Precambrian fission-track ages of sphene from the Caledonides of Mount Åreskutan, Sweden

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Fission-track ages were determined on idioblasts of sphene originating from two localities of the Caledonian Fröå-Bjelke Nappe at Mount Åreskutan. The specimens occur (1) as gangue in a strata-bound Cu-Zn ore from the Fröågruvan Mine and (2) in a calc-silicate gneiss as adjoining rock of the strata-bound Cu-Zn ore of the Bjelkegruvan Mine. The sphene from the Fröågruvan Mine yields a corrected fission-track age of t_w 1500±325 m.y., and that from the Bjelkegruvan Mine of t_w 1761±349 m.y. The corresponding closing temperature is 389° C. The consequences of the unexpected Proterozoic cooling ages on the stratigraphical and tectonical position of these sphene-bearing rocks and ores and their metamorphism are discussed.

In order to evaluate the F.T.A. results from Åreskutan, a sphene from an indisputably Precambrian environment, the Svecofennides, was analysed. The sample was taken from a fissure at the Mossgruvan Mine in the Nordmarks Odalfält mining field in Värmland. The corrected fission-track age was analysed to t_w 1764±406 m.y., and a corresponding temperature of 389°C was calculated.

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Introduction

The recent development (see, for instance, Fleischer et al. 1975) of the fission-track method for dating minerals supplies a new inexpensive means for the dating of thermal events in the geological history. Although fission-track ages give a measure of the time over which tracks of ^{238}U fission events are stored in the mineral, these ages will require upward correction if the fission-track density in the mineral is lowered by accompanying thermal events. Moreover, age measurements are limited to intervals since the mineral last reached a temperature for complete annealing of these fission tracks. Fission track-ages of rocks and minerals are thus only of service for establishing true geological ages in the volcanic range. On the other hand, for plutonites and metamorphic minerals, only cooling ages can be measured, not crystallization or metamorphism ages.

Usually, there is at least one mineral present in common igneous and metamorphic formations which is suitable for fission-track dating. In the present paper, for the first time, sphene fission-track ages from Sweden will be reported. The present authors are aware of only two previous fission-track studies of minerals in Sweden. Welin et al. (1972) reported fission-track studies of hornblende, biotite, and phlogopite, wheras Koark et al. (1978) measured fission-track ages of apatites of Precambrian apatite-iron ores (northern and central Sweden). Considering the Fennoscandian shield three further fission-track studies may be mentioned. van den Haute (1977) reported apatite fission-track datings of Precambrian intrusive rocks from the southern Rogaland (south-western Norway). Lehtovaara (1976) measured fission-track ages of apatites of different synorogenic intrusives from the Svecokarelides in Finland. Haak (1975) reported fission-track measurements of garnet and vesuvianite from Arendal (Norwegian basement).

In selecting sphene samples for the present fission-track studies the authors were careful that the crystals satisfied the conditions for methodically

Table 1. Experimental fission-track results and data for sphene samples from Sweden.

Location	Absolute number of counted tracks Spontaneous/induced		Fission-track areal densities in $10^4/cm^2$		p_s/p_i	Integrated neutron flux n in neutrons per cm^2
			p_s	p_i		
Froågruvan Mine, Åreskutan, Jämtland	3030 2887	221 257	$40{,}40 \pm 0{,}73$ $38{,}49 \pm 0{,}72$	$2{,}95 \pm 0{,}20$ $3{,}43 \pm 0{,}21$	$13{,}69 \pm 0{,}96$ $11{,}22 \pm 0{,}72$	$2{,}37 \times 10^{15}$ $2{,}37 \times 10^{15}$
Bjelkegruvan Mine, Åreskutan, Jämtland	2727 2822	214 232	$36{,}36 \pm 0{,}69$ $37{,}62 \pm 0{,}71$	$2{,}85 \pm 0{,}19$ $3{,}09 \pm 0{,}20$	$12{,}76 \pm 0{,}88$ $12{,}18 \pm 0{,}82$	$2{,}77 \times 10^{15}$ $2{,}77 \times 10^{15}$
Mossgruvan Mine, Nordmarks Odalfält, Värmland	2938 2771	291 334	$23{,}50 \pm 0{,}43$ $22{,}17 \pm 0{,}42$	$1{,}16 \pm 0{,}07$ $1{,}34 \pm 0{,}07$	$20{,}26 \pm 1{,}28$ $16{,}54 \pm 0{,}92$	$1{,}98 \times 10^{15}$ $1{,}98 \times 10^{15}$

unobjectionable datings, i.e. a certain size, homogeneous uranium distribution, few inclusions and a low iron content (Märk et al., in preparation; Gleadow 1978). It was also seen to it that the defined and that fission-track age determinations and fission-track temperature estimates could contribute to the regional-geological history.

Of the three sphene samples examined in the present study two came from, respectively from the vicinity of the stratabound Zn-Cu ores that occur in the calc-silicate gneisses of Mount Åreskutan in Jämtland. This lithological unit belongs to a nappe transported in the Caledonian period. As these tectonic units can contain Precambrian, Algonkian, and Cambro-Silurian components, fission-track datings might be suitable to give indications, not only of the age of certain metamorphic cooling stages, but also of the relative age disposition of the present lithologic units. Furthermore, with the appropriate intergrowth conditions of ore and gangue — the latter includes the sphene, too — it is possible to deduce the approximate age of the ore formation.

In order to obtain a reliable evaluation of the results from the Caledonides a comparison was made with a sphene from an indisputable Precambrian environment, a Proterozoic basement deposit of central Sweden (Nordmarks Odalfält mining field in Värmland).

Fission-track technique and results

The theory and the experimental technique of fission-track dating have been given in detail elsewhere (Fleischer et al. 1975). For convenience, certain points pertinent to fission-track dating of the present samples are summarized in the following. The uncorrected fission-track age can be calculated from the measured spontaneous and induced fission-track areal densities, p_s and p_i, using a relationship given by Fleischer et al. (1965):

$$t = \frac{1}{\lambda_\alpha} \ln \left(1 + \frac{\lambda_\alpha \cdot \sigma_f \cdot I \cdot n}{\lambda_f} \cdot \frac{p_s}{p_i}\right), \qquad (1)$$

where

$\lambda_\alpha = 1{,}54 \cdot 10^{-10} yr^{-1}$ time constant for the α-decay of ^{238}U (Kunz et al. 1959),

$\lambda_f = 0{,}84 \cdot 10^{-16} yr^{-1}$ time constant for spontaneous fission of ^{238}U (Spadavecchia et al. 1967),

$\sigma_f = 582$ barn fission-cross section of ^{235}U for thermal neutrans (Hanna et al. 1969),

$I = 7{,}26 \cdot 10^{-3}$ isotope-abundance ratio of $^{235}U/^{238}U$ (De Wet et al. 1968), and

n ...... integrated neutron flux.

As fission tracks under the influence of increased temperature become partly annealed, it is necessary to correct the above equation. One method of correction is based on the observation in apatite (Märk et al. 1973) and in sphene (Vartanian 1975, Märk et al., in preparation) that, as a sample of these minerals is heated, the lengths of tracks decrease at the same rate as the track density decreases. Thus, the corrected fission-track age is given according to Märk et al. (1973) by

$$t_w = \frac{1}{\lambda_\alpha} \ln \left(1 + \frac{\lambda_\alpha \cdot \sigma_f \cdot I \cdot n}{\lambda_f} \cdot \frac{p_s}{p_i} \cdot \frac{\bar{l}_i}{\bar{l}_s}\right) \qquad (2)$$

Table 2. Fission-track age data of sphene samples from Sweden. All ages in 10^6 y.

Location	Fröågruvan Mine, Åreskutan, Jämtland	Bjelkegruvan Mine, Åreskutan, Jämtland	Mossgruvan Mine, Nordmarks Odalfält, Värmland
t	1325 ± 239	1545 ± 275	1601 ± 279
$\bar{l}_i/\bar{l}_s$	1,15 ± 0,05	1,16 ± 0,04	1,12 ± 0,07
t_w	1500 ± 325	1761 ± 349	1764 ± 406
T_w in °C	389	389	389

where $\bar{l}_i/\bar{l}_s$ = ratio of average lengths of induced tracks and spontaneous tracks. In addition, following Märk et al. (1973) and Märk et al. (in preparation) it is possible to determine by means of a theoretical calculation a temperature value T_w corresponding to this corrected fission-track age t_w (temperature age) in case the cooling rate of the rock formation has been linear. Märk et al. (1973) and Bertel (1977) have shown that t_w is the time, since fission tracks have been reduced by temperature to a minimum length l_{min}; l_{min} is the minimum track length which can be observed in the microscope ($l_{min} = 2 \mu m$ in sphene). In other words t_w is the age of those tracks with the shortest length which can be detected today.

Several pairs of slices were cut from each sample perpendicular to the optical axis. Half of the slices of these pairs were annealed for 60 minutes at 800°C to remove all existing fission tracks and were then irradiated with thermal neutrons to produce induced fission tracks. Then all slices were glued to glass slides, ground and polished. The subsequent etching of the samples was done in a solution of $H_2O : HCl\,(37\,\%) : HNO_3\,(65\,\%) : HF\,(48\,\%) = 6:3:2:1$ at room temperature for about 25 to 35 minutes. Then the track densities p_i and p_s were counted with a phase-contrast Reichert microscope at a magnification of 1250x in oil immersion (see Table 1). It could be shown that the uranium content of these samples is homogenously distributed.

Table 2 shows the experimental results obtained for the uncorrected fission-track age, for the ratio l_i/l_s, for the corrected ages and the corresponding temperatures. The reported error boundaries represent the experimental uncertainties combined with the error of the various constants in the age formula.

Fission-track ages of sphene from the Caledonian transported Seve Nappe in the Åreskutan region in Jämtland

On two sphenes, one from a Cu-Zn ore deposit of the Fröågruvan Mine, the other from the immediately adjoining rock of one of the ore beds of the Bjelkegruvan Mine, the following corrected fission-track ages t_w were determined:

Fröågruvan Mine:	1500 ± 325 m.y.
Bjelkegruvan Mine:	1761 ± 349 m.y.

The corresponding temperatures for both datings were calculated with $T_w = 389°C$. The Fröågruvan Mine sphene as well as the sphene from the Bjelkegruvan Mine are idioblasts, grown in closed fabric, with the typical sphenoidal cross section.

The sphene from the Fröågruvan Mine comes from a fahlband with chalcopyrite, pyrrhotite and some sphalerite. Besides the sphene the gangue comprises quartz, calcite, actinolite, and diopside. Adjacent to the fahlband there is a barren layer rich in quartz and feldspar, with insignificant actinolite and diopside, but sphene again occurring as idioblast.

The Bjelkegruvan Mine sphene comes from the country rock of the sulfide-ore deposits, a diopside gneiss, consisting of quartz, oligoclase, microline, diopside, calcite, and some white mica and chlorite. Vogt (1887) observed wollastonite as well.

Neither of the two samples had any radioactive accompanying minerals that could have influenced the nuclear disintegration.

Vogt (1887) classified the structure of the ore deposits on the northern slope of Mount Åreskutan as regular, layered impregnations (fahlbands) — less frequently compact deposits —

of pyrrhotite, pyrite and chalcopyrite, in places also of bornite and sphalerite. According to Helfrich (1967) the Fröågruvan ores are locked to a lower, the Bjelkegruvan ores to an upper marble horizon, embedded in calc-silicate gneisses that alternate with amphibole schists.

According to Vogt (1887) these sulphide ores are of sedimentary origin, formed simultaneously with the surrounding rocks. Although Helfrich does not exclude a syngenetic-sedimentary-exhalative formation he rather toys with the idea of epigenesis.

The rock complex of Mount Åreskutan is considered part of the Seve Nappe, a tectonic macro-unit of the Caledonides, vertically and laterally composed of a number of subsidiary nappes. Opinions on the age of the rocks involved are divided. Törnebohm (1896) regards the more metamorphic components as a unit of Eo- or Precambrian age, transported from a central zone of the Caledonian geosyncline, and his view is shared by Asklund (1938). The majority of authors, however, attributes the metasediments and metavulcanites of the Seve Nappe to the Cambro-Silurian period, and the intrusives to the Caledonian (Brøgger, A. Gavelin, Goldschmidt, Frödin, Helfrich, O. Holtedahl, Quensel, Th. Vogt et al.). Not so sure about the age are Ghosh et al. (1978), who hold that the Seve sediments were deposited in the late Precambrian or Lower Paleozoic era.

Helfrich (1967) subdivides the Seve Nappe in the Åreskutan region into three subsidiary nappes, from bottom to top: the Amphibolite Schist Nappe, the Fröå-Bjelke Nappe and the Åre Nappe. The first is composed mainly of amphibole-, garnetiferous, mica- and quartzitic schists, the Fröå-Bjelke Nappe of calc-silicate gneisses, marbles, quartzitic gneisses, and peridotites, and the Åre Nappe of cyanite-sillimanite-garnet gneisses, potash-feldspar gneisses, garnet-orthopyroxene-clinopyroxene amphibolites and migmatites.

This shows that the degree of metamorphism rises from bottom to top, i.e., it reaches from the epidote-amphibolite to the granulite facies. In the basal zone we find considerable diaphthoresis, followed by weak, progressive recrystallization under conditions of the lower amphibolite facies (Gee 1975).

The sphenes determined by F.T.A. come from the middle tectonic unit, the Fröå-Bjelke Nappe. Lithological and stratigraphical considerations led Helfrich to regard the rock units that make up the nappe as of Lower Ordovician age. Presupposing syngenesis this dating would hold true for the ore formation too.

As to the age of the metamorphic crystallizations in the Seve Nappe, Williams & Zwart (1978) have the opinion that the crystallizations under conditions of granulite facies generally date from the Precambrian, those of the amphibolite facies from the Caledonian. Applied to the nappes of Mount Åreskutan this would mean that the last progressive recrystallization of the rocks of the Åre Nappe took place in the Precambrian, of the Fröå-Bjelke Nappe in the Caledonian, whereas Arnbom & Troëng (1979), on the basis of structural considerations, assume Caledonian age for the granulite-facies metamorphism of Åreskutan.

Other datings in the Seve Nappe

So far no datings of the Åreskutan region have been published. However, we find a statement by Claesson (1977) that suggests Caledonian migmatization age for the highly metamorphic Seve rocks of Mount Åreskutan. It may be assumed that the material for these analyses came from the top nappe of Åreskutan, Helfrich's Åre Nappe.

Rock datings based on the Rb-Sr total analysis in other parts of the Seve Nappe, the rocks of which had previously been attributed to the Cambro-Silurian period, now indicated — or suggested — Precambrian age. Reymer (1977), for instance, determined metamorphic ages of 1000 to 1200 m.y. — that would correspond to the Sveconorwegian regeneration — in Seve gneisses of Mount Marsfjället, about 220 km NNE. of Åreskutan. Allegedly some datings even suggest an age of 1750 m.y. The high initial value of $^{87}Sr/^{86}Sr$ of 0,72/0,74 is considered an indication of a prolonged, pre-Caledonian Rb/Sr development. Reymer also dated biotites and white mica with the Rb/Sr method and found Caledonian ages of 410—440 m.y.

Obviously, given the distances, the conditions of tectonostratigraphy as well as of age datings do not unconditionally apply to the whole Seve Nappe system. As Caledonian-transported nappes and subsidiary nappes can consist of Precambrian, Eocambrian and Cambro-Silurian units which were more or less transformed together by Caledonian regional metamorphism(s), particulars of the location of samplings should be given when age datings are to be seen in the context of geological and stratigraphical questions. Moreover, a meaningful geological interpretation of the datings requires careful petrographic examinations of the samples, especially with regard to their metamorphic state, the course of the metamorphic development and to the original material. Bearing this in mind, the datings of Claesson and Reymer, made public only in the form of short papers, must be assessed with some reservations, as details about sampling locality and tectonostratigraphic position, and petrogenetic documentations are not yet accessible.

More recently Precambrian ages have been found in various "Caledonian" rock series of more western, inner parts of the Caledonian orogen (Heier et al. 1972; Brueckner 1973; Andresen et al. 1974, 1975; Sigmond & Andresen 1976). Of these the tectonostratigraphic documentation of the Stavanger region reminds of the conditions of Mounts Åreskutan. There, too, allochthonous crystalline nappes occur on top of fossiliferous Cambro-Silurian.

The sphene from the Mossgruvan Mine

In order to evaluate the unexpected F.T.A. results of Mount Åreskutan it seemed useful to have a comparison and analysis of a sphene from an indisputably Precambrian environment, in this case the Meso-Proterozoic basement of central Sweden. The sample was taken at the Mossgruvan Mine in the Nordmarks Odalfält mining field in Värmland. The corrected fission-track age was determined to $t_w = 1764 \pm 406$ m.y., and a corresponding temperature of 389° was calculated.

The analysed sphene crystal comes from a calcite-filled joint. According to Magnusson (1929) these joints are found mainly in actinolite-garnet-pyroxene skarns with more or less magnetite ore, resp. in the successive rock formed by the alteration of pyroxene to garnet and of garnet to epidote. These skarns are, together with the accompanying iron and manganese ores, as reaction skarnoids of the regional metamorphism a typical compound of the marble-granofels association within the Leptite Group.

The word "granofels" is used, instead of "leptite", as a non-genetic concept to define regionally metamorphic, phyllosilicate-poor, granoblastic quartz-feldspar rock of supracrustal origin which does not clearly show tectonic rock facies. The term "leptite" is rejected because of its ambiguity. It is known that "leptite" is used as a synonym for acid to intermediary metavulcanites, but also as a collective term for all fine-grained, phyllosilicate-poor, quartz-feldspar metamorphites, i.e. including metasediments and metasomatites. In principle, the terms employed should reflect primary formation and alteration, but experience has shown that such decisions require a lot of work, and as long as this cannot be done the word "granofels" will be nused as a provisional fieldterm.

Besides the dominating calcite the joint paragenesis often consists of amphibole, pyroxene, epidote, chlorite, magnetite, sphalerite, galena, arsenopyrite, pyrite, pyrrhotite, and chalcopyrite. Sphene is less frequent, as well as apatite, apophyllite, aragonite, argentite, axinite, bismuthinite, cobaltite, cosalite, datolite, feldspars, fluorite, galenobismuthite, hematite, marcasite, molybdenite, nordmarkite, niccolite, pyroraurite, pyrosmalite, quartz, safflorite, scapolite, scheelite, vesuvianite, and wurtzite and the free metals gold, silver, bismuth, and copper. Radioactive accompanying materials that could have influenced the nuclear reactions in sphene have definitely not been observed so far.

Magnusson attributes the filling of joints and pockets and the above mentioned alteration of the skarnoids to contact-metamorphic influences of late orogenic granites, without, however, giving more detailed documentation or explanations of the whys and hows. Isotope age measurements of these joint mineralizations and their neighbouring rocks are lacking, as are datings of the more distant surroundings. The, so far, very small number of datings of occurrence of the Leptite Group at some distance from the Nordmarks Odalfält mining field allows only approximative values for their units. According to these estimates the supracrustal might have been formed 2200—1900 mt.y. ago, the synorogenic intrusives 1900—1700 m.y. ago, and the late orogenic granites 1700—1600 m.y. ago. Data about the number and iscotopic age of the regional metamorphisms are not available either. These might have influenced the period of the synorogenic to late orogenic development, i.e. about 1900—1600 m.y. ago. The tectonic appearance of joints and the fabric and composition of their fillings suggest stages of formation after the intrusion of the synorogenic intrusives which could have lasted into the late orogenic period.

Geological interpretations

More precise knowledge of the age development of the Leptite Group is lacking, due to the fact that physical age determinations on its rocks and metamorphic crystallizations have been made only sporadically. Therefore, the corrected fission-track age $t_w = 1764 \pm 406$ m.y. of the Nordmark sphene cannot be applied to isotopic formation, mixing, and cooling ages. Its occurrence as a fissure mineral allows us — according to our actual knowledge — to choose between two periods as times of formation: the late stages of the synorogenic or late-orogenic development. The fission-track age of 1799 ± 406 m.y. rather points at a late synorogenic formation and cooling, judging from the approximative values given on page 9, even if the late-orogenic scope cannot be excluded because of the quite large error boundaries. Modern petrographic works which could give numbers, courses, temperature and pressure fields, tectonic rock facies etc., of the regional metamorphisms are lacking. Therefore, there is no answer to the question if a late-orogenic metamorphism may have reinfluenced or regenerated an earlier closing of the sphere. In spite of these uncertainties there is no doubt that the sphene in question crystallized primarily and got its fission-track closing in the Proterozoic. This knowledge is sufficient when comparing the Nordmark sphenes to the sphenes from Mount Åreskutan.

The sphenes from the Caledonian-transported Fröå-Bjelke Nappe on Mount Åreskutan have Precambrian closing ages as well ($t_w = 1500 \pm 325$ m.y. and 1761 ± 349 m.y., respectively). This was a surprise with regard to the so far dominating opinion, that these rock series are of Cambro-Silurian age and their metamorphic crystallizations of Caledonian age. Radiometric analyses verifying this interpretation do not yet exist. Up til now, neither rocks nor metamorphic crystallizations from the Fröå-Bjelke Nappe have been dated with isotopical methods. The Caledonian Rb/Sr ages from so-called neosomes of migmatites (Claesson 1978), belonging to the topping tectonic unit at Åreskutan, cannot be transferred to the lower units without further ado. Moreover, it is not clear so far, whether the migmatites in the Åre Nappe arose from decomposition or from admixture. In the latter case, a Caledonian age for the added pegmatitic material should be quite intelligible, whereas the old rock, including the metamorphic crystallizations, can be of Precambrian age.

As is evident from the preceding chapters regarding the conditions at Mount Åreskutan, there is a series of contradictory opinions on age and development of rocks, tectonism and metamorphism. An estimation of the respective criteria is not always possible to make. Although a great number of papers — by Scandinavian standards — have been produced on this problem, a few essential questions are still waiting for an answer. This hinders an optimal interpretation of the fission-track determinations. Among other things, analyses of the structural behaviour of the rockforming components concerning their relative age in the metamorphic course and their phase-petrological position are lacking. Those analyses might give a deeper understanding of the number and courses of the regional metamorphisms and could point out differences between the several nappe divisions.

Moreover, it would be of importance for the geological interpretation of the F.T. determinations to know in which stage of the tectonic development the different metamorphic crystallizations of the nappe took place, e.g. in the present local position or during the nappe transport, or before it. The fact that the metamorphic grade in the nappe pile increases upwards, makes it plausible that the crystallizations so indicating hardly can be Caledonian local products. Under the given circumstances there is no intelligible explanation for the mechanism of such an inverted metamorphism. Accordingly, it is more probable, that the pretendingly different pro-grade character of the nappe divisions was formed at another place. This may have happened in Precaledonian but also in Caledonian time. In the last stages of the nappe movements, however, low-grade conditions and diaphthoresis dominated.

Similar questions could be discussed on the tectonic structures as well: Which structures originated in Precaledonian time? Which are of Caledonian age? It is of great importance to know, when and where the latter structures were formed during the Caledonian orogenesis. Only structures proved to be from the same stage allow correlating fixings with regard to regional age classifications. Thus, similarly corrected orientations or, for instance, lineations in tectonically and stratigraphically different positions cannot be proofs that they originated from the same stage.

Such controls on repeated crystallizations and deformations concerning time and space should be a supposition also for studies on element distributions in co-existing phases and their thermodynamic interpretation, especially if regional metamorphic events (temperature and pressure estimations) are derived. This could help to prevent things having been formed in the course of different stages to be treated as one-stage crystallizations.

Arising from the above mentional shortcomings, the reductions of the geological interpretation only suffer the following comments. The investigated sphenes from the calc-silicate gneisses of the Fröå-Bjelke Nappe and from included sulphide ores are idioblasts sometimes containing internal relicts of quartz, feldspar and sulphide. The reaction $TiO_2 + \text{calcite} + \text{quartz} \rightarrow \text{sphene} + CO_2$ can be given for the formation of the sphene. Ti may also be derived from silicates, e.g. biotite. This reaction is valid not only for low-grade and medium-grade conditions, but also for high-grade circumstances, provided that calc-silicate gneisses are present, as in this case.

In this section, the sphene does not show any reaction relations to neighbouring phases. Perceptible crystallizations definitely younger than sphene are not present. This brings about, with regard to the Precambrian F.T. age of the sphenes, that Caledonian crystallizations could not be found by certainty.

The Precambrian F.T. ages of the sphene also lead to a relative age information for the sulphide ores. The fact that sphene and sulphides enclose each other makes it easy to assume that they finally crystallized or recrystallized almost simultaneously. From this the conclusion can be drawn that the sulphide ores are not of Cambro-Silurian or Caledonian age, as was supposed hitherto, but primarily were formed already in the Precambrian.

Deformation can only be recognized as post-crystalline ruptures in the sphenes and the other components. They do not show any geometrical (or causal) relations to older pre- or para-crystalline textures, i.e. grain extensions and grain orientations. The consequence must be that these textures, which even may be described as foliations, are of Precambrian age, the sphene being part of the textures. On this basis it may be supposed, that at least the now treated parts of the Fröå-Bjelke nappe did not experience any radical texture modifications during the nappe transport. It is probable that this part was rather moved "en bloc" and that the Caledonian tectonite facies was formed only at overthrust planes and in certain zones. As described earlier, such planes distinctly differ from planes due to diaphthoritic influences exerted by a predominant greenschist facies.

The closing temperature of the sphenes, 389°C, shows — with given closing ages — that the processes connected with the Caledonian orogenesis cannot have exceeded this temperature. If so, signs of this should be indicated by the fission tracks.

The F.T. ages and closure temperatures of the sphene, discussed above, are up til now the only contributions to the Precambrian cooling history in the Fröå-Bjelke Nappe. In the future, further analyses on other rock forming minerals could be of help in order to get an answer on some of the raised questions, especially the delimitation of Precambrian and Caledonian crystallizations and their course of formation and cooling. The pre-conditions for this are favourable. The rocks of the Fröå-Bjelke Nappe consist of components which are suitable for both the higher and lower cooling ranges. The higher temperature range could be investigated with Rb/Sr and K/Ar datings on amphibole (K/Ar $>$500°C), muscovite (Rb/Sr $\sim$ 500°C, K/Ar $\sim$ 300°C) and biotite (Rb/Sr $\sim$ 300°C) (Hart 1964; Jäger 1969; Hanson & Gast 1967). The low-temperature history could be reconstructed by E.T. determinations on andradite 300—260°C, epidote 260—220°C, vesuvianite 155—115°C (Haack 1976), and apatite. An extension of such examinations to the other tectonic units of Mount Åreskutan could help to emphasize the respective differences regarding age, metamorphic grade and course, and the cooling history.

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