



## Modified Folk Sandstone Classification

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### Article info

Original: 06.10.2015  
Accepted: 17.04.2016  
Published online:  
01.05.2016

#### **Key Words:**

*Folk classification,  
Modified Folk,  
Sandstone, Matrix*

### Abstract

The Folk's method of sandstone classification has been very commonly used by many sedimentologists. However, problems may be encountered using this method of classification. The problems include the size of matrix, the components used in the poles of triangular diagram, inability to classify some sandstone samples and the fact that the description of sandstone and its position in the diagram do not always match. In the proposed modified Folk classification, all of these problems have been resolved, the boundary between grain and matrix size is chosen to be 0.0625 mm, and if the matrix is 10 to 50%, wacke term is preferred. To use this term, it is enough to add wacke to sandstone name after omitting the arenite, if it was.

### Introduction

Classification and nomenclature of rocks both are necessary to facilitate communication and to organize our thinking (Pettijohn et al., 1972). Names contain a set of features that are easily remembered. There are several different systems for classifying sandstones, in most of which triangle diagrams are used.

Fisher (in Pettijohn et al., 1987) was the first to express sandstone composition by a triangle diagram. Krynine (1948) produced a composition triangle that considered only the detrital fraction and divided the sandstones into classes based on the three-component system. The end members are: (1) quartz, (2) feldspar plus kaolin, and (3) micas plus chlorite (including MRF's and matrix together). Based on the percentage of participation of each of these poles, five sedimentary rock types including orthoquartzite, arkose, low- rank greywackes, impure arkoses and high- rank greywackes are recognizable.

Folk (1951, 1954) redefined Krynine's classification by introducing the abundance of clay as an index of textural maturity. He noticed rocks such as arkose, in Krynine classification, with more than 35% feldspar could have a very wide range of textures. Therefore, he stated that this classification can't be sufficiently accurate and added to clan name a scale of maturity texture. Depending on the amount of clay and the sorting of the framework fraction, sandstones would be classed as immature, submature, mature, or supermature. Then, he (Folk, 1961) proposed the five-fold, textural maturity/mineralogical classification. These five properties are: grain size, chemically precipitated cements, textural maturity, miscellaneous transported constituents, and clan designation.

Gilbert (in Williams et al., 1954) classified sandstones based on both the composition of framework grains and the abundance of matrix. He divided sandstones into two broad groups: arenites, containing little or no matrix (<5%), and wackes, containing more than 5% matrix. Combining the matrix parameter with composition yields six kinds of sandstones: quartz arenites and wackes, feldspathic arenites and wackes, and lithic arenites and wackes.

Pettijohn (1954) in order to overcome the classification defect, with the assumption that the rock is composed solely of sand grains, framework, and intergranular voids that still remained vacant, presented a new method. In his method, framework, sand size, grains are made of quartz plus chert, feldspar, and rock fragments. By considering the ratios of quartz plus chert to total feldspar plus rock fragments ( $Q_{(R+F)}$ ), and feldspar to rock fragments ( $F_R$ ), combining with the matrix parameter, sandstones are classified into four major classes, greywackes, orthoquartzite, arkosic sandstones and lithic sandstones, and several smaller ones.

McBride (1963) revised sandstones classification and due to the problems of their use in the field and laboratory, introduced a new classification. His classification was based on detrital framework grains grouped into the three-end members (1) quartz plus chert and quartzite, (2) feldspar, and (3) fine-grained rock fragments exclusive of those in item 1. Detrital constituents, other than the three main components, such as mica, glauconite, or fossils, with considerable frequency, mentioned as the "miscellaneous transported constituents". Folk (1968) offered it with some modifications.

Dott (1964) defined matrix as all particles finer than 0.03 mm, and based on abundance matrix he divided sandstones into arenite (matrix <10%) and wacke (10 % < matrix <75 %) groups. Pettijohn et al. (1972) and Pettijohn (1975) modified Dott's classification. They classified sandstones based on grain types (grains can be quartz, feldspar or rock fragments) and abundance of matrix. In their diagram, the end members are quartz plus chert, feldspar, and lithic fragments (all rock fragments except chert). They divided sandstones, based on texture, into arenites (matrix <15%) and wackes (15 % < matrix <75 %). Based on the ratios of their grain types, wackes type includes greywacke (feldspathic graywacke, lithic graywacke), and quartz wacke. Arenites types are also divided into quartz arenite, sublitharenite, litharenite, arkose and subarkose. Litharenites are subdivided according to the lithic type into sedarenite, volcanic arenite and phyllarenite. Folk (1974, 1980) to follow Pettijohn et al. (1972) and Pettijohn (1975) changed distribution of the end members and moved chert fragments from the Q-pole to the R-pole, and granite plus gneissic fragments from the R-pole to the F-pole. Then, he introduced a new sandstones classification system according to chemical and mineralogical properties.

Folk (1980) classification is used to classify sandstones by several sedimentologists (e.g., Nichols, 2009; Carranza-Edwards, 2015). But his classification contains some problems. The aim of this paper is to demonstrate its problems and to present modified Folk classification.

### **Folk classification**

One of the popular sandstone classifications is that of Folk (1974, 1980). Folk classified sandstones based on three components. He used a main triangle and three sub-triangles for his propose (Figure: 1). There are Q, F and R letters in the poles of main triangle. The Q- pole consists of all types of detrital quartz grains (including metaquartzite except chert), the F- pole consists of all detrital feldspars (plus granite and gneissic fragments), and the R-pole includes metamorphic-, volcanic-, and sedimentary- rock fragments as well as chert. Based on the percentage of participations of the Q-, F-, and F- poles are known seven main sandstones types; quartz arenite, subarkose, sublitharenite, arkose, litharenite, lithic arkose, and feldspathic litharenite.

In this classification, sub-triangles are related to the origin of rock fragments or feldspars. Arkose term in arkose, subarkose and lithic arkose types based on feldspar mineral types is divided into alkali-feldspar arenite ( $K>P$ ) and plagioclase-arenite ( $K<P$ ). If the sandstone is a litharenite, a sublitharenite or a feldspathic litharenite, the percentage of rock fragments are re-calculated to 100% and attempt to identify the relative abundances of all rock fragments and plot the appropriate point in the R sub-triangle to obtain the appropriate clan name. If the sample falls in the sedarenite field, re-calculated all the sedimentary rock fragments to 100% and plot its point on the SRF sub-triangle. The relative abundances of sandstone fragments (Ss), shale fragments (Sh), detrital carbonate rock fragments (CRF), and chert fragments (Ch), determine whether the rock is a chert arenite, calcilithite, sandstone-arenite, or shale-arenite (Figure: 1).

### **Folk classification problems**

Folk classification has some problems. For example, according to the Folk (1974, 1980) classification, quartz arenite is the sandstone composed of more than 95% quartz. Also, in his description, sandstone with 5 to 25% feldspar or rock fragments, based on the F/R ratio is subarkose ( $F/R > 1$ ) or sublitharenite ( $F/R < 1$ ). In his diagram, subarkose and sublitharenite consist of 75 to 95% of Q-pole.

While, if a sample contains less than 5% feldspar (e.g., 4.5%) and less than 5% rock fragments (e.g., 4%), based on his description, it does not have a name, because the abundance of Q-pole is less than 95% (can't be quartz arenite) and the amount of the F-pole is less than 5% (can't be subarkose). Whereas, based on his diagram, it is subarkose ( $75\% < Q = 91.5\% < 95\%$ ) (example 1A; Figure: 1). If the amounts of QFR poles are changed from 91.5% to 90/1% (1A to 1B), the problem does not go away. But, when the amounts of either F- or R- poles are more than 5%, the name of rock based on his description and diagram are coinciding (examples 1C and 1D, table 1). These examples indicate following points:

1. In some case there is no compatibility between Folk's description and his diagram,
2. Some samples with QFRF components do not have name based on Folk's description, and
3. Based on Folk's description, the lower limit of quartz arenite can be changing from 95% to 90% of Q-pole.

Table- 1: Components of example 1 and their nomenclature based on Folk sandstone classification

Example	Q%	Components		Rock name based on Folk's	
		RF%	F%	description	diagram
A	91.5	4	4.5	No name	subarkose
B	90.1	4.95	4.95	No name	subarkose
C	89.9	4.9	5.2	subarkose	subarkose
D	94.9	--	5.1	subarkose	subarkose

According to the Folk's description, sandstones (example 2, Figure: 1) include 24.99% feldspar and less than this amount of rock fragments (from 0 to < amount of feldspar; here 5%) are subarkose. These indicate the lower limit of subarkose, unlike the diagram (above 75% quartz), could have less than 75% (between 50-75%) quartz. The same is true for sublitharenite. So, in the example above, unlike the Folk's diagram, sandstones with less than 75% quartz may be called subarkose or sublitharenite.

The other thing is about subarkose and sublitharenite samples; when sandstone samples include equals F and R percentages, for example, sandstone with 7% F-, 7% R- and 86% Q- poles, based on his classification (diagram and description) does not have a name.

There is a difference between his description and diagram for arkose, too. Folk (1980) states, arkose contains feldspar that exceeds rock fragments ( $F/R > 3$ ); and the abundance of feldspar is greater than 25%. His diagram indicates, arkose has less than 75% quartz and the  $F/R$  ratio is more than 3. While, a sandstone with 70% quartz, 24% feldspar and 6% rock fragments (example 3, Figure: 1), based on his description is subarkose (feldspar ranging from 5 to 25%), whereas in his diagram it is arkose (quartz less than 75% and  $F/R > 3$ ). This problem is also true for litharenite, feldspathic litharenite and lithic arkose.

In addition, grains with a small percentage may be contributed in the nomenclature. For example, a sample with 60% quartz, 4% chert, 5% detrital carbonate rock fragments, 4% sandstone rock fragments, 2% shale rock fragments, 12% volcanic rock fragments, 5% metamorphic rock fragments and 8% feldspar is a sandstone-arenite (sample 4A, table 1, Figure: 1). If the amount of sandstone rock fragments (changes from 4% to 2%) with an amount of shale rock fragments (changes from 2% to 4%) (sample 4B, table 2), or total amounts of sandstone and shale rock fragments (change from 6% to 4%) with amount of chert (changes from 4% to 6%) (sample 4C, table 2), or carbonate rock fragments (changes from 5% to 7%) (sample 4d, table 2), changed, the rocks are called shale-arenite, chert arenite or calcilithite, respectively (table 2).

Table- 2: Components of example 4 and their nomenclature based on Folk sandstone classification

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Components

Samples	Q%	F%	VRF%	MRF%	Sh-RF%	Ss-RF%	Calc-RF%	Ch-RF%	SRF%	Sum	Name
A	60	8	12	5	2	4	5	4	15	100	Sandstone-arenite
B	60	8	12	5	4	2	5	4	15	100	Shale-arenite
C	60	8	12	5	2	2	5	6	15	100	Chert arenite
D	60	8	12	5	4	--	7	4	15	100	Calclithite

Folk (1980) described chert arenite as the sandstone whose chert fragments are dominant detrital rock fragments. He also stated calclithite is a sedarenite containing more than 50% of detrital carbonate type. However based on his diagram, which was proposed, components with low percentage (e.g., example 4) can be in the nomenclature.

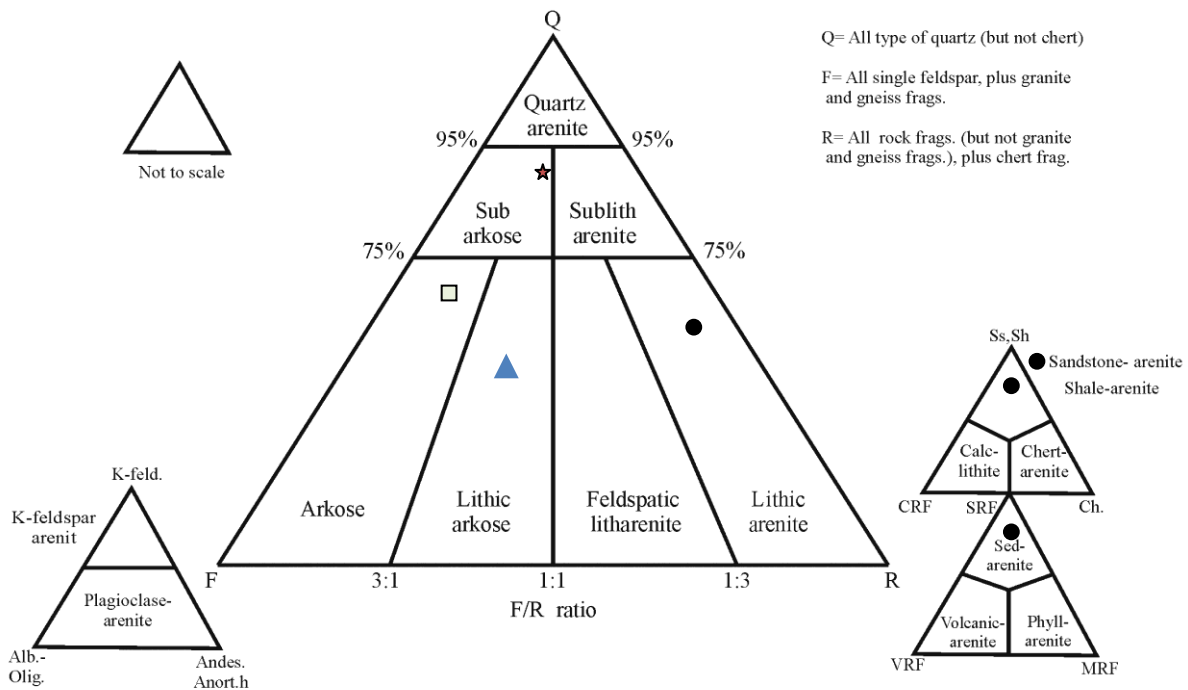


Figure-1: Folk (1974, 1980) sandstone classification. The star, triangle, square and circle shapes represent the position of the examples 1-3 and 4a in diagram, respectively.

Folk (1980) didn't consider matrix in his classification. But by considering the textural maturity in his five-fold classification, matrix size in his classification is less than 4μ. However, he also introduced the mica particles with less than 0.03 mm as the matrix. Thus, in his five-fold classification, particles with diameters between 0.0625 mm to 4μ or at least between 0.0625 to 0.03 mm have not been considered.

Also, there isn't logical relationship between five-fold sandstone and terrigenous (textural classification of gravel-bearing sediments) of Folk classifications. For example (example 5; table 3), samples A and B don't have same name in sandstone classification, but they have same name based on terrigenous classification.

Table- 3: Components of example 5 and their nomenclature based on Folk clastic classifications

Components	Rock name based on classification of
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Samples	Q% (sand size)	Mat.%	sandstone	texture of gravel-bearing sediments
A	97	3	Quartz arenite	Sandstone
B	91	9	Immature quartz arenite	Sandstone
C	89	11	Immature quartz arenite	Muddy sandstone
D	51	49	Immature quartz arenite	Muddy sandstone
E	49	51	No sandstone	Mudstone

**Modified Folk classification**

Folk (1974, 1980) in his classification used the percentage of Q-pole in the two sides of the QFR-triangle, and this caused some problems. For example (example 6; table 4), a sandstone consisting of 65% quartz, might be arkose (30% F and 5% R), lithic arkose (27% F and 8% R), subarkose (20% F and 15% R), sublitharenite (15% F and 20% R), feldspathic litharenite (8% F and 27% R), or litharenite (5% F and 30% R).

Table- 4: Components of example 6 and their nomenclature based on Folk sandstone classification

To overcome these problems in the modified classification, the percentages of the F-pole and the R-pole and

Samples	A	B	C	D	E	F
Q%	65	65	65	65	65	65
F%	30	27	20	15	8	5
R%	5	8	15	20	27	30
Name	arkose	lithic arkose	subarkose	sublitharenite	feldspathic litharenite	litharenite

25%), instead of Q percent (95% and 75%), have been used in the two sides of the modified QFR-triangle. The equivalent points of the two sides of the QFR-triangle have been connected similarly to the diagram of Pettijohn et al. (1987). The lithic subarkose (McBride, 1963) has been added to the modified diagram, too. Lithic-subarkose is the sandstone containing 5 to 25% feldspar and having "F/R ratio" between 3 to 1/3 (Figure: 2). The new field is good for sandstone samples with equals F- and R- poles percentages, for example sandstone with 7% F, 7% R and 86% Q poles.

In the modified diagram, three sub-triangles (on the Q-pole, R-pole and SRF-pole) and three lines (on the F-pole, IRF-pole and Ss,Sh- pole) are used for classification of sandstones. The sub-triangles and the lines are graded by using the ratios of each end member at 1:1, and the equivalent points in sub-triangles are connected. This has led each sub-triangle is divided into 4 fields with equal areas.

In this diagram a sub-triangle at the Q-pole, with poles for polycrystalline quartz (Qp), monocrystalline quartz of undulatory extinction (Qu), and monocrystalline quartz of non-undulatory extinction (Qnu) are added (e.g., Lewis and McConchie, 1994). After omitting the grains that do not participate in the poles of the sub-triangle and recalculated them to 100%, depending on the predominant framework composition, quartz arenites are broken down into Qu- quartz arenite, Qnu- quartz arenite, Qp-quartz arenite, and polyquartz arenite. Polyquartz arenite is the sandstone with diversity of quartz types.

The F-pole includes all monocrystalline feldspar, without granite and gneissic fragments. To determine source rocks, arkose based on  $K/P$  ratio has been divided into alkali feldspar arenite ( $K/P > 1$ ) and plagioclase arenite ( $K/P < 1$ ).

At the R-pole are grouped all igneous-, sedimentary-, and metamorphic- rock fragments. The sub-triangle, R, based on the amount of rock fragments are divided into igneous-arenite (e.g., Lewis and McConchie, 1994), sedarenite, phyllarenite and polyolitharenite (Folk, 1980). Polyolitharenite is a litharenite with subequally mixed of sand-sized sedimentary-, metamorphic-, and volcanic- rock fragments. Therefore, in the modified Folk classification, the rock fragments name is used in the nomenclature when its frequency is more than 50%, otherwise sandstone is called polyolitharenite (Folk, 1980). For example, a sample with 45% igneous rock fragments, 30% sedimentary rock fragments and 25% metamorphic rock fragments does not have a name similar to a sample consisting of more than 50% igneous rock fragments and the rest of other rock fragments. In the modified classification, they are called polyolitharenite and igneous arenite, respectively. All samples in the igneous arenite field, based on the ratio of volcanic (V) to plutonic (P) rock fragments are divided into volcanic arenite ( $V/P > 1$ ) and plutonic arenite ( $V/P < 1$ ).

If the point falls in the sedarenite field, after re-calculating all sedimentary rock fragments to 100%, then plot the appropriate point in the SRF-sub-triangle. This determines whether the rock is a chert arenite, calcithite, sandstone-arenite, shale-arenite or polysedarenite. The polysedarenite is a useful term for samples when the frequency of each pole is less than 50%. The samples lies in Ss-arenite or Sh-arenite, based on relative  $Ss/Sh$ , by using the graded line, are divided into sandstone-arenite ( $Ss/Sh > 1$ ) and shale-arenite ( $Ss/Sh < 1$ ).

In the modified Folk classification, quartz arenite is the sandstone which has less than 5% of either feldspar or rock fragments. Dott (1964) and Pettijohn et al. (1987) have applied this description to quartz arenite, too. Therefore, in the modified Folk classification, the lower limit of quartz arenite can be changing more than from 95% to 90% of the Q-pole components.

It is better to use this classification for sandstones with less than 10% matrix (e.g., Gilbert in Williams et al., 1954; Blatt and Tracy, 1996). If the amount of the matrix is between 10 to 50%, wacke term is preferred. To use this term, it is enough to add wacke to sandstone name in the modified classification after omitting the arenite, if it was (e.g., Gilbert in Williams et al., 1954). For example, if the subarkose includes 10 to 50% matrix, it is called subarkose wacke. The amounts of the 10% and 50% are obtained from the boundaries between sandstone-muddy sandstone, and muddy sandstone-mudstone (table 3), respectively, follow to Folk (1980) clastic classification for terrigenous sediments and Dott (1964). The samples with greater than 50% matrix, as Folk (1960) states, are called mudstones. Using these values will create a logical relationship between Folk's clastic classifications. Therefore, the wackes are the transitional group between arenites and mudstones. Pettijohn et al. (1987) have selected the amounts of 15% and 75% matrix as the boundaries between arenite-wacke and wacke-mudstone, respectively.

Although, to cover all detrital particles from sand to mud and ease to study, in modified classification, matrix is defined as detrital particles less than 0.0625 mm in size which corresponds to the usage of mud in descriptions of modern sediments (e.g., Tucker, 2001).

The terms introduced by Folk (1980) for rocks that do not logically fit QFR-triangle, such as "glauconite-arenite," and that with at least 10% of a grain type, other than the three main components, such as "micaceous quartz arenite" remain unchanged.

## **Conclusions**

(1) In the modified model, the components of the Q-pole remain unchanged and design the sub-triangle with Qp, Qu and Qnu poles for quartz arenite suites. The F-pole represents all type of monocrystalline feldspars, and the R-pole represents all igneous-metamorphic- and sedimentary rock fragments as well as chert fragments. In addition, using the amhounts of 5% and 25% (percentage of F- and R- poles) instead of 95% and 75% (percentage of Q-pole) ave caused to be classified all sandstones and coincident description of all sandstones with the modified triangle QFR.

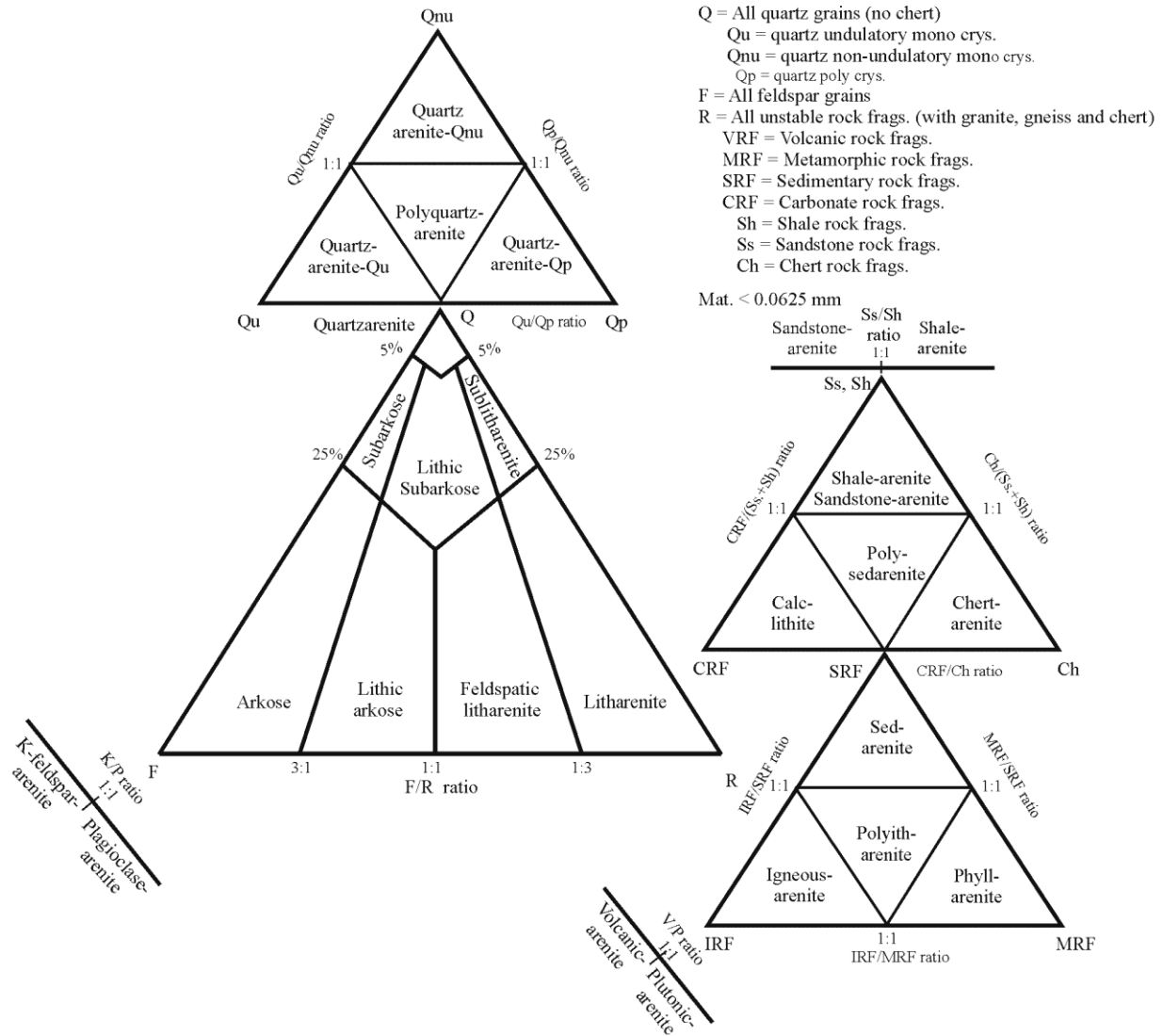


Figure-2: Diagram of modified Folk sandstone classification.

(2) The modified QFR-triangle is divided into eight main groups and based on diagram, quartz arenite is the sandstone which has less than 5% of either feldspar or rock fragments.

(3) In the modified Folk classification, sandstones are classified according to their texture and composition. In this classification matrix is clastic particles smaller than 0.0625 mm. So in this classification, all particles less than sand size have been considered as a matrix. Sandstones, based on matrix amount, are divided into arenite (<10% matrix) and wacke (10% to 50% matrix) groups. Accordingly, wacke is the synonym for muddy sandstone (example 5; samples D and E). To use wacke term, it is enough to add wacke to sandstone name in the modified classification after omitting the arenite, if it was. It is better to use the particles frequency less than 10% and the size smaller than 0.0625 mm for matrix in textural maturity, too. Using these values will create a logical relationship between Folk clastic classifications.

(4) In the Folk sandstone classification, the rock name has been changed by a small change in percentage of particles. But in the modified classification, the rock name is changed when the percentage of one of the poles of sub-triangles is more than 50%. Otherwise, the prefix "poly" will be added to rock name.

## **Acknowledgments**

I am deeply grateful to organizing committee of Geo Kurdistan II, particularly Dr. Ibrahim Jaza, two reviewers and Dr. Sirwan H. Ahmed. I also thank Sharmin Zaheri for her valuable assistance during this study.

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