UNESCO Chair on
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Abstract:

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Paleoseismological Studies and Structural Evolution of the North Tabriz Fault

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Paleoseismological studies and structural evolution of the North Tabriz Fault

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Author: Mohammad Faridi

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Contents

Table of Figures

Table of Table

Abstract

Based on the studies conducted, the main earthquakes in the northwest of Iran show a shallow focal depth of up to 15 kilometers, and there is no complete evidence of significant sub-crustal mobility. Investigating and comparing historical and instrumental seismicity in the northwestern part of Iran show the occurrence of large historic earthquakes in contrast to small instrumental earthquakes. Although historical evidence and catalogs of historical earthquakes show that the northwestern region of Iran has experienced devastating earthquakes, most of our knowledge about the amount of damages and death tolls during these earthquakes is mostly limited to the events that destroyed the city of Tabriz (Nazari et al, 2019).

The study of earthquakes in the area of Tabriz based on the available data shows that this area has been seismically active since 634 AD. Although there are many recorded earthquakes for which no macroseismic information is available. However, these earthquakes were strong enough to be reported by ancient chroniclers. Various reports of earthquakes mention the history of these events in a confused and confusing way.

In general, the different faults in the northwestern part of Iran can be separated into three separate categories from a structural point of view. The right-lateral strike-slip faults, which are the main factor in the

present-day deformation of this area, are generally seen in the northwest-southeast direction. Reverse faults with east-northeast and west-southwest directions, which are usually systems related to the main strike-slip structures of the area, have a smaller length than the first category, and play a relatively lesser role in seismotectonic processes. And left-lateral strike-slip faults, which are at least less abundant than the previous categories, and based on historical and instrumental seismic evidence, play the least important role in today's deformations. These faults are scattered in the area as sub-structures and with the northeast-southwest direction (Nazari et al, 2019).

The present study deals with the paleoseismological structural evolution and slip rate of the dextral fault system with historical seismogenic background (North Tabriz Fault System) (Faridi, 2018). The results of paleoseismological research using radiocarbon and luminescence dating of sediment samples exposed in trenches dug along the North Tabriz Fault (in the northwest and southeast of Tabriz city) made it possible to trace at least six ancient earthquakes that were accompanied by surface rupture and they have occurred during the last 3500 years. The moment magnitude of these earthquakes is estimated from Mw 6.3 to Mw 7.5. These investigations showed that the North Tabriz Fault has the ability to create surface ruptures approximately 50 km long during large earthquakes, and the size of the slip in each event can be up to 5.7 ± 0.20 meters.

Combining the ages obtained from the displaced sediments with the data from the kinematic location surveys, which were carried out on isolated geomorphic features along the North Tabriz Fault, indicates a horizontal slip rate of 6.4 ± 0.5 mm per year (average for the last 7500 years) for this section of the North Tabriz Fault. The size of the vertical uplift on the Tabriz Fault during the same period of time suggests an accumulation rate of 1± 0.1 mm per year. The geometrical and seismic parameters introduced in this research and the data obtained from the seismic behavior of the fault system are used in re-reading and re-evaluating the earthquake risk in the vicinity of Azerbaijan (Nazari et al, 2019).

Introduction:

In post-collisional tectonics, strike-slip faulting is an indicator of the stages of evolution and maturation of orogenic belts, and in most active faults that have an intracontinental location, strike-slip displacement component is dominant. The emergence of strike-slip fault systems and the horizontal movement of large crustal masses in the Azerbaijan region compensate for an important part of the progressive north-south shortening in this part of the Alpine-Himalayan orogeny. The present investigations provide structural, paleoseismological, and morphotectonic data for northwestern Iran, and in turn, it is a step that has been taken to identify the geometry and seismic behavior of dynamic faults in this region. Seismic catalogs and models are essential tools in short-term and long-term prediction of earthquakes. To identify important tectonic events in an area that is involved with dynamic tectonics and contains large seismic sources, preparing accurate geological maps is a necessary step and an important prerequisite. However, the role of small sympathetic faults and the mutual influence of faults in the shaking of adjacent large faults are still not well known. Existence of detailed information about the array and pattern of dynamic faults in an area can be a good indicator and guide to identify the processes that lead to earthquake shaking and successive ruptures.

This knowledge can shed light on understanding the spatial-temporal distribution of cluster earthquakes. The present studies provide structural information to understand the pattern of brittle deformation. Due to the fact that many dynamic faults in the northwestern region of the country remain unknown, the identification of sources in the Azerbaijan region is one of the important goals of this research. Looking at the history seismic of earthquakes in the last 1200 years in the northwestern part of Iran, in most of the earthquakes, the North Tabriz Fault is often mentioned as the main cause (Figure 1). However, within a radius of fifty kilometers of this fault, there are several other seismic faults that have shifted the Quaternary features and the focus of small and medium instrumental earthquakes in the last few decades coincides with them (Nazari et al, 2019).

During this research, the kinematic characteristics and geometric parameters of dynamic strike-slip faults in the region, some of which were ignored or less identified, were analyzed. Also, the geometry and mechanism of another series of strike-slip and dynamic faults in this region have been introduced as sources of seismicity that actively participate in the seismicity of the region. Due to their cross extension with respect to the main structural trend of the Azerbaijan region, these faults have not been of great importance in the study history of the region and have received less attention in the structural and geodynamic analyzes carried out by various researchers. However, in order to achieve reliable results with a high degree of certainty in the analysis of the Coulomb stress changes, the topic of induced earthquakes and earthquake migration, it is necessary that all seismic sources be taken into account and their geological and seismic parameters should be identified and considered (Nazari et al, 2019).

Also, parts of this research are related to paleoseismology and the slip rate of two important dextral strike-slip faults in the northwestern region of the country, that is, the North Tabriz Fault and the Qosha Dagh Fault. During the last two decades, valuable paleoseismological investigations and especially the slip rate of the North Tabriz Fault has been carried out by various researchers. However, the deficiencies in the list of historical and destructive earthquake events in the northwest region are significant. During the present investigations, with the aim of adding to the paleoseismological data of the North Tabriz Fault and filling some information gaps in the catalog of ancient earthquakes of the region, by digging three paleoseismological trenches on this fault and at a distance closer to the city of Tabriz, the ancient earthquakes, which were accompanied by surface ruptures, were identified and dated. Geomorphological and paleoseismological studies of the Qosha Dagh Fault were also prioritized in the field works of this research, because not only was its contribution in compensating the geodynamic displacements of the region unclear, but also its structural and kinematic characteristics remained unknown. The earthquake doublet of August 08, 2012 occurred on two separate seismic sources, which were not properly identified. These devastating events led us to a comprehensive identification of the geometry and behavior of seismic sources in the region. Providing new structural and paleoseismological information for the Qosha Dagh Fault was a more important goal, therefore, during these studies, this fault was subjected to paleoseismological excavations for the first time.

In the framework of this research, structural geological surveys, dating of events and accurate measurement of isolated Quaternary features with kinematic location surveys allowed to estimate the slip rate of different segments of the Qosha Dagh Fault. From the point of view of the importance of land hazards, the number and frequency of dynamic faults and seismic sources in the northwestern part of the country have caused this region to have high seismicity. On the other hand, the dense population that faces these natural hazards in the cities and villages of the region in non-resistant settlements causes this region to be considered as one of the high-risk and highly vulnerable regions in Iran. The data obtained from the current studies can be used in the assessment of land hazards and seismic analysis, which are the basic needs of the developing society of Iran today. (Nazari et al, 2019).

The location of the paleoseismic trenches was selected in the areas outside the city around Amand village (12 km northwest of Tabriz city) and Kondrood and Seyd Abad villages (10 and 20 km east and southeast of Tabriz, respectively) (Table 1). Seyd Abad trench was dug 20 km east of the city of Tabriz and 3 km northeast of Seyd Abad village on the North Tabriz Fault (Table 2). Amand trench was dug 12 kilometers northwest of Tabriz city, 3.5 kilometers southeast of Amand village and 2 kilometers east of Amand dam on the North Tabriz Fault (Table 3), and Kondrood trench was dug 8 km east of Tabriz city and 1 kilometer northeast of Kondrood on the North Tabriz Fault (Nazari et al, 2019).

Table 1:Geometrical parameters and obtained seismic parameters from the Ammand, Kondrud and Seyedabad trenches. The quantities derived from measurements on three trenches on NTF and their restored logs. (V = Vertical separation, Ds = Dip slip= ($V \times Sin^{-1} \times \delta$), Ss = Strike slip, Sn = Net slip=$(Ds^2 + Ss^2)^{1/2}$, Pitch or rake = Arc Cos (Ss/Sn), L = Rupture length (proportional to net slip): Sn/L≈1/20,000), F = Focal depth (according to modern earthquakes and locking depth, (Vernant, 2015)), A = Rupture Area = L × F, Mw = Energy magnitude or Moment magnitude (Wells and Coppersmith, 1994) = 2/3 Log M0g –10.7, M0g: Seismic moment (Kanamori, 1977) or Geologic moment = μ × A × Sn, μ = Shear or Rigidity module = 3×10^{11} (dyne/cm^2). e.g.: M0g = 3×10^{11} (dyne/cm^2) × (14.5×10^5 (cm) × 12×10^5 (cm) × 0.80×10^2 (cm) = 3.93×10^{25} (dyne cm), Mw = 2/3 Log 3.93×10^{25}-10.7 = 6.4).

Trench	Event ID	Event horizon	Displaced units	Age (Cal AD)	Ds (m)	V (m)	Ss (m)	Sn (m)	Pitch (deg.)	L (km)	F (km)	A Km^2	M_{0g} dyne cm	M_w (±0.2)
NTF. Ammand	AM-E (X)	Base of unit 6	U1, U2, U4 & U5	Post-date of U5 (292 Cal BC ± 86 yr), pre-date of U6 (160 Cal AD ± 114 yr)	0.94 ± 0.10	0.90 ± 10	2.03 ± 0.20	2.3 ± 0.20	27	≈30	≈13	390	2.6426	6.9
	AM-E (X + 1)	Base of unit 5	U1, U2 & U4	Post-date of U4 (538 Cal BC ± 60 yr), most close to date of U5 (292 Cal BC ± 86 yr)	1.28 ± 0.10	1.20 ± 10	2.51 ± 20	2.8 ± 0.20	27	≈40?	≈13	520	4.3726	7.1
	AM-E (X + 2)	Base of unit 4	U1 & U2	Post-date of U2 (1371 Cal BC ± 260), pre-date of U4 (538 Cal BC ± 60 yr)	0.65 ± 0.1	0.60 ± 1	0.90 ± 0.2	1.1 ± 0.2	36	≈15?	≈13	195	6.4425	6.5
NTF. Kondrud	KR-E (X)	Base of top-soil (U15)	U1, U2, U2a, U2b, U13 &U14	Post-date of U14 (1299 Cal AD ± 114)	1.44 ± 0.10	1.25 ± 0.10	3.1± 0.20	3.4 ± 0.20	25	40	13	520	5.3026	7.1
	KR-E (X + 1)	Base of unit 14	U2, U5, U6, U7, U8, U10, U12 & U13	Post-date of U13 (821 Cal AD ± 157)	0.43 ± 0.10	0.35 ± 0.1	0.91 ± 0.2	1.0 ± 0.2	25	15	13	195	5.8525	6.5
NTF. Seyed abad	SA-E (X)	Base of top soil	U1 to U9	Post- date of U9 (After 1523 Cal AD ± 125 yrs)	0.77 ± 0.10	0.55 ± 0.10	3.62 ± 0.10	3.7 ± 0.20	12	50	13	650	7.2226	7.2
	SA-E (X + 1)	Base of unit 8	U1 to U7	Post- date of U7 (after 1319 Cal AD ± 98 yr or 1087 CE ± 270 yr)	1.17 ± 0.10	1.10 ± 0.10	5.5± 0.20	5.7 ± 0.20	12	50	13	650	1.0727	7.3
	SA-E (X + 2)	Base of unit 7	U1 to U6	post-date of U6 (OC10: 157 Cal BC ± 210 yr (FZ:OC8): 616 Cal BC ± 206 yr (AVE: 389 Cal BC ± 22 yr)	0.46 ± 0.10	0.40 ± 0.10	2.2± 0.20	2.3 ± 0.20	12	30	13	390	2.6326	6.9
	SA-E (X + 3)	Base of unit 6	U1 to U5	post-date of U5(1502 Cal BC ± 191 yr), pre-date of U6 (most close to 616 Cal BC ± 206 yr)	0.86 ± 0.10	0.62 ± 0.10	4.1± 0.20	4.2 ± 0.20	12	40	13	520	6.5526	7.2

Table 2: Description of sedimentary units exposed on the Seydabad trench wall. The calibrated ^{14}C and OSL dating results are included.

Unite No.	Description
U10	Top soil, porous, organic rich gravelly mud contains plant root and stems.
U9	Light brown to gray, stratified, sub-angular, poorly sorted grain supported muddy graved. (^{14}C age: OC7: 1523 Cal AD ± 125 yr.).
U8	Light yellowish brown, moderately compact, matrix supported, gravely mud.
U7	Inhomogeneous, chaotic (non-stratified) light grey, grain-supported muddy-gravel. Containing angular boulders (up to 50 cm) and cobbles. (^{14}C age: OC9: 1319 Cal AD ± 98 yr.), (OSL Age: Osl9 cam: 577 CE ± 240, mam: 1087AD ± 270).
U6	Fine grained sandy and silty gravel, occasionally contains boulder sized gravels floating in dark-gray non-stratified sandy and silty matrix. Deposited on uneven unconformity surface. (^{14}C age: OC10: 157 Cal BC ± 210 yr, OC8: 616 Cal BC ± 206 yr., averaged: 389 Cal BC ± 22 yr).
U5	Muddy gravel, light gray, non-stratified, matrix supported, bad sorted, containing sub-angular to rounded cobbles and pebbles. Cracks and fissures filled by the younger fine-grained sediments. (^{14}C age: Oc3: 1502 Cal BC ± 191 yr).
U4	Compact, dark-gray, fine grained gravely and Sandy mud, well sorted, stratified. Used as key horizon in the trench wall.
U3	Inhomogeneous, poorly-sorted, light yellowish grey sandy gravel contains boulder sized sub-angular to sub-rounded grains, mainly sourced from nearby eroded turbiditic outcrops.
U2	Moderately compact, stratified, grey gravely mud, Pebble sized grains floating within fine sand and silty matrix. (^{14}C age: OC6: 2054 Cal BC ± 228 yr, OSL age: OSL6 cam: 1053 BCE ± 190 mam: 1063 BCE ± 350)
U1	Sandy gravel, non-stratified, grain supported, bad sorted, with angular to sub-rounded cobbles and boulders. Angular grains indicating proximal source area.

Table 3: Description of sedimentary units exposed on the Ammand trench wall. The calibrated 14C and OSL dating results are included.

Unite No.	Description
U7	Top soil, porous, organic rich gravelly mud contains plant root and stems.
U6	Colluvial wedge: Gravels of various size embedded in muddy matrix, inhomogeneous, bad sorted, matrix supported gravely mud derived from the upraised positive flower structure. ^{14}C age: 160 Cal AD ± 114 yr.
U5	Colluvial wedge: Light-yellow to grey, compact, chaotic, bad sorted gravelly mud, contains cobbles and boulders. Aggregates resulted from erosion of free-face of up-thrown fault block, pinch out toward the north and south. Averaged ^{14}C age: 292 Cal BC ± 86 yr.
U4	Sag pond deposits: Brownish-grey, stratified, moderately compact mud, contains gravels in various sizes (up to boulder) To the north restricted between organic rich horizons in top and bottom. ^{14}C age: 538 Cal BC ± 60 yr.
U3	Fine sand, occasionally gravels, in lens and tongues within U2.
U2a	Fault rock, mixed and sheared in fault zone, mainly deformed U2.
U1a	Fault rock, mixed and sheared in fault zone, mainly deformed U1.
U2	Debris flow deposit: Brown colored, matrix supported, bad sorted and poorly consolidated conglomerate, stratified, clayey matrix and gravely particles mainly derived from the underlying eroded bed rocks. The debris flow sediments to the north interfinger with alluvial and fluvial deposits in lens, tongue and channel shapes, radiocarbon age: 1371 Cal BC ± 260, OSL age: 5310 ± 270 to 4180 ± 210 yr.
U1	Latest Miocene bed rocks, Stratified, brown colored gypsiferous marl, greenish grey siltstone, (Equivalent to Lignite beds of Tabriz, Obtained Fission track age: 10 to 11.6 Ma.

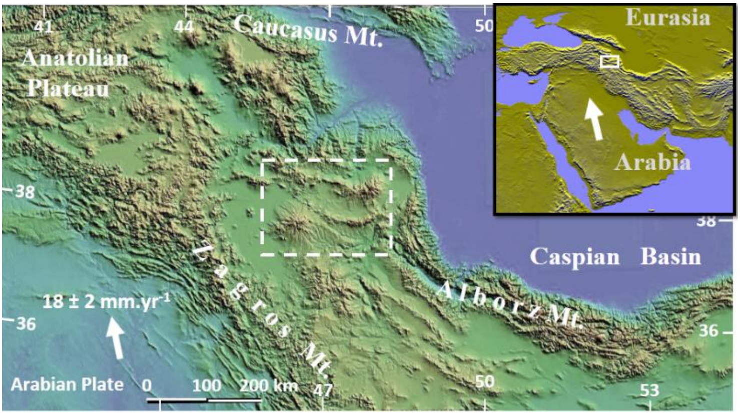

Figure 1: Tectonic setting of the study area (dashed rectangle) on the SRTM background image. The collision zone of the Arabian-Eurasian plates (image in the upper right corner) along with the movement speed of the northeastern margin of the Arabian plate ((Agard et al., 2011), 18 ± 2 mm yr-1) are shown in the figure (Nazari et al., 2019).

Discussion:

In terms of topography, the land of Azerbaijan is a relatively high plateau. In such a way that the height difference between the lowest point of Azerbaijan (Urmia depression) and the Caspian depression reaches about 1300 meters. The middle part of this plateau is depressed (Urmia depression) and it is divided into two uneven parts, eastern and western, by the aforementioned depression.

The study area is located in the Aras structural block, Northwestern Iran, (Berberian and Yeats, 1999).

This region is located in the collision zone between the Iranian, Arabian and Caucasus plates and is involved in the movements caused by the interaction of these three plates, and in this sense, it has unique seismotectonic characteristics.

The North Tabriz Fault (NTF) is part of a large strike-slip fault system that extends from the northwestern borders of the country to the end of the Bozgush range (north of Mianeh) with a length of about 350 km. This fault system includes segments of the Gelato-Siah Cheshmeh (Chaldoran)-Khoy (GSK) faults near the northwestern borders of Iran, the North and South Mishu Faults (NMF & SMF), NTF and the North and South Bozgush Faults (NBF & SBF). According to tectonic studies (Mesbahi et al., 2017, Alavi, 2007), the Tabriz fault system corresponds to a collisional geosuture that is influenced by post-collision convergences, due to reorganization in the tectonic movements of the Arabian Plate, since the Neogene (probably from Late Miocene) has been reactivated as a convergent strike-slip fault system. The kinematic data show that the North Tabriz Fault has suffered transpressional deformations in today's tectonic regime (Mesbahi et al., 2016) and the dominant mechanism of this fault is dextral strike-slip (Nazari et al, 2019).

The results of the first paleoseismological investigations on the North Tabriz Fault, which were carried out at the Khvajeh Marjan site, located about 20 km northwest of Tabriz city (Hessami et al., 2003), indicate the ability of this fault to produce strong earthquakes with a magnitude greater than 7.5. Based on these investigations, the movements of the North Tabriz Fault (in the northwest of Tabriz) in the last 3600 years have caused at least 4 strong earthquakes along with surface ruptures with a length of about 50 km on the earth. These pioneers of paleoseismological studies on the North Tabriz fault, based on the data obtained from kinematic studies, have concluded that the ratio of strike-slip to dip-slip is 4:1 and on each of the surface ruptures of the ancient earthquakes detected, the amount of right-lateral horizontal displacements was about three to four meters and the component of the reverse dip-slip in them was about one meter on average.

In order to complete the list of Tabriz earthquakes and obtain the geometrical and seismic parameters of this fault, as well as compare it with the data obtained from previous paleoseismological excavations, during these investigations, three paleoseismological trenches were dug on this fault in the northwest, east and southeast of Tabriz city and the samples taken from these trenches were dated by radiocarbon (^{14}C) and optically stimulated luminescence (OSL) dating. Also, in order to obtain the size of the displacements and separations in the morphotectonic features and prepare digital height models of the topographic features around these trenches, kinematic location surveys (RTK/GNSS) were carried out. The location of the paleoseismic trenches was selected in the areas outside the city around Amand village (12 km northwest of Tabriz city) and Kondrood and Seyd Abad villages (10 and 20 km east and southeast of Tabriz, respectively).

The eastern wall of Seyd Abad trench was subjected to paleoseismological investigations. In this wall, the North Tabriz Fault is exposed in a 30-meter stretch consisting of more than 10 fault branches with different mechanisms (F1 to F10). The combination of these faults has created imbricated and positive and negative rosette structures. Fault branch F7, located at 125/80 NE, with a dextral-reverse mechanism, has exhibited the highest vertical displacement (nearly two meters) in the sedimentary layers. Accurate surface mapping of landforms with RTK survey indicates dextral strike-slip displacements up to 13.8 meters in the topographic features around the trench, including waterways and drainages. Also, the maximum cumulative uplift in the hanging wall of these faults was approximately 2.7 meters. The vertical-to-horizontal displacement ratio indicates the dominance of the strike-slip component and the average pitch angle of 12 degrees of the displacement vector on this part of the North Tabriz fault (Nazari et al, 2019) (Figure 2).

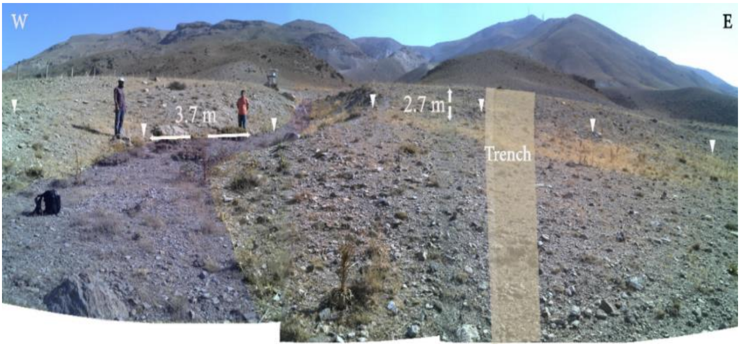

Figure 2: The location of the Seyd Abad trench and the 3.7-meter separation of the waterway in the west of this trench. The height of the fault scarp is 2.7 meters (Nazari et al, 2019).

Based on the results of dating, in general, the eastern wall of Seyd Abad trench represents a history of large earthquakes of a segment of the North Tabriz Fault in a period of 3500 years (from 1500 BC to present-day) (Figure 3). There are some local discontinuities in the mentioned time period, which indicate the absence and removal of part of the history of paleo earthquakes. Four tectonic events preserved in the sediments of this trench were identified on numerous fault branches, the youngest of which occurred after the deposition of unit U9 (1523 Cal AD ± 125 yr) and the oldest event occurred after the deposition of unit U5 (1502 Cal BC ± 191 yr). Under the surface soil horizon, the U9 unit is cut by faults F1, F3, F4 and F5, so by removing the surface soil and reconstructing the unit U9, the geometric parameters of the youngest earthquake event with rupture (EX event) are traced in this trench (Nazari et al, 2019).

In the southern part of the western wall of the Amand trench (Figure 4), the North Tabriz Fault is exposed in a 7-meter section consisting of 8 steep to vertical fault branches. Most of these faults have a southern dip direction and lead to the subsurface soil layer. The fault branch F1, located at 130/70 S, is the northernmost fault branch of this system, which together with the fault branch F2, located at 135/60 N, both have a dextral-reverse mechanism, and have created a positive rosette. From the point of view of lithology and sedimentology, the unit U1 is equivalent to the late Miocene lignite-bearing strata of Tabriz, 10.8 ± 0.8 Ma, (Faridi and Khodabandeh, 2015b; Reichenbacher et al., 2011) consisting of gypsiferous marl and siltstone layers, which are exposed as bedrock only in the southern part of the trench and in the hanging wall of fault F1. In order to reach the bedrock in the northern part of the bottom of the trench, a borehole was dug to a depth of 70 cm. This borehole reached the Miocene bedrock (U1) at a depth of 35 cm from the bottom of the trench. The obtained depth was used in the reconstruction of the upper boundary between the Miocene bedrock and the young Holocene sediments. The sedimentary unit U2, which is placed on the top of unit U1 with a discontinuity, is actually Holocene terrigenous sediments and the result of erosion and destruction of the unit U1 (Nazari et al, 2019).

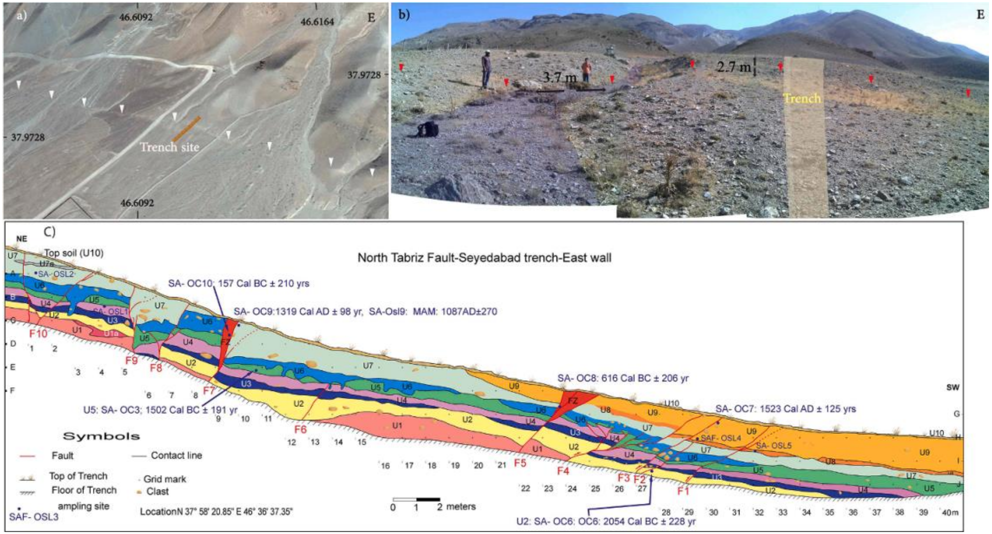

Figure 3: a: Trace of NTF and location of Seydabad trench on Google image; b: Fault scarp and deflected drainage nearby the trench site; c: Trench log showing the sedimentary units (U1 to U10) displaced by fault planes (F1 to F10), sampling points and calibrated ages of the units are given in AD calendar. A, B and C on vertical axis have 1 m intervals. Re-stored sections are illustrated in Supplementary Materials.

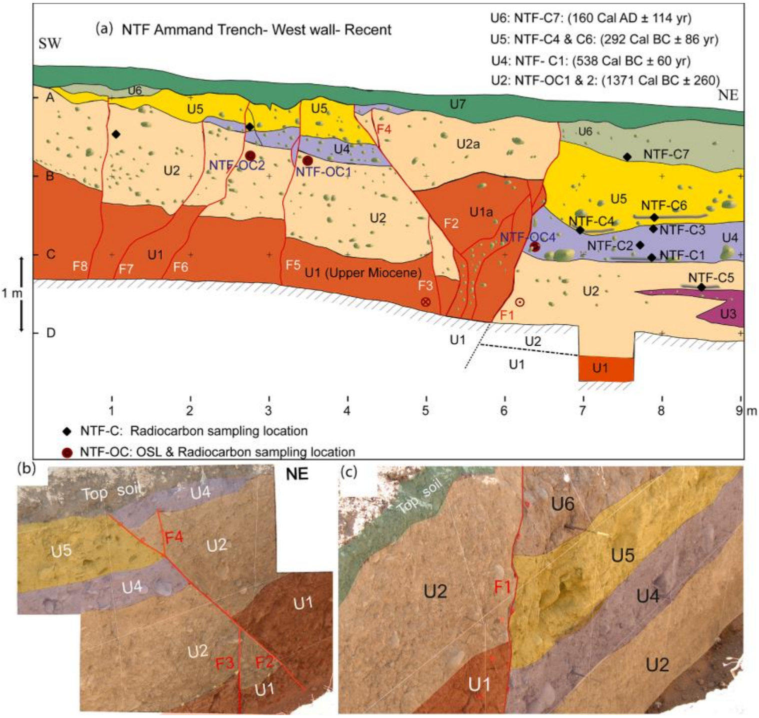

Figure 4: a: Profile of the western wall of trench Ammand displaying the sedimentary units (U1 to U7) and fault planes (F1 to F8) with a positive flower structure raised at the center of the fault zone. Sampling points for 14C and OSL dating and calibrated ages of the units are given in AD calendar. A, B, c and d on vertical axis have 1 m intervals; b & c: Close view of the trench wall represent the displaced U1 to U4 units on hanging wall of F1 and F2 fault branches and the U5 and U6 colluvial wedges deposited at the footwall of the faults.

The age of the sample taken from the horizon rich in organic matter within the sedimentary unit U2 was determined to be 5251 Cal BC ± 49 yr by carbon 14 dating. However, the OSL dating of NTF-OSL 1 and NTF-OSL 2 samples from the unit U2 is 5310 ± 270 yr to 4180 ± 210 yr, respectively. There is a relatively long term gap (at least 3.7 ka) within the younger unit U4, which was deposited on the top of unit U2 as stratified deposits in fault-related basins. Terrigenous units U5 and U6 are as wedge-shaped tongues, which are reduced to the north and south of their thickness and then removed. The constituents of these units are the result of the erosion of the hanging wall block. These units are the thickest in the vicinity of faults F1 and F2. Under the surface soil horizon, the youngest sedimentary unit (U6) shows a radiocarbon age of 114 ± 160 AD, which indicates a gap in the last 1800 years in this trench. Due to the erosion and leveling of the high topography (positive rosette), it is most likely that the mentioned gap is due to the removal of sediments due to erosion.

Based on the dating results, in general, the western wall of the Amand trench (Figure 4) represents a discontinuous and interrupted history of the seismic behavior of a segment of the North Tabriz fault in a period of 1900 years (from 1630 BC to 270 AD). At least three tectonic events preserved in the sediments of this trench were identified on different fault branches, the youngest of which occurred before the deposition of unit U6 (160 Cal AD ± 114 yr) and the oldest event occurred after the deposition of unit U2 (1371 BC ± 260). Under the surface soil horizon, the unit U6 is not cut by the fault F8, so by removing the surface soil and reconstruction the unit U6 on the sides of the rosette, the first earthquake event with rupture can be traced in this trench. Event E(X) is the youngest earthquake detected in Amand Trench.

Kondrood trench was excavated 8 kilometers east of Tabriz and one kilometer northeast of Kondrood on the North Tabriz Fault. (Figure 5) In this place, like other outcrops of the North Tabriz Fault, the topographic features, including the waterways intersecting with the fault, have undergone rightward separation, however, due to the proximity of this site to the city of Tabriz and human manipulations in urban and construction projects, the waterways adjacent to the trenches, especially in the downstream, have changed their direction towards artificial channels, and measuring their deviation does not provide reliable separation values (Nazari et al, 2019).

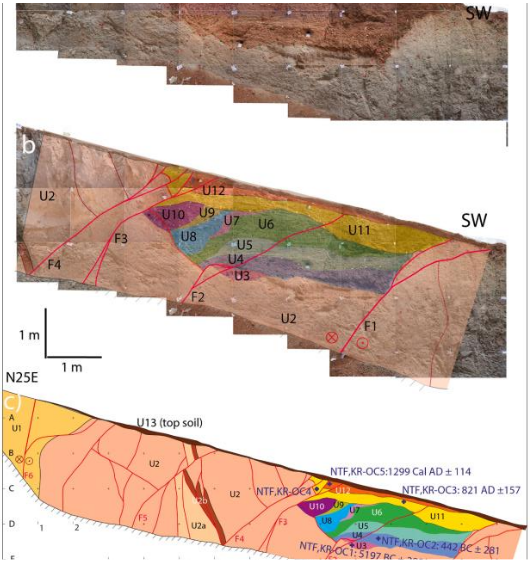

Figure 5: a: Photomosaic of eastern wall of Kondrud trench; b: Compiled trench log on the photomosaic displaying the Quaternary paleo-channel-fill deposit (sedimentary units U3 to U12) and fault zone (F1 to F4); c: A far view from the trench wall representing the U1 U2 main fault contact which overthrust the Miocene Red Beds (U1) on Sahand Volcanoclastic rocks (U2). Sampling points for dating and calibrated ages of the units are given in AD calendar. Letters A, B, C, on vertical axis have 1 m. intervals. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The eastern wall of the Kondrood trench was subjected to paleoseismological investigations. In an important part of this 40-meter wall, Pliocene thick layers of volcanic ash and rhyolitic tuff (part of the Sahand fish-bearing layers with a fission track age of 7.5 to 10 million years, (Reichenbacher et al., 2011) are exposed. The upper Miocene sandstone and marl layers cropped out at the northern end of the trench, which came into contact across fault with the mentioned tuff and volcanic ash layers (fault F6). Several fault branches (F1 to F4) in a 6-meter area caused the displacement of young sediments filling the old river channel (paleo-channel fill deposits). In general, the 14C dating of the samples taken from different sedimentary units filling the river channel, provides ages from 5197 Cal BC ± 288 yr (unit U#) to 299 Cal AD ± 114 yr (Unit U12).

Based on the dating results, in general, the eastern wall of the Kondrood trench, due to the characteristics of the Holocene sediments that were formed only in a small river channel and moved by fault branches F2, F3 and F4, only represents the history of the two large earthquakes on the North Tabriz Fault in the maximum period of 750 years (821 Cal AD ±157 to 1299 Cal AD ±114). The absence of sediments younger than unit U12 most likely indicates the gap or the removal of an important part of the history of the second millennium AD from the history of ancient earthquakes in the wall of this trench. The two tectonic events preserved in the sediments of this trench specifically occurred on the fault branches F2, F3 and F4, the younger event was after the deposition of unit U12 (1299 Cal AD ± 114) and the older event was after the sedimentation of unit U11 (821 Cal AD ±157) (Nazari et al, 2019).

In a general look at the results obtained from the three trenches of Seyd Abad, Amand and Kondrood, (Table 2 and Table 3) it can be said that regardless of the unrecorded or eroded and unpreserved events, a total of six earthquake events with surface rupture can be traced in these trenches. The events identified in three trenches were compared with each other. Moreover, they were compared with the results of previous paleoseismological works (Hessami et al., 2003). Seyd Abad trench has a more complete sedimentary sequence than Amand and Kondrood trenches (from 1502 Cal BC±191yr to present) and has only a gap of about 500 years in the middle part of its sequence, which an important earthquake event may have been removed in this time interval and among this sequence. The aforementioned gap can be seen in all three trenches. Amand trench contains sediments older than 292 Cal AD ± 86 yr and was not able to preserve or record events younger than this age. In the Kondrood trench, sediments younger than 821 Cal AD ± 157 yr are exposed on the bedrock, and therefore, Quaternary events older than this date are not recorded. Correspondence of some events (especially D and F) in the eastern and western trenches of Tabriz (Seyd Abad, Amand and Khajeh Marjan), doubts the segmentation of the fault and its subdivision into the northwestern and southeastern segments of the NTF (Karakhanian et al., 2004) and indicates the continuous rupture of this fault and its failure to be limited to the mentioned segments (at least in the mentioned events). However, large-scale mapping of the central part of the NTF [Faridi and Khodabandeh, 2015b and Faridi, 2016] indicates the integrity of this fault from Sufian (northwest of Tabriz) to Bostan Abad (southeast of Tabriz). The moment magnitude calculated for the detected events was $6.5 \leq Mw \leq 7.3$.

Kinematic location surveys (GNSS/RTK) were conducted in order to prepare topographic maps and accurate digital elevation models (DEM) of geomorphic features and especially the location of the diversion of waterways, and the results were integrated with dated samples of isolated sedimentary units. The data obtained by measuring the vertical displacements of sedimentary units in the paleo-seismological trenches were also included in the calculation of the formation rate of the hanging wall. The reconstruction of waterways and alluvial sediments adjacent to Seyd Abad trench (southeast of Tabriz city) has indicated a horizontal slip rate of 6.4 ± 0.6 mm/year (average for the last 2400 years) for this part of the Tabriz fault. The vertical uplift value of these sediments on the Tabriz Fault during the same period of time was 2.7 ± 0.1 meters, which suggests formation rate of 1 ± 0.1 mm per year. Also, the reconstruction of the waterways adjacent to the Kondrood trench provides an almost similar value of the horizontal slip rate of 6.3 ± 0.3 mm per year (average for the last 7500 years) (Nazari et al, 2019).

Conclusion:

From a structural point of view, Azerbaijan is a region where shear deformation is distributed on numerous faults with different geometry and mechanism. The series of left-lateral faults with NNE-SSW direction, in a conjugate manner with right-lateral faults, contribute to the present-day deformation of the northwestern part of the country. Both series of these dynamic faults are involved in compensating the shortening (approximately north-south) between the Arabian and Eurasian plates, as well as compensating regional eastward movements of crustal blocks. The mentioned left-lateral faults have caused large-scale lateral displacements in the important topographical features of the region, such as Bozgush, Qosha Dagh, Sablan and Sahand mountains. Changes in stress, stress transfer and successive ruptures shaking between conjugate and sympathetic faults could lead to the clustering of earthquakes, which can be seen in the seismic behavior of these faults and the historical record of earthquakes in the northwest of Iran.

The Pliocene and Quaternary volcanic complexes of Sablan and Sahand, which were created on active faults, have been transformed under the influence of the movements of these faults. The structure of Sablan volcano has been affected by both Qosha Dagh and Aghmion cross faults, and according to the presence of synsedimentary deformation structures recorded in the pyroclastic layers of this stratovolcano, it can be concluded that the aforementioned faults played an active role in the formation and initial eruptions of Sablan. In the case of Sahand Volcano, the displacements observed in the western slope of this volcanic complex indicate the activeness of a basement fault with NE-SW direction (Dehkhargan fault) under this volcanic complex, the location of which corresponds to the maximum damage area of the historical earthquake of 1641 in the regions of Osku and Dehkhargan (now Azarshahr) (Nazari et al, 2019).

The frequency and temporal distribution of ancient events identified during paleoseismological excavations on the North Tabriz Fault indicate irregular (and non-periodic) seismic behavior. Also, the parameters obtained from the detected events indicate that this fault does not follow a uniform slip model during past events, on the other hand, "variable slip model" is more suitable for the behavior pattern of this fault. The statistics of historical destructive events attributed to the North Tabriz Fault have also shown an irregular spatial and temporal distribution of the earthquakes of this fault (Nazari et al, 2019).

References:

Agard, P., Omrani, J., Jolivet, L., Whitechurch, H., Vrielynck, B., Spakman, W., Monié, P., Meyer, B. and Wortel, R., 2011. Zagros orogeny: a subduction-dominated process. Geological Magazine, 148(5-6), pp.692-725.

Alavi, M. 2007. “Structures of the Zagros Fold-Thrust Belt in Iran,” Am. J. Sci. 307, 1064–1095.

Berberian, M. and Yeats, R. S., 1999. Patterns of historical earthquake rupture in the Iranian plateau, *Bull. Seismol. Soc. Am.*, 89, 120-139.

Faridi M. and Khodabandeh, A. 2015b. Geological Map of Tabriz I Quadrangle, Sheet No. 5266II SW, Scale 1:25000 (Geological Survey of Iran).

Faridi, M. 2016. Geological Map of Sahlan Quadrangle,” Sheet No. 5266III NE, Scale 1:25000 (Geological Survey of Iran).

Faridi, M. 2018. Active tectonics and earthquake potential of seismogenic sources of northwestern Iran, (A morphotectonic and paleoseismological approach), PhD thesis of Geology-Tectonics, Research Institute for Earth Sciences, Tehran, Iran and ETH, Zurich, Switzerland, (in Persian) .

Hessami, K., Pantosi, D., Tabassi, H., Shabanian, E., Abbassi, M., Feghhi, K., Solaymani, S., 2003. Paleoearthquakes and slip rates of the North Tabriz Fault, NW Iran: preliminary results, *Ann. Geophys.*, 46, 903–915.

Kanamori, H., 1977. The energy release in great earthquakes. J. Geophys. Res. 82 (20), 2981–2987. https://doi.org/10.1029/jb082i020p02981.

Karakhanian, A. S., Trifonov, V. G., Philip, H., Avagyan, A., Hessami, K., Jamali, F., Bayraktutan, M. S., Bagdassarian, H., Arakelian, S., Davtian, V., Adilkhanyan, A., 2004. Active faulting and natural hazards in Armenia, Eastern Turkey and North-Western Iran, Tectonophysics, 380, 189-219.

Mesbahi, F. Mohajjel, M. and Faridi, M. 2016. “Neogene oblique convergence and strain partitioning along the North Tabriz Fault, NW Iran,” Journal of Asian Earth Sciences No.129, P. 191–205.

Mesbahi, F., Mohajjel, M., Oberhänsli, R., Moazzen, M. 2017. “The mafic rocks along the North Tabriz Fault, possible remnants of Neo-Tethys oceanic crust in NW Iran,” Geopersia **7** (2), PP. 301-311.

Nazari, H., Faridi, M., Esmaili, S., Fathiyan, A., Burg., J. & Rits, J. (2019). Stractural Genesis of North Tabriz Fault System Based on Paleoseismological Studies. Project No: 102- T- P- 98

Reichenbacher, B., et al., 2011. “Late Miocene stratigraphy, palaeoecology and paleostratigraphy of the Tabriz Basin (NW Iran, Eastern Paratethys),” Jour. Palaeogeography, Palaeogeography and Palaeoecology No. 311, 1-18.

Vernant, P., 2015. What can we learn from 20 years of interseismic GPS measurements across strike- slip faults? Tectonophysics 644–645, 22–35.

Wells, D.L., Coppersmith, K.J., 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. Bull. Seis. Soc. Am. 84 (4), 974–1002.