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A Model for Comprehensive Studies of Alluvial Fan Deposits, Case Study: Ramhormoz Mega- Fan in Southwest Iran)

Saeid Pourmorad[1]*, and Shakura Jahan[2]

[1]Geological Survey & Mineral Explorations of Iran (GSI), Ahwaz, Iran.
[2]Department of Earth, Ocean, and Atmospheric Science, Florida State University, Tallahassee, USA.

Abstract

A diligent study of detrital sediments and especially alluvial fan sediments requires a comprehensive model from different sedimentological, geochemical, morphotectonic and environmental perspectives.Ramhormoz alluvial fans have been selected as a study site, which is located in southwestern Iran, next to Bakhtiari and Gachsaran formations. These alluvial fans have been studied from the perspective of sedimentology, geochemistry, hydrochemistry, neotectonics and environmental hazards.Studies show that grain size varies from gravel to clay/mud size. Based on field evidence, 10 lithophyses: Gh, Gci, Gp, Gcm, Gmg, Gmm (gravel), Sh, Sp, Sm (sandy) and Fi, Fm (mud) have been identified, of which five structural elements CH, GB, SG, SB, FF are formed. The presence of these structural elements indicates that these sediments were formed in a fluvial sedimentary system (of the cut type with gravel bed), where sediments were transported along gullies. Petrographic studies show that the most abundant sediments are calcareous gravels.This study show that the provenance of these sediments in Ramhormoz region are from Gachsaran and Bakhtiari formations. Sedimentological studies have led to the division of alluvial fans into three parts: proximal (near the origin), medial (middle) and distal (farther from the origin.The results of geochemical analysis show that calcium and magnesium oxides have the highest percentage of overall oxides in this region. In addition, the most abundant percentages of rare earth elements include elements like Ce, La, Nd, Y, and the most abundant heavy metals are Zn, Pb, Cu, and Cd. The correspondence of geochemical and petrographic data indicates the study area is in active continental margin. The study of environmental pollution with the help of geochemical data show that Ramhormoz region is in an alarming situation in terms of pollution caused by V, Ni, Pb, Zn and Cu elements.Mineralogical studies performed by XRD technique show that chlorite and illite are the most abundant clay minerals in the studied samples. In addition, hydrochemical studies show high hardness of groundwater in Ramhormoz area due to the presence of Gachsaran Formation and as well as high amount of sulfate, sodium and calcium in this region. Tectonic studies conducted in the study areas show that the most important tectonic element in Ramhormoz region include Ramhormoz fault, which is a Persian anticline directly related to the transport of sediments in this area.

Keywords: Ramhormoz Mega-fan; Alluvial fan; Petrographic analysis; Geochemical studies; Environmental studies; Southwest Iran.

Introduction

Alluvial fans are in general conical or funnel in shape, which form at the edges of mountains, and its thickness decreases from the mountains top to the plains, while its with increases [1]. The shape of these fans depend on the tectonic and climatic conditions of the region [2,3]. The identification of alluvial fan deposits is economically important. For example, alluvial sediments can be the center of groundwater accumulation, and most groundwater reservoirs within the sedimentary basin are fed by water from alluvial sediments [4]. Most of the gold in the world is also extracted from the deposits of ancient alluvial fans in South Africa, which have survived in placer form. In addition, large amounts of uranium placer are also extracted from old alluvial fan deposits in the South African sedimentary basins [5].Alluvial fan sediments were rarely studied in detail. In fact, the studies that have been done so far have only been done in a specific dimension, such as sedimentology or geomorphology. Therefore, a comprehensive study model on these sediments is vital. In this study, the main objective is to construct a comprehensive model for Mega-fan Ramhormoz based on geochemical, sedimentological, morphotectonic and environmental analysis.

Geology of the region

The study area is located in southwestern region of Iran, within the city of Ramhormoz in Khuzestan province, and is part of the large fold belt of the Zagros (Figure 1A). The Zagros fold and thrust belt (Zagros FTB) is an approximately 1800-kilometres (1,100 mi) long zone of deformed crustal rocks, formed in the foreland of the collision between the Arabian Plate and the Eurasian Plate. It is the host to one of the world's largest petroleum provinc**es,** containing about 49% of the established hydrocarbon reserves in fold and thrust belts (FTBs), and about 7% of all reserves globally. The Zagros FTB extends from the Bitlis suture zone in the northwest to the boundary of the southeast Makran Trench, east of the Strait of Hormuz .The lithology of the study area mainly includes gravel, sand, silt, clay, gypsum and anhydrite, which consists of upstream formations of the region that include Gachsaran (gypsum and anhydrite evaporation), and Bakhtiari (clastic sediments).

Study Methods

The methods used for this study include fieldwork, land surface data collection, geochemical, and hydrochemical analyses. This research can be generally divided into four sections: data collection, field studies, laboratory studies, and supplementary studies.The data collection was

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***Corresponding author:** Saeid Pourmorad, Geological Survey & Mineral Explorations of Iran (GSI), Ahwaz, Iran, Tel: 00989167696529; E-mail: Omid2red@gmail.com

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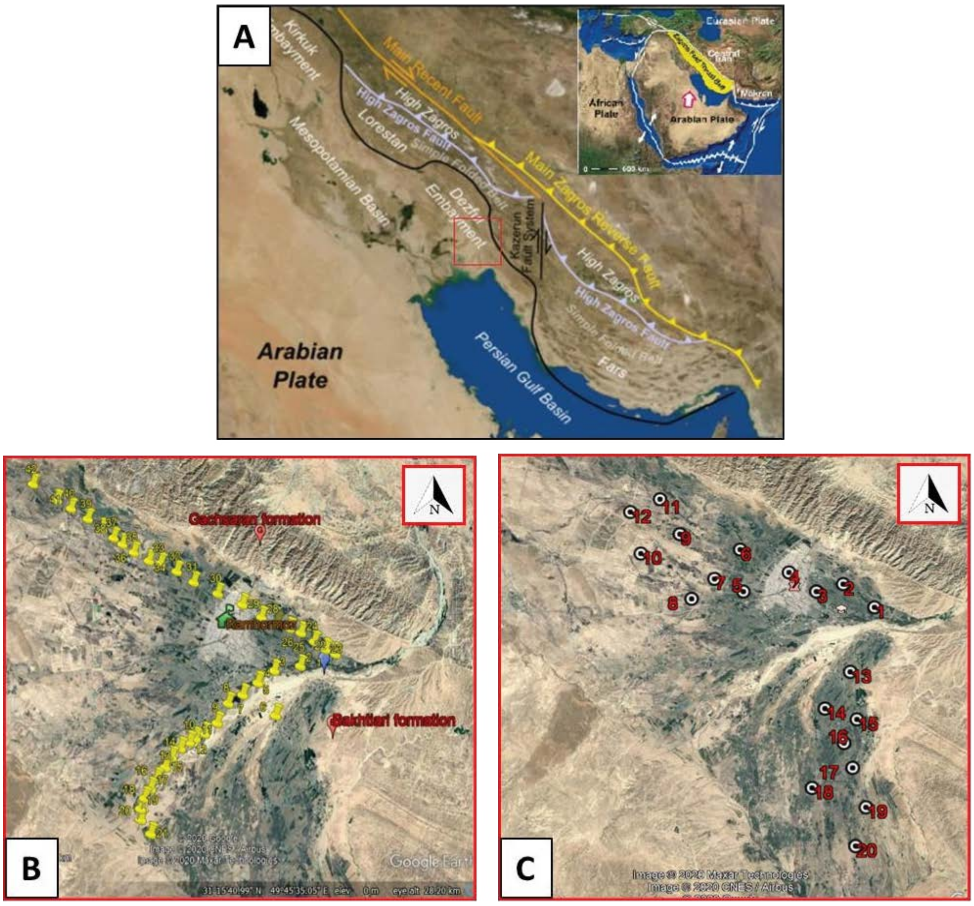

Figure 1: (A) Location of the study area in the Zagros fold belt (red box). (B) Sample locations (yellow pins) for sedimentological and geochemical studies. (B) Location of harvested points (black circles) for hydrochemical studies.

carried out through literature review, and reading maps and well logs. Field studies include two sections: (i) Fieldwork (sedimentological and morphotectonic field studies); and (ii) Sample collection (84 sediment samples collected from 42 different locations for sedimentological and geochemical studies, and 20 water samples from groundwater wells in the region for hydrochemical studies). Sampling was done systematically from the bottom of the main river canals in 2 different sections along with the sampling standards (Figures 1B and 1C). Laboratory studies include sedimentological studies (granulation studies of 84 sediment samples and 56 petrographic samples) and geochemical studies (geochemical study of 84 sediment samples and 20 water samples) in the study area.

Discussion

Grain-size analysis

Particle size analysis can be used to determine the sedimentary environment, identify sedimentation processes, and the type of flow [6]. The upstream part of the fan has the most abundant percentage of particles, which belong to -3to-4 Phi size (medium to coarse gravel), the middle part belongs to 0 to 1 Phi (coarse sand), and the bottom part belongs to particle size >4 Phi (silt and clay) (Figure 2A-C). The cumulative frequency curves show that the samples from the upstream and middle parts have poor sorting compared to the downstream samples. This poor sorting indicates high ambient energy in these part of the alluvial fan. The frequency curves for the middle and downstream part of the alluvial fans show high slope fractures. The presence of these fractures indicate the abundance of fine particles in these part of the alluvial fans due to moving away from top of the alluvial fan and thus reducing the ambient energy to carry larger grain particles in these parts (Figure 2).

Statistical parameters

For detailed study, sorting, skewness, median, kurtosis and other curves have been drawn. The results of grain size analysis from the studied samples show that the particle size from the upstream to the downstream of the alluvial fan show sediments are in the size that range from gravel to sand gravel at the top into gravelly sand to mud sand at the middle, and these changes in size results in sandy mud in the parts leading to the floodplain .The higher abundance of coarse-grained particles among the finer-grained particles in Ramhormoz area indicate two important facts. The first fact is that the floods carrying these sediments in the Ramhormoz area were faster (but not necessarily higher in discharge), and the second was that the sediments were transported from humid and dry environments and dominated by physical degradation.One appropriate method to investigate the shrinkage process in environments with sedimentary discontinuities is to divide the study area into separate sedimentary linkages based on identified discontinuities [7]. The Ramhormoz fan has larger area, gentle slope, lack of significant lithological changes, no significant sedimentary discontinuity, and the process of particle fineness is gradual with same sedimentary continuity (Figure 2E). The intermediate study of these sediments in Ramhormoz region shows that two climatic transition stages have occurred from wet to relatively dry period. Thus, the median of sediments in this region, especially in the upstream part, has the lowest median value, which indicates that the particles were deposited by floods with strong but less persistence energy. (Figure 2F). In this region, poor sorting (at the apex of the alluvial fan) to relatively good sorting (downstream) are observed due to the changes in grain size from the apex to the downstream and the lack of sedimentary discontinuity (Figure 2G). In the upstream part of the study area, the degree of inclination towards fine-grained particles in the middle part is almost symmetrical, and the inclination towards coarse-grained particles changes in the downstream part (Figure 2H). The presence of positive tilt in these alluvial fans along with negative sorting indicates the presence of relatively calm to strong river currents at different time to settle these particles of varying sizes. In addition, the positive distortion is due to the presence of large amounts of suspended solids, such as silt and clay, in the river that some of these particles remain in the sediments after deposition. Rivers that carry large amounts of coarse-grained particles may be negatively skewed.

Study of the sedimentary facies

Sedimentary facies varies in different stratigraphic unit in terms of lithological and paleontological features [8]. Rock facies identified in Ramhormoz alluvial fan based on grain size analysis, which are classified into three categories: coarse grain (Gmm, Gmg, Gcm, Gci, Gp, Gh), medium grain (Sm, Sh, Sp), and fine grain (FM, Fl), according to Mial Classification (2014). The five identified structural elements include channel filling sediments (CH), dams and gravelly layers (GB), deposits of gravitational sediment flow (SG), sandy layers (SB), and fine-grained sediments of floodplain (FF) (Table 1 and Figure 3).

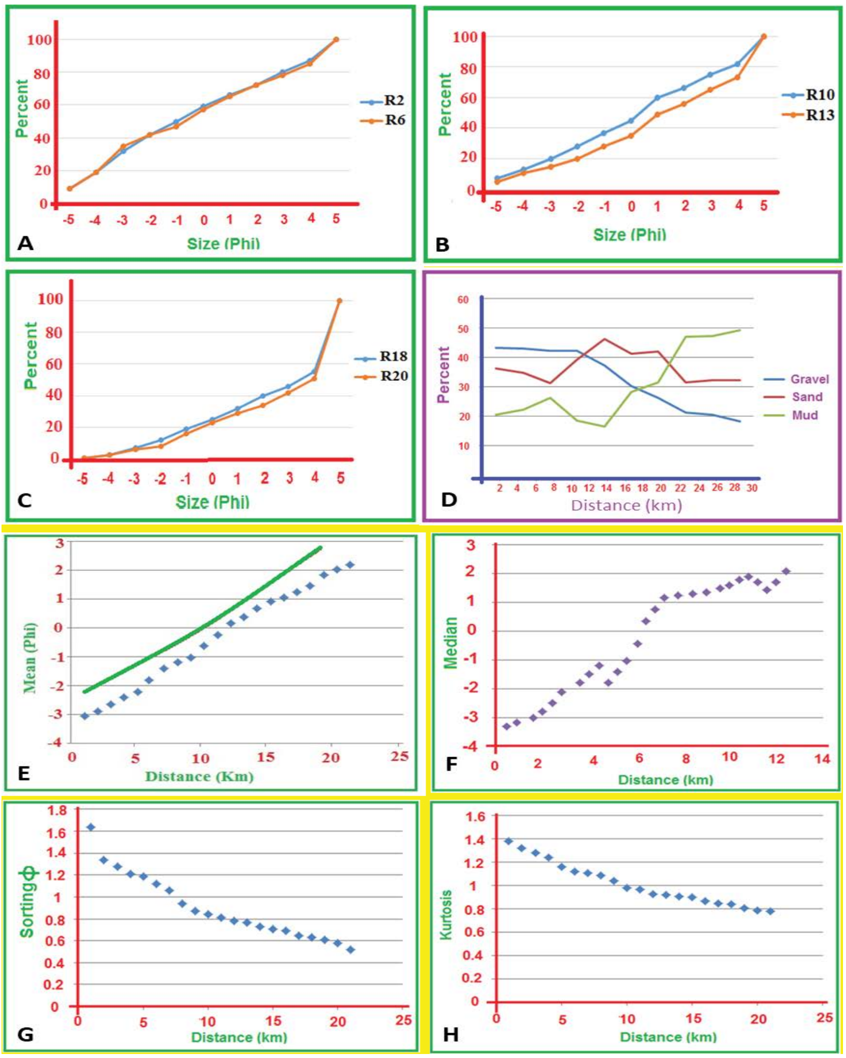

Figure 2: Representative cumulative curves for alluvial fans of Ramhormoz region. (A) The upper part of the alluvial fan (blue and orange lines for sample R2 and R6, respectively). (B) the middle part of the alluvial fan (blue and orange lines for sample R10 and R13, respectively). (C) downstream part of the alluvial fan (blue and orange lines for sample R18 and R20, respectively). (D) Changes in the percentage of different particles relative to the distance from the tip of the alluvial fan in the study areas. Plots of (E) mean grain size, (F) Median, (G) Sorting, and (H) Kurtosis versus distance from the apex of alluvial fans. The green line in (E) represent the sedimentary continuity among the sedimentary discontinuities.

Structural elements	Sedimentary facies assemblages	Lithofacies	Interpretation
GB	Sm, Gmm	**Gmm**=Matrix supported massiveConglomerate**Gmg**=Matrix supported graded	It is the result of the migration of gravel barriers or is in the form of residual sediment in the channel floor; it is usually lenticular in shape.
CH	Gp, Gcm, Gh, Gmm, Sh	Gravel**Gcm**=Clast supported massiveGravel	It represents channel filler sediments; the lower boundaries are erosional; generally, it is lenticular and widespread.
SG	Gmm, Gmg, Gcm, Gci	**Gci**=Clast supported gravel**Gp**=Planar cross bedded Gravel**Gh**=Horizontally bedded	Debris flows are adjacent to the provenance area; they have thick sheet-like structures, erosional boundaries, abundant coarse gravels, poor sorting and lack ofstratification.
SB	Sh	Gravel**Sm**=Massive Sandy**Sh**=Horizontally bedded**Sp**=Sand	sheet-like, widespread; usually, they are in the form of channel filler sediment, locating in downstream.
FF	Fl, Fm	Planar cross beddedSand	It contains off-channel fine sediment, in massive and sheet-like forms.
		Fm=Massive mud and silt	
		Fl=Laminated mud and silt	

Table 1. Summary of properties and facies in the studied structural elements in Dezful and Ramhormoz regions based on Mial classification.

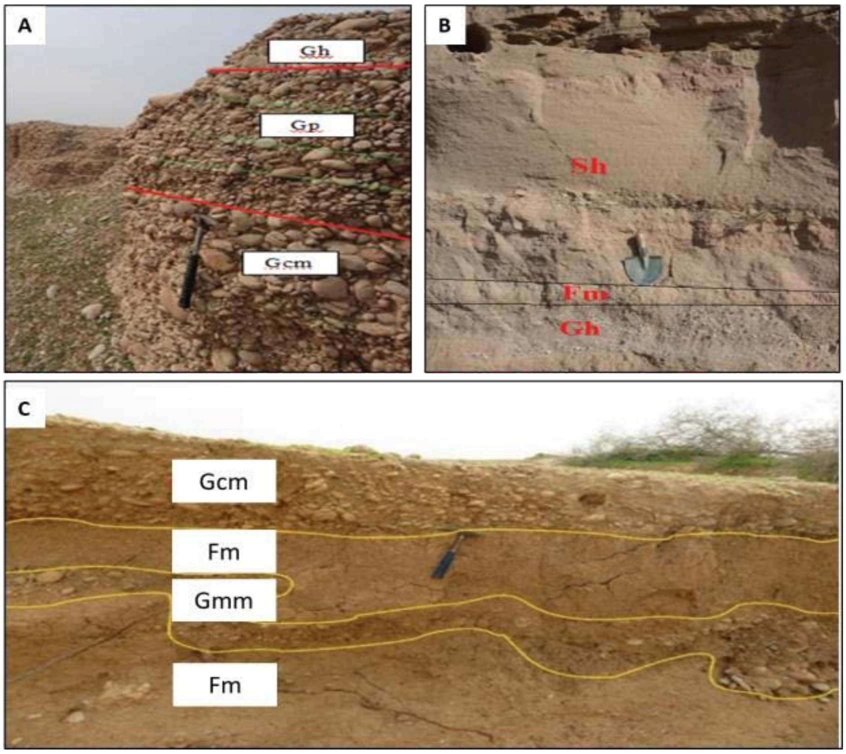

Figure 3: Representative outcrops in the Ramhormoz region.(A) Sudden upper contact of Gcm facies with Gp facies in the north of Ramhormoz city (looking east). (B) Sandstone facies with horizontal layers along a sudden boundary with the Fm facies north of Ramhormoz. (C) Sudden and erosive boundary of Fm facies with Gcm and Gmm facies (east of Ramhormoz).

Calculation of Long-Standing Hydrological Parameters Using Sedimentary Properties

The study of long-standing hydrological estimates of river flows is done using two methods of regime and capacity, which are based on the estimation of long-term floods [9]. In this study, 2 field sections were selected and the average size of 10 large rock pieces was used to calculate the flow strength. [10] equation has been used to determine the average value of channel depth from the thickness of diagonal layers in gravelly facies: H = 0.086 (dm) 1.1, where, H= Average thickness of diagonal floors in meters and dm= average channel depth in meters. The equation [11] has been used to calculate the average flow velocity based on the size of the gravel parts: V = 0.18d0.49, where, V= Water velocity in terms of ms-1 and d is the length of the mean axis in the largest part of the gravel. The equations from [12] have been used to determine the mean/maximum or peak discharge current: Q = 0.29Wb1.28 D max 1.10; Q2.33 = 2.66Wb 0.90 D max 0.68, where, Q = Average discharge current in m3s-1, Q2.33= Average annual peak discharge peak in m3s-1, Dmax = maximum channel depth in meters, and Wb = channel width in meters. The maximum grain size in the measured sections of the study areas is related to two facies (Gcm and Gmm). According to the values calculated for river strength based on the size of the above sections in the four studied locations, the maximum estimated value for river strength is related to Gmm rock facies in section 1 in the northeast of Ramhormoz city, which may be related to a major flooding event.The maximum current power (591.82 W) corresponds to the maximum current discharge rate (166.32 m3s-1). According to the obtained data, Gmm and Gcm facies in the study area are associated with high values of power and flow velocity, while Gh and Gp facies in each of these areas have the lowest calculated velocity and power (Table 2). A study of the annual discharge history in the study areas show that the calculated depths of the canal also vary between 2.36 and 2.95 meters. Using the the width of the canal is calculated, which varies between 25.12 to 66.3 meters. Similarly, the average and maximum annual discharges are calculated based on [13] equations. The average discharge varies between 68.36 to78.12 m3s-1.

Petrographic studies

The study of petrographic properties of the studied samples in Ramhormoz region show that the mentioned samples originate in large to small sizes, and from the Bakhtiari upstream formations of Gachsaran, which are described in the following section:

Petrography of upstream formations: In Ramhormoz region, both Gachsaran and Bakhtiari Formation is present as upstream cone formations. Bakhtiari Formation in this region is mainly composed of gravel (limestone, chert, sand and volcanic fragments) with an average of 86% of monocrystalline and polycrystalline quartz with an average of 10% of feldspar (including plagioclase and potassium feldspars) and an average of 1.8% minerals. Heavy metals (such as sphene, tourmaline and epidote) are formed with an average of 1.1%. In this unit, the constituent particles are generally observed as semi-angled, granule to pebble size gravels (Figures 4). The sandstone sections of Gachsaran Formation show most abundant percentage of rock fragments (average 89%). In addition to limestone particles, monocrystalline and polycrystalline quartz have an average frequency of 8.1%. The amount of feldspar in this formation is about 1.6%. The constituent particles in these samples are semi-angular to semi-rounded with medium to weak sorting, and contain more than 10% of the matrix (Imchor to Sub-Machur stage) (Figures 4).

Petrographic properties of the studied sediment sample: Petrographic study of the studied samples show that the main components of these sediments include particulate matter (chert, lime, sand, and igneous aggregates) with an average of 85%, quartz (monocrystalline and polycrystalline) samples with an average of 10.6%, feldspar (potassium and plagioclase) with an average of 2.1%. These sediments have relatively good sorting and are semi-angular (Figure 4B). In this petrofacies, the size of the quartz grains varies from fine sand to coarse sand, and often has a straight to wavy extinction. Some monocrystalline grains contain a variety of inclusions (often of zircon and muscovite minerals). In general, the amount of monocrystalline quartz is higher than polycrystalline quartz, which can be due to In addition, potassium long-term transport during the re-sedimentation cycle (Figures 4C).feldspar is more abundant in these samples than plagioclase (Figure 4C and F). Petrographic studies of the

discharge rate)m3s-1(	Channel cross sectionA (m2)	power W(wm-2)	Velocity (ms-1)	Maximum average grain size d(mm)	facies	Location	NO
166.32	70.21	591.82	2.62	220.8	Gmm	31º14'45"N49º 36'59"E	1-1
108.28		113.81	1.31	112.3	Gmg	31º 14'2"N49º 35'54"E	2-1
156.82		526.25	2.36	239.8	Gcm	31º 12'39"N49º 33'50 E	3-1
31.6	65.3	61.36	0.95	248.2	Gmm	31º 13'39"N49º 37'34"E	1-2
66.4		438.25	2.16	148.2	Gcm	31 º 12'33"N49º36'52"E	2-2
17.92		16.2	0.61	110.6	Gp	31º 10'48"N49º 37'1"E	3-2

Table 2. Estimation of long-term discharge strength and velocity based on gravel particle size in different sedimentary facies of the studied areas in sections 1 (Ala River), No. 2 (Khanomi River).

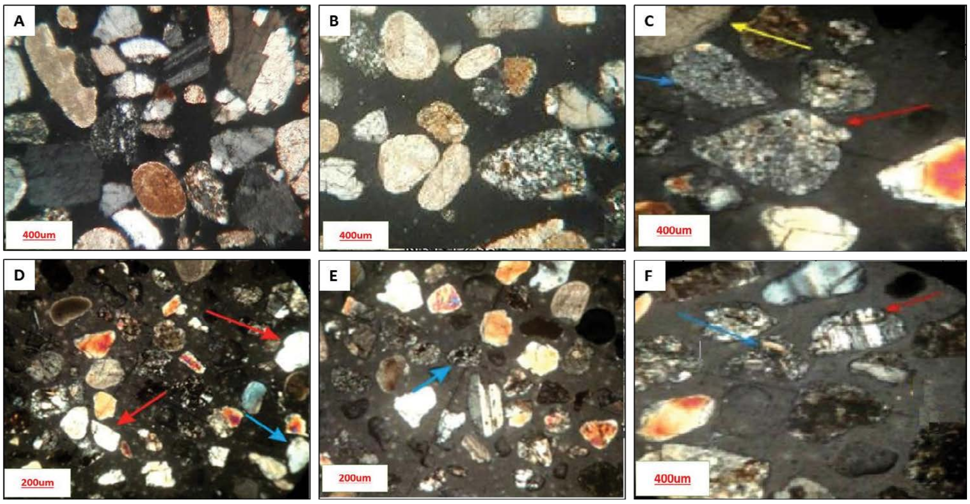

Figure 4: Photomicrographs of the samples in the studied areas. (A) Sediments of the middle part of Dezful alluvial fans showing good grain sorting and medium to good grain roundness. (B) Sediments of the middle part of Ramhormoz alluvial fans showing relatively good and semi-angular grain sorting. (C) Monocrystalline quartz (red arrow) and potassium feldspar (blue arrow), in the samples from the northeast of Andimeshk. (D) Semi-altered potassium feldspar (blue arrow), from west of Dezful samples. (E) Decomposing feldspar (red arrow), chert particle (blue arrow) and carbonate particle (yellow arrow), samples from northeast of Ramhormoz. (F) Potassium- containing feldspar (Microcline) (red arrow), samples from east of Ramhormoz.

studied samples show that petrographic results are consistent with the data obtained from Bakhtiari and Gachsaran Formations (sandstone section) and indicate that these formations are the main sources of these sediments. Based on the percentage of major constituents in all studied samples (quartz, feldspar and gravel), these samples are in the range of litharenite in the [13] classification table (Figures 5A).

Petrography and tectonic position: In general, the composition of sand sediments depends on the characteristics of the origin, transport distance, and changes after sedimentation. The primary relationship between the origin and sedimentation in a basin is controlled by tectonic processes. The sandstone (quartz, feldspar) composition and particulate matter can be used to determine the relationship between tectonic position and sedimentation [14]. In this study, the diagrams of Qt,F,L and QM,F,L, [14] (Figure 5B-D) have been used. From all three [15] diagrams, the percentage of sandstone components fall in the Undissected Arc for all the samples of Ramhormoz and Dezful regions. The samples in these regions has the high percentage of carbonate particles.

Classification of alluvial fans

The alluvial fans of Ramhormoz region can be divided into three different sections from top to bottom based on granulometric and facies information:

Upstream or proximal part: Sediments of the proximal part (close to the source) mainly consist of coarse-grained particles, extending from the apex to the middle parts of the alluvial fan. These sediments include alluvial deposits that result from erosion of Gachsaran Formation outcrops present in Ramhormoz drift superstructure, and are generally have relatively poor sorting. The grain size decreases from the top of the alluvial fan to downstream due to the decrease in flow intensity (Figure 6A).

Medial section (middle): These sediments extending from the proximal end to the distal apex include smaller size grains than the proximal sediments. In this section, the transport of coarse particles from the top to this part is less and particles are mainly medium to fine grains, due to the reduction of energy (Figure 6B).

Distal part of the source: The sediments of this section mainly consist of fine-grained silty and clay deposits with outgrowths of sand and gypsum lenses, which form the end parts of the Ramhormoz alluvial fan and gradually turn into floodplain sediments (Figure 6C). Sediments of this section, are mainly free of coarse-grained particles due to reduced flow intensity.

Sedimentary model

The use of accurate sediment model for the study area is requirement to study the alluvial fan. In Ramhormoz region, the alluvial fan is divided into three parts: proximal, medial and distal, based on changes in grain size and slope of the region. These changes occur due to sediment transport them from the heights of Gachsaran Formation to the downstream parts. The alluvial fan originates from the top of Gachsaran Formation, which is underlain by Aghajari Formation along with Ramhormoz thrust, and bounded in the eastern and southeastern part by Lahbari section. In these areas, changes in the characteristics of sedimentary structures occur due to changes in river flow intensity, especially in the proximal part. In the medial part, the intensity of the small currents is reduced and as a result less facies diversity has been seen than the proximal part. The distal part in this region extended in the southwestern parts and is limited in the southern and southeastern parts due to the thrust of Lahbari Formation (detrital lithology) (Figure 6D).

Geochemical studies: Geochemical studies was carried out using XRD, XRF, ICP MASS studies, which have produced extensive results that are discussed in the following section-

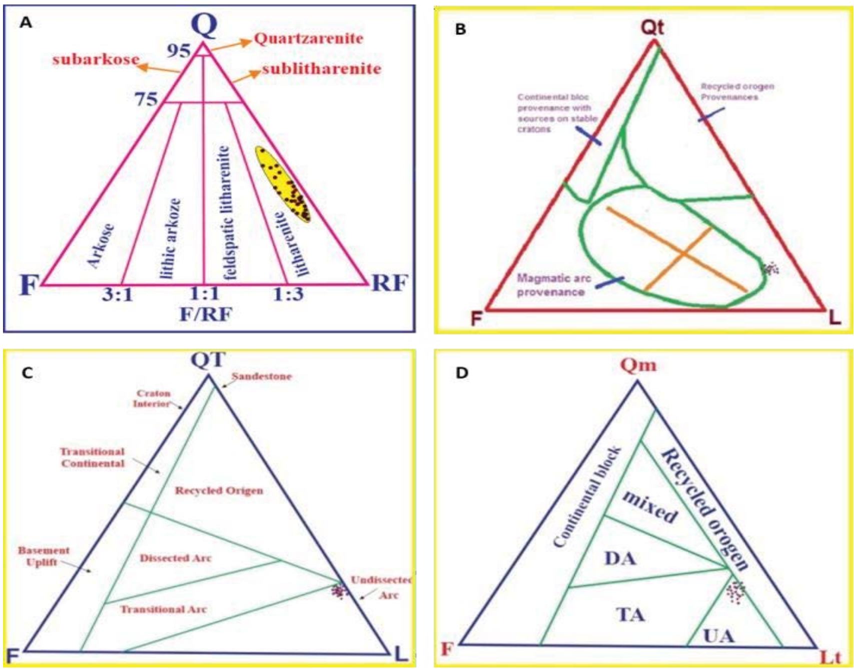

Figure 5: Ternary plots derived from petrographic studies (A) Sample data obtained using point counting technique show the litharenite composition for the studied samples [18]. (B and C) Qt, F, L plots, and (D) Qm, F, Lt plot were used to determine the tectonic position of the studied sand samples in Ramhormoz area, which show the origin of Undissected Arc for these samples.

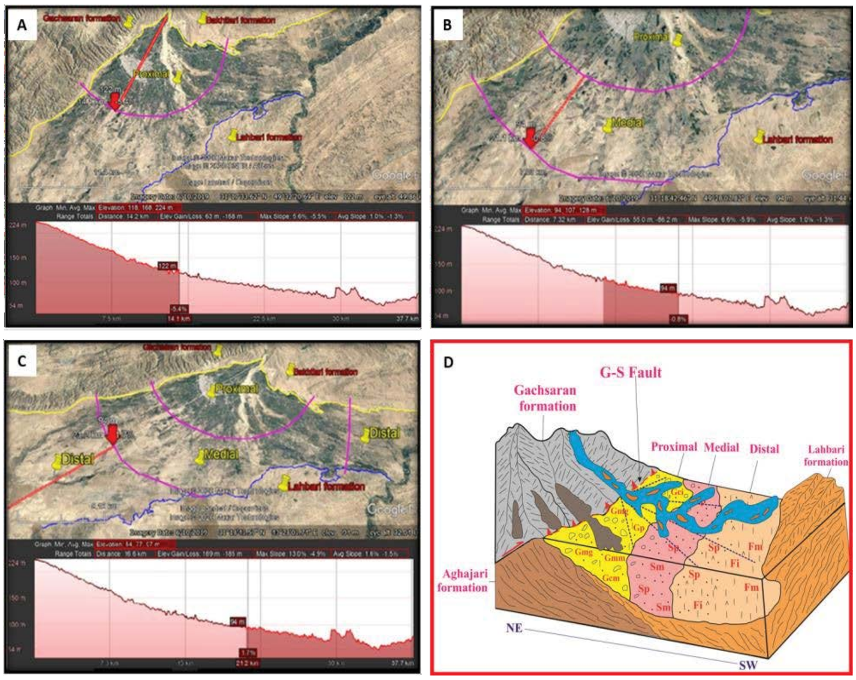

Figure 6: Position and range of (A) proximal section, (B) medial section, and (C) distal part in Ramhormoz alluvial fan cone in satellite images. (D) Schematic diagram for a sedimentary model of the study area.

Study of oxides : The results of the analysis show that calcium oxide (CaO) and magnesium oxide (MgO) are the most abundant oxides available, and minor oxides in these areas are: Na_2O, P_2O_5, SrO, TiO_2, and K_2O oxides (Figure 7A).

Sub-elements: The results of the study of sub-elements show that the most abundant sub-element in the study area is titanium (Ti). The other elements present in terms of ppm include: Zr, V, Ce, and La (Figure 7B).

Rare earth elements: The most abundant rare earth elements in Ramhormoz region include Ce, and other elements are: La, Y, Nd, Sc, Pr, Sm, Gd, and Dg (Figure 7B).

Discussion of geochemical results

Aluminum oxide is considered as a constant factor during diagnosis, weathering and metamorphism [16]. Therefore, this factor is used as a scale in the study of the main elements in detrital sediments [17]. However, the elements CaO, Na_2O, and K_2O in sandstones are known as the most mobile phases [18]. In the studied samples, the average percentage of aluminum oxide is about 4.03%. In this region, the oxide shows a positive trend with Fe_2O_3, K_2O, MgO, and TiO_2 with some extent of SiO_2, but show a negative correlation with CaO oxide (Figure 7C-E and 7G-H).Examination of the changes of TiO_2 with Al_2O_3 show that these two oxides have a positive trend relative to each other. These oxides are an average of 0.53% in Ramhormoz region. The element titanium is more concentrated in phyllosilicates and is a good indicator for the interpretation of source rock compared to other elements due to inactivity and displacement during sedimentary processes [18]. The cross-linking of Al_2O_3 with TiO_2 may indicate the association of TiO_2 with phyllosilicates in these areas [17]. In addition, the study of titanium oxide changes with V and Cr elements, which indicate a positive relationship between them. In addition, the correlation of Cr and V with TiO_2 oxide (Figure 7F and J) indicates the presence of heavy minerals in these areas because these elements are associated with iron and titanium [19]. The presence of heavy minerals has been confirmed from petrographic data. Comparison of trace elements such as scandium (Sc), vanadium (V), thorium (Th), cobalt (Co), niobium (Nb), chromium (Cr), and lanthanum (La) show similar correlation with aluminum oxide Al_2O_3. The existence of a positive correlation between Al_2O_3 and Cr show the presence of heavy minerals in these areas [17].

Geochemical classification of sediments

In addition to petrographic methods, the classification and separation of mature and immature sediments were also obtained [19]. The diagram of log (Fe_2O_3/K_2O) versus log (SiO_2/K_2O) is used to classify sandstones (Herron, 1988). The location of the data plotted on the diagram indicates that most of the specimens are fall in light arenite to iron sands classification (Figure 8A). The diagram of log (Na_2O/K_2O) versus log (SiO_2/K_2O) is based on chemical maturity indices, was used to classify detrital sandstones .According to this diagram, most of the samples in Ramhormoz area have litharenite composition, which is also consistent with petrographic data (Figure 8B).

Preliminary weathering studies of sediments: Geochemical analysis- Sandstone is the main element of detrital rocks, which can be used as a suitable tool for determining the tectonic position that have not been strongly affected by diagenesis and metamorphism or other alteration and weathering processes [19]. The most widely used index in this regard is the Chemical Index of Alteration (CIA) proposed by Nesbitt and Young. This index is obtained using the following formula and oxides are expressed in molar ratio:$CIA=(Al_2O_3 / (Al_2O_3+CaO^*+Na_2O+K_2O))\times100$. The average of this index for 10 samples from Ramhormoz region is 12.3, which indicates hot and humid climatic conditions in the source area. The average of the CIA index calculated for the study areas: $CIW' = (Al_2O_3 /(Al_2O_3+Na_2O))\times100$.

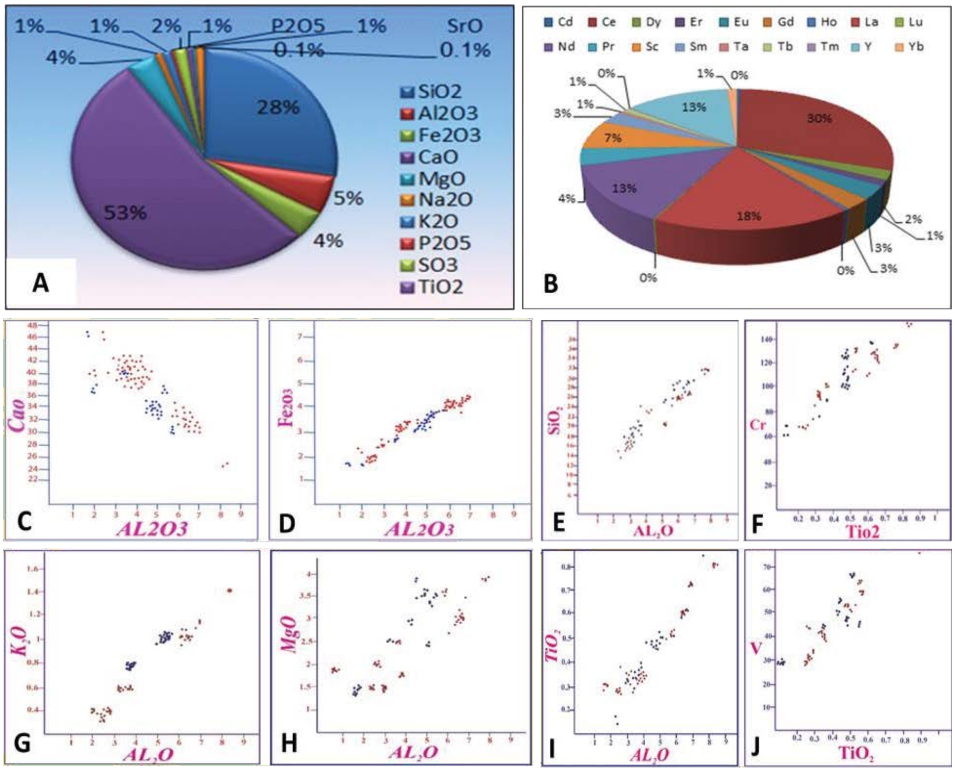

Figure 7: Pie charts showing (A) Average percentage of major oxides in the studied samples. (B) Average percentage of abundance of rare earth elements in the studied areas. Plots of major oxides versus aluminum oxide. (C-E and G-I). (F and J) Plots of titanium oxide (TiO2) versus vanadium (V) and chromium (blue points for Ramhormoz region).

The results of this index for the samples of Ramhormoz region are 77 on average. This number indicates the long distance of sediment transport from the origin to the sedimentation area and humid climate in the source area. The moderate weathering obtained for these samples may indicate intense re-sedimentation cycle activity in humid to semi-humid climates or the presence of recycling in semi-arid to arid climates [19]. In addition, from the A-CN-K diagram, the weathering path can be obtained from both weathering profile and thermodynamic estimation methods [20]. The diagram shows that the data are close to or parallel to the A-CN line.The samples plot in this diagram show scattered patterns in both regions and a wide range relative to the feldspar connecting line suggest severe chemical weathering or the presence of a recirculation cycle in detrital sediments [21] (Figure 8C). By plotting the SiO2 against Al2O3 + K2O + Na2O [22], it is possible to understand the long-term climatic conditions in the source area (the river). According to this diagram (Figure 8D), the ancient climate in Mansha region was humid at the time of sedimentation in Ramhormoz region. These results are completely consistent with the results shown in chart [23].The results obtained are completely consistent with the current climatic conditions of the studied sediments from central part of Iran - Chaharmahal and Bakhtiari province.

Determining the tectonic position of sediments

By changing the values of the main elements, the detrital sediments of oceanic arc islands, continental arc islands, active continental margin and inactive margin can be separated from each other [24]. Determining the tectonic position of sediments in the study area according to Bahatia's diagram [24] show that the samples of this area mainly fall in the Active continental margin. Their data is consistent with the data obtained from our petrographic studies (Figure 8E-G). In addition to the diagrams used to determine the tectonic position, the diagram [25] based on sub-elements was used. All the samples in the study area fall in the active margin of the continent (ACM) (Figure 8H). The study [26] diagram to determine the geological location of the specimens in the Ramhormoz area also confirms the geological location of the Active Continental Margin for these specimens (Figure 8I).Ratios of the main elements in relation to the source stone-Detrital sediments of oceanic arch islands, derived from calc-alkaline andesites, are distinguished from other sedimentary samples by higher levels of Na2O, Al2O3, TiO2 and Fe2O3 and relatively low amounts of SiO2 and K2O [27]. In addition, the main and secondary elements of felsic source rock contains higher values of Sr and Ba, and lower amounts of Ni, Co, Cr, V compared to the mafic source rock [28]. The diagrams obtained by plotting TiO2 versus Zr are used to distinguish between the intermediate and felsic source rocks [29] (Figure 9A). Sub-elements such as Nb, Zr, Hf, Th, La are more abundant in acidic rocks and elements such as Ni, Cr, Co, Sc are more abundant in mafic rocks [24]. Cullers used these elements to separate the source rock. Cr/V versus Y/Ni and La/Th versus Hf [30] are also used to identify the source rock (Figure 9B-D). The amount of TiO2 in the Ramhormoz area varies between 0.1 and 0.5%, while the amount of Zr in this area generally varies between 80 and 110 ppm (Figure 9A). According to this diagram, the sediments probably have a moderate felsic origin in the Ramhormoz area. These samples are of siliceous origin in the Th/Co versus La/Sc diagram (Figure 9B). In addition, the La/Th versus Hf diagram was used to combine the source rocks of the study areas [30] (Figure 9C). It can be concluded from this diagram, that the source rock falls in the felsic and mafic interface.

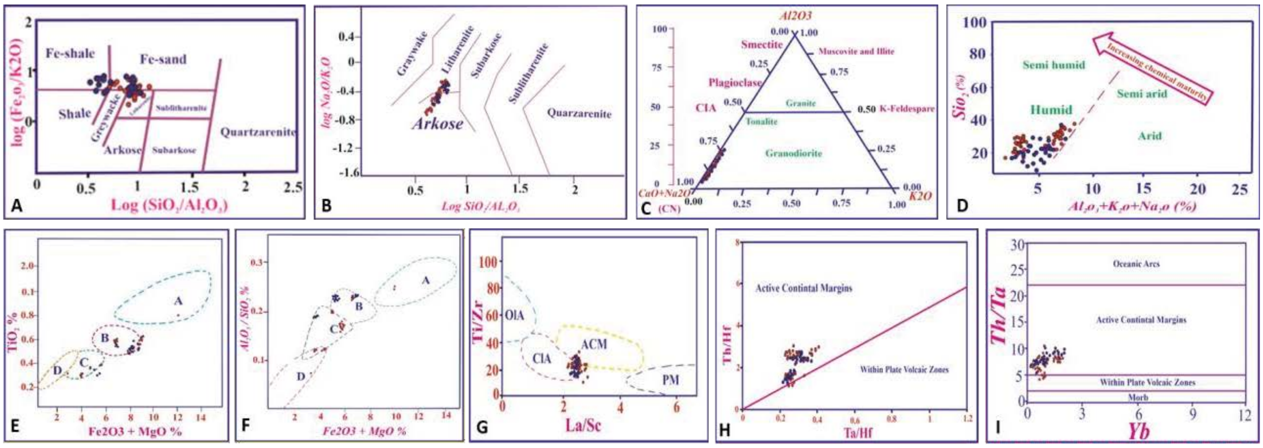

Figure 8: Geochemical classification of sediments in the study area. (A and B) Samples plotted on the diagram by Herron and Pettijohn, respectively. (C) Ternary plot of A-CN-K, samples of the studied areas were plotted in a diagram by[38]. (D) Diagram showing ancient weather conditions in the study area [46]. Plots showing the tectonic position of sediments in the study area. (E and F) Major oxides composition plotted on Bhatia's diagram [9].(G-I) Composition of the sub-elements were plotted to determine the tectonic [9]. A=OIA: Oceanic island Arc, B=CIA: continental island Arc, C=ACM: active continental margin, D=PM: passive continental margin

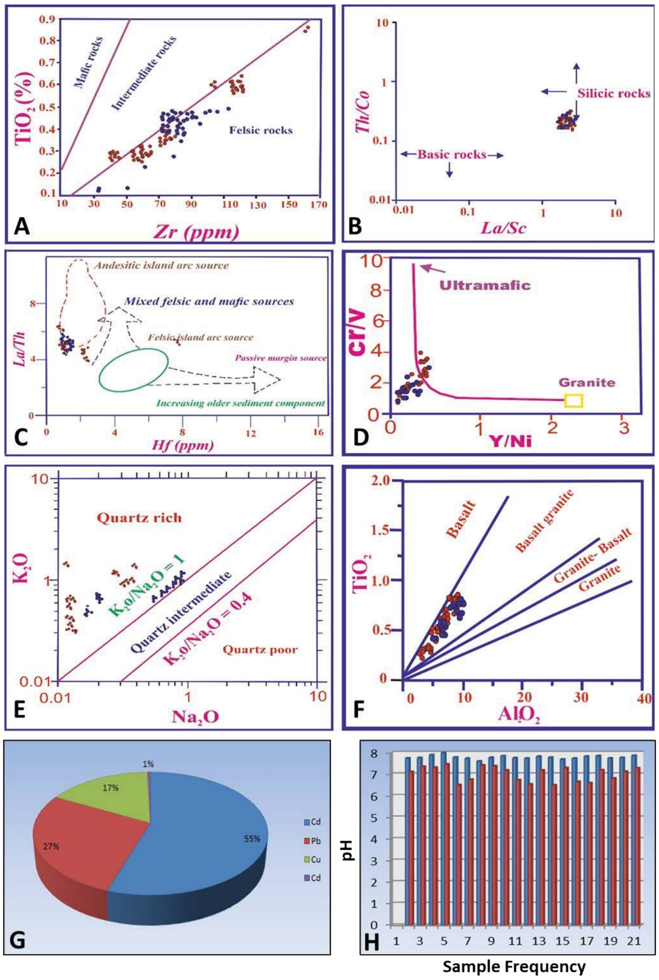

Figure 9: Provenance plots of the sediment data for the studied areas. (A) Data plotted on the TiO_2 - Zr diagram [23]. (B) The source composition of the studied samples on the Th / Co versus La / Sc plot (Cullers). (C) Plot showing sub-elements of the studied samples on the La / Th versus Hf diagram [17]. (D) Plot showing trace elements of the studied samples on the Cr / V versus Y diagram. (E) Plot showing source composition based on the Na_2O-K_2O diagram [9]. (F) Diagram of AL_2O_3 vs. TiO_2 to determine the origin of the studied sediments (Amajor).(G) Frequency of heavy metals in the studied areas. (H) Comparison of the percentage of pH changes in the studied aqueous samples.

Mineralogy studies: Mineralogical study by X-ray diffraction (XRD) along with petrographic studies show very good information about the mineralogical properties of the studied sediments [31]. In this study, 66 samples of Ramhormoz region were analyzed by XRD device available in the Geological Survey of Iran. The data from these studies show that chlorite and illite are the most abundant clay minerals. In this region, calcite, quartz, feldspar, dolomite and gypsum are among the non-clay minerals.

Tectonics and morphotectonics of the region: The role of tectonic and morphotectonic factors and the transport of their sediments in the formation of alluvial fans is quite clear and direct, and studies conducted on these sediments can give accurate information about these sediments. In the following section, the tectonic and morphotectonic properties of the studied sediments are used as a model:

Tectonics: The most important tectonic factors of this region include folds and faults which include the following:

Ramhormoz fault: Ramhormoz fault is a longitudinal drift with northwest-southeast direction that has a slope to the northeast. It is more than 100 km long and passes near Ramhormoz region. This fault in the southern edge of the Persian anticline has caused the Gachsaran Formation to be pushed on the Bakhtiari Formation. The southwestern edge of this anticline is inverted in the fault wall (Figure 10A).

Folds: The folded structures in the region are along the main trend of the Zagros in the northwest- southeast direction. These structures include anticlines and synclines that are often have an asymmetric geometry inclined to the southwest and their southwest edge is intersected by thrust faults. The main chain in the region includes the Persian anticline. In addition to the main-fold, sub-folds in the form of parasitic folds are also observed. Parasitic folds are more common in Gachsaran Formation (Figure 10B). Due to the existence of Gachsaran Formation and uncoordinated deformation, the geometry and position of the folds in Fars group, Asmari and older formations are different.

Persian anticline: It is a closed and asymmetric anticline whose axial plane is inclined in a northwest-southeast direction and has a steep slope to the northeast. The Chinese axis in this region is almost horizontal, but has a moderate inclination at the two anticline terminals outside the region. The anticline core is formed by Gachsaran Formation in which many sub-folds can be seen. The southwestern edge of the anticline is intersected by the Ramhormoz thrust fault, which causes so most places to be covered with alluvial fan deposits.

Geomorphology of the region

The appearance of the region includes the mountainous part, Mahour hill and plain, which is a hilly area near the city of Ramhormoz, in the core of the Persian anticline of the Gachsaran Formation. The highest altitude in the study area is in the satellite hills of Gachsaran Formation in the northeast of the region with an altitude of 464 meters above sea level. The erodibility of marl and evaporitic deposits has led to the spread of satellite hills in these units. Ramhormoz plain in the southwest of the study area with a height of about 94 meters is the lowest. Waterways in most areas are in the form of tree branches or dendrites. In rock outcrops, their bed is narrow, but in the plains, it is wide and loose, and covered with sediments. Alluvial barracks are formed around the Khanomi River, Shifa, and other waterways, which are seen at different altitudes.

Morphotectonic properties

In the morphotectonic analysis of the region, the use of geomorphic index as a primary and rapid tool to estimate the relative changes of tectonic activities has been expanded [32]. This information plays a very important role in the study of alluvial fans [33]. To evaluate the morphotectonic properties of the studied areas from various indicators

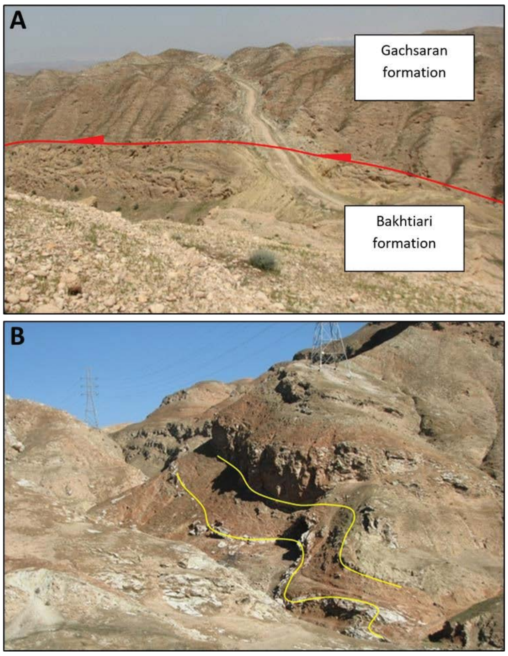

Figure 10: (A) Drift of Gachsaran Formation on Bakhtiari Conglomeration Due to Ramhormoz Fault - Southwest Edge of Parsi Anticline (Northeast View). (B) Parasitic folds in Gachsaran Formation (Westward View).

such as Mountain Front Sinuosity Index or Mountain Front Sinuosity (SMF), Drainage Basin Asymmetry (Af), Basin Shape Index (BS), and River Sinuosity Index (S), which are discussed in the following section:In these studies to calculate the SMF, BS, S and Af index,[33] formulas were used which include: $SMF = LMF/LS$, $AF = 100*(Ar/At)$, $BS = BI/BW$ and $S = C/V$, respectively. The results using mentioned indices show that Ramhormoz region has an active to semi-active tectonic position. Undoubtedly, this active tectonic position is one of the main factors in sediment transport in the alluvial fans. In this region, the presence of Ramhormoz thrust fault has an important role in intensifying tectonic activity, and the resulting shortening and uplift. This uplift, by extensive erosion in the supra-wall areas of the drift has increased the sediment yield of rivers and large waterways, the formation of alluvial fans in the front of the fault, and its sub- wall.

Environmental properties

Accurate environmental studies are an integral part of any careful study of alluvial fan sediments, especially in areas close to residential areas [19]. Now-a-days, soil pollution with heavy metals is considered as one of the most important environmental pollutants [19]. These metals are classified as the most dangerous group of pollutants in terms of toxicity and stability, soil pollution properties, toxicity, long shelf life, and their accumulation in living tissues. There are many ecological and biological aspects about the pollution [34]. In the current study, 68 sediment samples were studied and evaluated (Table 3). The frequencies of these metals in the study area include Zn (37.8 ppm), Pb (19 ppm), Cu (11.5 ppm) and Cd (0.33 ppm) (Figure 9G).

Study of environmental indicators

Igeo Geoaccumulation Index: This index is an early method of extracting heavy metals into sediments relative to the concentration of the metal substrate [35]. In this index, Cn is the measured concentration of the element in the sample and Bn is the concentration of the same element in the background sample, which is obtained from the relation opposite to this concentration: x+ s (middle + standard deviation.

Pollution factor (CF): Contamination factor is one of the common indicators to determine the level of soil pollution, based on which the amount of elements can be measured relative to its normal value and the amount of soil pollution can be determined. This factor is calculated according to the following relation for the studied elements [36]: $CF=(C_{metal})/(C\ background)$. In this equation, the pollution index is obtained from the ratio of the concentration of each metal to the amount of natural ground concentration of that metal. The Hakanson classification [37] is also used for the pollution factor to assess heavy metal pollution.

Discussion of pollution indicators: The data obtained from the average pollution caused by different elements (Zn, Ni and v elements) in the Ramhormoz region show moderate pollution. The results using contamination and pollution factor for 10 samples for the study area show nearly similar results obtained from using contamination method by the [35]. The contamination in the Ramhormoz area was probably due to the presence of drilling fluids or the outflow of oil through the seams and crevices of the rock cover to the upper parts in the upstream area (Mamatin oil field).

Groundwater chemistry: Groundwater is one of the important sources of alluvial fans, has a very important role in supplying water for human and non-human use, so the pollution of these important resources can play an important role in the living conditions of the surrounding areas [38]. According to the studies, the pH of the water in the studied wells from Ramhormoz area is normal, which ranges from 6.5 to 7.9, is the standard for drinking water and agriculture used by the American Environment Organization (EPA) and Iran (6.5-8.5) (Figure 9H). Therefore, it does not impose restrictions on various uses such as drinking, irrigation and agriculture. Comparison of the amount of different elements in the water samples of the studied areas show that in Ramhormoz region the amount of potassium, sodium, calcium elements and sulfate are significantly higher than the level of these elements attributed to the Gachsaran Formation in Ramhormoz region, which result in high hardness of water in this formation. In fact, the solubility of salt and gypsum as well as the erodibility of sediments in this formation as a limiting factor of passing water resources, which causes undesirable salinity of water and increases the amount of hardness and other elements in this area. The results indicate a very high salinity of water samples in the large alluvial fan of Ramhormoz. These results are consistent with the available evidence which includes abundant salt deposits in the Ramhormoz area.

Conclusion

The most important results are presented in a concise and case-by-case manner:

The results from histogram and normal distribution diagrams of Ramhormoz regional samples show that the most abundant particle size in the upstream part is between -3 to -4 Phi (medium to large gravels), middle part range from 0 to 1 Phi (coarse sands), and 4 Phi (silt and clay) in the downstream. According to the studies, the amount of sorting in Ramhormoz region has increased from the top to the downstream, the amount of tilt at the top is fine-grained, in the middle part is almost symmetrical, and coarse-grained particles in the downstream part. In addition, the amount of elongation of the specimens is elongated in the upstream part, medium to elongated in the middle part, and medium to wide in the downstream part. Rock facies in Dezful and Ramhormoz regions are divided into three categories of gravel, sand, and mud in five structural elements. Flow strength estimation study shows that Gmm and Gcm facies have the highest power and flow velocity in both regions, and Gh and Gp facies have the lowest values. The results from petrographic study from Dezful and Ramhormoz show that the studied samples are similar to Gachsaran and Bakhtiari formations in terms of petrographic properties and can be considered as the sources of the mentioned sediments, which are in the range of Lith-Arenite. The most abundant oxides identified in this range are calcium oxide (CaO) and magnesium oxide. The most abundant rare earth elements in this area include Ce, La, Y, and Nd. The abundance of heavy metals includes Zn, Pb, Cu and Cd. The study of the tectonic position based on geochemical results show that the sedimentary samples of Ramhormoz region are mainly located in the Active continental margin region. According to the Igeo index, the average pollution caused by Cu, Zn, Pb, Ni, and V elements in this region is caused by vanadium (V) and to some extent high amount of Ni and Zn. Data from XRD mineralogical studies show

Source	Matrix	Maturity	Sphericity	Roundness	Form	Sorting	Name	Part
BK- Gs	Silt, clay, medium sand	immature	Semi- stretched	Semi-angled	L›I›S	Medium to poor	G.S.M	Proximal
Gs-BK	Silt, clay, fin sand	Sub- mature	Semi- stretched	Semi- angular	L›I›S	Medium	S.G.M	Media
BK- Gs	Silt, clay, fin sand	Sub- mature	Semi- stretched	Semi- stretched	L=I›	Medium to good	M.S.G	Distal

Table 3. Abstract of general sedimentary properties of different parts of Ramhormoz alluvial fan in the study sections.

that chlorite and illite are the most abundant clay minerals in this region, and calcite, quartz, feldspar, dolomite and gypsum minerals are among the non-clay minerals. According to hydrochemical studies, the pH in this area is normal, the electrical conductivity is high due to the Gachsaran evaporite formation. In addition, the amount of sulfate, sodium and calcium in this area is also high. The most important tectonic factors in this region include Ramhormoz drift fault and Persian anticline. The results of morphotectonic studies also wza+- indicate that the region is tectonically active.

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