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Morpho-Tectonic Study of Zagros Structural Belt of SW Iran Using Remote Sensing Techniques

KAZEM RANGZAN° and IQBALUDDIN*
°Department of Geology, Faculty of Science, Shahid Chamran University, Ahwaz, Iran
*Remote Sensing Applications Centre, 7-B, Old Shibli Road, Aligarh Muslim University, Aligarh - 202002

ABSTRACT

The morphotectonics of Zagros Structural Belt (ZSB) of SW Iran has been controlled by collision tectonics of the Arabian and Iranian plates. Morphotectonically ZSB has been distinguished into four lithotectonics units namely, Imbricate Zone (IZ), Sanandaj-Sirjan Zone (SSZ), Zagros Folded Belt (ZFB) and Molasses Cover Sequence (MCS). The collision generated morphogeny and vertical tectonics in ZSB. The opening of the Red Sea has contributed to vertical tectonics @ 1 mm/year, and during the last 4-5 million years a relief of about 4 km has been generated in ZSB which resulted in development of erosional cycles. The Sanandaj-Sirjan Zone (SSZ) and Imbricate Zone (IZ) became positive tectonic topography with opening of Red Sea. The exogenic geomorphic processes resulted in the erosion and SSZ was exhumed to lower level than IZ. The ZFB and MCS underwent vertical tectonics @ 1 mm/year. The Neo-tectonism is expressed as anomalous drainage and compressed meanders in MCS. The humid cycles (?) during the Quaternary period resulted in fluvial erosion and cuesta, hogbacks, structural and erosional hills and valleys were carved in ZSB in Iran. The NW-SE tectonic trend of ZFB has determined the morphotectonics and the geomorphic grain of ZSB of in SW Iran.

Introduction

The geomorphic studies of Zagros Structural Belt (ZSB) have been conducted for tectonic analysis of the ZSB. The Zagros extends for 1500 km from the Tarus mountains in southeast Turkey, through southwest Iran, terminating near the strait of Harmoz at the mouth of the Persian Gulf (Berberian, 1976), abutting against the Minab Transcurrent Fault and forming a natural fortification on the southwestern frontiers of Iran. The main structural architecture of the Zagros is defined by Zagros Fold Belt (ZFB), which attains an average elevation of over 3000 m (AMSL).

The study area comprises four lithotectonic units namely Imbricate Zone (IZ), the Sanandaj-Sirjan Zone (SSZ), Zagros Folded Belt (ZFB) and the Molasses Cover Sequence (MCS). These lithotectonic units have distinct geomorphic signatures in space data output which have been used in the present study for establishing the morpho-chronology of the ZSB (Fig. 1).

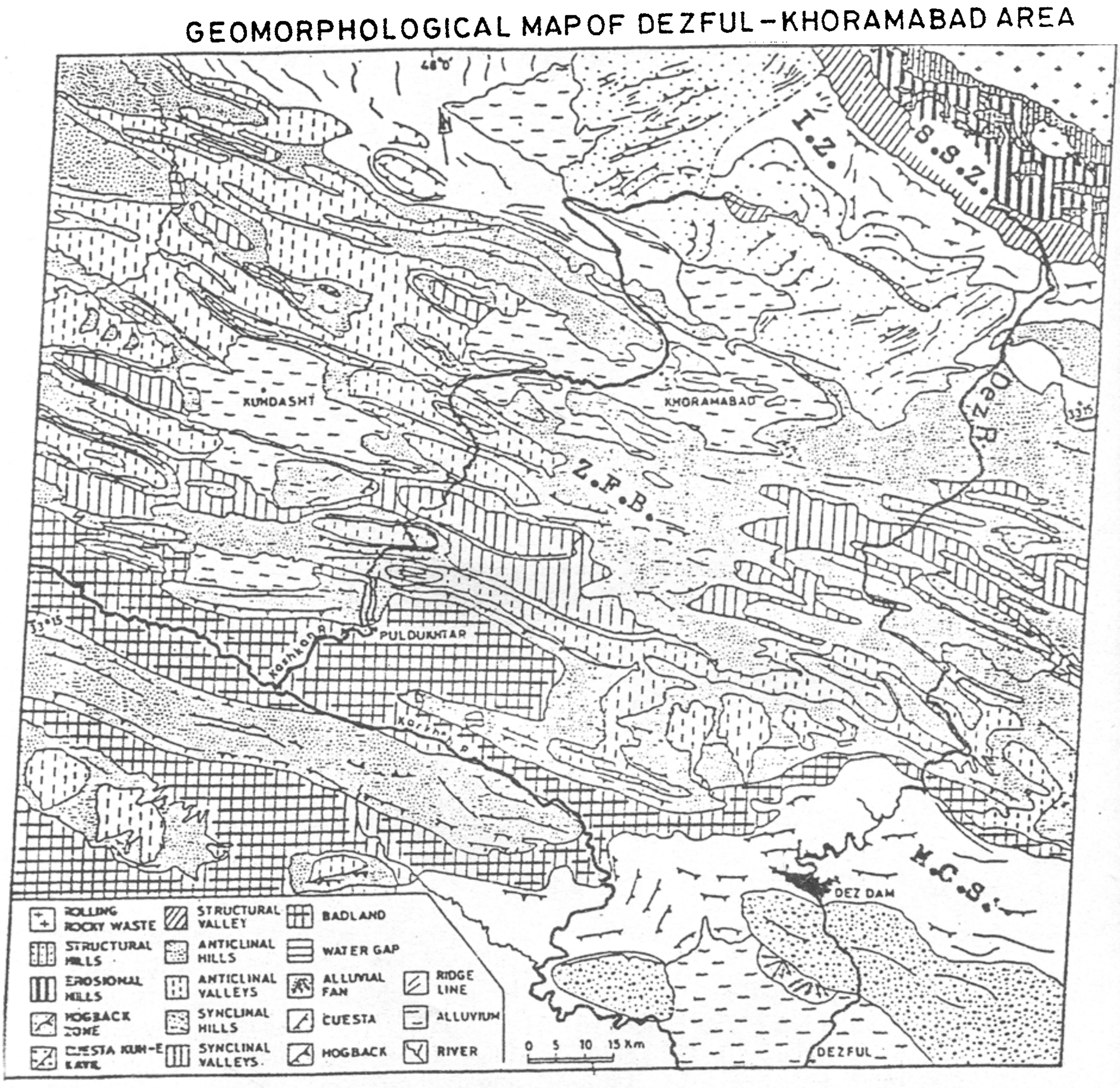

Fig. 1. Geomorphological map of study area, as deduced from LANDSAT MSS FCC.

In the study area, the SSZ comprises of metavolcanics, metasediments, granite and granodiorite of Mesozoic age. The rocks of IZ range from Cambrian to early Miocene consisting of chemogenic, clastogenic sediments with lateritic and spilitic volcanics and radiolarite, ZFB constitutes mainly carbonaceous and clastic rocks from late Triassic to late Miocene in age, and the Aghajari and Bakhtiari Formations constitute the MCS of Mio-Pleistocene age (Table-1).

Area and Scope

The area between the longitudes 47°08'-49°00' E and latitudes 32°20'-34°00' N of ZSB (Fig. 1) was studied for morpho-chronology, landform analysis, drainage morphometery and morphotectonics in an attempt to develop model of landscape evolution and to correlate the same with the tectonic processes that control the evolution of the fold belt on the SW frontier of Iran. The geomorphic zonation of the study area has been attempted on the basis of drainage morphometry, altimetry and landscape morphology and patterns. The geomorphic analysis exhibits correlation between morphochronology and tectonics at the margin of the Arabian and Iranian plates.

Methodology

The geomorphic studies have been carried out using LANDSAT MSS data, namely FCC of the bands 1, 2 and 4 on scale of 1:250,000 for visual analysis of the landforms. The recognition elements such as colour hue, textural pattern, drainage pattern, landuse, landcover, relief and erosion have been utilized for the convergence of evidence in terms of geomorphic elements.

The standard procedure for landform analysis through visual interpretation techniques was followed in the present study (Rangzan, 1990, 1993). The data output was registered on a base map of 1:250,000 scale. Geomorphological units/elements were identified, extrapolated and plotted on the base map using patterns and line symbols. Finally the extracted places of information were traced on an overlay from the base map and final drawing for the landform output was prepared on 1:250,000 scale map.

Drainage Network

The drainage network of the study area was mapped in order to evaluate the role of lithology and tectonics in development of drainage system. The map exhibits development of distinct drainage patterns in different lithotectonic zones of ZSB (Fig. 2). The SSZ in the NE show the development of coarse dendritic drainage pattern over the granite granodioritic rocks, whereas the foliation-controlled parallel drainage is seen over the metasediments (Fig. 3). The IZ exhibits chaotic pattern of drainage. Over the allochthonous sequence, north of Khorambad city, which is possibly a klippen representing the southwestern lapel of the Main Zagros Thrust (Rangzan, 1993), the higher order drainage has angular relationship with the general NW-SE trends of Zagros. The other parts show dendritic to sub-dendritic drainage network (Figs. 2 and 4). The ZFB represents Tertiary folding expressed into ridge-valley due to which almost the entire zone exhibits trellis drainage pattern following the NW-SE trend of the Zagros (Figs. 2 and 5). Though the ZFB and MCS were subjected to same tectonic forces, their morphotectonic responses have been different. The ZFB developed trellis pattern controlled by cuesta, hogback and ridge and valley topography. The MCS developed sub-dendritic pattern (Figs. 2 and 6) because the total deformation of MCS was dominated by translation with little distortion. The presence of the Gachsaran formation acted as sliver between ZFB and MCS which contributed to translation instead of distortion which is characteristic of the underlying ZFB sequence in SW Iran.

Geomorphic Elements

The present day geomorphic surface of the study area represents four well-defined morphotectonic units as indicated by the landform characteristics, drainage pattern and relief features. The dating of the geomorphic surfaces/levels has not been carried out in the Zagros. The landscape as seen in the area is young. The available information indicates immature topography which is in a dynamic state. However, on the basis of present day computations on vertical tectonics of the ZSB (Lees and Falcon, 1952; Berberian and King, 1981) morphochronology of the four morphotectonic units namely MCS, ZFB, SSZ and IZ have been worked out (Table-2) and their elements described.

DRAINAGE MAP OF DEZFUL-KHORAMABAD AREA

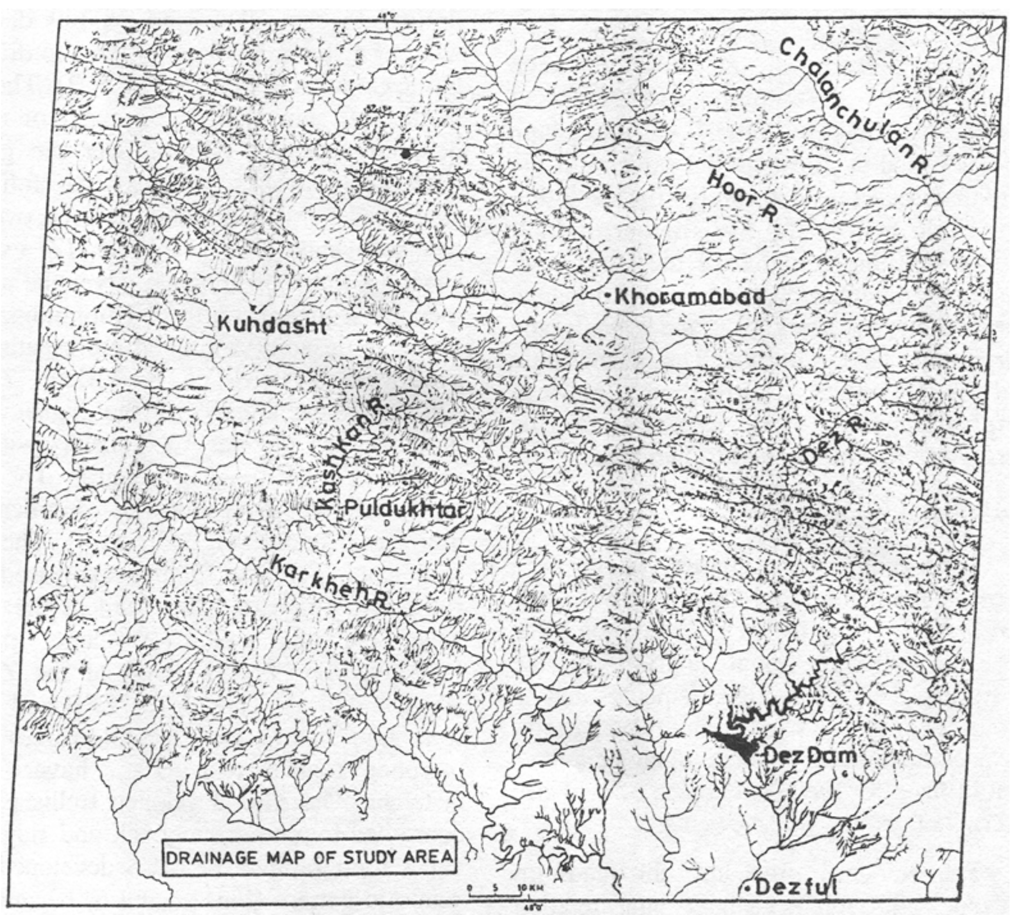

Fig. 2. Drainage map of study area, as deduced from LANDSAT MSS FCC.

Table 1. Geological correlation of different lithotectonic Units of ZSB.

Geological Time		*Zagros Fold Belt (ZFB)*	*Imbricate Zone (IZ)*	*Sanandaj-Sirjan Zone (SSZ)*
CENOZOIC	Pleistocene Pliocene Miocene Oligocene Eocene Palaeocene	Bakhtiari Formation Aghajari Formation Gachsaran Formation Asmari Formation Pabdeh Formation: Shabazan Formation Kashkan Formation Taleh Zang Formation Amiran Formation	Bakhtiari Formation .... Marl, Sandstone, Sandy limestone and nodular limestone Asmari Formation Shabazan Formation Alveolina limestone Kashkan Formation .... Amiran Formation & Limestone	
MESOZOIC	Upper Cretaceous Lower Jurassic Triassic	Gurpi Formation Bangestan Group: Ilam Formation Surgah Formation Sarvak Formation Kazdumi Formation Garau Formation Khami Group: Daryian Formation Gadavan Formation Fahliyan Formation Hith Formation Surmeh Formation	Gurpi Formation Limestone, radiolarite spillite Dark Grey to Grey Limestone Marl limestone Jurassic-Cretaceous undivided limestone, white lime-stone & volcanics Surmeh Formation Shale, limestone & laterite volcanics Upper dolomite member Khanekat middle dolomite member Formation dolomite, shaley dolomite	Intrusives; granites, granodiorite & quartzdiorite metamorphic & spotted schist, hornfels and marble sandy tuffs slate marbles metavolcanics, marble & slate
PALEOZOIC	Permian	....	Grey dolomite	marble
	Devonian	....	Dalan Formation	....
	Silurian	....	....	....
	Ordovician	....	....	....
	Cambrian	....	Mila Formation	....
	Pre-Cambrian	Arabian Basement	Arabian Basement	Arabian Basement (?)

Table 2. Geomorphic zones of Zagros Structural Belt.

ZONES	*MORPHOMETRY OF WATERSHED*	*LANDFORM/GEOMORPHIC FEATURE*	*RELIEF (AVERAGE) METERS*
MCS	MBR = 4.88 DD = 1.72 SF = 0.83	Less deformed folded sequence Cuesta & Fans etc.	25-1267
ZFB	MBR = 4.63 DD = 3.39 SF = 4.01	Elongated dome & basin, Trellis drainage Pattern	2500
SSZ	MBR = 4.05 DD = 3.39 SF = 3.17	Hill & Range Moderately Dissected	1900
IZ	MBR = 3.64 DD = 2.73 SF = 2.20	Highly Dissected Terrain Hogback-Cuesta, (ridge & valley)	2969

MBR Mean Bifurcation Ratio DD Drainage density SF Stream Frequency

1. *Imbricate Zone*

The morphotectonic unit represented by IZ in the ZSB exhibits development of structural hills, cuesta zone, hogback zone and structural valleys. The IZ, as a morpho-tectonic unit, has been separated from the SSZ in the NE on the basis of relief variation, and from ZFB in the SW on the basis of the penetrative NW-SE structural grain of the ZFB with which the structural hills, valleys, cuestas and hogback zone of the IZ exhibit structural discordance (Fig. 1).

The structural hills (Ali, 1992) in the IZ are seen around Kuliders, Dehsorkheh villages etc. Morphologically the unit is characterized by positive relief and trends which are isotropic, morphotectonically controlled by lithology and strike of multi-directional faults. In the space data the unit is characterized by isotropic ridge trends and sub-dendritic radial drainage. The relief has been carved out dominantly by fluvial erosion. The hue in the FCC is pistachio greenish to light brownish and texture is coarse and uneven.

The cuesta (Hill, 1986; Davis, 1989; Lobeck, 1939; Thornburry, 1954) seen in IZ around Kuh-e-Kavil extends as an arcuate zone from Kuh-e-Bagh Chashm in the SE to Kuh-e-Ranjeh in the NW. The cuesta forms the ridges of Kuh-e-Kavil and Kuh-e-Kharsan, characterized by steep obsequent slope in the NE which terminates against

Ranjan Fault. The dip slopes of the unit are characterized by gentle to moderate south-westerly gradient. The unit in the LANDSAT FCC is characterized by light greenish hue, sub-dendritic and trellis drainage pattern. The 1st order exhibits parallel drainage channels morphotectonically controlled by joints. The SW limit of the Kuh Kavil cuesta is defined by the Hoor river thrust against which the geomorphic trends abut with the hogback unit of the IZ.

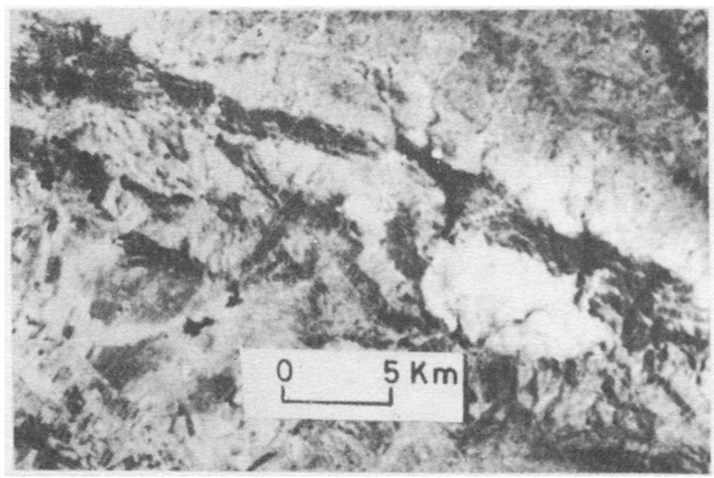

Fig. 3. Photograph shows part of SSZ, depicting the drainage pattern developed over intrusive igneous (top right corner) and metasediments.

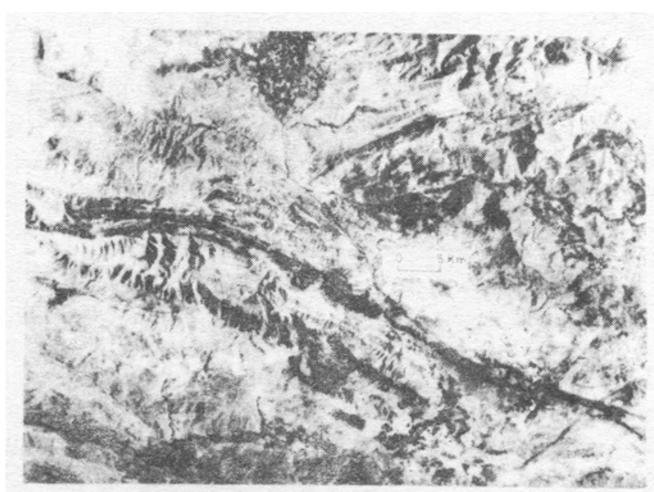

Fig. 4. Photograph shows parts of IZ (top portion) and ZFB (lower part). Note the structural discordance of these the lithotectonic units of ZSB.

The hogback (Cotton, 1944, 1952; Lobeck, 1939; Thornburry, 1954) of the IZ occur in the three different spatial domains namely to the SE of Kuh Kavil cuesta around Chenareh village, NW of Kuh Kavil cuesta round Parask and extending from Kafshgiran in the NW to Kagheh Dorud in the SE. The valley is rectilinear in disposition, characterized by the development of thick soil cover, high moisture content and extensive landuse, exhibited as agricultural fields and human settlements. The population density is high. The drainage pattern exhibited by the Chalanchulan river system is sub-dendritic. The main Chalanchulan river is linear and misfit in the 5 to 17 km wide valley which was carved out possibly in humid regime.

The Hoor river valley occurs as a linear valley cutting across different lithotectonic units. It is a structural valley whose drainage trends are determined by the thrusting and faulting in the area. The valley is narrow with a flat valley floor and narrow flood plain. The locked-up moisture along the valley is high which is expressed by reddish hue in the MSS FCC. The landuse is extensive, exhibited by the development of human settlement and accompanying agriculture. The valley is young, local sinuosity in the drainage is morphotectonic expression of the Neo-tectonism in the area.

2. *Sanandaj - Sirjan Zone (SSZ)*

It is geologically the oldest litho tectonic unit in the area, geomorphologically younger than IZ, carved out dominantly by the processes of erosion. On the basis of the shape and relief characteristics, it is separated into three geomorphic units, namely Rolling Rocky Waste, Structural Hills and Erosional Hills (Fig. 1).

2a. Rolling Rocky Waste : The peneplained and exhumed topography of granite granodiorite intrusives in the NE part of the area around Kabootran forms the rolling rocky waste, characterized by fracture-controlled angular drainage pattern. Thin soil cover occurs along the drainage channels. The drainage is characterized by flat valleys with rectangular cross section which separate the granite granodiorite into a mosaic of rocky waste as seen in MSS FCC. The topography is rounded and hummocky characterized by the accordance of the level of humps. This accordance is suggestive of a planation cycle in the area.

2b. Structural Hills : The structural hills in the SSZ represent the remnants of the metamorphics metasedimentary sequence and are picked up in the MSS FCC from their bluish green hue. Their morphotectonics is controlled by regional foliation, and are separated by elongated valleys exhibiting structurally controlled trellis pattern; locally the structural hills near the MZT have sub-dendritic drainage and are characterized by rugged tops.

2c. Erosional Hills : Oblong elongated domal outcrops of granite, granodiorite, marble and limestone characterized by fracture-controlled subangular to subdendritic drainage, erased and rounded topography carved out dominantly by exfoliation weathering have been mapped as erosional hills (Locks, 1939) in SSZ. The important erosional hills have been mapped around Bichoon. The erosional hills are separated from structural hills on the basis of their lower relief and smooth surface. The lithological inhomogeneity of the granitic bodies with the surrounding metasedimentary sequence is exhibited as hue contrast between bluish-green metamorphic and yellowish white to yellowish green colour of granite granodiorite and accompanying regolith cover in FCC. The bluish hue reflects the mafic components and yellowish white is due to sialic components of the Erosional Hills.

3. *Zagros Folded Belt (ZFB)*

The ZFB is the classical example of a folded mountain belt, and exhibits pronounced development of anticlines and synclines which have controlled the major architecture of the Zagros mountains in Iran. Geomorphologically, ZFB is younger than the IZ and SSZ but it is older than the MSC. It has rugged and dissected topography, NW-SE alignment of ridges, trellis drainage pattern etc. The geomorphic landscape is complex, the anticlinal hills coexist with anticlinal valleys, and synclinal valleys occur together with synclinal hills, exhibiting geomorphic paradox. The limbs of the broken anticlines have developed into hogback and cuestas overlooking the eroded valleys in the rugged landscape of the Zagros mountains (Fig. 1).

Anticlinal hills occur as en-echelon elongated hummocky domes around Pul-e-dukhtar, Fazelabad, Chambagh etc. In the east, the anticlinal hills are compressed doubly plunging folds whereas in the western part of the area, folds are elongated and tight. The contrast in the strain pattern is clearly brought out by the course of the Kaskgan river which is the morphotectonic expression of the close and open-fold fence in the ZFB.

The anticlinal valleys (Lobeck, 1939) in the ZFB have been recorded from north of Talehzang railway station, Razeh, north of Malavi villages, Kuhdasht town etc. The accelerated erosion of the softer lithologies generated anticlinal valleys, which occur in two distinct geomorphic settings, namely, the anticlinal valleys abutting against synclinal valleys, and anticlinal valleys juxtaposed with synclinal hills. The former suggest immature topography and the latter geomorphic setting points to topographic maturity, where the accelerated erosion beyond geomorphic null (representing planation cycle?) has resulted in the development of anticlinal valleys.

In the MSS FCC the anticlinal valleys are picked up through the development of rectilinear drainage pattern along the valley axes and convergent drainage pattern of the 1st order channels on the obsequent slopes.

The synclinal hills (Lobeck, 1939) are seen as linear ridges sandwitched between anticlinal valleys. The preservation of the synclinal hills is due to resistant lithological covers and apparently low-fracture density in the axial zone of the synclinal structures in the ZFB. The presence of synclinal hills in the area indicates a possible development of the planar surface defined by the accordance of summit levels of the synclinal hills. The accelerated erosion beyond the geomorphic null possibly controlled by neo-tectonism resulted in the relief mutation of the structural units i.e. synclines acquired higher position and anticlines eroded to lower structural levels during the geomorphic evolution of the landscape.

The synclinal valleys are developed as complement to anticlinal hills. The synclinal valleys are characterized by linearity of the drainage in the axial zone of the synclines. The hue and texture of the sides of the valleys are characterized by uniformity and homogeneity of colours, reflecting dip slopes. The sides of the valleys are expressed as hogbacks and cuesta ridges where geomorphology is immature. Afrineh township, Bard-e-Kheryreh area and north of Dorabi etc. provide good examples of the synclinal valleys.

The asymmetric folds of ZFB are morphotectonically expressed as cuesta and hogback ridges. The fold limbs are relatively steeper in the SW and gentle in the NE direction. The erosion of the resistant cap rocks in the folds have resulted in the development of the ridge system, where southwestern limbs have formed hogbacks and northeastern limb have given rise to cuesta slopes. The cuesta and hogback ridges are picked up by the development of banded hue (tone) and texture on obsequent slopes and homogeneous hue and texture on the dip slopes. The separation of the hogbacks and cuestas has been done on the basis of the length of the 1st order channels; where 1st order channels are of equal length the ridges have been mapped as hogback while the ridges with unequal length of the 1st order channel development on the obsequent and dip slope have been mapped as cuestas.

The badlands (Fairbridge, 1968) are extensively developed in the study area, over the evaporite deposit of Gachsaran formation which separates the ZFB from MCS. The badland in MSS FCC is distinguished by its fine drainage texture, low relief, dissected terrain and grey greenish hue. The badlands, can be seen around Puldukhtar, Razeh, Chem-e-Chenar and Shahbazan, Samand Kuh and Sultan Kuh villages etc., where subdendritic drainage has generated highly dissected sub-basin. The interfluves in the badlands are devoid of any vegetal cover.

In the ZFB the regional slope is towards SW. In conformity with the regional slope, the drainage pattern has carved its major flow direction towards the Persian Gulf. The higher order channels have cut across the regional trends of cuesta and hogback ridges in the area to generate water gaps. The erosion of the ridge lithologies concomitantly with the tectonic rise of the ZSB-generated gorges and canyons across the structural grain of the ZFB. These water gaps in the LANDSAT imagery are expressed by break in the lithologies, abrupt termination of the ridges, and darker hue (along the water gaps). In areas where the formational units have risen to higher tectonic levels above the valley floor due to asymmetry of the folds (Fig. 1), the water gaps have become wind gaps as defined by Lobeck (1939) and Thornbury (1954).

4. *Molasse Cover Sequence*

It forms the youngest geomorphic unit, structurally occurring as thrust sheet over the ZFB. The Molasse Cover Sequence (MCS) comprises clastics of the Aghajri and Bakhtiari formations of Mio-Pliocene age. The MCS comprise cuesta topography and fans (Winder, 1965). The fans are formed by the rivers emerging from the newly raised tectonic lands into plains overlooking the Persian Gulf. The hard and resistant nature of the clastics in the MCS has given rise to synclinal hills and cuesta flanks which at places rise upto 100-500 metres above the valley floors. The Karkheh and Dez are two main rivers which drain the area from NE and NW. These rivers exhibit compressed meandering, which is morphotectonic expression of the Neo-tectonism in the MCS.

The development of the fans at the frontal margin of the cuesta and synclinal hills suggests that the fans are the youngest geomorphic features (landforms) in the area. The southwestern margin of the MCS comprises the rolling plains (Finch *et al.*, 1957) which progressively merge with coastal zone of the Persian Gulf (Fig. 1).

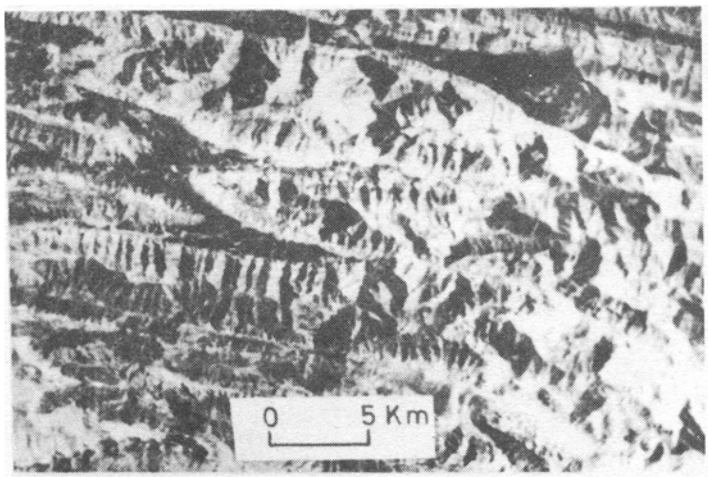

Fig. 5. Photograph shows a portion of ZFB which clearly illustrates the development of trellis drainage pattern.

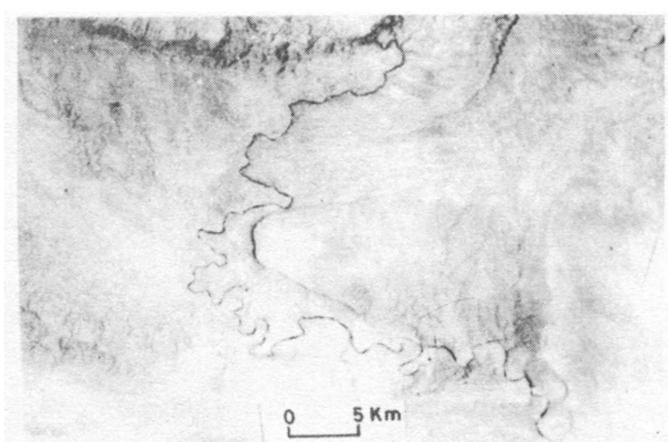

Fig. 6. Photograph shows a portion of MCS which exhibits different drainage pattern than that of ZFB.

Landscape Evolution

The geomorphological study of the Zagros collision zone reveals that the Zagros morphogeny is the morphotectonic expression of the Alpine-Himalayan subduction cycle and collision of the Arabian and Iranian plates. The Iranian and Arabian lithospheric plates were separated by an oceanic crust upto the Cretaceous (Takin, 1972). During the Createaceous the subduction started as a global event which led to the closing of the Neo-Tethys (Takin, 1972; Berberian and King, 1981), in Iran. This event is recorded as IZ where the subduction related ophiolite and coloured melange were accreted to the Zagros sediments in the late Cretaceous time (Takin, 1972). The IZ remained negative tectonic topography from Paleocene to Mio-Pliocene and formed part of Zagros trough which received sediments from SSZ in the north and probably from the Arabian plate in the south (James and Wynd, 1965). The deformation of the IZ started in Eocene (55-25 Ma) and continued upto Miocene. Collision-related compressional tectonics has resulted in the upliftment of the IZ and the formation of the ZFB, and the sedimentary environment changed from marine to continental in the Zagros trough. During early Miocene the Gachsaran evaporites were deposited over which the MCS was deposited in front of the newly raised tectonic lands of ZFB and IZ, and isolated patchels in the inner part of the belt.

The Zagros trough closed around Miocene (25-5 Ma) concomitantly with the opening of the Red Sea (Sultan *et al.*, 1992). The collision of the Arabian and the Iranian plates led to the annihilation of the subduction below the IZ. This process of collision has generated morphogeny in the SSZ, IZ and ZFB. The closing of the foreland basin has generated vertical tectonics in the ZFB and decollement in the MCS.

The morphogeny in the Zagros mountains has taken place during the last 4-5 Ma concomitant with the opening of Red Sea @ 1 mm/year which generated a relief of about 4 km above MSL (Falcon, 1974; Rangzan, 1993) and resulted in the development of erosional cycle. The collision resulted in tectonic jumbling and juxtaposition of different lithotectonic units which resulted in the structural discordance of the internal fabric of IZ with the regional NW-SE grain of the ZFB. This internal fabric is geomorphologically expressed as hogback ridges of IZ (Dewey and Bird, 1975; Gansser, 1981).

In response to opening of the Red Sea the Sanandaj-Sirjan Zone (SSZ) and IZ underwent vertical tectonics and acted as areas of positive relief. Later geomorphic processes resulted in extensive erosion of the SSZ so much so that its present day disposition at lower altitude than the IZ has exhumed the deeper levels of the older rocks in the area. The ZFB together with the MCS are rising @ 1 mm/yr (Falcon, 1974; Rangzan, 1993). The tectonic activity in these zones is well documented by the development of anomalous drainage and compressed meanders in the study area. The fluvial erosion of the newly raised tectonic lands during the humid cycles in the Quaternary has generated the cuesta and hogback ridges, and structural and erosional hills and valleys.

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