active during deposition of the

arkosic sands. This is not unlikely when bringing into mind the large amount of amphibolites within the Telemark formation, which are considered to be of volcanic origin.

Later the deposit was metamorphosed producing minerals like braunite, rhodonite and spessartine. The availability of silica (quartz and microcline) probably strongly influenced the resulting products.

Probably as the result of retrograde metamorphism rhodonite was altered into spessartine (graphic intergrowth, fig 3).

During the hydrothermal phase minerals like fluorite, rhodochrosite, piemontite and native copper were formed along fissures.

SAMMENDRAG PÅ NORSK

Brandsnuten manganforekomst i vest-Telemark tolkes som en synsedimentær forekomst relatert til vulkanske ekshalasjoner. Forekomsten er knyttet til en arkosisk metasandstein som er metamorfosert i staurolit - almandin subfacies tilhørende nedre del av amfibolitt facies. Videre omvandling er knyttet til retrograd metamorfose og hydrotermal aktivitet.

Paragenesen består av 18 identifiserte manganoksyd, -silikat og -karbonat mineraler. Rhodonitt, braunitt and spessartin er de vanligste mineralene i det undersøkte materialet fra forekomsten.

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Table 6: Minerals of the Brandsnuten manganese deposit

Mineral	Chemical composition	Relative frequency	Zone of occurrence
Oxides			
Jacobsite	$Mn^{+2}Fe^{+3}_2O_4$	1	O
Hausmannite	$Mn^{+2}Mn^{+3}_2O_4$	2	O
Pyrophanite	$MnTiO_3$	1	O
Ilmenite	$FeTiO_3$	1	T,M
Hematite	Fe_2O_3	1	O,T,M
Braunite	$Mn^{+2}Mn^{+3}_6[SiO_4]O_8$	3	O
Långbanite	$Mn^{+2}Mn^{+3}_6[SiO_4]O_8$	1	O
Pyrolusite	MnO_2	1	O,T,M
Silicates			
Tephroite	$Mn_2[SiO_4]$	2*)	O?
Spessartine	$Mn_3Al_2[Si_3O_{12}]$	2	O
Spandite	$(Ca,Mn)_3(Fe,Al)_2[Si_3O_{12}]$	1	T
Manganese Grossular - Andradite	$(Ca,Mn)_3(Fe,Al)_2[Si_3O_{12}]$	2	M
Piemontite	$(Ca,Mn^{+2})_2Fe^{+3}AlO.OH[Si_2O_7][SiO_4]$	1	O,T
Titanite	$CaTiSiO_5$	1	T,M
Johannsenite	$Ca(Mn,Fe^{+2})[Si_2O_6]$	1	O
Rhodonite	$(Mn,Fe,Ca)[SiO_3]$	3	O
Bustamite	$CaMnSi_2O_6$	2?*)	O,T?
Manganoan biotite	$K_2(Mg,Mn,Fe^{+2})_6[Si_6Al_2O_{20}](OH,F)_4$	1	O,T
Caryopilite	$(Mn,Mg,Zn,Fe)_3(Si,As)_2O_5(OH,Cl)_4$	1?*)	O,T?
Bannisterite	$KCa(Mn^{+2},Fe^{+2},Mg,Zn)_{20}(Si,Al)_{32}O_{76}(OH)_{16} \cdot 4-2H_2O$	1?*)	O,T?
Chlorite	$(Mg,Fe,Al)_6(Al,Si)_4O_{10}(OH)_8$	1	T,M
Plagioclase	$(Na,Ca)Al(Al,Si)_3O_8$	1	T,M
Microcline	$KAlSi_3O_8$	3	T,M
Quartz	SiO_2	3	T,M
Carbonates			
Rhodochrosite	$MnCO_3$	1	O,T
Calcite	$CaCO_3$	1	M
Others			
Apatite	$Ca_5(PO_4)_3(F,Cl,OH)$	1	T,M
Fluorite	CaF_2	1	O,T,M
Pyrite	FeS_2	1	O
Native Copper	Cu	1	O
O=Ore zone, T=Transition zone, M=Metasandstone 1=rare to minor, 2=common, 3=dominant *) estimated from Larsen 1978, 1988 **) estimated from Raade 1981			

Table 7: Garnet analyses in wt% and with structural formula based on 16 cat-ions

Selected Analysis :	7/ G8 Spessartine, manganese ore	9/ G9 Spessartine, manganese ore	23/ Pr8.2 Manganese rich andradite, transition zone	27/ Pr25.3 Manganoan grossular- andradite, metasandstone	29/Pr31.2 Manganese rich andradite, metasandstone
SiO ₂	37,75	36,36	33,89	38,07	35,57
Al ₂ O ₃	19,98	16,75	0,85	14,37	6,53
TiO ₂	0,00	0,00	0,00	0,00	0,00
MgO	0,00	0,08	0,07	0,18	0,00
FeO	1,28	3,77	25,15	8,87	19,72
MnO	35,77	38,64	18,47	23,64	12,97
CaO	4,70	4,61	21,15	15,78	24,59
Sum	99,48	100,21	99,58	100,91	99,38
<i>Structural formula based on 16 cations: X₆Y₄Z₆O₂₄</i>					
<i>In tetrahedral co-ordination</i>					
Si	6,182	5,995	5,748	6,114	5,862
Al	0,000	0,005	0,170	0,000	0,138
Fe ³⁺	0,000	0,000	0,000	0,000	0,000
Sum	6,182	6,000	5,918	6,114	6,000
<i>In octahedral co-ordination</i>					
Al	3,856	3,250	0,000	2,720	1,130
Ti	0,000	0,000	0,000	0,000	0,000
Fe ³⁺	0,000	0,520	3,567	1,050	2,718
Mn ³⁺	0,000	0,240	0,433	0,000	0,292
Sum	3,856	4,010	4,000	3,770	4,140
<i>In cubic co-ordination</i>					
Mg	0,000	0,020	0,000	0,043	0,000
Fe ²⁺	0,175	0,000	0,000	0,141	0,000
Mn ²⁺	4,962	5,156	2,220	3,216	1,518
Ca	0,825	0,814	3,843	2,715	4,342
Sum	5,962	5,990	6,063	6,115	5,860