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Paleoseismological investigationa along the North Tabriz Fault (NTF)

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Paleoseismological investigation along the North Tabriz Fault (NTF)

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Paleoseismological investigation along the North Tabriz Fault (NTF)

Author: Aram Fathian

نشرخزه

اطلاعات گزارش

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Abstract

Tabriz City as an important population center in northwestern of Iran, is located in a 150 km long fault damage zone. This right lateral strike slip fault is composed of two right-step segments. In the overlap zone formed between two segments, recent right lateral movements have led to formation of al extensional basin. Historical large earthquakes in Tabriz area reveal the activation of North Tabriz Fault in term of seismicity. Among them, at least two destructive earthquakes in 1721 (M_S = 7.3) and 1780 (M_S = 7.4), is known to be caused by reactivation of North Tabriz Fault. After 1780 earthquake until present day, this fault has not shown any major seismic event. In the past years, some paleoseismological studies has been carried out along the northwestern and southeastern segments of North Tabriz Fault.

Due to the lack of any data from overlap zone of aforementioned fault segments, in this study we located an appropriate construction site for digging a paleoseismological trench in 6 km northwest of Tabriz City based on aerial photos, satellite images and field surveys. Then by digging a trench perpendicular to the strike of fault scarp and carrying out paleoseismological studies, we introduced at least two megaseism events.

Introduction

The Northwest of Iran, is a structural zone showing intensive deformation and historical seismicity, which bounded between two thrust belts including Caucasus form north and Zagros from south (e.g. Berberian, 1997). Tabriz City as major population center (with a population more than 1600000) in northwest of Iran, is located within a fault damage zone, which given to the increasingly development of the city (especially in the damage zone), there is an argent need to know the seismotectonic characteristics of the fault in order to carrying out earthquake hazard studies.

The researches carried out on historical earthquakes occurred in north-west of Iran (Berberian, 1997T Amberaseys and Melville, 1982), revealed that the Tabriz area has experienced many destructive earthquake events. Whereas the available data indicated at least 10 historical destructive earthquakes in the Tabriz area, no instrumental major earthquake has been recorded in this area. Meanwhile, the North Tabriz Fault as the main possible cause of these earthquake events which has been around 240 years since the last event attributed to it (the destructive earthquake in 1780), in recent century didn’t experienced any important seismic event (Soleymani Azad, 2009). Given to previous findings such as temporal clustering of seismic events in Tabriz area (Berberian and Yeats, 1999; Soleymani Azad, 2009) and spatio-temporal concentration of earthquakes attributed to North Tabriz Fault (Soleymani

Azad et al., 2009; Hessami et al., 2003) as well as regarding the absence of large earthquakes in the past 240 years (e.g. Masson et al., 2006), more researches is needed on the background of earthquakes occurred in this area.

Research Method

Paleoseismology is the study of prehistoric earthquakes (in term of location, time and magnitude), in which the geologic evidence created during individual paleoearthquakes are interpreted. In surveying using neotectonic, which is the study of slow or rapid crustal movements during the Cenozoic, paleoseismology focuses on the almost instantaneous deformations of landforms and sediments during earthquake events, which permits the study of spatial distribution of paleoearthquakes over periods of several thousands to about ten thousand years. Such long history of paleoearthquakes help us better understand many aspects of neotectonic, such as regional patterns of seismicity and tectonic deformation, or seismogenic behavior of specific faults (McCalppin, 1996).

Paleoseismology is the analysis of paleoearthquakes (in term of location, time and magnitude), in which the geological indicators caused by any event are investigated. In surveying using neotectonic, which is the study of slow or fast movements of earth’s crust during the Cenozoic, paleoseismology focuses on the sudden deformations of geomorphs and sediment caused by earthquake events, so that we can study the spatial distribution of paleoearthquakes in a period of several thousands to about ten thousand years. Providing this long history from paleoearthquakes help us to better understand neotectonic aspects, such as local patterns of seismicity and tectonic deformation, or seismic behavior of special fault (McCalppin, 1996).

Generally, based on incomplete or complete emergence of surface ruptures related to earthquake faulting, paleoseismologic studies are possible in two forms including indirect and direct (digging trenches in an appropriate location on the fault scarp) investigations. After digging the trench, its wall will be cleaned and meshed. Then the stratigraphic units are separated and geological and structural phenomena, as the direct paleoseismological investigations, are be studied. After that, the trench wall log is drawn on a scale of 1:20. In second step, by identifying event and post event horizons, the counting and restoring of paleoseismic events will be done. Finally, by use of proper samples, these horizons will be dated by methods like C^{14}, OSL & …, in order to determine the age of paleoseismic events. It is worth to note that dating by OSL (Optimal Simulation Luminescence) method, reflects elapsed time since the last exposure of a quartz-rich horizon to the time of sampling.

Literature review

Several scholars have studied the North Tabriz Fault. The paleoseismological studies on this fault was first conducted by Hessami et al., (2003), on the northwestern segment, and then Soleymani Azad (2009) studied the southeastern segment using paleoseismic approach.

Problem Definition

The North Tabriz Fault is one of the seismic faults in northwestern Iran. This right-lateral strike-slip fault, consist of two segments in a right-step array. In the overlap zone formed between these two segments, the recent dextral movements have formed an extensional basin. The banks of this basin are coincide with splays and branches of the mentioned two segments. Since the previous researches conducted in the Tabriz area have been focused on the northwestern and southeastern segments of Tabriz Fault, in this study, by supplementing the data to carry out earthquake risk estimation as accurate as possible for Tabriz City, the overlap zone between two segments were studied in active tectonic and paleoseismic points of view.

Regional Tectonics of Iranian Plateau

Iranian Plateau with a relatively weak continental curst is sandwiched between two more rigid continental crusts, forming a wide and heterogeneous collisional zone. Collision and convergence of Eurasia plates in north and Arabian plate in south caused elevation and deformation of orogenic belts, forming present geomorphological features and active tectonics in Iran.

Geological evidence indicates that during Paleozoic, Iran formed a part of northern continuation of continental Arabian platform (*Figure 1*)

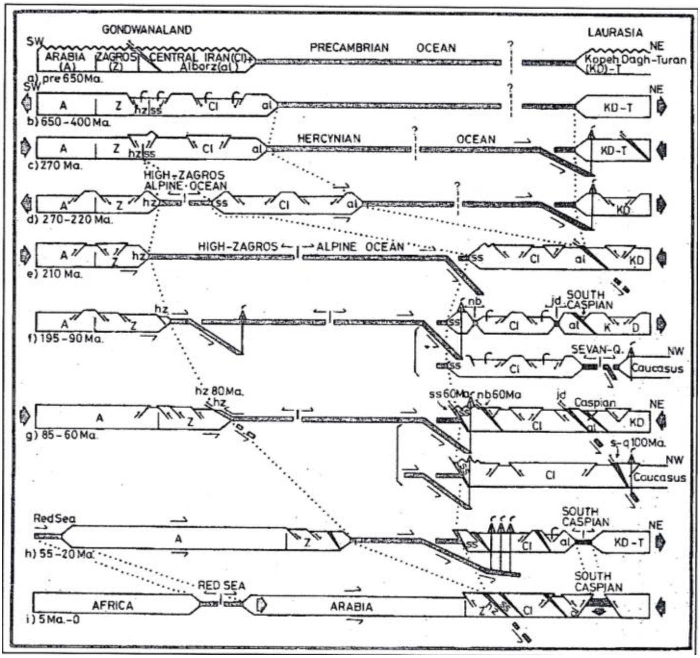

Figure 1: A schematic cross-section showing structural evolution in different periods of time and during different orogenies in Iran.

In case of existence of any considerable opening between Eurasia and Arabian plates, it should be looked for in north of Iran. It is thought that subsidence of

Southern Caspian, consisted of oceanic crust, reflect the sea remnants observed in north of Iran, referred as Paleothetys (Stocklin, 1974).

Closure of Paleothetys (while leaving Caspian remnants) is thought to be resulted from Iranian-Arabian plate subduction beneath the Eurasia plate during Late Triassic. On the other hand, the intra continental rift of the Iranian-Arabian plate is occurred along the Main Zagros Fault during Triassic and probably Late Paleozoic, which proceeded to separation of Iranian and Arabian continental fragments from each other and development of an oceanic basin. If developing this young ocean immediately after rifting along the Main Zagros Fault, then the closure of Paleothetys Ocean in the north and spreading Neothetys in the south, presumably can be considered as two separated process which caused by northward movement of Iranian plate (Stochlin, 1974; Berberian and King, 1981).

It seems that the development of more faults in the Iranian plate during Late Mesozoic, was associated with forming smaller plates (Central Iran and Eastern Iran) which surrounded by an oceanic trench (a branch of Neothetys).

Northward motion of the Arabian plate during Late Cretaceous, resulted in narrowing Neothetys and collision of continental margins of Iranian and Arabian plates along the Zagros crush zone. This collision led to compression of Iranian plate, closure of Neothetys branches in eat and northwest of Iran, reunification of central and eastern segments of Iranian plate and foldings in Central Iran and Alborz (*Figure 2*).

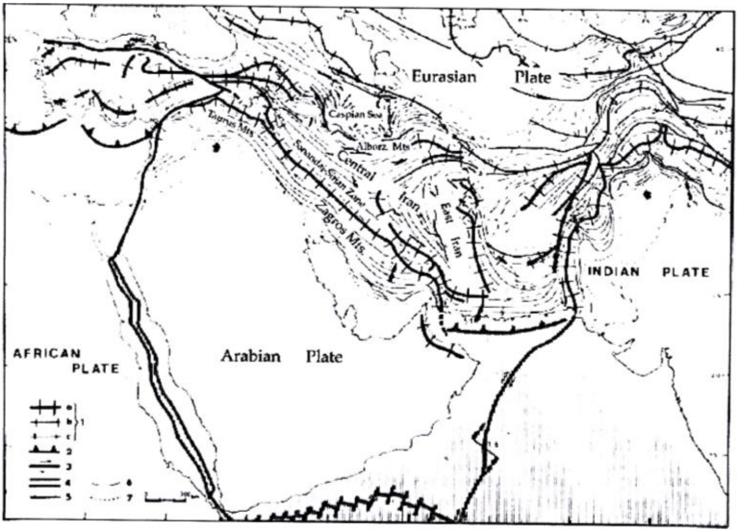

Figure 2: Schematic tectonic map of Iran-Himalaya along with extensive deformation trapped between two old cratons in the north and the south and the two impinging zones (marked by thick small arrows) in the east and the west. Reverse faulting is the dominant mode of deformation in the trapped continental crust (Berberian, 1981).

Structural Evolution of the Northwest of Iran

Northwestern area of Iran, as one of the components of Caucasus Margin Structural Zone, in its southwestern part, named Turkish-Iranian Plateau, is located in the collisional zone between Iranian-Arabian-Caucasus (*Figure 3*).

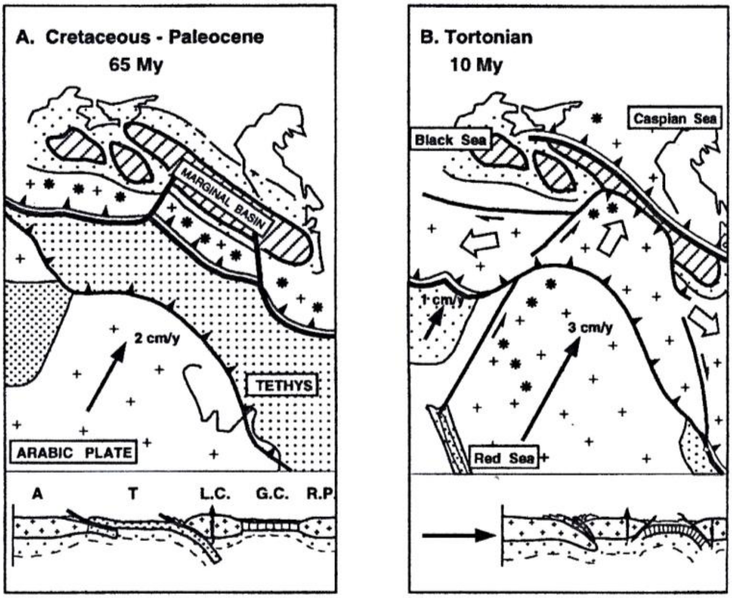

Figure 3: Structural evolution of northwestern area of Iran and the southern margin of Caucasus at two time points: A) 65 Ma and B) 10 Ma. Note the sinistral displacement caused by difference in convergence velocity in two adjacent convergence zones along the Jordan Fault (Philip et al., 1989).

In an overview, this area consists of regions of Turkey, Azerbaijan, northwest of Iran, and south of Armenia. The Turkey-Iranian Plateau is a part of convergence zone between Arabian-Eurasia plates, which emerged by beginning of continent-continent convergence (13-10.7 Ma) and shrinking Paratethys Sea and gradually disappearing the connections between its remnants (between Black Sea and Caspian Sea) caused by its related uplift (Van Covering and Miller, 1971). From a morphological point of view, the average elevation of this plateau is about 2 kilometers.

Caucasus Margin Structural Zone consists of two N-S convergence zone, one between Arabian and Asian plate (with a convergence rate of 30 mm/y) and the other between African and European plate (with a convergence rate of 10 mm/y) (Cisternas and Philip, 1997).

The difference in rates of two convergence zones reflects left-lateral strike-slip movement of the Jordan fault (with NNE-SSW trend) along the boundary between Arabian plate (in the west) and African plate (in the East).

By opening the Red sea (about 10 Ma) northward movement of Arabian plate, the Anatolian (Central Turkey) and the Iranian blocks began to move toward west and east, respectively, while the Central part, Caucasus, began to shorten and subsequent deformation (folding and reverse faulting) (Cisternas and Philip, 1997) (*Figure 4*).

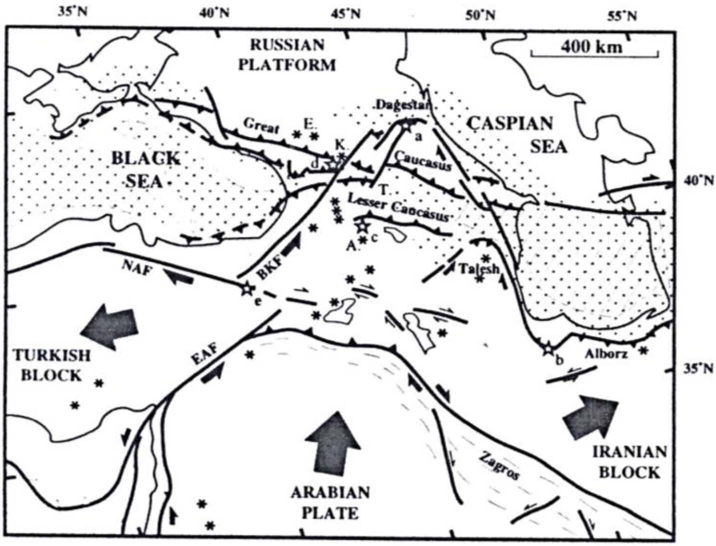

Figure 4: Active tectonic and the distribution and active faults in the northwest of Iran, east of Turkey and Caucasus (Cisternas and Philip, 1997).

Methodology

As mentioned, paleoseismology is the science of ancient earthquakes (from a spatial, temporal and magnitude point of view), based on geological evidences created by any individual ancient event.

Until 1980s, in many countries, the spatial and temporal earthquake risk assessment, was only based on historical earthquake. However, many researchers (e.g. Allen, 1975) has seriously pointed out the shortcoming of this method, many of new maps of earthquake risk assessment has prepared only based on historical data.

The science of paleoseismology has been used in United States Since the late 1960s. After that, in the 1970s and 1980s, researchers from several countries such as New Zealand, Italy, Japan, China and Algeria stepped into such research area. In Iran, as the same way, since the mid-1990s, the paleoseismological studies on Kahrizak, Eshtehard, and North Tabriz Faults has started and continues with studies on North Tehran, Mosha, Rey, Firoozkuh, Taleghan, Dehshir, Astaneh and Anar faults.

Science of paleosiesmology, by identifying and determining large ancient earthquakes, can help complementing historical and instrumental data. In most countries the seismicity data used in earthquake risk assessments dated back only to a few centuries. Therefore, many of active fault zones are lacking evidences indicating historical or ancient large earthquakes. For example, studying ruptures related to ancient earthquakes along the Wasatch fault zone in the west of United States, indicate that the average of return period of large earthquakes is three time longer than the known history of the area (i.e., 145 year) (McCalpin and Nishenko, 1996). Paleosiesmological studies in many areas (both in plate boundaries and far away from them) indicate that earthquake risk assessment based on short-term historical data can overestimate earthquake possibility. Even in areas with a long history such as

China and Middle East, where ancient and historic earthquakes have been recorded since thousands of years ago, there are not enough observations to identify all seismic fault. So, the major part of the history of seismicity of most of the faults, can only be obtained through paleosiesmological methods (McCalpin, 1991; Vittoral et al., 1991; McCalpin, 2009).

Among factors that fasten the spread of paleosiesmology throughout the world, the following can be pointed out:

- Frequency of devastating seismic events in a historical period with many financial and human losses
- Development of surface ruptures even more than 200 km with and displacement more than 10 m
- Identification of geological structures with potential of creating devastating earthquakes.
- Inadequacy and incompleteness of historical earthquakes catalogue for calculations of earthquake risk estimation
- Migration of rural population into the urban areas, increasing urban population and need for more construction
- High concentration of urbanization in the vicinity of active faults
- Need to construction of nuclear power plants and other essential facilities in the zones with seismic hazard potential (Vittoral et al., 1991)

Important findings in paleosiesmic researches are:

- Determining the time of ancient earthquakes by use of dating maps before or after faulting
- Return periods of large earthquakes on the fault or fault segment
- Quantifying intensity of historical and ancient earthquakes
- Complementing seismic catalogue in the studied area
- Implementing various dating methods in order to test the hypotheses
- Identifying fault behavior in response to any individual ancient event
- Determining accuracy and precision of ancient earthquake dating methods
- finding the length of prehistoric surface ruptures and investigation of their future possible development
- Determining the amount of slip on the fault plane and estimating the torque magnitude (M_W) of the ancient earthquake
- Dating earthquakes occurred between 5 to 50 thousand years ago
- Finding the occurred last earthquake, calculating time elapsed and long term predicting the last large earthquake
- Providing necessary data for segmentation of the fault

- Preparing a seismic pattern on the considered fault or fault segment.

It is worth to note that however, achieving all above targets seems impossible by use of a single methods discussed in paleoseismology literature, but by incorporating data obtained from various methods, it will not be farfetched.

Geological records of earthquakes include an array of various structures that are approximately complicated, named "seismite". The term "seismite" first introduced by Seilacher (1969) to represent the deformation characteristics of deposits that have endured seismic tremors. Ancient earthquake records referred to preserve geological deformation related to large earthquakes ($M_W > 6.5$) or megaseism ($M_W > 6.5$), because deformation related to small to moderate earthquakes have rarely occurred or preserved near earth surface (McCalpin, 2009). The first step in paleoseismological studies is to identify the seismic sources of geological structures (identification of seismites).

The main purpose of paleoseismological studies is to prepare data required to earthquake risk assessment. The key point in earthquake risk assessment studies is to determining identity of earthquake source that is determining magnitude and return period for large and devastating earthquakes caused by fault activities near vital facilities. Thus earthquake risk assessment aims to finding the largest. If a time interval for such an earthquake is specified, the earthquake is called the maximum earthquake. If no time limit is specified, then the earthquake is called maximum credible earthquake (MCE).

Paleoseismological investigation along the North Tabriz fault

Many scholars considered the North Tabriz Fault as the eastern-but disconnected- continuation of the North Anatolian Fault (e.g. Westway, 1990; Jackson, 1992), but others suggested that it is eastern continuation of the Gilato-Siah Cheshme-Khoy fault system (Karakhanian et al., 200; Soleymani Azad, 2009).

Soleymani Azad et al., (2009) believed that this fault system can be considered as a fault network (including several fault system) whose most eastern part consists of Tabriz Fault System. Among its faults, the North Tabriz Fault, located in central part, plays a fundamental role in the Tabriz fault System (with right-lateral strike slip mechanism) (*Figure 5*).

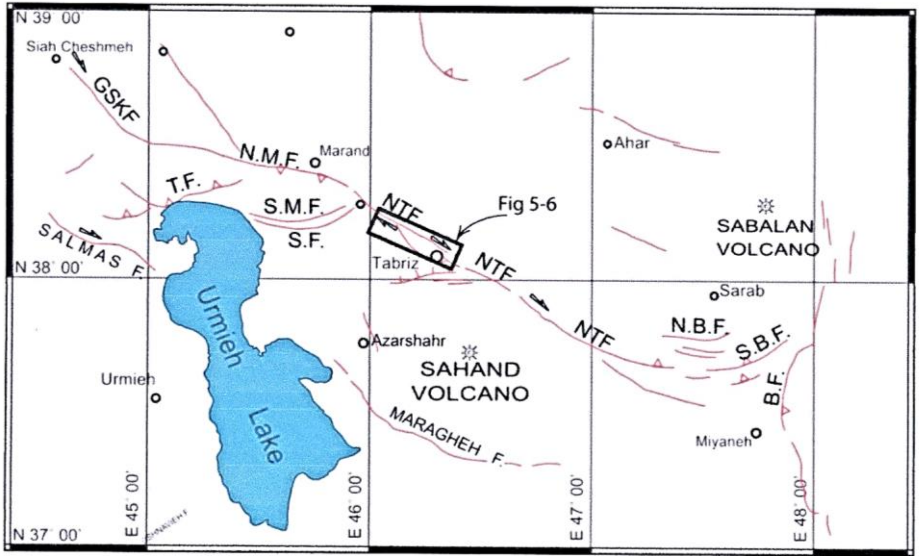

Figure 5: Tabriz Fault System in the northwest of Iran (edited from Soleymani Azad, 2009 and Atlas of Tabriz siesmotectic, 1:250000. NTF: North Tabriz fault; NMF: North Misho Fault; SMF: South Misho Fault; SF: Sufian Fault; TF: Tasuj Fault; NBF: North Bozghush Fautl; SBF: South Bozgush Fault; BF: Bozgush Fault; GSKF: Gilato- Siah Cheshme- Khoy fault.

Berberian (1997) considering North Misho Fault as the northwestern continue of North Tabriz Fault, estimated its length to be 210 k, which starts from south of Marand and continued to the southeast passing through the north of Tabriz City, until near Bostanabad. Hessami et al., (2003) suggested its length to be 150 km. Soleymani Azad (2009) considering Sufian in northwest to the southeast Bostanabad estimated its length as 120 km. the NTF strike 110°-135° trend, to the northwest and southeast accommodated along two reverse and oblique-slip fault zones (with a E-W trending) (*Figure 5*) (e.g. Berberian and Yeats, 1999; Soleymani Azad, 2009).

Historical earthquake catalogue of northwest of Iran reveals that the Tabriz area has devastated by some earthquake events (*Figure 6*) (Ambraseys and Melville, 1982). Based on our best knowledge the NTF has caused at least 3 devastating earthquakes in 1042 (M_W = 7.3), 1721 (M_W = 7.3) and 1780 (M_W = 7.4) which it has been 240 years since the last event attributed to it (1780 AD) and it has not experienced any large earthquake in the 20^{th} and 21^{st} century. However, seismological studies carried out on this fault revealed evidences that reflect microseismic activity and shallow earthquakes limited to a depth of 7-21 km (Siahkali Moradi, 2008).

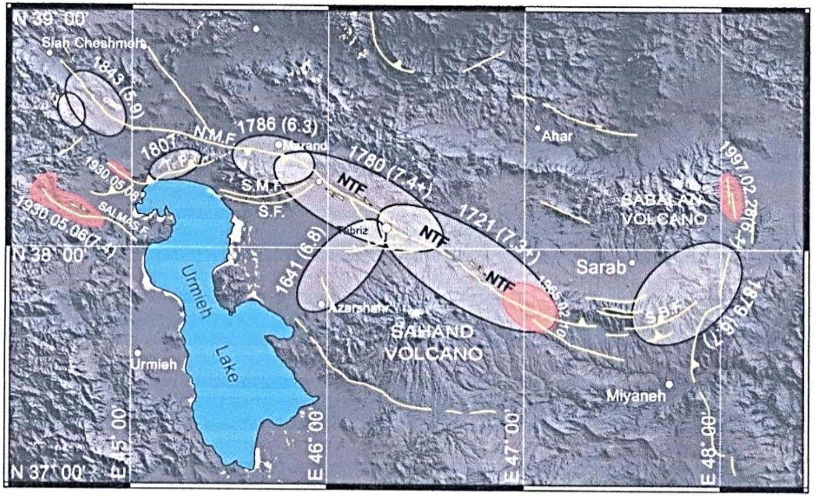

Figure 6: Macroseismic areas of historical (light colored) and instrumental (dark colored) earthquakes in Tabriz City and its vicinity, along with temporal distribution of that earthquakes. Ruptures of 1721 and 1780 earthquakes has occurred along the northwestern and southeastern segments. Macroseismic area of the largest instrumental earthquake occurred in the northwest of Iran (1930 Selmas earthquake, M ~ 7.4) also shown in the northwest of Lake Urmia (adapted from Tabriz rectangle seismotectonic Atlas, in press; faults adapted from Soleymani Azad, 2009).

Berberian and Yeats (1999) believed that seismicity in Tabriz area shows a cluster temporal distribution, so that in a 65 years' period of time, the North Tabriz Fault System and the reverse faults around it, has ruptured because of three earthquakes in 1721, 1780 and 1786. In addition, Soleymani Azad and et al., (1388) suggested that occurrence of five cosecutive devastating earthquakes in 1593, 1721, 1780, 1786 and 1807 from more eastern areas (Sarab) towards the west (Tasuj) can be the interaction of fault segments of the larger Tabriz Fault system so that the northwestern and southeastern segments of the North Tabriz Fault are the main contributors in developing right-lateral strike-slip movement.

Given to temporal clustering of seismic events in Tabriz area, spatio-temporal concentration of earthquakes associated with NTF as well as absence of any large earthquake since the last 240 years (e.g., Masson et al., 2006), as a part of inter-cluster period, in order to better understand seismic history in this area also seismic behavior of active faults, more paleoseismological researches along the NTF seemed necessary.

For this regard a site named Mayan has been located in order to complementation of previous paleoseismological data, in 6 km northwest of Tabriz City (Fathian, 1389). This site, located in south of Tabriz-Jolfa railway, can be accessed through Tabriz-

Marand Road. The Tabriz International Airport is located about 2 km northeast of the site.

After site locating, a N 057° trending trench perpendicular to fault scarp, in E46° 38' 07'' and E46° 12' 00'' with a depth of 5 m and a length of 23 m was dogged out (*Figure 7*).

Figure 7: Mayan paleoseismological trench. a) a view of fault scarp (with height of 1 m) and right-lateral displacement (about 5 m) near the western channel (adopted from seismotectonic atlas of Tabriz, in press). b) determining the trend of trench for digging (adopted from seismotectonic atlas of Tabriz, in press). c) Trench dogged out by excavator (view to the northeast). d) an internal view of the trench dogged out

after cleansing the walls, networking and flagging in order to separating sedimentary units and the other horizons.

It should be noted that because of marl and clay lithology where the trench has dug, tracking and logging the fault is not easy. In the next step, the direct paleoseismological studies after cleaning and networking the trench wall, the sedimentary units and geological and structural events are distinguished and then the trench log is prepared in 1:20 scale (*Figure 8*).

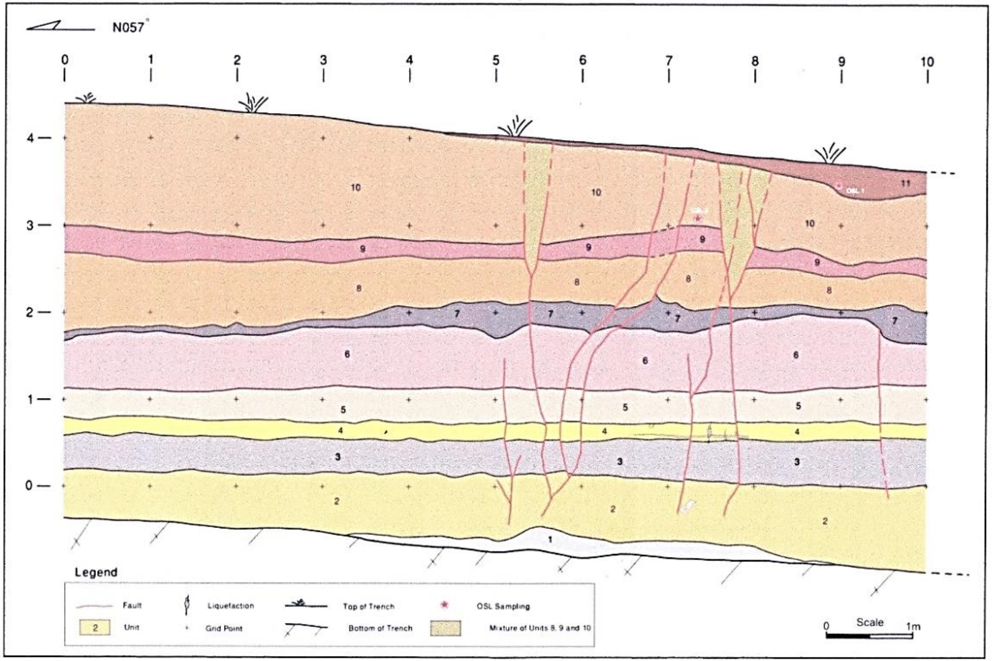
N057°
Legend
Fault
Unit
Liquefaction
Grid Point
Top of Trench
Bottom of Trench
OSL Sampling
Mixture of Units 8, 9 and 10
Scale
0
1m

Figure 8: The paleoseismological log of the western wall of Mayan trench (scale: 1:20).

Discussion and Conclusion

- Satellite images and aerial photos along with field observations, indicate that the young fault branches (fault splays) have formed in extensional basins located in overlap zone of the two northwestern and southeastern segments of the NTF.
- Morphological evidences revealed that fault branches and splays connecting major segments of the NTF (northwestern and southeastern segments) in overlapping zones, has cut the recent deposits that confirm their activity.
- Based on our finding, the NTF has a maximum horizontal right-lateral displacement about 170 m in the north of Tabriz Airport.
- Displacement estimated in the present study is more or less consisted with the 1100 mm right-lateral displacement suggested by Hessami and Jamali (2008) along a second-order branch of fault (Mehranrood branch). This estimate is also generally consistent with the total displacement suggested by Soleymani Aazad (2009) along the northwestern and southeastern segments of the NTF (100 m along the northwestern and 300 m along the southeastern segment).
- In the Mayan site, there is clear evidences indicating right-lateral strike-slip movement of a fault with an about 1m high scarp and an

earthquake-caused right-lateral displacement about 5 m.

- In this study we identify at least two megaseism events.
- The most recent megaseism magnitude recorded in the seismological trench estimated about 7.4, which seems associated with the 1780 earthquake (M_W = 7.4). sampling and dating this event can help more accurate estimations.
- Access to seismogenic parameters (slip rate, return period, …) can provided by dating tests.

Therefore:

- Given to increasingly developing Tabriz City inside of fault damage zone, it is necessary to more researches and revise the earthquake risk estimation for this important populous city.
- In addition to paleoseismological studies, we need geomatics and geophysics (especially seismological and geo-electrical studies) in regard to complement the previous findings.
- Finally, based on many researches carried out on the NTF, a moderate to large earthquake causing by reactivation of NTF seems credible and so the construction and promotion measures sounds necessary in order to minimize its harmful consequences.

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