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SOURCE, TRANSPORT AND DEPOSITION OF METALS

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The genesis of BIF in the Transvaal Supergroup, South Africa

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ABSTRACT: Early Proterozoic banded iron-formations were deposited in an intra-cratonic, gradually shallowing basin with mixed sea water - fresh water conditions. Evidence is: a) Erosion and non-deposition near the southern rim of the basin during pre-BIF carbonate deposition. b) Facies and chemical evidence during the carbonate-BIF transition of a shallowing basin with a fluctuating fresh water - sea water realm. c) Endoclastic upper BIF and autochthonous lower BIF have virtually the same composition but endoclastic BIF bear evidence of very shallow water deposition. Therefore the origin of autochthonous BIF below a deeper marine chemocline seems unlikely. d) Contemporary ensialic, possibly rift related volcanism occurred. e) Lateral thickness changes in BIF previously interpreted as of sedimentological origin, are tectonic in nature, allowing for a new environmental model. f) BIF cover strata consist of upward coarsening, fine grained deltaic sequences. A topographically very subdued hinterland was maintained throughout the lifetime of the basin.

1. INTRODUCTION

1.1 *The iron ore deposits*

The Sishen iron ore deposit in the Northern Cape Province, South Africa is one of the few very large high grade occurrences of its kind in the world. It represents a local enrichment of precursors BIF by hydrothermal or supergene processes or both.

1.2 *A shelf slope origin for BIF*

The Kuruman and Griquatown BIF of the Early Proterozoic Ghaap Group in Griqualand West underly an area of 500 x 50km^2. They were recently modelled chemically (Beukes and Klein, 1990; Beukes et al., 1990) as shelf slope deposits below a chemocline in a stratified, marine water column deepening southwards. Fe is thought to have been supplied by hydrothermal exhalative submarine sources and periodic upwelling. This explanation is apparently confirmed by stratigraphic evidence that the two BIF-sequences overlying carbonates, thicken in a southerly direction toward an open sea and away from a stable platform to the north (Figs. 1 and 2). The underlying carbonates on the other hand thin southwards and develop deeper water facies there, e.g. turbidites.

It is important to note that all paleo-environmental research undertaken on these BIF is severely limited by the fact that their E-W maximum outcrop width is only 50km because of thrusting and erosion.

2. AN ALTERNATIVE MODEL

For the upper Ghaap Group an intra-cratonic and shallowing, sheltered basin with mixed sea-water fresh-water conditions is favoured by the following evidence:

1. The Campbellrand Subgroup displays mainly tidally influenced and intertidal facies where exposed south of the Griquatown Fault (Figs. 1 and 2). (Altermann and Herbig in press). The single, graded interbeds that are occasionally found are tempestites, not turbidites. An increased thickness of the carbonates towards the north is attributed to faster accumulation because of a higher rate of submergence matched by carbonate production on a subtidal stromatolitic platform. This means that, while a typical carbonate platform was established in the north, at times non deposition and even erosion reigned closer to the basin margin in the south.
2. Along 500km of N-S exposure the carbonate - BIF transition zone displays rapid internal facies variations in a vertical and lateral sense. This includes shales, black shales, ferruginous mudstones, clean and ferriginous (sideritic-ankeritic) cherts, carbonates and oxidic BIF. The drastic chemical and mechanical changes thus recorded can best be explained by mixing of fresh water and sea water in a shallowing basin becoming

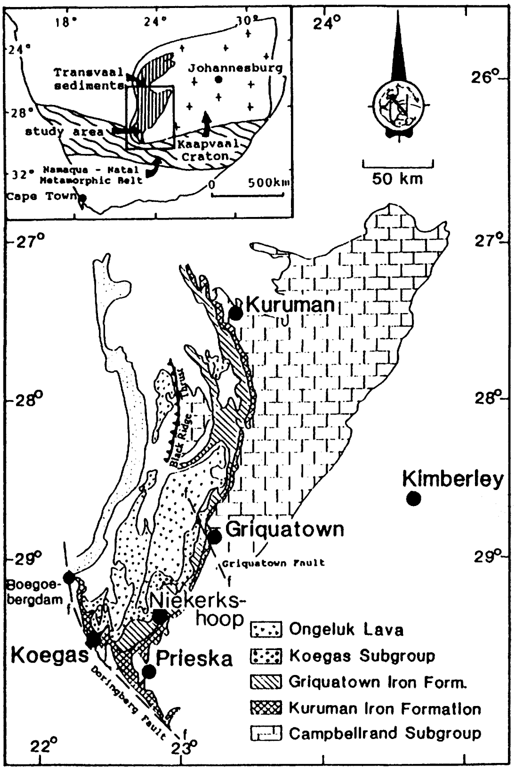

Fig. 1 Major lithostratigraphic units in Griqualand West, South Africa Note: Makganyene glacials between Ongeluk Lava and Koegas Subgroup are too thin to depict separately.

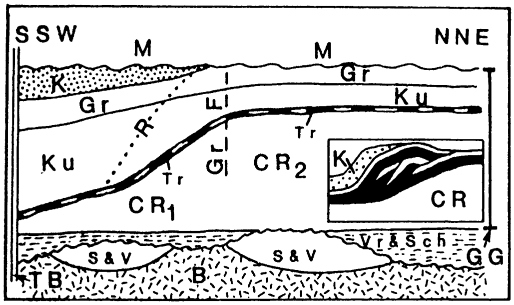

Fig. 2 Schematic stratigraphic profile of the Ghaap Group in central-southern Griqualand West. TB = Doringberg lineament = ±1000 Ma old tectonic boundary of Kaapvaal Craton. The latter consists of basement granite = B (2900 Ma) and metavolcanics of Seekoebaart Formation (age ?), probable equivalent of Ventersdorp Group (2700 Ma) = S + V. Vr + Sch = Vryburg and Schmidtsdrift sandstones, shales, dolomites (2557 ±49 Ma, Jahn et al., 1990) and volcanics. CR1 = Campbellrand Subgroup tidal stromatolite facies (former deep water facies). CR2 = Campbellrand platform facies. Tr = Transition zone between carbonate and BIF. Ku = Kuruman autochthonous BIF (interbedded volcanics = 2432 ±31 Ma, Trendall et al. 1990). Gr = Griquatown endoclastic BIF. K = Koegas Subgroup of fine deltaic clastics. M = Makganyene glacials. GG = Ghaap Group. G r F = Griquatown Fault zone. R = northern boundary of riebeckitization of BIF and K. Inset: Schematic example of southward thickening of two BIF units by thin-skin tectonics. Ku = black, Gr = white. Ongeluk Lava (2230 Ma) unconformably overlies M.

more sheltered and stabilizing with time (Hälbich et al., submitted). Gradually southward increasing volumes of fine clastic load in this zone point to a closer shoreline in that direction with more clastic river input. If it is argued that fine clastic shales are shelf slope deposits, it is neglected that this material would then have to be transported from the north across a carbonate platform. In addition, it must then be assumed that contemporaneous coarse clastics, of which there is no evidence, were deposited in the north. Stable isotope characteristics of S, C and O are also in favour of increasing fresh water input and therefore probably better sheltering of an original marine incursion onto the craton. The ferruginous chert - mudstone sequence intercalated with oxidic BIF in the transition zone north of the Griquatown Fault has a major element chemistry very closely comparable to that of the BIF (Table 1).

It is likely that these mudstones represent a redeposited carbonate regolith supplied by slightly elevated and deeply weathered and eroded parts of the originally very wide carbonate platform. This, and the steady and abundant supply of Fe and Si in solution by sluggishly flowing rivers from a very low-lying hinterland (Reimer, 1987) with extremely mature topography (a condition that could also have applied during the deposition of 1500m thick carbonates previously) abundant acid rain ($HCO3^-$) and elevated temperatures were instrumental in supplying enough solute (Lepp, 1987) for the deposition of thick BIF with a very constant composition in a steadily submerging intra-cratonic basin.

Table 1. Comparative chemistry of BIF and mudstone.

Wt%	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO
BIF	50.20	0.04	0.93	38.08	0.15	1.63	1.98
Mudstone	46.00	0.17	3.56	38.12	1.03	0.87	0.98

Wt%	Na2O	K2O	P2O5	LOI	H2O-	TOT.
BIF	0.11	0.05	0.07	5.85	1.34	100.37
Mudstone	0.10	0.94	0.27	5.76	2.12	100.40

3. The mesoband major- and trace-element chemistry of the lower autochthonous Kuruman BIF and the upper, largely endoclastic Griquatown BIF is virtually the same over the entire thickness and outcrop area (Horstmann and Hälbich, submitted), (Table 2).

Table 2. Comparative mesoband chemistry of Griquatown and Kuruman BIF.

Lith.	Magnetite Chert		Magnetite-carbonate Chert		Riebeckite-carbonate Chert	
Fm.	Griquat.	Kuruman	Griquat.	Kuruman	Griquat.	Kuruman
SiO_2*	48.73	45.49	43.70	46.03	51.57	40.20
TiO_2*	0.06	0.04	0.02	nd	0.05	0.02
Al_2O_3*	0.02	0.39	0.20	0.21	0.27	0.13
Fe_2O_3*	19.58	22.13	29.98	25.90	22.92	19.42
FeO*	22.90	26.61	13.65	18.93	17.73	20.42
MnO*	0.58	0.21	0.58	0.24	0.40	0.35
MgO*	3.48	3.03	3.97	3.57	3.24	2.91
CaO*	2.69	2.08	3.35	2.16	2.17	3.62
Na_2O*	0.87	0.63	0.77	1.16	2.02	1.60
K_2O*	0.99	0.56	0.22	0.25	0.36	0.25
P_2O_5*	0.04	0.28	0.12	0.11	0.07	0.15

*Weight % on volatile free basis.

If the endoclastic Griquatown BIF was redeposited in shallow water (as can be demonstrated from the occasional preservation of mud-cracks other desiccation features and gypsum rosettes (Hälbich et al., submitted) without changing chemically, then there is little reason why autochthonous Kuruman BIF should have originated in relatively deep water below a chemocline with other chemical stability characteristics. The only environmental difference was greater tranquility in the water body (and possibly the atmosphere) during Kuruman BIF-times. This may mean better sheltering and lesser wind-agitation. Water depth in the almost closed or temporarily closed basin was kept very constant right through the year by evenly distributed water influx and evaporation. Proof of very shallow water (mud cracks and fenestral structures) was found near the base of the Kuruman I.F. in the far south.

4. Interlayered tuffs (2500 Ma old) in the upper carbonates, the transition zone and the BIF sequence provide stable trace element evidence for proximal basaltic volcanism during carbonate deposition. This was followed by distal andesitic volcanism (Hälbich and Lamprecht, in preparation) in the transition zone, whereas Horstmann & Hälbich (submitted) find variations from basaltic to dacitic in tuffs from BIF. Any affinity to MORB is totally lacking. The most proximal basaltic tuffs appear farthest south (Altermann, 1991). This is once more an indication of a basin shallowing southwards.

5. Tectonics, ranging from very early soft sediment slumping, to at least two phases of severe north to eastward directed overthrusting have affected these BIF and the overlying Koegas Subgroup (Fig. 2) south of the Griquatown Fault. Regional greenschist grade and locally (in thrust zones) amphibolite grade metamorphism develops in the south. Bedding parallel thrusts have developed as far north as Kuruman (Fig. 1) (Altermann and Hälbich, 1990). The D2 thrust episode is dated at ~2000 Ma. Internal southward thickening of the BIF sequence by thin-skin, ramp-flat tectonics was found. The poorly exposed and therefore inferred Griquatown Fault is here interpreted as a major, northernmost thrust ramp. (Altermann and Hälbich, in press). South of this ramp bedding parallel shear zones in BIF are commonly enriched in riebeckite. Sodium enrichment along southward dipping movement planes is more evidence for an earlier southward shallowing of the waterbody where more sabkha-like conditions may have prevailed over a wide coastal strip for a time span of 10^6 years. Probable evaporite crystal vugs detected in cherts below the Kuruman I.F. near Prieska (Hälbich and Altermann, 1991) substantiate this conclusion. These evaporite contributions were instrumental in preferential triggering of thrusts in the BIF. Evidence of wide spread alkaline playa lake occurrences on the Kaapvaal Craton dates back to Ventersdorp (Seekoebaart times - Figure 2) (Karpeta, 1989).

6. The conformably overlying Koegas Subgroup (Fig. 1) has only developed south of the Griquatown Fault, and displays fine grained, upward coarsening deltaic cycles. Transport directions and sedimentological details have not yet been established. It is also thrust in the far south and marks the closing episode of the shallow water sequence of the Ghaap Group. Finally, this Group was uplifted and eroded on a regional scale before being covered up by the continental Makganyene diamictite. After further erosion the Ongeluk basaltic to andesitic lavas (Schütte and Cornell, 1990) poured out under shallow marine conditions 2230 Ma ago.

3. CONCLUSION

Except for the Campbell carbonates and possibly some of the clastics and thin carbonates of the basal Schmidtsdrift Subgroup, marine conditions need not be invoked to explain the genesis of the Ghaap Group and its iron ore precursors.

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