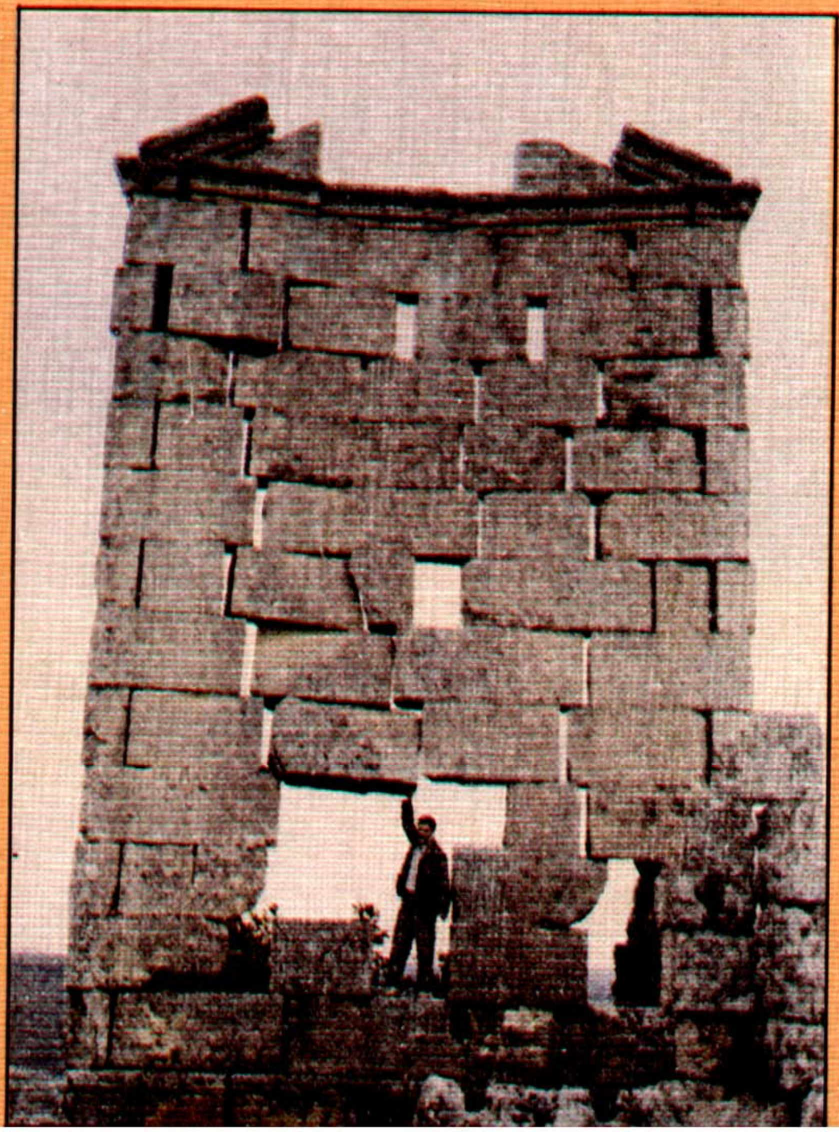
SYRIAN ARAB REPUBLIC
ATOMIC ENERGY COMMISSION (AECS)
Damascus

PROCEEDINGS OF THE REGIONAL WORKSHOP *ON* ARCHAEOSEISMICITY IN THE MEDITERRANEAN REGION

November 4-7, 1992

Damascus



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Investigation of Active Tectonics along the Major Faults in Syria Using Geomorphic Techniques

Youssef Radwan and Haitham AL - Najjar*

Abstract

Tectonic geomorphologic tectoniques have been applied in an attempt to reconstruct the neotectonic events occurred along the major tectonic lines in Syria: the northern segment of the Dead Sea Leaky Transform Fault i.e. the Syrian Lebanese Fault, the NE - SW trending Palmyridean Faults and along the NW - SE trending faults in the south and northwest of the country.

The regional reconnaissance investigations involved measuring the values of stream - gradient index, mountain front sinuosity and ratio of valley - floor width to valley height along the aformentioned faults, and comparing them with such valies measured in know tectonically - active areas in the west of the United States. The comparision revealed that the faults investigated are still active.

The landforms accompanying the Syrian Lebanese Fault (linear valleys, sag ponds, pressure ridges and shutter ridges) represent indeed distinguished tectonic structures characteristic for active strike slip faults.

Detailed site - specific investigations carried out with the analysis of the offsetted streams and alluvial fans along the Syrian Lebanese Fault give a slip rate of > 12 mm/y.

The analysis of the seismic damage observed in the Castle of the knights (Qalaat Al Hosn) gives an estimated maximum slip rate of 20.5 mm/y during the time span from 1203 - 1306 AC .

Phenomena indicative for very tectonics were observed along the NE - SW faults in the Coastal Range, where a bridge forming part of the Aleppo - Lattakia highway was destroyed fifteen years ago. Repareted earth shaking were recorded also in the country during the last few years.

1. Introduction

The Geological Mapping Team of the Geology Department at the AEC of Syria performed in 1989 a geological and structural study area east of Homs in central Syria.

As a continuation of this study investigations on active tectonics along the major faults in Syria i.e

The Syrian lebanese Fault, The Palmyridean Faults and the NW-SE , E-W Faults, were conducted.

Through these investigations basic geomorphic techniques were applied in an approach to evaluate the neotectonic deformation and to assess the deformational rates. Since some phenomena along the mentioned faults, indicative for active tectonics were reported, such Study is of vital importance for earthquake prediction and seismic hazard assessments to mitigate the seismic risks to a minimum.

The tectonic geomorphology, which is defined as the study of landforms of tectonic origin which aims to delineate the mutual interrelation between tectonics and geomorphologic processes, can prorvide solutions for problems of reciprocal nature.

Thus, through selection, identigying and analysing the geomorphologic characteristics of landforms of tectonic origin the tectonic history can be reconstructed, and in turn having enough data on the tectonic history of an area the evolutional steps of the landforms can be determined. Such kinds of studies aim to connect between tectonics and morphology of landforms have developed rapidly. The works of Wallace 1978, Bull & Mcfadden 1977, Wallace 1977, (all cited in Mayer 1986) for studying the mutual influence between tectonics and landforms resulted by tectonic events can be considerd as a base for tectonic interpretation.

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Through tectonic geomorphological investigations, the tectonic events of an area can be properly reconstructed and the nature, history and the associated seismicity of faults during time spans extend to ten thousands of years can be revealed. These time spans may stretch to hundred of thousands of years if the landforms studied have longer age such as mountain fronts, and fault escarpments(Mayer 1986).Thus tectonic geomorphology is a powerfull and effective tool in detecting netectonics that occurred in the last few thousands to hundred thousands of years and still active.

According to the scale used in such studies, investigations of active tectonics depending on geomorphic techniques can be divided into:

- Regional Reconnaissance Works.

- Site - specific near surface processes-response studies.

The regional reconnaissance works help in delineating places and areas of distinguished active tectonics. They usually involve the use of geomorphic indices (rock resistance to erosions, climatic change) and tectonic processes. They involve aslo the use of landform assemblage formed or midified by recent active tectonics.

The near surface processes - response studies involve integrated connecting of landformes, rocks, geomorphologic processes and active tectonics through the time.

Such studies analyze faulted Holocene deposits and faulted landformes (offsetted streams, alluvial fans and alluvial and mairne terraces) and trace all changes in fault scarp morphology through time, in order to estimate the rates of active tectionics (slip rate along faults, subsidence and uplifting rates, recurrence intervals of damaging earthquakes) (Keller 1986).

Slip rates can be calculated through geomorphologic estimations by measuring the amount of change in a landform or feature through time, hence chronological sequence of events can be set up.

In this regard, recognition and measuring the changes are much easier than setting up their chronological sequences. Nevertheless, the evaluation of the importance of tectonic change rates measured, due to different geological constraints, is very difficult, since these changes are temporal- and spatial- controlled. For example, the slip rate varies at different segments of the same fault due to variations in the tectonic framework (spatial control). In turn the uplifting rates of landforms and terraces vary in time as a function of mechanics of deformation (temporal control), (Keller 1986).

These investigations and studies provide basic data necessary for long term earthquake prediction through two approaches;

- Calculating slip and uplifting rates and recurrence intervals of earthquake through the analysis of landforms.

- Reconstructing of paleoseismicity through studying faulted Holocene deposits. (Keller 1986).

2- The Tectonic Geomorpholgical Analysis of the Studied Area

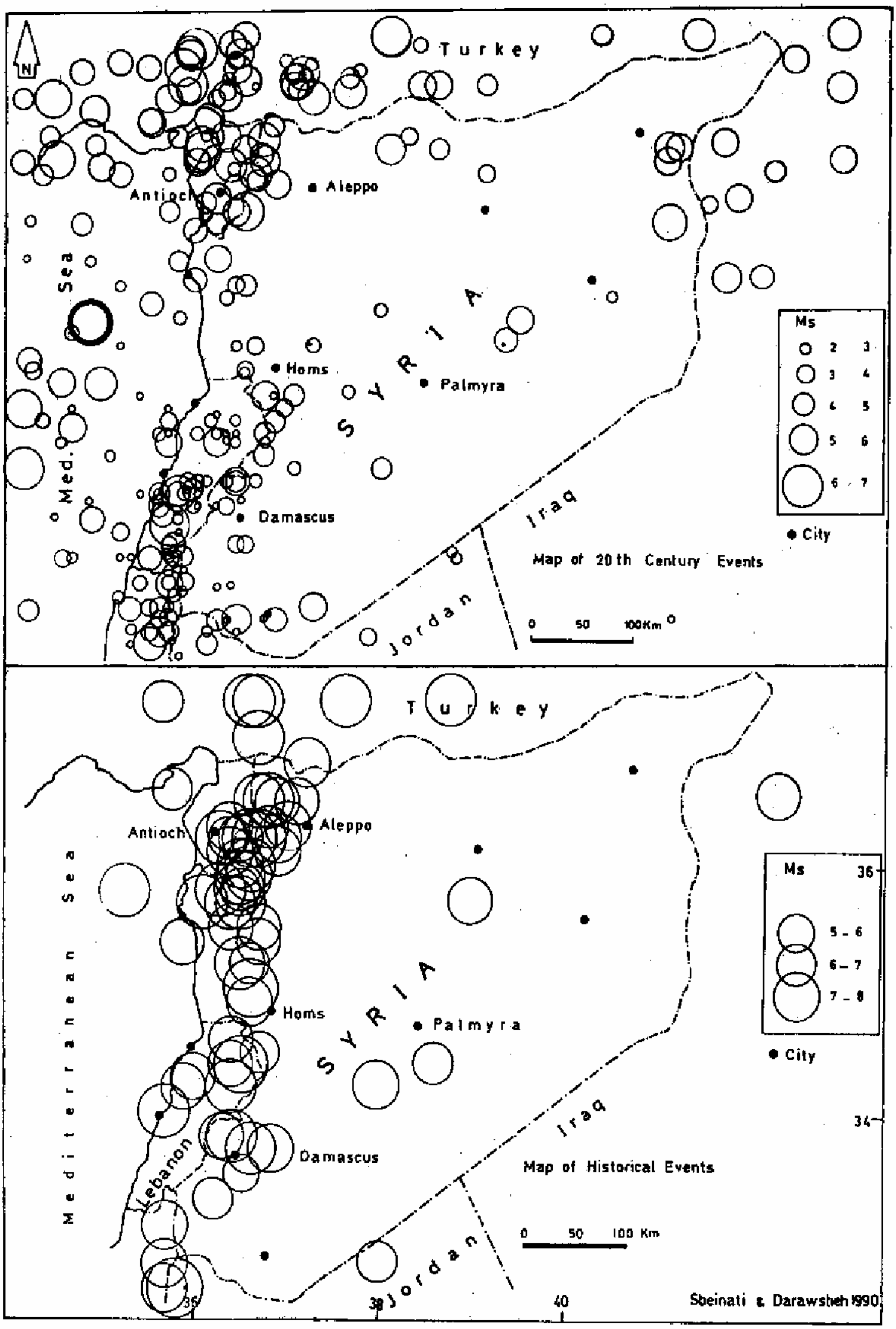
2- 1 Regional reconnaissance investigations

The comparison between structural and geological map of Syria on one hand, and the historical and instrumental seismic map of Syria (Sbeinati and Darawcheh 1990) on the other, enables delineating different landforms of tectonic origin and major structural lines which were not only behind regional volcanism during Quarternary at least, but also behind numerous damaging historical earthquakes as well (Figs 1 , 2 , 3)

Among the most important lines of them the following are to be counted:

1) The Syrian Lebanese Fault

Actually this fault is comprised of many vigorous N - S trending faults which stretch over few hundreds of kilometers. The southern extension of this fault in Jordan and Palestine is termed Wadi Araba Fault, characterized by distinguished structures such as Jordan Graben, Dead Sea and Tiberias and AL Hule lake.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Map of 20th Century Events
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Map of Historical Events
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Sbeinati & Darawsheh 1990

Fig. - 1

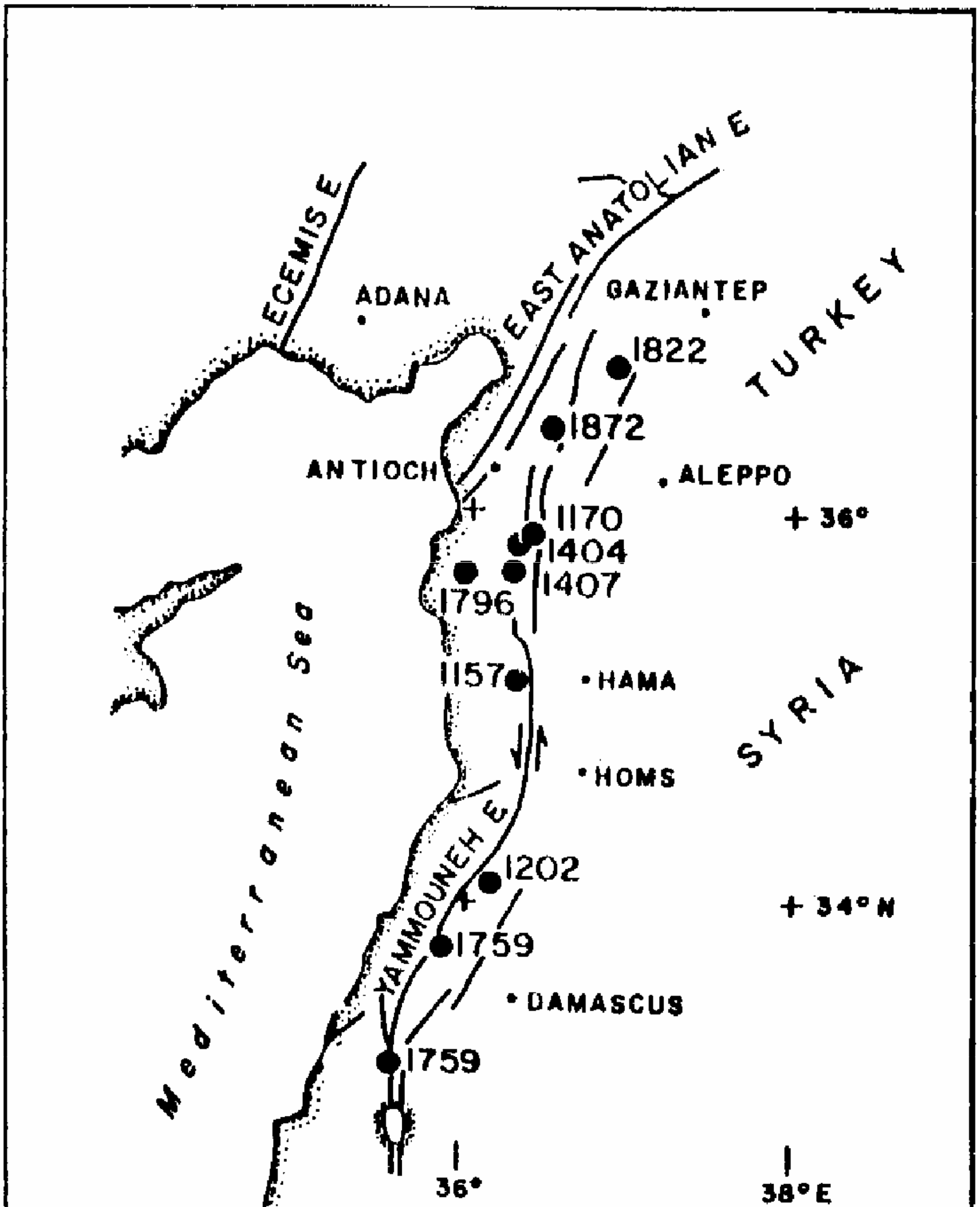


Fig. 2- Major historical earthquakes distribution east of the Mediterranean After Ambraseys & Barazangi (1989).

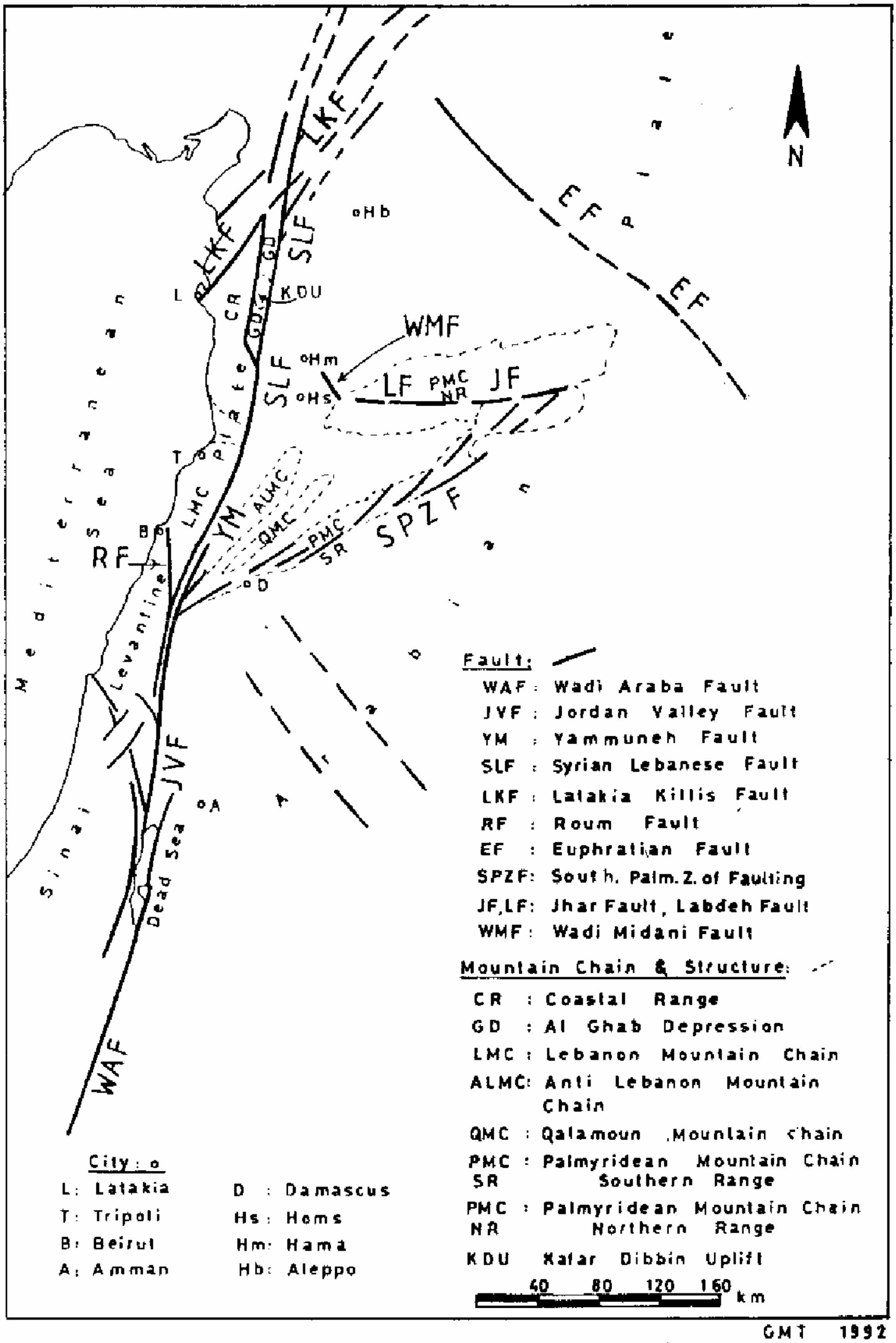


Fig. 3- Major structures east of the Mediterranean.

Whereas, in Lebanon it deflects towards NNE having a local name (AL Yammouneh Fault) forming in turn a unique structure i.e. AL Bekaa Valley.

Its northern extension in Syria has again the regional overwhelming trend i.e. N - S, termed locally Al-Ghab Fault, forming there a very peculiar structure known as AL Ghab Valley, where some phenomena indicative for active tectonics have been observed.

2) The Southern Palmyrides Faults

They represent indeed a faulting belt trending NE - SW of a few hundreds of kms length.

Indications for neotectonics activity have been reported in the Holocene deposits that overlie one of these faults that bounds the southeastern limb of Abou AL Ata anticline near Damascus.

3) The E-W and NW-SE trending Faults

The NW - SE faults, dominating in the south of the country, are the feeders of the extensive Holocene basaltic flows. Many faults of this type are reported in the western parts of the Palmyrides, deformations (Holocene faulting, recent collapse of rock masses) were observed.

2-1-1 Geomorphology indices used in regional reconnaissance investigations indicative for active tectonics

2-1-1-1 Stream gradient index

This index can be defined after (Hack 1973, cited in keller 1986) as follows:

$$SI = (\Delta H / \Delta L) L$$

where: SI = Stream gardient index.

$\Delta H / \Delta L$ = Local gardient of the stream reach where the index is computed.

ΔH = Drop in elevation of the reach.

ΔL = Length of the reach.

L = Total channel length from the drainage divide to the center of the reach measured along the channel.

This index reflects roughly the stream power hence the stream's ability to transport its load. Such ability is defined as a product of two factors:

- water discharge, which is proprtional to stream load discharge.
- slope of the surface, which approximates the slope of channel bed.

The index is very sensitive to any change in slope, thus it is a valuable and powerfull tool for assessing active tectonics of strong vertical component. Nevertheless, it is sensitive to any change in rock resistance to erosion as well. This makes the differention between changes generated by tectonics and others caused by the difference in rock resistance to weathering, very difficult.

However, SI values are usually high in areas of near surface vertical active tectonics and in areas of resistant rock.

Therefore, anomalously high SI values in areas of rocks ductile to weathering can be considered as a possible indicator for active tectonics (keller 1986).

The values of SI index along different faults in the area concerned, their minima, maxima and frequencies are summerized in table 1 :

Tabel - 1

Fault	Direction & category	Area of comutation	Minimum	SI freq.	Values maxim.	Freq.	med.
Wadi Midani Fault	MNW left lateral wrench fault	eastern block	37	1	418	1	170
		western block	25	1	131	1	88
Wadi AL-La badeh Fault	E - W right lateral	northern block	49	1	169	1	84
The Syrian Lebanese Fault	N - S left Lateral Leaky Transform Fault	eastern block	53	1	634	1	306
		western block	45	1	900	1	327

The analysis of Sl value computed from topographic sheet of 1 : 25000 scale along Wadi Midani Fault reveals that such values on the eastern block of the fault is one and half times those on the western one. This may suggest a relatively higher vertical neotectonics component on the eastern block, inspite both block posses a very low vertical tectonic activity in general.

The comparison between Sl values computed along Wadi Midani fault and those measured along the Syrian Lebanese Left Lateral Wrench Fault proofs that the SI values on the latter are twice those along Wadi Midani Fault and trice those along the northern block of Wadi Al-Labdeh fault. Thus it can be logically concluded that vertical tectonic activity along Wadi Midani and Wadi Al-Labdeh faults is much weaker than that along the Syrian Lebanses Fault, although they all are generally of very low Sl values when compared with other areas of high vertical tectonic rates and seismic activity such as San Gabriel Mountain in Southern California keller 1977 , (cited in keller 1986).

keller 1986 concluded from his investigations in California that Sl values are relatively low along stike slip and wrench faults, where the horizontal movement crushes the rocks producing zones low in resistance to erosion, and also low in areas of soft sedimentary rocks ductile to weathering. These conclusions may explain the exterme low Sl values along Wadi Midani, Wadi Al-Labdeh and the Syrian Lebanese Fault since they are wrench faults which usually have a higher horizontal component compared with the vertical one. Moreover, the rocks of the studied area are sedimentary in bulk having low resistance to erosion.

2-1-1-2 Mountain front sinuosity.

This index is an effective reconnaissance criterion for evaluating the amount of changes attributed to active tectonic prosesses. It can be easily and rapidly computed from photographs, Satellite imegeries and topographic sheets. It is defined as:

$$Smf = Lmf / Ls$$

whereas:

Lmf= Length of mountain front along the mountain - pedimont junction.

Ls= Length of straight line along the sinuous mountain front.

This index reflects the balance between the tendency of stream and slope processes to produce a sinuos mountain front, and the tendency of vertical active tectonic to produce a prominent straight front, (Bull & Macfadden 1977, cited in keller 1986). Thus, mountain fronts associated with active uplifting are relatively straight. Nevertheless, if the uplifting rate is reduced or ceased, then erosional processes start to form sinuous front which becomes more irregular with time. (keller 1987).

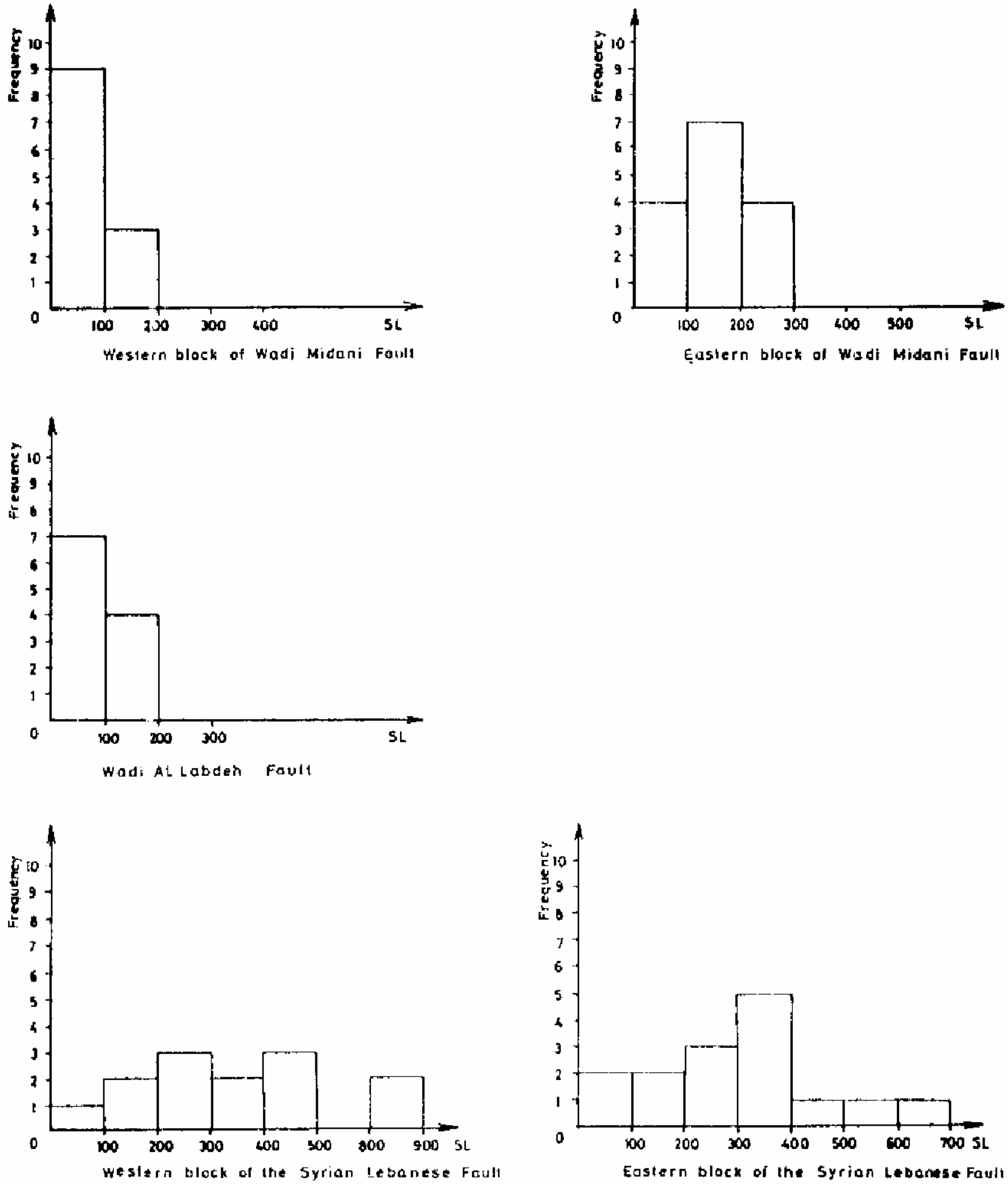


Fig. 4- Distribution of Sl values.

Low Smf values measured along Garlock Fault in California are indicative for active tectonic on the northern block of the fault, while on the southern block high Smf values indicative for relative quiescence are computed, (Bull & Macfadden 1977 , cited in keller 1986). In similar way Rockwell & Keller 1986 (cited in Keller 1987), found that Smf values in other sites in California range between 1 and 3 . They believe that low Smf values in order of 1.01 to 1.14 are characteristic for tectonically active fronts, and can be maintained over the whole area if a threshold rate of uplift greater than 0.4 mm/yr is maintained.

Topographic sheets at scale 1/25000 of the studied area were used to compute the sinuosity of mountain fronts prominent in the area. The Smf index on the eastern block of WNW - trending Wadi Midani Fault reaches a mean value of 1.409 , but it does not exceed 1.188 on the western block of the mentioned fault. While the Smf values are in the order 1.11 - 1.16 on the eastern block of the N - S trending Syrian Lebanese Fault, they swing between 1.25 and 1.42 on its western block.

Along the E - W trending Wadi Al-Labdeh Fault the Smf values was around 1.242 , and decrease to 1.063 - 1.116 along the NE - Palmyridean style - Jabal As-Sawwan Fault.

Although the aformentioned faults do not have a remarkable vertical component i.e uplift or subsidence, since they are either transform, wrench and strike slip faults (Syrian Lebanese Fault, Wadi Al-Labdeh fault), or thrust faults (Jabal As-Sawwan fault), nevertheless, they posses very low Smf values in prticular along Jabal As-Sawwan fault. Through the comparison of these values with those given by Rockwell & Keller 1987 (cited in Keller 1987) for areas of pronounced uplift and vertical tectonics in California estimated at 0.4 mm/yr , a striking similarity between the Smf values is marked (1.01 - 1.14 in California, 1.063 - 1.116 in Jabal As-Sawwan). This suggestes that an occurrence of neotectonic activiteis along the mentioned faults is not excluded especially along Jabal As-Sawwan Fault.

2-1-1-3 Ratio of Valley - Floor Width to Valley - Height

This ratio is expressed in the following equation:

$$Vf = 2\ Wfw/[(Eld - Esc) + (Erd - Esc)].$$

where: Wfw = Valley floor width.

Eld and Erd are the elevation of the left and right valley divides respectively.

Esc is the elevation of the valley floor.

All of these data should be measured at given distance up from the mountain front.

This index mirrors the differences in the nature and the development of the stream valleys that emerge from different mountain fronts, or from different parts of the same mountain front.

U - shaped broad valleys with high Vf values indicate a relative quiscence of the mountain front and lateral movement with erosion. While V - shaped vallys and Vf values suggest a vertical active uplift of the mountain front giving chance for downcutting erosinal processes to occur. The Vf values on the northern block of Garlock fault in California calculated by Bull & Macfadden 1977, (cited in Keller 1986), range between 0.05 to 4.7 . They considered these values as indication for active uplifting of this block. Rockwell & Keller 1986) attained similar results in adjoining areas.

This index is computed from 1: 25000 topographic sheets of the area concerned. The comparison between Vf values computed along Wadi Midani and along the Syrian Lebanese Fault with those of the active Garlock Fault, shows a clear closeness bespeaking a similar tectonic activity of the former faults.

Despite the fact that the Vf value along the Syrian Lebanese Fault are approximately one third to one half of the Vf values computed along Wadi Midani fault, which denotes a double or triple activity of the former compared with the latter fault.

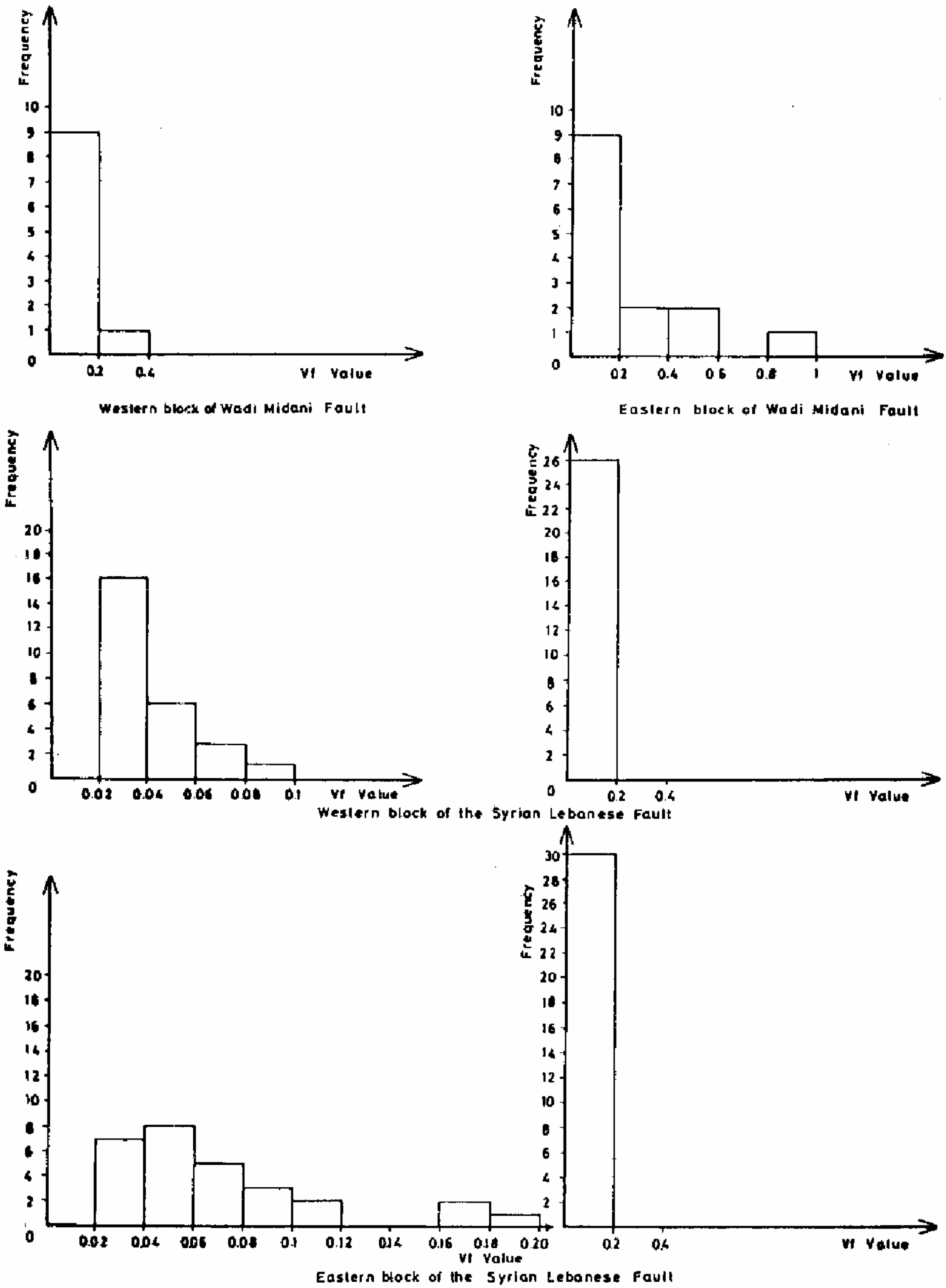


Fig. 5- Distribution of Vf values.

2-1-2 Tectonic geomorphology and landforms assemblage

The tendency of geomorphologic processes to produce a distinguished landforms assemblage makes a genetic classification of different landforms possible. For example, vertical tectonic processes trend to generate straight mountain fronts and V-shaped valleys of sharp gradient. At smaller scale active tectonics processes along a mountain front of a fault zone, produce and/ or modifty characteristic alndforms assemblage. For instance, alluvial fans posses varying morphology compatible with the variations in the generating effecting

Table -2

Fault	direction & type	Vf Values						
				min.	Freq.	max.	Freq.	mean
Wadi Midani Fault	WNW left lateral wrench	Eastern Western	Block Block	0.021 0.027	1 1	1 0.22	1 1	0.23 0.08
Syrian Lebanese Fault	N - S leaky transform	Eastern Western	Block Block	0.033 0.021	4 6	0.2 0.1	1 1	0.07 0.05

tectonic. Similary, strike slip faults produce generally specific and distinguished landforms.

The anlysis of landforms assemblage requires an implicite assumption that the most the landforms retain their primary appearence without changes or modifications, the younger they are (Keller 1986).

2-1-2-1 Landforms assemblage associated with strike slip fault

Active tectonics along strike slip and transform faults yied very distinctive landforms assemblage include linear valley, shutter ridges, pressure ridges, sags, benches, scarps, and small horst and grabens tremed microtopography (Wesson et al. 1975, cited in Keller 1986). See Fig. 6.

The formation of many of these landforms can be explained through simple shear that produces contraction and extension(Wilcox et al.1973, Sylvester & Smith 1976 and keller et al. 1982 all cited in keller 1986). Others are better understood as a result of contraction and extension at the site of bending or stepping of the fault trace (see Fig. 7) (Crowell 1974, Dibblee 1977, cited in keller 1986).Through analysis of different topographic features along strike slip and transform faults within the studied area and the adjoining countries, a set of landforms assemblage can be classified into the following categories:

2-1-2-2-1 Linear Valleys;

The N-S trrending Wadi Araba which stretches over (140 Km) to the south of the Dead Sea and the Jordan Valley (105 Km) to the north of it, Beside the NNE Al Bekaa Valley (125 Km) and N - S Al-Ghab Valley (200 Km), are very good examples of linear valleys characteristic for active neotectonics associated with the left lateral Dead Sea Leaky Trasform Fault.

The vertical throw of the eastern block of Wadi Araba and Jordan valley Faults at Jabal Dyab is estimated at 1697 m, Bender 1974. Freund et al. 1970 (Cited in Hancock & Atiya 1979) believes that the 105 - 110 Km left lateral displacement along the Dead Sea Leaky Transform Fault since Late Cretaceous can be divided into:

60 Km from Late Cretaceous to Miocene outset.

40 Km from Miocene outset to the Late Upper Pliocene.

10 Km in post Upper Pliocene.

150 m at least during Quaternary.

They believe that the offsetting of the Maastrichtean ophiolite attains 70 Km, While the Pliocene basalt in Sheen trap is 8 Km left laterally offsetted. It is worth mentioning that the left lateral offset on the southern segment of the Dead Sea leaky trasform Fault (Wadi Arba, the Jordan Valley) Which is estimated by Freund 1979) as much as 105 Km, never exceeds 25 Km on the nothern segments of the mentioned fault (The Syrian

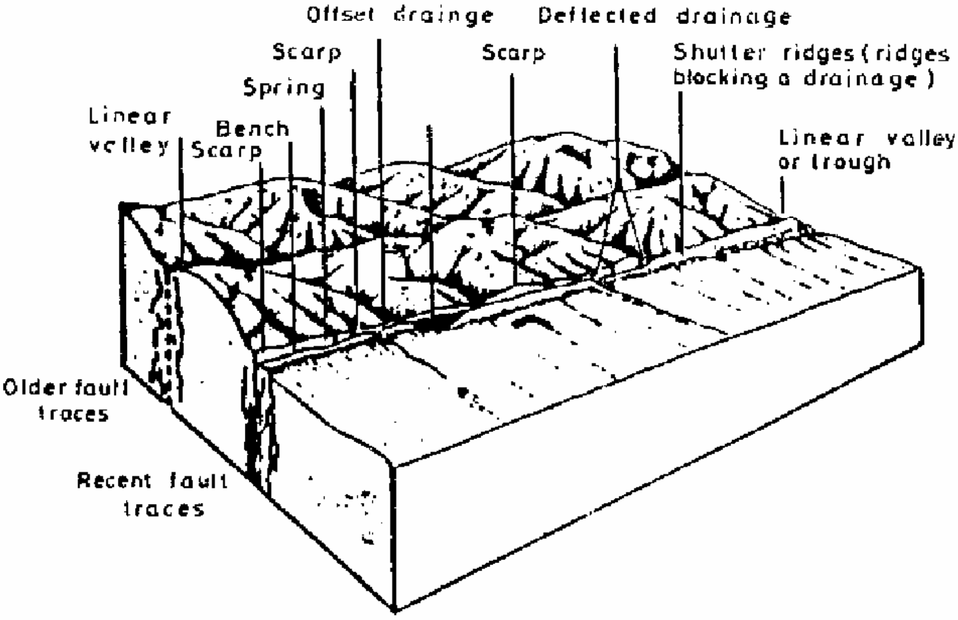


Fig. 6- Assemblage of landforms associated with active strike slip faulting. Modified from:(Wesson et. al. 1975, cited in Keller. 1986).

Lebanese fault), (Trifonov et al. 1983, cited in Chaimov & Barazangi 1990), and is given a value of 30 Km by Quennell 1984.

A remaining difference valued 80 Km is explained by Chaimov & Barazangi 1990 through a tectonic model similar to the one suggested by Quennell 1958 (cited in Chaimov & Barazangi 1990). From the neotectonic point of view this model is very important, since it implies independent developmentof the two segments before Pliocene which means, an offset attained 65 Km on the southern segment occurred during the time span 6 - 20 m. yr ago, while the northern segment has not yet been existed since it was formed only 6 m. yr ago, Fig. 9.

The formation of the northern segment was followed by a left lateral displacement on both segments measured 20 - 25 Km.

Thus, a remaining 20 - 25 Km difference represents the difference between the total displacement of 105 Km and the sum of all individual displacements aformentioned .

Chaimov & Barazangi 1990 argued that this difference is consumed through shortening generated by folding in the Palmyridean Belt. This assumption is based on their interpretation of the balanced and restored cross sections.

Thus, the formation of the Syrian Lebanese Fault and Al-Yammouneh Fault are products of a continuing neotectonic activity resulted in an estimated of slip rate 7 - 10 mm/ yr during Pliocene - Pleistocene, 1.5 - 3.5 mm/ yr during the last 1000 - 1500 years (Garfunkel et al., 1981).

Accordingly, the total offset can be detailed as follows:

Period	Left lateral displacement (Km).	
	Northern segment of the Dead Sea Leaky Transform Fault	Southern segment of the Dead Sea Leaky Transform Fault
Befor 6 - 20 M.yr.	N.A.	65
During the last 6 M.yr.	20 displacement + 20 shortening	40
Total displacement during the last 20 M.yr.	40	105

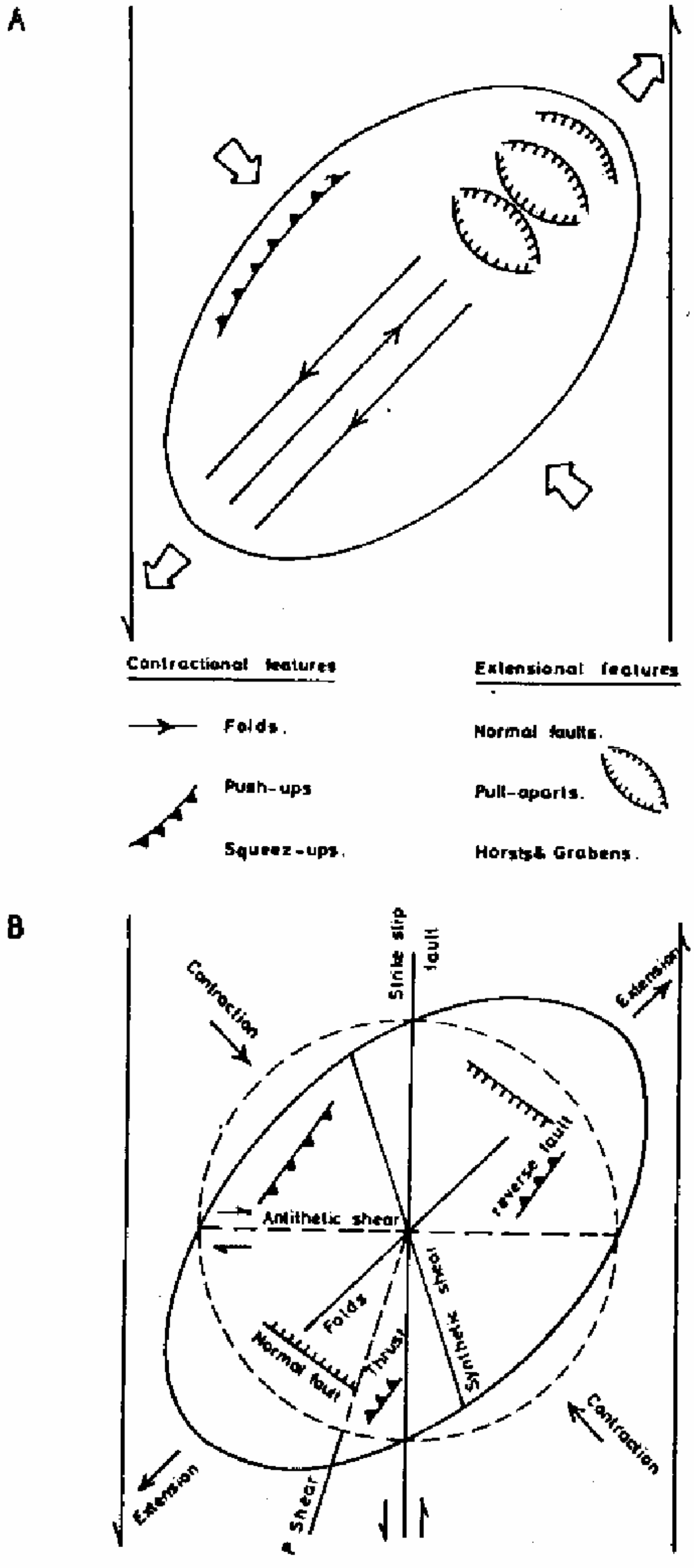


Fig. 7- Simple shear associated with strike-slip faulting produces preferred orientation of fractures, fault and folds (A) as well as extensional and contractional landforms (B). Modified from: Willcox et. al. (1973), Sylvester and Smith (1979), and Keller et al., (1982), cited in Keller et. al. (1986).

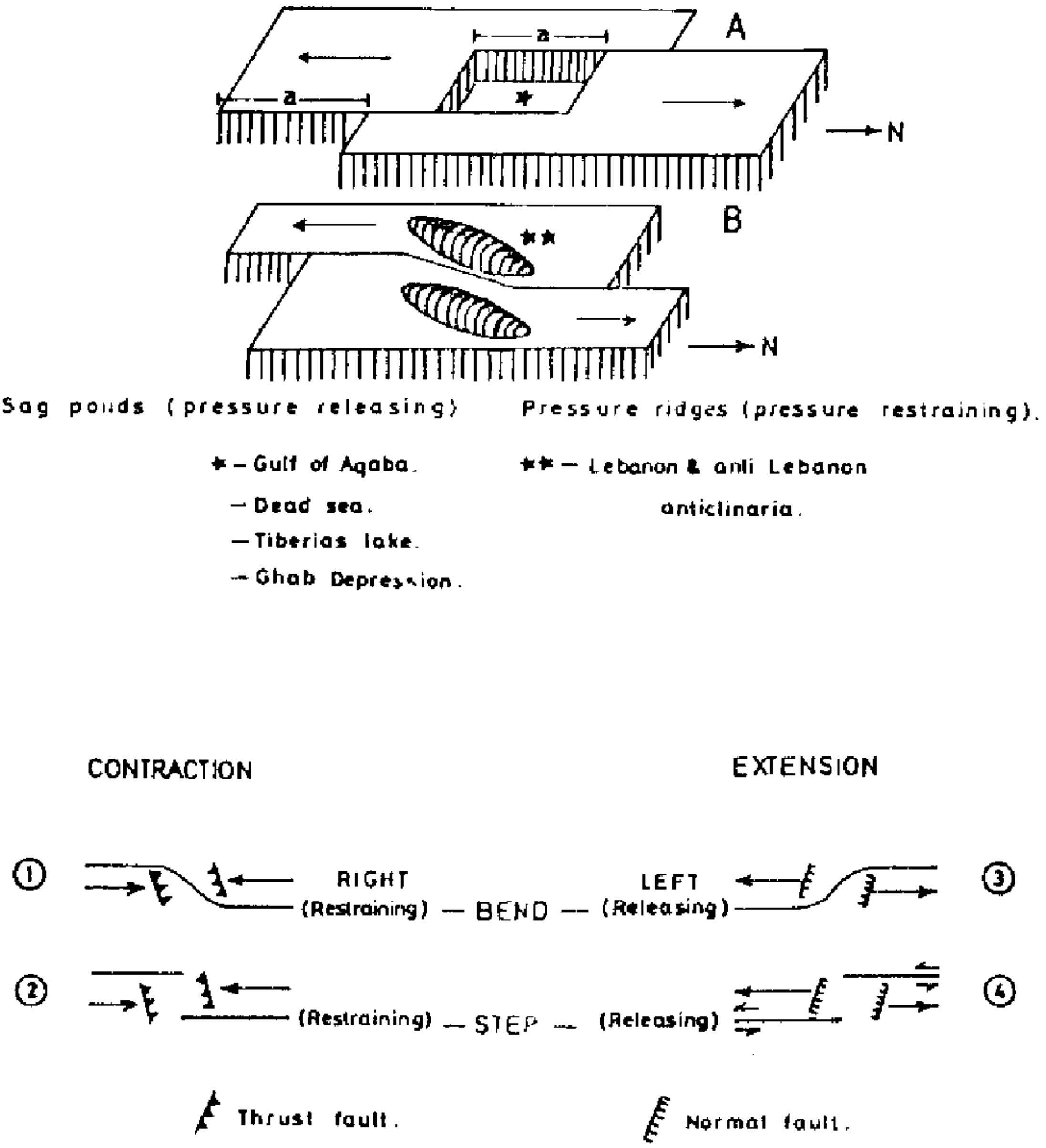


Fig. 8- Pressure ridges and sags associated with restraining and releasings bends and/or steps along strike-slip faults. Modified after: Dibbklee (1974), cited in Keller (1986).

2-1-2-2-2 Sag Ponds:

Gulf of Aqaba (230 Km), Dead Sea (80 Km), Tiberias lake and the Ghab Valley are exellent examples for pull - apart - basins which represent subsiding structures developed perpendicular or oblique to the maximum extension as areas of pressure release. From geomorphological point of view these structures are considerd as vast valleys filled by alluvials derived from adjacent high terrains to form alluvial fans, or by the run off to make up such as the once swamp of Al-Ghab Valley , or to develop into small intracontinental seas such as the Dead Sea (Fig. 10).

Differernt concepts and theories were presented to explain the origin and the development of these structures. They vary from ramp valley - to geosuture - to graben de subsidence - to pull - apart basin - theory. The ramp valley theory is attributed to a compression directed E - W associated with a frequent subsiding of a

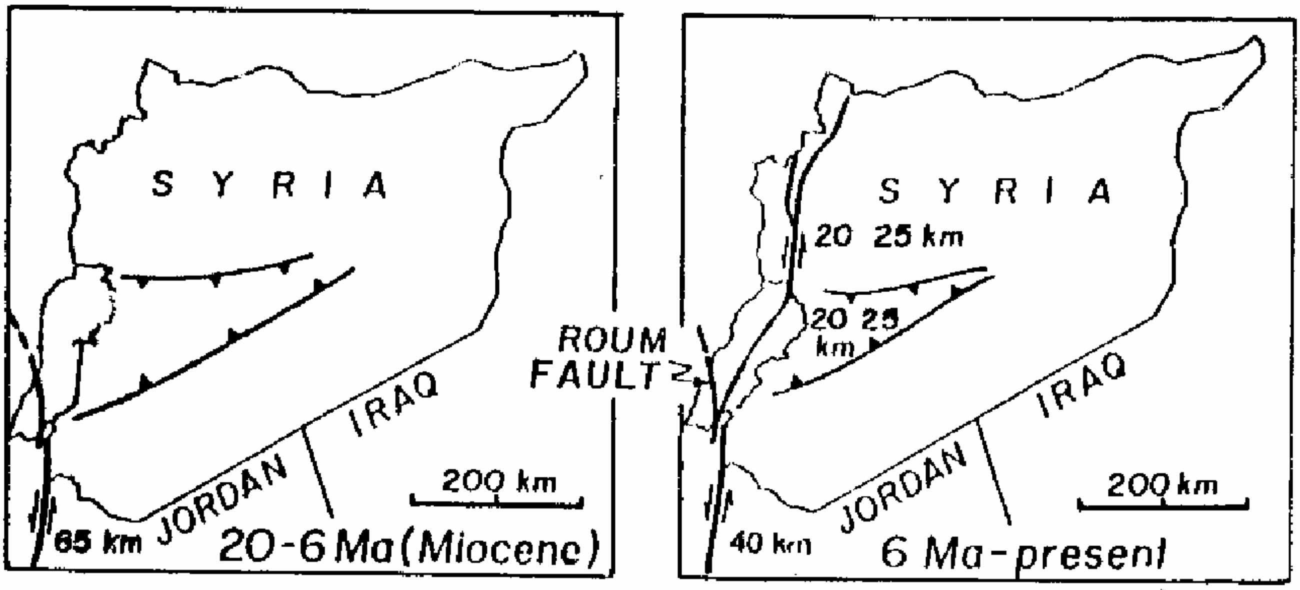


Fig. 9- A possible kinematic model to explain the apperent discrepancy between left-lateral offsets observed on the segments of the northern versus the southern Dead Sea fault system. the Roum fault may have been the main northward continuation of the Dead Sea system during the Miocene. (Chaimov & Barazangi 1990).

N - S elongated narrow block which continued subsiding through vertical movement of earth crust (Willis 1928 cited in Bender 1974)

The geosuture theory introduced by Lartet 1869 (cited in Bender 1974), is based on the presence of faulting zone along the eastren block of the graben and on the subsidence of the part of the crust in Palestine which accompanied by southward displacement. While Quennell 1959 (cited in Bender 1974) believed that the part of the crust in Jordan shifts northwards. Other theories were presented by (Wetzel & Morton 1959, cited in Bender 1974) which bespeaks a graben de subsidence generated by a frequent subsidence since Cretaceous. Another theory describes the formation of rhomb graben or a pull - apart basin, developed as a result of continuous left lateral displacement generated by left shear along the vigorous N - S Faults, is suggested by Quennell 1959 , (cited in Garfunkel et al., 1981).

Nevertheless, the widely accepted theory depecting their formation is the pull - apart basins theory, (Freund et al., 1968 , Garfunkel 1970, Ben Avraham et al., 1979, all cited in Garfunkel et al., 1981). The presence of pull-apart basins per se is considered among the most powerfull criterion indicative for neotectonic activity (Wesson et al., 1975, cited in Keller 1986).

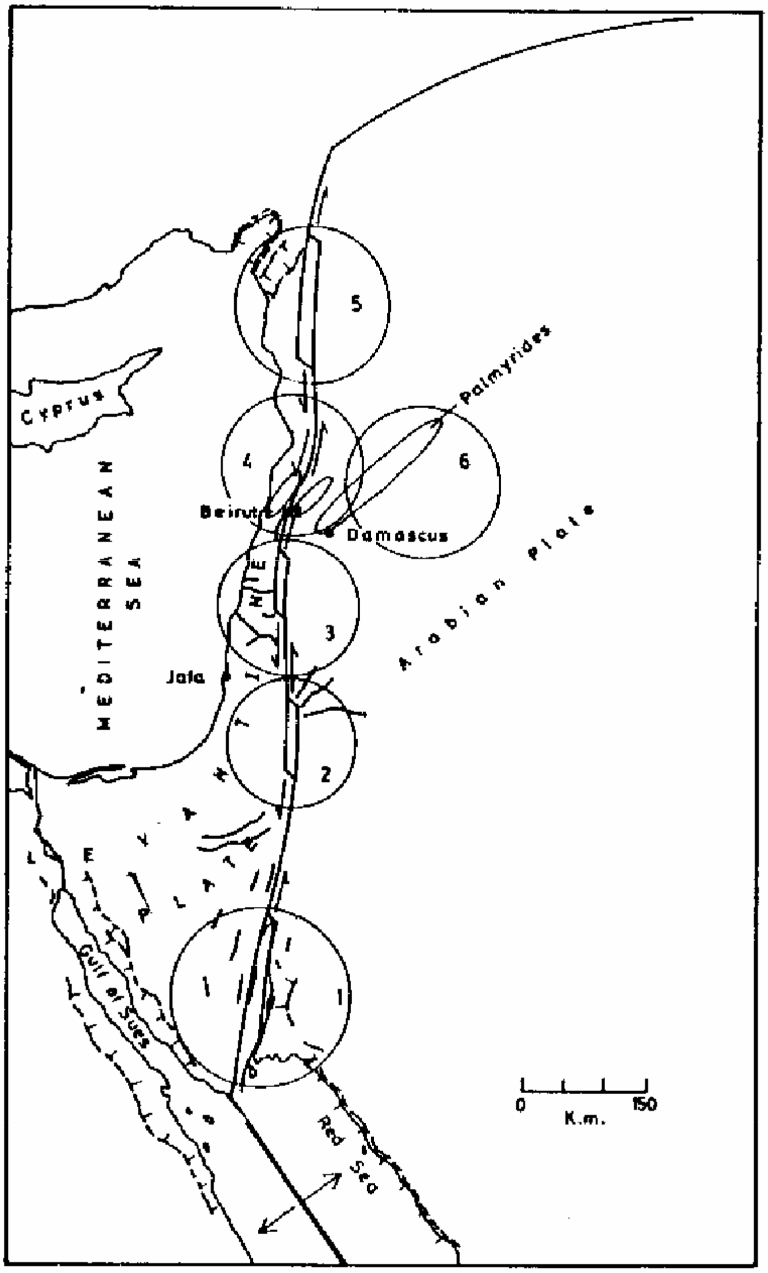
A strong evidence for such neotectonic activity during Quaternary is the 600 m - left lateral displacement in the unconsolidated Quaternary deposits in the southern Wadi Araba (Garfunkel et al., 1981).

2-1-2-2-3 Pressure ridges

Pressure ridges are distinctive structures suggestive for active tectonic at the sites of deflection of strike slip faults. In this regard,. Al-Yammouneh Fault in Lebanese can be considered as the bended segment of the Syrian Lebanese Fault trending NNE - SSW in contrary to its N - S regional trend. The deflection is attributed to pressure restraining and contraction affecting this site, (Figs. 8 & 10), where Lebanese - and Anti Lebanon Anticlinoria are formed as typical pressure ridges whose folding axis strike NNE. In this concept, Al-Bekka valley is a tectonic depression separates the mentioned, anticlinoria, through which Al-Yammouneh Fault runs. This defelection is associated with a 20 Km shortening in the Palmyrides (Chaimov & Barazangi 1990).

2-1-2-1-4 Shutter ridges

They are defined as ridges locking the adjoining wadis due to a horizontal displacement along strike slip faults. Good examples of such ridges were mapped to the north of Misyaf where Jurassic hills in Dahr Khatwat



1 - Gulf of Aqaba.
2 - Dead Sea.
3 - Tiberias lake.
4 - Lebanon & Anti Lebanon Anticlinaria.
5 - Ghab Depression.
6 - Palmyride Folding Belt.

1,2,3,5 - Pull apart basin.
4 - Pressure ridge.
6 - Shortening zone.

Fig. 10- Landforms assemblage associated with the Dead Sea leaky Transform Fault.

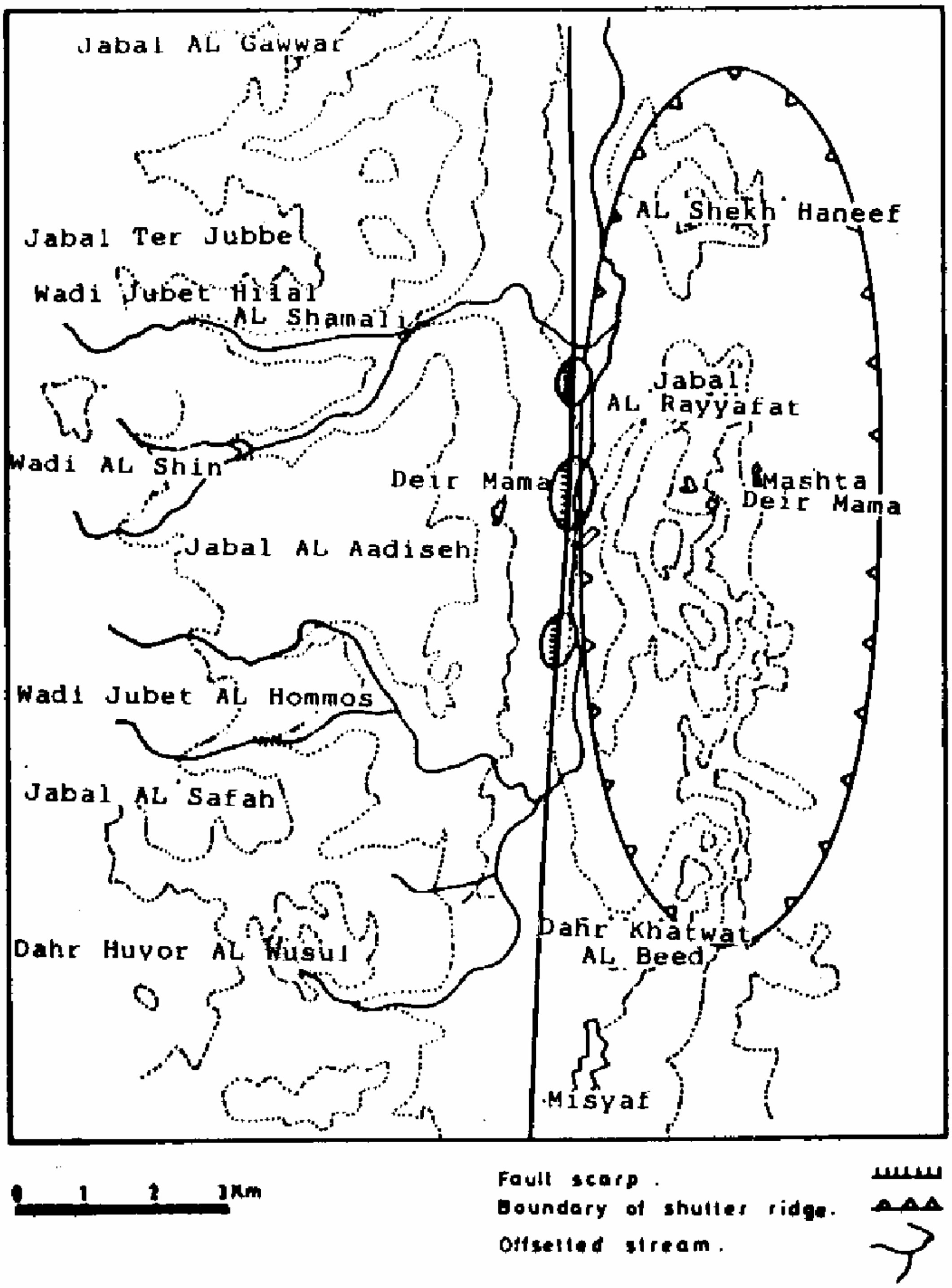


Fig. 11- Shutter ridges north of Misyaf.

Photo 1- Shutter ridge enforcing an eastward draining stream to change its course towards north, north of Misyaf.

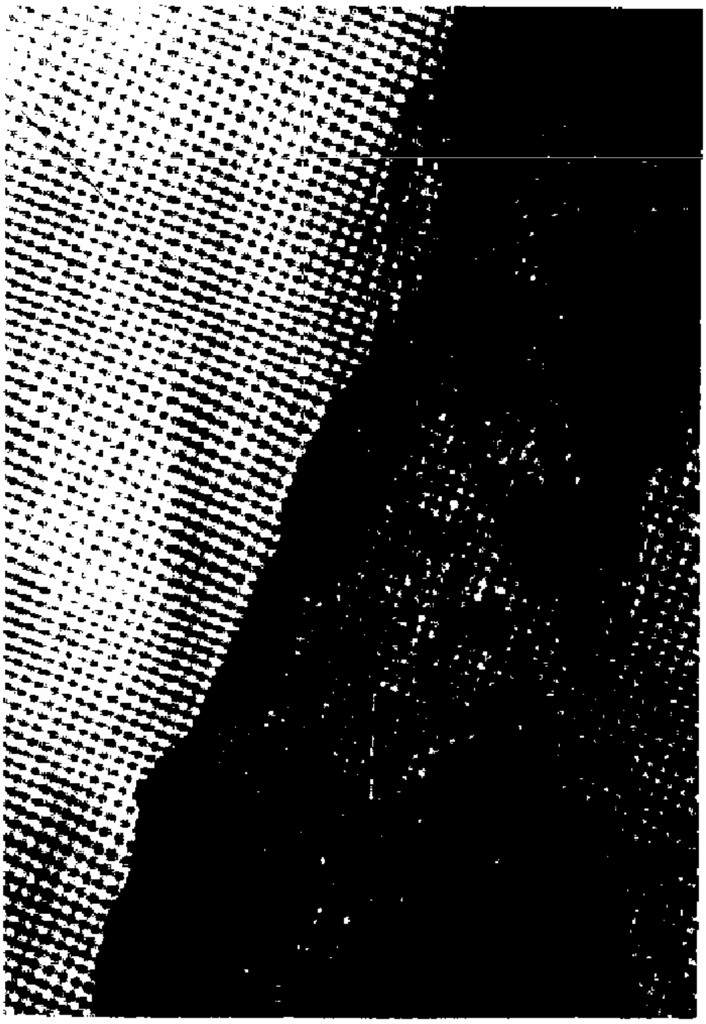


Photo 2- Steep fault scarp, north of Al-Btar.

Al-Bied, Jabal Al-Rayyafat and Al- Shek Hanif, lock the E -W trending Wadis (Wadi Al-Qabu, Wadi Jubet Al-Hammus, Wadi Al-Shien, Wadi Jobet Hilal Al-Shemali) which slopes down from the western block of the Syrian Lebanese Fault towords east, hence enforced by the Jurassic hills to change their draining direction of their courses from the east to the north (Fig 11, photo 1).

Additionally, many fault escarpments varying in height from few meters to few tens of meters are frequent features along the Syrian Lebanese Fault, especially to the south of Misyaf near Beit Utk, Al-Findara, as well as north of Misyaf at Qairon and Al-Mqabara. At the deflection point of the fault, where it forms AL Ghab pull - apart basin, very steep fault escarpments at Al-Haideriyyeh and Sakiyat Najam (80) are mapped. In this respect it is widely agreed that the steeper the fault scarp is the much younger it is considered (photos 2 & 3).

2-2 DETAILED EVALUATIONS

Processes - Response Models: Active Tectonic Rates

These models are designed to include investigations on earth, soil and landforms. They involve as well the setting of the Upper Pleistocene - Holocene chronological sequence in order to extract active rates (uplifting & subsidence rates, damaging earthquakes, recurrance intervals). These investigations provide essential basic data required for earthquakes prediction such as the Paleoseismic record reconstruction through different approaches and methods. The most important of which are:

1- Estimation of the rates of uplift and subsidence and the rates of offsetting along active faults, by dating the offsetting of landforms (alluvial fans, sea terraces and offsetted etc.) and streams.

2- Analyzing of faulted Holocene alluvials sequences. (Keller 1986).

2-2-1 Faulted landforms

2-2-1-1 Offsetted fans

At Al-Mzeyneh, north of Tell Kalakh, a 3 Km left lateral displacement of an alluvial fan overlies the Syrian Lebanese Fault, has been mapped. Due to sharp decrease in the energy of transportation medium, the fan's dolomitic and basaltic cobbles and gravles are poorly sorted and rounded, and randomly scattered within flood mud. Unfortunatelly, these deposits do not show any traces of sorting or grading that can help retaining traces

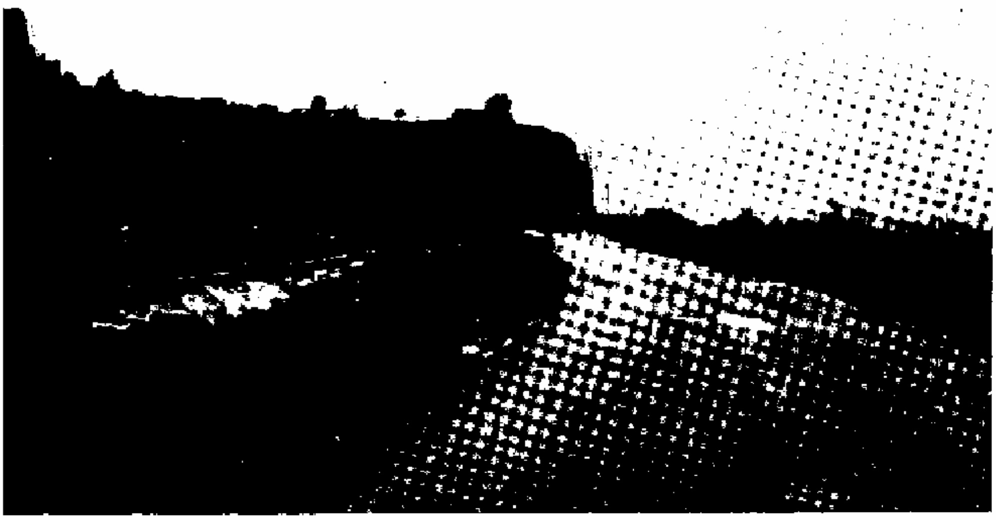


Photo 3- Steep fault scarp, Qalaat Al-Jrass, Al-Ghab valley.

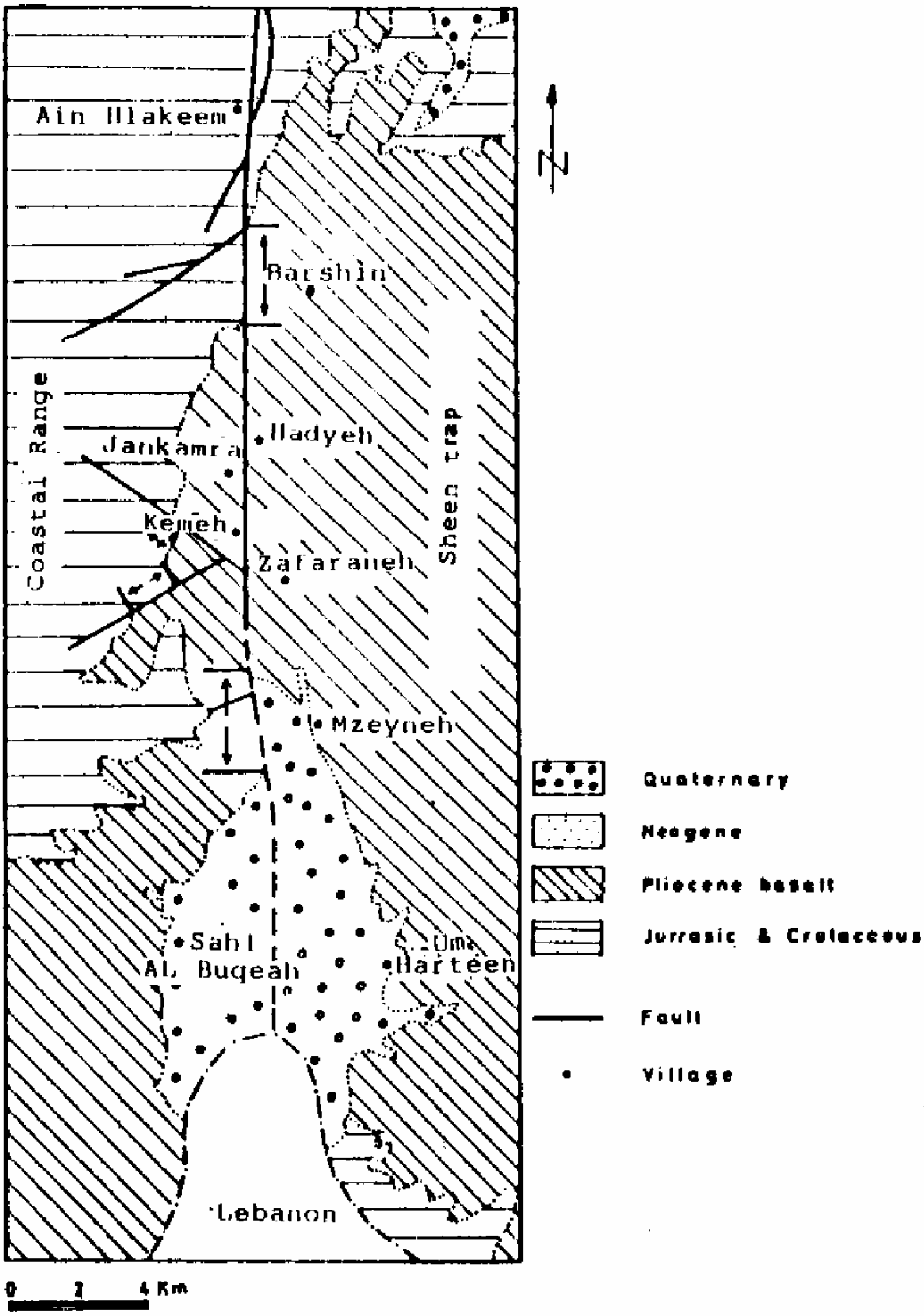


Fig. 12- Offsetted Quaternary alluvial fan and Pliocene basalt, north of Tell Kalakh.

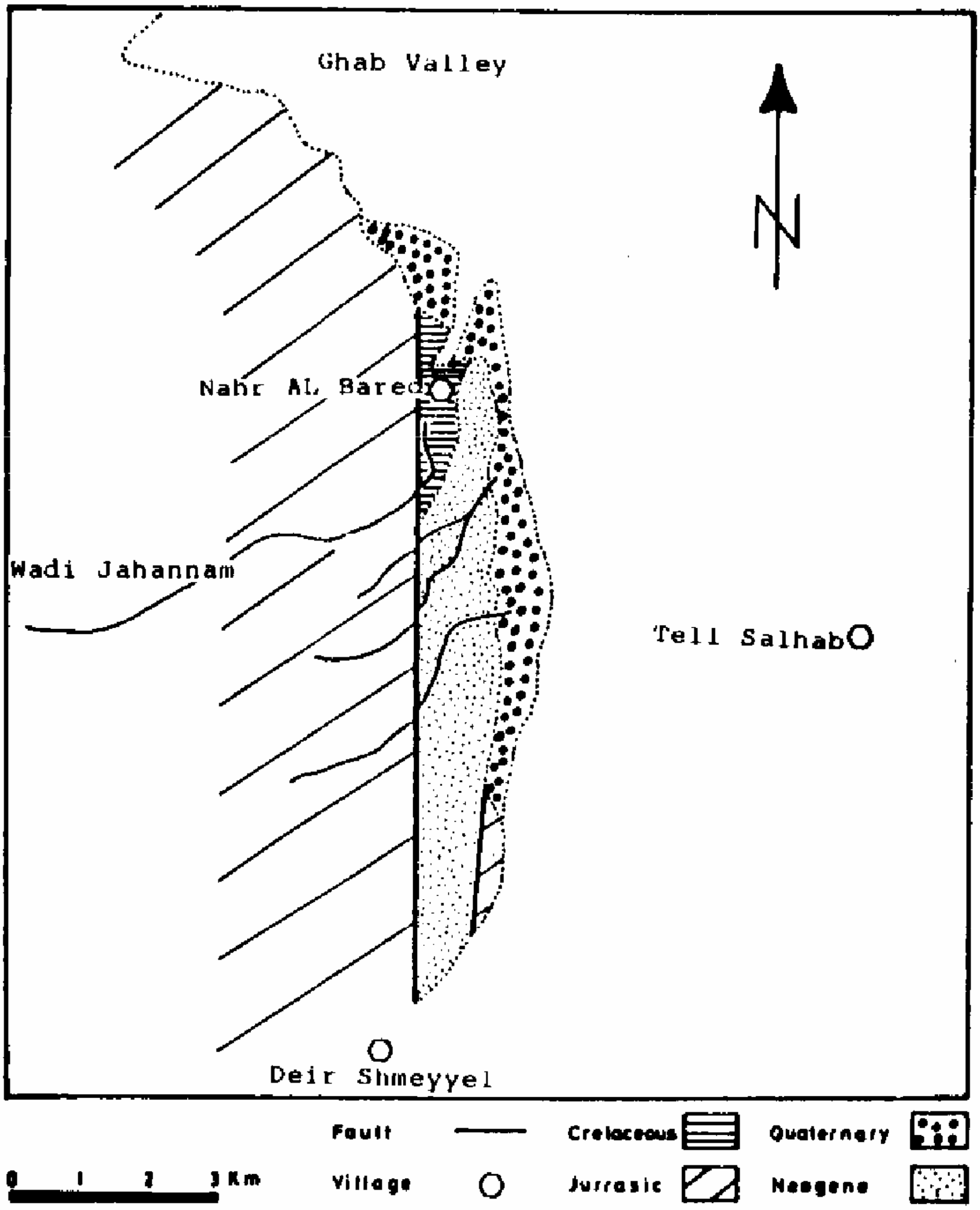


Fig. 13- Offsetted stream along the Syrian-Lebanese Fault west of Tell Salhab.

of deformations or displacenet attributed to active tectonics. Fig. 12 shows a 2800 m left lateral displacement in the Pliocene basalt outcropped to the north of this fan and in the Q3 alluvial fan. It can be logically concluded that the displacement occurred in the post Q3 time i.e. during the Late Q3 and Q4 , since equal displacements in rocks attributed to different ages are mapped (Q3 alluvial, and Pliocene basalt).

In other words this displacement is generated by active tectonics happened in the last 10000 - 600000 years i.e. at an annual slip rate of $\geqslant$ 5 mm/ yr.

On the western block of Syrian Lebanese Fault, a 440 m left lateral displacement in the Pliocene basalt along the NW faults is mapped, while a 1300 m displacement along the conjugate ENE fault is recognized. Although it is confirmed that these displacements occurred during Holocene and Quaternary i.e. during the last 1.8 m yr , nevertheless, the exact time of their occurrence still imbigeous.

2-2-1-2 Offsetted streams

To the west of Tell Salhab, the streams draining towards east are approximately 100 - 120 m offsetted. This offset should have happened during Holocene (recent 10000 years). This suggests an annual slip rate computed as much as 10 - 12 mm/ yr. However, it is not know wether displacement rates have been constant and steady over this time interval. (Fig. 13). Tlass & Al-Jallad 1990 cited from Ksara observatory records description of such events depicting rock collapse caused by the 1546 AD. earthquake, whose epicenter was in Wadi Fara in north Palestine where collapsed rock masses in Jordan Valley have blocked the river flow for a while. Similary it can be concluded that a collapse has blocked the river course till the river has cut down a new course.

2-2-1-3 Landslides

It is frequent and very common phenomenon in the Pliocene Sheen trap that overlies the Syrian Lebanese Fault. The basalt here has undergone sever weathering alternating it into lubricant horizon. In the area between Al-Mzeyneh, Castle of the knights, northward to Jankamra the basic pyroclastic sequence composed of basal volcanic bombs coverd by lapillistone overlain in turn by tuff, reveals frequent landslides and soil creeps, (photos 4 & 5). The difference in elevation of the downsliding hills attains at Beit Utuk 60 m. This phenomenon is much more common in the laterite at the eastern block of the fault near the town of Sheen and in Particular at Al-Mqabara where damaging and mighty landslides are reported in the last 70 years.

Nevertheless, this phenomenon should be carefully evaluated, since a great deal of the land slides observed in this area is of aseismic nature. They are rather caused by soil instability due to high slope gradient and high precipitation.

2-2-1-4 Damaged historical and recent constructions

Many historical sites and constructions situated along or adjacent to the Syrian Lebanese Fault are reported to be frequenty damaged by earthquakes of 1157 , 1170 , 1201 , 1306 , 1408 , and 1759 AD. (Taher 1979).

Castle of the knights in particular, underwent a total damage through the 1170 and 1201 AD. earthquakes. Through a carfull analysis of the castl's different segments, a remarkable phenomenon manifested by a deflection in the straightness of the castl's southern wall, indicated by arrow 1 in photo 6 , is observed. This wall is built by unworked basaltic buildstones. The deflection site corresponds with the intersection of the southern wall with a N - S oriented Wadi (arrow 2) parallels the Syrian Lebanese Fault. It is marked by arrow 3 in photo 6.

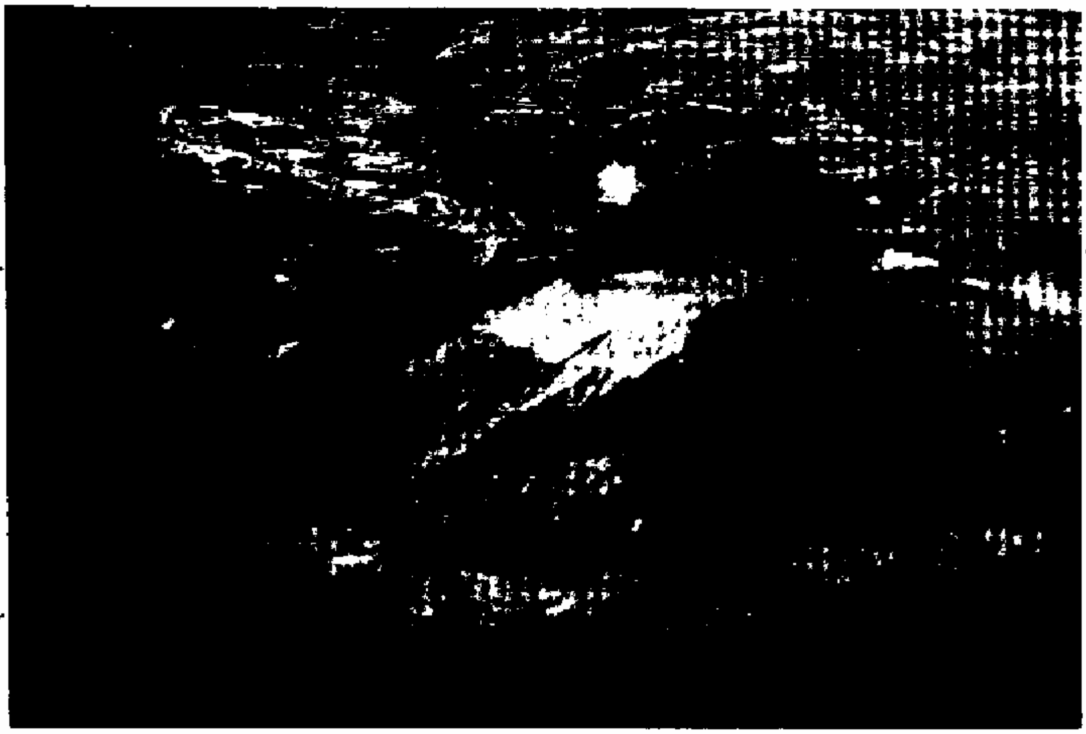


Photo 4- Landslide, south of Bayder Rafii.

Photo 5- Landslide, Bait Utk.

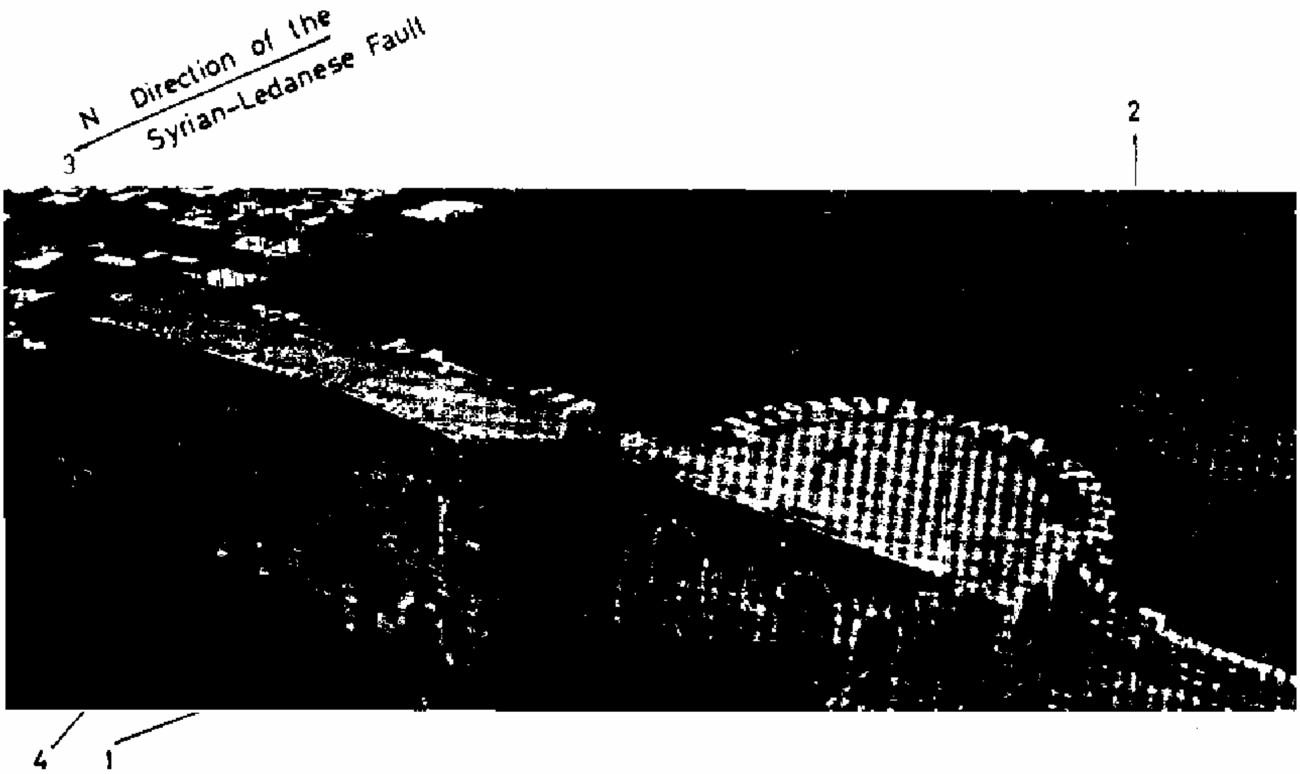


Photo 6- The southern wall of the 8 - 9 trunk, Castle of the knights.

The break in the straightness of the wall at the junction of block A & B on one band, and the style of curving the interconnecting white building stones (photo 7) on the other, are powerfull indications suggesting that these white building stones are deliberatly cut and curved to connect between the block A & B which should have had a similar initial straightness represented by the current straightness of block B. The break in straightness might be generated by a northwards movement capable of displacing block A relatively to block B. This assumption is strengthened by the presence of recent cracks penetrating the white curved building stones themselves and the binding cement as well. This in turn may indicate, that the northward driving force offsetted block A continued after restoration of the wall. The big cracks in block A (illustrated in photo 6 and detailed in photo 9), which widen toward the ceiling of the gallery, bespeak that a kind of stress is still being exerted. The amount of lateral displacement can be easily computed as: (Fig. 14).

$$102 - 92 = 10$$

$$\tan 10 = \frac{X}{12000 \text{ mm}} \Rightarrow X = 2112 \text{ mm}$$

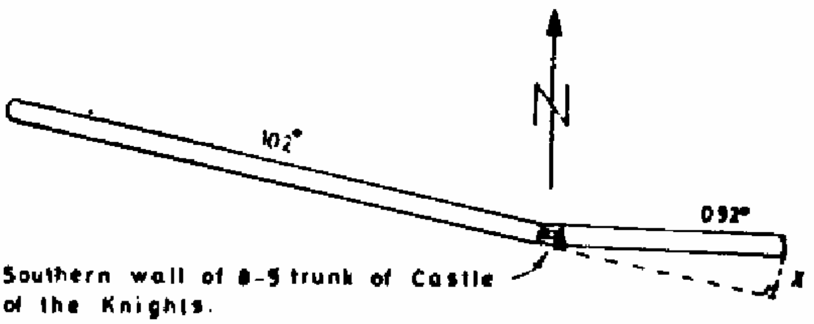


Fig. - 14

Photo 7- Details of the deflected site built by curved white stone, marked by arrow 1 in Photo 6, 8 - 9 trunk, southern wall, Castle of the Knights.

Phtot 8- Cracks Penterate the curved white stone illustrated in Photo 7, as well as the binding cement.

By reviewing the historical record of construction, the castle's different segments, explaining indications of the previous observations helpful in estimating the slip rate, have been collected.

In 1110 AD. the crusaders seized the castle and started, during the first crusadean phase (1110 - 1170 AD.), erecting new constructions and fortifications (Tlass & AL Jallad 1990) (Fig n15). After the bi170 AD. earthquake, and during the second crusadean phase (1170 - 1200 AD.), the Hospitalers began constructing an outer wall (dashed line in Fig. 15). Different parts of the then unfinished outer wall, in addition to the southern parts of the inner wall were destroyed by the consequent earthquakes of 1201, 1201 and 1203 AD. (Tlass & Al-Jallad 1990). At the commence of the third crusadean phase (1203 - 1271 AD.) the Hospitalers built the 8 - 9 trunk (badaneh), (Fig. 15). In this connection, Tlass & Al-Jallad (1990) observed the absence of any fitting junction between the wall - corner (labelled* in Fig. 15) and tower 8 on one hand, and between the wall corner and trunk 8 - 9 on the other. This per se, suggests that the corner should be attributed to a former construction in which it represents the southeastern corner of an older wall whose erection should be commenced after the 1170 AD. earthquake. Nevertheless, it was destroyed later by the 1201 - 1203 AD. earthquake (Fig. 15). It is believed that the crusaders annexed a triangular area (hachured area in Fig. 15), and encircled it later by the 8 - 9 trunk, which they built by thickly cemented, unworked building stones. Thus, it is most likely that the

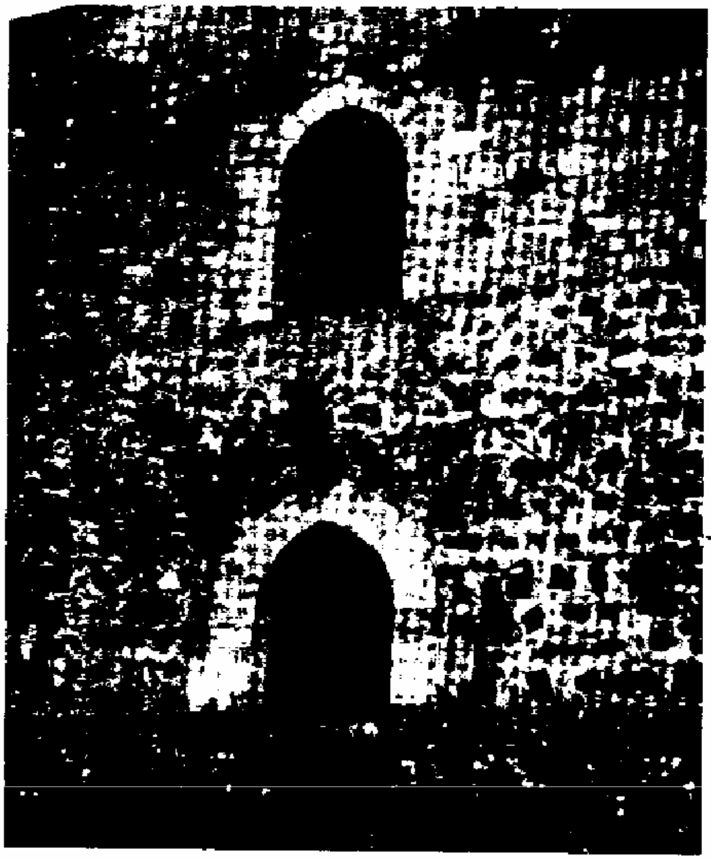


Photo 9- Details of the crack, marked by arrow 4 in photo 6 .

crusaders rushed to build the 8 - 9 trunk just short after the 1201 - 1203 AD. earthquakes. Tlass & Al-Jallad 1990 observed a deflection in the middle of this trunk at obtuse angle toward the inside of the castle. We believe that this deflection is most likely resulted by a displacement of the rock basement underlying part A of the southern wall of the 8 - 9 trunk relatively to part B. This caused a 10° northward tilting of part A apart from the initial straightness of the above mentioned wall represented by the current straightness of part B. Such a displacement and tilt could be triggered by an earthquake succeded the erection of the 8 - 9 trunk.

A remarkable scarcity in recording seismic and aseismic events the castle experienced, since it was regained by the Mameluke in 1271 AD. and during its submission to the Ottoman rule, is observed. This can be justified partly by the reteat in its military and strategic importance, and partly by its remoteness from the period new transportation roads. However, a carefull check up of the historical references and the catalogue of historical earthquakes, 1989, points to a vigorous earthquake hitted Bilad Ash-Sham and Egypt in 1302 AD. This event is described by Ibn Al-Dawadari (cited in Taher 1979) as the following: (The land has been violently shaken, shaking has propagated in the entire Ash Sham and Egypt. It lasted a quarter astronomic hour). On the same event, Al-Maqrizi (cited in Tlass and & Al-Jallad 1990) reported a sever earthquake in Safad that damaged most of the city citedel, and cracking of the walls of the Omayad mosque in Damascus. He reported of twenty days of earth shaking. According to the catalogue of historical earthquakes, 1989, this earthquake hitted Syria in general and Damascus and Homs in particuler. Its estimated Ms, depending on the mass of destruction described, attains 6.7 . In this regard a landslide occurred in Baarin in 1306 AD. is mentioned by Al-Nuwairi (cited in Taher 1979) and by Ibn Tagri Bardi (cited in Tlass & Al-Jallad 1990) and described in 2-2-1-2 .

Photo 10- Details of the same crack illustrated in photo 9 as it appears in the ceiling of the gallery.

Photo 11- Collapsed rock masses along NE trending pronounced joints. Al-Qastel - Khan Al-Jooz, Aleppo - Latakia highway.

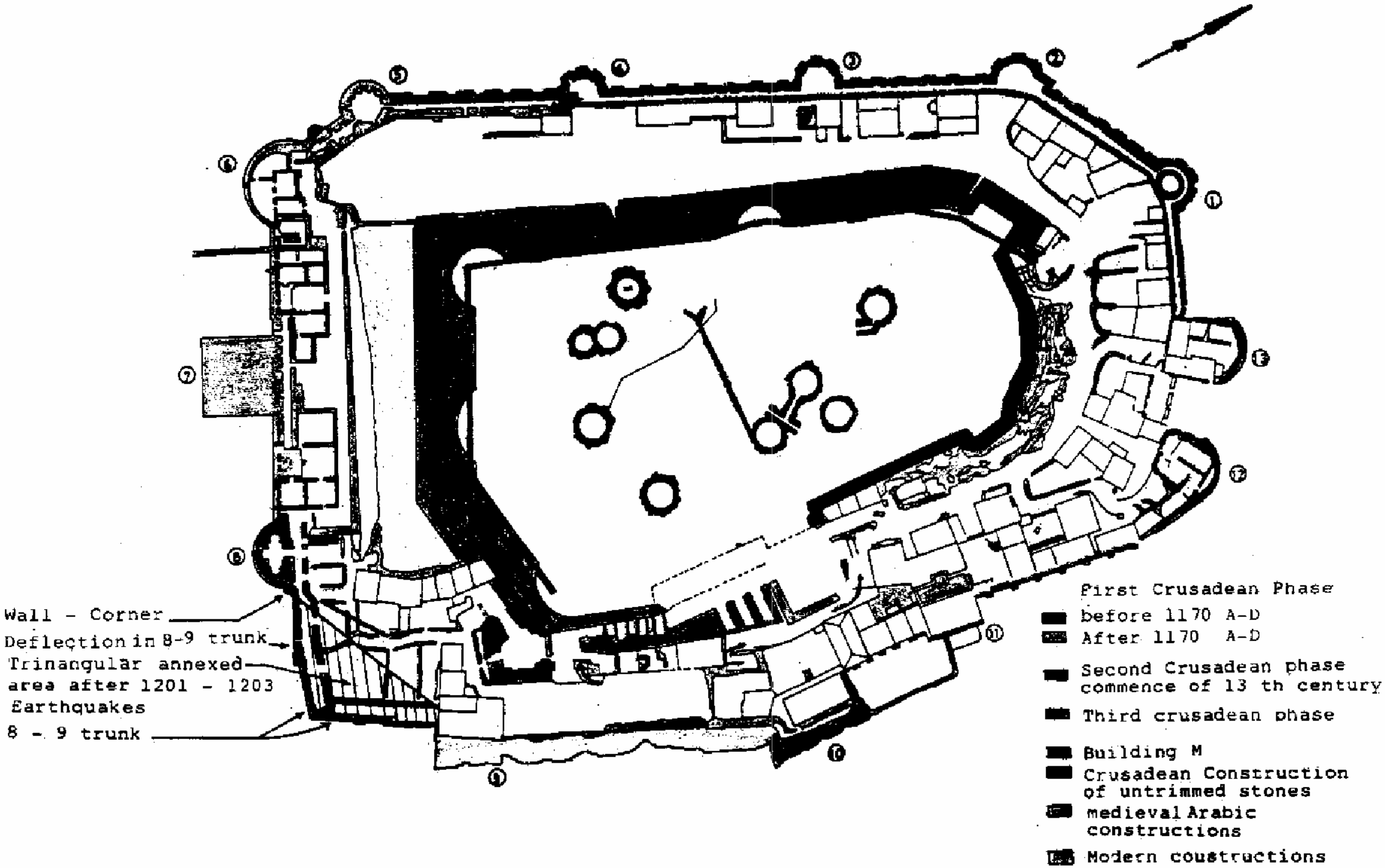


Fig. 15- Modified form Deschamp 1934.

As a basisi for discussion, if we propose, depending on the above cited description of the earthquake damage, that the 1302 AD. earthquake and the succeding landslide happend in the neary in 1306 AD., were behind a left lateral displacement of the 8 - 9 trunk in the Castle of the knights (photo 6) then a slip rate during the time from 1203 to 1306 AD. can be easily computed as:

$$\frac{2112 \text{ mm}}{1306 - 1203} = 20 \text{ mm/ yr}$$

And if we assume, for the sake of argument, that the displacement was not resulted by 1302 AD. earthquake but by another mighty earthquake of the year 1408 AD. whose Ms is estimated at 7.4, according to the catalogue of historical earthquakes, 1989, Al-Maqrizi (cited in Tlass & Al-Jallad 1990 and in Taher 1979) stated that this event affected all Bilad Ash-Sham including all coastal cities south of Tripoli, accompanied by sever landslide and earth rupturing in Selfohom in Sheen trap, see 2-2-1-3, then the slip rate of part A of the southern wall of 8 - 9 trunk during the time interval 1203 - 1408 AD., can be calculated as much as:

$$\frac{2112 \text{ mm}}{1408 - 1203} = 10.3 \text{ mm/ yr}$$

In this respect Tlass & Al-Jallad (1990) didn't exclude a volume of damage hitted the castle through the 1408 AD. earthquake, despite no damage in the historical references has been reported. The authors believe in turn, the lack of citations in references of any damage in the Castle of the knight through 1302 and 1408 AD. earthquakes is insufficient, invalid and unable evidence to confirm the castle's avoidance of the damage reported elswhere in the country which is quoted to be causued by the aforesaid earthquakes.

This belief is supported by a similar absence of any damage generated by the mighty and devestating 1759 AD. earthquake, through its Ms is estimated at 7.4 too, (catalogue of historical earthquakes, 1989).

At the northern parts of the Syrian Lebanese Fault, interesting phenomena indicative for active tectonics are also observed. On Aleppo - Latakia highway between AL Qastal and Khan Al Jooz villages, a cojugate NE trending fault to the Syrian Lebanese Fault bounds the Maastrichtean clayey limestone with the Cenomanian - Turonian, metric - spaced, jointed limestone. Rock masses collapse is a frequent phenomenon in this site (photo 11). The inhabitatnts of these villages and the neighboring areas are quoted as saying, collapse of tons of rock masses occurred in Oct. 1989 . At the adjacent Al Kabir village a heavy shaking was felt in the same time, causing cracking and damaging of some houses. In addition, a bridge forming a part of the old Allepo - Latakia secondary raod, crossing a NE - trending fault - valley, east of Khan AL Jooz, collapsed in 1976 (photo 12).

The westward sliding of the upper segment of the bridge pillar supports the belief that this segment is more likely shifted by a horizontal of a brute force rather than by a sudden flood of the westward draining stream. Such flood should have shifted the lower segment westwards relativity to the upper one which contradicts the actual situation (Fig. 13). This favors the assumption that the bridge is most likely collapsed through a basement rocking generated by a reactivation of the NE faults.

To the south of Damascus, in AL Safa and AL Laja, important phenomena of different nature pointing also to active tectonics are mapped. Quaternary basaltic lavas extruded from NW striking faults control the distribution of volcanic scoria cones. The basaltic consolidated lava in Kherbet AL Ombashi encloses remains of goats bones and chared woods. Tyrell 1930 , (cited in Ponikarov 1966), depending on biblical evidences of volcanic eruptions in Palestine and AL Harra (Kherbet AL Ombashi), gave them an age of 2500 years .

A C14 dating of the chared wood, enclosed in the basalt, gave them an age of 4000 years (Dubertret 1933 , cited in Ponikarov 1966). This dating confirms that the basaltic lava in AL Safa & AL Laja is exturded as a result of reactivation of the deep NW faults 4000 years ago. Later reactivations of these faults during the recent 4000 years, yet to an extent unable to extrude lava, is not excluded. It is vital important to perform a new dating of Kherbet AL Ombashi lavas by modern isotops dating techniques in order to confirm its age, since the dating given by Dubertret is sixty years ago, meanwhile dating techniques and methods been tremendously developed.

Photo 12- Collapsed bridge, near Khan AL Jooz, Aleppo - Latakia highway.

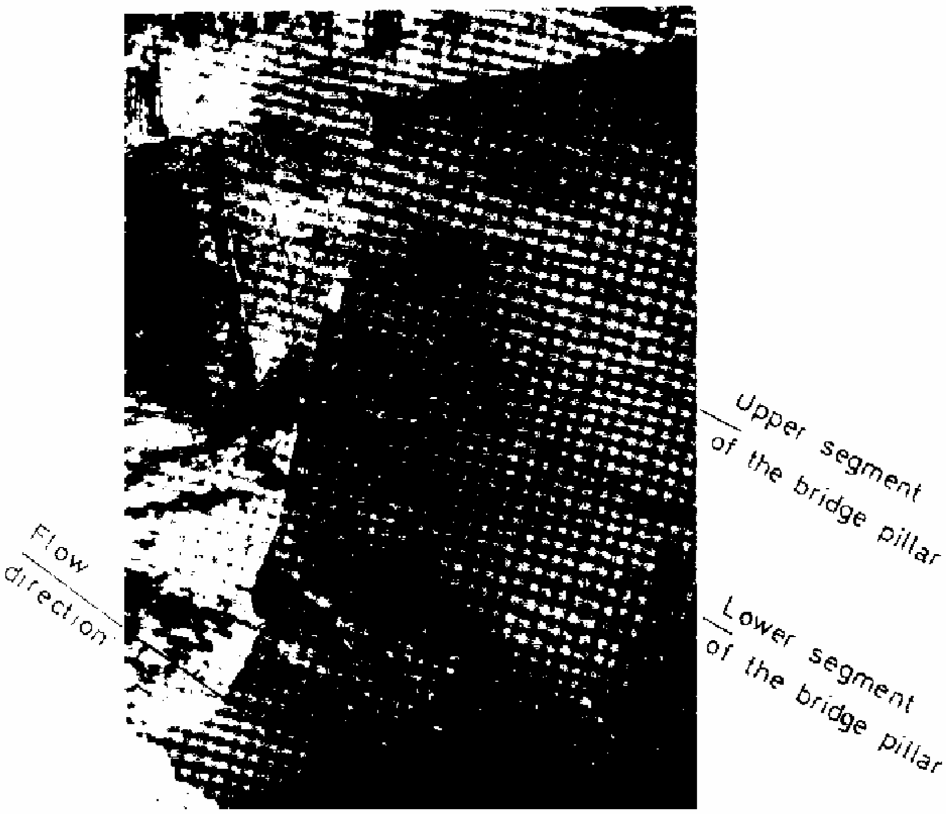


Photo 13- Westward sliding of the bridge pillar's upper segment, Khan AL Jooz.

Photo 14- Remains of goats bones enclosed Quaternary basalt, Kherbet Al Ombashi

2-2-2 Faulted holocene deposits:

Deformation phenomenon are encoutered in the Holocene alluvial deposits that overlie the NE trending Damascus Fault, 5 km northwest of Adra on the roadside going to Hafeer At Tahta. Horizontal Holocene alluvial deposits are at fault contact with other Holocene deposits tilted 45° (photo 15), and huge boulders(1.5 m) composed of Holocene alluvials in the same Holocene depositional basin.(photo 16).

A similar phenomenon is reported 6 km east of Maaloula on the roadside of Damascus - Homs Highway. A NW - SE trending fault offsets the Maastrichtean chalky limestone and the overlying alluvial Holocene. The southwestern block is 2.5 m downthrown. Nevertheless, there is no discernible expression of the fault to be the surface, since intensive erosional processes have levelled the relief difference caused by faulting, a negative factor that makes detecting of new faults, and tracing reativations of old faults much more difficult. (photo 17).

An accurate C 14 dating of the reactivation of Damascus Fault near Adra requires the dating of the Carbonate caotings encircling the alluvial components(photo 16). Such dating is also recommended to be done for the thin new carbonate fillings in the joints parallel to the NW fault near Maaloula (photo 17). Since, these newly formed carbonate must be either contemporaneous or slightly younger than the fault itself.

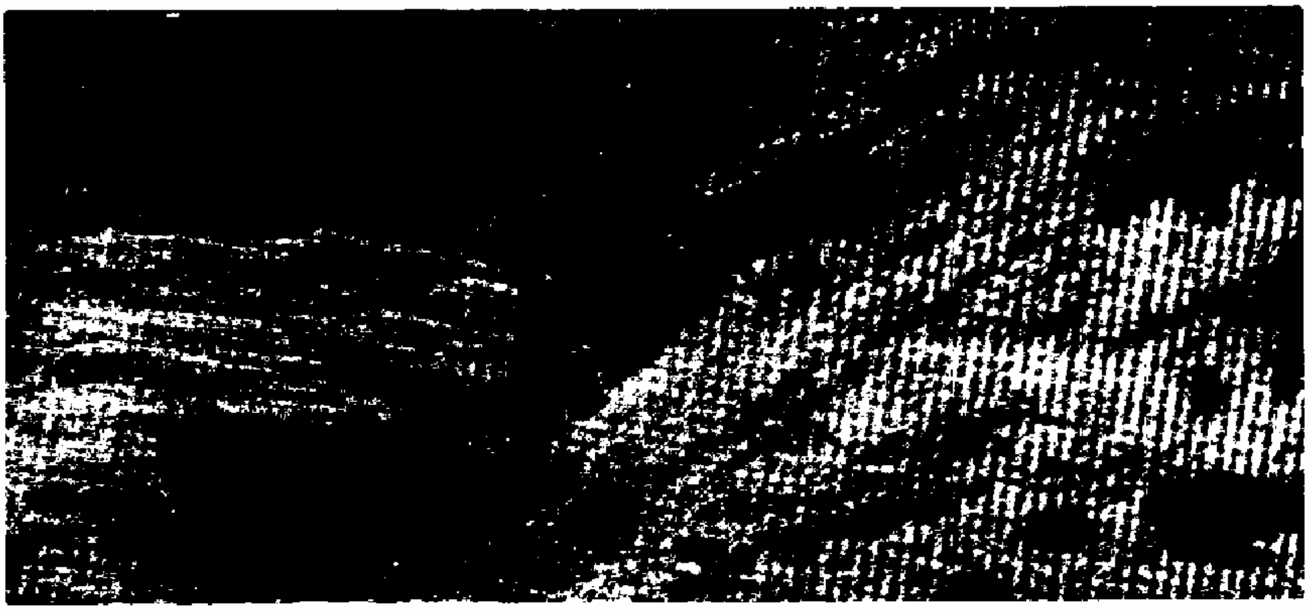


Photo 15- Faulted Holocene deposits covering the NE trending Damascus Fault, Hafeer At Tahta road, Harasta, Near Damascus.

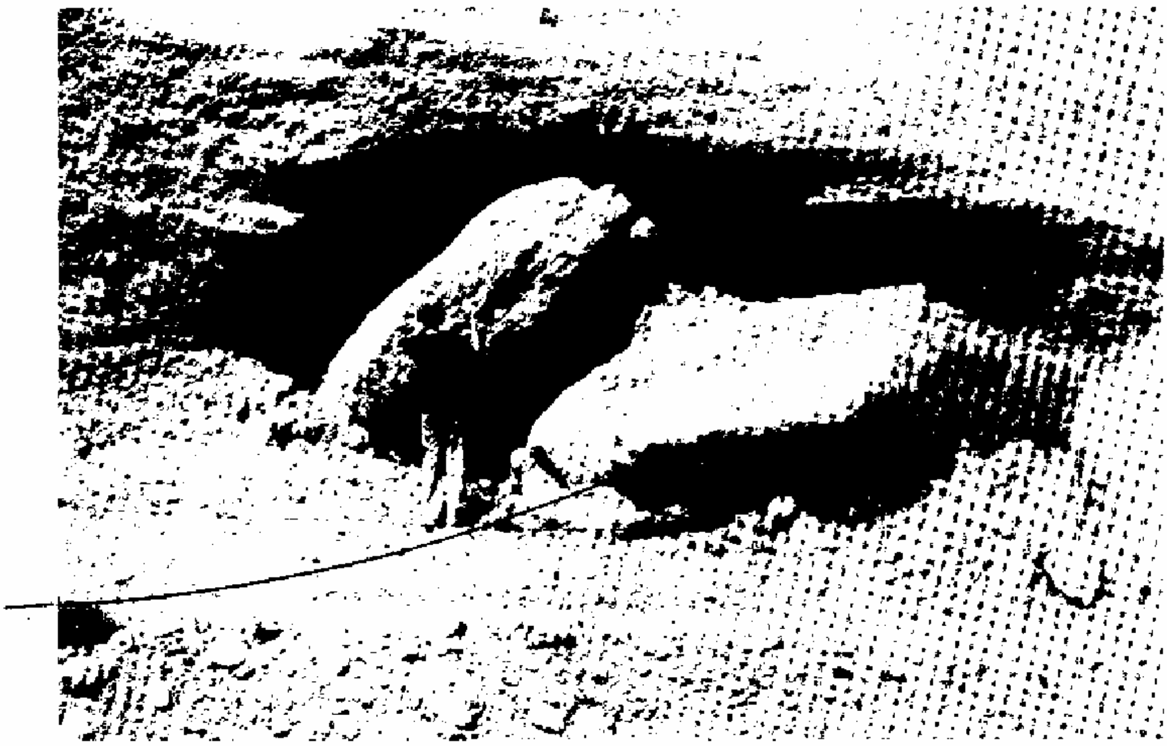


Photo 16- Haphazard huge boulders of Holocene alluvials. Hafeer at Tahta road, Harasta, near Damascus.

Photo 17- Faulted Holocene deposits, east of Maaloula, Damascus Homs highway.

In the northern Palmyrides Range some NW striking faults express possible reactivation. For example, in the Holocene deposits on the norhtern block of NW - SE trending Wadi Midani Fault, joints and cracks trending in the same sence were mapped(photo 18). This may bespeak a possible reactivation of this fault, during the Holocene i.e. the last 10000 years. However, such reactivation has not exceeded the creation of pronouced joints parallel to Wadi Midani Fault, hence incapable of dislocating the Holocene deposits. In this regard, it is extremly important to use soil geomorphology discipline to establish the chronology of the Pleistocene - Holocene deposits, a very effective technique in estimating the rate of deformation attributed to active tectonic, (Keller et. al. 1982 a, b ; Dembroff 1982; Rockwell 1983; Rockwell et. al. 1984). The basic concept in this discipline is to set up the soil chronosequence which consists of consequent soil series, from the youngest to the oldest of a specified site where deformation is encounterd.

The physical and chemical properties of the soil series are the criteria applied in relative chronology, while dating by isotops e.g. C14 is usually used in absolute chronology. The soil chronosequence established can be adopted and applied over a larger area surounding the site of deformation without doing any further absolute dating. (Keller et.al. 1984 a,b ; Demproff 1982; Rockwell et.al. 1984; all cited in keller 1986).

Photo 18- Mighty joints parallel to Wadi Midani Fault, As Sayed, east of Homs.

Accordingly, the soil chronological profiles in all aformentioned sites within the area of study, where indications of possible active tectonics were encountered, should be carefully established and studied in order to date the neotectonic events and estimate the rate of deformations mapped in each soil series separately. In absolute dating, daughters of Uranium decay series can be used, for example, 230 Th /234 U ratio applicable in dating the carbonate coatings encircling the bottom side of gravels and cobbles that comprise the most upper portions of faulted alluvials deposits and carbonaceous soil. It can be used as well, in dating carbonate in general and aragonite in particular which was formed during the last 2000 - 10000 years in cavities, and that found in bones too, (Pierce 1986). Another ratio i.e. 226 Ra / 230 Th can be also applied for the same time interval. While the 231 Pa / 235 U ratio is applied for a time interval ranging between 10000 - 12000 years. A prerequisite for applying the aforesaid methods necessitates that all materials and daughters used must have been preserved in closed chemical systems, (coleman & Peirce 1979, cited in Pierce 1986).

C 14 dating methods is widely used in dating perhistorical reactivation of existing faults, it can be succesfully applied in establishing the Holocene chronology as well.

Nevertheless, this methods is subjected to errors arisen from fluctuations in carbon content in the atmosphere, (Pierce 1986).

The rates of deformation generated by active tectonics should be carefully interpreted since, they are temparal and spatial dependent i.e. they vary from a time span to another at a specific place, and vary from place to another located on the same fault during a definite time interval. This dependecy is due to different geologic constraints such as, faulting type and mechanism of folding.

3 - Conclusions and Recommendations

3-1 Tectonic geomorphology is a rapid and very efficitive tool in prospecting the mutual interrelated influence between characteristic landforms - generating tectonics and different geomorphic processes that modify the landforms through the time.

3-2 The comparison of the values of different geomorphologic indicies used in regional reconnaissance investigations, computed along the major structural lines in the area concerned, with those values reported in tectonically active areas in California supports the belief that the structural lines in the area under investigation are still active.

3-3 The comparison of the landforms assemblage associated with the Syrian Lebanese Fault (linear valleys, sag ponds, pressure ridges, shutter ridges) with those characteristically associated with active strike slip faults backs in turn the belief that the Syrian Lebanese Fault is an active strike slip fault.

3-4 The detailed site-specific studies applied in estimating active tectonics gave a rate of active tectonics higher or equal to 5 mm/yr, computed in the alluvial fan north of Tell Kalakh. This rate attains 10-12 mm/yr estimated from the amount of stream offset west of Tell Salhab (Al Ghab Valley).

3-5 Depending on the phenomena recognized in the Castle of the Knights, the left lateral displacement rate along the Syrian Lebanese Fault in the time span 1170-1306 AD. is estimated at 20.5 mm/yr, in the case of these phenomena being resulted by the 1306 AD. earthquake, but if they were resulted by 1408 AD. earthquake, then the slip rate determined may lessen to 10.3 mm/yr.

3-6 The faulting mapped in the Holocene deposits that overlie the NE-trending Damascus Fault, and that overlie a NW trending fault near Maaloula, beside the presence of mighty joints in the Holocene deposits parallel to NW-trending Wadi Midani Fault, point to a possible reactivation of these faults during the Holocene (10 000 years) once at least.

3-7 Recent Massive landslides mapped in the laterite along the Syrian Lebanese Fault in Sheen trap, and frequent rock collapses during the last few years along a NE trending fault near Khan Al Jooz (Aleppo-Lattakia Highway) indicate also that the fault mentioned is still active.

3-8 The volcanic eruptions in Kherbet Al Ombashi, which were fed by numerous NW trending faults south of Damascus, which are responsible for succeeding volcanic eruptions during Quaternary, are a powerful evidence for the reactivation of the aforesaid faults 4000 years ago.

3-9 It is very important to set chronology of the active tectonics through dating of the deformations mapped along NE-Damascus Fault (near Adra) and along NW-Faults (near Maaloula) by the use of the very recent carbonate coating encircling Holocene deposit's gravels, and by carbonate fillings in the faults-parallel joints, and last by the use of chared wood and bones enclosed by recent volcanics erupted through NW-Faults at Kherbet Al Ombashi.

3-10 Establishing of a seismic monitoring network in Syria, and a contiuous of radon content in soil and water for a considerable number of years, are extremly important in seismic prediction and in mitigating of seismic risks in an area, all evidences evince its seismotectonic activity.

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