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A Correlation of structural patterns and lithostratigraphy at Otjosondu with the Damara Sequence of the southern Central Zone, Namibia

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This paper compares the structural development and the lithofacies evolution of the manganese-bearing sedimentary sequence at Otjosondu in the east with that of the Damara Sequence as it is developed laterally along the tectonic strike of the exposed southern Central Zone of the Damara inland branch. Structural patterns of three deformational events can be correlated. D_1 folds are recognised throughout the Central Zone; the D_2 phase is the dominant deformation event in all areas, whereas D_3 patterns increase in their intensity towards the southwest. The facies distribution reflects two major Late Proterozoic transgressions. The first one (base of the Swakop Group) marks the opening of the Adamastor Ocean, in which sequences were deposited on an uneven topography. The second one at the base of the Chuos Formation was associated with the opening of the Khomas Sea which led to a major transgression throughout the area under consideration, and to the development of pelagic shelf Mn and Fe deposits at Otjosondu. The facies differentiation within the Chuos Formation reveals different depositional controls laterally along the shelf platform of the southern Central Zone. The detailed study of deformation patterns and lithostratigraphy confirms the validity of previous broad correlations of the lithologies at Otjosondu with those of the Damara Sequence as a whole.

Introduction

A comprehensive overview of lithostratigraphy and tectonic patterns throughout the tectonostratigraphic zones of the Damara Belt has been given by Miller (1983b). For the western part of the southern Central Zone (referred to as sCZ) correlation of tectonic patterns has previously been relatively straightforward (e.g. Miller, 1979; Miller, 1983b).

A lithostratigraphic scheme in a broad sense was proposed by SACS (1980) based on work in the well-exposed area to the west of Okahandja (Fig. 1). To the east of Okahandja, however, correlation of sequences mapped in various study areas has been more difficult.

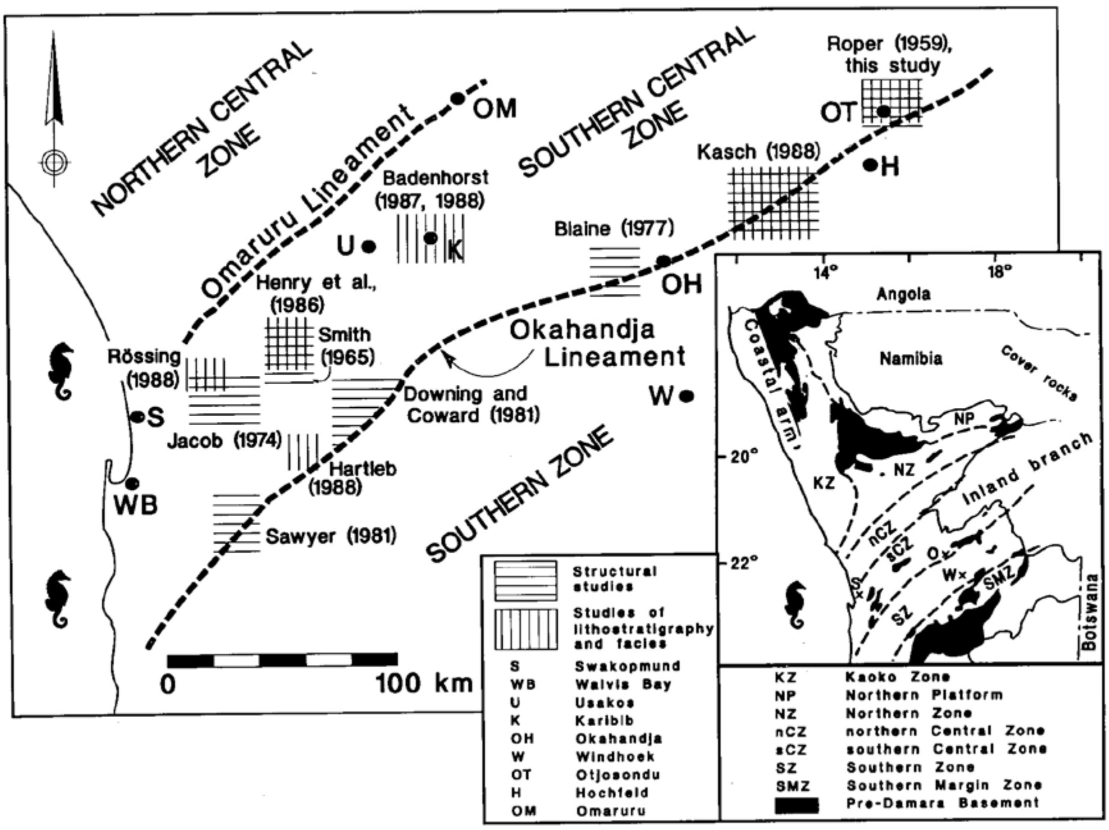

Figure 1: Locality map showing the southern Central Zone (sCZ) in the inland branch of the Damara Orogen (inset). The regional location of previous studies on lithostratigraphy/lithofacies and structural geology in the sCZ are outlined

West of Okahandja			Okahandja	East of Okahandja		
Jacob (1974)	*Sawyer (1981)*	*Downing and Coward (1981)*	*Blaine (1977)*	*Kasch (1988)*	*Bühn et al., (1991); Bühn (1991)*	
folding	folding and thrusting	folding and thrusting	folding and thrusting	no F_1 folds and thrusts, D_1 simple shear deformation	folding, simple shear	D_1
parallel to bedding, penetrative	sub-parallel to bedding		in places oblique to bedding	penetrative foliation (s_2)	sub-parallel to bedding	s_1
recumbent	recumbent	recumbent	recumbent		recumbent and upright	F_1
	E	NW	E		NNE	vergence
	present		present	present (l_2)	present	l_1
prominent		prominent	prominent	prominent (D_3)	prominent	D_2
present.	weak (s_3)	penetrative	penetrative	prominent (s_3)	present	s_2
upright, slightly inclined	tight, isoclinal	isoclinal, originally recumbent	recumbent	upright to SE-vergent	tight to isoclinal, upright	F_2
tight	tight to isoclinal, steeply inclined to upright (F_4,F_5)	upright, close, tight	open structures	open (F_4)	open	F_3
NNE, NNW	N-S		northerly	NW	NNW-SSE	plunge
crenulation cleavage (s_4)	schistosity and crenulation cleavage	mineral fabric	no schistosity	weak	not developed	s_3

Table 1: Comparison and correlation of deformation phases and styles along the tectonic strike of the southern Central Zone

This is largely due to the deterioration in exposure towards the sub-Kalahari erosion surface, and to changes in sedimentary facies. In this regard the exposures of the Otjosondu mining district bear important information from the eastern part of the sCZ. In addition, the variably strong metamorphic overprint of the Damaran rocks of the sCZ renders the lateral correlation of depositional sequences difficult. Stratigraphic correlation is therefore based mostly on lithostratigraphic analysis of unconformity-bound, genetically related sequences (Martin, 1965; Hoffmann, 1990). Structural patterns may furthermore be used to distinguish Damaran rocks from older sequences.

During the last decades many authors have studied structural patterns and facies in the west of the sCZ in Namibia (Fig. 1). Knowledge of structural and lithofacies evolution in the eastern part has been increased by recent work of Kasch (1988) east of Okahandja, and of Bühn *et al.* (1991; in press) and Bühn (1991) at Otjosondu. Kasch's findings have not yet been incorporated into the overall pattern of the orogen, and the geological sequence at Otjosondu has only provisionally been correlated with the Damara Sequence by Roper (1959), Martin (1965) and Miller (1983a). This paper focusses in detail on the regional comparison of the eastern and western parts of the sCZ and summarises the structural and sedimentological evolution of areas just north of the Okahandja Lineament.

Correlation of structural patterns in the sCZ

Three main phases of ductile deformation are developed in the southern Central Zone (Miller, 1983b; Miller and Grote, 1988). In the eastern part of the sCZ we correlate the D_1 event at Otjosondu (Bühn *et al.*, 1991) with the second phase of deformation of Kasch (1988) (Table 1). In both areas this fold generation is associated with a penetrative foliation and a prominent lineation. Structural analyses suggest that these folds are the result of simple shear deformation (Kasch, 1988; Bühn *et al.*, 1991). The F_2 folds of Kasch (op. cit.) have folded an earlier foliation (s_1), but neither at Otjosondu nor in Kasch's study area is there evidence for earlier folds or thrusts. The deformation phases D_2 to D_4 of Kasch are correlated with D_1 to D_3 at Otjosondu and elsewhere in the sCZ.

Bühn *et al.* (1991) suggested that polyharmonic folding was responsible for upright and recumbent F_1 folds at Otjosondu. This phase produced an s_1 cleavage which is largely parallel or subparallel to bedding with a prominent l_1 lineation developed throughout the sCZ. To the west of Okahandja, folding and thrusting are the main deformation mechanisms of D_1 (Table 1). F_1 folds there are rare and styles have been described as recumbent (Jacob, 1974; Jacob *et al.*, 1983; Blaine, 1977; Downing and Coward, 1981; Sawyer, 1981). This fold generation may go unnoticed where early folds have been reactivated during later compressional phases (Bühn *et*

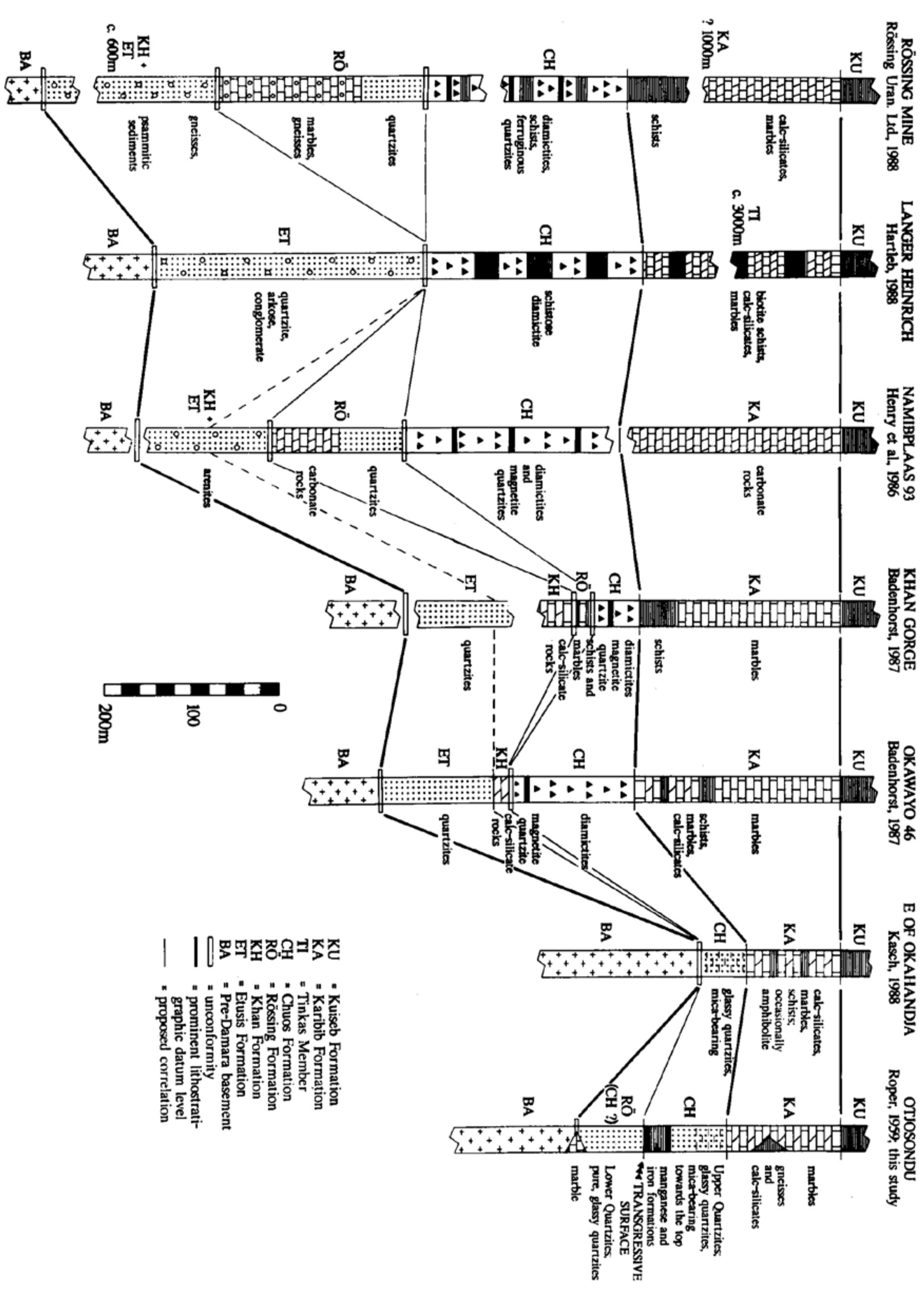

Figure 2: Lithostratigraphic correlation of the Damara Sequence in the southern Central Zone. The Karibib/Kuiseb Formation boundary is used as a datum level for the lithostratigraphic sections. The correlation of part of Kasch's (1988) sequence with the Karibib and the Chuos Formations is an interpretation by the present authors

al., 1991). We correlate this deformation phase with D_1 at Otjosondu. The vergence of F_1 folds varies from east (Blaine, 1977; Sawyer, 1981) through north-northeast (Bühn *et al.*, 1991) to northwest (Downing, 1982) while Smith (1965) recorded northwest-trending F_1 folds. This suggests an overall north-northeast vergence of the F_1 fold structures.

The D_2 phase is the dominant deformation event observed throughout the sCZ (Fig. 2) and other Damaran tectonostratigraphic zones. F_2 folding may be accompanied by thrusting (Miller, 1983b) and an s_2 cleavage is normally well developed. F_2 folds are tight and have been described as varying between recumbent (Blaine, 1977; Downing and Coward, 1981; Coward, 1983) and upright (Smith, 1965; F_3 of Kasch, 1988; Bühn *et al.*, 1991) in attitude.

Superposition of D_2 on D_1 has resulted in dome crescent mushroom patterns in areas where overturned to recumbent F_1 fold styles prevailed (Bühn *et al.*, 1991). The overall northeasterly strike of F_2 folds is prominent in all study areas as mentioned previously.

The intensity of the D_3 event appears to decrease from the west to the east. Sawyer (1981) and Downing and Coward (1981) reported tight, isoclinal D_3 structures in the west, whereas in the eastern parts open F_3 folds (equivalent to the fourth deformation event of Kasch, 1988) are represented as broad, open undulations (Table 1). D_3 structures plunge to the north in the west (Jacob, 1974; Blaine, 1977; Sawyer, 1981).and more to the northwest in the east (F_4 of Kasch, 1988; Bühn *et al.*, 1991). The decreasing intensity of the D_3 event is also manifested by the lack of an associated s_3 schistosity at the eastern end of the exposed part of the sCZ (Blaine, 1977; D_4 of Kasch, 1988; Bühn *et al.*,1991; Bühn, 1991), whereas a well-developed s_3 fabric was observed in the west by Sawyer (1981) and Downing and Coward (1981).

Although it may be considered possible that pre-Damaran structures have been completely obliterated by Damaran deformation, one should expect at least relic textures or refolded folds in pre-Damaran lithologies. We thus use the lack of pre-Damaran structures as a further justification for the correlation of the Otjosondu units with the Damara Sequence.

Correlation of the Damara Sequence in the sCZ

Lateral changes in facies along the tectonic strike of the sCZ are illustrated on the correlation diagram of Figure 2. The early Damaran Nosib Group (Etusis and Khan Formations) is developed only in the west of the inland branch. The fluvial deposits of the Etusis Formation (Miller, 1983b) and the overlying Khan Formation pinch out eastwards (Porada, 1983). Henry *et al.* (1986) pointed out that all pre-Karibib formations of the sCZ decrease in thickness towards the northeast. Using the terminology of Henry *et al.* (1990), this also applies to all synrift units of the inland branch (Nosib Group, Rössing Formation) and the early postrift Chuos Formation.

The Rössing Formation is non-uniformly developed in the sCZ and pinches out locally against older units and basement lithologies (Fig. 2). This indicates that the marine transgression related to the opening of the Pan-African South Atlantic (Henry *et al.*, 1988; Adamastor Ocean of Hartnady *et al.*, 1985) interacted with an uneven fault-block topography associated with the continuing rifting in the inland branch. The Lower Quartzite unit at Otjosondu may represent a shallow-water facies equivalent of the thin-bedded quartz-rich sandstones developed in the Rössing Formation of the western inland branch.

A well-defined unconformity is developed at the base of the Chuos Formation in the western inland branch (Fig. 2). This unconformity is interpreted by Henry *et al.* (1990) as another continental break-up unconformity, related to the initiation of oceanic crust in the Khomas Sea. We correlate this transgressive event with the sudden change from shallow-marine quartz-arenites to pelagic manganostones and ironstones at Otjosondu (Bühn *et al.*, in press). For the area east of Okahandja, we envisage correlation of Kasch's (op. cit.) "coarse-grained quartzite" unit with this major transgression, in this case over pre-Damaran basement rocks.

The Karibib Formation appears to be more uniform along strike with changes in thickness representing the only major lateral variation. Carbonate rocks with intercalated pelite horizons are predominantly developed within this unit. Lithostratigraphic comparison strongly invokes correlation of Kasch's (op. cit.) carbonate unit with the Karibib Formation. The uniform development of the Karibib Formation suggests deposition on a stabilised shelf with a smooth topography, indicating that sedimentation has largely levelled the previously irregular footwall topography. For this reason, the top surface of the Karibib Formation has been chosen as a lithostratigraphic datum level in Figure 2. The Kuiseb Formation consists of pelitic and psammitic sediments throughout the area. Kasch (1988) has given a three-fold subdivision of this formation east of Okahandja based on structural evidence.

Correlation of the Chuos Formation in the sCZ

The correlation of the manganostone- and ironstone-bearing sequence at Otjosondu with the Chuos Formation has previously been proposed by Roper (1959), Martin (1965) and Miller (1983a) on general grounds. Henry *et al.* (1986) gave evidence for a prominent erosion surface at the base of the Chuos Formation which cuts down into various lithostratigraphic levels even in a single study area, notably even into pre-Damaran basement rocks. This is also apparent on a regional scale in Figure 3, which shows the Chuos Formation overlying Rössing lithologies (at Rössing Mine, Namibplaas 93, Krantzberg and, we conclude, at Otjosondu), Etusis

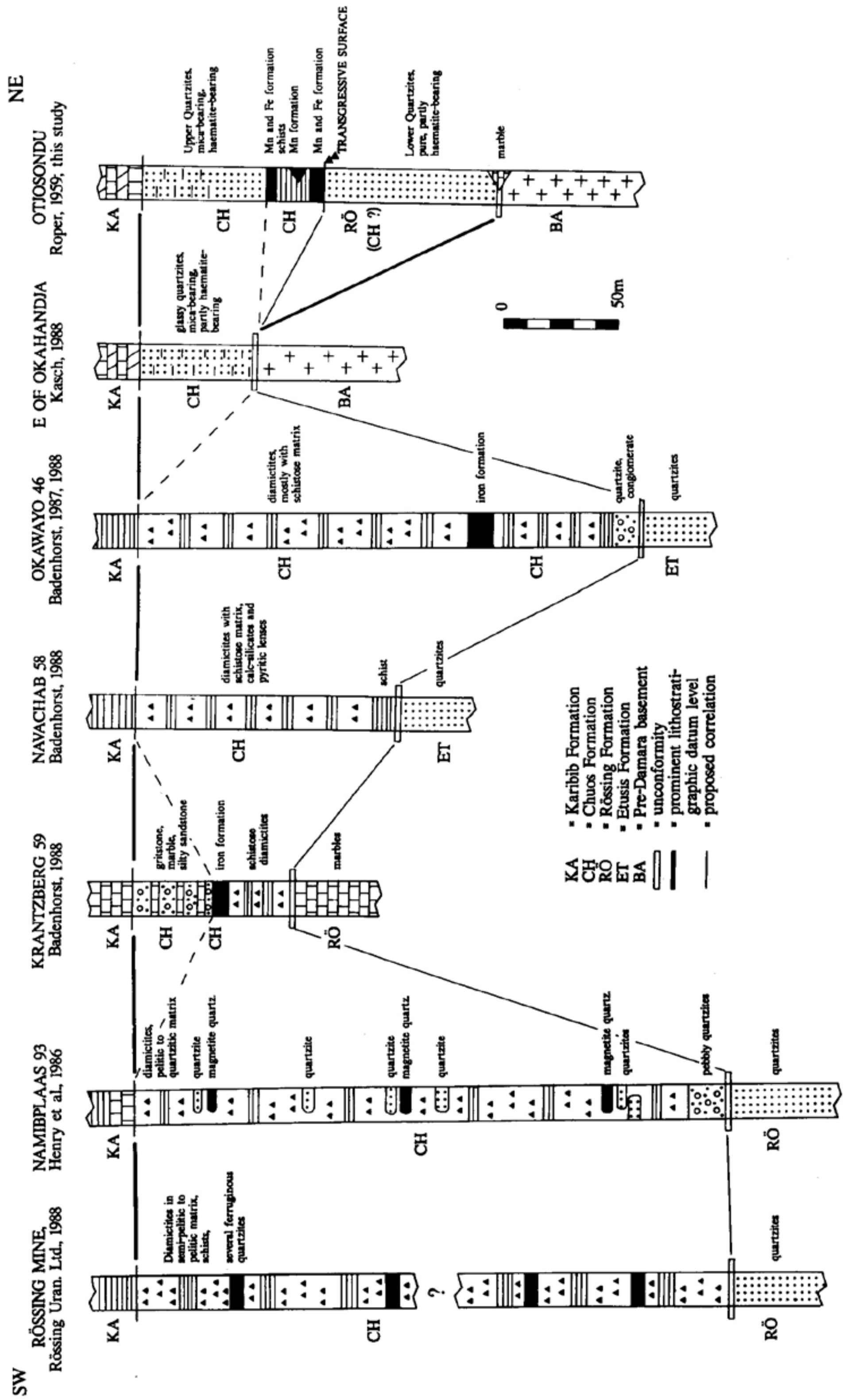

Figure 3: Facies correlation of the Chuos Formation in the southern Central Zone. The erosion surface beneath the Chuos Formation cuts down into various lithologies, i.e. Etusis Formation, Rössing Formation and pre-Damaran basement, respectively. The Chuos/Karibib Formation boundary has been used as a datum level

Formation quartzites (at Navachab and Okawayo) or basement rocks (east of Okahandja), respectively. The Lower Quartzite unit at Otjosondu is correlated with the Rössing Formation although its correlation with early Chuos quartzitic rocks of Henry *et al.* (1988) and Badenhorst (1987, 1988) is also possible. Manganese and iron formations at Otjosondu correspond with iron formations and magnetite quartzites throughout the sCZ. The opening of the Khomas Sea propagated eastwards (Stanistreet *et al.*, 1991; Bühn *et al.*, in press) and this explains the initial deposition of deeper-water iron formations in the west and shallower-water manganese formations on the outer shelf at Otjosondu (Blibo *et al.*, in press). Impure sandstones and iron formations, which developed within the Mn and Fe-bearing horizon at Otjosondu, are considered to be facies equivalents of the bedded feldspar-quartzites and iron-rich quartzites described by Henry *et al.* (1986) from the western portions.

The Upper Quartzite unit overlying the manganese and iron formations at Otjosondu is not developed in the western end of the inland branch. A unit of "gritstones" and silty sandstones was however reported by Badenhorst (1988) in an equivalent part of the sequence from Krantzberg in the Karibib area (Fig. 3). We correlate the Upper Quartzites at Otjosondu with the basal quartzite of Kasch (1988), which would explain the absence of Chuos Formation iron and manganese formations in his profile. This again indicates the irregularity of the gneissic basement topography, probably reflecting tilted fault blocks. The glaciomarine mixtite layers of the western Chuos Formation thin towards the northeast and the clast sizes in the mixtites decrease (Henry *et al.*, 1986). A diamictite facies is not developed at Otjosondu nor in the whole area east of Okahandja, which may reflect the areal distribution of ice sheets and ice shelves on land and within the Adamastor Ocean and the Khomas Sea.

Conclusions

All deformation phases at Otjosondu can be correlated with Damaran deformation patterns elsewhere in the Central Zone in terms of both styles and trends. F_1 and F_2 folding becomes less intense towards the north, whereas F_3 folding intensity decreases towards the east. We attribute these deformation events to the closure of the Khomas Sea and the Adamastor Ocean, respectively.

Facies developments, both on a large scale within the Damara Sequence as a whole and on a smaller scale within the Chuos Formation, can be correlated from the eastern exposed portions of the sCZ to the west. Pre-Karibib formations decrease in thickness or pinch out towards the east and exhibit a facies differentiation along the tectonic strike of the sCZ. This is attributed to the eastward-propagating rift of the Damara inland branch and to the prominent erosion surface underlying Chuos Formation lithologies. We conclude that previous attempts to correlate the Otjosondu Sequence with the Damara Sequence as a whole are fully validated in detail both on the grounds of tectonic patterns and the lithostratigraphic/lithofacies development.

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