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Palaeomagnetism of Permian through Early Triassic sequences in central Spitsbergen: contribution to magnetostratigraphy

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A total of 297 samples for palaeomagnetic studies were collected from Upper Gzhelian through Spathian sediments of the Isfjorden area (central Spitsbergen). In spite of extensive Cenozoic remagnetisation the studied rocks yielded palaeomagnetic poles and magnetostratigraphy. Almost all Permian samples were reversely magnetised during Kiaman superchron. Normal-polarity samples appear in the Ufimian and Kazanian sediments. The topmost samples from the Kapp Starostin Formation (Upper Permian) contain reverse polarity. The magnetic polarity record noted in the Early Triassic (Griesbachian-Spathian) sequences is fully convergent with magnetic polarity schemes obtained in the Canadian Arctic and Deltadalen type section.

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INTRODUCTION

Studies of Permian succession on Spitsbergen gave a chance to recognise the structure of the Kiaman reversed-polarity superchron and establish the position of the Illawarra basal reversal that finished it (Irving and Parry, 1963). The position of this reversal in the global composite scale is still controversial. Russian Platform data that locate the Illawarra basal reversal in the Tatarian stage (Pechersky and Khramov, 1973; Gialenella *et al.*, 1997) are inconsistent with results from north China and southwestern Australia where the end of Kiaman reversed-polarity superchron was interpreted as occurring in the earlier Ufimian stage (Theveniaut *et al.*, 1994; Embleton *et al.*, 1996). However, an Ufimian age of the Illawara basal reversal was contested by Menning and Jin (1998).

Permian and Triassic strata are well exposed on Spitsbergen (Fig. 1A) and have been the subject of various geological studies. The mass extinction crisis at the Permo-Triassic (P-Tr) boundary was especially monitored by chemostratigraphic methods. A significant (7.5‰), positive stable carbon isotope ($\delta^{13}C$) shift occurs in the Upper Kazanian-Lower Tatarian strata (Gruszczyński *et al.*, 1989; Mii *et al.*, 1997). It was followed by a rapid decrease in stable carbon and oxygen ($\delta^{18}O$) isotope values at the top of Permian succession (Gruszczyński *et al.*, 1989). The later event may be a diagenetic artifact and a continuous character of P-Tr boundary has been contested (Mii *et al.*, 1997). However, according to Wignall *et al.* (1998), the Late Permian to Early Triassic succession from Spitsbergen is continuous and they place the P-Tr $\delta^{13}C$ negative shift within the part of the section that had been considered as Early Triassic.

A palaeomagnetic investigation of Upper Gzhelian through Spathian sediments from central Spitsbergen has been carried out here in order to (1) interpret the duration and structure of long reversed-polarity Kiaman superchron, (2) to refine the Permian-Early Triassic palaeotectonic and palaeogeographic position of Spitsbergen (Nawrocki, 1999). The aim of this paper is to present the magnetostratigraphic results of this investigations.

PERMIAN-EARLY TRIASSIC STRATIGRAPHY ON SPITSBERGEN

Steeply dipping (dip 60–90°) Permian and Triassic rocks form a narrow belt in the western part of Spitsbergen. Rocks of

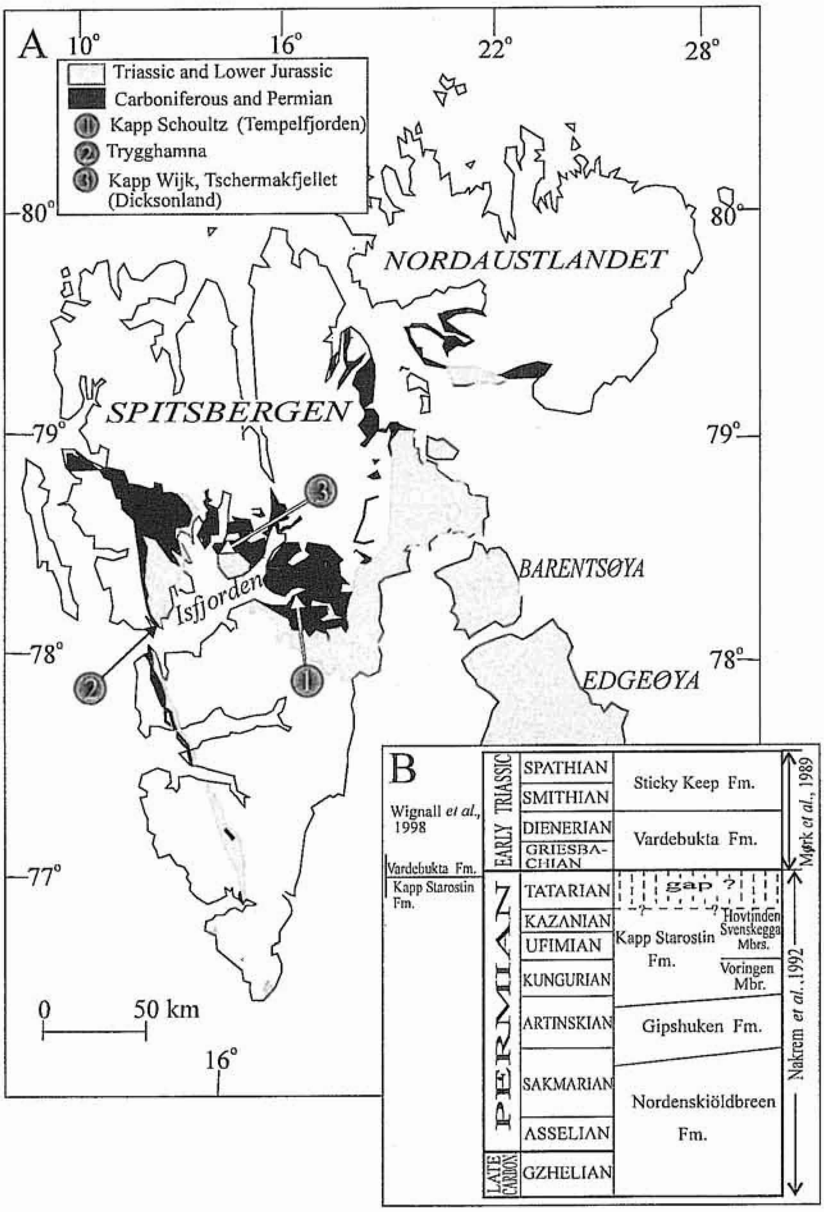

Fig. 1. **A** — Carboniferous-Lower Jurasic outcrop areas in the Svalbard Archipelago (after Mørk *et al.*, 1989; Nakrem *et al.*, 1992); regions of palaeomagnetic investigations have been marked by arrows; **B** — Late Carboniferous-Early Triassic stratigraphy in Spitsbergen; continuous (Wignall *et al.*, 1998) or discontinuous (Nakrem *et al.*, 1992) nature of Permian-Triassic boundary are illustrated

this age are also exposed in the central and eastern parts of the island (Fig. 1A) where their tectonic disturbance is very small (dip 0–15°). Moscovian-Sakmarian stages at Spitsbergen consist of limestones, dolomites and sporadic sandstones. They are classified as Nordenskiöldbreen Formation (Fig. 1B). This formation is covered by mainly evaporitic sediments of Gipshuken Formation attributed to the Sakmarian and Artinskian (Nakrem *et al.*, 1992). Evaporitic series are overlain by cherts, spiculitic shales and limestones with rich brachiopod and bryozoan faunas of the Kapp Starostin Formation (KSF). Biostratigraphic data support the Kungurian-Kazanian age of the KSF but there is no biostratigraphic evidence to indicate the presence of Tatarian stage (Nakrem *et al.*, 1992). It should be stressed, however, that the last 30–50 m of this formation do not contain any diagnostic fauna. The maximum thickness of the whole Permian sequence reaches of about 800 m.

In the Triassic period, Spitsbergen was a part of an extensive Boreal Basin and 250 to 1200 m of clastic sediments with small intercalations of carbonate rocks were deposited during numerous transgressive-regressive cycles. The Lower Triassic

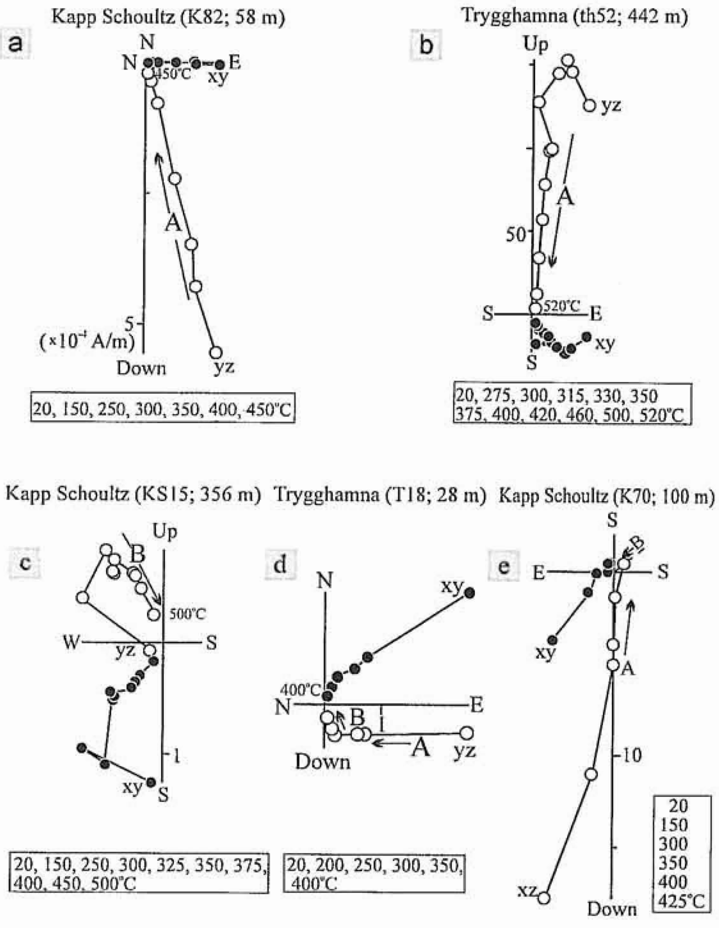

Fig. 2. Orthogonal demagnetograms of representative samples of Late Gzhelian-Early Triassic rocks from central Spitsbergen

a, **b** — totally remagnetised samples with Cenozoic component A (*in situ* coordinates); **c** — sample containing component B (after bedding correction) of Late Carboniferous-Permian age; **d** — sample with component B (after bedding correction) of Early Triassic age; **e** — sample containing component B that is strongly overlapped by component A (after bedding correction)

succession consists of two (Fig. 1A), or locally three major cycles which often consist of several subcycles (Mørk *et al.*, 1989). Biostratigraphic documentation of these sediments (Birkenmajer and Trammer, 1975; Gaździcki and Trammer, 1977; Weitschat and Dagys, 1989), based mainly on ammonoids, together with sequence stratigraphy markers allows subdivision into standard chronostratigraphic units. Despite this there is a problem in defining the P-Tr boundary because the topmost beds of KSF contain no age diagnostic fauna and the oldest ammonite *Otoceras boreale* has been found about 20 m above the base of Vardebukta Formation (Tozer and Parker, 1968). Traditionally this boundary has been placed at the top of the KSF and bigger or smaller hiatus between the KSF and Vardebukta Formation has been assumed (see Nakrem *et al.*, 1992). Completely different solution has been presented recently by Wignall *et al.* (1998). They placed the P-Tr boundary within the lower part of Vardebukta Formation and defined the P-Tr transition as complete taking the presence of the Late Changxingian fungal spore *Tympanicysta stoschiana* in the lowest Vardebukta Formation (Mangerud and Konieczny, 1993) and the results of chemostratigraphic investigations into account.

MATERIAL AND PALAEOMAGNETIC PROCEDURE

A total of 297 drill samples for palaeomagnetic studies were collected from Isfjorden area. Uppermost Carboniferous and Lower Permian rocks (Nordenskiöldbreen and Gipshuken formations) were sampled in Tempelfjorden (locality Kapp Schoultz; Fig. 1A). Kapp Starostin Formation and Early Triassic sediments were examined in western Dicksonland (locality Kapp Wijk and Tschermakfjellet) and near the entrance to the Isfjorden (locality Trygghamna). In Tempelfjorden and Dicksonland areas beds of the rocks studied were characterised by a very small dip that did not exceed 10 degrees. A different tectonic situation was in the Trygghamna area where beds were steeply (60–85°) inclined towards ENE (KSF) or NE (Vardebukta Formation) direction.

The natural remanent magnetisation (NRM) of specimens was measured using spinner and cryogenic magnetometers. Some pilot samples were subjected to an alternating field demagnetisation experiment. Because this method was not effective, the majority of the sample set has been subjected to the stepwise thermal demagnetisation in a m-metal shielded oven,

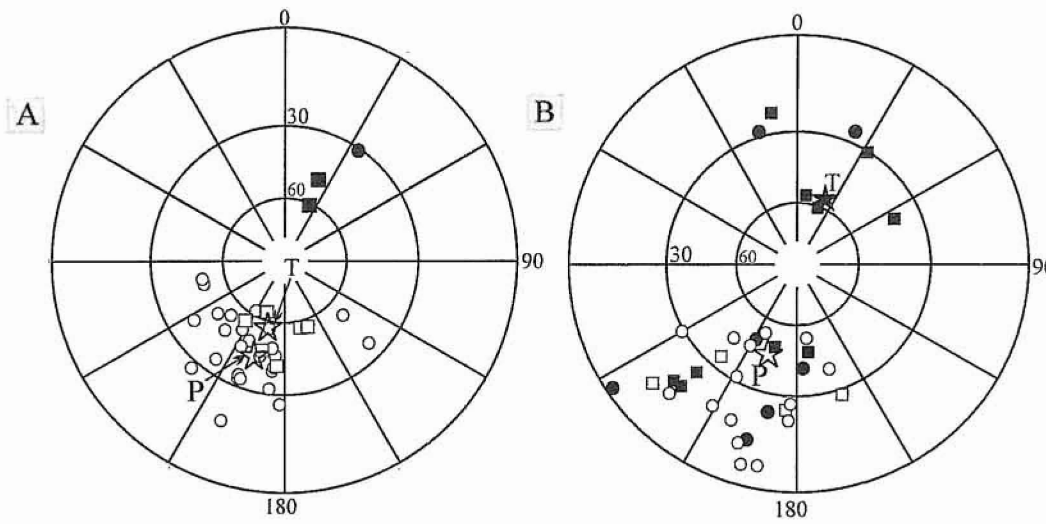

Fig. 3. **A** — stereographic projection of the Late Gzhelian-Permian (circles) and Griesbachian (squares) line-fit directions from Kapp Schoultz and Trygghamna sections; **B** — stereographic projection of the directions obtained on the terminus levels of thermal demagnetisation (before rapid increase of magnetic susceptibility at temperatures of about 425°C) of the Late Gzhelian-Artinskian (locality Kapp Schoultz) and Early Triassic (locality Tschermakfjellet) partly remagnetised samples; the asterisks with the letters P and T show the mean Permian and Triassic direction respectively; in stereoplots, open (closed) symbols denote upward (downward) pointing inclinations

which reduced the ambient field close to a few nT. After each thermal demagnetisation level a magnetic susceptibility signal was monitored. Least-square line fit methods, as presented by Kirschvink (1980), was used to calculate the components of NRM and their unblocking temperature spectra. Thermomagnetic analysis and analysis of isothermal remanent magnetisation (IRM) acquisition were used to determine the nature of magnetic carriers. For some samples, hysteresis loops were also prepared. Results of the rock magnetic investigations were presented in the earlier paper (Nawrocki, 1999). The Permian-Triassic remanence resides in the magnetite or titanomagnetite grains with the unblocking temperatures between 450 and 500°C.

RESULTS OF PALAEOMAGNETIC ANALYSIS

During thermal demagnetisation at temperatures between 380 and 435°C, an abrupt increase of magnetic susceptibility was observed in the bulk of samples, and their demagnetisation was terminated at this point. In many samples from all sections only one distinct component A with very steep, positive inclination (75–90°) was isolated (Fig. 2a). This component results most probably from a widespread remagnetisation that affected Spitsbergen in the Cenozoic time (see e.g. Halvorsen *et al.*, 1996). Some samples from a narrow tectonic zone which cuts the Trygghamna section also contain the steep component A, but with a negative inclination (Fig. 2b). In this tectonic zone, the NRM intensities were about an order of magnitude higher than those in the remagnetised samples with a positive inclination.

Fortunately, about 50% of the samples also retained a component B with moderate angles of negative or positive inclination. The degree of remagnetisation of these samples, as demonstrated by the presence of the component A, waried. In 12% of the sample collection, the component B, which is interpreted as primary magnetisation vector, was well defined (Fig. 2c, d) and calculated as a line-fit vector. NRM intensities of these weakly magnetised samples have never exceeded 3 x 10^{-4} A/m, which is at least three times lower than intensities in the samples containing only the component A. The maximum unblocking temperature of component B remains unknown since magnetic susceptibility was increased. We know only that it is higher than 400°C. Line-fit directions obtained in the Kapp Schoultz section cluster well in the upward, south-west quadrant. Likewise, the line-fit B directions isolated in 9 Permian and 6 Triassic samples from Trygghamna section display a similar trend after tectonic correction (Fig. 3A). Three of these B directions from Trygghamna are antipodal, downward toward north-east. Prior to tectonic correction, all directions B from this locality are shallow upward to the east, in contrast to the expected postfolding Cenozoic overprint inclinations which should be almost vertical.

Most of the samples used for construction of polarity diagrams were strongly remagnetised, but lost their component A at temperatures higher than 400°C (Fig. 2e). The endpoint directions, defined before a rapid increase of magnetic susceptibility, did not attain the expected Permian-Triassic directions. Nevertheless these endpoint directions and trends of

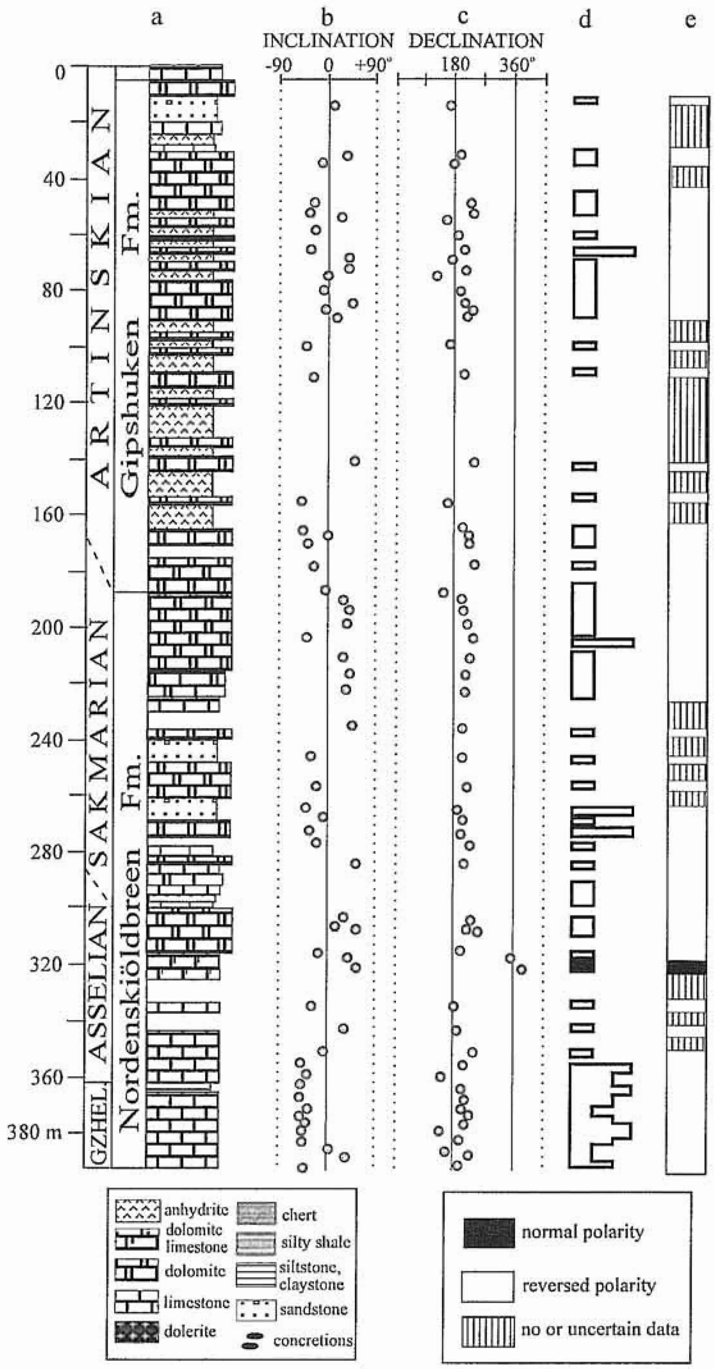

Fig. 4. Lithological column and stratigraphy (a), inclination (b) and declination (c) graphs, polarity pattern graphs (d) and composite polarity scale (e) constructed for the Late Gzhelian-Artinskian formations from Kapp Schoultz locality

The longest polarity bars represent the first category of data (see text); intermediate bars are the second category of data; the third category of data yielded polarity interpretation marked by the shortest bars

demagnetisation paths indicated the polarity of the underlying component B (Fig. 3B). Results of the rock magnetic investigations were presented in the earlier paper (Nawrocki, 1999). The Permian-Triassic remanence resides in the magnetite or titanomagnetite grains with the unblocking temperatures between 450 and 500°C.

MAGNETIC STRATIGRAPHY

Palaeomagnetic results were divided into three categories of reliability. In the first category, marked by the longest polarity bars in the polarity diagram (Figs. 4–6), characteristic directions

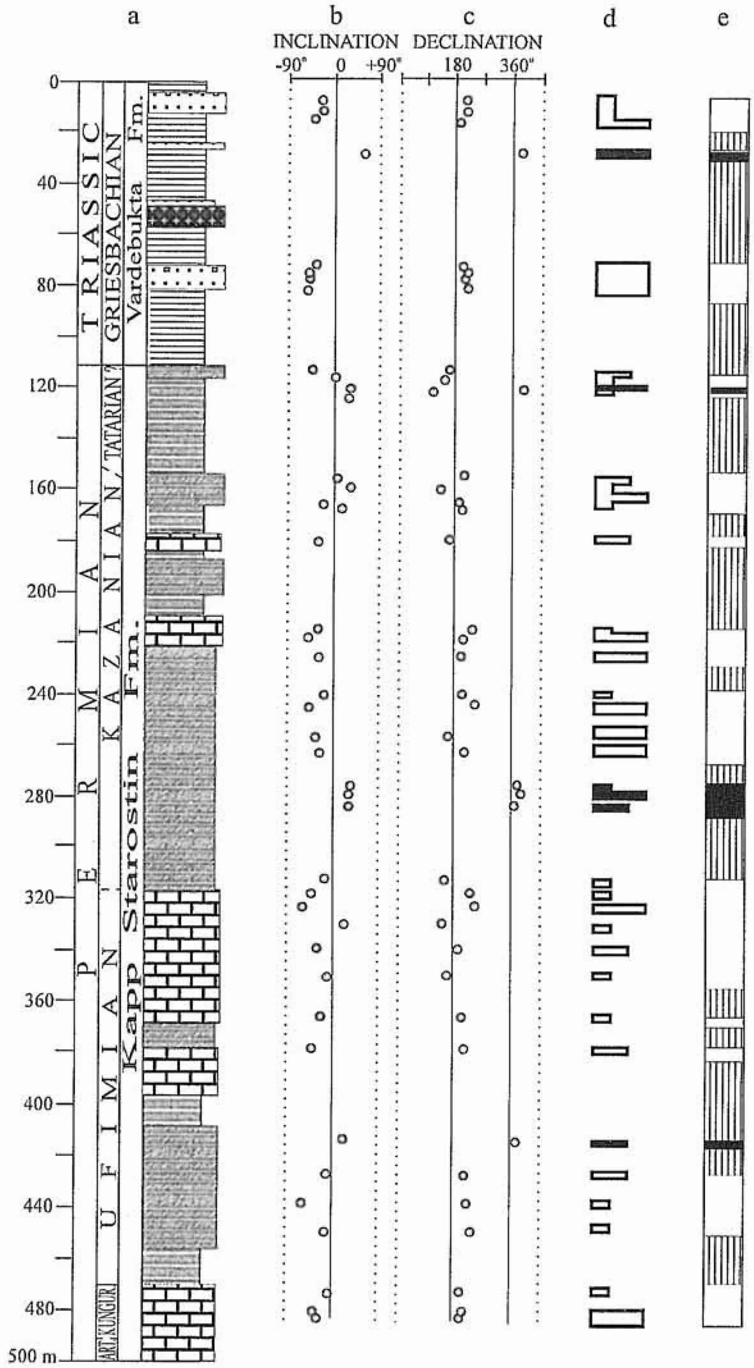

Fig. 5. Lithological column and stratigraphy (a), inclination (b) and declination (c) graphs, polarity pattern graphs (d) and composite polarity scale (e) constructed for the Late Artinskian-Griesbachian formations from Trygghamna locality

could be calculated by line fitting. The second category, indicated by intermediate-length bars, are the samples in which characteristic directions are determined as stable end points. Results from the samples in which polarities were interpreted from trends of demagnetisation paths and the endmost direction, are the third category of reliability, marked by the shortest bars in the polarity column.

The polarity column for nearly the entire Late Gzhelian-Artinskian sequence of Kapp Schoultz is reversely magnetised (Fig. 4). Only two samples from the middle part of the Asselian stage indicate a possible short normal-polarity zone. The Late Artinskian-Griesbachian polarity diagram for the Trygghamna section (Fig. 5) is full of gaps. Nevertheless, it is apparent that reversed-polarity dominates. The lowest normal-polarity samples are from Ufimian and Early Kazanian sediments. The dispersed palaeomagnetic samples in the Permian of Kapp Wijk section are generally of reversed-polarity (Fig. 6). Only two adjacent samples from Ufimian cherts

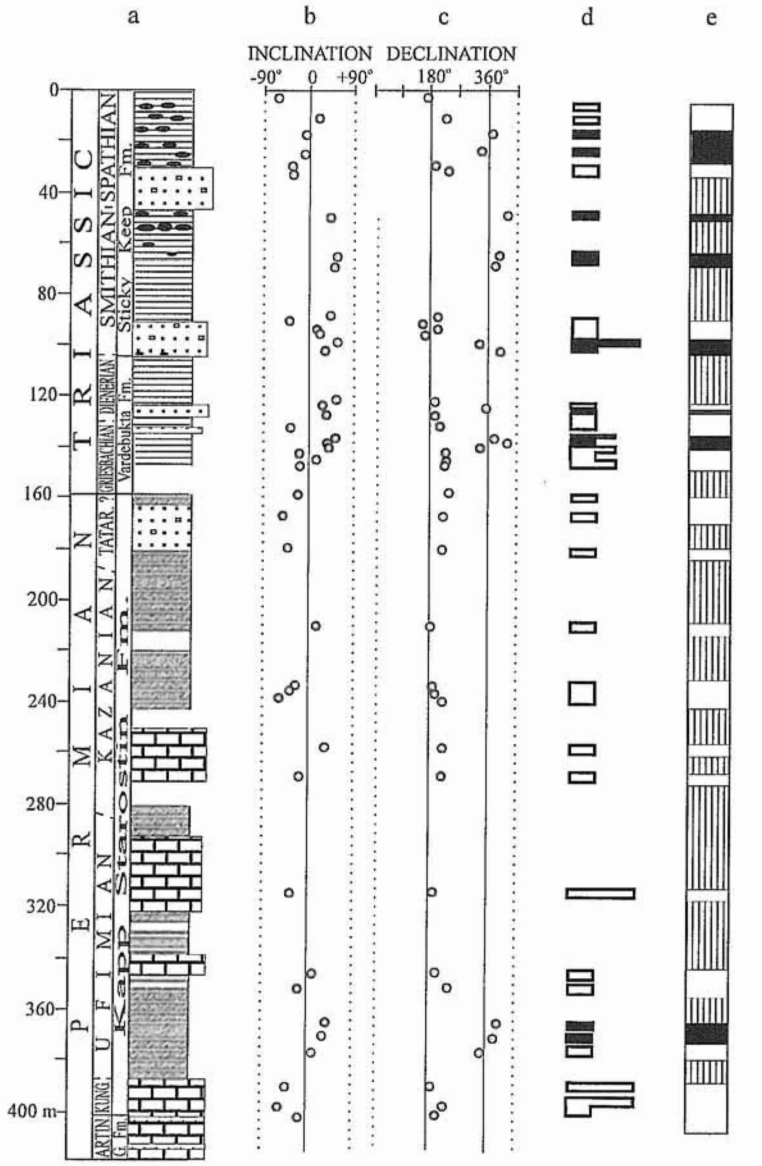

Fig. 6. Lithological column and stratigraphy (a), inclination (b) and declination (c) graphs, polarity pattern graphs (d) and composite polarity scale (e) constructed for the Late Artinskian-Spathian formations from Kapp Wijk, Tschermakfjellet localities

showed normal-polarity trends of demagnetisation paths. The Lower Triassic strata from Tschermakfjellet section display a pattern of mixed polarity.

A composite magnetic polarity scale (Fig. 7) was constructed from all sections studied. For the purposes of comparison, it is assumed that evaporites and clastic sediments were deposited more rapidly than carbonates. Because of this fact most Early Permian intervals with uncertain polarities were compacted by half in the composite polarity scale.

MAGNETOSTRATIGRAPHIC CORRELATIONS

In spite of numerous gaps in the composite magnetic polarity column, some correlations with the other sections is possible (Fig. 7). The Kiaman reversed-polarity superchron is confirmed by almost continuous reversed-polarity record in the Late Gzhelian to Kungurian sediments. It was probably interrupted only by a thin normal-polarity zone in the Asselian. Unfortunately, the resolution of magnetostratigraphy in the Upper Permian part of the studied sections is inadequate to point definitely where the Kiaman superchron was finished. The first fully reliable Permian normal-polarity zone appears in the Kazanian.

Magnetostratigraphic correlations do not exclude the presence of the Tatarian strata in the last dozens of metres of the Permian sequence from Spitsbergen. They should contain mainly normal-polarity record. Samples from the uppermost beds of the Kapp Starostin Formation are reversaly magnetised. In the Tethys sections, the P-Tr transition beds also contain a reversed-polarity record (Zhu and Liu, 1999).

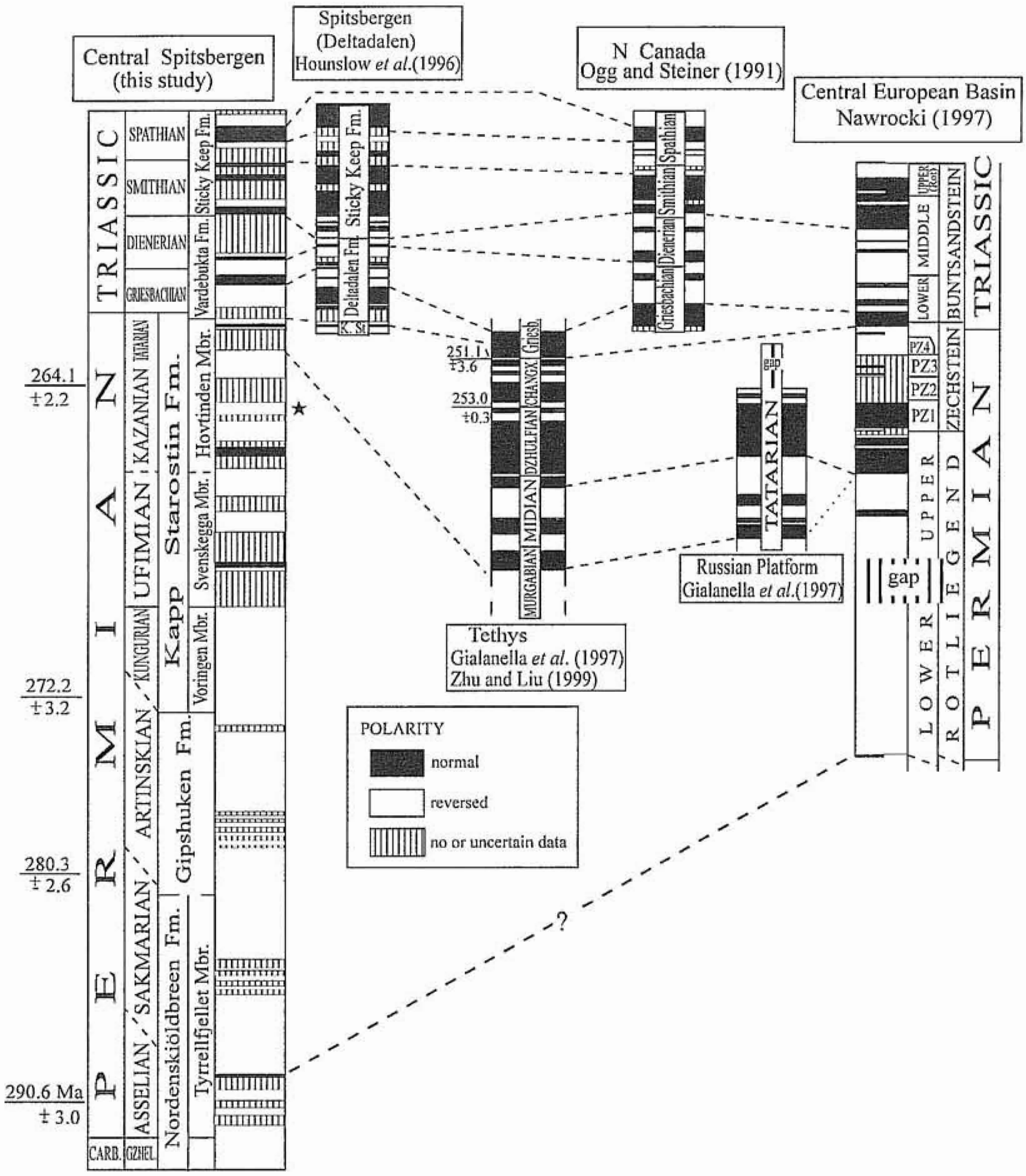

Fig. 7. Composite Late Gzhelian-Spathian polarity scale for central Spitsbergen and its correlation with magnetostratigraphy from other localities

Permian absolute ages were adopted from Yugan *et al.* (1997); an asterisk marks the place with significant positive stable carbon isotope shift (Gruszczyński *et al.*, 1989; Mii *et al.*, 1997)

In spite of poor quality of data the Early Triassic parts of the synthetic polarity scale are fully convergent with the composite magnetostratigraphic scheme obtained in the northern Canadian Arctic (Ogg and Steiner, 1991). There also seems to be a good correlation with an Early Triassic polarity sequence from the Deltadalen section of Spitsbergen (Hounslow *et al.*, 1996).

Correlation of the polarity patterns from Spitsbergen and other marine sections to the Rotliegend and Zechstein formations in the Central European Basin would help to establish the age of the latter. Two versions of correlation of the Upper Rotliegend and Zechstein with the Russian, Tethyan and Spitsbergen polarity sequences are presented in Figure 7. According to the "short" version (marked by a broken line), the Upper Rotliegend and Zechstein are the time equivalent of the Tatarian stage. The "long" version of correlation (marked by a dotted line) has a Kazanian through Tatarian age of the Upper Rotliegend and Zechstein. The P-Tr boundary in the Central European Basin could be defined in the upper part of the Top Terrigenous Series (magnetised in reversed direction) that cover the last Zechstein cyclothems.

CONCLUSIONS

Palaeomagnetic studies of the Permian-Early Triassic rocks from central Spitsbergen reveal widespread remagnetisation. In spite of the extensive Cenozoic remagnetisation, the Permian and Triassic components were resolved in several samples of the suites. Almost all Permian samples were reversely magnetised during Kiaman superchron. Scattered, thin, normal-polarity zones are within the Ufimian and Kazanian sediments. The topmost samples from the Kapp Starostin Formation (Upper Permian) contain reversed-polarity record. Early Triassic parts of the synthetic polarity scale are fully convergent with the composite magnetostratographic scheme obtained earlier in the northern Canadian Arctic.

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