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THE ORIGIN OF THE NIGERIAN IRON-FORMATIONS ESPECIALLY OF THE SILICATE FACIES

INTRODUCTION

Various models about the origin of iron-formations are known. In most of these models (e. g. Goodwin, 1973; Button, 1982; James, 1992; Klein and Beukes, 1992) the protolith of the iron-formation precipitated as chemical sediment from a relatively open Precambrian ocean. This ocean was stratified consisting of an upper oxic layer which overlies a much larger volume of deep anoxic water in which iron and silica, both originating from a submarine hydrothermal source, are dissolved. Through upwelling or other mixing processes the anoxic water masses were mixed with the more oxygenated shallower water with the result that iron precipitated in the form of iron hydroxides and/or oxides, carbonates and sulphides. The nature of iron precipitates formed in aqueous media is governed in large part by the pH and Eh-conditions of the depositional environment. Therefore in all the models distinct precipitation products are distinctly distributed within the marine basins. This lead James (1954 and 1992) to classify iron-formations according to their mineralogical associations which are known as the so-called facies. Four major facies are known. These are the oxide, silicate, carbonate and sulphide facies. The oxide facies is subdivided into the magnetite and hematite subfacies. Within the marine basins of the various models, three of the four facies, namely the oxide, carbonate and sulphide facies have a defined position whereas the silicate facies is not considered within these models.

In this paper, the attempt will be undertaken to close this gap. As an example, the Nigerian iron-formations are considered, where the oxide (magnetite and hematite subfacies; the latter is not considered in this paper) as well as the silicate facies are developed in nearly the same proportions. The development of the Nigerian Algoma-type iron-formations which, in comparison to many other iron-formations of the world, are relatively rich in Mn and Al, will be briefly presented according to Mücke and Annor (1993), Mücke et al. (1996) and Annor et al. (1997). In the basement complex, the latter being an ancient shield reworked in the Pan-African, various schist belts occur (Malumfashi, Maru, Birnin Gwari, Kushaka, and Egbe-Isanlu), composed of metasediments including the meta-protoliths of the iron-formations and metavolcanics. Within various schist belts, mainly located in northern Nigeria, the iron-formations occur as one or a few closely spaced and relatively thin (30 cm to 20 m thick

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and usually less than 7 km long) tabular sheets. The iron-formations are concordantly interbanded with metasedimentary phyllites (= host rocks of the iron-formations) with which they share common metamorphic and deformational imprints. The alternated banding of iron-formation and phyllite is considered to be the result of material from two sources to the marine basin(s) of Nigeria during Birimian time. Sediments of continental origin and of pelitic to psammitic composition were slowly, but continuously deposited, while hydrothermal solutions of volcanic-exhalative origin were discontinuously, but rapidly supplied and deposited as a mudstone-like chemical precipitate. During regional metamorphism (probably of Eburnian age), the continentally derived material was transformed into phyllite and the sediments which precipitated from hydrothermal solutions into the mineral assemblages of the iron-formation. The alternating distribution of layers of iron-formation within the phyllites is the result of the intermittent deep sea hydrothermal activity.

WHOLE-ROCK COMPOSITION

Comparison of the chemical composition of the iron-formations with that of the associated phyllitic host rock clearly reveals that the iron-formations have relatively high Mn, Fe, Ca and low alkalis (Na and K), Al and Si concentrations, whereas the phyllite reveals just an opposite element concentration. Using these characteristic element oxides in the form of the $(Al_2O_3 + Na_2O + K_2O)/(FeO_{tot} + MnO)$ -diagram (Fig. 1) it becomes obvious that the analytical points of the phyllites are distinctly distributed and clearly separated from those of the iron-formations with the analytical points of

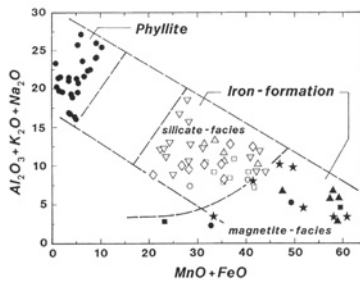


Fig. 1: $(Al_2O_3 + Na_2O + K_2O)/(FeO_{tot} + MnO)$ - diagram and the analytical points of the phyllites, the magnetite and silicate facies.

the silicate facies lying between those of the magnetite facies and the phyllites. Similar to Fig. 1, the Al_2O_3/SiO_2 -diagram of Fig. 2 shows that the analytical points of the silicate facies have the same position lying between the phyllites and the magnetite facies. The phyllites show continuous compositions between clayey-pelitic pronounced (on the left side) and sandy-psammitic pronounced material (on the right side). Having slightly to moderately reduced Al_2O_3 and SiO_2 contents, the silicate facies shows a similar compositional range. Due to their high Fe-content, the analytical points of the magnetite facies lie predominantly in a small field between in maximum about 10 wt% Al_2O_3 and 40 wt% SiO_2 .

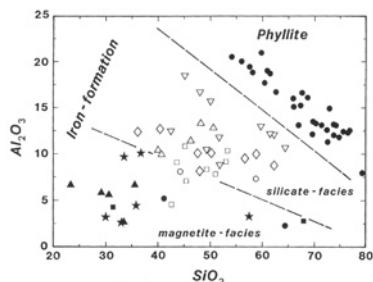


Fig. 2: The $\text{Al}_2\text{O}_3/\text{SiO}_2$ -diagram and the analytical points of the phyllites, the magnetite and silicate facies.

MINERALOGICAL COMPOSITION

The mineralogical composition of the three rock types are (in brackets: variation of the minerals) as follows. **Phyllite**: muscovite, rarely biotite and strongly varying proportions of quartz (30 to 60 vol%); **magnetite facies**: magnetite $\text{Fe}^{2+}\text{Fe}^{3+}_2\text{O}_4$ (10 to 55 vol%), quartz (20 to 50 vol %), almandine-spessartine garnet $(\text{Mn,Fe})_3\text{Al}_2[\text{SiO}_4]_3$ (10 to 40 vol%), Mn-bearing grunerite-cummingtonite $(\text{Fe, Mg, Mn})_7[(\text{OH})_2/(\text{Si, Al})_8\text{O}_{22}]$ (0.0 to 20 vol%); and **silicate facies**: grunerite-cummingtonite (10 to 80 vol%), almandine-spessartine (20 to 60 vol%), quartz (5 to 40 vol%), and Mn-bearing ilmenite $(\text{Mn,Fe})\text{TiO}_3$ (1 to 5 vol%).

Deduced from whole rock compositions the $\text{FeO} : \text{Fe}_2\text{O}_3$ -ratio varies within the magnetite facies from 0.17 to 0.52 (on average of 14 analyses: 0.33), the silicate facies from 4.2 to 10.5 (on average of 28 analyses: 6.4) and the phyllite from 1.1 to 6.5 (on average of 12 analyses: 3.8).

DISCUSSION

The phyllites represent continental-derived material which was laid down in the marine basins of Nigeria during phases of strongly reduced or even absent volcanic activity, whereas the protolith of the magnetite facies was formed during phases of high volcanic activity. Both the $\text{Al}_2\text{O}_3 + \text{Na}_2\text{O} + \text{K}_2\text{O} / \text{FeO} + \text{MnO}$ and the $\text{Al}_2\text{O}_3/\text{SiO}_2$ -diagrams show that the position of the silicate facies lies between the composition of materials of the two sources mentioned above. Therefore the protolith of the silicate facies consists of mixtures of Al-bearing continental-derived material and material which precipitated from volcanic exhalations which, in contrast to other iron-formations, are relatively rich in manganese. The abundance of garnet and amphibole in the silicate facies resulted from the Al_2O_3 -content of the admixed continental-derived material. Therefore it can also be inferred, based on the relationships presented in Fig. 2, that the SiO_2 -content of the Nigerian iron-formations is not necessarily only of exhalative origin, but may be substantially continentally derived.

The two facies cannot only be differentiated by differently composed sedimentary protoliths, but also by their differing $\text{FeO}:\text{Fe}_2\text{O}_3$ -ratios established within their mineralogical equivalents after metamorphism. This implies that the metamorphic

formation of the magnetite and the silicate facies depended not only on temperature and pressure (according to greenschist facies conditions), but also on the existing redox conditions. The silicate facies (as well as the host rock) represents conditions of low oxygen fugacity where minerals predominantly containing divalent iron were formed. Under more oxidizing conditions magnetite was formed. The differing redox conditions of the two facies is inferred to be the result of whether the protoliths are in interaction with carbon supply (probably mainly from benthic organism) or not. According to Klein and Beukes (1992) the organic carbon supply to the marine basin is much higher during the regressive than in the transgressive stage. This implies that the occurrence of the two facies is the result of changes from regression to transgression or vice versa. In the regressional stage or close to it, the protolith of the silicate facies was laid down together with a substantial amount of organic material.

REFERENCES

- ANNOR, A., OLOBANIYI, S.B. and MÜCKE, A., 1997: Silicate facies iron-formation of the Egbe-Isanlu Palaeoproterozoic schist belt, southwest Nigeria. *Jl. Afr. Earth Sciences* 24: 39-50.
- BUTTON, A. et al., 1982: Sedimentary iron deposits, evaporites, and phosphorites. State of the art report. In: HOLLAND, A. D. and SCHIDLOWSKI, M. (eds.) *Mineral deposits and the evolution of the biosphere*. Springer, Berlin: pp 259-273.
- GOODWIN, A. M., 1973: Archean iron-formations and tectonic basins of the Canadian shield. *Econ. Geol.* 68: 915-933.
- JAMES, H. L., 1954: Sedimentary facies of iron-formations. *Econ Geol* 49: 235-93.
- JAMES, H. L., 1992: Precambrian iron-formations: nature, origin, and mineralogic evolution from sedimentation to metamorphism. In: WOLF, K. H. and CHILINGARIAN, C. V. (eds.) *Development in Sedimentology* 47: pp 543-589.
- KLEIN, C. and BEUKES, N. J., 1993: Proterozoic iron-formations. In: CONDIE, K. C. (ed.) *Proterozoic crustal evolution. Developments in Precambrian geology*, Vol. 10. Elsevier, Amsterdam-Oxford-New York: pp 383-418.
- MÜCKE, A. and ANNOR, A., 1993: Examples and genetic significance of the formation of iron oxides in the Nigerian banded iron-formations. *Mineralium deposita* 28: 136-145.
- MÜCKE, A., ANNOR, A. and NEUMANN, U., 1996: The Algoma-type iron-formations of Nigerian metavolcano-sedimentary schist belts. *Mineralium Deposita* 31: 113-122.