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by

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ABSTRACT

The Gariep Belt forms part of the coastal branch of the Pan African Damara Orogen. It is an arcuate N-S-trending tectonic unit extending along the coast from SE of Lüderitz to Kleinzee for a distance of about 400 km with a maximum width of about 80 km. The Gariep Belt consists of an eastern parautochthonous unit, the Port Nolloth Zone, and a western ophiolitic terrane, the Marmora Superterrane. The stratigraphic succession within the Port Nolloth Zone records the transition from an intracontinental rift to a passive continental margin, recording the opening of the Adamastor Ocean. The closure of the Adamastor Ocean is recorded by three deformational phases. The two earliest deformational phases, D_1 and D_2, are associated with N- to NW-trending thrusts. D_1 thrusts are bedding-subparallel, whereas D_2 thrusts cut F_2 fold limbs at high angles.

Lateral variations in stratigraphic thickness along the prominent Rosh Pinah thrust show that it had an older history prior to the compressional phase. Other key aspects for the recognition of this inversion structure are the presence of syn-rift sediments and volcanics, as well as associated SEDEX mineralization along the Rosh Pinah thrust. During extension the Rosh Pinah fault acted as a down-to-the-west syn-sedimentary normal fault. During compression, inversion took place along the extensional fault to produce an eastward directed low-angle reverse fault, presently exposed as the Rosh Pinah thrust.

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INTRODUCTION

The Late Proterozoic/Early Palaeozoic Gariep Belt forms part of the Pan African system of orogenic belts (Fig. 1; Clifford, 1967; Stowe et al., 1984). It is part of the southern coastal branch of the extensive Damara Orogen, which links with the Saldanha Belt of the south-western Cape Province and northwards with the coastal branch comprising the Kaoko Belt of northern Namibia. Porada (1979) has suggested that the western extension of the Damara Orogen is represented by the Ribeira Belt of Brazil (Fig. 1), which is also supported by geochronological data of Cordani et al. (1990).

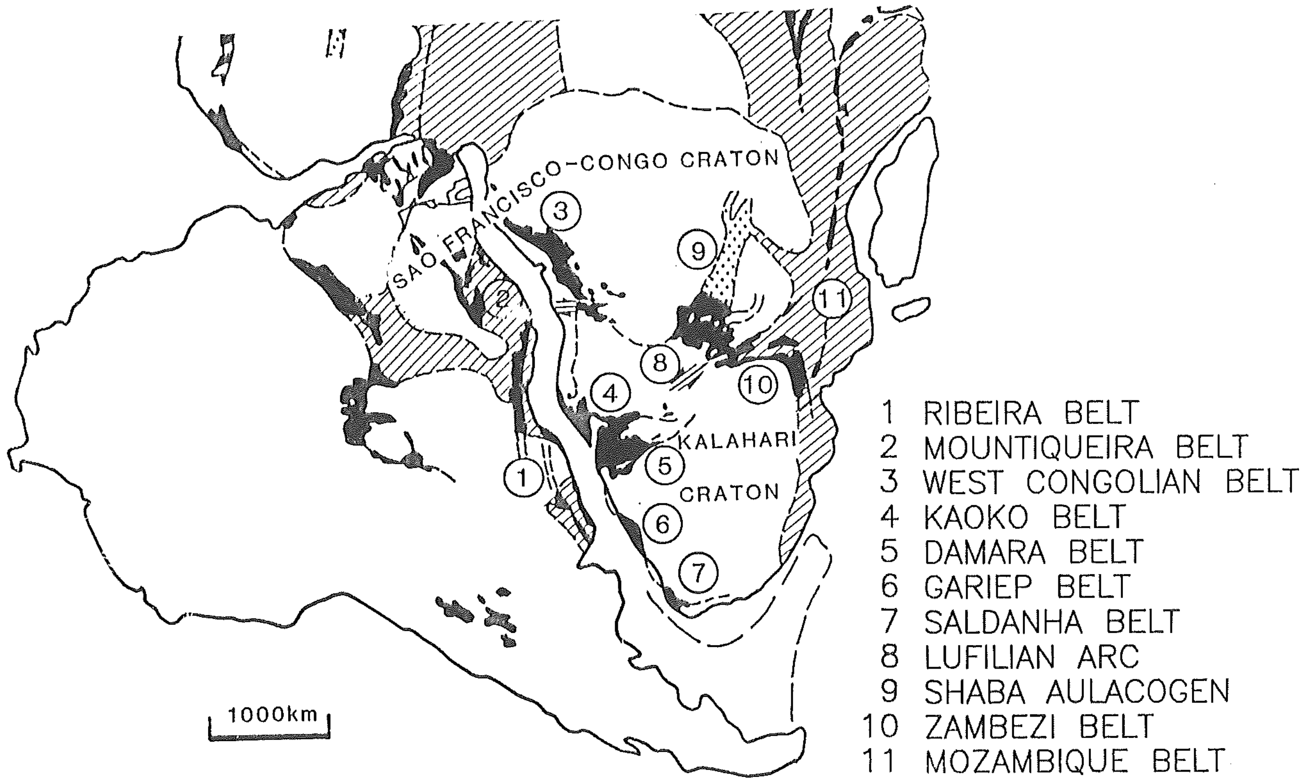

Figure 1: Pan African framework of Southern Africa and South America (modified after Porada, 1989).

The Gariep Belt is an arcuate north-south trending tectonic unit extending along the coast of Namibia from immediately south-east of Lüderitz to Port Nolloth in South Africa, a distance of nearly 400 km. The belt has a maximum exposed width of about 80 km (Fig. 2) and consists of an eastern, parautochthonous terrane, termed the Port Nolloth Zone, which developed as a transition of a rift-to-passive continental margin on the western edge of the Kalahari Craton. This zone also contains stratiform Zn-Pb-Cu-Ag-($\pm$ Ba)-sulphide mineralization in syn-rift sediments. A western, allochthonous ophiolitic terrane, the

Marmora Superterrane (Von Veh, 1988; Hartnady et al., 1990; Jasper, 1994), was thrust onto the Port Nolloth Zone along the Schakalsberge Thrust (Fig. 2) during an extensional phase in the evolution of the Gariep Belt and which occurred between 780 Ma and 670 Ma (Jasper, 1994). The compressional history of the Gariep Belt was initiated after the deposition of the Gariep Group lithologies and ceased at about 500 Ma following the deposition of Nama Group sediments into peripheral foreland basins (Stanistreet et al., 1991; Jasper, 1994).

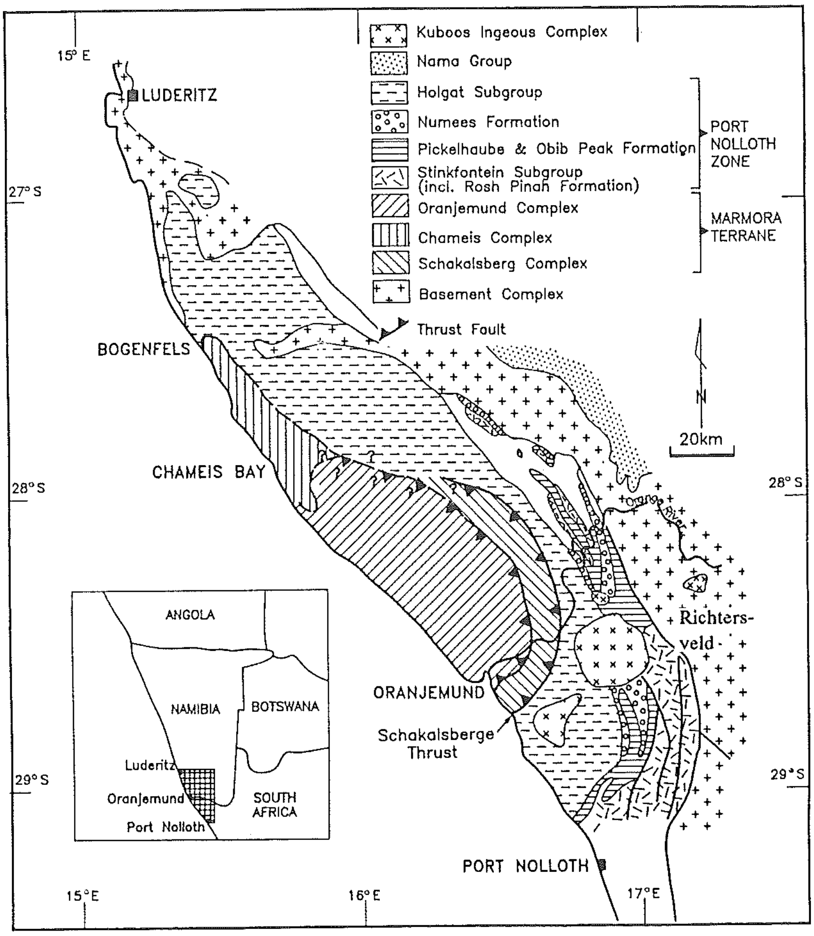

Figure 2: Simplified geological map of the Gariep Belt (modified after Hartnady et al., 1990).

Within the Gariep Belt a number of pre-, syn- and post-tectonic intrusions are present. Throughout the Gariep Belt, the up to 100 km wide Gannakouriep dyke and sill swarm, consisting of north- to northeast-trending mafic and ultramafic sills and dykes (De Villiers and Söhnge, 1959; Middlemost, 1964; McMillan, 1968; Kröner and Blignault, 1976; Reid, 1979; Jasper, 1994) is intrusive into the basement rocks and into the rocks of the Stinkfontein and lower Hilda Subgroups. In the Richtersveld, Gariep Group lithologies are intruded by the Kuboos-Bremen and Garub Intrusives (Van Biljon, 1939; Söhnge and De Villiers, 1946; Kröner and Hawkesworth, 1977). The latest intrusions into Gariep Group lithologies are recorded by mainly northerly trending Mesozoic Karoo dolerite dykes, which have been traced from Dreigratberg (Fig. 3) to north of Trekpoort Farm, approximately 25 km north of Rosh Pinah.

Little geological research has been undertaken in the Gariep Belt immediately north of the Orange River. According to McMillan (1968) the earliest survey of this area was carried out from 1912 to 1913 by German workers engaged on a regional survey of the eastern Sperrgebiet (Diamond Area No.1) south of Lüderitz. The first detailed geological account of the study area was made by Beetz (1926), who concentrated on the Witputs area located approximately 40 km north of Rosh Pinah. Further geological work within the Sperrgebiet was undertaken by Kaiser (1926) and Knetsch (1937). Later, Söhnge and De Villiers (1946) published a brief report on the geology of the eastern Sperrgebiet, immediately north of the Orange River and Martin (1965) undertook some reconnaissance work in the Obib Mountains within the Sperrgebiet. The first comprehensive geological mapping, at a 1:100 000 scale, was undertaken by McMillan (1968) in the Witputs-Sendelingsdrif area. Geological studies of the Rosh Pinah Zn-Pb-Cu-Ag-deposit and its immediate surroundings were undertaken by Page and Watson (1976), Watson (1980), Van Vuuren (1986), De Kock (1987), Siegfried (1990), and Lickfold (1990). Davies and Coward (1982) undertook regional structural studies within Diamond Area No.1 and Smith and Hartnady (1984) investigated the geochemistry of the Grootderm volcanics. Allsopp et al. (1979) undertook geochronological studies on Gariep rocks and on rocks of the Kuboos-Bremen line of intrusives and the Richtersveld and Bremen Igneous Complexes of southwestern Namibia and the Richtersveld. The most recent geological work on the structural evolution and the stratigraphic succession of the Gariep Belt was undertaken by Von Veh (1988) in the Richtersveld of South Africa, situated south of the study area (Fig. 2). Von Veh (1988) also attempted a re-interpretation of the Rosh Pinah-Sendelingsdrif area mapped earlier by McMillan (1968).

The tectonic effects of oceanic closure and continental collision along the Gariep Belt were described by Jasper et al. (1994).

In this paper the authors describe the extensional evolution of a half-graben system and its subsequent contraction and inversion within the Gariep fold and thrust belt of southern Namibia. It will be demonstrated that the geometries of syn-depositional Late Precambrian extensional faults (and the architecture of the sediment bodies and graben systems) strongly influenced and locally controlled the subsequent thrust fault geometries and inversion.

STRATIGRAPHY OF THE GARIEP BELT

Detailed sedimentological and structural field investigations in southern Namibia (Jasper 1994; Jasper et al., 1992/93) suggested that the Port Nolloth Zone-stratigraphy in southern Namibia consists of the Stinkfontein Subgroup, comprising: (1) the Rosh Pinah Formation, a mixed clastic/volcanic rift phase; (2) the Gumchavib Formation, a mixed terrigenous/marine clastic phase; (3) the Hilda Subgroup, comprising the Pickelhaube Formation, a platform carbonate and continental shelf clastic phase; (4) the Obib Peak Formation, a fluvial phase and (5) the Numees Formation, a mixed glaciomarine/interglacial phase (Table 1).

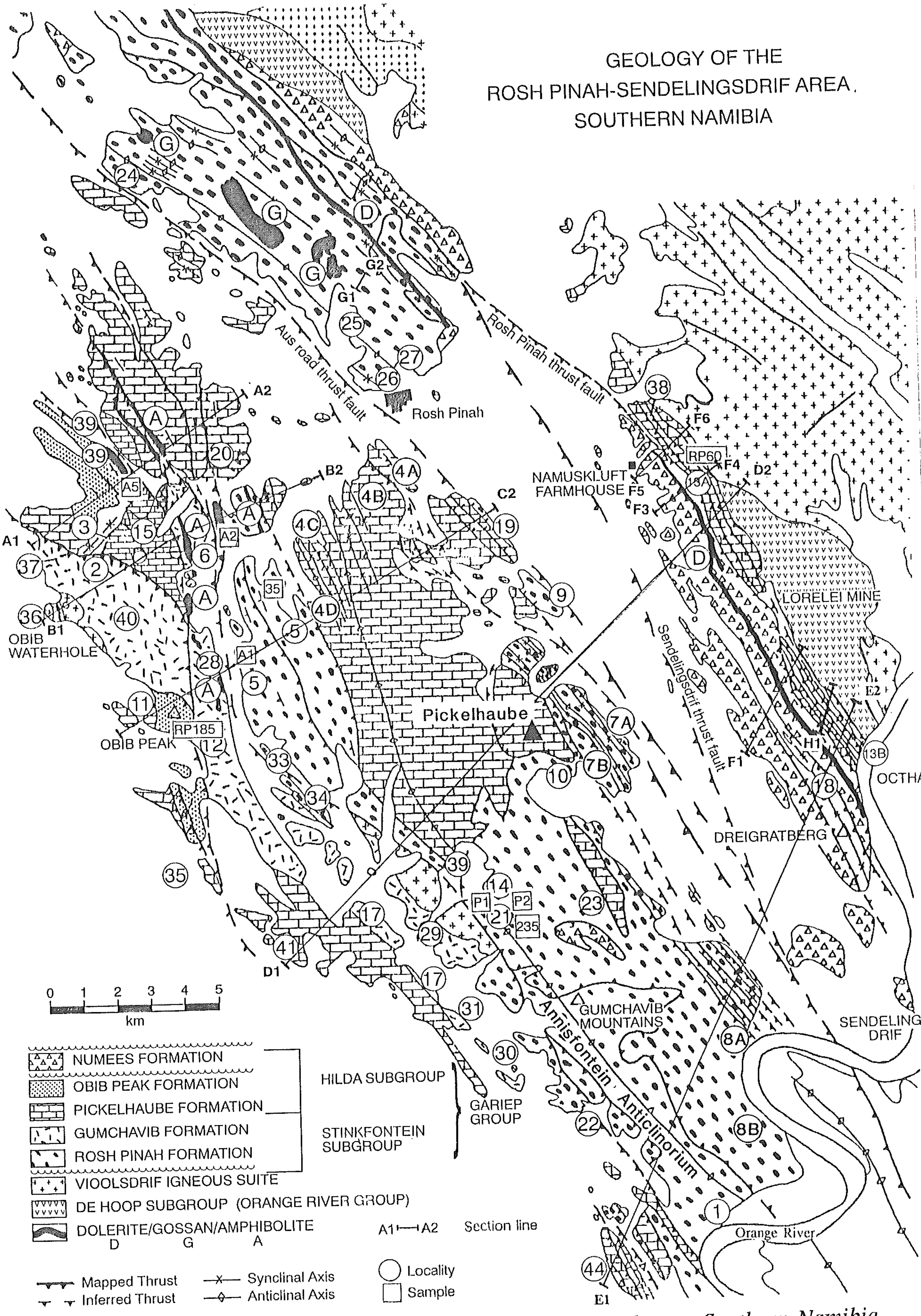

Figure 3: Geological map of the Rosh Pinah - Sendelingsdrif area, Southern Namibia.

Table 1: Stratigraphic subdivision of the Gariep Group of southern Namibia (after Jasper, 1994)

SUBGROUP	FORMATION
Hilda	Numees
	Obib Peak
	Pickelhaube
Stinkfontein	Gumchavib
	Rosh Pinah

TECTONICS OF THE GARIEP BELT

Three phases of deformation, of which the first two are associated with a conspicuous cleavage development, have been distinguished in the Gariep Belt of southern Namibia. The most prominent structural features, which form the structural grain of the study area, are N-S to NW-SE-striking, small-to large-scale D_2 folds with northerly and southerly plunging fold axes. These are associated with major northerly to northwesterly striking thrusts which generally dip towards the W or WSW (Jasper, 1994; Jasper et al., 1994; Jasper et al., 1992/93; Figs. 3 and 4). In the Rosh Pinah-Sendelingsdrif area (Fig. 3), the northerly continuation of the Annisfontein anticlinorium of the Richtersveld (Von Veh, 1988) is the most conspicuous fold structure, which occurs in the vicinity of Gumchavib Mountain (Fig. 3). These folds deform, around their hinge line, an earlier, bedding-subparallel fabric, some minor intrafolial isoclinal folds, and associated minor thrusts which characterize the D_1 deformation phase. Subsequently, the D_1 and D_2 deformational structures were deformed by E-W to NE-SW-trending small-to large-scale folds, which represent the D_3 deformational event. The three recognized deformational events, D_1, D_2 and D_3, are defined by the following main structural characteristics: (1) D_1 by a bedding-subparallel S_1 cleavage, intrafolial F_1 folds, and an l_1 stretching lineation of grains, clasts, and boulders; (2) D_2 by an axial planar cleavage (S_2) and N-S to NW-SE-trending F_2 folds.; and (3) D_3 by E-W to SW-NE-trending F_3 folds and a poorly developed axial planar cleavage (S_3). Kinematic analyses in the Gariep Belt of southern Namibia (Jasper, 1994) revealed that the progressive D_1 and D_2 deformational events are associated with the closure of the Adamastor Ocean. The closure of the Adamastor Ocean was associated with an initially northwestward directed subduction of oceanic crust under proto-South America. Subduction was associated with the development of tectonic mélanges and the accretion of three allochthonous exotic terranes, namely the Oranjemund, Chamais and Schakalsberge Complexes (Fig. 2; Hartnady et al., 1990). Oceanic closure culminated in the collision of the Port Nolloth Zone continental margin and the accreted Marmora Superterrane as an allochthonous tectonic block during D_2. The collision of the South American Craton with the Port Nolloth Zone continental margin

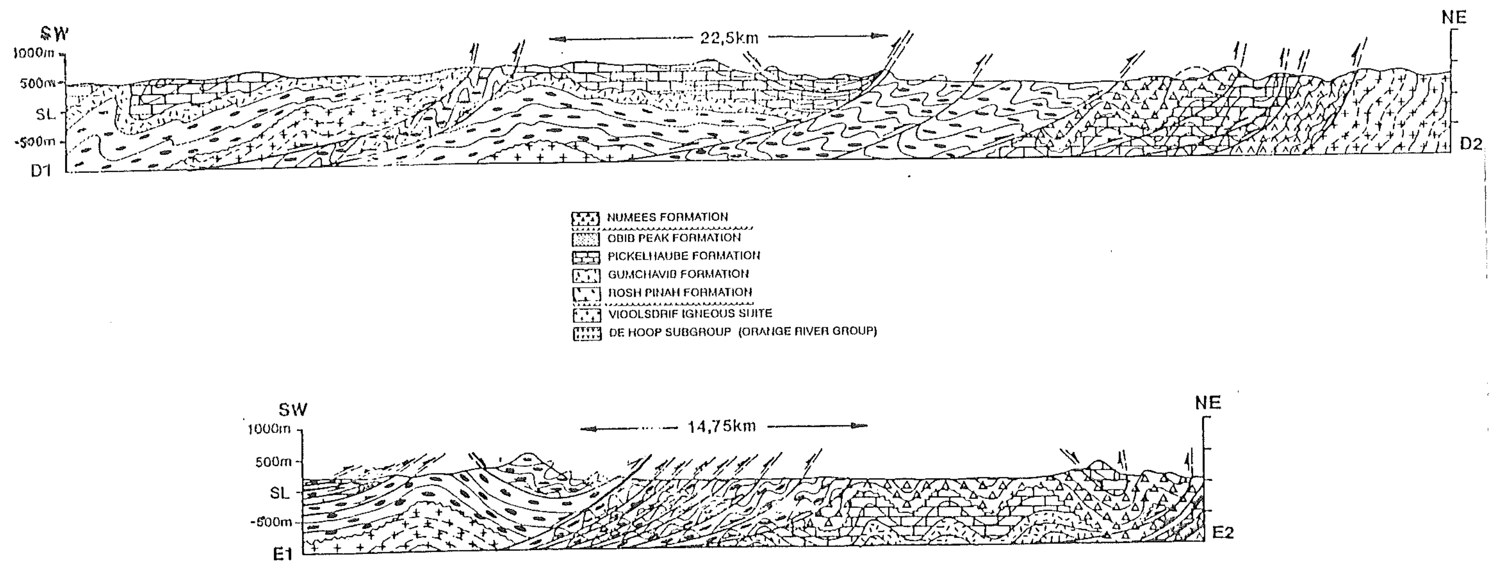

Figure 4: A) Structural SW to NE cross-section D_1-D_2 cutting through parts of the Obib thrust slice south of Obib Peak in the SW, and parts of the Ostrich, Rooikat, Pickelhaube, Gemsbok, and Dreigratberg thrust slices, as well as the autochthonous zone in the NE.
B) Structural SW to NE cross-section E_1-E_2 cutting through parts of the Ostrich, Gumchavib and Dreigratberg thrust slices, as well as the para-autochthonous zone in the NE.
Position of cross-sections are shown in Figure 4.

was associated with the obduction of ophiolitic material on the Port Nolloth Zone lithologies along the Schakalsberge Thrust. The closure of the Adamastor Ocean and the collisional event were accompanied by intense southeastward (D_1) and, subsequently, eastward (D_2) directed tectonic transport, resulting in intense folding and thrusting of Port Nolloth Zone sediments and volcanics during the Adamastor Orogeny. After the collision of South America and the Kalahari Craton, a sinistral movement developed along the defined fault zones, deforming both Gariep and unconformably overlying Early Palaeozoic Nama Group sediments during the D_3 deformational event.

The collisional event was accompanied by a Barrovian-type metamorphism with a geothermal gradient of about 20° C/km (Jasper, 1994). The compressional evolution of the Gariep Belt ceased at about 500 Ma (Jasper, 1994; Jasper et al., 1994; Stanistreet et al., 1991).

TECTONO-STRATIGRAPHIC SETTING OF THE GARIEP BELT

Field evidence indicates the presence of major thrust faults associated with the D_1 and D_2 deformational events within the Gariep Belt, defining the boundaries of several tectono-sedimentary units and juxtaposing various thrust slices.

Major changes in fabric and fold morphology occur between the different parautochthonous thrust slices and the basement-floored sequence east of the Rosh Pinah thrust fault (Figs. 3, 4A, 4B, 5). The thrust slices are parautochthonous, whereas the basement-floored unit is autochthonous. The thrust slices are named after the floor thrust fault of each thrust slice. The structural units (Fig. 5) comprise: (1) the autochthonous unit in the east of the study area, immediately east of the Rosh Pinah thrust fault and the associated imbricate thrust zone; and to the west, the parautochthonous (2) Dreigratberg thrust slice, (3) Pickelhaube thrust slice, (4) Gumchavib thrust slice, (5) Rooikat thrust slice, (6) Ostrich thrust slice, (7) Obib thrust slice and (8) Gemsbok thrust slice.

EXTENSIONAL FAULTING IN THE GARIEP BELT

Inversion Tectonics Within other Fold and Thrust Belts

The basin architecture of several fold and thrust belts, as shown by the example of the Kechika Trough in the western Rocky Mountains of northern Canada (McClay et al., 1989), can exert a distinct influence on the contractional tectonics. The reactivation of extensional structures during compressional tectonics has been noted in various thrust and fold belts, e.g. the Cordilleran Fold and Thrust Belt (Taylor and Stott, 1973; Thompson et al., 1987; McClay et al., 1989). The recognition of fault inversion and lateral asymmetries of thicknesses of stratigraphic sequences on either side of reversed faults and the presence of syn-rift sediments and volcanics is therefore of great importance as direct proof for extensional faulting.

Location of Inverted Faults in the Gariep Belt of Southern Namibia

Within the area investigated an autochthonous region in the east has been differentiated from a parautochthonous area in the west (Figs. 3 & 5), which comprises a set of basement-cored thrust slices. The major structural boundary between the two is the Rosh Pinah fault (Figs. 3 & 5), which can be followed over a total strike distance of about 85 km from an area situated about 40 km northwest of Rosh Pinah and about 15 km northwest of Trekpoort Farm, southeastwards into the Richtersveld, where it splays into the Klipneus, the Grasvlakte and the Vandersterrberg faults (Von Veh, 1988).

In the northern part of the area investigated, the Rosh Pinah thrust slice and the autochthonous unit to the east of it are juxtaposed along the Rosh Pinah thrust fault. In the southern parts of the study area, the Dreigratberg thrust slice is juxtaposed with the autochthonous assemblage in the eastern parts of the Rosh Pinah-Sendelingsdrif area, which overlies the basement unconformably (Figs. 3 & 5).

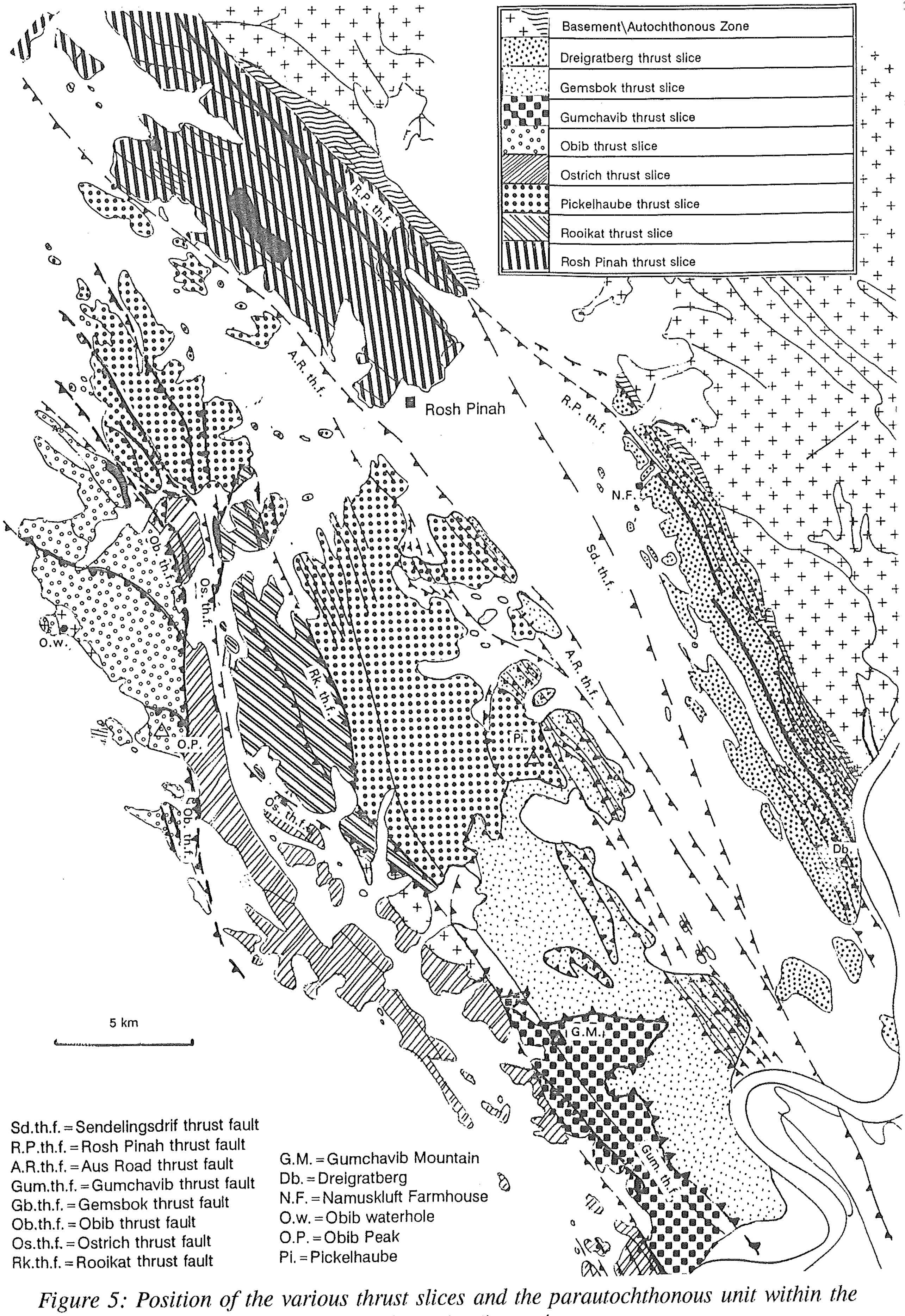

Figure 5: Position of the various thrust slices and the parautochthonous unit within the study area; locations shown in Figure 4.

Stratigraphic Thickness Variations Along Inverted Faults in the Gariep Belt of Southern Namibia

The untelescoping of thrust faults within the study area reveals considerable lateral thickness variations of stratigraphic sequences, providing direct evidence for faulting during the extensional phase of the evolution of the Gariep Belt.

The important structural boundary represented by the Rosh Pinah fault is coincident with the major stratigraphic break which occurs in the study area. To the east of this fault, rocks of the Pickelhaube and Numees Formations unconformably overlie basement rocks. To the west of the fault, most of the entire sequence, comprising the Rosh Pinah, Gumchavib and Pickelhaube Formations, unconformably overlies basement (Fig. 6).

Because more complete sequences are only preserved to the west of the Rosh Pinah fault, it is obvious that the fault acted with a normal sense of throw with down-to-the-west movement during the sedimentary history. Because this is the most major stratigraphic break, it suggests that the Rosh Pinah fault was the master low angle fault controlling extension in the study area (Fig. 7). It is not surprising that the thickest and best development of the intracontinental rift sequence, represented by the Rosh Pinah Formation, is preserved just to the west of this major extensional structure. The Aus Road fault to the west of the Rosh Pinah fault (Figs. 3 & 5) probably also acted as a low angle extensional fault, giving rise to the formation of a sub-basin (Fig. 7).

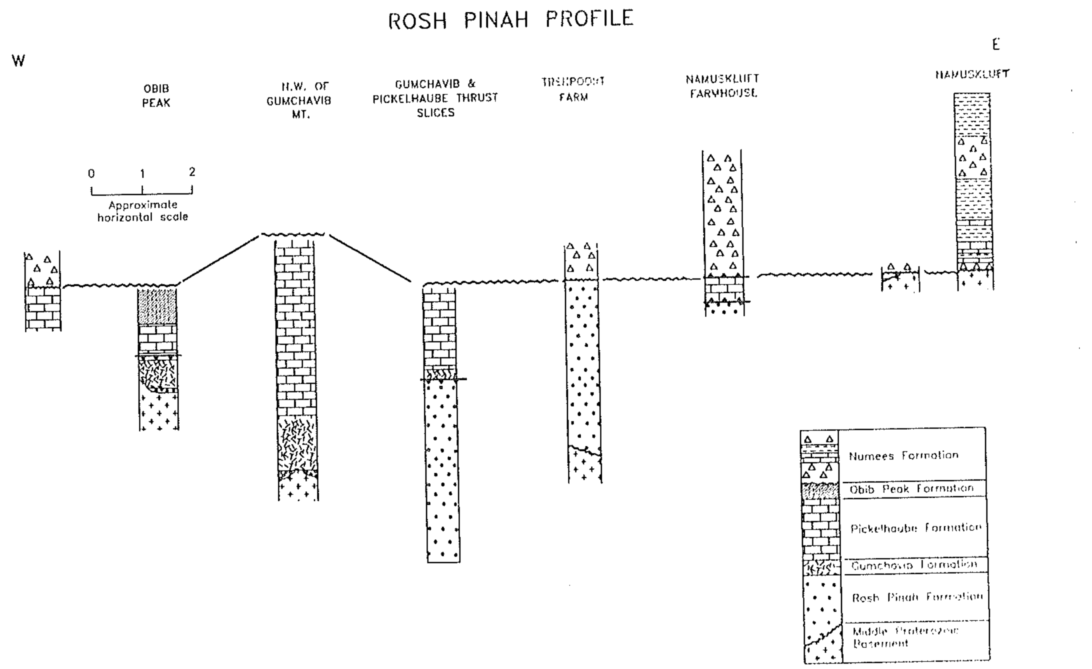

Figure 6: Schematic diagram showing stratigraphic thickness variations within the study area.

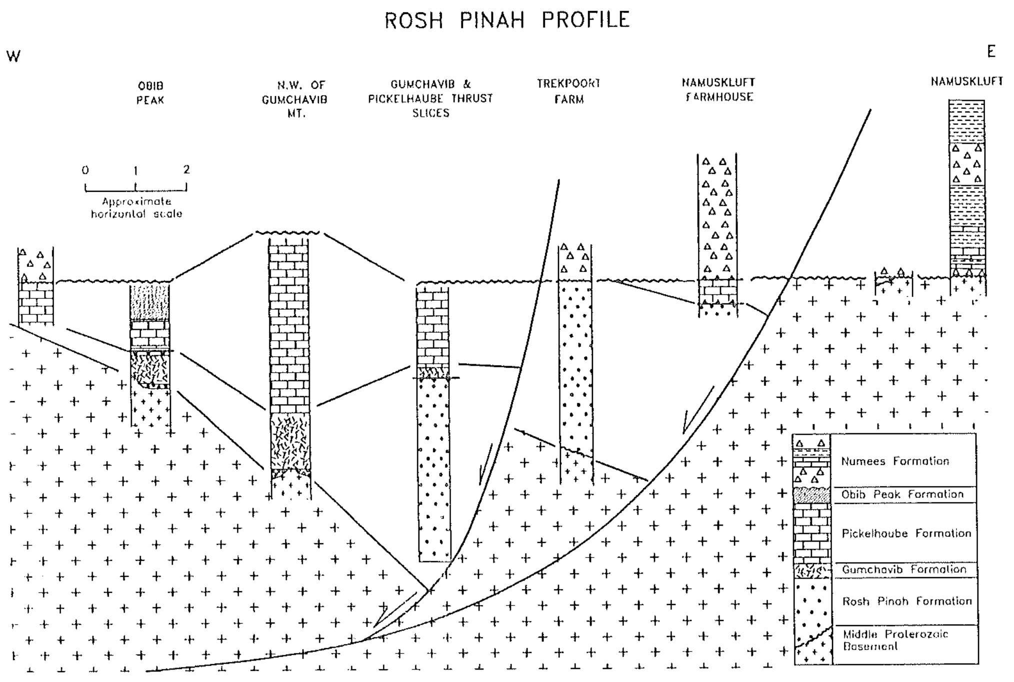

Figure 7: Interpretation of Figure 6, showing the position of syn-sedimentary faults, which controlled the deposition of the Gariep Group sediments within the study area.

Tectono-sedimentary History of the Study Area

Lateral variations in stratigraphic thickness along the Rosh Pinah thrust fault have shown that it has an older history prior to the compressional phase, which affected the sedimentation of almost the entire Gariep Belt. During subsequent compression, inversion took place along the extensional fault to produce an eastward-directed, low-angle reverse fault, presently exposed as the Rosh Pinah thrust zone.

The basin architecture within the Gariep fold and thrust belt has exerted a profound influence on the contractional tectonics in the study area. The geometries of the extensional faults controlled the level of detachment and apparent thrust fault sequences. The example of the Rosh Pinah basin, situated west of the inverted extensional Rosh Pinah fault, demonstrates how the early basin architecture shaped this section of the Gariep fold and thrust belt.

The Rosh Pinah thrust fault represents a most conspicuous inversion structure. A model that illustrates the sequential contraction and inversion of the Rosh Pinah half-graben system is shown in Figure 8. Another key aspect for the recognition of structural inversion is the identification of a syn-rift (or passive infill) sequence (Cooper et al., 1989). The sediments and volcanics of the Rosh Pinah Formation represent syn-rift deposits (Jasper et al., 1992/93; Jasper, 1994) and, therefore, add further evidence for possible structural

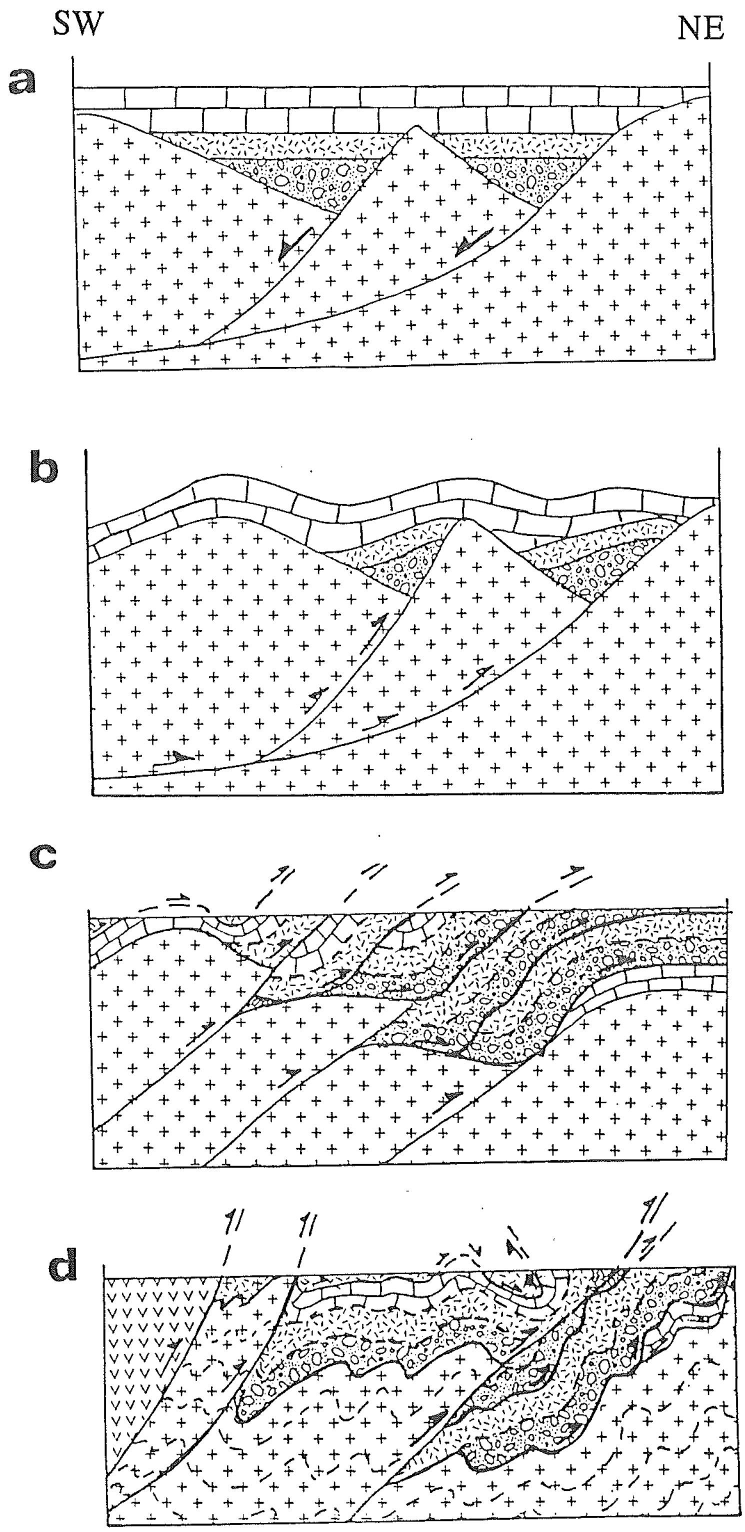

Figure 8: Schematic model for the inversion of the Rosh Pinah half graben. (a) Pre-inversion geometry of the half graben with deposition of syn-rift sediments and volcanics. (b) Initial inversion showing reactivation of half graben bounding listric fault. (c) Continued deformation with bedding sub-parallel thrusting along the extensional listric fault plane (D_1). (d) Subsequent folding and associated thrusting (D_2) along the reactivated extensional fault plane.

inversion. The extensional faults (Fig. 8a) were reactivated during the early stages of contraction (Fig. 8b). During continued contraction lithological boundaries both along the basement contact and within the syn-rift and post-rift cover sequences, were used as thrust planes during the D_1 deformational phase (Fig. 8c). Further contraction along the same thrust fault planes led to intense folding and associated thrusting during the D_2 deformational phase (Fig. 8d). Intense folding and imbrication of the half-graben sediments is attributed to the space problem generated by the shortening of the half graben during inversion. In addition, high cut-off angles of the faults suggest that imbrication did not only take place during the D_1 deformational event, but also during and after D_2 folding. Duplex structures are a common feature within the inverted Rosh Pinah half graben.

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