The quest for an ideal classification of sandstones

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> *"The most useful piece of learning is to unlearn what is untrue"*
>
> Antisthenes

Introduction

The recognition of importance of sandstones dates back the initial phase of development of Earth Sciences. Since the second half of eighteenth century, sandstones are being considered as the storehouse of information regarding the earth's surface processes, contemporary geodynamics and climatic conditions, and extra-terrestrial interferences. As one of the major host rocks, sandstones are also being explored for the different natural resources through ages. Sandstones, thus, received special attentions from generations of Earth Scientists. In spite of such a long history of sandstone research, an unanimously accepted standardized classification of sandstone could not be worked out. The degree of efficiency in categorisation of the variants of an item into well-defined sets based on unambiguously defined attributes reflects the level of understanding of the subject. In case of sandstones that precision is yet to be attained. The present study intends to identify the areas of contradiction between different propositions with a view to find out a rational way to get out of this crisis.

Sandstone classifications – a comparative study

Classification is the systematic arrangement in different categories according to some defined criteria by which each category can be recognized, differentiated, and understood. It is the concise expression of concepts in a logical and orderly way to facilitate communication. Rodgers (1950) summarized the gradations between the proposed forms of classification in the following way:

> *Descriptive* — classification in which terms convey a conception of the physical character of the rock. The terms should be descriptive, objective, and precise.
>
> *Analytical descriptive* — classification which segregates descriptive terms into similar and dissimilar categories. The aim of such a classification is to call attention to genetically significant properties by comparing like and unlike characteristics.
>
> *Genetic* — classification in which the terms employed convey an adequate conception of the inferred or believed origin of a particular rock
>
> *Operational genetic* — classification in which the genetically significant criteria serve to separate distinct rock types.

Rodgers (1950, p. 299) emphasised that "the operational genetic classification approaches the analytical descriptive classification and will coincide to form the ideal classification towards which we are striving". Such an ideal classification conveys both descriptive and genetic characteristics. However, in case of sandstones such an unequivocal classification is yet to be worked out. Since 1940 sandstone classifications were designed for different purposes, and more than fifty classification schemes have so far been proposed (Okada, 1971). A few selected schemes, particularly those either in use or of some historical importance are being considered in the present discussion.

The earlier approaches

In the first formal classification, Krynine (1940, p. 50-51) recognized six broad sandstone types:

Arkose — contains more than 30 percent feldspar

Feldspathic sandstone — contains 15-30 percent feldspar

Graywacke — contains more than 20 percent dark rock fragments or dark-coloured ferromagnesian minerals

Schist arenite — contains more than 20 percent metamorphic rock fragments, but is light-coloured in hand specimen

Quartzose sandstone — contains more than 95 percent quartz and is cemented by nonsiliceous materials

Quartzitic sandstone — contains 100 percent quartz grains cemented by silica.

Although three detrital end members (quartz, feldspar, rock fragments) were recognized, no common parameter was used as the basis of this classification. Moreover, incorporation of colour, cementing material etc. made it quite ambiguous and conveyed some wrong massages, e.g. the fragments of metamorphic rocks were assumed to be light-coloured while the others were considered as dark ones. In reality the lithic fragments of slate, phyllite, and pelitic schists, most common constituents of sandstones, are incidentally metamorphic in origin and dark in colour giving rise to the 'salt and pepper' appearance of the rock in combination with other light-coloured constituents. Keeping these limitations in mind, Krynine (1948) reorganised the descriptive parameters and accordingly classified the detrital rocks in three broad categories for objective megascopic and field use (Fig. 1):

1. The *Orthoquartzite Series*, made up of quartz with or without detrital chert grains.
2. The *Graywacke Series*, made up of quartz plus chert grains plus abundant rock fragments plus an abundance of micas and chlorite either as large flakes or, more commonly, as a micaceous or chloritic clay. Feldspar may or may not be present.
3. The *Arkose Series*, made up of quartz plus large amount of feldspar with a subordinate (20 percent) amount of kaolinitic clay impurities.

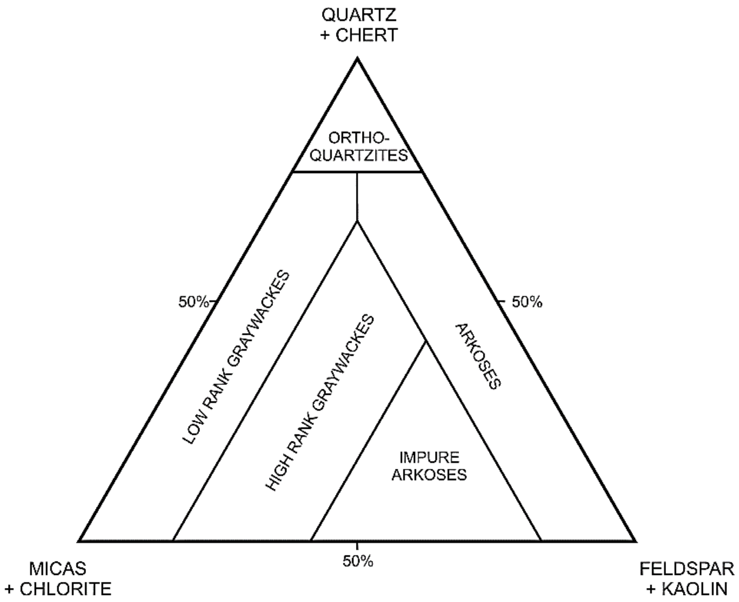


Figure 1. Mineral composition of the detrital fraction of the major petrographic series of sedimentary rocks as proposed by Krynine (1948). [Reproduced from Fig. 4 of Krynine, 1948].

These definitive properties of different categories were, however, not fully apparent in this first ternary scheme for sandstone classification. Unfortunately, this classification was wrongly portrayed by Klein (1963, Figure 1). It is noteworthy that Pettijohn (1943, Figure 2, p. 944) was first to propose the ternary system of plotting sandstone mineralogical end members (feldspar, quartz, and intergranular detritus <0.02mm). However, the formal classification came from him after six years.

Pettijohn (1949, p. 226), in the first edition of his textbook *Sedimentary Rocks*, pointed out that the *arenites* (derived from the Spanish word *arena* meaning sand) fall into three major groups – epiclastic, cataclastic and pyroclastic, and most sandstones belong to the first group. Pettijohn (1949, Table 55, p. 227) divided the epiclastic arenites into two major groups based on the binding material: (1) grains held together by mineral cement and (2) grains bound by primary interstitial clay-like detritus, and greywacke represents the principal member of this category. The arenites with mineral cement were further subdivided on the basis of the detrital constituent (Fig. 2). He, however, admitted that “the limits placed on each type were artificial and arbitrary”.

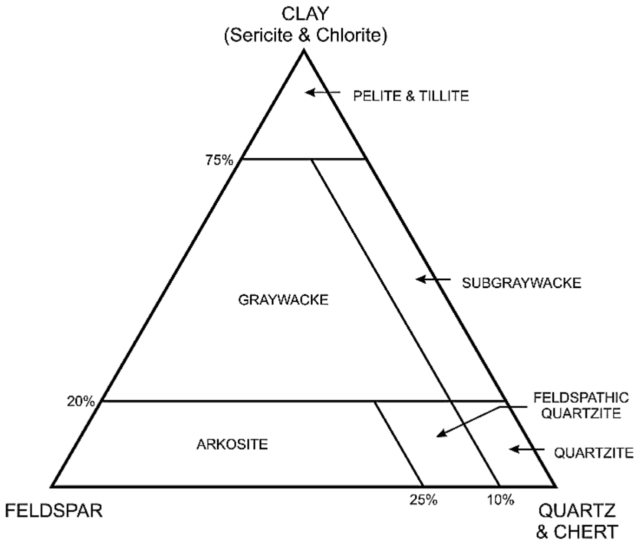


Figure 2. Classification of the arenites based upon the mineral composition of the detrital fraction as proposed by Pettijohn (1949). [Redrawn from Fig. 76 of Pettijohn, 1949].

In the same year another classification was put forward by Tallman (1949). He was of the opinion that the definitions proposed by Krynine (1948) were not precise enough for the separation of certain intermediate type of sandstones, and accordingly, based on the microscopic studies of 183 thin sections and 94 rock descriptions from literature, he proposed a five-fold classification of sandstones.

1. *Orthoquartzite*: Sandstones with greater than 90 percent of the detrital constituents made up of quartz grains.
2. *Feldspathic sandstone*: sandstones with feldspar grains making up to 25 percent of the total detrital constituents and with the argillaceous components less than 10 percent.
3. *Arkose*: Sandstones with feldspar making up greater than 25 percent of the detrital constituents and with the argillaceous components less than 10 percent.
4. *Graywacke*: Sandstones with the argillaceous component making up greater than 25 percent of the total rock.
5. *Subgraywacke*: Sandstones with the argillaceous component making up 10 to 25 percent of the total rock, plus those sandstones having less than 10 percent of feldspar or argillaceous material, as well as less than 90 percent of quartz.

The definition of the ‘subgraywacke’ appears to be ambiguous. On one hand, Tallman (1949) described this as the group of rocks with “argillaceous component making up 10 to 25 percent of the whole rock”, and on the other hand he included the sandstones with “less than 10 percent of feldspar or argillaceous material” under this category. It is not clear how did he differentiate these two types of argillaceous material. However, the basic point by which Tallman’s proposition, departed from the contemporary ideas, was the consideration of both detrital and the argillaceous components as the basis of classification. Further developments in the field of sandstone classification clearly indicates acceptance of this idea. Reflection of these ideas (without due acknowledgement) is apparent in the classification scheme proposed by Gilbert (1954), who considered four principal detrital components of sandstones: (1) quartz, quartzite and chert, the abundant stable grains; (2) feldspars, the most abundant unstable mineral grains; (3) fragments of relatively unstable fine-grained rocks; and (4) argillaceous material. He classified the sandstones into two broad classes based on degree of sorting: (1) arenite, “relatively well sorted, containing little clay (if any)”; and (2) wacke, “unsorted or poorly sorted characterized by the abundance of matrix made up of clay and fine silt”. He claimed “considerable genetic significance attaches to these two types”. Arenites were considered to have been selectively and slowly accumulated and well washed by currents, and the wackes, on the other hand, were interpreted as sediments “poured in” to a basin of deposition at a comparatively rapid rate without appreciable selection or reworking by currents after deposition. It is worth mentioning that a similar opinion that “sedimentary structures of the two depositional types provide a basis for division of sandstones into two suites: (1) the graywacke suite, deposited by turbidity currents, and (2) the arkose–quartzose sandstone suite deposited by traction currents” was put forward by Packham (1954). In favour of this view Packham (1954) argued that “the percentage of matrix is not an ideal choice for the textural study of sandstones since it gives little indication of the entire grainsize distribution”. Whatsoever, the boundary between the arenite and wacke was arbitrarily drawn by Gilbert (1954) at 10 percent (reminds Tallman) argillaceous matrix, and no attempt was made to relate it with the conceived depositional mechanisms. Therefore, it appears that a ‘genetic’ tag was intended to be attached to a ‘descriptive’ parameter. These two varieties were further classified based on the three principal detrital constituents other than matrix (Fig. 3). Certain aspects of Gilbert’s classification, however, lead to some ambiguities. The scheme of subdivisions of *wacke* and *arenite* as proposed by Gilbert (1954) is markedly asymmetric (Fig. 3). Sub-fields with prefix subfeldspathic were delineated within the fields of lithic wacke and lithic arenite respectively. Therefore, mixed populations of feldspar and lithic fragments were taken into consideration. On the other side, the fields were divided into feldspathic (feldspar content between 10% and 25%) and arkose based exclusively on feldspar content and the possibility of the presence of lithic fragments was not considered. Gilbert (1954), however, did not elucidate the basis of this marked asymmetry or why the presence of lithic fragments was not considered within the arkosic sandstones.

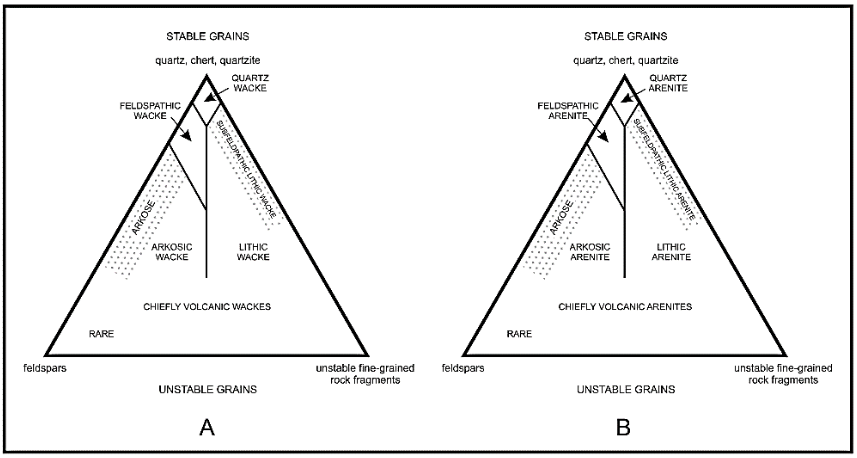


Figure 3. Classifications of (A) impure and (B) pure sandstones as proposed by Gilbert (1954). [Redrawn from Figures 96 and 97 of Gilbert, 1954].

In the same year another scheme was proposed by Pettijohn (1954), and that also was based on similar four detrital components. Pettijohn (1954), however, advocating the genetic implications of these components, identified three factors as “of greatest genetic importance”:

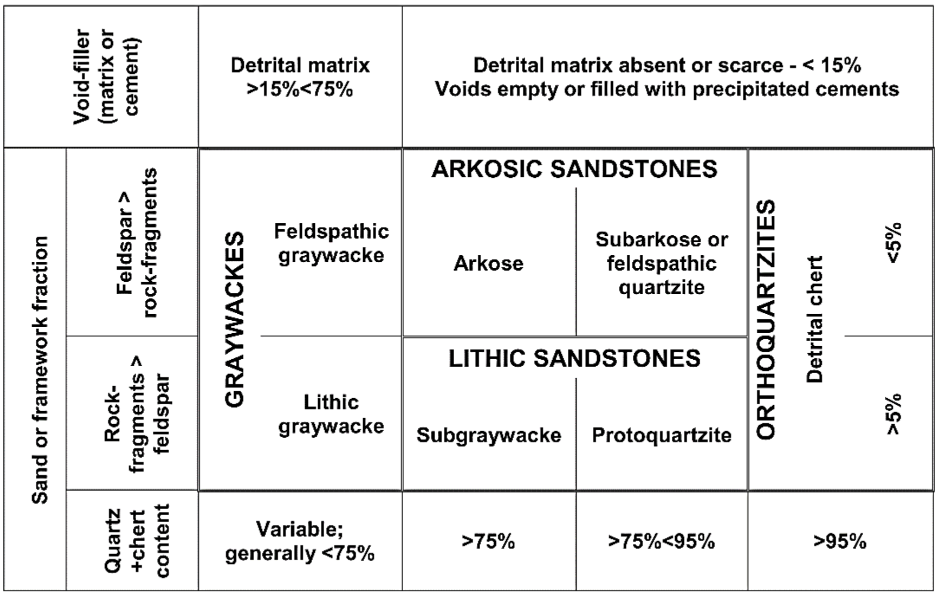
(1) *Provenance factor* - The dominant source materials for sands can be broadly classified into two categories: (1) the crustal rocks, and (2) the supracrustal materials. Since ‘sand’, by definition is restricted to the 0.0625 to 2.00mm range of grain diameters, the granitic crust contributes mineral grains (mainly quartz and feldspar) to the sand population. Coarser constituents of supracrustal materials may also be the other contributors. Lithic fragment (described as “rock particle” by Pettijohn, 1954) can be defined as a particle containing the mineralogical and textural properties of the parent rock. Since for a sand-sized particle these properties are to be accommodated with a space of maximum 2mm diameter, the lithic fragments are to be derived essentially from fine-grained rocks, and obviously a supracrustal derivation can be inferred. Since for the quartz grains the distinction between the plutonic and metamorphic provenance may lead to some confusions, Pettijohn (1954) considered feldspar as the better representative of granitic source, and suggested the ratio of feldspar to the lithic fragments as the provenance index and a measure of the relative importance of the contributions of the crustal and the supracrustal source rock.

(2) *Maturity factor* - Maturity of the terrigenous sediments is conventionally expressed in terms of mineralogical composition and certain textural parameters. The mechanical and chemical durability of the mineral constituent is, thus, the primary concern for definition of the maturity. Pettijohn (1954) proposed quartz content as a measure of the mineralogical maturity of a sand population. He further suggested that as most of the quartz was originally plutonic and closely associated with feldspar, the maturity may also be expressed by the disappearance of the feldspar or by the quartz/feldspar ratio. He, however, admitted that “the paucity of feldspar in the source material would lead to a deceptively high quartz/feldspar ratio”. Accordingly, he revised his idea and proposed that since the lithic fragments, excepting chert, derived from a supracrustal material are of low chemical and mechanical stability, the ratio of chert/noncherty lithic fragments would be an appropriate maturity index for such sands. Moreover, since most sands have a complex source, the maturity indices might best be combined so that the influence of source rocks would be eliminated. The index, therefore, would be quartz plus chert/feldspar plus lithic fragments. Pettijohn (1954) further pointed out that the compositional maturity is rarely attained without a corresponding achievement of textural maturity, which is defined in terms of degrees of sorting and roundness. Since the correlation between these two parameters is poor, Pettijohn (1954) remained silent about the incorporation of the textural maturity in defining the maturity index.

(3) *Fluidity factor* - Pettijohn (1954) was of the opinion that the effectiveness of the sorting process is dependent mainly on the density and viscosity of the transporting medium. In case of higher density contrast between the particles and the transporting fluid the separation is rapid and complete, otherwise it remains incomplete or lacking. He thus concluded that “the mixed sediments or "wackes" must be

mainly the products of deposition from media of high density or viscosity". "The presence or absence of a detrital clay-sized matrix in a sand is thus an index of the effectiveness of the sorting ability of the transporting medium and therefore of the sediment/fluid ratio of that medium". Based on this criterion he suggested that sands and sandstones may be divided into two major groups on the basis of the binding material. One group is held together by an introduced precipitated pore-filling material, and the other group is bonded together by a fine-grained primary interstitial detritus or matrix of clay-like nature or the authigenic derivatives therefrom.

He proposed four major classes of sandstones (Fig. 4): *graywackes*, *arkosic sandstones*, *lithic sandstones*, and *orthoquartzites*. Each group was further classified into the constituent members (Fig. 4). Although this classification was proposed based on "properties believed to be genetically significant", Pettijohn (1954, p. 365) finally concluded that, the classification was based upon simple observable characters and not genetic, and also opined that "a knowledge of the origin is not necessary to name or classify the sandstone". Literature survey reveals that the classification proposed by Pettijohn (1954) was not widely accepted. This classification and the 'genetic factors' were included in the second edition (Pettijohn, 1957) but not in any subsequent edition of his textbook *Sedimentary Rocks*. It was perhaps due to ambiguous nomenclature. Excepting arkose, Pettijohn (1954) termed the sandstones as varieties of either graywacke or quartzite. Even the sandstones containing nominal amount of matrix (detrital matrix absent or scarce - < 15%, Pettijohn, 1954, Fig. 1) were designated as *subgraywacke*, and that might have caused confusion in understanding the rock. Another serious contradiction in the ideas of Pettijohn is reflected within this classification. In defining sandstone, Pettijohn (1949) specifically advocated the minimum sand content of 50 percent by volume is the prerequisite for a rock to be designated as sandstone. But, the detrital matrix content of the graywackes, as suggested by Pettijohn (1954), ranges between >15% and <75%.



Void-filler (matrix or cement)		Detrital matrix >15%<75%	Detrital matrix absent or scarce - < 15% Voids empty or filled with precipitated cements		
Sand or framework fraction	Feldspar > rock-fragments	**GRAYWACKES** Feldspathic graywacke	**ARKOSIC SANDSTONES** Arkose	Subarkose or feldspathic quartzite	**ORTHOQUARTZITES** Detrital chert <5%
	Rock-fragments > feldspar	Lithic graywacke	**LITHIC SANDSTONES** Subgraywacke	Protoquartzite	Detrital chert >5%
	Quartz +chert content	Variable; generally <75%	>75%	>75%<95%	>95%

Figure 4. Classification of sandstones (excluding tuffs and calcarenites) as proposed by Pettijohn (1954). [Redrawn from Fig. 1 of Pettijohn, 1954].

Klein (1963, p. 556) was of the opinion that the mineralogical basis of sandstone classification was pioneered in its modern form by Krynine and by Pettijohn and most of the classifications can be recognized as their "modified descendants". This perception might have been developed due to consideration of certain points, like broad divisions of Gilbert's (1954) classification based on matrix content or the finer divisions based on framework composition, as reflections of Pettijohn's ideas of fluidity index and the maturity index respectively. However, the fact is that the Gilbert's (1954) classification was published prior to that of Pettijohn (1954), and Pettijohn (1954, p. 363) adopted the term 'lithic' from Gilbert's proposition. In reality, both the classifications were based on detrital and the argillaceous components and thus can be identified as the 'modified descendants' of Tallman's classification.

Inspired by the published work of Krynine (1948), Folk (1954) suggested a triangular classification (Fig. 5) for quantitative mineralogical definitions of terrigenous sedimentary rock types. He made "modifications in the mineral assemblages represented by each pole, in the divisions of the fields, and in some of the rock names". Folk (1954) was of the opinion that classification of medium- and coarse-grained terrigenous sedimentary rocks into several compositional types (ortho-quartzites, arkoses, graywackes, and transitional classes) is a matter of considerable importance in interpreting the paleogeographic and tectonic background of sedimentary rocks and their source areas, and the only tenable basis for such a classification is the mineral composition. Accordingly, the detrital constituents were identified and the three poles of the proposed triangular classification were labelled Q, F, and M. The Q (for quartz) pole represents ultrastable minerals of the silica group (i.e., chert plus all types of quartz except metamorphic strained polycrystalline quartz). The polar rock type here is the orthoquartzite. The F (for feldspar) pole represents the feldspathic constituents (single grains of K-feldspar and plagioclase, and igneous rock fragments derived from plutonic or extrusive rocks) and indicates an igneous source area. The polar rock type here is the arkose. The third or M (for mica or metamorphic) pole represents micas and chlorite, including micaceous hash of coarse silt size or larger; recognizable metamorphic rock fragments, such as gneiss, schist, phyllite, slate, stretched meta-quartzite; and composite grains of deformed metamorphic quartz, showing undulose extinction, often accompanied by stretching or suturing, and composed of two or more individuals with distinctly different crystallographic orientation. These minerals indicate derivation from a metamorphic source area. Folk (1954) further advocated that "the graywacke is the archetype of a sediment derived wholly from a metamorphic source, it deserves full and not subordinate rank; therefore, it should be called graywacke not sub-graywacke". According to Folk (1954), a large number of rocks do not have enough feldspar or metamorphic rock fragments to be classed as arkose or graywacke, and these are fittingly classed as 'subarkose' and 'subgraywacke'. A few rocks show evidence of a complex source area, in that they contain materials of both igneous and metamorphic derivation; these fewer common rocks are the impure arkose, feldspathic graywacke, and feldspathic subgraywacke. Folk (1954) further emphasised that "none of the three poles can be as ideal as one might hope, inasmuch as feldspar and mica may both be derived from granite or gneiss, and such constituents as polycrystalline metamorphic quartz must, for practical reasons, be placed with the metamorphic constituents instead of with ordinary quartz; but it is believed that this is the most meaningful division that can be made if one wishes to base a quantitative classification on the lithology of the source area".

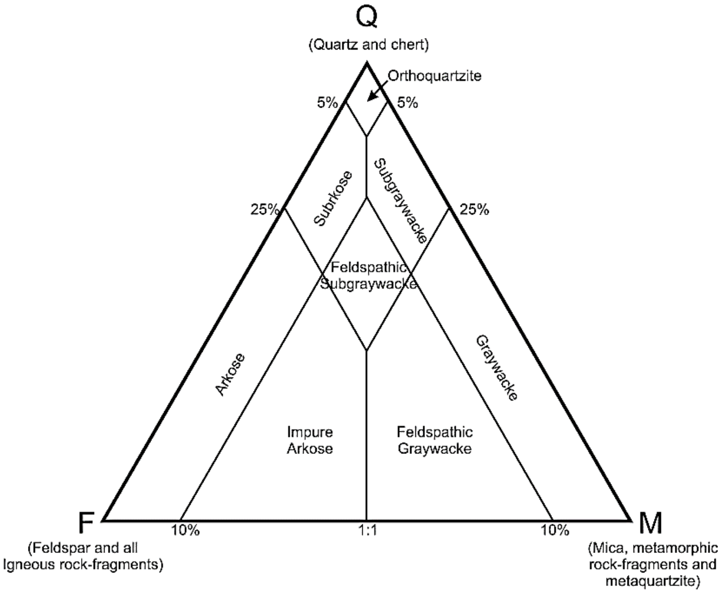


Figure 5. The eight types of terrigenous sedimentary rocks, as defined by the mineral composition of the detrital sand fraction, disregarding chemical cements and detrital clays. [Redrawn from Fig. 2 of Folk, 1954].

High clay content in a sandstone may be correlated with the depositional process, but there is no direct relation between the clay enrichment and metamorphic provenance. Therefore, the correlation between the graywackes and metamorphic provenance as postulated by Folk (1954) does not stand valid. The undulose extinction is also not unequivocal evidence of metamorphic derivation. This specific optical property is the manifestation of lattice deformation of quartz grains, and may develop during metamorphism or emplacement of igneous plutons (Blatt et al., 1980). On the other hand, in high grade metamorphic quartz grains, due to recrystallization, this lattice defect is obliterated. The identification of quartz grains showing undulose extinction with metamorphic provenance or otherwise with igneous provenance thus may lead to an erroneous conclusion. However, the most serious issue with this classification involves a basic conceptual problem. Folk (1954) considered lithic fragments of plutonic rocks and gneisses within the framework population of sandstone. However, by definition, a sand grain may be of maximum diameter of 2mm, which is smaller than the average grain size of plutonic igneous rocks or gneisses, so there is no question of presence of identifiable fragments of these rocks as 'lithic fragment' within framework population of any sandstone. It was also pointed out by Crook (1960) that no provision was there for the sedimentary rock fragments in the parameters described by Folk (1954), and the difference in tectonic implication of presence of plutonic and volcanic detritus within sediment was totally ignored by grouping of all igneous detritus into one parameter.

Critical examination the classificatory schemes proposed by Pettijohn (1954), Packham (1954), Folk (1954) and Gilbert (1954) led Crook (1960) to conclude that "only Packham's classification, which uses sedimentary structure as the parameter is validly based genetically". Crook (1960), however, pointed out that

Packham's (1954) classification does not have any provision for field and laboratory nomenclature; is inadequate for arenites with large number of labile grains; and the homonymy causes difficulties in identification of arenites without any knowledge about the associated sedimentary structures. With an idea that "amplification of the terms descriptive of labile rock types is desirable" Crook (1960) came forward with a generalised QFR diagram (Fig. 6), which, according to him, can be used for naming of the arenites in the field and the laboratory, and after examination of the evidence from sedimentary structures the final name can be assigned, in conjunction with Packham's classification, with both descriptive and genetic connotations.

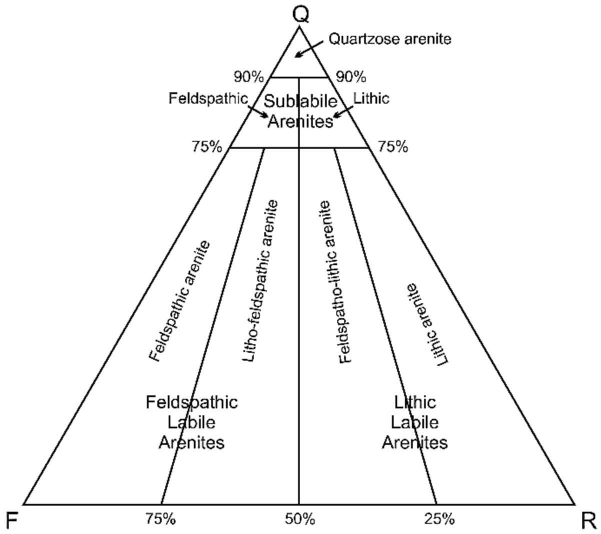


Figure 6. Generalised QFR diagram for arenites as proposed by Crook (1960). [Redrawn from Fig. 7 of Crook, 1960].

The post 1960 developments

McBride (1963) critically analysed the available classifications of sandstones and was of the opinion that "greywacke should be applied only to indurated rocks that have the combined properties of a high matrix content (>15%), abundant rock fragments (>10%), and appreciable feldspar (>5%) - properties that characterize the 'type' graywackes of Germany", and thus has the status of a special rock type. He also categorically excluded 'clay' or 'matrix' as a component for classifying other sandstone types. McBride (1963) synthesised "most desirable features of other classifications, chiefly those of Folk (1954), Gilbert (1954), and Pettijohn (1957)" to proposed a descriptive classification of sandstones based on the composition of framework grains, grouped into (1) quartz plus chert and quartzite, (2) feldspar, and (3) rock fragments (Fig. 7). He designated all sandstones as 'arenite', each with the dominant framework constituent as adjectival modifier. In order to provide a convenient number of different categories so that rocks of significantly different composition can be differentiated by name, the ternary classification was subdivided into eight distinct sectors (Fig. 7). The boundary values to define these sectors were same as those proposed by Folk (1954) (Fig. 5). As admitted by McBride (1963), this classification, although designed to be descriptive, the grouping of the end-member constituents were also indicative of the provenance factor (Pettijohn, 1954). McBride (1963) did not, however, explain why did he propose to consider the detrital framework constituents of >0.02 mm (McBride, 1963, p. 666), a size range covering the grains finer than the finest sand of 0.0625mm diameter, in naming of a sandstone.

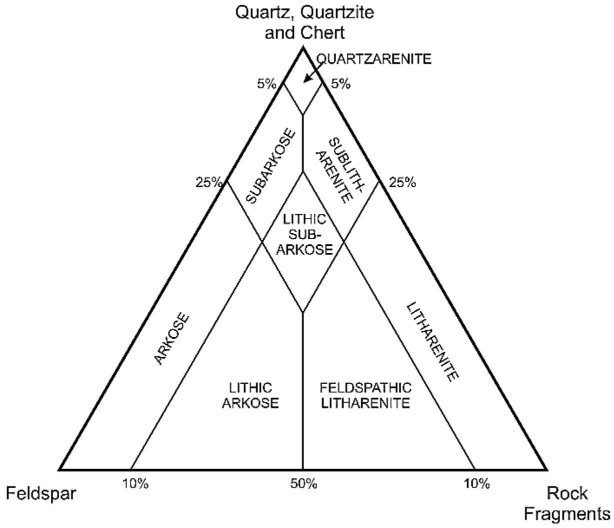


Figure 7. Classification of common sandstones as proposed by McBride (1963). [Redrawn from Fig. 1 of McBride, 1963].

A different view was expressed by Dott (1964) regarding the graywackes. He was of the opinion that "by the popular criteria both of original or majority usage of graywacke over the years, the 'texturalist' school appears vindicated, and apparently the wrong properties have been over-emphasized by the 'compositionists'. Clearly the original or 'type' definitions both in German and English could not have been truly petrographic. It seems absurd to restrict a long-standing name to the rigid petrographic compositional limits of the 'type' examples 200 years after its use was well established". He thought it to be "more propitious to leave for them very broad meanings which can be applicable in the field and to establish refined new varietal types". Dott (1964) preferred conceptual adaptation of Gilbert's schemes and compiled those in a single scheme of sandstone classification "better to portray the continuous nature of textural variation from mudstone to arenite and from stable to unstable grain composition" (Fig. 8).

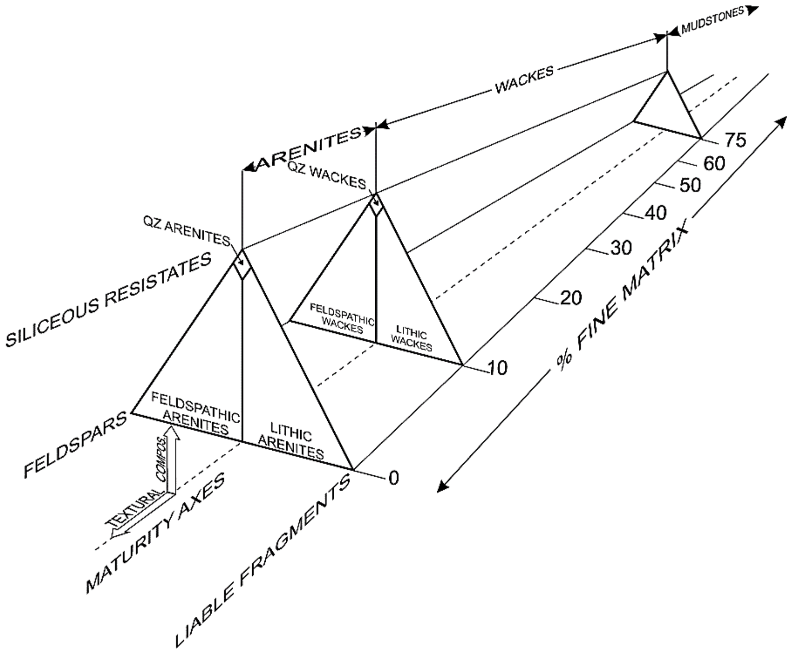


Figure 8. Modified portrayal of Gilbert's classification of silicate sandstones as proposed by Dott (1964). [Reproduction of Fig. 3 of Dott, 1964].

Although Dott (1964) described his proposed scheme as a conceptual adaptation of Gilbert's propositions, the former differs significantly from the latter on certain important points. The term 'Arkose' was replaced by 'feldspathic sandstone' "for its little descriptive value". Dott (1964) considered only the end members and no provision was suggested for the mixed populations (like feldspathic litharenite etc.) of the framework grains to reflect the continuous nature of grain composition, as claimed by him (Dott, 1964, p. 628). This limitation was, however, covered up by Pettijohn et al. (1972), who slightly modified the scheme of classification as proposed by Dott (1964) by introducing the fields of subarkose and sublitharenite (Fig. 9). Pettijohn et al. (1972) also restored the terms arkose and greywacke, and redefined the boundary between the arenites and wackes at 15 percent matrix content. No specific reasons were put forward to justify these changes. The boundary between the wackes and mudstone at 75 percent argillaceous material as proposed in the original classification of Dott (1964) and its modified version proposed by Pettijohn et al. (1972) seriously contradict the prerequisite condition of 50 percent sand content for a rock to be designated as sandstone, as proposed by Pettijohn (1949). However, from the realisation "as ideas are subject to evolution and change, so, too, will classifications evolve and change, and obviously the sandstones are not the exceptions" (Pettijohn et al., 1972, p. 150), Pettijohn replaced his own classification by this revised version of Dott's (1964) scheme (with proper citation) in the third and subsequent editions of his text book *Sedimentary Rock* (Pettijohn, 1975).

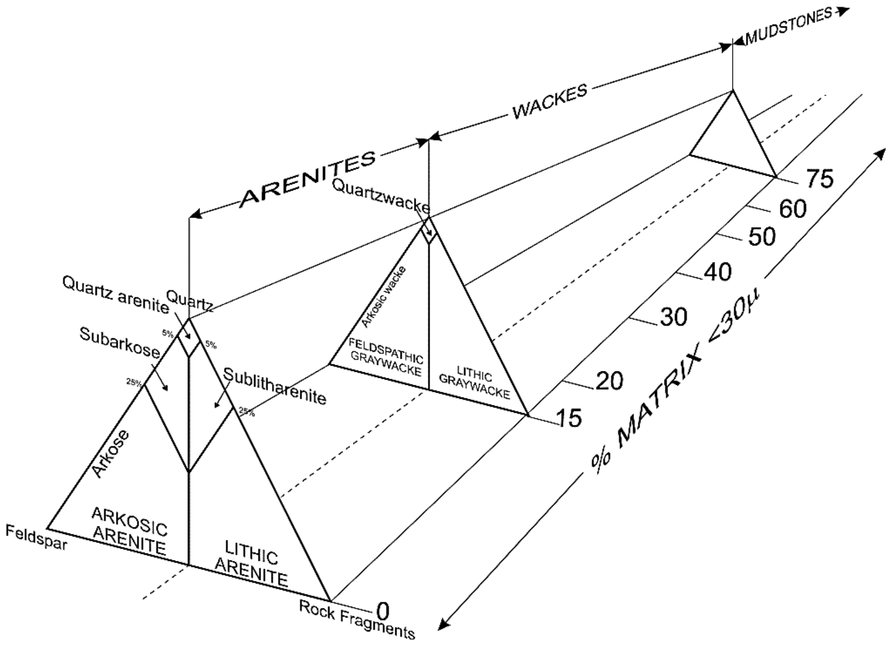


Figure 9. Classification of terrigenous sandstones (Modified from Dott, 1964, Fig. 3) as proposed by Pettijohn et al. (1972). [Redrawn from Fig. 5-3 of Pettijohn et al., 1972].

It is a fact that there are lot of differences in opinion regarding the depositional mechanisms involved in deposition of greywackes. Cummins (1962) specifically pointed out that "modern sediments of comparable origin, whether found in nature or produced experimentally, are not greywackes", and finally concluded that "the peculiar texture of greywackes cannot be an original detrital feature, but must be the result of post-depositional alteration of 'normal sand', and several independent lines of evidence support this hypothesis for the origin of greywacke". According to Folk (1974, p. 126) "the word 'graywacke' is encumbered by so many radically differing definitions that it has been rendered almost useless", and that led him, "after much soul-searching", to propose a workable sandstone classification (Folk et al., 1970) based on the framework composition (Fig. 10). This classification, claimed to have been presented by Folk for informal discussion in 1966 and somewhat more formally in 1968, is basically a modified version of the QFR diagram for arenites proposed by Crook (1960). Folk (1974, p. 126) admitted that "this change was done after prolonged discussion with Earle F. McBride, Keith A. W. Crook, and Harvey Blatt; many of their ideas have been incorporated into the new revised version". According to him, the main difference between this and his previous classification (Folk, 1954) is "the lumping of all rock fragments (except plutonic ones, granite and gneiss) into the third or 'rock fragment' pole of the triangle, and the switching of chert, which is in reality a rock fragment, from the Q-pole to the RF-pole". He further opined that "by putting all rock fragments regardless of genesis in one pole, the main triangle loses almost all its source-area significance; but splitting the rock fragments on the subordinate RF triangle restores much of this loss".

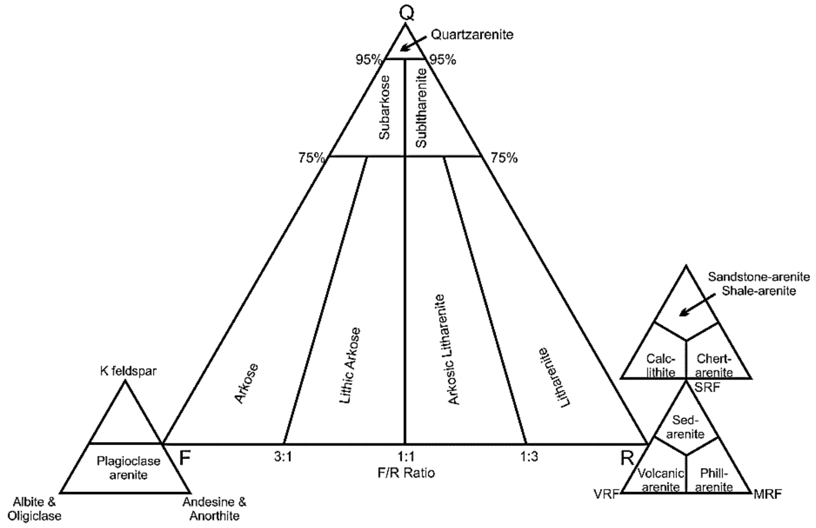


Figure 10. Sandstone classification after Folk et al. (1970) showing the primary arenite triangle. According to the original authors the second and third order triangles can be used for refinement of the nomenclature given in the primary triangle. [Redrawn from Figures 8 and 9 of Folk et al., 1970].

Recently, Garzanti (2019) proposed a petrographic classification of sand and sandstones discarding all earlier approaches, which, according to him, were “in the illusion that a classification could be genetic at the same time as descriptive”. He, however, did not mention whether this is a universal problem or applicable to sandstone only. He thus challenged the basic premise of the concept of an ‘ideal classification’. If so, then how do the genetic classifications in other fields of petrology exist? He basically tried to impose a classification as of sandstone, designed based on recent sand samples, in a very aggressive manner by making the comment “The commandment ‘genesis must and does permeate our classification’…….. or the promise that plotting a point into a QFL diagram is sufficient to reveal a geodynamic context ……… are traps into which we should not fall”. Reverting back to a descriptive classification with an idea that the ideal classification is the utopia, which cannot be achieved, is nothing but a retrograde approach. He did not elucidate how and why this scheme of classification, based on recent sands, without considering the composition of a single known sandstone deposit, be extended to sandstone. Since the passage from sand to sandstone is a long journey and the sediments experience significant changes in this process, no idea about the character of the resultant sandstone is expected to be conceived from the initial sand deposit. The basic objective of sandstone study is not just the identification of the provenance. It helps, in conjunction with other information, in unfolding the tectonosedimentary history of the basin. However, Garzanti (2019) in his proposed scheme arbitrarily identified fifteen varieties of sandstones based simply on descriptive parameters. Incidentally, Garzanti (2019) could not cite a single example of feldspathic (F) arenite, where neither quartz nor lithic fragments do exceed 10% of the framework population. On the other hand, only three samples were plotted within the rhomboidal field representing lithic (L) variety (Garzanti, 2019, Fig. 6), one from each of Karun, Piave and Tagliamento river sand samples. If the source data are probed, it is found that the 83% of the bulk composition of Piave and Tagliamento river sand samples is represented by fragments of carbonate rocks (62% dolomite fragments and 21% limestone fragments) (Garzanti et al. 2006, Table 2). According to Picard and McBride (2007, Table 1), the proportion of total carbonate fragments in the sand samples of Boite-Piave Rivers ranges between 44.3 and 99.4. Out of the 14 samples (average carbonate fragment content 68.84%) studied by them, 12 samples yielded carbonate fragment content well above 60%. In Karun river sand the estimated carbonate fragment content was 72% (Garzanti et al., 2016, Table 1). Now, the question is what is the possible fate of these three sand deposits? If these populations survive, the resultant rocks would be calcarenites, that is limestone and not sandstone. Sandstones, by definition, is a siliciclastic rock. Lithic fragments of carbonate rocks may be present in a sandstone as minor constituent, not the major one. In fact, no sandstone composition has so far been reported to comply with such composition of feldspathic (F) and lithic (L) fields delineated by Garzanti (2019). Hence, these are virtual varieties of samdstone, not viable in reality. In any formal classification provisions for unrealistic varieties, only for the sake of symmetry of the scheme is not acceptable. In fact, the scheme could be any type dividing the triangle in different regular patterns. Hence, the question, to what extent this classification can help in understanding the sandstones, and particularly the depositional history, the main purpose of the study of sandstones, remains open. Unfortunately, this type of approaches fails to serve the purpose of advancement of understanding.

The critical problems

The plethora of sandstone classifications appearing in the geological literature is causing considerable communicative confusion among sedimentologists (Klein, 1963), and the learners are the worst sufferers. The classifications so far proposed are based on descriptive parameters and some of the authors tried to find out some genetic justification to the proposed criteria. The application of different classifications thus generates different conclusions about the depositional history and it often becomes quite difficult for a student to identify the appropriate classification and to get any idea about the genetic implications of a sandstone from its name. In most cases, they are guided to follow a classification as per the preference of their respective instructors without analysing the merits and demerits of the other schemes of classification. Their analytical faculty thus, instead of getting flourished, are eclipsed by dogmatic biasness. An example is of Prof. Stephen A. Nelson, who blended, without any justification, different classifications to present the sandstone classification in a course (http://www.tulane.edu/~sanelson/eens212/sandst%26cong.htm) offered by him at Tulane University. Finite solution to these serious problems can only be arrived at after proper diagnosis of the basic problems. In this process, the critical analysis of the proposed classifications reveals some serious areas of ambiguity and fallacy.

The matrix problem

Two distinct schools of thought can be identified from the basic approaches towards the classification of sandstone. One group (Tallman, 1949; Gilbert, 1954; Pettijohn, 1954; Dott, 1964) considered matrix material as a major component, indicating the fluid character of the depositing medium, while the other school (McBride, 1963; Folk et al., 1970) considered only the framework constituents. Pettijohn (1975) in a discussion on ‘matrix problem’ admitted that “the problem becomes one of explaining simultaneous sedimentation of sand and mud. Normal aqueous currents sort so that sand and mud are separately accumulated. Even sands of dominantly mudcarrying rivers are relatively ‘clean’ and mud-free”. Possibility of deposition of matrix-rich sand in deep marine condition from turbidity current has also been ruled out by Hollister and Heezen (1964), Kuenen (1966), and Garzanti (2017). The only option left was the infiltration of argillaceous material from overlying sediments (Klein, 1963; Pettijohn, 1975, p. 228). Whetten (1969) was of the opinion that sand deposited from tractive currents in aeolian, fluvial, shallow-marine, or deep-marine environments cannot contain large amounts of primary cohesive mud. Deposition of clay-rich sand, as rightly pointed out by Garzanti (2017), is only possible in case of debris flow deposits and occasionally in flood-plain deposits due to rapid deposition from suspension cloud at the initial stage of overflooding of the stream channel. In the latter case, however, sands are expected to be very fine-grained. The concept of ‘fluidity factor’ was supposed to be reconsidered after the identification of four possible types of matrix by Dickinson (1970). Out of these four varieties pseudomatrix, epimatrix and orthomatrix are of secondary origin and are the dominant varieties compared to the primary protomatrix. Protomatrix is characterized by its even distribution throughout the rock while the other three varieties occur only at the space previously occupied by their precursors. In case of sandstones of aqueous medium presence of protomatrix can be attributed to clay infiltration, and in aeolian deposits this may be due to mixing of different size populations during differential ablation. Pseudomatrix is normally found within litharenites, where the fragments of mechanically susceptible grains of shale, phyllite, pelitic schists etc. were crushed during compaction. The arkoses, particularly those deposited during low rate of basin subsidence, are often rich in epimatrix. Arkoses deposited under high rate of basin subsidence attains a very advanced stage of diagenesis, and are often rich in orthomatrix. In case of very early lithification, sandstones are often devoid of any finer-grained component. Consideration of matrix material as “of greatest genetic importance” as claimed by Pettijohn (1954) may also lead to an erroneous conclusion. For example, in the case of Sub-Himalayan Lower Siwalik sandstones, the river-borne deposits of foreland setting, the sediments were originally rich in lithic fragments derived from the Himalayan thrust blocks, and after compaction and lithification became rich in pseudomatrix. Due to this high matrix content these may be identified as quartz wacke following the scheme of Dott (1963) or its revised version (Pettijohn et al., 1972), and according to the idea of ‘fluidity factor’ of Pettijohn (1954) this character is supposed to indicate deposition from high density flow. Crook (1960) rightly pointed out that the boundaries between the arenites and wacke drawn at 10 percent (Gilbert, 1954; Dott, 1964) or 15 percent matrix content (Pettijohn et al. 1972) are arbitrary having no sedimentological implication. Grim (1962) demonstrated that the viscosity of a clay-water mixture changes sharply with increase in clay content, and for native clays this critical value ranges between 24 and 32 percent of clay content. The matrix of a sandstone is indeed important in revealing the diagenetic history, an essential component for reconstruction of the tectonosedimentary history of a basin, but its ‘genetic implication’ as ‘fluidity factor’ does not stand valid.

Problems related to the concept of maturity

The concept of maturity was introduced in sedimentary petrology by Plumley (1948) and was subsequently advocated by Pettijohn (1949). The crux of the idea was that a sediment tends inevitably to approach the most inert end state possible, through both physical and chemical processes experienced during the journey from source to sink.

The stability of constituent mineral grains of sandstone was specially considered from the early days of sandstone research. However, identification of grains as the indices of mineralogical maturity conveys a wrong message, because the grains like feldspar, basic glass etc. are indeed susceptible to chemical weathering but that is in aqueous environment under warm-humid climatic condition. On the other hand, these grains are quite stable under dry aeolian or cold glacial conditions. Whatsoever, study of recent sediments indicated that fluvial transport does not play significant role in compositional maturity of the transported particles (Russell, 1937; Shukri, 1950). However, in the course of river incorporation of relatively ‘unstable’ material may, on the other hand, cause a reverse trend (Picard and McBride, 2007). Enrichment in mechanically and chemically durable grains at the expense of more labile components is generally held to be a most obvious effect of recycling (Johnsson, 1993), but this may not also a thumb rule (Garzanti et al., 2015). The effects of diagenetic processes are much more drastic than those of weathering in elimination of mechanically as well as chemically metastable components leading to an impression of compositional maturity of the framework population (Andò et al., 2012).

Problems related to the interpretation of provenance

During study of a sandstone sample, it must be kept in mind that most of the sand deposits are the assemblage of sand particles derived from different source rocks, and different sand grains may bear the signatures of respective parent rocks. After studying all the grains, the overall provenance may be worked out. The lithic fragments, possessing mineralogical and textural properties of the source rock, can thus be considered as the best provenance indicator. The detrital mineral grains, however, are open to interpretation from the circumstantial evidences.

Folk (1974, p. 66) pointed out that the study of quartz types is one of the most fascinating and valuable aspects in sedimentary petrology. Krynine's genetic classification of quartz as modified by Folk (1974, p. 69) can be considered as the starting point for provenance studies. With a view to refine these interpretations from quartz grains, Basu et al. (1975) and Basu (1985), based on study of undulosity and polycrystallinity of medium sand sized (0.25-0.50 mm) detrital quartz in Holocene fluvial sands derived from “known source rocks”, proposed a diamond classification for identification of provenance. The method could have been more convincing if they would carry out the same study in the quartz grains of the original rocks rather than in the sand grains derived there from. After all, the theoretical correlation between the quartz properties and so-called “known source rocks” remains subjective. The role of diagenesis in modification of composition of a sand deposit must also be considered during provenance interpretation. According to McBride (1985) “Diagenetic processes that alter the depositional composition of sands must be considered when making provenance interpretations”. Johnsson (1993) also opined that “during chemical weathering prolonged feldspar hydrolysis can transform the source granitoid rock into residual sand almost entirely of quartz, and thus the fingerprint of parent lithology can be obliterated”.

Helmold (1985) identified four key intrinsic properties which enable feldspars to be used as provenance indicators for sandstones. These are chemical composition, twinning, zoning, and structural state. He further pointed out that the utility of feldspar as a provenance indicator is moderated by its chemical and mechanical instability in the sedimentary environment, which may effectively modify or remove feldspar from the detritus thereby altering its composition. These modifications must be recognized in order to correctly decipher the provenance of a sandstone.

Hence, any attempt to interpret the provenance of a sand deposit based on the proportion of three framework constituents – quartz, feldspar and lithic fragments would be too generalised approach. Moreover, consideration of stability during identification of provenance factor, as was done by Pettijohn (1954), is fallacious. Pettijohn (1954), during proposition of the ‘provenance factor’, grouped chert and quartz together. He, however, considered quartz primarily as a representative of crustal rock while chert fragments have essentially supracrustal provenance.

Problems in defining sandstone types

One of the basic objectives of any classification is also to characterize each category with distinctive definition. If the proposed classifications are critically assessed, the scheme of Folk et al. (1970) appears to be most convenient in this regard, and each variety of sandstone can be specifically defined. For example, according to this scheme (Fig. 10) the sandstone, with quartz content ≥ 95% of the framework population, is designated as quartz arenite irrespective of the proportion of other two framework components. In similar other schemes proposed by Gilbert (1954) (Fig. 3), McBride (1963) (Fig. 7), Dott (1964) (Fig. 8) and Pettijohn et al. (1972) (Fig. 9) the diamond-shaped field of quartz arenite, according to the principle of triangular graph, indicates that the quartz content may vary from 90 to 100 percent, but this interval is not enough to define quartz arenite. If the quartz content is less than 95 percent, the proportion of the other two constituents becomes more important for definition of the rock as quartz arenite. Here feldspar and lithic fragment together may constitute >5 percent to as much as 10 percent. However, for definition of the rock to be a quartz arenite, proportion of none of these two constituents can exceed 5 percent. Otherwise, the composition would depart the field of quartz arenite. Hence, the sandstones with more than 90 percent of quartz may not always be quartz arenite. For other members, for obvious reason the conditions would be more complicated. Thus, it may not be always possible to name the rock readily from the modal composition of the framework population without plotting the values on a triangular graph. Thus, assignment of specific compositional definition for each sandstone variety becomes difficult. The definition based on descriptive parameters is not likely to be so complicated. In the scheme proposed by Garzanti (2019) the apical members, lithic, feldspathic, and quartzose sands are defined with reference to the proportion of the minor constituents (each must be <10%) instead of the major constituent. Hence, out of all the proposed schemes of sandstone classification the descriptive one proposed by Folk et al. (1970) appears to be the most rational one for practical purposes. This may be the best available working classification but being a descriptive one cannot be the ideal classification. Folk (1974, p. 126) was quite optimistic about further advancement towards an unequivocal classification of sandstone. In his words “It is hoped that those of us seriously interested in sandstone classification can, some decade, all get together and use some compromise system, so this classification is tentative and subject to change should such a miracle come to pass".

Control of basin tectonics on sandstone composition

The most important objective of the study of basin-fill succession is to work out the tectonosedimentary history of the basin. The sandstone composition, determined after taking the diagenetic changes in consideration, plays a vital role in this context. Dickinson and Suczek (1979) demonstrated that the detrital framework modes of sandstones are function of provenance types governed by the tectonic settings. As admitted by Dickinson and Suczek (1979), the basin tectonics has a direct bearing on the generation, transportation, deposition and diagenesis of the sedimentary particles. The resultant sediments incorporate all the possible variable factors. Hence, correlation of the detrital modes only with the provenance has inherent problem, and the composition of the sandstones from established tectonic settings, instead of indicating the provenance, as described by Dickinson and Suczek (1979) and Dickinson et al. (1983), are supposed to give some idea about the relationship between the provenance, depositional mechanism, subsidence and diagenetic history. It was rightly pointed out by Mack (1984) that processes like weathering, depositional reworking and diagenesis can significantly mask the source-rock signature. Mack (1984) was also of the opinion that "the interpretation of tectonic setting based on data exclusive of petrography does not coincide with the interpretation of tectonic setting based on their location on compositional diagrams". Critical analysis of the four specific situations of mismatch identified by Mack (1984) reveals some basic discrepancies in correlation of the provenance and tectonic settings from the detrital framework modes. With a view to arrive at a rational solution to this problem, the modal composition of the framework population of sandstones from well-defined tectonic settings from different parts of the world (Table 1) were plotted on QFL ternary diagram for delineation of compositional ranges of respective tectonosedimentary settings.

A rational approach to find out the logical explanation of these discrepancies, would be the redefinition of the areas delineated as 'continental block provenances', 'recycled orogen provenances', 'magmatic arc provenances' in the QFL plots by Dickinson and Suczek (1979, Fig. 1) and its modified version proposed by Dickinson et al. (1983, Fig. 1) as (1) stable continental margin setting, (2) intracratonic block-faulted setting, (3) foreland setting and (4) island arc setting (Fig. 11)**.**

According to Mack (1984, p. 215) "The Hartselle should plot in the recycled orogen field on the provenance diagrams, ……. However, the Hartselle plots in the continental block provenance field on the QFL diagram, despite the fact that it was derived from an orogenic source". More precisely, Hartselle plots (Mack, 1984, Fig. 1) in the 'craton interior' of Dickinson et al. (1983). Now, according to Mack (1984, p. 215) "Hartselle was deposited in barrier-bar and shelf-bar environments …….. Marine reworking of the Hartselle is suggested by excellent rounding and sorting".

The stable continental margin is the site for development of passive margin basins, characterized by very slow rate of basin subsidence. As a result, the sediments, derived from a vast continental block, are accumulated along the continental shelf, and are exposed to prolonged subaerial processes. The chemically susceptible grains undergo alteration, and the resultant material is washed out by the continuous wave action leading to the concentration of mechanically and chemically stable components. The duration of subaerial exposure and climatic condition play the prime role here irrespective of provenance types. Hence, in the situation depicted by Mack (1984), the Hartselle sandstones, in spite of their orogenic source, plot within 'craton interior' of Dickinson et al. (1983), and that matches well with their deposition within passive margin basin.

The intracratonic rift, foreland and island arc settings, on the other hand, are tectonically active, and are characterized by high rate of basin subsidence. As a result, the metastable components like feldspar, lithic fragments etc. derived from the close vicinity are quickly buried, and are likely to be preserved. However, some of these metastable components may suffer mechanical breakdown or chemical alteration during diagenetic processes. In case of early cementation, the metastable components are preserved. As the sediment undergoes advanced stage of diagenesis, secondary matrices are formed at the expenses of the metastable framework grains, and the modal proportion of quartz tends to increase in the framework population. Hence, these rocks are to be studied with proper emphasis on the diagenetic signatures for proper interpretation of the tectonosedimentary history of the sand deposit. In case of pseudomatrix, which is quite common in litharenites, the nature of precursor lithic fragments can easily be identified, and it is important because identification of the lithic fragments can help in distinguishing between sandstones of foreland and island arc settings. Since the preservation potential is high, the composition of the sediments of these three settings bear strong imprints of the provenance. Presence of various supracrustal materials in the source terrain thus often lead to 'anomalous' (Mack, 1984) composition of the detrital modes not fitting well into the predictable models. One such anomalous composition cited by Mack (1984) is the of sandstones of Camp Rice Formation, which plot within arc provenance in the QFL diagram (Mack, 1984, Fig.1) despite the fact that these sandstones were deposited in a continental rift. The same sandstones plot within the dissected arc field of the revised QFL diagram of Dickinson et al. (1983), and the provenance problem could somehow be resolved. However, these remain out of the tectonic setting of deposition, and so 'anomalous'. Sandstones of multiple provenance with wide variation in supracrustal materials are obviously characterized by mixed populations of the detrital modes containing theoretically unexpected constituents. In any classification these populations are to be taken into consideration. The ultimate interpretation of the tectono-sedimentary history is never solely guided by the petrography, that may give some initial clues. Hence, 'anomalous' composition would rather help in recognition of the multiple interferences.

The present proposal

Each sandstone is truly a product of multivariate system. Factors like provenance, depositional medium, climatic conditions, burial history and diagenetic processes leave their respective imprints within the resultant deposit. Each aspect must be given proper weightage for correct identification of the stages of formation of a sandstone. No thumb rule thus works properly in standardisation of either the descriptive or the genetic parameters for all varieties. Characterization of the sandstone varieties of different tectonic settings by Dickinson and Suczek (1979) made a significant contribution in categorization of the sandstone varieties within a genetic framework. The described four tectonic settings – (1) stable continental margin setting (passive margin), (2) intracratonic block faulted setting, (3) foreland setting, and (4) island arc setting are of high preservation potential and covers major part of the available sandstone deposits. Since the sandstone types were defined with reference to quartz, felspar and lithic fragments, a combination of these well accepted descriptive parameters with the tectonic setting may lead to formulation of an ideal classification of sandstones. Critical analysis of the QFL diagram of Dickinson and Suczek (1979) (Fig. 11) reveals that the sandstones of stable continental margin setting are characterized by quartz content of more than 85 percent.

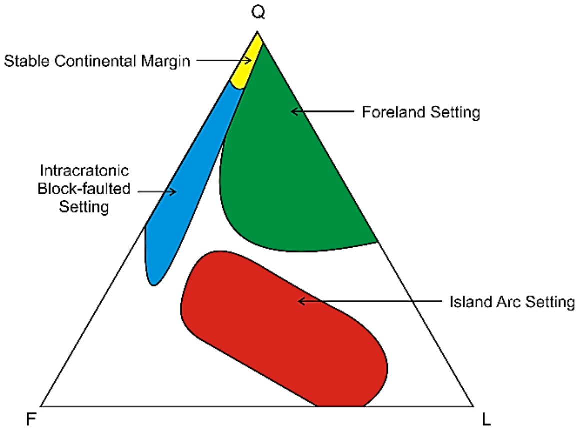


Figure 11. QFL diagram showing the fields of framework modes of sandstones of different tectonic settings. [Modified after Fig. 1 of Dickinson and Suczek (1979).

Very few sandstones of foreland setting fall within this field. The quartz content of majority of the sandstones of foreland setting and intracratonic block faulted setting varies between 40 and 85 percent. A few sandstones of intracratonic block faulted setting and the sandstones of island arc setting contain quartz less than 40 percent. Hence, in the first step these sandstones can be classified based on quartz content and two distinct boundaries can be drawn at quartz content of 40 and 85 percent. Now if the QFL diagram of Dickinson and Suczek (1979, Fig.1) is compared with the scheme of sandstone classification as proposed by Folk et al. (1970), it is found that in sandstones of intracratonic block faulted setting the felspar is to lithic fragment ratio remains greater than 3:1. On the other hand, for majority of sandstones of foreland setting this ratio lies below 1:3. The major representatives of sandstones of island arc setting are characterized by the felspar is to lithic fragment ratio lying between 3:1 and 1:3. So the felspar is to lithic fragment ratio as proposed by Folk et al. (1970) appears to have some genetic bearings. Hence, in view of these observations the scheme proposed by Folk et al. (1970) can be modified to get an analytical descriptive classification with some genetic implications. A new scheme (Fig. 12) of sandstone classification is being proposed with nine categories identified with well-defined genetically meaningful framework composition with reference to the sandstone composition of different tectonic settings as proposed by Dickinson and Suczek (1979) and putting them in a structure modified after the descriptive classification proposed by Folk et al. (1970).

1. Quartz arenite: Quartz content is ≥85 percent, felspar and lithic fragments may constitute the rest ≤15%. The sandstones of stable continental margin setting fall within this category.

2. Quartzo felsarenite: Quartz content varies between 40 and 85 percent, felspar content is greater than three times that of lithic fragments. Majority of the sandstones of intracratonic block faulted setting fall within this category.
3. Quartzolithic felsarenite: Quartz content varies between 40 and 85 percent, felspar is to lithic fragment ratio lies between 3:1 and 1:1. This variety is represented by some of the sandstones of foreland setting.
4. Quartzofelspathic litharenite: Quartz content varies between 40 and 85 percent, felspar is to lithic fragment ratio lies between 1:1 and 1:3. This variety is also represented by some of the sandstones of foreland setting.
5. Quartzo litharenite: Quartz content varies between 40 and 85 percent, felspar content is less than one-third of the lithic fragment content. This variety is represented by most of the sandstones of foreland setting.
6. Arkose: Quartz content is less than 40 percent, felspar content is greater than three times that of lithic fragments. A few of the sandstones of intracratonic block faulted setting may fall within this category.
7. Lithic arkose: Quartz content is less than 40 percent, felspar is to lithic fragment ratio lies between 3:1 and 1:1. Most of the sandstones of undissected island arc setting are of this composition.
8. Arkosic litharenite: Quartz content is less than 40 percent, felspar is to lithic fragment ratio lies between 1:1 and 1:3. All types of sandstone of island arc setting fall within this composition range.
9. Litharenite: Quartz content is less than 40 percent, felspar content is less than one-third of the lithic fragment content. Some of the sandstones of dissected island arc setting may show this this composition.

This classification, conveying both descriptive and genetic characteristics of sandstone types, can be considered as an ideal classification of sandstones.

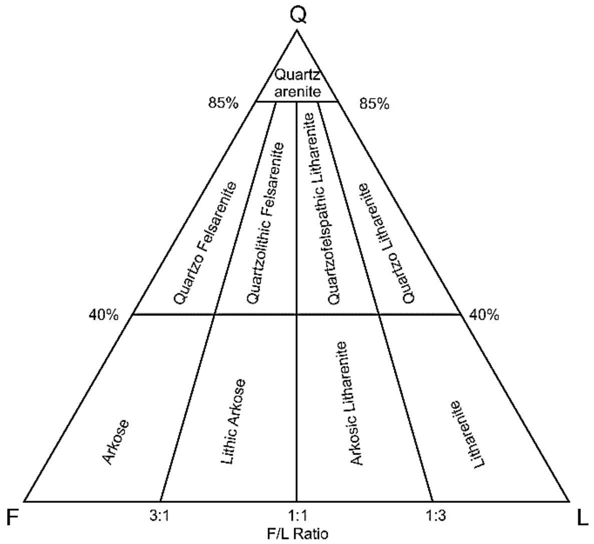


Figure 12. Classification of sandstones into nine different categories based on the major framework components quartz, felspar and lithic fragments.

Discussion and conclusions

Advancement of knowledge is only possible when the trend of development finds a proper line of evolution. The history of sandstone research, however, witnessed phases of retrogression with the reiterated efforts to introduce matrix, a subsidiary constituent, (presence or absence of which does not affect the status of a rock to be designated as a sandstone) as an important basis of the classification. Continuation of this effort, even after establishment of the fact that most of the matrix types are of secondary origin and do not bear the speculated 'genetic significance' related to the character of the depositing medium, the dogmatism for an old battle-scarred rock name *greywacke* becomes apparent. Since its introduction in 1785 by mine director F.W.H. von Trebra, the term graywacke (grauwacke in German; greywacke in American literature) remained at the centre of controversy as was expressed by Mawe (1818) "geologists differ much respecting what is, and what is not, Gray Wacce". Even after more than hundred and fifty years, the legacy was maintained through the suffix *wacke,* and was stretched to the extent (mud content up to 75%) that 'sand', the definitive constituent of a sandstone became the minor component. In this total journey only two descriptive classifications of arenaceous rocks were found free from this hangover – one proposed by McBride (1963) and the other by Folk et al. (1970). Based on the principles of triangular graph the classification scheme proposed by McBride (1963) has limited scope to be used for specific definition of each category of sandstone, and the scheme of Folk et al. (1970) stands out as the most rational descriptive classification of sandstones. Critical comparison between the QFL diagram of Dickinson and Suczek (1979) showing the defined domains of sandstone composition of different tectonic setting and the QFR diagram of Folk et al (1970) reveals that certain modifications of basic structure of this descriptive classification may help in accommodating sandstones of different tectonic settings with defined genetic implications. Accordingly, in the present study, a new scheme of classification has been worked out with nine distinct sandstone types with well-defined genetically meaningful framework composition of sandstones of all major tectonic settings. A real classification of sandstones is thus obtained by combining an operational genetic classification and an analytical descriptive classification.

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