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Facies and Facies Association of the siliciclastic Brak River and carbonate Gemsbok formations in the Lower Ugab River Valley, Namibia, W Africa

F.V.P. Paciullo[a*], A. Ribeiro[a], R.A.J.Trouw[a] and C.W. Passchier[b]

[a] *Instituto de Geociências, Departamento de Geologia, Universidade Federal do Rio de Janeiro, 21949-900 Rio de Janeiro, Brazil*

[b] *Institut für Geowissenschaften, Johannes Gutenberg University, 55099 Mainz, Germany*

Abstract

The Neoproterozoic Zerrissene Turbidite Complex of central-western Namibia comprises five turbiditic units. From base to top they are the Zebrapüts Formation (greywacke and pelite), Brandberg West Formation (marble and pelite), Brak River Formation (greywacke and pelite with dropstones), Gemsbok River Formation (marble and pelite) and Amis River Formation (greywacke and pelites with rare carbonates and quartz-wacke).

In the lower Ugab River valley, five siliciclastic facies were recognised in the Brak River Formation. These are massive and laminated sandstones, classical turbidites (thick- and thin-bedded), mudrock, rare conglomerate and breccia. For the carbonate Gemsbok River Formation four facies were identified including massive non-graded and graded calcarenite, fine grained evenly bedded blue marble and calcareous mudrock. Most of these facies are also present in the other siliciclastic units of the Zerrissene Turbidite Complex as observed in other areas.

The vertical facies association of the siliciclastic Brak River Formation is interpreted as representing sheet sand lobe to lobe-fringe palaeoenvironment with abandonment of siliciclastic deposition at the top of the sucession. The vertical facies association of the carbonate Gemsbok Formation is interpreted as slope apron sucession overlain by periplatform facies, suggesting a carbonate slope sedimentation of a prograding depositional shelf margin.

If the siliciclastic-carbonate paired sucession would represents lowstand relative sea-level and highstand relative sea-level, respectively, the entire turbidite sucession of the Zerrissene Turbidite Complex can be interpreteded as three depositional sequences including two paired siliciclastic-carbonate units (Zebrapüts-Brandberg West formations; Brak River-

Gemsbok formations) and a incomplete sucession without carbonate at the top (Amis River Formation).

Keywords: Neoproterozoic sucessions; Zerrissene Turbidite Complex; Facies and Facies Association; Deposicional Sequences; Sequence Stratigraphy.

Introduction

The Neoproterozoic Pan-African orogeny in Africa and the Brasiliano orogeny in eastern Brazil generated several collisional mobile belts welding ancient cratons. In Namibia three of these mobile belts are arranged in a triple junction pattern related to the Damara Orogen (Miller, 1983). The three arms are the Inland Branch or Damara Belt (s.s), the Southern Coastal Branch or Gariep Belt, and the Northern Coastal Branch or Kaoko Belt (Miller, 1983; Hoffmann, 1987; Fig. 1). The succession they contain are interpreted as deposits of intraplate continental margin basins developed between the Kalahari and Congo cratons, and probably the Rio de La Plata craton. These successions were later deformed and metamorphised during neoproterozoic subduction and collision (Porada, 1979, 1989; Barnes and Sawyer, 1980; Miller, 1983; Kukla and Stanistreet, 1991; Prave, 1996; Chemale Jr., 1998; Goscombe et al., 2003a,b).

In the Lower Ugab River area, southern Kaoko Belt, Neoproterozoic turbidites crop out in an area of about ten thousand square kilometers (Fig. 1). They are known as the turbiditic Swakop Group successions (Miller, 1983; Miller and Grote, 1988), Zerrissene Turbidite System (Swart, 1992) or Zerrissene Turbidite Complex (Swart, 1995). The complex comprises five formations including siliciclastic and carbonate turbidites. These are the Zebrapütz, Brandberg West (carbonate), Brak River, Gemsbok River (carbonate) and Amis River formations (Miller et al., 1983a, b; Swart, 1992; Fig. 2). The siliciclastic units are mainly constituted of feldspathic metasandstones and gray metapelites including feldspathic siltstones. The carbonate successions include cream and brown marbles, thin black pelite intercalations and blue marble on top. Miller et al. (1983a) interpreted the turbidite complex as deepwater deposits equivalent to shelf successions of the Swakop Group exposed in the west, which depositional age is between 750 and 540 Ma (Table 1). Swart (1992) recognised nine siliciclastic facies indicative for lobe to lobe-fringe and distal lobe-fringe sucessions and four cabonatic facies indicating outer-apron sucessions, both in an unconfined basin floor environment (Table 2). The siliciclastic turbidites source was a granite rich recycled orogen and his paleocurrent data indicate a shift in transport of sediments from southwest to west and northwest in contrast to the palaeocurrent direction of Miller. Based on these data the turbidites were interpreted “as the distal portion of a major submarine turbidite system, the more proximal parts of which now lie west of the exposed basin, either under the Atlantic Ocean or in eastern South America”.

The turbidites are deformed into N-S trending kilometric scale D_1 folds with predominant westward vergence. Micro- and meso-scale coaxial D_2 folds deformed the D_1 structures. D_1 and D_2 deformational episodes are related to the Northern Coastal Branch closure. These structures were later refolded by E-W trending kilometric scale D_3 folds interpreted as related to the closure of the Inland Branch (Miller et al 1983a; Porada et al 1983; Passchier et al., 2002; Goscombe et al., 2003a). Because of the peculiar structural geology and lithostratigraphy the Lower Ugab River area has been considered as a separate tectonic domain named the Lower Ugab Domain (Hoffmann, 1987; Hoffman et al., 1994), the Southern Kaoko Zone (Miller and Grote, 1988), or the Ugab zone (Goscombe et al. 2003a,b).

This work presents the facies and facies association of deformed siliciclastic Brak River Formation and carbonate Gemsbok Formation in the Lower Ugab Domain. The data obtained reinforce the palaeocurrent directions of Miller and the palaeoenvironments of Swart. A simple sequence stratigraphy division of the Zerrissens Turbidite Complex is also suggested using regional correlation with equivalent siliciclastic-carbonate shelf sucessions of the Swakop Group.

The Turbidite Sucession in the Lower Ugab Domain

The two detailed stratigraphic sections elaborated in the Lower Ugab Domain include the Brak River and the Gemsbok River formations in a large scale D_1 overturned syncline with axis plunging shallowly to the south and with the Gemsbok River Formation in the core. One section was taken in the normal limb comprising the Gemsbok River Fm in the Ugab River (letter A in Fig. 2) and the other in the overturned limb comprising the Brak River Fm along the Rhino Wash (letter B in Fig. 2). The Brak River Formation is ca. 306 meters thick (Fig. 3a) and the Gemsbok River Formation 97.5 meters (Fig. 3b). Primary structures and composition are sufficiently well preserved to allow protolith recognition, despite ductile deformation and low-grade metamorphism.

The Siliciclastic Brak River Formation

The lithofacies of this formation were characterized according to the scheme of Walker (1978, 1992) for deepwater deposits subdivided into five facies associations, 1) classical turbidites, 2) massive sandstones, 3) pebbly sandstones, 4) conglomerates and 5) pebbly mudstones, debris flows, slumps and slides. Massive and laminated sandstones, classical turbidites, mudrock, rare conglomerate and breccia were identified in the Brak River Formation (Fig. 3a). Most of these facies are also present in the other siliciclastic units of the Zerrissene Turbidite Complex as observed in other areas, and described in the sections presented by Swart (1992).

Massive and laminated sandstones

Massive sandstones, mainly grey feldspathic arenites, predominate in the studied sections of the Brak River Formation. They correspond to facies B_1 of Swart (1992). Individual beds are medium (10-30cm) to very thick (>1m) tabular, laterally continuous and have a planar or smooth irregular erosive base. Intraclast, flute and load structures occur locally. Beds appear amalgamated or with thin mudrock separations forming up to 10 meters thick successions (Figs. 4a and 4b). Horizontally laminated sandstones are an associated facies also amalgamated in up to 10 metres thick successions (Fig. 3a). Both facies appear also as isolated intercalations in thin-bedded turbidites (column 13, Fig. 3a).

Massive sandstones may register the deposition of high density turbidite currents (Lowe, 1982) or cohesive sandy debris flows (Shanmugan and Moiola 1994; Shanmugan 1999, Stow and Johansson 2000). In high density currents a lower concentrated laminar flow layer and an upper turbulent flow constitute the overall flow. The laminar flow may deposit massive and laminated sand beds whereas the turbulent flow generates classical turbidites (Postma et al., 1988). Rip-up clasts in the upper part of the formation suggest erosional currents rather than cohesive debris flows. Massive and laminated sandstone records the infilling of wild channels, suprafan deposits on the mid-fan or sheet sand in lower fan lobes (Walker 1992; Bouma 2000).

Classical turbidites

This facies association is characterized by a monotonous alternation of sharp-based sandstones and interbedded mudstones. Almost all the sandstones can be described using the Bouma sequence (Walker 1992). It includes two main facies; thick-bedded and thin-bedded turbidites as according to bed thickness (generally over one metre thick for the former and thinner than a few tens of centimeter for the latter). Classical turbidite is the second most frequent facies association present. It occurs in up to 10 meters thick successions, locally coarsening and thickening upward (column 17, Figs.3a and 4b). *Thick-bedded turbidite* (T_1) comprises sandstone beds of 10-50 cm thick separated by pelitic beds of 1-10 cm thick. Medium- to fine-grained feldspathic arenites and mudstone are the main rock types. The sandstones are massive, with sharp planar bases and tops, or normally grading to mudstone in the upper centimetres. The mudstones are massive, with transitional bases and sharp planar tops. The sand-mud couplets comprise Bouma AE divisions of 50cm to up to 1 metre thick. Ocasionally, massive medium-grained and laminated fine-grained sandstones comprising Bouma AB divisions constitute the couplet beds. *Thin-bedded turbidites* (T_2) are mainly constituted by silt-mud couplets with bed thickness varying from 1 to 10 cm. Feldspathic siltstone and mudstone are the main rock types. Sand and silt beds have sharp planar bases and often grade to pelitic tops. They are mainly massive or with subtle lamination and rippled (A, B and C Bouma divisions). Facies T_1 and T_2 correspond to facies C_1, D_1 and D_2 of Swart (1992).

Classical turbidites record lobe-fringe or levee-overbank deposits (Walker 1992).

Conglomerate and intraformational breccia

Pebbles are rare in the Brak River Formation. Intraformational breccia constituted of angular mudrock fragments in a coarse sandy matrix occur locally (column 21, Fig. 3a) and a single lenticular conglomerate bed appears in the studied section (column 17, Fig. 3a). The conglomerate contains rounded pebbles of granite and granite gneiss and minor vein quartz, granophyre, rhyolite, basalt and carbonate rock fragments. The coarse sandy matrix grades upward to pebbly sandstone. Isolated granite and vein quartz pebbles also occur in the massive sandstones (columns 16, 20, 24; Fig. 3a).

Isolated cobbles up to 1.75 meter in diameter were reported in other sections of the formation and, due to their range in size and piercing of underlying beds, interpreted as glacial dropstones (Jeppe, 1952; Miller et al., 1983a,b; Swart, 1992). In this study no evidence of soft deformation due to falling pebbles nor glacial features such as striated fragments were recognised. The isolated fragments may also be interpreted as extraclasts in a sandy debris flow deposit. As rudites constitute a single bed with channel forms and very restrict occurrence it seems to register the cut and fill of shallow and ephemeral distributary channels on turbidite lobe or sheet sand deposits.

Mudrock

Mainly massive dark gray phyllites interpreted as deformed mudstone, clayed siltstone and claystone represent the mudrock in the analised sections. They correspond to facies G of Swart (1992). These mudrocks appear in thin layers between massive sandstones and in the upper interval of the classical turbidites. They also constitute up to 2 meters thick strata isolated between classical turbidites or massive sandstones.

Vertical facies succession

The Brak River Formation may be divided into a lower sand-rich unit and an upper mud-rich unit (Fig. 3a). Amalgamated or isolated massive sandstone beds dominate the lower unit. Thin-bedded classical turbidites and mudrock predominate in the upper unit. Although the interpretation presented here is based on one section it is broadly compatible with the sections presented by Swart (1992). The sand-rich units are interpreted as sandstone lobes due to the scarcity of erosive features such as scours and channels. The pronouced tabularity of the beds and their extensive lateral continuity over a large area (Swart, 1995) suggest sheet sand deposits build-up by stacking and shifting of progradacional lobes in a relatively unconfined basin. The mud-rich units are interpreted as lobe-fringe deposits due the absence of rip-up clasts, climbing ripples and convolute structures (CCC turbidite of Walker, 1992) typical of levee-overbank deposits (Pickering et al., 1995; Walker, 1992; Mutti and Ricci Lucchi, 1972). The vertical arrangement of the sand and mud-rich units shows thickening and thinning upward tendencies that suggest progradation of lobes and lobe-fringe depositon (Mutti, 1992). The thick mudrock strata on the top of the formation record the termination of the siliciclastic deposition before the iniciation of carbonate deposition of the Gemsbok River Formation more than an lobe fan abandonment.

The Gemsbok River Formation

The carbonate facies of this formation are described based on carbonate slopes models of Enos and Moore (1983), Cook and Mullins (1983), McIlreath and James 1979, Coniglio and Dix (1992). Some limitations with respect to carbonate facies determination have to be kept in mind. Recrystallisation of carbonate is significant therefore apparent structureless carbonate rock may have contained delicate primary structures that disappeared due to deformation and recrystalization. Furthermore, dissolution and formation of diagenetic bedding (pseudobedding) are common processes in carbonates contributing to the difficulty of characterisation of bedding parameters and depositional structures.

Massive non-graded and graded calcarenite, fine grained evenly bedded blue marble and calcareous mudrock were identified in the measured section of the Gemsbok River Formation. They correspond to the facies Cc, Gc and G of Swart (1992), respectively. Carbonate breccia, facies Ac of Swart (1992), appears in the upper part of the formation in the Brak River valley area. The calcarenites and mudrock intercalations comprise a mappable lower unit of ca. 50 meters thick and the blue marble an upper unit of ca. 47 meters thick.

Massive non-graded calcarenite

This facies consists of massive non graded white to creamy fine to medium calcarenite. The calcarenite occurs in thin (<10cm) to thick (up to 100cm) individual beds isolated in bedded turbidites and mudrock layers or amalgamated in up to 5 meters thick units (Fig. 3b). Calcarenite beds are tabular, laterally continuous and have sharp planar base and top (Fig. 5a). The range in bed thickness may be due, in part, to tectonic deformation that produced attenuation in normal limbs and thickening in overturned limbs of D_1 folds (Swart, 1992; Passchier et al., 2002). The processe to deposit non-graded calcarenite are interpreted in several ways in the literature: i) a modified grain flow mechanism whereby the addition of lime mud matrix and turbulence may have aided dispersive pressures in supporting the grains during transport (Lowe 1976); ii) reworking of previously deposited slope sediments (McIlreath and James, 1979); iii) sandy debris flow (Shanmugan, 1999) and iv) intense bioturbation. No evidence of bioturbation was recognised and the massive calcarenite facies may record one of the three mentioned depositional process.

Graded calcarenite

This facies is also constituted of white to cream calcarenites that show Bouma intervals and look like the classical turbidites of Walker (1992). Beds are thin to medium thick tabular, lateraly continuous and have a sharp base and a sharp or transitional mudrock on top (Fig. 5b). A and B Bouma intervals predominate over the ABD, BD and BC intervals. The distinction between non-graded and graded calcarenite and the A interval is somewhat arbitrary. When no other Bouma divisions are observed (B, C or D) the facies is interpreted as non-graded calcarenite. When Bouma divisions and transitional mudrock tops are present the facies is interpreted as classical turbidite similar to the allodapic limestone of Meischner (1964).

Mudrock

Very thin-bedded or laminae of siltstone and argillite couplets with variable amounts of calcite, quartz and fine white mica comprise this facies. A turbiditic origin for the mudrocks is inferred where it is possible to recognise a gradational transition between calcarenite and mudrock (Fig. 5b). Abrupt contact was interpreted as indicative of hemipelagic deposition. Although this is a generalisation valid for the measured section it is important to note that the rocks are metamorphosed and hence contacts between the calcarenites and the mudrocks tend to become abrupt. Moreover, pressure solution during burial greatly decreases the preservation potencial of bedding surface structures resulting in common abrupt carbonate-to-shale transitions (Coniglio and Dix, 1992).

Blue marble

A light to dark blue fine grained marble constitutes the main facies in the upper unit of the Gemsbok River Formation (columns 15 to 22 in Fig. 3b). The marble appears in thin (1-10cm) to medium (10-30cm) thick beds with planar or wavy base and top and very thin mudrock partings. Diffuse horizontal lamination and current ripples, structures not previosuly described by Swart (1992, 1995) occur locally (Fig. 6). Most of the beds seem to be massive and show a light blue base and a dark blue top. This gradational colour change was interpreted as normal grading (Miller et al., 1983a, b) or as "a response to an increase, either of dissolution seams, or of carbonaceous material near a pseudobedding plane" (Swart, 1992). The very fine grain size, the horizontal lamination and the parted bedding suggest suspension settling of fine carbonate detritus. The current ripples register the migration of small scale silty or sandy bed forms under lower flow regime probably related to contour bottom currents.

The blue marble may correspond to the parted or evenly bedded limestone that commonly occurs in the periplatform zones. It therefore probably represents a hemipelagic slope deposit similar to the periplatform ooze of Schlager and James (1978) or to the periplatform facies of Coniglio and Dix (1992).

Carbonate breccia (R_3)

Carbonate breccia, facies Ac of Swart (1992), was recognised in the upper unit of the Gemsbok Formation in the Brak River valley (Figs. 7a and 7b). The breccia contains angular pebbles of massive, laminated and thin-bedded limestone, rare vein quartz pebbles and pelite intraclast in a calcarenite matrix. Beds are lenticular, medium to thick (10-100cm), have irregular probably erosive base and grade laterally and upward to pebbly calcarenite. Swart (1992) suggested an allochthonous source for some of the laminated carbonate pebbles. However, a similar laminated lithotype found just below a breccia bed and pelite intraclasts indicate an intraformational, rather than an allochthonous origin. The data also suggest that the breccia is derived from slope outcrops (McIlreath and James, 1979) and represents channelised facies. Gravity mass flow is postulated to form carbonate breccias (Enos and Moore, 1983; Cook and Mullins, 1983). Nevertheless, in the absence or scarcity of clay matrix the transport mechanism could be a combination of debris flow and grain flow (Middleton and Hampton, 1973).

Vertical facies association

The Gemsbok River Formation includes a lower calcarenite-mudrock unit and an upper blue marble unit with a single intercalation of calcarenite and mudrock (boudinated bed, Fig. 3b). Both units were recognized to continue regionally (Swart, 1992). This facies association is probably due to the nature of slope deposition where, in modern carbonate environments, sediments from the platform are resedimented by gravity flows and continuous settling of pelagic and hemipelagic material. The lower unit may register periodical turbidite flows and quiet conditions during which only the fine background material is deposited. The upper blue marble unit consists of evenly bedded periplatform carbonate and registers suspension transport and gravitational settling of platform derived fine detritus. The isolated calcarenite-mudrock bed indicates instability in the source area and could represent an isolated catastrophic event that generated a turbidite flow and hemipelagic mud. Alternatively, it may also represent a lateral interdigitation between the slope and the periplatform units.

The type of shelf margin, rimmed or unrimmed, and the depositional or bypass slope morphology influence the type of vertical facies association that will be deposited (Schlager and Camber, 1986; Emery and Myers; 1996; Coniglio and Dix, 1992). The measured section of the Gemsbok River Formation shows similarity with the depositional model proposed by McIlreath and James (1979) which includes a shelf margin rimmed by a shallow water reef.

The facies are well defined and localized: periplatform talus breccia in the upper slope, pelagic/hemipelagic lime or periplatform ooze in the middle slope, massive and graded sand and hemipelagic mud at the base of the slope and basin plain. Moreover, since the lower calcarenite rich unit is overlain by periplatform facies, the formation could be interpreted as a progradational shelf margin succession.

Palaeocurrent data

Palaeocurrent data from current ripples and flute casts were obtained in thirty localities of the Zerrissene turbidites taking in mind the facing of the beds (Passchier et al., 2002; Fig. 8). Ripples are best preserved in the marble units. Paleocurrents direction are mainly pointed to the south in the lower Zebraputs and Brandberg West formations. Data ranging from 200^0 to 220^o and 190^0 to 280^0 were registered in the Brak River and Gemsbok River formations respectivally (cf. Passchier et al., 2002). This data shows a progressive shifting of the palaeoflow from southward in the lower formations to southewestward and westward in the upper Brak River and Gemsbok River formations. The data indicate that the turbidite complex source area was located to the north, northeast and east of the present outcrop, probably in the Kamanjab inlier, part of the Congo palaeocontinent. This is in agreement with Miller et al (1983a) but not with Swart (1992) who reported opposite paleocurrent directions and deduced source areas in the west.

Depositional settings

Carbonate and siliciclastic deposition represent contrasting environmental conditions in intraplate continental margin basins. Carbonate deposition is best developed during relative sea-level rises when space for accumulation is created in all environments along the continental margin (i.e. shelf margin, slope and basin plain). When the carbonate production exceeds accommodation (the “keep up” phase of Neumann and Macintyre 1985) re-sedimentation occurs elsewhere, especially on the slope and basin plain (the “highstand” shedding of Emery and Myers 1996). This is the best condition to develop carbonate turbidites and associated slope and basin facies. During relative sea level falls, the “carbonate factory” ceases its production and the carbonate beds are exposed if the relative sea level has fallen significantly below the shelf margin. Carbonate sedimentation on the slope and basin become starved and, if terrigenous clastic sediment input is high, siliciclastic turbidites and associated basin facies are deposited onlapping the carbonate slope. A striking difference between siliciclastic and carbonate slope sedimentation is that the former usually has a single point source (canyons) and a submarine dendritic drainage system (submarine fan). In contrast, carbonate slopes have multiple point sources delivering sediments along the whole platform margin that will be carried downslope by debris flow and turbidity currents. Carbonate deepwater deposits commonly occur as slope aprons, sheets and debris wedges (Cook et al. 1972, Cook and Egbert, 1981; Enos and Moore, 1983; Cook and Mullins, 1983; McIlreath and James 1979; Coniglio and Dix, 1992; Emery and Myers 1996).

The depositional models described above fit the siliciclastic Brak River and the carbonate Gemsbok River formations satisfactorily. The siliciclastic turbidites have been intepreted as sea-level fall deposits possibly related to a glaciogenic event (Miller et al., 1983a,b; Swart, 1992). As the correlative shelf deposits in the Damara Sequence are ca. 750 Ma or older (Miller, 1983) the turbidites may be Vendian in age (800-600 Ma; Eyles and Eyles, 1992). Although only one detailed stratigraphic section was elaborated the vertical facies association can fit the Brak River Formation on two depositional models: the fine-grained turbidite system model of Bouma (2000) and the turbidite systems or stages of growth model of Mutti (1992). Massive sandstones of the lower unit of the Brak River Formation could represent lower sheet sand lobes of the fine grained turbidite model of Bouma or sandstone lobes of type I stage of growth of Mutti model. Classical turbidites and mudrock upper unit may represent lobe-fringe and basin plain deposits of the Bouma model or types II and III stages of growth of Mutti model.

The Mutii model predicts that each stage of growth is the product of relative sea-level oscillations. Thus types I and II deposits are associated with periods of relative sea-level falls; type III deposits are associated with relative sea-level rises and are “the deepwater expression of actively prograding delta systems on the adjacent shelfal zone” (Mutti 1992). Following these concepts the lower and middle units of the Brak River Formation composite section comprises a lowstand relative sea-level period. The thin-bedded and mudrocks units of the upper part of the section will represent a transgressive period with abandonment events of lobe deposition.

The Gemsbok River Formation turbidite is interpreted as carbonate slope sedimentation (slope aprons) of a prograding depositional shelf margin (McIlreath and James 1984) during relative sea-level rise of postglacial period. Thus, considering the siliciclastic and carbonate turbidites, the Brak River and Gemsbok formations will comprise a single depositional sequence with lowstand, transgressive and highstand system tracks deposits (Figure 9). Based on the paleocurrents data, the channelled and leveeded middle and inner fan facies are supposed to be present at far east of the Ugab Domain.

Sequence stratigraphy analysis

The successions of the Brak River and Gemsbok River formations constitute a depositional sequence probably related to glacial and postglacial events. The lower sand rich unit of the Brak River Formation represents the lowstand system tract whereas the upper unit is interpreted as a transgressive system tract. The general thickening upward tendency of the lower unit is indicative of fan progradation. The thinning upward tendency, the abundance of mud and the relative scarcity of sand in the upper unit register fan retrogradation. The thick mudrock on top of the upper unit (Fig. 3) would record the maximum flooding and the abandonment of turbidite deposition probably related to postglacial sea level rise. The Gemsbok River Formation is interpreted as a carbonate slope succession in a prograded depositional shelf margin (McIlreath and James, 1979). The lower and upper carbonate units constitute the highstand system tract of the depositional sequence, developed in response to postglacial accomodation. Further work may confirm the existence of two other sequences in the Zerrissene Turbidite Complex. A lower sequence constituted of the siliciclastic Zebrapütz Formation, which may include the lowstand and the transgressive system tracts, and of the Brandberg West Formation probably a highstand carbonate system tract. The Amis River Formation possibly represents the lowstand system tract of the third and uppermost sequence in the complex.

Sequence stratigraphy regional correlations and predictions

The correlative shelf deposits of the Zerrissene turbidites are exposed in the Northern Platform and in the Northern and Central Zones of the Damara Belt (Fig. 10). A sequence stratigraphy regional correlation reveals three major depositional sequences:

- the lower sequence is constituted of the siliciclastic-carbonate pair of the Zebrapütz and Brandberg West formations. The siliciclastic units probably represent the lowstand and transgressive system tracts whereas the carbonate unit represent the highstand system tract. Possible correlatives are the Okonguarri turbidites, the upper Nosib Group units and the carbonates of the Abenab Subgroup which include Vendian age stromatolites (Cloud and Semiklatov, 1969). The Rössing or Dome Gorge Formation comprises an equivalent siliciclastic-carbonate pair deposited in shelf-margin, shelf and mixed environments.

- The middle depositional sequence comprises the slope to basin plain deposits of the Brak River and Gemsbok River formations. The Chuos diamictite may record the glaciogenic lowstand and the overlying carbonates of the Tsumeb and Karibib formations may represent the correlative transgressive and highstand deposits in the shelf and mixed environments.
- The upper depositional sequence may include the Amis River Formation lowstand and transgressive turbidites. The Kuiseb Formation pelites possibly register the subsequent highstand related to the ultimate flooding in the Damara basin.

All the metasedimentary units considered above are interpreted to be contemporaneously deposited into three NE-SW rifts (Miller, 1983). The Zerrissene turbidites were probably related to a rifting phase in the interval 730-650 Ma. This age interval encompasses the end of rifting in the Inland Branch and the initial continental convergence ca. 650 Ma. This means that part of the Zerrissene turbidite deposition, if not all, was time-equivalent to the opening of the Inland Branch rather than to the Northern and Southern Coastal branches.

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TABLE CAPTIONS

Table 1 - The Zerrissene Turbidite Complex as deepwater deposits equivalent to shelf successions of the Swakop Group (Miller et al 1983a).

Table 2 – The siliciclastic and carbonate facies recognised by Swart (1992) in the Zerrissene turbidites.

FIGURE CAPTIONS

Figure 1 – Simplified tectonostratigraphic map of Namibia showing the position of the studied area (after Miller 1983; Hoffmann 1987; Miller and Grote 1988).
Inset figure: neoproterozoic cratons and mobile belts in Brazil and western Africa, previous to the Gondwana break-up.

Figure 2 – Simplified geological map of the Zerrissene Turbidite Complex (after the Geological Map of the Damara Orogen, 1:500.000, Miller and Grote 1988). Localities of measured section as black strip (B) or white strip (A).

Figure 3a – Detailed stratigraphic section of the top of the Brak River Formation plus the Gemsbok River Formation in the Ugab River (section A in fig. 2). Legend as in fig. 3c.

Figure 3b – Detailed stratigraphic section of the Brak River Formation in the Rhino Wash (section B in fig. 2). Legend as in fig. 3c.

Figure 3c – Legend for figs. 3a and 3b.

Figure 4a – Massive sandstone-rich sucession in the lower unit of the Brak River Formation at Rhino Wash section.

Figure 4b – Classical turbidite-rich sucession in the upper unit of the Brak River Formation at Rhino Wash section.

Figure 5a – Massive non-graded calcarenite beds intercalated with graded calcarenite in the lower unit of the Gemsbok River Formation at the Ugab River section.

Figure 5b – Graded beds with basal carbonatic layer to a more pelitic top (facies Cc at Lookout section of Swart 1992).

Figure 6 – Current ripples in the blue marble unit (facies Gc at Lookout section of Swart 1992), upper unit of the Gemsbok River Formation.

Figure 7 – Massive (a) and laminated (b) carbonate pebbles in a calcarenite matrix. Carbonate breccias in the upper unit of the Gemsbok River Formation at the Brak River valley, 10 km south of the Ugab River.

Figure 8 – Paleocurrent data from parts of the Zerrissene Turbidite (Passchier *et al.* 2002).

Figure 9 – Brak River and Gemsbok River formations interpreted as a single depositional sequence. The architectural style of the siliciclastic turbidite is based on Mutti's model from the inset composite section.

Figure 10 – Possible stratigraphic correlations between the Zerrissene Turbidites and it´s shelf sucessions equivalents.

Table 1

Southern Kaoko Zone			Correlates in Damara Belt			
Group	Formation	Lithology	Group	Subgroup	Formation	Lithology
SWAKOP	Amis River (650 m)	Schistose siliceous turbidites, consisting of metagreywacke bases and metapelite tops; most distal in west; local, graded, gritty quartzite in east	SWAKOP	Khomas	Kuiseb	Al-silicate pelitic schists, calc-silicate fels, marbles and quartzites; Matchless amphibolite and associated mafic and ultramafic rocks
	Gemsbok River (200 m)	Turbiditic limestone, impure limestone, schist; yellow and brown in lower half to 2/3 rd, blue and foetid in upper 1/3 rd			Karibib	Marble, pelitic schist, calc-silicate fels
	Brak River (350 m)	Schistose siliceous turbidites, mainly metagreywacke; local conglomerate, isoleted boulders		Tsumeb	Chuos	Mixtite, rudite, itabirite, quartzite, shale, pebbly schist, amphibolite, calc-silicate fels
	Brandberg West (10 m)	Turbiditic limestone; yellow and brown base, becoming blue at top		Ugab	Dome Gorge (Rössing)	Pelitic schist, marble, quartzite, metarudite, calc-silicate fels, amphibole schist
	Zebrapüts (500 m)	Schistose siliceous turbidites, mainly metagreywacke			Okongarri	Siliceous and calcareous turbidites consisting of quartzite, siltstone and schist; rudaceous dolomite, grey dolomite, calcareous quartzite and schistose marl

Table 2

Siliciclastic Facies	Simbology	Carbonate Facies	Simbology
Disorganaised conglomerates	A_2	Disorganised and graded marble breccias	Ac
Horizontally laminated to massive greywackes	B_1	Graded carbonates	Cc
Classical turbidites	C_2	Hemipelagic marbles	Gc
Sandstone-shale couplets base cut-out Bouma sequences	D_1	Pelagic shales	G
Sandstone-shale couplets with less sand than shale and base cut-out Bouma sequences	D_2		
Coarse, discontinuous sandstone-shale couplets	E		
Slumped units	F		
Shale	G		
Glacial dropstones	H		

Fig 1:

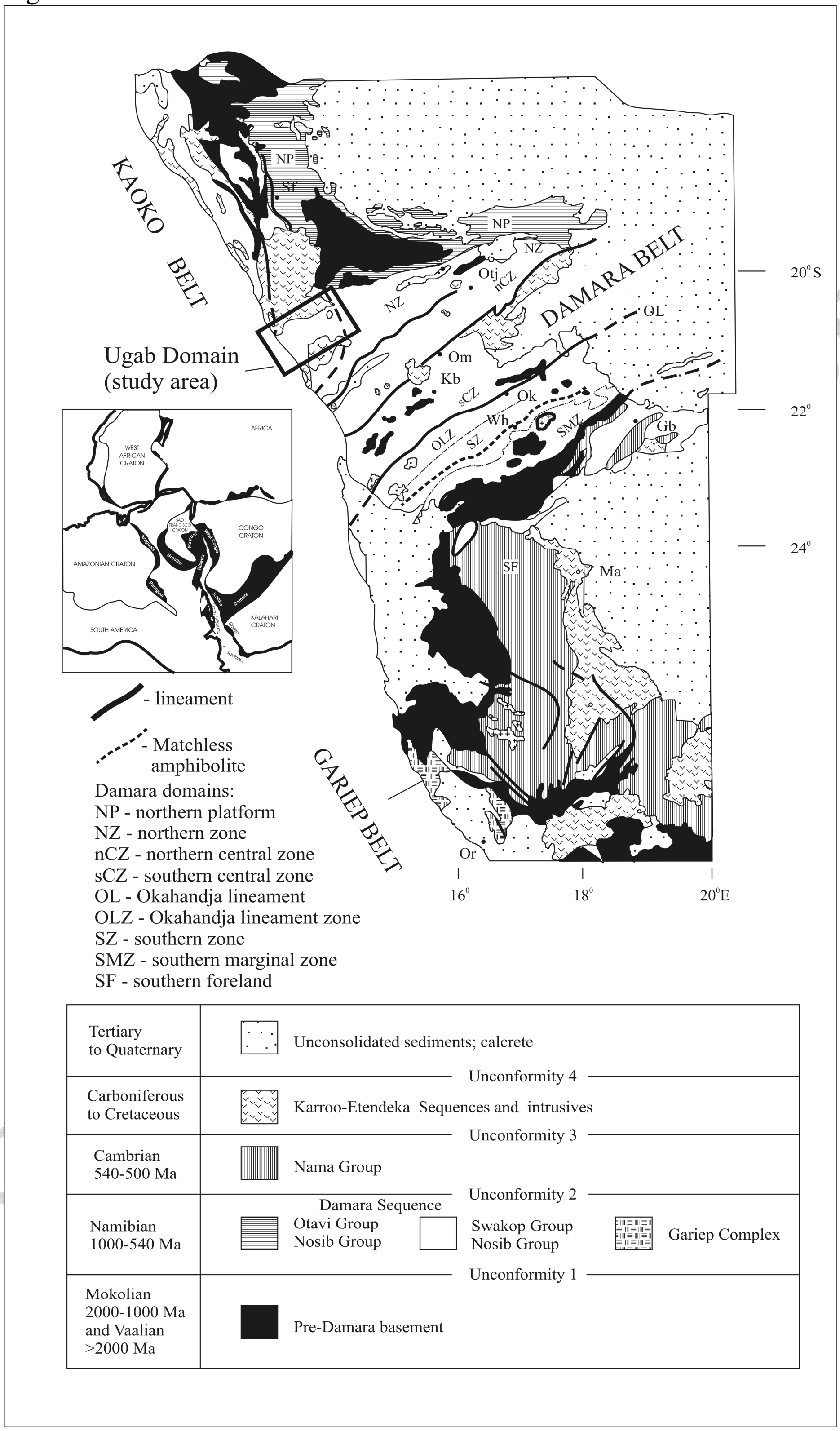

KAOKO BELT
DAMARA BELT
GARIEP BELT
Ugab Domain
(study area)
NP
Sf
NZ
Otj
nCZ
OL
Om
Kb
sCZ
Ok
Wh
OLZ
SZ
SMZ
Gb
SF
Ma
Or
20° S
22°
24°
16°
18°
20°E
AFRICA
WEST AFRICAN CRATON
CONGO CRATON
AMAZONIAN CRATON
SOUTH AMERICA
KALAHARI CRATON
Damara
Kaoko
- lineament
- Matchless amphibolite
Damara domains:
NP - northern platform
NZ - northern zone
nCZ - northern central zone
sCZ - southern central zone
OL - Okahandja lineament
OLZ - Okahandja lineament zone
SZ - southern zone
SMZ - southern marginal zone
SF - southern foreland
Tertiary to Quaternary
Unconsolidated sediments; calcrete
Unconformity 4
Carboniferous to Cretaceous
Karroo-Etendeka Sequences and intrusives
Unconformity 3
Cambrian 540-500 Ma
Nama Group
Unconformity 2
Namibian 1000-540 Ma
Damara Sequence
Otavi Group
Nosib Group
Swakop Group
Nosib Group
Gariep Complex
Unconformity 1
Mokolian 2000-1000 Ma and Vaalian >2000 Ma
Pre-Damara basement

Fig 2:

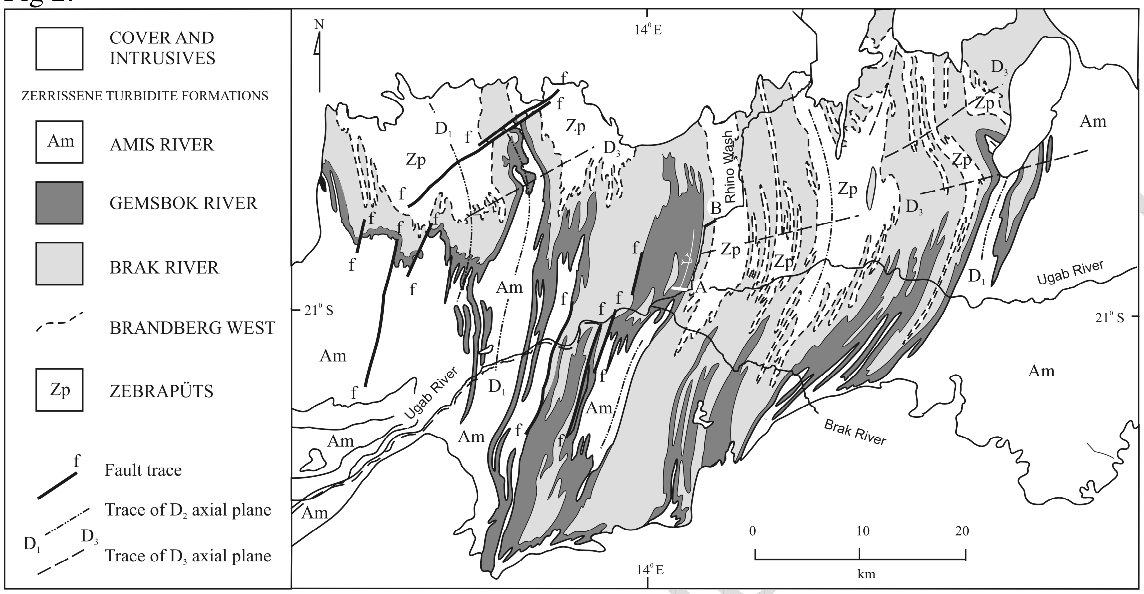

COVER AND INTRUSIVES
ZERRISSENE TURBIDITE FORMATIONS
Am
AMIS RIVER
GEMSBOK RIVER
BRAK RIVER
BRANDBERG WEST
Zp
ZEBRAPÜTS
f
Fault trace
Trace of D2 axial plane
D1
D3
Trace of D3 axial plane
N
14° E
21° S
Rhino Wash
Ugab River
Brak River
0
10
20
km

Fig 3a:

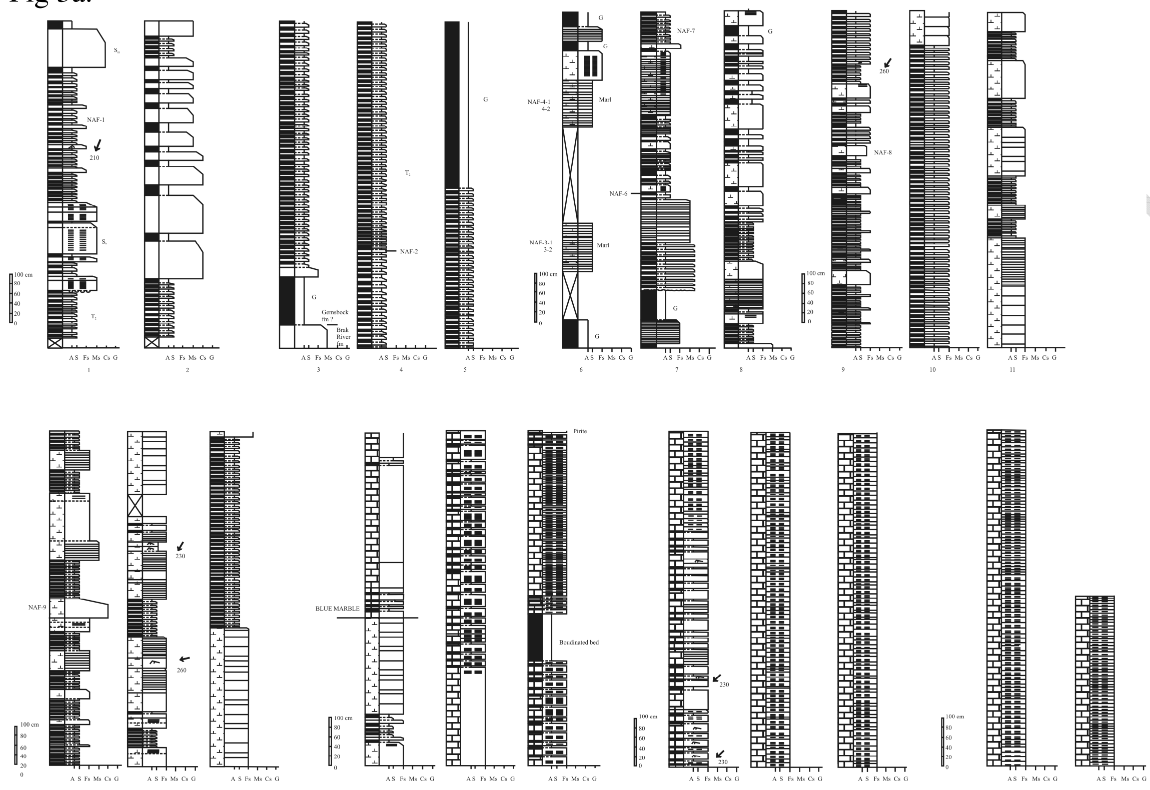

NAF-1
210
Gemsbock fm ?
Brak River fm
NAF-2
Marl
NAF-6
NAF-7
NAF-8
260
NAF-9
230
BLUE MARBLE
Pirite
Boudinated bed
100 cm
A S Fs Ms Cs G

Fig 3b:

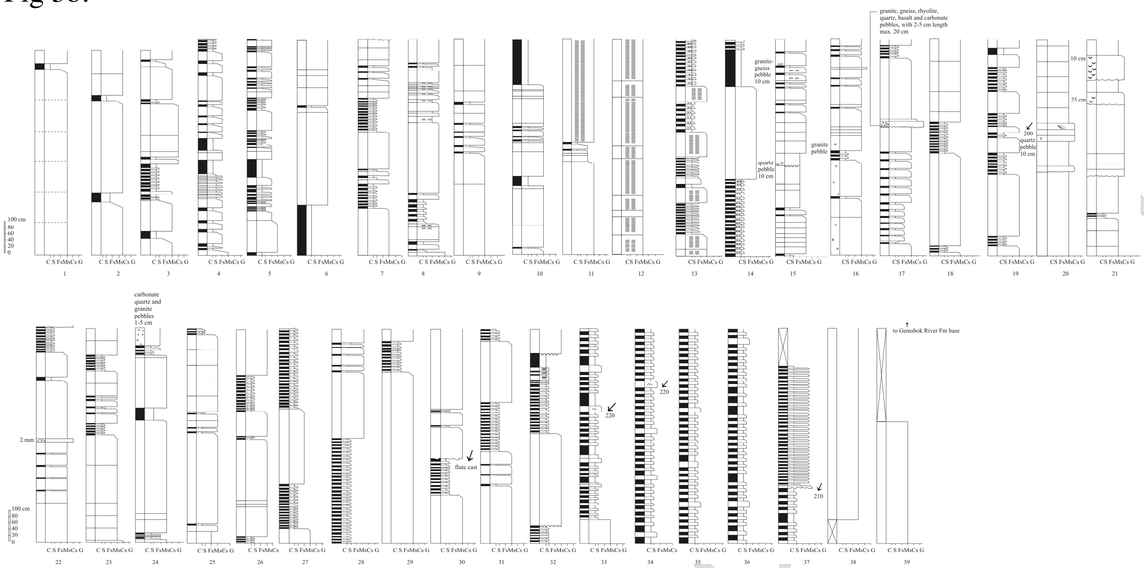

granite, gneiss, rhyolite, quartz, basalt and carbonate pebbles, with 2-5 cm length max. 20 cm
granite-gneiss pebble 10 cm
quartz pebble 10 cm
granite pebble
200
quartz pebble 10 cm
10 cm
75 cm
100 cm
carbonate quartz and granite pebbles 1-5 cm
to Gemsbok River Fm base
2 mm
flute cast
220
210

Fig 4a:

Fig 4b:

Fig 5a:

Fig 5b:

Fig 6:

Fig 7a:

Fig 7b:

Fig 8:

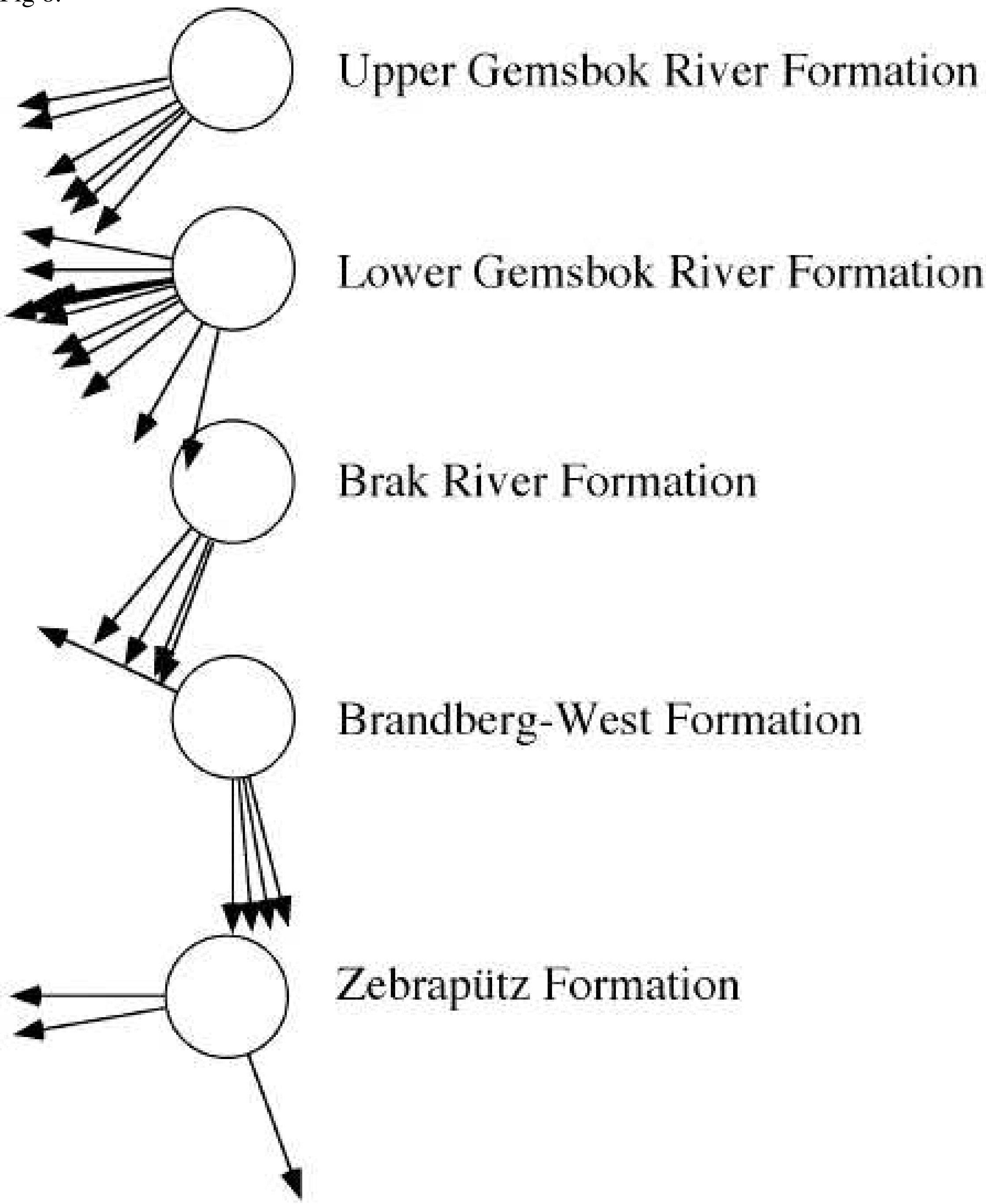
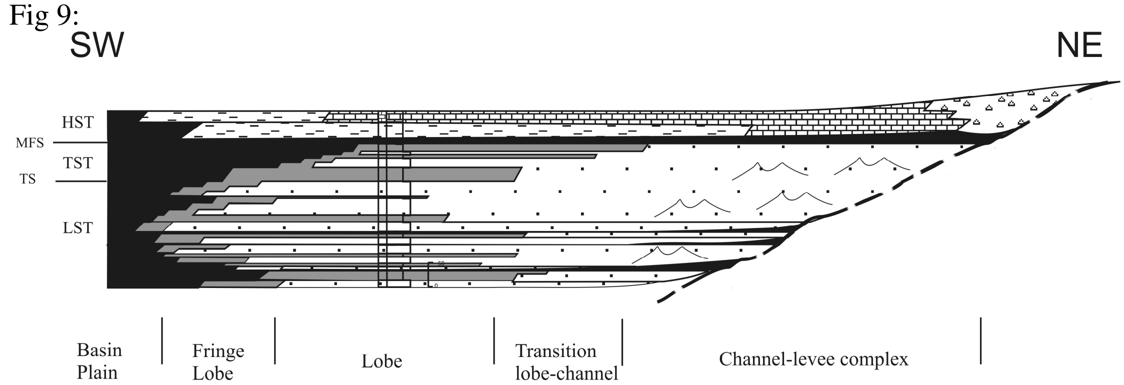
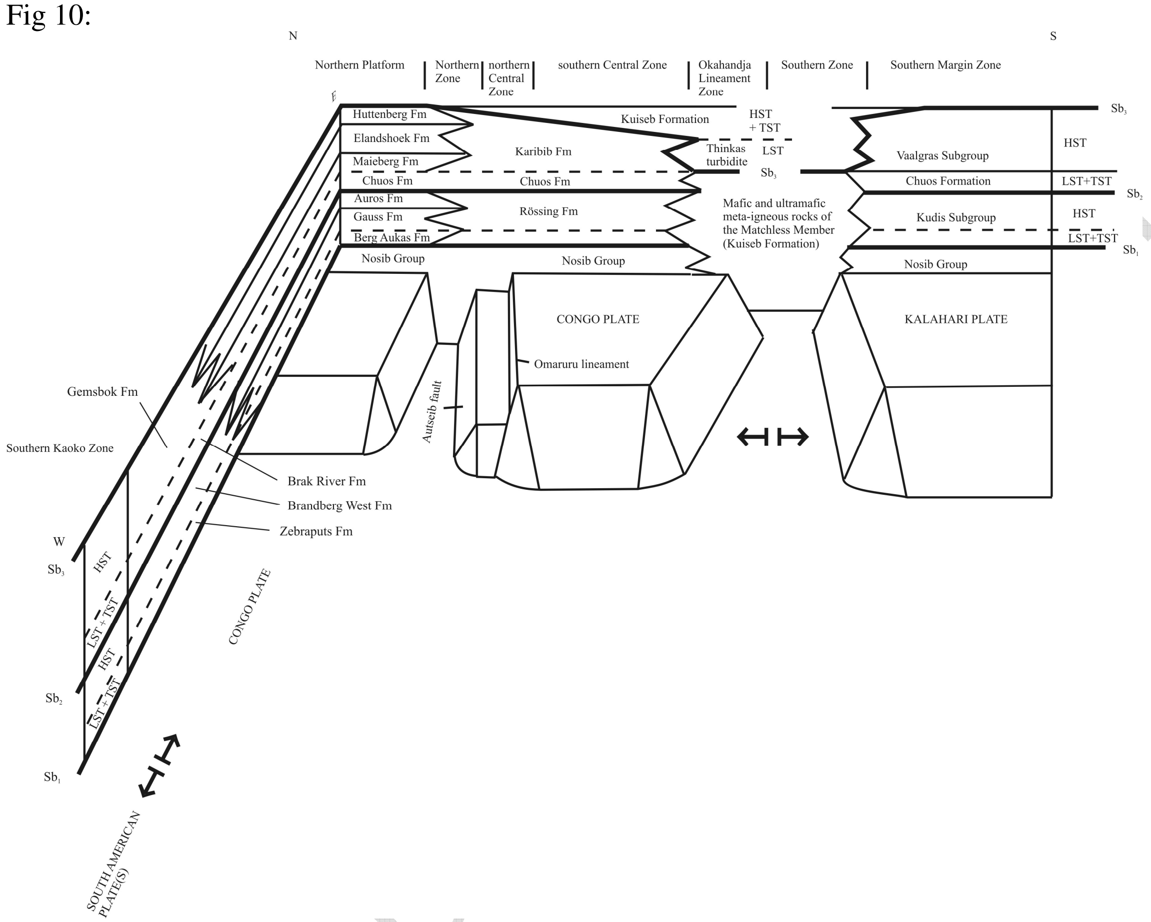

Upper Gemsbok River Formation
Lower Gemsbok River Formation
Brak River Formation
Brandberg-West Formation
Zebrapütz Formation

Fig 9:



Gemsbok River Formation	Basin plain mudstone (hemipelagic)	Massive and graded calcarenite	Periplatform carbonate and talus
Brak River Formation	Basin plain mudstone/muddy channel-levee complex	Thin-bedded sandstone-mudstone couplet of lobe-fringe deposit	Thick-bedded sandstone lobe and channel-fill deposit
	LST - Lowstand system track TST - Transgressive system track HST - Highstand system track	TS - Transgressive surface MFS - Maximun flood surface	

Fig 10:


N
S
Northern Platform
Northern Zone
northern Central Zone
southern Central Zone
Okahandja Lineament Zone
Southern Zone
Southern Margin Zone
Huttenberg Fm
Elandshoek Fm
Maieberg Fm
Chuos Fm
Auros Fm
Gauss Fm
Berg Aukas Fm
Nosib Group
Kuiseb Formation
Karibib Fm
Chuos Fm
Rössing Fm
Nosib Group
HST + TST
Thinkas turbidite
LST
Sb3
Mafic and ultramafic meta-igneous rocks of the Matchless Member (Kuiseb Formation)
Vaalgras Subgroup
Chuos Formation
Kudis Subgroup
Nosib Group
Sb3
HST
LST+TST
Sb2
HST
LST+TST
Sb1
CONGO PLATE
KALAHARI PLATE
Omaruru lineament
Autseib fault
Gemsbok Fm
Southern Kaoko Zone
Brak River Fm
Brandberg West Fm
Zebraputs Fm
W
Sb3
HST
LST + TST
HST
Sb2
LST + TST
Sb1
CONGO PLATE
SOUTH AMERICAN PLATE(S)