Use of feldspar grains in provenance determination and the study of transportation and depositional history, examples from central and NW Iran

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Abstract
Feldspar grains, as a significant provenance indicator, of two terrigenous formations from Central Iran, the Upper Red Formation, and Moghan area, Zivah Formation, are used for provenance determination and the study of transportation and depositional history. The Upper Red Formation (URF) is volumetrically the most important siliciclastic unit of the Central Iran and Zivah Formation (ZF) represents the most important hydrocarbon reservoir in northwest Iran. Two representative sections of the URF in the southern foot hills of Central Alborz and three representative sections of the ZF in the northern foot hills of Talesh Mountains are investigated in this study. The sections represent best outcrops of the formations in their basin margin. Chemical composition, zoning and twining are the main characteristics of the feldspar grains used for this study. Results from facies analysis of the formations show that ~68% of the URF and ~73% of the ZF facies are suitable for this study, for having considerable amount of feldspar grains (>5% detrital feldspars). Results from the study of chemical composition, zoning and twining of detrital feldspars of the URF facies indicate dominance of intermediate (andesite to dacite) volcanic rocks in their source region. In the same way, volcanic sources with dominance of basic to intermediate rocks (basalt to andesitic basalt) are determined as provenance of the ZF facies. These results point to the Eocene age volcaniclastic-dominated Karaj Formation (green series) as major source of the URF facies and the Eocene volcanics of the Talesh Mountain (Talesh series) and Middle Eocene Peshtasar Basalt as major sources of the ZF facies. Comparison of the composition, zoning, and twining of the detrital feldspars with those of proposed sources indicate higher alteration/modification of the feldspars of the URF facies. Greater alteration/modification of the feldspars of the URF facies, despite their less humid and warm depositional condition, is related to more rapid deposition and shorter transportation of the ZF facies. These results indicate greater subsidence of the ZF basin and/or uplift of its source region than that of URF. Greater structural deformation of the Moghan area than Central Alborz during development of the studied formations is understood from this study.

Key Words: *Feldspars, provenance, Upper Red Formation, Zivah Formation, Central Iran, Moghan area*

Introduction

Feldspar grains are known as the most important unstable minerals in the terrigenous rocks, which presence necessitates special conditions in the source region, transportation pathway, and post-depositional history (e.g. Folk 1980; Zuffa, 1985; Pettijohn *et al.,* 1987; Tucker 1991). They are important provenance indicators in sedimentary rocks, because of their relative abundance and variable physical and chemical properties (e.g. Sibley and Pentony 1978; Helmold 1985; Pettijohn *et al.,* 1987; Haughton *et al.,* 1991). Chemical composition, twinning, zoning, and structural-state are the main properties used in such studies (e.g. Pittman 1963, 1970; Trevena and Nash 1979, 1981; Maynard 1984). The first 3 characteristics are employed here for provenance determination and the study of transportation and depositional history of two terrigenous formations from central (Upper Red Formation) and northwest Iran (Zivah Formation). The structural-state determination is of little value for plagioclase grains (Helmold 1985), particularly in Ca-rich types (Hutchison 1974), that are dominant feldspars of the studying rocks.

The Upper-Miocene URF is volumetrically the most important siliciclastic unit in the Central Iran. Results from provenance studies have shown that the main detrital components of this formation in the north margin of its basin are derived from Eocene age volcaniclastic-dominated Karaj Formation (also known as green series), the Oligo-Miocene Qom Formation, and the Lower-Miocene Lower Red Formation (LRF) (Amini, 1997). These formations are exposed in the southern part of the Central Alborz Mountains. Significant outcrops of the URF in the south foot hills of the Central Alborz provide a great opportunity for the study of structural deformation and evolution history of this mountain range (e.g. Axen *et al.,* 2001; Allen *et al.,* 2003; Guest *et al.,* 2006; Brunet *et al.,* 2009; Green *et al.,* 2009).

The Oligo-Miocene Zivah Formation (ZF) is the most important siliciclastic unit in northwest Iran (Moghan area), for being hydrocarbon reservoir (e.g. Willm *et al.,* 1961; Narani 1968; Fotohi 1973). Results from sedimentary petrology, depositional environment, and sequence stratigraphic studies of the Zivar Formation (Amini 2003, 2006, 2009) indicate its development in the fluvial-dominated deltas on the south margins of the Para-Tethys, which were regularly receiving sediments from south/southwest mountains (Talesh to Lesser Caucasus). This is the best exposed formation in the north foot hills of the Telesh Mountains, suitable for the structural evolution study of the Moghan area and South Caspian region (see Allen *et al.,* 2002; Brunet *et al.,* 2003; Morton *et al.,* 2003; Egan *et al.,* 2009; Brunet *et al.,* 2009; Green *et al.,* 2009).

This study aims to use the chemical and textural properties of detrital feldspars of the studied formations for provenance determination and to compare transportation and depositional history in the Central Alborz and Talesh Mountains. The study is part of a wider project which aims to compare the provenance of Neogen siliciclastic deposits in Central Iran with their counterparts in the Moghan area. Results from the present study, are expected to provide a fundamental base for comparison of these two settings in terms of structural deformation, subsidence/uplift rate, and palaeoclimate history.

Geological Setting

The Central Iran is one of the 9 major geological zones of Iran (Nabavi, 1976) that is bordered by major W-E trending faults in the north, NW-SE trending faults in the south/southwest and N-S trending faults in the east. Southwest Iran is considered to be part of the Arabian Plate that has subducted beneath central Iran along the NW-SE trending, Zagros thrust belt (Berberian & King 1981). The Eocene volcanic belt (one of the major geological zones) represents the volcanic arc and the adjacent parts of the Central Iran make up the back arc setting (Nabavi, 1976). The URF derives its name from its colour and position, as the topmost of two terrigenous units that sandwich the carbonate-dominated Qom Formation (Fig. 2) (Gannser, 1955). The topmost beds of Qom Formation are Burdigalian in age (Amini 1991). Lignite beds, interlayered with the topmost part of the URF in the northwest of the basin contain the Pontian flora and fauna (Rieben1966; Nabavi 1976) suggesting Tortonian to Pontian age for the URF. This formation extends over a much wider area than other Cenozoic deposits in the Central Iran and displays a highly variable thickness, from a few hundred up to 6000 metres (Huber, 1959).

Results from provenance and depositional environment studies of the URF indicate its development in a number of alluvial fans to ephemeral fluvial systems which were discharging the eroded sediments from bordering mountains in the north/southwest to the Central Iran basin (Amini, 1997). The best exposures of the formation are observed along the northern and southern margins of the Central Iran. In this study 2 inclusive and structurally less deformed sections of the northern margin are selected for detail description and sampling (Fig. 1).

The studied sections of the formation (Bone-Kuh and Evan-e-Key) are located in the south foothills of Central Alborz (Fig. 1), in which the thickness of formations is measured 3.5 and 5km, respectively. The formation is comprised of mudstone, gypsiferous mudstone, gypsum lenses, sandstone and conglomerate, which the last two are characterized by dominance of often-fresh feldspars. Direction of cross-beddings, asymmetrical ripples, flute casts, gutter casts and trends of parting lineations and channels indicate that these marginal deposits were derived from highlands immediately to the north (Amini 1997).

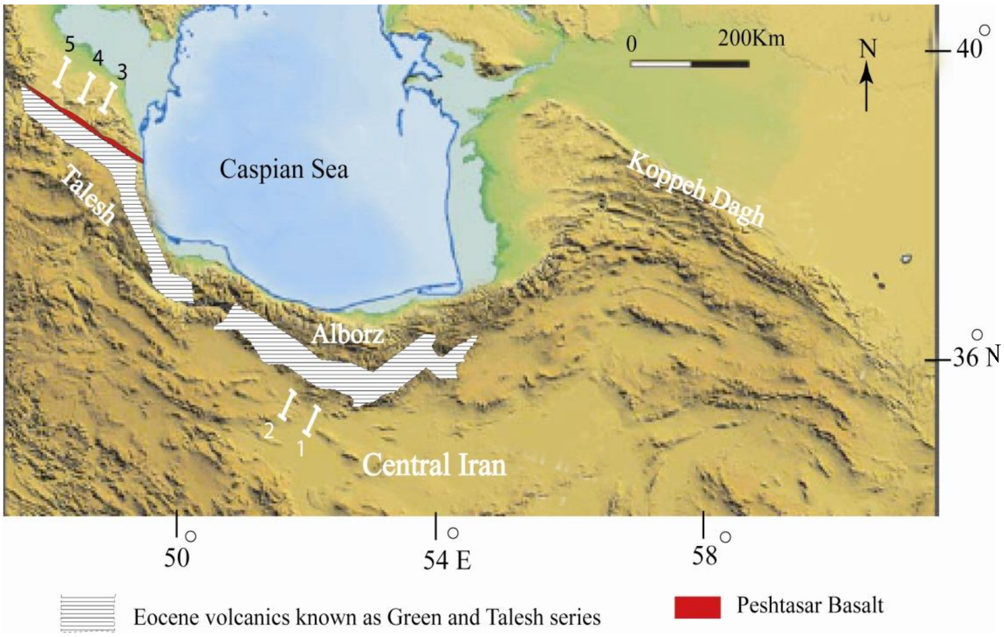

Figure 1: Location map of the studied sections, shown by white I shape lines (1= Bon-e- Kuh, 2 = Evan-e-Kay, 3= East Moghan, 4 = Central Moghan, 5 = West Moghan) in the Central and NW Iran. Position of the green and Talesh series are redrawn from GSI 1986. The Peshtasar Basalt is not scaled in this figure

The studied area in northwest Iran, known as Moghan area, is located at latitudes of 39.00º to 39º45´N and longitudes of 46º42' to 48º30'E (Fig.1). This area characterizes the northern flank of Talesh-Lesser Caucasus orogens, and the southern margin of the Kura Basin, that is known as a back are setting (Brunet *et al.,* 2009).

A strong extension in the Eocene, that was associated with E-W trending normal faulting, resulted in development of volcaniclastic-dominated rocks in the Central Alborz (Green Series) and thick volcanic to volcaniclastic rocks (Talesh Series) in the Talesh and Lesser Caucasus region (Brunet *et al.,* 2009). Such extension is well evidenced by emplacement of E-W trending, Middle Eocene, Peshtasar Basalt throughout the Moghan area (Figs. 1 & 2).

Compressional deformations related to the Arabian-Eurasian collision in Late Eocene to Early Miocene (Brunet *et al.,* 2009) resulted in the uplift of the Talesh/Lesser Caucasus Mountains and significant sediment supply to the environments along the southern margin of the Kura Basin. The Oligo-Miocene age Zivah Formation is the result of deposition in fluvial dominated deltas along the southern margin of this basin (known as Para-Tethys), which was characterized by rapid subsidence of the basin floor, uplifting of the surrounding mountains, and high sediment supply from south/southwest (Amini, 2003, 2006, 2009). The studying sediments here are time equivalent of major reservoir units (Mikop Series) in Azerbaijan (Willm *et al.,* 1961; Reynolds *et al.,* 1996; Brunet *et al.,* 2003).

The Zivah Formation is related to Middle Oligocene to Middle Miocene (Mogharebi, 1972, Willm *et al.*, 1961) based on the paleontological studies of its facies and neighboring Ojaghgeshlagh and Turtonaian deposits (Fig. 2). It is characterized by dominant sandstones and conglomerate facies, all rich in feldspar grains, with common mudstones and minor coal seams (see Amini, 2003). The formation has significant outcrops in the Moghan area, from which 3 sections in the east, west, and central part of the area were selected for this study (Fig. 1)

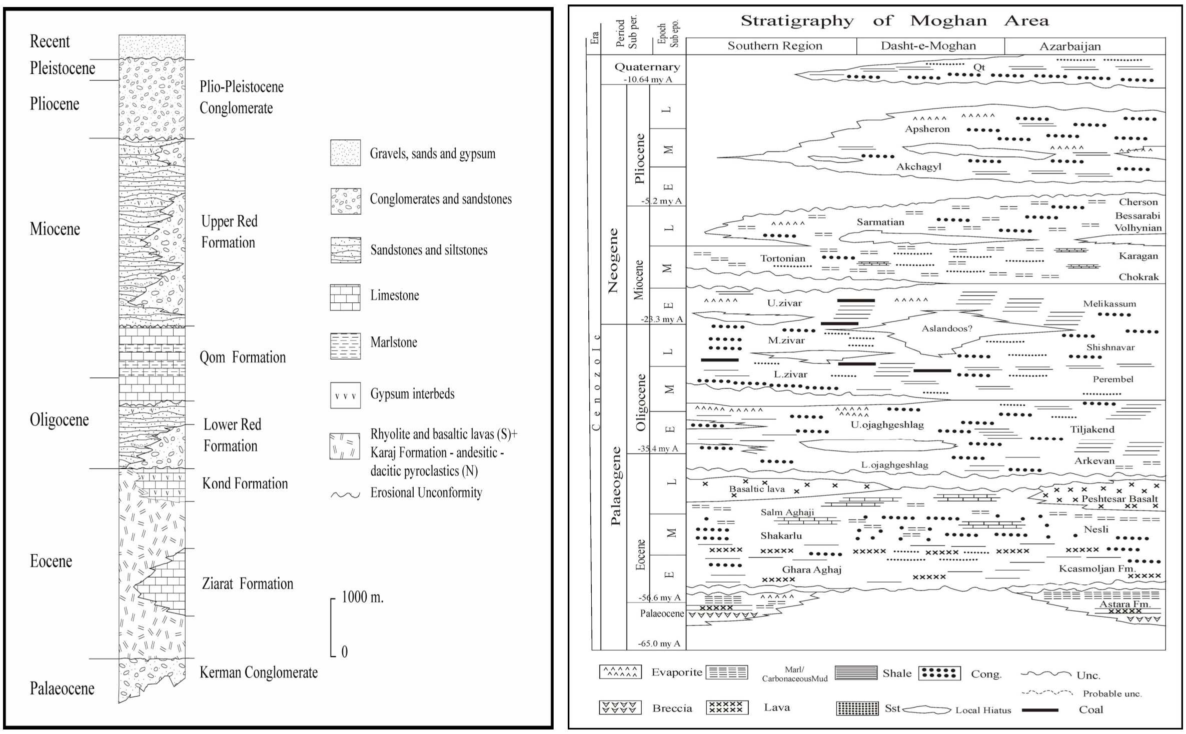

Figure 2: Position of the studied formations on simplified Cenozoic stratigraphic columns of the Central Iran (left) and Moghan area (right). The stratigraphic column of the Moghan area is from Amini, 2003.

Methodology

Sampling based on lithological variation was carried out in the selected sections, two sections in the Central Iran and three sections in the Moghan area (Fig. 1). Using petrographic screening, samples containing more than 5% feldspar were selected for petrographic, SEM studies and chemical analysis. Assignment of the feldspars into oscillatory zoned, progressively zoned, or unzoned categories was made by point-counting procedures using the methods of Pittman (1963, 1970). Feldspars were categorized into C- twinned, A-twinned, or untwinned following Gorai (1951). Two to three samples from each petrofacies (facies recognised in petrographic studies) were analyzed until 100 feldspars were counted. Low abundance of feldspars in some samples necessitated point-counting of more than 3 thin sections in order to reach the required number.

For chemical composition 630 feldspar grains from 30 samples (average 3 samples from each facies) of the Central Iran and 470 feldspars from 39 samples (from 13 facies) of the northwest Iran were analyzed. Samples with minimum alteration effects were selected for this purpose.

A Scanning Electron Microscope, Jeol model JSM6400, equipped with computer based energy dispersive X-Ray analyzer (Link EXL) in the Manchester University, was used for the samples from Central Iran. Analytical conditions were as follows: acceleration voltage 15 Kv, sample current 1.5 nA, working distance 39mm with beam diameter of less than 1μm. Two analyses, one in the grain centre and one at the grain margin, excluding the grain overgrowths, were made for each crystal and the average reported as grain composition (Trevena & Nash 1981). The extracted feldspars from the samples of Moghan area were analyzed by XRF and ICP in the chemistry department of university of Tehran, for their chemical composition. In both areas, analyses with total weight percentage of less than 95% and more than 101.5% were eliminated (Trevena and Nash 1979, 1981). The An, Ab, and Or content of the samples are achieved by calculation of CaO/(CaO+Na2O+ K2O), Na2O/(CaO+Na2O+ K2O), and K2O/(CaO+Na2O+ K2O) ratios respectively (Trevena and Nash 1979, 1981).

To evaluate the reliability of feldspar grains in provenance determination, results for provenance determination of the studied facies are continuously compared with those of previous works (Amini, 1997, 2003). Characteristics of the detrital feldspars in representative samples are compared with those of proposed source rocks (Eocene volcanic in the bordering mountains of the studies sections) to identify any changes that may have taken place during their weathering, transportation and/or deposition.

Facies Characteristics

Sedimentary structures, geometry, macrofossils , trace fossils, and the nature of strata surfaces were investigated in the field studies of the rocks. Textural properties of the rocks, their mineralogical composition and microfossil content were studied in the lab, using petrographic methods. Results from field and laboratory studies were put together for a comprehensive description of the constituent facies (cf. Walker & James, 1992; Reading and Levell, 1996: Selley, 1996). Some 12 terrigenous facies including 2 coarse-grained (conglomerate), 8 medium-grained (sandstone), 2 fine-grained (argillaceous), and 1 evaporitic facies were determined in the URF of Central Iran, which characteristics are shown in table 1 (see Amini, 1997 for details).

Table 1: General characteristics of the URF facies and their abundance in the studied sections of Central Iran. Freq. = Frequency, FW = Framework, Q= Quartz, Lv = Volcanic lithics/glasses, Ls = Sedimentary lithics, Opq. = Opaque minerals, Fe/Mg = Fe/Mg minerals, Ca. = Calcite, Zeol., Zeolite, Fe = Iron oxide.

Facies	General description	Facies freq.	Feldspar freq. in FW	Other components of the Framework (FW)
Gm	Massive to crude stratified, poorly sorted, texturally and mineralogically immature paraconglomerate, with ~17% matrix and ~20 cement	3	15	Q, Lv, Ls, Opq., Fe/Mg 16 60 5 3 1
Gmp	Massive to crude stratified poorly sorted, texturally and mineralogically immature, pebbly (mud rip up clast) ortho conglomerate with 4-12 % matrix and 21-25% Ca cement.	2	18	17 58 4 2 1
St	Trough cross stratified (crude), convoluted in places, moderate to poorly sorted, texturally and mineralogically submature, volcanic arenite, with ~ 5% matrix and ~14% Zeol. Cement.	7	15-27	18 37 10 5 3 to 38 32 9 4 1
Sp	Planar stratified (crude), locally convoluted, poorly sorted, texturally and mineralogically submature, pebbly volcanic arenite, with ~ 10% matrix and ~17% Ca. cement.	12	10-32	8 65 5 3 1 to 19 34 4 4 2
Spm	Mud rip up clast rich, massive to crude stratified, feldspathic arenite, with ~ 11% matrix and ~35% Ca. cement.	3	25-46	8 41 2 3 1 26 18 20 7 3
Sm	Massive, locally matrix supported, poorly sorted, texturally and mineralogically immature feldspathic grey wacke, some SSD and RA, with ~ 36% matrix and ~14% Ca. cement.	8	30-39	18 25 17 8 4 to 21 11 20 7 2
St/c	Trough cross stratified mostly convoluted, moderate to poorly sorted, texturally and mineralogically submature, feldspathic grey wacke, with ~ 16% matrix and ~15% cement (Ca.> Fe.)	2	25-30	17 25 18 5 5 to 19 22 15 7 6
Se	Erosional scour fill, poorly sorted, texturally and mineralogically immature feldspathic arenite, with ~ 8% matrix and ~39% cement (Ca.> Fe.)	10	31-45	11 34 2 6 2 to 17 29 13 7 3
Sl	Low angle cross stratified (crude), poorly sorted, texturally and mineralogically immature feldspathic wacke, with ~ 37% matrix and ~13% cement (Ca.> Fe.)	13	24-33	23 16 14 9 5 to 24 11 25 11 4
Sr	Ripple cross stratified, poorly sorted, texturally and mineralogically submature feldspathic arenite, with ~ 7% matrix and ~28% cement (Ca.> Fe.)	8	20-24	23 22 22 5 4 to 18 25 14 3 5
Fl	Fine laminated physilitic mudstone, gypsiferous in places, alternate with thin lenses of gypsum locally	5	____	____
Fm	Massive mudstone, red to pink, gypsiferous in places, thin lenses of sandstone (Sh)	25	____	____
Ev.	Gypsum with thin lenses of mud, highly deformed, green to blue/brown in colour, thin lenses of Sh.	2	____	____

All coarse- and medium-grained facies of the formation (that construct ~68% of the formation) are involved in this study for having noticeable feldspar content (Table 1).

In the same way, 17 terrigenous facies including 4 conglomerates, 9 sandstone, and 4 argillaceous types and a coal facies were determined in the ZF of Moghan area (see Amini, 2003 for details), which characteristics are shown in table 2. All coarse and medium grained terrigenous facies (that construct ~73% of the formation) contain more than 5% feldspar (table 2), so they are involved in this study.

Table 2: General characteristics of the facies of Zivah Formation and their abundance in the studied sections of northwest Iran. Symbols are the same as those in table 1.

Facies	General description	Facies freq.	Feldspar freq. in FW	Other constituents of the Framework (FW) Q, Lv, Ls, Op, Fe/Mg
Gt	Pebble to cobble size, trough stratified poorly sorted, texturally and mineralogically immature, ortho-conglomerate.	2	14	13 70 8 4 3
Gm	Massive to crude stratified poorly sorted, texturally and mineralogically immature, ortho-conglomerate	7	14	15 64 12 6 4
Gmp	Mud rip-up clast rich, massive, poorly to moderately sorted, texturally and mineralogically immature, orhto-conglomerate with plant debris.	3	17	14 57 15 5 2
Gms	Matrix supported, massive, paraconglomerate. Other characteristics similar to Gm.	4	15	15 60 5 3 2
St	Cross stratified, moderate to poorly sorted, texturally and mineralogically immature, sandstone. Volcanic arenite to tuff in the petrographic studies	7	22	23 40 10 3 2
Sp	Cross stratified, moderate to poorly sorted, texturally and mineralogically immature, pebbly sandstone. Feldspathic arenite/arkose in the petrographic studies	8	32	16 20 18 8 6
Spm	Mud rip-up clast rich, pebbly sandstone. Carbonate lithic greywacke in the petrographic studies	12	18	22 18 25 10 7
Sh	Parallel laminated, poorly sorted, texturally and mineralogically immature, medium to fine sandstone, volcanic greywacke in the petrographic studies	4	17	17 45 13 5 3
Sr	Ripple cross laminated, poorly sorted, texturally and mineralogically immature sandstone. Feldspathic wacke in the petrographic studies	3	25	16 28 18 8 5
Sl	Low angle (4-5^o) cross laminated sandstone. Lenticular and wacke appearance in places (scour fills). Feldspathic wacke in the petrographic studies	3	29	23 20 12 11 5
Sm	Massive sandstone. Poorly sorted, texturally and mineralogically immature with erosional base. Abundant plant remains and reactivation surfaces.	15	31	15 27 10 10 7
Se	Erosional scour fills, poorly sorted, texturally and mineralogically immature sandstone. Feldspathic wacke in the petrographic studies.	2	32	18 24 13 7 6
So	Organic rich massive sandstone. Characterized by abundant plant remains and coal seams. Volcanic greywacke in the petrographic studies	3	30	13 42 12 2 1
Fl	Fine laminated physilitic mudstone. Abundant soft sediments deformation. Plant remains are common.	5	——	——
Fm	Massive mudstone. Red to black, abundant SSD. And plant remains.	13	——	——
Fo	Organic rich mudstone to shale. Abundant plant remains and coal seams. Black to grey in color..	5	——	——
Fc	Calcareous mudstone/shale. Abundant microfossils and shell fragments. Physilitic in nature.	3	——	——
C	Coal, thin laminated, few mm to few Cm thick.	1	——	——

Composition of the Feldspar grains

Most unaltered to least altered feldspars of the studied facies, as individual grains or phenocrysts within the volcanic lithics, were analyzed for their major elements. The average percent of An, Ab, and Or values was calculated for each sample, totaling the An+Ab+Or to 100%, and plotted on ternary diagrams (Fig. 3a). Nearly pure albite and K-feldspars are excluded from consideration here because of high probability of their being authigenic in origin (cf. Land & Milliken 1981).

The percentage of plagioclase grains exceeding An50 in the URF of Central Iran is

31% as compared to 52% in the ZF of northwest Iran. The mean anorthite contents are 41.25% for the feldspars of the URF facies, representing andesine, and 54.44% for those of ZF facies, lying just within the labradorite range. The overall compositional range is greater in the URF facies than in the ZF (Fig. 3b), most likely reflecting a wider range in the source rocks' composition.

Frequency curves of the feldspars composition are shown in Fig. 4. In the ZF facies a unimodal distribution records the highest frequency for feldspars with ~58% An (labradorite). Whereas, the frequency curve for the feldspars of the URF facies is bimodal. Labradorite is again present but less significant than andesine (35% An) which comprises the major mode (Fig.4).

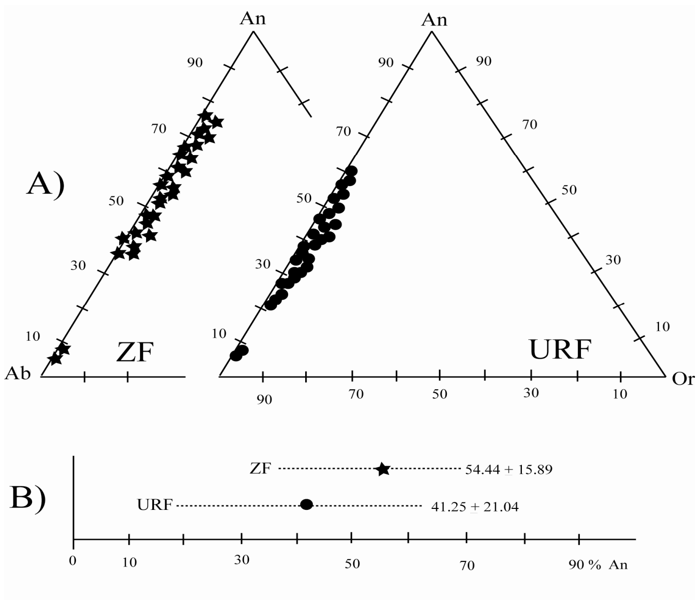

Figure 3: A:Ternary diagrams illustrating the composition of detrital feldspars from Zivah Formation (ZF) and Upper Red Formation (URF). Each point represents mean value of 10-30 analyses. B: Compositional range and mean values for detrital feldspars of the studied formations.

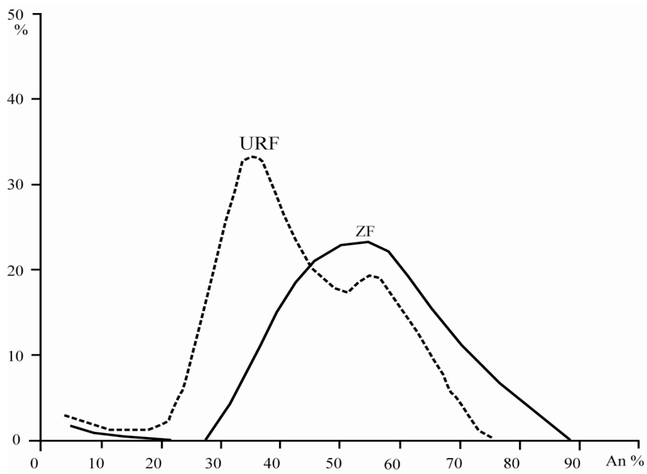

Figure 4: Frequency curves representing the feldspars distribution in the studied formations. Anortite content is measured in 10% intervals. Feldspars with ~ 58% An (Labradorite) have greatest frequency in the ZF facies, whereas andesine (~35% An) has greatest frequency in the facies of URF.

Zoning of the Feldspar grains

Zoned K-feldspar was not observed in the studied facies. All feldspars were examined for; oscillatory zoning, where successive thin bands of alternating extinction are obvious under crossed nicols; progressive zoning, where a broad wave of extinction is observed; and no zoning (Fig. 5).

Oscillatory zoned feldspars are more common in the facies of ZF, whereas unzoned feldspars are more common in the facies of URF (Fig. 6a). The proportion of progressive zoning is nearly similar in the feldspars of both formations (Fig. 6b). In general, the range in abundance of the studied zonings in feldspars of the URF is greater than those of ZF (Fig. 6b), that seems to be due to the wider range of the URF source rocks' composition.

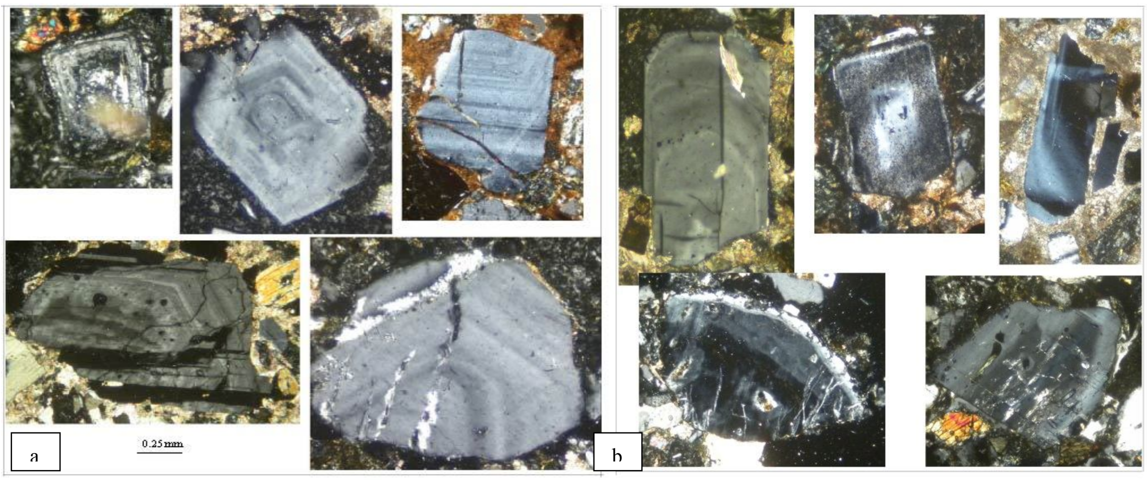

Figure 5: Representative photomicrographs of the oscillatory zoned (a) and progressive zoned (b) feldspars in the facies of studied formations. All figures are in XPL.

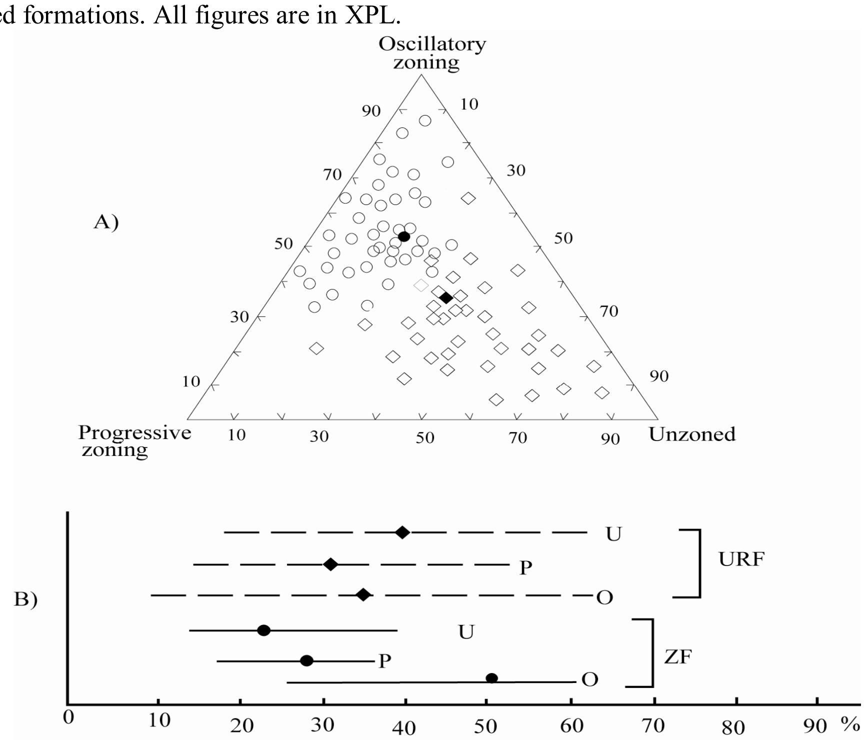

Figure 6: A: Distribution of zoning types in detrital feldspars of the ZF (open circles) and the URF (open rhomboids) facies. Each point represents mean values of 1-10 thin sections. Solid circles and rhomboids represent the mean values for each group. B: Range in abundance of oscillatory (O), progressive (P), and unzoned (U) feldspars and mean value for each group (solid circles and rhomboids).

Twinning of the Feldspar grains

Following the definitions given in the literature (e.g. Gorai, 1951), all plagioclase crystals twinned on the albite, pericline or acline laws are called A-twinned and those include simple twins and their modifications (Manebach, Baveno, Parallel, and complexes) are called C-twinned (Fig. 7).

The relative frequency of A-twinned, C-twinned, and untwinned feldspars in the facies of studied formations are shown in figure 8. In terms of twining, the feldspar grains of the studied formations show nearly similar characteristics, nevertheless, there is a tendency for C-twins to be more common in the facies of ZF (Fig. 8). Greater variety in twining of the feldspars of the URF is evident, that again reflect greater variety of rocks' composition in the source area. While comparing with feldspars from known sources (e.g. Gorai, 1951), the feldspars from both formations represent intermediate to volcanic origin. The untwined feldspars are rare or highly obscured by alteration products in both formations.

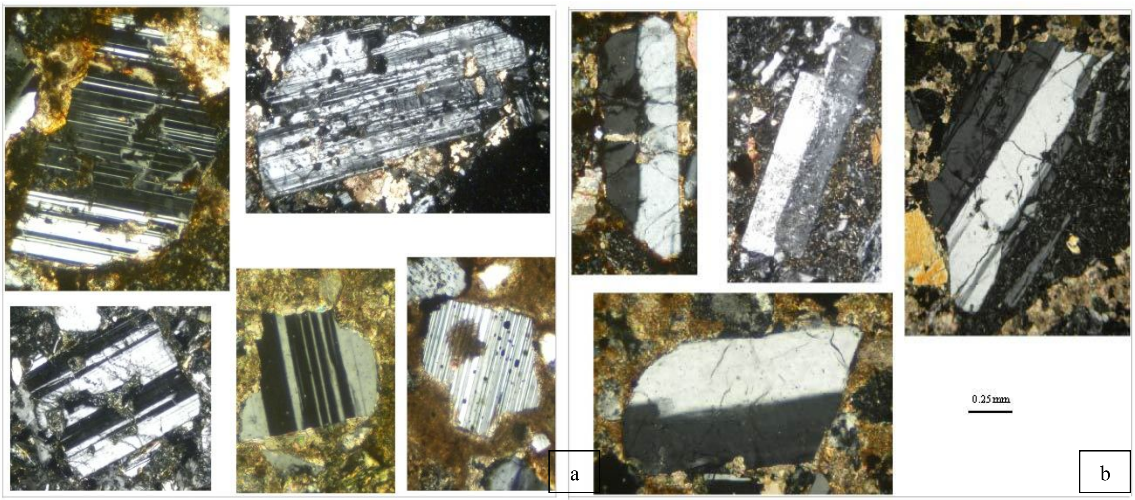

Figure 7: Representative photomicrographs of the A-twinned (a) and C-Twinned (b) feldspars in the facies of studied formations. All figures are in XPL.

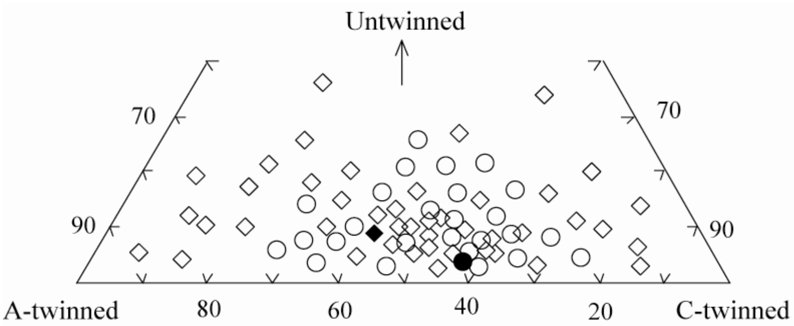

Figure 8: Distribution of major twin types in detrital feldspars of the ZF (circles) and URF facies (rhomboids). The solid circles and rhomboids represent mean values for each formation. Each point represents mean values of 1-10 thin sections.

Discussion

In terms of chemical composition, the feldspars from URF and ZF display a relatively high An content (41.25% and 54.44% respectively), characteristic of intermediate to basic volcanic sources respectively (cf. Sibley & Pentony, 1978; Trevena & Nash, 1979, 1981; Maynard 1984). These compositions suggest that andesitic to basaltic rocks dominated the source of the ZF facies (cf. Trevena & Nash, 1981; Sibley & Pentony, 1978; Maynard 1984) but for the URF facies the dacite and andesitic rocks were more important (cf. Pittman 1970; Maynard 1984). Compared to feldspars from known sources described by Trevena and Nash (1979, 1981), all grains fall into volcanic fields but they are less potassic. A slight increase in the Or content with decreasing anorthite also reflects characteristics of volcanic rocks (Trevena & Nash, 1979, 1981). This agrees with the conclusion of Maynard (1984) that calcic plagioclase with modal anorthite contents of around 40-50% in modern deep-sea sands is mainly derived from volcanic rocks. Sibley and Pentony (1978) reported a similar result.

The abundance of plagioclase with a mode of 58% anorthite in the ZF facies indicates the significance role of a basaltic source (cf. Pittman, 1970; Sibley and Pentony, 1978; and Maynard, 1984), most likely the Peshtasar Basalt and Talesh series in the source area. Abundance of ca-rich plagioclase (An>50%) show that basic rocks and/or andesites with calcic plagioclase phenocrysts were common in the source area (cf. Maynard, 1984). This does not, however, necessarily mean that basic rocks dominated the source area. It is possible that minor outcrops of basic volcanics within more acidic series, such as the Eocene volcanic series, could yield such a result due to the more rapid weathering of the basic rocks.

Composition of plagioclase grains from the URF facies indicates the dominance of intermediate and dacitic rocks in the source area (cf. Pittman, 1970). Basaltic and related source rocks appear to have contributed less in this part of the Alborz Mountain. This most likely points to the "green series", which are dominantly made up of tuffs with local lenses of andesitic lava (GSI 1986) as a source in this region.

Dominance of volcanic rocks in the source region is further indicated by the abundance of oscillatory-zoned plagioclase both in the ZF and URF facies, 52% and 35% of total feldspars respectively (Fig. 6a). High proportion of zoned plagioclase irrespective of the type of zoning, averaging 80% for the ZF and 63% for the URF, also suggests the superiority of volcanic rocks in providing detritus to the studied settings (cf. Pittman 1963; Folk 1980; Trevena and Nash 1981; Pettijohn *et al.,* 1987). When integrated with their composition, andesine to labradorite, the zoning indicates control of intermediate and basic rocks as provenance of URF and ZF facies respectively (cf. Pittman 1963, Trevena & Nash, 1981). The higher abundance of unzoned feldspars in the URF facies (Fig. 6b) most likely indicates that pyroclastic rocks were more important in the source region of the URF (Central Alborz) than that of the ZF (Talesh Mountains).

The significant contribution of volcanic rocks in the source region can also be seen in the relative abundance of C-twins, ~58% in the ZF and ~ 46% in the URF facies (Fig. 8). On the basis of twin types and frequency, while comparing with those reported from phenocrystic plagioclase of volcanic rocks (Gorai, 1951, Gill, 1981), the URF and ZF feldspars display similar characteristics to those that occur in the hornblende andesite and pyroxene basalts respectively. Relationship between the average An% of feldspar grains (Fig. 3) and the frequency of C-twins (Fig.8) also reflect andesitic to basaltic rocks as possible sources (cf. Gorai 1951, Gill 1981). The twin populations for the two formations show little difference. The rather higher proportion of C-twins in the ZF may be source controlled or reflect selective removal during weathering and transportation.

The composition of feldspars in the studied formations is compared with those of representative samples of their nominated sources (green series and Peshtasar Basalt). The slight difference in the average composition of detrital feldspars and those from proposed source rocks reflects some degree of alteration in these grains (Fig. 9). The detrital feldspars have higher Ab content but lower Or and An contents compared to those of proposed source rocks. The difference is more significant in the feldspars of the URF than those of ZF (Fig. 9).

These results indicate more leaching of K than Ca and Na contents during weathering and transportation. Low abundance of K feldspars in the studied facies (Fig. 3) is partly due to preferential weathering of these grains during transportation (cf. Maynard 1984). Increase in Ab content of the detrital grains is probably related to albitization during transportation and/or early diagenesis (cf. Carozzi, 1993).

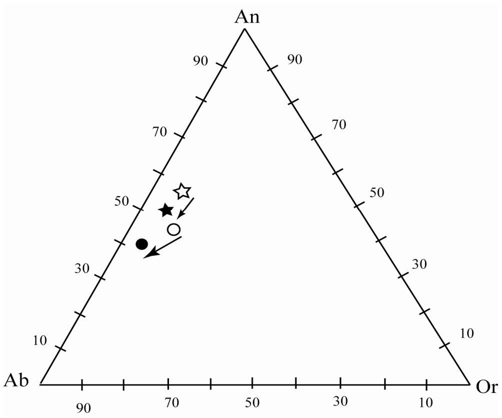

Figure 9: Differences in the average composition of detrital feldspars of the ZF (solid star) and the URF (solid circle) facies in comparison to their proposed sources (open star and circle respectively). The arrows show alteration trend of the feldspars during transportation.

Results from facies analysis of the formations indicate warmer and more humid conditions in depositional environment of the ZF than that of URF (Amini, 1997, 2003). The source rocks of the ZF facies are found to be more basic than those of the URF facies (discussed above). Nevertheless, less modification in the feldspars of the ZF than those of URF is observed (Fig. 9). Such a difference is almost certainly related to different transportation and depositional history of the formations. More rapid deposition along with shorter travelling distance seems responsible for less modification of the ZF feldspars. These are in turn the result of greater structural deformations of the Moghan area than Central Alborz during deposition of the studied formations (Amini 2003).

Comparison of the zoning of the detrital feldspars in the studied formations with those of proposed sources show a noticeable decrease in the oscillatory and progressive zoning with a concomitant increase in the unzoning (Fig. 10). Such differences are related to weathering effects during transportation and/or shortly after deposition. However, zoning in some detrital plagioclase grains is probably obscured by abrasion/alteration of the grain surfaces. Moreover, some unzoned detrital grains could be the result of disintegration of a coarsely zoned plagioclase (cf. Helmold, 1985).

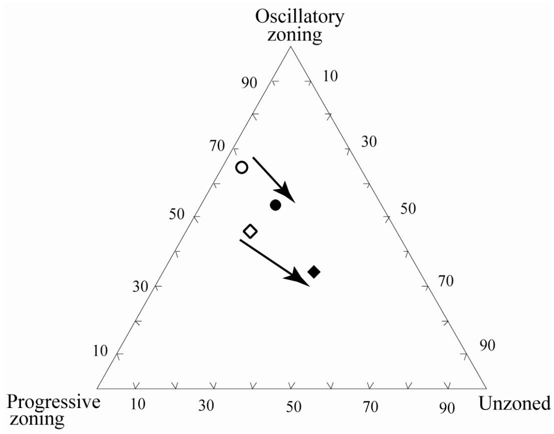

Figure 10: Differences in the average abundance of zoning types in detrital grains of the ZF (solid circle) and the URF (solid rhomboid) facies in comparison to their proposed sources (open circle and rhomboid respectively). The arrows show variation trend of the feldspars during transportation.

In terms of zoning, greater modification of the feldspars of the URF than those of ZF facies, despite their less temperate and humid depositional conditions (Amini, 1997, 2003), is again related to their different transportation and depositional history. More rapid deposition, due to the higher uplift of the source region and subsidence of the deposition site and shorter transportation of the ZF facies seems the main causes for such differences.

No significant differences in the twining of the detrital feldspars and those of nominated sources are observed (Fig. 11). Negligible increase in the population of untwinned feldspars along with a tiny decrease in the frequency of C-twinned and A-twinned types of detrital grains (Fig. 11), possibly record weathering during transportation or early diagenesis.

Insignificant differences in the twining of the detrital feldspars and their counterparts in the proposed source rocks seem to be mostly due to their minor effects from alteration and disintegration. In other words twining is less obscured by abrasion/alteration of the grain surfaces than zoning. Disintegration of the coarsely twinned feldspars produces smaller grains that reveal twining in some extent (cf. Helmold, 1985).

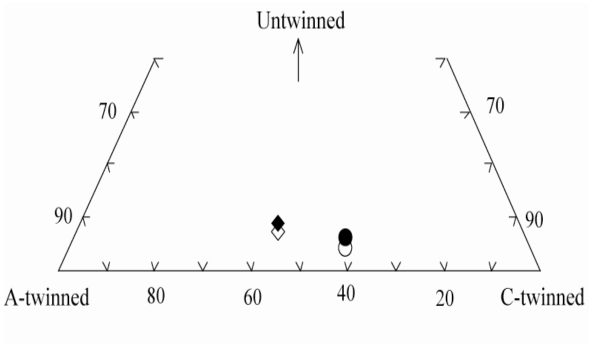

Figure 11: Differences in the average abundance of twining types in detrital feldspars of the ZF (solid circle) and the URF (solid rhomboid) facies in comparison to their proposed sources (open circle and rhomboid respectively).

Conclusion

Results from the composition, zoning, and twining of the detrital feldspars indicate that the provenance of the studied facies was undoubtedly dominated by volcanic rocks, most likely andesite to dacitic tuffs ("green series") for the URF and basaltic to andesitic rocks (Eocene volcanic of Talesh series and Peshtasar Basalt) for the ZF facies.

rocks suggests that pyroclastics rather than Comparison of characteristics of the detrital feldspars with those of the proposed source lavas within the Eocene volcanic sequences provided the greatest amount of material to the studied formations, especially in the URF basin. This is most likely due to their relatively higher susceptibility to weathering.

In general, the feldspar contents of the studied formations are similar to those of modern plagioclase rich sands indicating deposition in tectonically active settings by a high rate of sedimentation. Such characteristics (active tectonic setting, high deposition rate) were more significant in the Moghan area, where less modification in the feldspar grains is recorded.

It has not been possible to determine whether modifications in the feldspar grains took place during weathering, transportation, early diagenesis or a combination of all three. More analyses from constituents of the studied formations and their proposed sources are needed to reach a comprehensive conclusion to this issue.

Acknowledgements

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