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ON THE ORIGIN OF FELDSPATHIC MUDROCKS ASSOCIATED WITH QUARTZ ARENITES[3]

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ABSTRACT

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Two lithostratigraphic units in southeastern Nigeria, the Maastrichtian Ajali and the Eocene Nanka Formations, described as quartz arenites, have been found to contain significant amounts of feldspars in their intercalated mudrocks. If intense chemical weathering prior to transport could eliminate feldspars from the source rocks of these formations, it ought to have been reflected equally in both the sandstones and the mudrocks. Diagenetic elimination (intrastratal solution) may be discounted in these cases on the grounds of lack of petrographic evidence as well as its demonstrable ineffectiveness in the older (Turonian) Makurdi Formation of the same area whose sandstones and mudstones both are dominantly feldspathic or arkosic.

It is therefore suggested that feldspars, which are characteristically mechanically unstable, become progressively comminuted along cleavage and twin composition planes, and bypass the coarser bedload during transport. The result is the impoverishment of bedload in feldspar and simultaneous enrichment of suspension load. The impervious nature of mudrocks protects the feldspars from intrastratal solution. The result is a feldspathic mudrock in a feldspar-poor sandstone. Comminution and sorting together are therefore considered effective processes that are capable of producing quartz arenites in a sedimentary system.

INTRODUCTION

Quartz arenite is defined as a mineralogically and texturally mature sandstone in which quartz forms 95 or more percent of the framework fraction and the interstitial matrix constitutes less than 10 or 15 percent of the volume (WILLIAMS ET AL., 1954, p. 292; PETTIJOHN, 1975, p. 212). The definition also includes, by amplification, the fact that quartz should be largely monocrystalline and well-rounded, sorting of grains should by good so that the sands are texturally and mineralogically supermature. These rocks are thought to be the endproduct of long and intense weathering, abrasion and sorting in a tectonically stable region, or the products of several cycles of sedimentation. The lack of quartz arenites in modern depositional environments led to speculative discussions on the origin of ancient quartz arenites (PETTIJOHN, 1975, p. 235). The crux of the problem is to explain satisfactorily the processes by which feldspar and other labile particles are eliminated to give the sand population its essential attribute of mineralogical maturity.

The elimination of feldspars can take place at one or more of several stages during the formation of a quartz arenite. Chemical weathering and lateritic decomposition of granitic source rocks have been suggested as capable of eliminating almost all feldspars and labile components in a weathering profile (PETTIJOHN ET AL., 1973, p. 227; BLATT, 1967). Direct derivation of feldspar-poor detritus would be enhanced by prolonged tectonic stability (FOLK, 1980, p. 139) and high rainfall (over 200 cm precipitation per year). Tectonism and climate have been emphasized as the major controlling factors in the availability of feldspars for entrainment in a sedimentary system by KRYNINE (1935), STRAKHOV (1967, p. 4), PETTIJOHN (1975, p. 186), SUTTNER (1974), YOUNG ET AL. (1975) and BASU (1976).

Sediment transport is another stage during which feldspars can be lost. In low gradient streams, feldspars may not decrease appreciably, but in high gradient streams, destruction of feldspars and other labile components is enhanced (POLLACK, 1961; HAYES, 1962; BREYER & BART, 1978; BLATT ET

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AL., 1980, p. 297). The relative increase of feldspars in the finer size grades of a sandstone has been demonstrated by ODOM ET AL. (1976) and is attributed to abrasion and sorting. Oscillatory movement in high-energy shallow-marine environments has the effect of increasing transport before burial and promoting mineralogical maturity (FOLK, 1960; SWETT ET AL., 1971).

Feldspars can also be removed during diagenesis. Intrastratal solution can be very effective in modifying the composition of sandstone (BRAMLETTE, 1941; PETTIJOHN, 1975, p. 495; HOWER ET AL., 1976; MORTON, 1979). HEALD & LARESE (1973) have concluded that post-depositional solution of feldspar is an important process in porosity development in some formations that may reduce the amount of feldspar considerably and change the proportion of feldspar types significantly.

In a study of the proportion of feldspars, quartz and chert in modern fluvial interbedded muds and sands (mud-sand pairs), CHARLES & BLATT (1978) observed that the ratio F/(Q+C+F) in a mud is higher than in the associated sand; but in a single size fraction (4-4.5 phi) common to both the mud and the sand, the ratio is the same in a mud-sand pair, reflecting the composition at the time of deposition. They argued that if the above ratios in the common size fraction of ancient mud and sand beds differ, it is because feldspar has been removed by diagenetic processes.

In a petrographic survey of several Cretaceous sandstones of southeastern Nigeria, HOQUE (1976, 1977) has shown that all the post-Santonian sandstones are quartz arenites (feldspars less than five percent). Two of these sandstone formations have been studied in some detail. The sandstones of the Maastrichtian Ajali Formation and the Eocene Nanka Formation have been found to be mineralogically supermature and texturally submature quartz arenites (HOQUE & EZEPUE, 1977; NWAJIDE, 1980). The mudrocks within these formations were not examined by earlier workers for their feldspar content. An investigation using the pyrosulphate fusion technique has now shown that the associated mudrocks in the Ajali and the Nanka Formations contain significant amounts of feldspar. This report therefore seeks to explain how sandstone bodies, sufficiently devoid of feldspars to be classified as quartz arenites, acquired and retained considerable amounts of feldspars in their mudrock intercalations.

EXPERIMENTAL PROCEDURE

The aim of this aspect of the investigation is to isolate for further study, a representative portion of any feldspar present in a given mudrock sample. The mudrock specimens were obtained by sampling mudrock beds or intercalations such as flasers and drapes within a sandstone bed. Two samples each were taken from different locations within the Makurdi, the Ajali and the Nanka Formations (Fig. 1). Each sample was

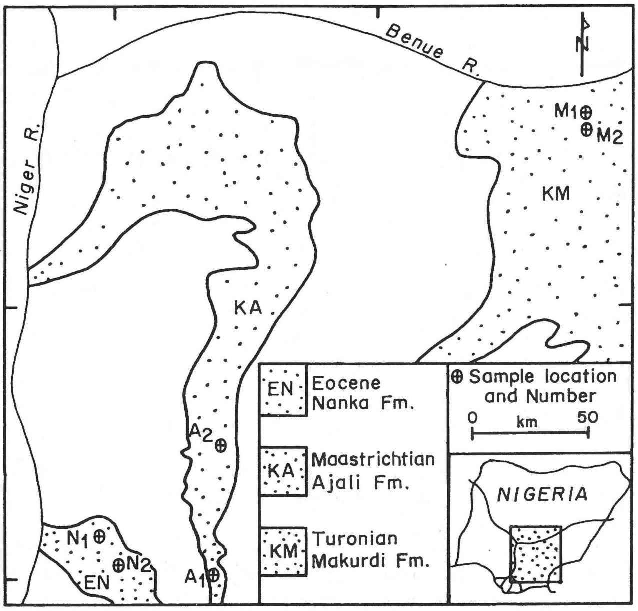

Fig. 1
Generalised geological map showing sampling locations and the formations under study.

then treated following a slightly modified version of the pyrosulphate fusion technique outlined by CHARLES (1977, p. 70-71). The basic role of the pyrosulphate fusion technique is that it completely eliminates the phyllosilicates, i.e., the clay minerals, by dissolution. (BLATT ET AL., 1982).

To isolate quartz and feldspars from a given mudrock the sample was oven-dried at 100°C for about four hours, disaggregated, and a two-gram portion weighed in a platinum dish. Twenty grams of sodium bisulphate ($NaHSO_4$) were added to the sample in the platinum dish. A few drops of water were used to wet the sample. The dish was gently heated on a Bunsen burner until frothing ceased. The heat was then increased and applied for about 15 minutes. The dish and contents were transferred to a 600 ml beaker containing 300 ml of 0.10 N HCl. The beaker was placed on a hot plate and as soon as the fusion cake was dissolved, the dish was freed and rinsed with 1.0 N HCl. On complete dissolution, the whole mass was filtered and the residue rinsed with 1.0 N NaOH. The residue and filter paper were then transferred to another 600 ml beaker containing 400 ml 0.50 N NaOH and heated to boiling for 20 minutes. The mass was again filtered and washed alternately with 1.0 N NaOH and 1.0 N HC1 and finally, several times with distilled water. The residue and the filter paper were dried partially in an oven at 100°C for about an hour and then transferred to a platinum dish. The dish was then placed in a Gallenkamp muffle furnace set at 800°C. After two hours the filter paper had been burnt off completely. The dish and the contents were weighed to facilitate an assessment of recovery (Table I).

A thin section of the residue was then prepared by mounting the grains in Lakeside thermoplastic cement. Two

Table I.
Quartz and feldspar recovery in pyrosulphate solution.

Samples	Exact sample weight used (gm)	Weight of Sodium bisulphate used (gm)	Weight of Quartz + Feldspar recovered (gm)	% recovery
N1	2.02	20.08	0.76	37.62
N2	1.99	20.04	0.30	15.07
A1	2.05	21.41	0.56	27.32
A2	2.01	20.15	0.62	30.85
M1	2.02	20.07	0.75	37.13
M2	2.08	20.69	1.37	65.87

slides were prepared from each of the six mudrock samples thus fused. Each slide was studied using a Leitz Orthoplan petrographic microscope fitted with a Swift point counter. Point counting was done by the line method (GALEHOUSE, 1971). No counting limit was set, but as GALEHOUSE recommends, over 300 grains were counted in each case, the actual number depending on the area of the mount.

A number of shortcomings attend this technique, the most serious of them being that the fusion process attacks feldspar especially the very small and partially weathered grains. CHARLES (1977, p. 80) used correction factors to make up for such a loss, but since this investigation principally seeks to demonstrate the presence/absence characteristics of feldspars in the mudrocks vis-a-vis the arenaceous aspect associated with them, it suffices to observe that the recoveries are significant (Tables I and II). However, the recoveries should be regarded as the minimum possible, assuming that the fusion process has somewhat detracted from the maximum obtainable. The effect on quartz is mainly on cristobalite, which is completely destroyed. The present investigation does not however have much concern for quartz.

RESULTS

Table I shows that each sample yielded a significant amount of quartz plus feldspar. Table II shows feldspar ratios (expressed as a percentage of quartz plus feldspars) in different mud and sands samples of the three formations. The mudrock intercalations of the Nanka and the Ajali Formations have significant amounts of feldspars whereas the sandstone samples are almost completely devoid of feldspars. Both the mudrock and the sandstone samples of the Makurdi Formation are richly feldspathic; one of the samples (M2) shows the feldspar content to be almost equal in the mudrock and the sandstone of the pair.

Table II also shows that K-feldspar occurs more frequently than plagioclase in four of the six samples. The calcium bearing plagioclases are more susceptible to hydrolysis than pure albite or K-feldspar (BLATT, 1967). The larger plagioclase content in the other two samples is anomalous; earlier workers also found it to be quite puzzling (FIELD & PILKEY, 1969). They may have lost K-feldspars during the bisulphate fusion process. The more plausible explanation, however, is

Table II
Point count results.

Samples	Point Count Data in Mudrock					$\frac{100\,F}{Q+F}$ %	Size (mm) of feldspars in mudrocks	
	Q	K-F	Pl.	Total	$\frac{F}{Q+F} \times 100$	in associated Ss.	Range	Mean
N1	392	58	12	464	15.09	0.00	0.018-0.37	0.027 silt
N2	359	2	11	372	4.00	0.00	0.039-0.65	0.049 silt
A1	537	88	11	636	15.57	0.00	0.108-0.249	0.109 sand
A2	318	70	46	434	26.73	0.00	0.038-0.063	0.041 silt
M1	646	6	56	708	8.76	23.90	0.047-0.071	0.061 silt
M2	811	158	56	1025	20.88	19.93	0.038-0.139	0.052 silt

Key: Q = Quartz; K-F = Potassic Feldspars; Pl = Plagioclase; F = Total Feldspars.

given by BUCKE & MANKIN (1971) who suggested that any illite present in the mudrocks could act as an acceptor for K^+ as it is released from feldspars, thereby facilitating decomposition. Any Na^+ and Ca^{2+} equally released from plagioclases would soon saturate the interstitial waters and inhibit further alteration of the plagioclase.

The sizes of at least 30 feldspar grains were measured using the occular micrometer and logged with the point counter. The ranges and mean sizes, shown in the last two columns of Table II, may indicate that the feldspar grains are concentrated mostly in the coarse silt fractions of the mudrocks. Perhaps the fusion process has eliminated much of the medium and fine silt-size grains and thereby biased the recoveries for coarse silt grains.

DISCUSSION

The problem is to satisfactorily account for the significantly high content of feldspars within the mudrock portions of the quartz arenites. A rider, and perhaps a broader problem is the question of the origin of quartz arenites. The mode of origin of texturally immature but mineralogically supermature sandstones, such as the Ajali and the Nanka, does not appear to be readily available within the corpus of sedimentological literature. The Ajali Sandstone is characterised by its high (15-20%) polycrystalline quartz content, poor to moderate sorting, and subangular to subrounded nature of the grains (HOQUE & EZEPUE, 1977). Similarly, the Nanka Sand is composed of subrounded and moderately well sorted grains, most of them (65%) polycrystalline quartz (NWAJIDE, 1980). HOQUE (1976, 1977) has suggested that a high content of polycrystalline quartz is indicative of textural immaturity. Both formations have very little or no chemical cement and possess less than 5% matrix. Table III shows a comparison of the petrographic parameters of the three formations with the properties a typical quartz arenite should possess as described by PETTIJOHN ET AL. (1973, p. 214-216). The question then is, at what stage in the history of the Nanka and the Ajali Formations did the elimination of the feldspar take place: before derivation, during transport, or after deposition? The mineralogical supermaturity of the Ajali Formation is attributed to profound chemical weathering of the granitic source rocks of the Cameroun Highlands in a very humid climatic environment, very similar to the present day conditions (HOQUE & EZEPUE, 1977). Such a direct derivation must definitely have benefited from sufficiently prolonged tectonic stability. If, however, the feldspars were more or less completely removed during the weathering prior to transport, it would be reasonable to expect that such would be reflected in the entire product, mudrocks as well as sandstones; i.e., no feldspar should be expected even in the mudrocks. It therefore appears to be reasonable to accept that the presence of feldspars in the mudrocks reflects the situation in the entire detritus after derivation. Complete elimination at the source is therefore ruled out.

There is also no petrographic evidence for intrastratal solution within the formations under study, a mechanism

Table III.
Comparison of petrographic parameters of sandstones of the Nanka, the Ajali, and the Makurdi Formations with those characteristic of an ideal quartz arenite.

Units	Mineralogy	Polycrystalline quartz in percent	Texture	Chemical cement/ matrix	References
Ideal quartz arenite	Quartz 95%; few heavies	Usually low to nil	High roundness; usually v. good sorting	Silica or carbonate cement; usually v. low matrix	Pettijohn et al., 1973 p. 214-216.
Nanka sandstone	Quartz 95%; few heavies	About 65%	Subrounded; moderately sorted	No cement; matrix less than 5%	Nwajide, 1980
Ajali sandstone	Quartz 95%; few rock fragments	About 20%	Subangular to subrounded; poor to moderate sorting	No cement; matrix less than 4%	Hoque & Ezepue, 1977.
Makurdi sandstone	Quartz 68%, Feldspar 11%	About 6%	Subrounded; poorly sorted	Low cement; matrix about 20%	Nwajide 1982.

reported to be very effective in modifying the composition of sandstones. BLATT ET AL. (1980, p. 296), however, feel convinced that feldspar alteration by groundwaters during diagenesis is of minor importance. The Turonian Makurdi sandstone, which is older than both the Ajali and the Nanka and which has since Turonian time been subjected to groundwater circulation, retains a considerable amount of feldspars in its sandstone-mudrock pairs (Table II). It appears that intrastratal or diagenetic processes were not effective enough in removing the labile particles from this formation.

The most likely mechanism of feldspar reduction or removal from the coarse fraction of the detritus therefore lies in the transportation process. The task now is firstly to show that, in addition to processes already suggested by other workers, transportation can also produce quartz arenites, and secondly to satisfactorily explain the presence of feldspars in the mudrocks and their absence in the coarse fraction of the Ajali and the Nanka Formations.

EFFECT OF TRANSPORT ON FELDSPARS

In granitic rocks feldspars are generally more abundant than quartz; in sandstones, the reverse is the case. This is conclusive evidence for the loss of feldspars during the process of formation of a sedimentary rock from a crystalline source rock.

The depositional environment of the Ajali Formation has been suggested to be fluvial (HOQUE & EZEPUE, 1977) though BANERJEE (1979) has observed some indicators of tidal sedimentation. The Nanka Sand was deposited in a tidal environment (NWAJIDE, 1980), which normally prolongs transport before burial without increasing the distance from source. During transport the mechanical disintegration of grains is perhaps the most important textural change suffered by labile grains. Feldspars are generally more susceptible to chemical and mechanical weathering than quartz. The three good cleavages, the tendency to hydrolysis, and the frequent twinning all reduce the mechanical durability. Breakage is particularly facilitated along twin composition planes which are zones of weakness (BERRY & MASON, 1959, p. 133). PITTMAN (1969) found that Carlsbad twins, which are composed of only two subindividuals, tend to disappear in only 30-40 km of transport. This observation agrees with the documented rarity of Carlsbad twins in sandstones (BLATT ET AL., 1980, p. 297). Also POLLACK (1961) observed a small but significant downstream increase in the Q/F ratio in a river sand of large size grades (0.250 mm and 0.50 mm), and attributed the reduction of feldspars to breakage of large grains, which caused an 'artificial influx' of feldspars in smaller size grades (0.062 mm and 0.125 mm). BREYER & BART (1978) have noted that mechanical abrasion of coarse material would give rise to silt, not sand. However, decrease of feldspars as a function of distance of transport is not as significant as one would have imagined, even over distances of up to 1500 km, though it appears that most studies leading to this conclusion have been done on low gradient streams (POLLACK, 1961; HAYES, 1962; BREYER & BART, 1978; BLATT ET AL., 1980, p. 297). KOLDEWIJN (1955) and MACK (1978, figs. 3 and 4) have suggested that transport by itself would not destroy labile components, rather grain-to-grain collisions, especially in littoral marine conditions, can achieve such size reduction. The general tendency for feldspars, especially plagioclase, is to increase in relative abundance in the finer grain size of sandstones (HAYES, 1962; HUNTER, 1967; FIELD & PILKEY, 1969; MANN & CAVAROC 1973; YOUNG ET AL., 1975). The tendency has been observed even in non-transported gruss (MCEWEN ET AL., 1959). It has been pointed out that feldspars tend to be reduced in size by abrasion rather than be destroyed (ODOM, 1975; ODOM ET AL., 1976). Sorting then concentrates them in the smaller size fractions. The efficiency of comminution in size reduction of mono- and polycrystalline quartz grains in a variety of environments has been demonstrated by many workers (ROGERS ET AL., 1963; SCHUBERT, 1964; SMALLEY, 1966; SMALLEY & VITA-FINZI, 1968; KUENEN, 1969; VITA-FINZI & SMALLEY, 1970; HOQUE, 1976, 1977).

Comminution therefore appears to be significant process in size reduction of clastic particles. The process is more effective for feldspars because of their susceptibility to hydrolysis, frequent twinning, and good cleavage directions. Comminution may also be considered an intermediate stage in feldspar weathering, since the fine products possess very high surface area/volume ratio which confers high surface free energy and thus helps to destabilise them relative to the bulk material (HOLDEN & BERNER, 1979).

As the smaller size grades are produced during transport, whether in a stream channel or in a restricted environment with oscillatory circulation such as in a tidal area, the effect is an increase in the volume of mud load. Through bypassing (DUNBAR & RODGERS, 1957, p. 9), such newly produced feldspar grains become increasingly concentrated mostly in the suspension load which ultimately is deposited as a major mudrock bed or as an intercalation, depending on the energy conditions. It would then appear that the relative concentration of feldspars in mudrocks is a function of comminution which plays the dual role of simultaneously depleting the feldspar content of the bedload (essentially the sand size) and enhancing its concentration in a suspension load (Fig. 2). Thus the removal of feldspars by abrasion and comminution appears to be an important process in the origin of mineralogical maturity of many sandstones.

There are other ways by which feldspar can be eliminated from the sand size fraction once it is deposited. Kaolinisation of feldspars during diagenesis is one of such processes (MACK, 1978). The feldspars cannot easily be flushed out of a mudrock once deposited. The impermeability of mudrocks practically eliminates groundwater circulation; chemical decay of kaolinisation is slowed down in such protected niches. The

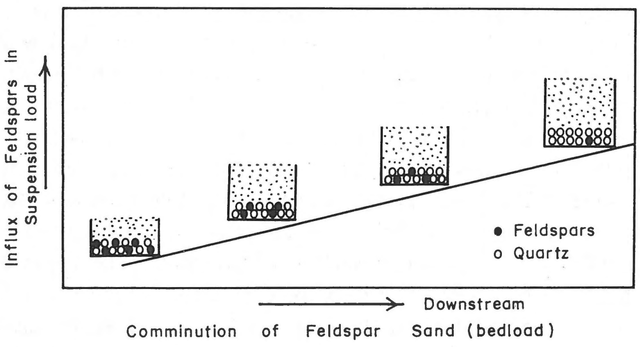

Fig. 2
A schematic representation of comminution of feldspar grains and their progressive downstream concentration in suspension load; the result is feldspar-poor bedload and feldspar-rich suspension load.

situation therefore favours feldspar preservation within the mudrock enclaves, even when such grains in the sand size fraction have been eliminated. Fig. 3 schematically summarises the modes of origin of quartz arenites through comminution and bypassing.

CONCLUSION

The problem has been to account for the significant presence of feldspars in mudrock intercalations within sand bodies classified as quartz arenites. The Maastrichtian Ajali and the Eocene Nanka Formations of southeastern Nigeria have been identified as quartz arenites by earlier workers, but their mudrock facies show a considerable amount of feldspars (high F/(Q+F) ratio). It can not be argued that an intense chemical weathering of such rocks depleted the entire feldspar population before the detritus were entrained. Had it been the case, the mudrock intercalations would also have been devoid of any feldspar.

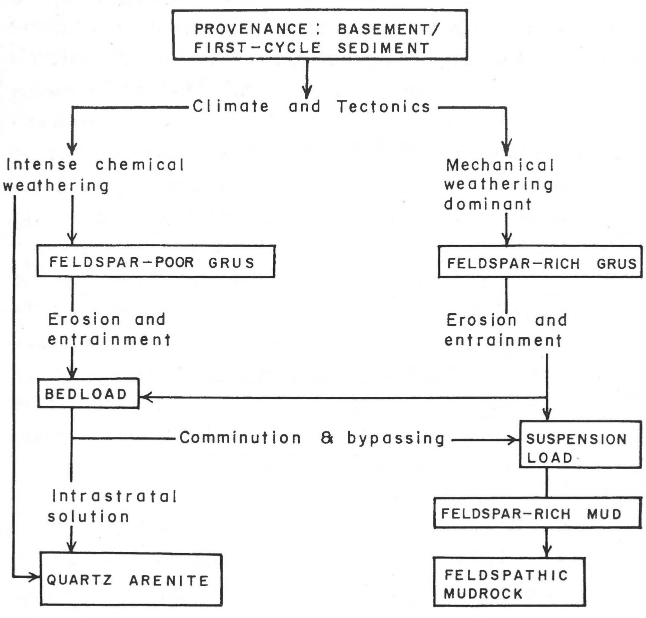

Fig. 3
Process-product model depicting the origin of feldspathic mudrock enclaves in quartz arenites.

An examination of an older sandstone body, the feldspathic Turonian Makurdi Sandstone of the same area showed the F/(Q+F) ratio to be significantly high both in the mudrock and the sandstone of a mud-sand pair, or to be higher in the latter. This may suggest that the intrastratal solution has played no significant role in the case of the Ajali and the Nanka quartz arenites.

Comminution of large feldspar grains is therefore suggested to be an effective process in concentrating feldspars in mudrocks. It would simultaneously impoverish the sand-size bedload and enrich the mud-size suspension load in feldspar content. Once deposited, the impervious nature of the mudrock would protect the feldspar from any effects of intrastratal solution.

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REFERENCES

Banerjee, I. 1979 Analysis of cross-bedded sequences: an example from the Ajali Sandstone (Maastrichtian) of Nigeria – Quart. J. Geol. Mining & Metal. Soc. India 51: 69-81.

Basu, A. 1976 Petrology of Holocene fluvial sand derived from plutonic rocks: implications to paleoclimatic interpretation. J. Sediment. Petrol. 46: 694-709.

Berry, L. G. & B. Mason 1959 Mineralogy, concepts, descriptions, determinations – W. H. Freeman & Co. (San Francisco): 630pp.

Blatt, H. 1967 Provenance determinations and recycling of sediments – J. Sediment. Petrol. 37: 1032-1044.

Blatt, H., R.L. Jones & R.G. Charles 1982 Separation of quartz and feldspars form mudrocks – J. Sediment. Petrol. 52: 660-662.

Blatt, H., G. Middleton & R. Murray 1980 Origin of sedimentary rocks, 2nd Ed. – Prentice-Hall (New Jersey): 782pp.

Bramlette, M. N. 1941 The stability of heavy minerals in sandstone – J. Sediment. Petrol. 11: 32-36.

Breyer, J. A. & H. A. Bart 1978 The composition of fluvial sands in a temperate semiarid region – J. Sediment. Petrol. 48: 1311-1320.

Bucke, D. P. & C. J. Mankin 1971 Clay-mineral diagenesis within interlaminated shales and sandstones – J. Sediment. Petrol. 41: 971-981.

Charles, R. G. 1977 The petrology of the solid silica plus feldspar fraction of recent interbedded muds and sands – Unpbl. M. Sc. thesis, Univ. of Oklahoma: 117pp.

Charles, R. G. & H. Blatt 1978 Quartz, chert, and feldspars in modern fluvial muds and sands – J. Sediment. Petrol. 48: 427-432.

Dunbar, C. O. & J. Rodgers 1957 Principles of stratigraphy – Wiley International (New York): 356pp.

Field, M. E. & O. H. Pilkey 1969 Feldspar in Atlantic Continental margin sands of the southeastern United States – Geol. Soc. Am. Bull. 80: 2097-2102.

Folk, R. L. 1960 Petrography and origin of the Tuscarora, Rose Hill and Keefer Formations, Lower and Middle Silurian, of eastern West Virginia – J. Sediment. Petrol. 30: 1-58.

—— 1980 Petrology of sedimentary rocks – Hemphill Publ. Co. (Austin): 182pp.

Galehouse, J. S. 1971 Point counting. *In:* Carver, R. E. (ed.): Procedures in sedimentary petrology – Wiley Interscience (New York): 385-407.

Hayes, J. R. 1962 Quartz and feldspar content in South Platte, Platte and Missouri River sands – J. Sediment. Petrol. 32: 793-800.

Heald, M. T. & R. E. Larese 1973 The significance of the solution of feldspar in porosity development – J. Sediment Petrol 43: 458-460.

Holden, Jr., G. R. & R. A. Berner 1979 Mechanism of feldspar weathering – I: experimental studies – Geochim. Cosmochim. Acta 43: 1161-1171.

Hoque, M. 1976 Significance of textural and petrographic attributes of several Cretaceous sandstones, southern Nigeria – J. Geol. Soc. India 17: 514-521.

—— 1977 Petrographic differentiation of tectonically controlled Cretaceous sedimentary cycles, southeastern Nigeria – Sediment. Geol. 17: 235-245.

Hoque, M. & M. C. Ezepue 1977 Petrology and paleogeography of the Ajali Sandstone – J. Min Geol. 14: 16-22.

Hower, J., E. V. Eslinger, M. E. Hower & E. A. Perry 1976 Mechanism of burial metamorphism of argillaceous sediments, I. Mineralogical and chemical evidence – Geol. Soc. Am. Bull. 87: 725-727.

Hunter, R. E. 1967 The petrography of some Illinios Pleistocene and Recent sands – Sediment. Geol. 1: 57-75.

Koldewijn, B. W. 1955 Provenance, transport and deposition of Rhine sediments II: and examination of the light fraction-Geol. Mijnbouw 17: 37-45.

Krynine, P. D. 1935 Arkose deposits in the humid tropics: A study of sedimentation in the humid tropics – Am. J. Science 29: 353-363.

Kuenen, Ph. H. 1969 Origin of quartz silt – J. Sediment. Petrol. 39: 1631-1633.

Mack, G. H. 1978 The survivability of labile light-mineral grains in fluvial, aeolian and littoral marine environments, the Permian Cutler and Cedar Mesa Formations, Moab, Utah – Sedimentology 25: 586-604.

Mann, W. R. & V. V. Cavaroc 1973 Composition of sand released from three source areas under humid, low relief weathering in the North Carolina piedmont – J. Sediment. Petrol. 43: 870-881.

McEwen, M. C. , F. W. Fessenden & J. J. W. Rogers 1959 Texture and composition of some weathered granites and slightly transported arkosic sands – J. Sediment. Petrol. 29: 477-492.

Morton, A. C. 1979 Depth control of intrastratal solution of heavy minerals from the Palaeocene of the North Sea – J. Sediment. Petrol. 49: 281-286.

Nwajide, C. S. 1980 Eocene tidal sedimentation in the Anambra basin, southern Nigeria – Sediment. Geology 25: 189-207.

—— 1982 Petrology and paleogeography of the Makurdi Formation, Benue trough, Nigeria – Ph.D thesis Univ. Nigeria, Nsukka, Nigeria.

Odom, I. E. 1975 Feldspar-grain size relations in Cambrian arenites, Upper Mississippi Valley – J. Sediment. Petrol. 45: 636-650.

Odom, I. E., T. W. Doe & R. H. Dott 1976 Nature of feldspar-grain size relations in some quartz-rich sandstones – J. Sediment. Petrol. 46: 862-870.

Pettijohn, F. J. 1975 Sedimentary rocks, 3rd Ed. – Harper and Row (New York): 628pp.

Pettijohn, F. J., P. E. Potter & R. Siever 1973 Sand and Sandstone – Springer (New York): 618pp.

Pittman, E. D. 1969 Destruction of plagioclase twins by stream transport – J. Sediment. Petrol. 39: 1432-1437.

Pollack, J. M. 1961 Significance of compositional and textural properties of South Candian River Channel sands, New Mexico, Texas and Oklahoma – J. Sediment. Petrol. 31: 15-37.

Rogers, J. J. W., W. C. Krueger & M. Krog 1963 Sizes of naturally abraded materials – J. Sediment. Petrol. 33: 628-632.

Schubert, C. 1964 Size-frequency distributions of sand-sized grains in an abrasion mill – Sedimentology 3: 288-295.

Smalley, I. J. 1966 The properties of glacial loess and the formation of loess deposits – J. Sediment. Petrol. 36: 669-676.

Smalley, I. J., & C. Vita-Finzi 1968 The formation of fine particles in sandy deserts and the nature of 'desert' loess – J. Sediment. Petrol. 38: 766-774.

Strakhov, N. M. 1967 Principles of lithogenesis, v. 1 (transl. by Fitzsimmons, J. P.) – Oliver and Boyd (Edinburgh): 245pp.

Suttner, L. J. 1974 Sedimentary petrographic provinces: an evaluation. *In:* Ross, C. A. (ed.): Paleogeographic provinces and provinciality – Soc. Econ. Paleontol. Mineral. Spec. Pub. 21: 75-84.

Swett, K., G. de V. Klein & D. E. Smit 1971 A Cambrian tidal sand body-the Eriboll Sandstone of northwest Scotland: ancient-Recent analog – J. Geol. 79: 400-415.

Vita-Finzi, C. & I. J. Smalley 1970 Origin of quartz silt: Comments on a note by Ph. H. Knenen – J. Sediment. Petrol. 40: 1367-1368.

Williams, H., F. J. Turner & C. M. Gilbert 1954 Petrography – Freeman (San Francisco): 406pp.

Young, S. W., A. Basu, N. Darnell & L. J. Suttner 1975 Use of size-composition trends in Holocene soil and fluvial sand for paleoclimatic interpretation – 9th Intern. Congr. Sedimentology (Nice), theme 1: 201-209.