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Report: Results of preliminary investigations into the geology of the Diaz Point Formation, Lüderitzbucht, Namibia

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The Diaz Point Formation is a highly sheared, late Proterozoic diamictite which crops out along the Namibian coast from Lüderitz to Wolf Bay. It lies with a marked structural discontinuity on gneissic basement, which forms part of the Namaqua Metamorphic Complex. Three units can be distinguished from each other by thrust faults. Alliithologies are characterised by strong, bedding-parallel foliation and intense north-northwest-trending mineral and stretching lineations.

A mixed fluvioglacial origin for these sediments is indicated by locally cross bedded channel forms, quartzite layers and rounding of many clasts. These highly tectoni sed lithologies are correlated with Nosib Group sediments of the Damara Sequence to the north and basal mixtites of the southern Gariep Group.

Introduction

Highly deformed metasediments consisting dominantly of diamictite occur as a narrow strip bordering the coastline south of Lüderitz, Namibia. Visibly different from the basement, these metasediments were termed the Diaz Point Formation by Greenman (1966) who interpreted the rocks to be mixtites of Gariep age. The Diaz Point Formation was supposedly older than the Bogenfels Formation (Martin, 1965) which occurs to the south of Grossebucht (Fig. 1). These formations overlie mid-Proterozoic basement of the Namaqua Metamorphic Complex to the east, which consists dominantly of quartzo-feldspathic migmatites.

The Diaz Point Formation was reinterpreted by Kröner and Jackson (1974) as representing refoliated basement, but present consensus is that these lithologies are part of the Gariep Group and have been highly tectonised (SACS, 1980; SWA/Namibia Geosurvey Map, 1982; Swart, 1989). The aim of this study is to describe the Diaz Point Formation's relationship to the underlying Namaqua basement and to discuss its position in the framework of Gariep Group deposition and deformation. It has been found that apart from the coastal strip, highly deformed metasediments occur as klippe scattered throughout the Lüderitz area extending southwards into diamond area No. 1. Refoliated slices of basement gneiss are also observed to be present in the area. It is hoped that further mapping of the area can be completed so that these basement slices can be studied and correlated. Restricted access to the south has limited mapping to between Halifax Point and Grossebucht.

General Geology

Lithologies

The basement on which the Diaz Point Formation rests consists of gneissic migmatites composed dominantly of orthoclase, quartz, plagioclase (An30), biotite, hornblende, epidote, almandine, muscovite and rare tremolite. Regional mapping in the area (Greenman, 1966; McDaid; 1976) indicates that these lithologies are part of the Gordonia Subprovince of the Namaqualand Metamorphic Complex which has an age of 1460-1200 Ma. (Hoal *et al.*, 1989). Pegmatites as well as quartz + orthoclase segregations are common. Basic intrusions are rare and indicate premetamorphic emplacement. Structural trends generally indicate very little involvement during Pan-African (500-600 Ma.) tectonogenesis except in close proximity to the Diaz Point Formation itself. Outcrops of the Gariep Group in Namibia (McMillan, 1968; Kröner, 1975; Davies and Coward, 1982; Von Veh, 1988), of which the Diaz Point Formation makes up the northernmost outlier, are limited to patchily distributed exposures (Fig. 1), the bulk occurring within Diamond Area No. 1. The Gariep Group has been divided into two major tectonostratigraphic terranes (Von Veh, 1988; Hartnady *et al.*, 1990). These are the eastern parautochthonous assemblage, the Port Nolloth Terrane, and the western allochthonous assemblage, the Marmora Terrane. The Port Nolloth Terrane is best developed in the Richtersveld and Rosh Pinah areas (Fig. 1) and consists of shallow-water clastics, acid volcanics, shelf carbonates and rift-related sediments. The formations comprising this assemblage are, in Namibia, the Rosh Pinah Formation, Spitzkop Formation, Hilda Formation, Bogenfels Formation, Diaz Point and Heiob Formation (SACS, 1980; Tankard *et al.*, 1983). In the Rosh Pinah area a basal mixtite, grossly similar to the Diaz Point Formation, but of limited thickness, is found at the contact with the basement granites.The Rosh Pinah Formation is a thick (500 m) sequence of feldspathic quartzites with minor interbedded carbonaceous argillites and minor basic volcanic flows. Of note is the laterally continuous mineralised chert and carbonate horizon which forms the Rosh Pinah massive sulphide deposit.

The Spitzkop Formation is composed in the lower parts of metabasic volcanics with extensive epidotisation while in the upper portions acid volcanics comprising ignimbritic and rhyolitic lithologies occur. On the farm Spitzkop III, laharic tuffs and lapilli tuffs grade

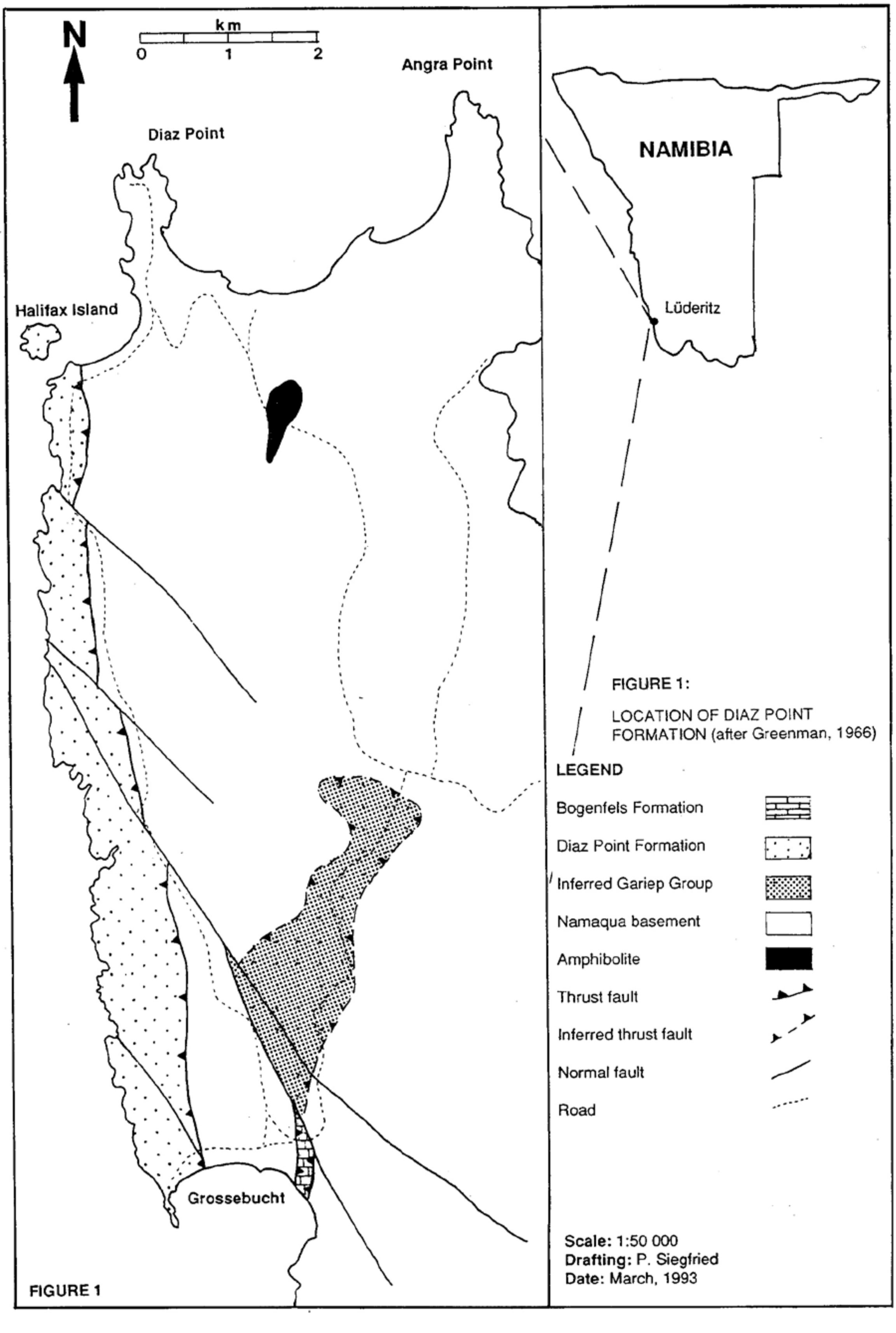


Figure 1: Location of Diaz point Formation (after Greenman, 1966)

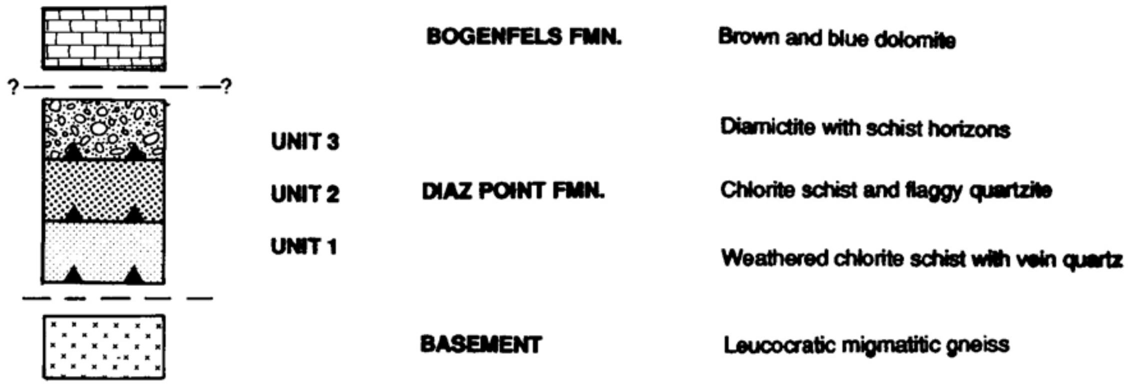


Figure 2: Cross section of Diaz Point Formation (cf. Fig. 4)

into volcanoclastics comprising clasts of the underlying volcanic rocks hosted in a coarse- to medium-grained matrix of basement-derived quartz and feldspar grains. These lithologies grade further into coarse-grained feldspathic quartzites, grits and arkoses indistinguishable from those of the Rosh Pinah Formation. Similar feldspathic quartzites and arkoses occur in the structurally overlying Hilda Formation.

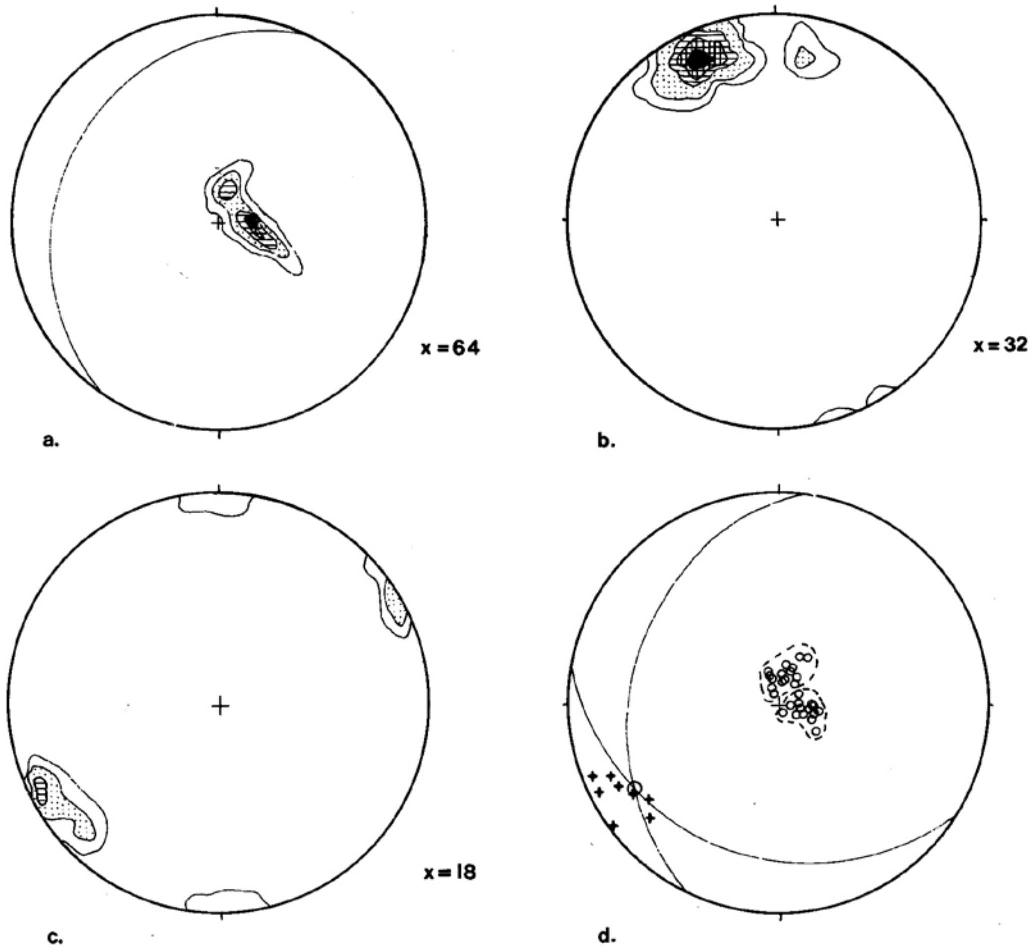


Figure 3: Stereonet data: a) poles to bedding and constructed mean S_0/S_1 plane; b) mineral and stretching lineations; c) lineation of crenulation fold axial trends; d) interpretation of combined structural data. The two groupings of S_0s result in an antiform axial trend mimicking the crenulation fold direction. It is possible that these folds also occur on a "giant" scale, suggesting that they formed during the later part of thrust deformation and did not become sheath folds. Similarly they could indicate that the later part of the deformation was dominated by lateral shear as opposed to compressive southeast-directed thrusting

The Hilda Formation is composed of blue-grey dolomites and limestones, brown limestones, fine-grained clastics and occasional coarse-grained sandstones and grits.

The Marmora Terrane, in contrast, consists dominantly of submarine mafic flows of oceanic affinity (Tankard, 1983; Hartnady *et al.*, 1990), deep-water cherts and carbonates as well as deep-water clastic sediments.

Three packages - the Chameis Complex, consisting of diverse metasediments and possible blue-schist related lithologies; the Oranjemund Complex, consisting of turbiditic metasediments; and the Schakalsberg Complex, composed chiefly of metabasalts - make up the Marmora Terrane.

It is separated from the Port Nolloth Terrane by a major discontinuity - the Schakalsberg Thrust.

Structure

Two main deformational events have been identified in the Gariep Group (Davies and Coward, 1982; Von Veh, 1988; Hartnady and Ransome, in prep., Jasper, in prep.). Initial deformation (D_1) caused by south-east-directed compression resulted in extensive thrusting and the development of a regional So-parallel foliation accompanied by mid-greenschist and localised epidote-almandine facies metamorphic mineral growth (Siegfried, 1986). A pronounced dip-slip mineral and stretching lineation formed coevally. Sheathfolds were formed, predominantly in carbonate lithologies (Davies and Coward, 1982; A.A.C., 1988). D_2 deformation appears to be a secondary response to continued compression. Overthrusting of the Schakalsberg Suite resulted in a foreland-propagating imbricate fan spreading through the Port Nolloth Terrane in the Richtersveld area (Von Veh, 1988), while in the Rosh Pinah area backfolding associated with lateral ramping produced the westward-vergent folds so typical of the area today (Siegfried, 1990). The stretching or transport lineation became oblique strike-slip in direction following the axialplanar cleavage of folds. Tight folds are characterised by coplanar overprinting of S_1 while most other folded areas developed a transpressive sigmoidal cleavage.

A later D_3 event produced localised dome-and-basin structures which have been observed in both the Hilda (J. Jasper, pers. comm.) and Rosh Pinah Formations.

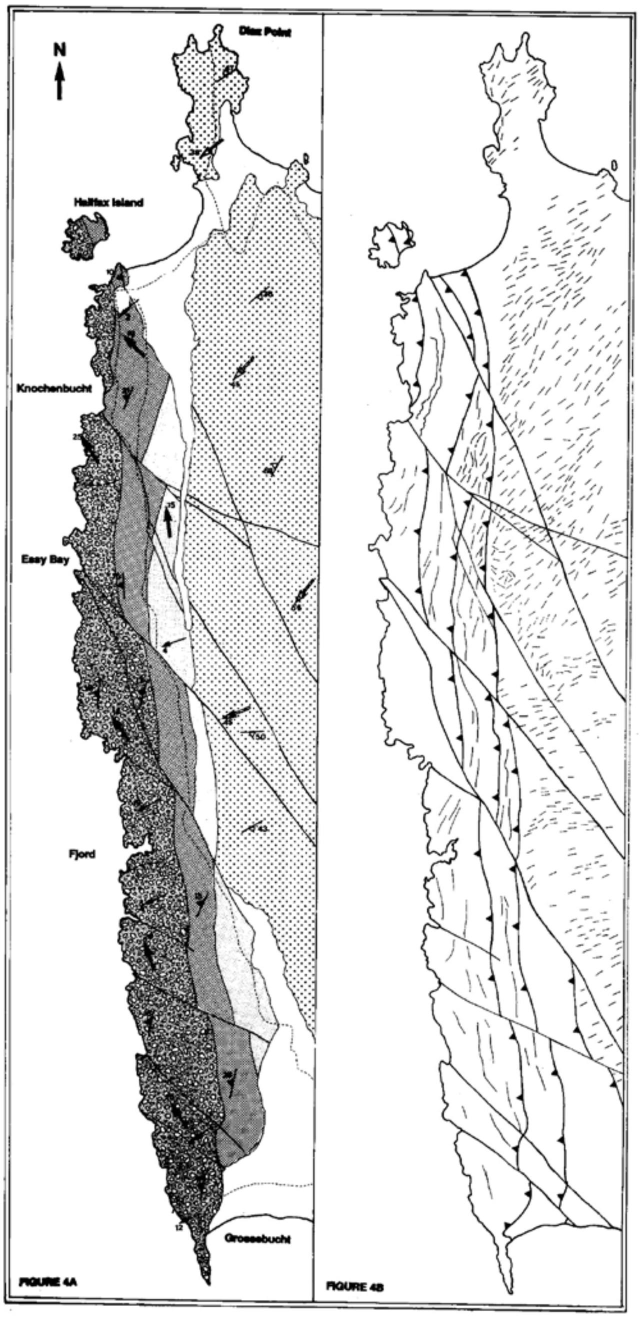
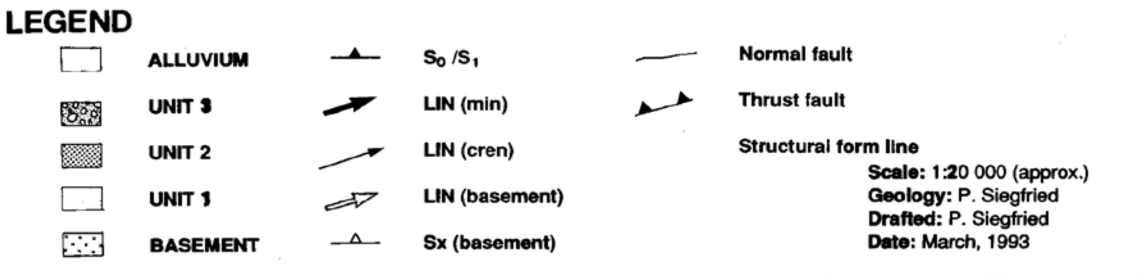


Figure 4: Simplified geology and structural interpretation of the Diaz Point Formation

Legend to Figure 4 **(Left)**



Geology of the Diaz Point Formation

Three units separated by thrust faults could be identified. The lowermost unit (UNIT I) consists of intensely weathered chloritic schists with extensive quartz veining. In some samples from the lower parts of this unit appreciable epidote was often observed. These lithologies are present as extremely subdued outcrop in rare exposures. The lowermost contact, presumably with the basement, is exposed as mylonitic quartzites near the eastern edge of Grossebucht. This fault zone is reflected in the linear depression from Guano Bay to Grossebucht. The middle unit (UNIT 2) consists of similar lithologies but also includes rare, flaggy quartzites interbedded with the schists. A dolomitic horizon was also observed in the vicinity of Ebelandsehohle and appears to be bounded by both floor and roof thrusts. The upper unit (UNIT 3) comprises the diamictite proper and is the most extensive of all the lithologies observed. It consists of a quartzite overlain by diamictite with minor interbedded chloritic quartz schists, some containing pyrite cubes. Rare, micaceous quartz sandstone lenses are also present. The total preserved thickness of the three units is in excess of 300 m. Towards the southern part of the study area normal faults have played an important part in dismembering the complete sequence (Fig. 4) and parts of the basement have actually been infaulted.

The thrust faults identified all occur at the base of the quartzite horizons (Fig. 2) and consist of c-mylonites, fault gouge and fault breccia and extensive secondary silicification. These quartzite horizons, which are never thicker than two or three metres, consist of medium- to coarse-grained, rounded quartz grains with regions of cataclastically deformed grains arranged broadly parallel to the S_1 surface. The quartzite which marks the contact between units 2 and 3 is characteristically a rich pink colour and has extensive crush breccia zones while the quartzite at the contact between units 1 and 2 is white and usually very flaggy.

The diamictite horizon of unit 3 is a polymictic, matrix-supported conglomerate consisting of clasts of pink, coarse-grained leucogranite (some clasts up to 2 m in diameter), leucocratic biotite gneiss, well-rounded quartzite boulders (occasionally showing copper staining), quartz pebbles and rare retrograded amphibolite clasts. The matrix is essentially fine-grained quartz, feldspar and chlorite with occasional larger biotite flakes, usually altered to chlorite.

Extensive quartz veining on both macro- and micro-scale (Fig. 5h) is observed within the matrix. A body of dirty micaceous sandstone occurs within the upper part of the diamictite near Essy Bay. It displays well-developed crossbeds 8-10 cm in height. These crossbeds have been much deformed during D_1 and appear to be the site of local sheath fold development. At the Halifax Point picnic area (Fig. 5c), two schist horizons occur with large granitic clasts transgressing the contact and depressing into the lower schist unit. These boulders are up to 100 cm in diameter and although deformed are extensively rounded.

Structure of the Diaz Point Formation

Faults

A parallel series of normal faults trending northwest-southeast, with downthrow of up to 20 m on the southern block, occurs across the study area. Preferential weathering along these faults has resulted in inlets such as the Fjord, Essy Bay, Klein Bogenfels and White Wall. They trend roughly 300° and although not always traceable, are of similar orientation to many of the faults in the basement.

The three main thrust faults observed are highly silicified, angular breccias with c-mylonites and mylonitic stoping on both macro- and micro-scales. These thrusts commonly have minor thrusts and splays associated with them but are often difficult to identify as they grade into the regional foliation. An intense transport lineation associated with these thrusts trends 330/21° and is defined by streaky quartz, slickenslides and quartz mineral growth.

Foliation

The dominant foliation occurring in the area is oriented 192/16°. It is bedding-parallel and associated with an intense mineral lineation trending 330/15° as well as extensive vein quartz. In the finer-grained lithologies such as units 1 and 2, an intensely cleaved fissile rock has resulted. In the diamictite of unit 3, clasts have been severely deformed as well as "wrapped" by the matrix material.

Clasts of quartzite in the diamictite show little observable deformation on a micro-scale apart from slight undulose extinction indicating that the bulk of the strain was taken up by the largely incompetent matrix, leaving the clasts generally unaffected. A mid-greenschist mineral as-semblage was developed at this stage, although later regrowth of chlorite can be observed in some samples.

A crenulation cleavage is observed in places as crinkling on clasts, quartz ribbons, large scale antiformal folds and folded clasts. The crenulation trends 230/04° and is concordant with folds observed (Fig. 3c). During petrographic study it was observed that the initial S_1 fabric is in places overprinted by a secondary compressive cleavage (Fig. 5g) roughly coplanar but oblique to the Sl foliation. This cleavage is probably synonymous with the crenulation observed and occurred towards the end of D_1 or during a less well-developed D_2 deformation event.

Structure of the basement

The basement migmatites have a steep foliation trending to the southwest. Dips are variable and usually steep. Various migmatitic textures can be observed. The dominant lineation trends 200° and is observed as a mineral lineation defined by hornblende.

Discussion

From the data presented it appears that the Diaz Point Formation is indeed correlative with deformed sediments of the Gariep Group and does not represent refoliated basement. The reasons for this are the absence of pegmatite intrusions in the lithologies observed, coupled with the definite sedimentary features present. Amphibolite-grade minerals present in clasts of unit 3 have all been retrograded to mid-greenschist assemblages during structural deformation.

The contrasting structural regimes of the basement and metasediments indicate little relationship between the two, although slices of refoliated basement have been observed to the east. The importance of this formation as the northernmost outlier of the Gariep Group yet identified cannot be overlooked. However, the relationship of the Diaz Point Formation to other Gariep lithologies is rather nebulous as it resembles many of the diamictites occurring in the Port Nolloth terrane. It is sedimentologic ally very similar to horizons of rounded granite and quartzite boulders which occur interbedded with the feldspathic quartzites of the Rosh Pinah Formation. These horizons are presumably associated with early rifting in the Rosh Pinah basin and disappear as one moves up the stratigraphy into the Hilda Formation.

"Unfaulted" exposures observed between the Gariep and the basement reveal a mixtite, very sheared and similar in appearance to the Diaz Point Formation. However, this diamictite is largely clast-supported and probably not equivalent to the Diaz Point Formation. This horizon is up to 3 m thick and grades into overlying chloritic schists, conglomerates, sandstones or volcanic lithologies.

Similar, poorly sorted polymictic debris flows and diamictites occur in the Rosh Pinah Formation where they are interbedded with feldspathic quartzites. An early, glacially derived diamictite has been identified overlying the Stinkfontein Sequence (Group) in the Richtersveld area and is termed the Kaigas Formation (Von Veh, 1990). However, no correlatives of this formation can be observed north of the Orange River and it is suggested that possibly this horizon is correlative with the Numees Formation.

The Numees Formation, which overlies much of the lower formations of the Port Nolloth terrane, contains many basement-derived boulders which appear to have the same provenance area as those occurring in the Diaz Point Formation. However, the common presence of limestone and dolomite clasts, which were presumably derived from the Hilda Formation, are absent and therefore argue against any correlation of the two formations. Recent findings (J. Jasper, pers. comm.) indicate that many horizons within the Numees Formation are actually devoid of limestone or dolomite clasts suggesting that the absence of carbonate clasts need not preclude the correlation of the Diaz Point Formation with the Numees Formation.

Similarly the basal ironstone which has been used to distinguish the Numees from other diamictites is also laterally impersistent and its absence in the Lüderitz area therefore does not preclude the Diaz Point Formation as part of the Numees Formation.

Evidence of dropstones as well as striated and faceted clasts suggests the Numees Formation to be of a glacial origin (Martin, 1956). The large boulders occurring at Halifax Point are possibly of dropstone origin although the intense rounding of most clasts could indicate extensive fluvial transport prior to incorporation within the host sediments. Glacial processes involved in the deposition of these sediments were therefore of secondary importance.

Highly deformed quartzites, conglomerates and marbles lie approximately 100 km to the north of Lüderitz at Spencer Bay and Black Cliffs. These lithologies were described by Kröner and Jackson (1974) and termed the Spencer Bay and Marble Point Formations, respectively, on the grounds of their similarity to the Nosib Group of the Damara Sequence and the "Kapok" or Stinkfontein Formation of the Gariep Group. This interpretation is supported by more recent stratigraphic correlation (Miller, 1983) and the rock types appear to have been deposited as fluviatile sediments during the early rifting of the Damaran ocean. The gross similarity of these pebbly quartzites and conglomerates to highly deformed lithologies observed in the vicinity of Atlas Bay (Fig. 1) indicates a possible stratigraphic link. These highly sheared quartz-pebble conglomerates and quartzites occur inconsistently but always structurally below limited exposures of the Diaz Point Formation.

The Marble Point Formation was correlated with the "lower Swakop Group" (Kröner and Jackson, 1974), now the Coas Formation of the Hakos Group (Hoffmann, 1990) and/or the Bogenfels Formation of the Gariep Group. The blue-grey and yellow marbles which lie to the southeast of Grossebucht appear to be very similar to Kröner and Jackson's description of the Marble Point Formation. At the turnoff to the Fjord occurs a yellow marble which has a silicified thrust fault at the base. If, as has been stated, the end of Nosib Group deposition is marked by the first appearance of shelf carbonates, the juxtaposition of these lithologies in the Lüderitz area as well as the southern Gariep could owe more to structural emplacement than gradual transgression.

It has been suggested that the Rosh Pinah and Spitzkop Formations are facies equivalents and were deposited during the inception of Gariep rifting (Siegfried and Moore, 1990). They would therefore be correlative or even earlier than the Lekkersing Formation of the Stinkfontein Sequence as these basal sediments in the

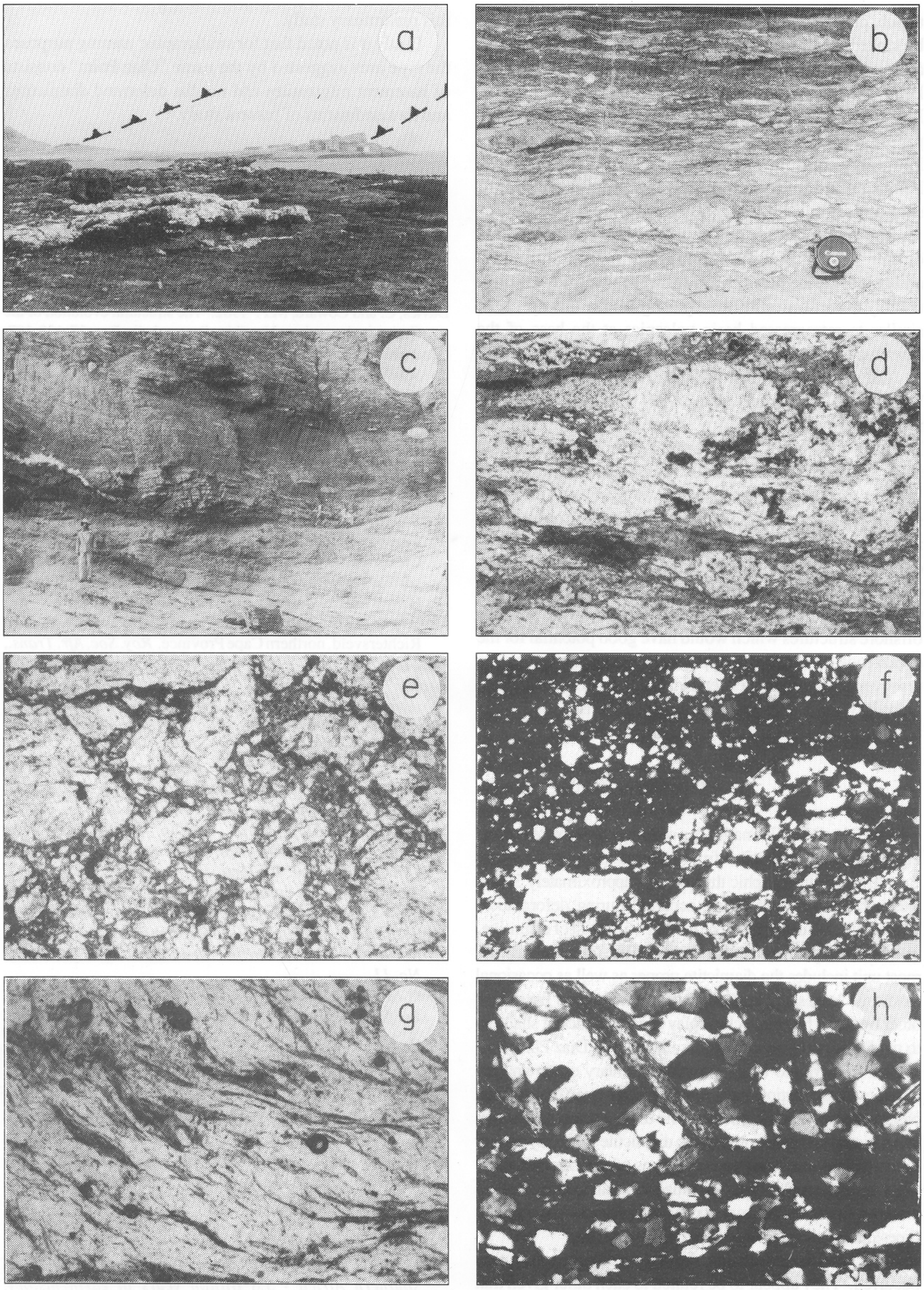


Figure 5: a) View looking north to Halifax Island showing units 1 and 2 and units 2 and 3 separated by thrust faults; b) highly deformed and sheared diamictite of unit 3, Halifax picnic site; c) contact between cobble-rich and more schisty layers in unit 3. Dropstones can be observed along the contact; Halifax picnic site; d) tectonised diamictite showing preferred deformation around feldspar grains as well as deformation of grains themselves; X10; e) crush breccia observed in thrust zone separating units 2 and 3; X10; f) mylonitic vein observed near thrust separating units 1 and 2; X10; g) transpressive sigmoidal cleavage developed during D_1 thrusting event. Characteristic S-shape of chlorite can be seen. Schist from unit 1; X20; h) development of vein quartz with c axes normal to cleavage indicating syndeformational growth; X40

Richtersveld' are far more mature than those of the Rosh Pinah Formation. Furthermore, ashfall tuff units occurring interbedded with these quartzites exhibit trace element geochemistry exceedingly similar to those of the Spitzkop Formation (Siegfried, unpub. data). A Kaigas equivalent would therefore have to be looked for in the Hilda or upper Rosh Pinah Formations and, as has been stated, similar horizons do occur. The Diaz Point Formation may therefore indeed be a part of the Kaigas Formation given that the underlying lithologies are part of the early Gariep or Nosib Groups. The Bogenfels Formation could therefore be correlated with the Hilda Formation and would indicate the start of shallow water, marine shelf deposition.

The abundance of epidote in the lower chloritic schists of unit 1 of the Diaz Point Formation is suggestive of the addition of basic volcanic material. The volcanics are presumably associated with the opening of the Gariep Basin similar to retrogressed basic volcanics at the base of the Spitzkop Formation.

The recent recognition that much of the area assigned as basement (SWA/Namibia map, 1980) consists of highly deformed and metamorphosed metasediments which extend into Diamond Area No. 1, would benefit from an extended field study to identify and correlate the various assemblages.

Furthermore, the recent work of Corbett (1989) has shown that extensive transport of aeolian concentrated diamonds occurred in the past. These "aeolian transport corridors" (ATC's) are the direct result of the erosion along many of the thrust zones identified in this area. Mapping of the Gariep structure would enable interpretation of possible offshore structures which would have good potential for the occurrence of aeolian transported diamonds. The recent discovery of major gravel deposits between Long Island and Atlas Bay along just such a submerged ATC is evidence that these structures are indeed worth further study.

Conclusions

The Diaz Point Formation is a sedimentary mixtite bordering the coastline of Namibia from Lüderitz southwards to Atlas Bay. It has a stratigraphic thickness of approximately 300 m although extensive flattening occurred during deformation. Three units are identified. The lower two consist of extensively weathered quartz-chlorite schists. The structurally uppermost unit includes the diamictite proper as well as occasional sandstone lenses. The three units are separated from each other by thrust faults which display characteristics of shallow- to medium-level (3-5 kb) emplacement. The Diaz Point Formation is proved to be of a metasedimentary origin and the previous interpretation that it represents a horizon of refoliated basement is untenable. Although no direct evidence of glacial deposition could be identified, the diamictite is grossly similar to the Kaigas and Numees Formations of the Gariep Group. Clast composition appears essentially the same as that of the Numees Formation except for the absence of dolomite and limestone lithologies.

Structural data indicate that two deformation events occurred. They appear to be related to each other given that they are the result of continued unidirectional compression from the north-northwest. This is supported by detailed structural studies completed in the Rosh Pinah, Marmora and Richtersveld areas.

Further mapping needs to be completed to fully explain the stratigraphic and structural complexities identified in this preliminary study.

Lastly it is noted that for stratigraphic naming purposes the type area suggested by the name "Diaz Point" consists of basement migmatites and not the deformed diamictites and metasediments of present study.

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