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Plate Tectonic Implications of the Structure of the Shackleton Range, Antartica

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Summary: The stratigraphy, metamorphism, and structural evolution described in the two papers of BUGGISCH et al. (this volume) are the basis for an interpretation of the local plate tectonics of the Shackleton Range presented in this paper. In the southern Shackleton Range, all shear-sense indicators substantiate transport of the back-arc basin deposits making up the Mt. Wegener Nappe southwards onto the East Antarctic Craton (e.g. the Read Group with its sedimentary cover, the Watts Needle Formation). Consequently, the structure of the Read Mountains is interpreted as resulting from „foreland thrusting". Depending on the position of the assumed subduction zone, the basement of the northern Shackleton Range (Pioneers and Stratton Groups) either was part of a different continent (microcontinent, terrane) than that of the Read Mts. or represents part of the magmatic arc.

Models for the Ross Orogen are discussed. Compressional kinematics normal to the orogen are known from North Victoria Land and the Shackleton Range. Strike-slip and transpression structures were not observed in the field. Therefore, primary bending of the Transantarctic and Shackleton branches of the Ross Orogen seems to be most probable.

Zusammenfassung: Aufgrund der Stratigraphie, Metamorphose und der tektonischen Entwicklung, die in den beiden Arbeiten von BUGGISCH et al. (dieses Heft) beschrieben sind, wird eine lokale plattentektonische Interpretation der Shackleton Range vorgestellt. In der südlichen Shackleton Range beweisen alle Schersinn-Indikatoren südwärts gerichteten Transport der Back-arc-Ablagerungen der Mount-Wegener-Decke über den ostantarktischen Kraton (Read-Gruppe und ihrer sedimentären Auflage, die Watts-Needle-Formation). Folglich ist die Struktur der Read Mountains als „Foreland Thrusting" zu deuten. Abhängig von der Lage der zu fordernden Subduktionszone gehören die Basement-Gesteine der nördlichen Shackleton Range (Pioneers- und Stratton-Gruppe) zu einem anderen Kontinent (Mikrokontinent, Terrane), oder sie stellen einen Teil des magmatischen Arc dar.

Mögliche Modelle für das Ross-Orogen werden diskutiert. Normal zum Orogen gerichtete Kompressionstektonik ist aus Nord-Victorialand und aus der Shackleton Range bekannt. Strike-slip- und Transpressions-Strukturen werden im Gelände nicht beobachtet. Daher wird es für wahrscheinlich gehalten, daß die Biegung zwischen dem Transantarktischen und dem Shackleton-Ast des Ross-Orogens primär ist.

INTRODUCTION

Structural field evidence

In contrast to the interpretation of most of the previous authors, clear evidence was found in the field that the structures of the southern Shackleton Range between the Otter Highlands and the eastern Read Mountains were mostly formed by thrust tectonics. Almost all boundaries between major rock units are reverse faults or more or less flat-lying thrusts.

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For instance, the high-grade metamorphic rocks of the northern part of the Otter Highlands are thrust over the low-grade metasediments of the Wyeth Heights Formation (of the former Turnpike Bluff Group). Overturned bedding at the northern edge of Clayton Ramparts suggests a similar situation north of Stephenson Bastion.

In the Read Mountains, the contact between the basement (Read Group) plus locally preserved sedimentary cover (Watts Needle Formation) and the low to very low-grade metasediments of the hanging wall (Mount Wegener Formation) is also a thrust plane. This thrust is bent around a fold axis striking east-west. Therefore, the crystalline basement, exposed in the centre of the Read Mountains, forms a tectonic window framed by the metasediments of the Mount Wegener Formation (Read Window). The minimum transport distance is estimated conservatively to be 20 km. Consequently, the Mount Wegener Formation represents a tectonic nappe, which is one of the first in Antarctica to be described (BUGGISCH et al. 1994, ROLAND et al. 1988; KLEINSCHMIDT & BRAUN 1988, BUGGISCH et al. 1990).

Minor faults and thrust zones occur within the individual rock units. The sense of displacement can be recognized in the field by (a) asymmetry of minor folds, (b) σ and δ clasts, (c) phacoids, (d) imbricate structures, (e) duplex structures, and (f) shear bands. Oriented samples and thin sections exhibit s-c and ecc fabrics (BUGGISCH et al. this vol., BRAUN et al. 1988). All shear-sense indicators display relative displacement of the hanging wall towards the south (180°-200°). Therefore, it seems reasonable to conclude that the main thrusting in the southern Shackleton Range is directed southward onto the East Antarctic Craton.

Further geological evidence

At some places the basement rocks within the Read Window (Read Group) are unconformably covered by undeformed and nearly unmetamorphosed rocks of the Watts Needle Formation (BUGGISCH et al. 1990, BUGGISCH et al. 1994). Evidence for the Eocambrian age of these rocks is provided by acritarchs (WEBER 1990) and stromatolites (GOLOWANOV et al. 1979). Therefore, the basement of the Read Window is part of the East Antarctic Craton.

The boundary of the craton seems to run more or less east-west somewhere to the north of the Read Mountains, dividing the Shackleton Range into a cratonic, southern part and a non-cratonic, northern part. This is substantiated by metamorphosed and deformed rocks which are possible equivalents of the Watts Needle Formation in the northern Shackleton Range (MARSH 1983, KLEINSCHMIDT 1989).

PLATE TECTONIC INTERPRETATION

Orogenic belts are commonly characterized by thrusting. One of the main thrust belts of an orogen is directed towards or onto the related craton. This thrusting is usually called „foreland thrusting". It may also be considered as a kind of „back-arc thrusting". The Proterozoic Albany-Fraser and Paterson orogenic belts in western Australia (MYERS 1990), the Cretaceous-Cenozoic Andean orogenic belt in South America (e.g. DALY 1989, EDELMANN 1991) and the Ross orogenic belt in Victoria Land (FLÖTTMANN & KLEINSCHMIDT 1991) provide examples of this.

Thus, „foreland thrusting" is the most important mechanism in the southern Shackleton Range, supported by the lithological composition of the main thrust sheets: The Read Group represents the autochthonous continental crust with an epicontinental sedimentary cover (Watts Needle Formation). The lithofacies of the allochthonous Mount Wegener Formation is interpreted as back-arc fill (BUGGISCH et al. 1994) thrust towards the continent.

Age of thrust structures

The main thrust event, i.e. the main compressional movements, is of Ross age (≈ 480-500 Ma), as established by the following evidence:
(i) The allochthonous rocks contain calcareous algae (e.g. *Epiphyton sp.),* echinoderms, trace fossils (e.g. *Oldhamia radiata* and *O.antiqua),* and microfossils (BUGGISCH et al. 1990, BUGGISCH et al. 1994). Therefore, the age of sedimentation of the Mount Wegener Formation is most probably Early (to Middle) Cambrian .
(ii) K-Ar dates between 485-515 Ma (BUGGISCH et al. 1994) are related to the low-grade metamorphism which accompanied or outlasted the main compressional movements.
(iii) The Blaiklock Glacier Group, which is probably of Ordovician age (BUGGISCH et al. 1994), was not affected by any metamorphic or compressional tectonic event, which is in contrast to the Early to Middle Cambrian and older rocks. We have to concede that this third argument is rather weak, as the Blaiklock Glacier Group occurs only in the northwestern corner of the mountain range, far from the main thrust region treated here.

REGIONAL SYNTHESIS

A synopsis of all structural, sedimentological, stratigraphic and radiometric data related to the Shackleton Range leads to several local plate-tectonic models, as presented by BUGGISCH et al. (1990): A basin developed (Mount Wegener Formation, Fig. 1) north of the East Antarctic Craton (Read Group) and its cover (soil and shelf sediments of the Watts Needle Formation). Because the Mount Wegener Formation is a back-arc basin facies, a magmatic arc has to be hypothesized further north. Two positions can be assumed for this magmatic arc:
• South of the now northern basement of the Shackleton Range: In this case, the northern basement (Pioneers and Stratton Groups) would be (part of) a different, more northern continent, microcontinent or terrane (Fig. 1a).
• The cratonic portion of the northern basement of the Shackleton Range are tectonically mixed up with the magmatic arc. Thus, the Stratton Group (± Pioneers Group) would represent parts of the East Antarctic Craton which were reworked by magmatic activity and separated from the main craton by a thinned (continental) crust below the Mount Wegener Basin (Fig. 1b).

Both models require a subduction zone directed southwards with corresponding structural and lithological fingerprints within the northern basement or north of it (e.g. thrusting to the north).

THE ROSS OROGEN IN ANTARCTICA

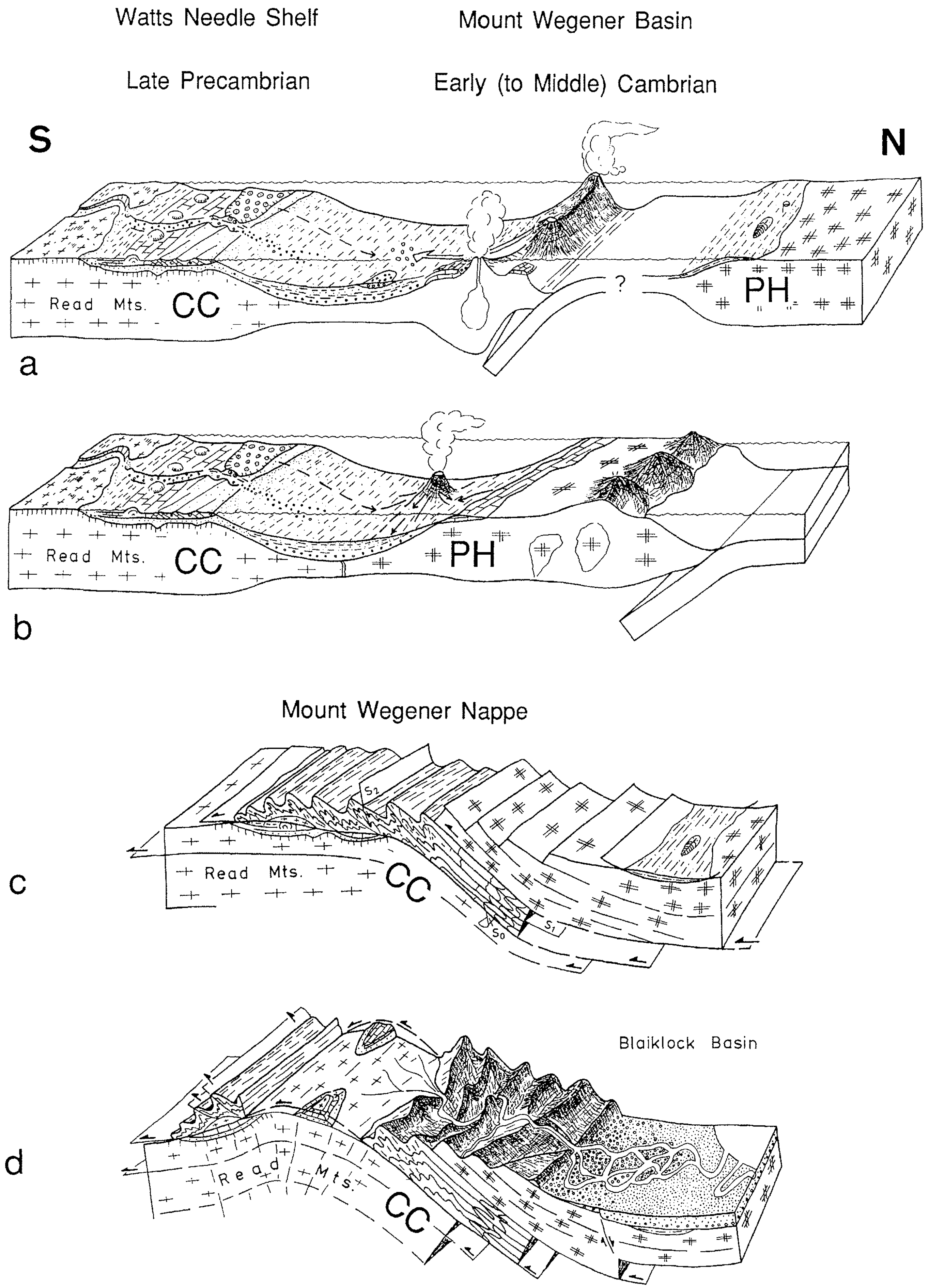
The data from the Shackleton Range confirm that the Cambro-Ordovician Ross Orogen (GUNN & WARREN 1962) continues from northern Victoria Land through the central Transantarctic Mountains and Pensacola Mountains (CRADDOCK 1972) to the Shackleton Range (KLEINSCHMIDT et al. 1991). Today, the Ross Orogen curves smoothly from northern Victoria Land to the Pensacola Mountains (Fig. 2a and 2b). From there to the Shackleton Range it appears to bend sharply to the east. This was anticipated by GRIKUROV & DIBNER (1979; see Fig. 2a) and is suggested on the Gondwana map (DE WITT et al. 1988; see Fig. 2b).

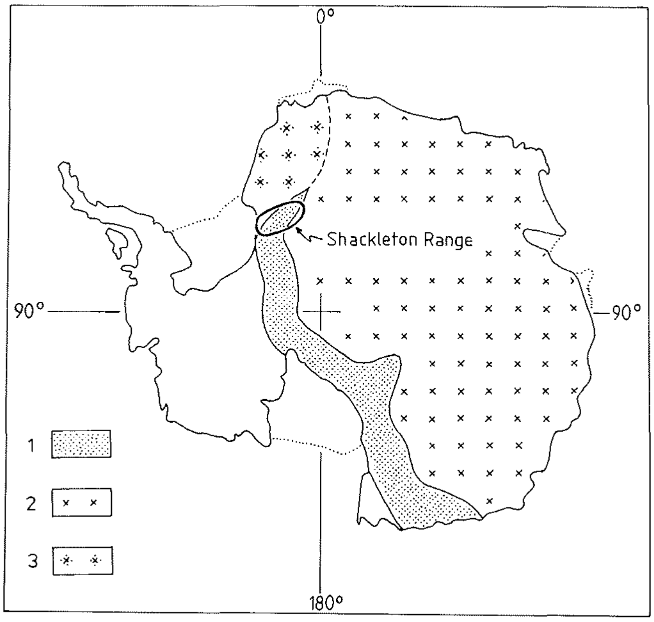
Conceivable plate-tectonic models

There are several models which can explain what we know

Fig. 1: Diachronous models of the sedimentation and tectonic evolution of the Shackleton Range; CC = Continental crust of the East Antarctic Craton (Read Group); PH = basement rocks of the northern Shackleton Range (Pioneers and Stratton Groups); a and b = alternatives of Late Precambrian to Middle Cambrian sedimentation (diachronous); c = Late Cambrian; d = Ordovician (according to BUGGISCH et al. 1990).

Abb. 1: Diachrone Modelle von Sedimentation und tektonischer Entwicklung der Shackleton Range. CC = Kontinentale Kruste des ostantarktischen Kratons (Read-Gruppe), PH = Kristallin der nördlichen Shackleton Range (Pioneers- und Stratton-Gruppe), a und b = Alternativmodelle für die jungpräkambrischen bis mittelkambrischen Sedimentationsräume (diachron), c = Oberkambrium, d = Ordovizium (nach BUGGISCH et al. 1990).


Watts Needle Shelf
Mount Wegener Basin
Late Precambrian
Early (to Middle) Cambrian
S
N
Read Mts.
CC
PH
?
a
Read Mts.
CC
PH
b
Mount Wegener Nappe
Read Mts.
CC
S_2
S_0
S_1
c
Blaiklock Basin
Read Mts.
CC
d



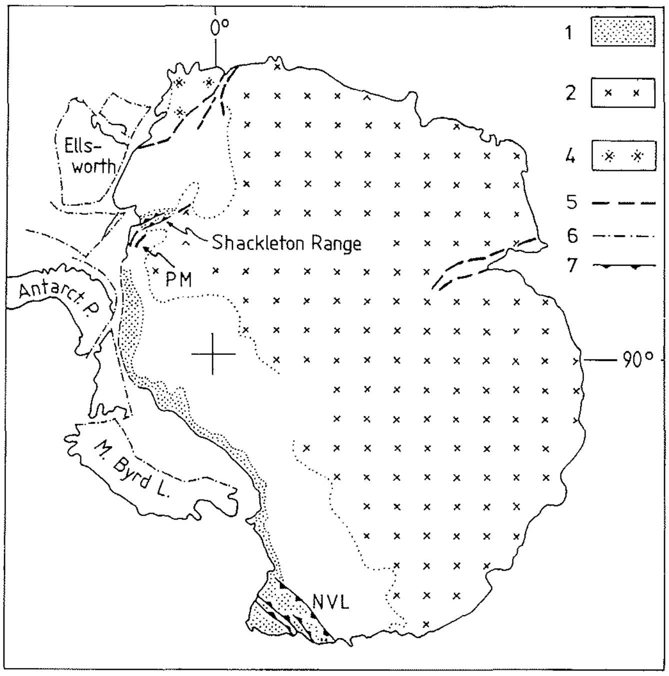


Fig. 2: The Ross Orogen in Antartcia and its relationship to the Shackleton Range. 2a = simplified according to GRIKUROV & DIBNER (1979); 1 = Ross Orogen, 2 = East Antarctic Craton, 3 = Weddell Sea Plate; 2b = simplified and supplemented according to the Gondwana reconstruction of DE WIT et al. (1988), NVL = North Victoria Land, PM = Pensacola Mountains; 1 = rocks of the Ross Orogen, 2 = rocks of the East Antarctic Craton, 3 = rocks of the northwestern part of the East Antarctic Craton, 4 = main fault, 5 = inferred Jurassic plate margins, 6 = Ross aged thrusts.

Abb. 2: Das Ross-Orogen in der Antarktis und seine Stellung zur Shackleton Range. 2a vereinfacht nach GRIKUROV & DIBNER (1979), = Ross-Orogen, 2 = ostantarktischer Kraton, 3 = Weddelmeer-Platte; 2b vereinfacht und ergänzt nach der Gondwana-Rekonstruktion von DE WIT et al. (1988), NVL = Nordvictorialand, PM = Pensacola Mountains; 1 = Gesteine des Ross-Orogens, 2 = des ostantarktischen Kratons, 3 = des Nordwestteils des ostantarktischen Kratons, 4 = Hauptstörungen, 5 = angenommener jurassische Plattenränder, 6 = rossorogenetische Überschiebungen.

about the present structure of the Shackleton Range and its relation to the Ross Orogen as a whole (Fig. 3).

On the one hand, the bending of the Ross Orogen to the east may be explained as a secondary effect: The Shackleton Range could have been rotated into its present position during post-Ross times (Fig. 3, Model A). But paleomagnetic data from basic dikes of pre-, syn- and post-Ross orogenic ages (HOTTEN 1993) are inconsistant with this model. But total exclusion of this model requires more paleomagnetic studies in the Shackleton Range and south of it to the Pensacola Mountains.

On the other hand, the change in the direction of the margin of the East Antarctic Craton between the Shackleton Range and the Pensacola Mountains could have taken place since the onset of crustal compression (Fig. 3, Model B). Accretion along such a curved margin during the Ross Orogeny, with compressional structures normal to the margin, has many present-day analogues, e.g. the plate-tectonic situation on the west side of South America. The Andean Orogen curves from N-S in Chile to NW-SE through Peru and Ecuador and finally to NE-SW in Colombia. Its Pacific side is marked by a subduction zone, its eastern margin is characterized by zones of eastward thrusting towards the Brazilian Craton (e.g. SAUER 1971). Bends in orogenic belts are commonly called „oroclines", originally meaning: bent around a vertical axis (CAREY 1958). Origins and dynamics, and even kinematics of relatively recent oroclines are not perfectly understood and are subject to controversy (e.g. BECK 1987, SACCHI & CADOPPI 1988, SEMPERE et al. 1989).

At present, it cannot totally be excluded that the southward thrusting of the Shackleton Range is due to transpression (Fig. 3, Model C). But we have no indication for this interpretation: all shear-sense indicators show clear evidence for movement to the south, normal to the main strike of all other structures.

A more sophisticated explanation would be to postulate two separate branches of the Ross Orogen with different kinematic histories (Fig. 3, Models D and E): Either the Shackleton Range branch is dominated by strike-slip movement and the Transantarctic branch by normal (i.e. compressional) movement or vice versa. However, there is no real indication of strike-slip movements in either the Transantarctic or the Shackleton branch. The strike-slip model for the Shackleton Range would fit rather well with a continuation into the large-scale NE-SW-trending mylonite zones in western Neuschwabenland (JACOBS 1988, 1991). However, JACOBS's recent observations contradict this interpretation; the kinematic analysis yielded only normal compression (i.e. NW-SE), and no NE-SW strike-slip movements of Ross age could be demonstrated.

Therefore, the most simple and most probable solution is to accept the bending of the Ross Orogen from the Transantarctic branch into the Shackleton branch as a primary feature and to understand it as an analogue of some of the recent „oroclines". With respect to the South American example given above, BECK (1987) writes: „It is, of course, perfectly reasonable to expect some mountain belts to form already bent". This has to be substantiated by a Ross-aged suture at least or a relict of it north of or in the northern part of the Shackleton Range.

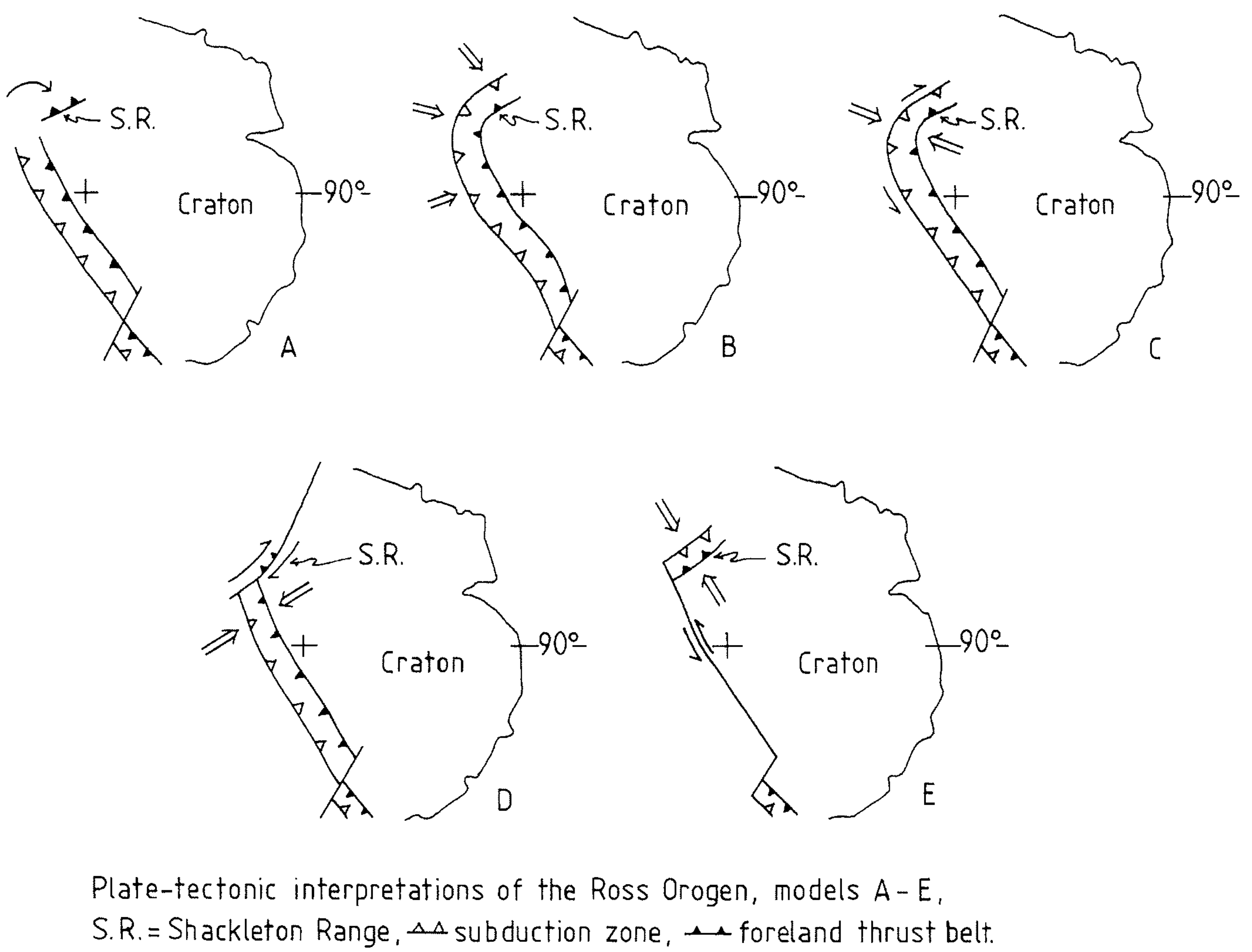


Fig. 3: Models A - E of plate-tectonic interpretations of the Ross Orogen; S.R. = Shackleton Range; line with open triangles = subduction zone; line with solid triangles = foreland thrust belt.

Abb. 3: Modelle (A bis E) der plattentektonischen Interpretation des Ross-Orogens. S.R. = Shackleton Range, Linie mit offenen Dreiecken = Subduktionszone, Linie mit schwarzen Dreiecken = Vorlandüberschiebungsgürtel.

All of the above models are oversimplified and imply no decision whether the accretionary history of the East Antarctic Craton was triggered by „normal" subduction with an ultimate continent-continent collision with participation of island arcs and/or allochthonous, exotic or suspect terranes. However, all of the models imply that the parts of Antarctica north of the Shackleton Range (westernmost Neuschwabenland and Coats Land, perhaps including the northwestern parts of the Shackleton Range itself) are more likely related to (Paleo-)Africa than to the East Antarctic Craton.

If this conclusion cannot be accepted, then we need a much more complicated model of the Ross Orogen in which the Shackleton Range forms an intracratonic branch of the Ross Orogen. However, our present field data on stratigraphy, lithofacies and biofacies, metamorphism, and structural evolution give no evidence for a model like that.

The final decision about which of the given models is the most probable requires more field data and exploration in the northern part of the Shackleton Range and in Coats Land.

Recently, models of a supercontinent in the southern hemisphere during the Eocambrian have been suggested which place the western margin of North America opposite the Pacific margin of the East Antarctic craton and extend the Grenville Orogen to the northern Shackleton Range and Neuschwabenland (DALZIEL, HOFFMANN and MOORES 1991). Our observations in the Shackleton Range do not support these models (TESSENSOHN et al. 1991), but they may encourage further research in the Shackleton Range as well.

An interesting and stimulating proposal has been put foreward by DALLA SALDA et al. (1992), who extended a „southern Iapetus Ocean" into the Shackleton Range so that the Ross-age orogeny in the Shackleton Range belongs to the Caledonides rather than to the Ross/Delamerian Orogen s.s. This hypothesis creates a convenient independence of the Ross-age structure of the

Shackleton Range and the main Ross Orogen. But their close positions on the maps of DALLA SALDA et al. (and DALZIEL 1992) show that the Shackleton Range/Ross problem has not really been solved.

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