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Abstract

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Paleoseismological site selection along the Khazar Fault, north Iran

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Paleoseismological site selection along the Khazar Fault, north Iran

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Scope of Paleoseismology

The Scope of Paleoseismology Definition and Objectives Paleoseismology is the study of prehistoric earthquakes, especially their location, timing, and size (McCalpin 2009). Whereas seismologists work with data recorded by instruments during earthquakes, paleoseismologists interpret geologic evidence created during individual **paleoearthquakes.** Paleoseismology differs from more general geologic studies of slow to rapid crustal movements during the late Cenozoic (e.g., neotectonics) in its focus on the almost instantaneous deformation of landforms and sediments during earthquakes. This focus permits study of the distribution of individual paleoearthquakes in space and over time periods of thousands or tens of thousands of years. Such long paleoseismic histories, in turn, help us understand many aspects of neotectonics, such as regional patterns of seismicity and tectonic deformation as well as the seismogenic behavior of specific faults. Paleoseismology also is part of the broader field of earthquake geology, which includes aspects of modern instrumental studies of earthquakes (seismology), tectonics and structural geology, historical surface deformation (geodesy), and the geomorphology of tectonic landscapes (tectonic geomorphology). Books by Yeats **et al.** (1997), Burbank and Anderson (2001), and Keller and Pinter (2002) give different perspectives on the field of paleoseismology. The driving force behind most paleoseismic studies is society's need to assess the probability and severity of future earthquakes (Reiter, 1995; Gurpinar, 2005). In the decade since the first edition of this book was published in 1996, deadly earthquakes occurred in 1999 in Turkey (17,118 dead), in 2001 in India (20,023 dead), in 2003 in Iran (31,000 dead), in 2004 in Indonesia (>250,000 dead from tsunamis accompanying the earthquake), in 2005 in Pakistan (80,361 dead), and in 2008 in Sichuan province, China (69,000 dead; U.S. National Earthquake Information Center). The 2004 Sumatra–Andaman Islands earthquake in Indonesia was the fourth most deadly earthquake in human history, and strained worldwide relief capacity. With the exception of the Turkish event, these earthquakes occurred on faults that had not generated a surface-rupturing earthquake in historical times or been studied by paleoseismologists. However, even where paleoseismologists have pointed out potentially dangerous faults, local governments have often not used that information to increase public awareness of seismic hazards or mitigate the effects of future earthquakes (e.g., Bilham and Hough, 2006). Before 1980, the assessment of earthquake hazard in industrialized countries such as the United States, Japan, and the USSR was based almost solely on the historical earthquake record. Although many geologists (e.g., Allen, 1975; Research Group for Active Faults, 1980) pointed out the danger in this approach, early maps of predicted strong ground motion were derived solely from historical data. In the twenty-first century most countries with seismically active faults consider paleoseismic data in both regional (e.g., Stuchi, 2004, http://zonesismiche.mi.ingv.it/; The Headquarters for Earthquake Research Promotion, 2005, http://www.jishin.go.jp/main/index-e.html; Petersen et al., 2008, http://pubs.usgs.gov/ of/2008/1128/) and site-specific seismic hazard analyses (Gurpinar, 2005). In the USA, the Quaternary Fault and Fold Database of the United States (U.S. Geological Survey, 2006) contains a summary of available paleoseismic data for most known active faults. Paleoseismology supplements historical and instrumental records of seismicity by characterizing and dating large prehistoric earthquakes. In many countries such as the USA, useful seismicity records extend back only a few centuries (Gutenberg and Richter, 1954; Stover and Coffman, 1993) and many active fault zones have no historical record of large earthquakes. For example, studies of prehistoric faulting along the Wasatch fault (Utah) show that the average recurrence interval between magnitude-7 earthquakes is probably three times longer than the 145-year period of historical settlement (McCalpin and Nishenko, 1996). In Europe, catalogs of historical large earthquakes are often considered complete back four to five centuries; for example, the Italian catalog (Stuchi et al., 2004) is considered complete for Intensity 8 and above back to the year 1600. Even in parts of China and the Middle East where earthquake catalogs extend back thousands of years (Ambraseys, 1982; Gu et al., 1989), historical observations are insufficient to identify all seismogenic faults. On a fault that has slipped episodically for many hundreds of thousands of years, even a 3000-year earthquake history such as China's covers only a tiny fraction of the history of the fault. Much of the seismic history of most major faults is accessible only through the techniques of paleoseismology. For the most part, the paleoseismic record is a record of large (moment magnitude, Mw > 6.5) or great (Mw > 7.8) earthquakes because geologic evidence of small and moderate-sized earthquakes is rarely created or preserved near the surface. Evidence of past earthquakes can range from local deformation of the ground surface along a crustal fault (fault scarps, sag ponds, laterally offset stream valleys, monoclinally folded marine terraces, scarp-dammed lakes), to indicators of the sudden uplift or subsidence of large regions above a plate-boundary fault (warped river terraces, uplifted or subsided shorelines, drowned tidal marshes), to stratigraphic or geomorphic effects of strong ground shaking or tsunamis far from the seismogenic fault (landslides, rockfalls, liquefaction features, tsunami deposits). A characteristic of most such features is that they formed instantaneously (from a geologic perspective) during or immediately after an earthquake. Features (deposits or landforms) formed during an earthquake are described as coseismic and are commonly contrasted with nonseismic features formed by processes of erosion, deposition, and deformation unrelated to large earthquakes. For example, seismogenic faults may creep between earthquakes or slip small amounts during small to moderate earthquakes that leave no signs of sudden slip. For this reason, nontectonic and nonseismic are better adjectives than aseismic (no detectable seismicity) for features unrelated to fault slip or strong earthquake shaking. The term aseismic should be restricted to seismology. Paleoseismologists can only study earthquakes that produce recognizable deformation (in the form of deformed stratigraphic units, displaced landforms, or earthquake-induced sedimentation). Vittori et al. (1991) and many succeeding European authors propose that the term seismites be used to describe all geologic structures and sediments genetically related to earthquakes. However, such usage poses two problems: (1) the original definition of seismites referred only to stratigraphic units containing sedimentary structures produced by shaking (Seilacher, 1969; AGI, 2007) and (2) there is considerable uncertainty in relating various geologic structures and strata to earthquakes (Wheeler, 2002). Thus, we suggest that the term "seismites" be restricted to its original definition. Another ambiguous term used in paleoseismology is "event" (used without a modifier) or "event horizon." Many paleoseismic publications use the term event too freely as a synonym for earthquake. Erosional, depositional, and deformational "events" are only inferred responses to earthquakes; commonly it is unclear whether an earthquake or some other type of "event" is being discussed. Including a modifier with "event" avoids some of this ambiguity (e.g., Scharer et al., 2007). For example, "fracturing events" are extensively documented in fault zone trenches near Yucca Mountain, Nevada, in the western U.S. (Keefer et al., 2004), and the addition of "fracturing" to "event" expresses the uncertainty about whether the fracturing resulted from coseismic slip on the exposed fault, slip triggered by movement on an adjacent coseismic fault, shaking-induced compaction, or nonseismic compaction. In a similar example, to avoid implying a tsunami origin for all anomalous sandy beds in a 7000-year sequence of lake sediment on the Oregon coast, Kelsey et al. (2005) termed the processes that deposited the beds "disturbance events." Even greater ambiguity may occur with the widely used term "event horizon," which combines the ambiguity of "event" with the uncertainty of "horizon," a term that may mean a former surface in some paleoseismologic contexts, a bed with finite thickness in others, and is easily confused with the "horizons" of soils that are central to many paleoseismologic interpretations. Among the specific terms that paleoseismologists might use instead of "event horizon" include "unconformity" and "disconformity," terms widely used in geology for more than a century (AGI, 2007). "Earthquake horizon" (e.g., Scharer et al., 2007) avoids ambiguity as long as the meaning of "horizon" is clear. Paleoearthquakes are prehistoric by definition, but does "prehistoric" mean the time before oral records, or the time before contemporaneous written accounts, or the time before written accounts with some uantitative observations of earthquakes? Most paleoseismologists follow the latter definition for "prehistoric." This broad definition reduces problems caused by uncertainty in the times of transition from oral to written history around the globe; for example, from 1831 BC in parts of China (Gu et al., 1989), from 550 BC in the eastern Mediterranean (Ambraseys and White, 1997), and from later than AD 1700 in New Zealand and northwestern North America (Stover and Coffman, 1993). Archaeology has contributed much to the understanding of the history of large earthquakes in some regions (Vita-Finzi, 1986); much of what we know of the seismic history of the Middle East and Mediterranean regions before the Christian era has come from archaeoseismic investigations (e.g., Stiros and Jones, 1996; see Chapter 2A). The older boundary on the time interval encompassed by paleoseismology studies is commonly the middle (4–6 ka, that is, 4000–6000 years ago) to early (7–10 ka) Holocene, but records of individual earthquakes may extend back into the late Pleistocene in regions of long recurrence (e.g., Crone et al., 2003; Keefer et al., 2004) or unusually well-preserved evidence (e.g., Ota et al., 1993; Marco and Agnon, 2005). Paleoseismology also enhances our understanding of some large historical earthquakes. As in studies of prehistoric earthquakes, such historical paleoseismology studies (Yeats, 1994) concentrate on measuring the amount or lateral extent of surface displacement on faults or describing the size and distribution of landforms or deposits produced by earthquake shaking. Historical paleoseismology includes studies of relatively recent earthquakes (e.g., AD 1886, Charleston, South Carolina, USA, Obermeier et al., 1990; AD 1857 Ft. Tejon, San Andreas fault, USA: Sieh, 1978a; Harris and

Arrowsmith, 2006; 1811–1812, New Madrid, Missouri: Tuttle et al., 2002; AD 1739, Yinchuan, China, Zhang et al., 1986; AD 1703, central Italy earthquakes: Blumetti, 1995), to earthquakes that occurred many centuries ago (AD 1638 and 1783, Calabria, Italy: Galli and Bosi (2002, 2003); AD 1510, Kondayama, Japan: Sangawa (1986); the Early Byzantine tectonic paroxysm (series of large earthquakes during the Early Byzantine period of the midfourth to mid-sixth centuries) between the mid-fourth and mid-sixth centuries A.D: Pirazzoli et al. (1996); 31 BC, Jericho, Israel: Reches and Hoexter (1981)). Historical paleoseismology has even shed light on some mythical events, for example the Oracle of Delphi (Piccardi, 2000; de Boer et al., 2001), the collapse of Mycenaean civilization in ancient Greece (French, 1996), and the destruction of Jericho in the Middle East in 1550 BC (Nur, 1991).

Paleoseismology of compressional Tectonic Environment

Introduction

Large compressional earthquakes in the upper crust, and even larger plate-boundary earthquakes in subduction zones, produce surface deformation recorded by displacements on reverse or thrust faults,by growth of surface folds, and by changes in the elevation of the land surface. Study of such stratigraphic and geomorphic features yields information about the size and recurrence of large earthquakes that is not available from historic sources in many regions. Coupled with regional-scale knowledge about structure, geophysics, and landscape development, such data allow characterization of seismic fault source zones in regions dominated by compressional tectonics (Chapter 9, See Book's companion web site). Stratigraphic and geomorphic features formed by active compressive faulting and folding are commonly more diverse, and often more subtle, than those formed by extensional or strike-slip faulting. As a result, reverse faults have often been overlooked near urban areas, even where seismic hazard studies have been carried out. It would not be an exaggeration to say that the most dangerous faults on the planet are subtle reverse faults and blind-thrust faults. This premise was first advanced by Stein and Yeats (1989), but has been underscored by events that occurred since the publication of our 1st Edition in 1996. During that time period, all the largest and deadliest earthquakes worldwide have been compressional events on reverse faults either previously unknown or not thought to be active (central Taiwan, 1999 (Uzarski and Arnold, 2001); Bhuj, India, 2001 (Jain et al., 2002); Bam, Iran, 2003 (Naeim et al., 2005); Sumatra, Indonesia, 2004 (Bilek et al., 2007); Kashmir, Pakistan, 2005 (EERI, 2006); Sichuan, China, 2008 (EERI, 2008)). Even moderate reverse earthquakes have had major impact, for example, the Mw 6.6

Chuetsu offshore earthquake of 16 July 2007 which occurred near the Kashiwazaki-Kariwa nuclear power plant in Japan, the world's largest NPP (8.2 Gw). The suspected seismogenic "F-B fault" had been identified in the preconstruction hazard assessments (1970s-vintage), but as "inactive" and only 7 km long (IAEA, 2007). This conclusion followed the beliefs of that time, that active folding was accomplished by aseismic, plastic deformation, and that the underlying blind faults were no longer seismogenic. A later 2003 study used modern tools for detecting active folds and blind thrusts, and a modern understanding of blind faulting and fault-propagation folding, and redefined the fault as "active" and 23 km long, a major change. This paradigm shift is probably the most important change in paleoseismology in the past two decades, but unfortunately occurred long after construction of the NPP. The unanticipated Mw 6.6 earthquake of 2007 caused ground shaking that exceeded the plant's design parameters. Although the lant underwent a safe shutdown and insignificant radioactive materials were released, as of this writing1.5 years later the entire NPP is still shut down, pending a reassessment of seismic hazard. Also subsequent to 1996, numerous active reverse faults in urban areas have been recognized or characterized for first time, using modern methods of investigation as described in this chapter and in Chapter 2A e.g., the Hollywood fault (Dolan et al., 1997) and the Santa Monica fault system (Dolan et al., 2000) in California; the Seattle fault and backthrusts in densely forested Washington State (Nelson et al., 2003; Sherrod et al., 2004). Previously unrecognized, relatively short (<50 km) active reverse faults have been found in areas of low seismicity, such as the Provence region, France (Chardon et al., 2005); the Pyrenees, France (Alasset and Meghraoui, 2005); the Tagus Valley, Portugal (Vilanova and Fonseca, 2004). In general, these "new-found" reverse faults are relatively short, have low Quaternary slip rates, with surface traces obscured by dense vegetation or by cultural smoothing. These hidden faults pose the current greatest challenge for paleoseismology.

Paleoseismological task: case study the Khazar Fault

1. Introduction

The Alborz Mountain accommodates some of the convergence between Central Iran and Eurasia, is characterized by active range-parallel fold and thrust structures. At present, the kinematics of the range involves a strain partitioning mechanism and clockwise rotation of the South Caspian Basin. Range-parallel, left-lateral strikeslip faulting dominates the central part of the mountain range, while reverse faulting affects its northern and southern borders. Several slip-rate studies have been carried out along active faults in the internal and southern parts of the range. However, the characteristics of the main northern bounding fault (the Khazar [Persian: Caspian] Fault) remain poorly known. The recent analysis provides new constraints on the activity of this fault (Nazari et al,2021, 2024). It shown that the fault generally is a hidden thrust fault, often associated with fault-bend and fault-propagation folds (forebergs). In the central part of the fault, the radiocarbon dating of an uplifted terrace allows estimating minimum vertical and average horizontal slip rates of 2.0 ± 0.5 mm/yr and 3 mm/yr respectively. hence, minimum slip rate along the fault reaches to 3.6 mm/yr. About 150 km further east, near the city of Behshahr, within the archeological site of Gohar-Tappe, a paleoseismological trench study on a young detachment fold suggests that at least 5 events occurred in the past 5,300 years, 3 of them with surface-rupturing between 5300- and 3900-years cal BP, our results confirm that the Khazar Fault is a major active structure in northern Iran, and represents a significant seismic hazard for the entire Central Alborz region.

Objective: To determine the slip rate, recurrence time, elapsed time, and conduct a hazard assessment of the Khazar fault in the north flank of the Alborz-Iran, covering both onshore and offshore zones of the south Caspian basin.

The primary goal is to assess the seismic hazard posed by the Khazar fault by determining its slip rate, recurrence time, and elapsed time since the last major earthquake. This will involve both onshore and offshore investigations to provide a comprehensive understanding of the fault's behavior.

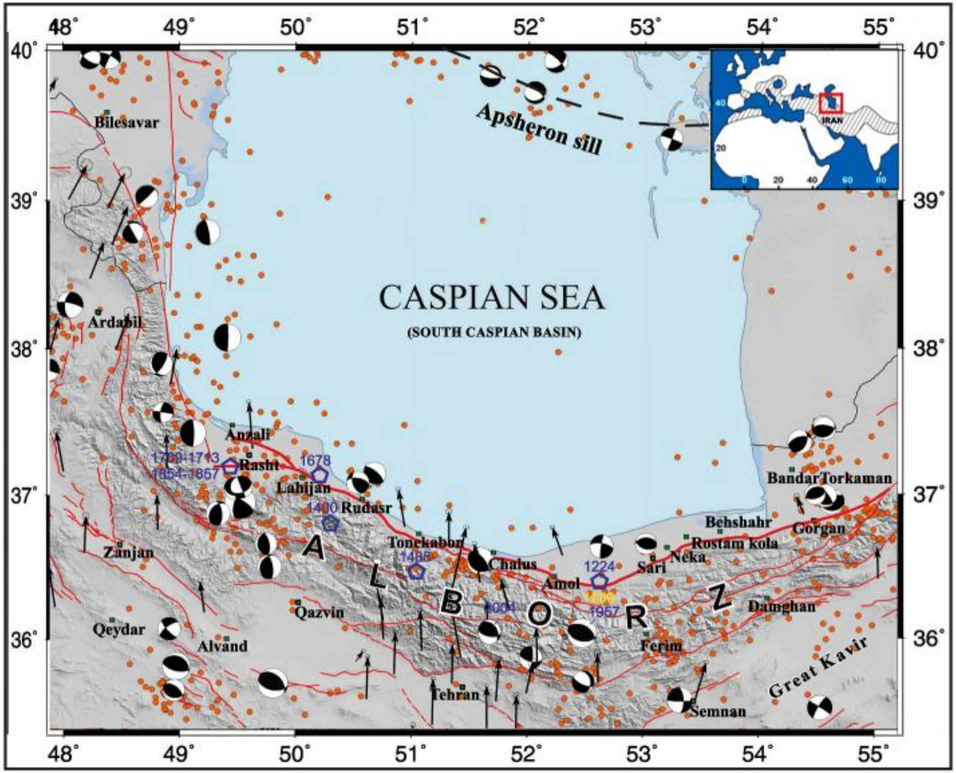
CASPIAN SEA
(SOUTH CASPIAN BASIN)
Apsheron sill
Bilesavar
Ardabil
Anzali
Rasht
Lahijan
Rudasr
Tonekabon
Chalus
Amol
Sari
Neka
Behshahr
Rostam kola
Bandar Torkaman
Gorgan
Damghan
Zanjan
Qazvin
Qeydar
Alvand
Tehran
Ferim
Semnan
Great Kavir
A L B O R Z
1678
1400
1485
1224
1957
IRAN
48° 49° 50° 51° 52° 53° 54° 55°
40° 39° 38° 37° 36°

Figure after Nazari et al.,2021: Seismotectonic sketch map of the South Cas pian region (modified after Talebian et al., 2013). The dashed thin and thick red lines represent inferred minor and major faults. The thick red line defines the Khazar Fault on the northern flank of the Alborz Mountain range. Earthquake focal mechanisms are summarized from Jackson et al. (2002), Tatar et al. (2007), and the global CMT catalog. All instrumentally documented earthquakes in the Alborz are shallower than about 35 km. orange dots show epi centers of earthquakes with Mw > 5 (Engdahl et al., 1998; Engdahl and Villasenor, ˜ 2002). Diamonds with dates represent historical earthquakes that may be associated with the Khazar Fault, after Berberian et al., 1992 and Berberian 1996 (white event AD, yellow event BC). Black arrows are GPS velocity vectors (in mm/yr) relative to Eurasia (http://www. ncc.ir).

2. Methodology

• Field Surveys: Detailed mapping and trenching along the fault, including geodetic precise topographic mapping by DGPS and Drone.
• Onshore: Conduct detailed geological mapping and trenching along the fault trace to identify and sample past earthquake ruptures.
• Offshore: Perform seismic reflection and refraction surveys to map the fault's structure beneath the seabed.
• Sampling: Collection of sediment samples for radiocarbon and Luminescence dating.
Collect sediment samples from trench walls for age determination to establish the timing of past earthquakes.
• Geophysical Surveys: Seismic reflection/ refraction, Ground penetration radar and Magnetotelluric and surveys in onshore and offshore areas.
Use geophysical techniques to image the fault at depth and identify any recent displacements.
• Data Analysis: Use of geomorphic indices and historical earthquake data.
Analyze geomorphic indices (e.g., stream offsets, fault scarps) and historical earthquake records to estimate slip rates and recurrence intervals.

AI can play a significant role in enhancing the efficiency and accuracy of a paleoseismological investigation along the Khazar fault. Here is some ways AI can be integrated into the project:

a. Data Collection and Processing

• Automated Geophysical Data Analysis: AI algorithms can process large volumes of seismic reflection and refraction data more quickly and accurately than manual methods. Machine learning models can identify patterns and anomalies in the data that indicate fault activity.
• Remote Sensing: AI can analyze satellite imagery and LiDAR data to detect surface deformations and fault traces, even in inaccessible areas.

b. Sample Analysis
• Radiocarbon Dating: AI can optimize the calibration of radiocarbon dates, improving the precision of age estimates for sediment samples.
• Sediment Analysis: Machine learning models can classify sediment types and identify microfossils or other indicators of past seismic events.

c. Predictive Modeling
• Slip Rate and Recurrence Interval Estimation: AI can integrate various data sources (e.g., historical earthquake records, geomorphic indices) to model the slip rate and recurrence intervals of the fault.
• Hazard Assessment: AI can simulate different seismic scenarios to assess the potential impact of future earthquakes, helping to develop more accurate hazard maps.

d. Data Integration and Interpretation
• Multidisciplinary Data Integration: AI can combine geological, geophysical, and geochemical data to provide a comprehensive understanding of the fault's behavior.

• Pattern Recognition: AI can identify patterns in the data that may not be apparent through traditional analysis, leading to new insights into fault dynamics.

3. Reporting and Visualization

• Automated Reporting: AI can assist in generating detailed reports by summarizing findings and creating visualizations such as maps and graphs.

• Interactive Dashboards: AI-powered dashboards can provide real-time updates and interactive visualizations of the data, making it easier for stakeholders to understand and use the information.

Integrating AI into your paleoseismological investigation can significantly enhance the project's efficiency, accuracy, and overall impact.

4. Conclusion

• This investigation will provide valuable insights into the seismic activity of the Khazar fault, enhancing our understanding of regional seismic hazards. The results will be crucial for developing effective mitigation strategies and improving earthquake preparedness in the region.

The estimation for coring and age determination in the offshore zone:

Coring in Offshore Zones

• Coring Techniques: Offshore coring typically involves using specialized equipment such as piston corers, gravity corers, and vibrocorers to extract sediment cores from the seabed. These techniques are designed to minimize disturbance and preserve the stratigraphy of the sediments.
• Core Recovery Rates: Core recovery rates can vary depending on the sediment type and coring method. Typical recovery rates range from 50% to 80%
Age Determination
• Radiocarbon Dating: This is the most common method for dating organic material within the sediment cores. It involves measuring the decay of carbon-14 to estimate the age of the samples.
• Optically Stimulated Luminescence (OSL): This technique is used to date the last time sediment grains were exposed to light. It is particularly useful for dating quartz and feldspar grains in the sediment.
• Tephrochronology: This method involves identifying and dating volcanic ash layers within the sediment cores, which can provide precise age markers.

Estimation of Costs and Time
• Coring Operations: The cost of offshore coring operations can vary widely depending on the depth of water, the type of coring equipment used, and the duration of the operation. A rough estimate for a comprehensive offshore coring campaign could range from $100,000 to $300,000.
• Age Determination: The cost of radiocarbon dating typically ranges from $300 to $600 per sample, while OSL dating can cost between $500 and $1,000 per

sample. The total cost will depend on the number of samples analyzed.

• Timeframe: The entire process, from coring to age determination, can take several months. Coring operations might take 1-2 months, followed by laboratory analysis and age determination, which could take an additional 3-6 months.

Integration with AI

• Data Processing: AI can be used to automate the processing of geophysical data and enhance the interpretation of core samples.

• Predictive Modeling: AI algorithms can help predict sediment deposition patterns and identify potential sites for coring.

• Age Calibration: AI can optimize the calibration of radiocarbon dates and improve the accuracy of age models.

Incorporating AI into the coring and age determination process can significantly enhance the efficiency and accuracy of the investigation and potentially reducing both time and costs.

Integration of AI

• Data Processing and Analysis: AI can streamline the processing of geophysical data and enhance the interpretation of core samples.

• Predictive Modeling: AI can help predict sediment deposition patterns and identify potential sites for coring.

• Age Calibration: AI can optimize the calibration of radiocarbon dates and improve the accuracy of age models.

Proposed Trenching Localities Along the Khazar Fault

To create a coherent list of trenching localities for a paleoseismological study along the Khazar Fault in Northern Alborz based on the Nazari et al.,2021 and Rashidi 2021, it's important to consider factors such as the geological significance, historical seismic activity, accessibility, and technical feasibility of the sites. Below is a prioritized list of potential trenching localities derived from the studies:

1. Gollestan Province

a- Gorgan Plain

- Local Name: ** Dasht-e Gorgan**

- **Description**: In the vicinity of the **Golestan National Park**, geomorphological features and reported fault traces make this region a potential site for trenching aimed at better understanding the seismic impacts of the Khazar Fault system. This broad flat area south of **Gorgan** features alluvial and sedimentary deposits that may provide crucial paleoseismic records related to the Khazar Fault activity.

- Priority: High

- Technical Reason: As a lowland area with sedimentary deposits, it may reveal distinct fault movement histories through trenching.

- Possibility: Easier access and fewer environmental constraints for excavation.

- Geological Characteristics:

- Composed of young sedimentary deposits that can capture recent fault activity.

- Evidence of geomorphic features related to faulting (e.g., uplifted terraces).

- Technical Characteristics:

- High accessibility for excavation.

- Low vegetation cover facilitates trenching.

- Geological Context: This region features sedimentary deposits that could provide crucial information regarding active tectonics.

- Rationale: The area's flat terrain and sedimentary record may yield insights into the timing and effects of seismic activity in the region.

b- Gorgan River Valley

- Description: The valley adjacent to the **Gorgan River** exhibits relationships between tectonic activity and sedimentation. Areas with visible faulting and deformation can provide crucial information regarding paleoseismic events.

c. Kordkuy area

- Priority: Moderate to High

- Technical Reason: Historical evidence of seismic events; potential for uncovering active fault traces.

- Possibility: Moderate accessibility, but prior studies may provide existing geological maps and data.

- Geological Characteristics:

  - Situated near the Khazar Fault with abundant evidence of past seismic activity, including fault scarps and deformed sediments.

- Technical Characteristics:

  - Moderate accessibility with some infrastructure in place for logistical support.

  - Topographical features may require careful planning for trench construction.

2. Mazadaran Province

a- Sari area

- **Geological Context**: The proximity to the fault and geological formations indicates a potential for exposed sedimentary layers related to faulting.

- **Rationale**: This site may reveal insights into historical events by providing sedimentary sequences that reflect past surface rupture events.

- Local Name: **Qaleh Jalil**
- Description: This area lies between **Sari** and **Babol**, where evidence of faulting is apparent. It is strategically positioned for trenching due to its well-exposed geological formations related to the Khazar Fault.

- Local Name: **Akhmim**
- Description: Located near **Sari**, this area exhibits active faulting and recent sedimentation. The geological parameters suggest the possibility of uncovering paleoseismic records, especially within alluvial sediments associated with historical earthquakes.

b. Babol area

<u>- River Valley</u>

- Priority: Moderate

- Technical Reason: The river valley may showcase geomorphic and sedimentary records related to faulting.

- Possibility: Some access issues due to the river dynamics, but potential for significant findings.

- Geological Characteristics:

  - Alluvial deposits might reveal historical flooding and fault history, with potential paleo-event markers.

- Technical Characteristics:

  - Site is accessible, but challenges in trench stability due to river dynamics.

  - Requires environmental monitoring during excavation.

<u>- Archaeoseismology in Ghale Bon</u>

Ghale Bon (also spelled **Qaleh Bon** or **Ghalebon**) is a locality in northern Iran where archaeological studies may provide insights into the region's seismic history. Given its proximity to the Khazar Fault, understanding the relationship between archaeology and historical seismic events can be instrumental in evaluating the seismic risk and paleoearthquake activity that may have affected ancient settlements, (Safari et al.,2021).

<u>Key Considerations for Archaeoseismology in Ghale Bon:</u>

1. Historical Background:

- Ghale Bon is known for its rich historical and archaeological significance. The area may contain ancient structures and artifacts that could be used to investigate past human responses to seismic activity.

2. Archaeological Evidence:

- Archaeological sites often reveal layers of construction and destruction, which may correlate with known seismic events. Evidence such as tilting, settlement patterns, and damage types found in archaeological ruins might suggest past earthquakes.

- Ghale Bon may contain remains of ancient structures and layers that could reflect histories of seismic activity, making it a suitable site for such a study.

- The discovery of artifacts, habitation layers, and features such as walls or foundations can help reconstruct past seismic impacts on the community.

3. Geological Context:

- Situated near active fault systems, particularly the Khazar Fault, Ghale Bon's archaeological stratigraphy can be closely examined to identify layers that might reflect significant seismic disturbances over time. Ghale Bon is located near the seismically active Khazar Fault, similar to Gohar Tappe. Its geological and tectonic setting provides a pertinent backdrop for investigating the impacts of seismic events on prehistoric and historic human settlements.

4. Site Selection:

- Areas of interest in Ghale Bon for archaeological investigations could include:

  - **Ruins of ancient structures**: Examining the foundational layers and any signs of structural failures that may indicate past seismic activities.

  - **Sediment layers**: Analyzing sediment deposits associated with past human activity could reveal shifts or deposits linked to seismic events.

  - **Artifact distribution**: Understanding how artifacts are distributed spatially can provide insights into community impacts from historical earthquakes.

5. Interdisciplinary Approach:

- Collaboration between geologists, seismologists, and archaeologists will enhance the understanding of the area's seismic history. Utilizing methods such as stratigraphic analysis, pottery analysis, and geoarchaeological measurements will provide a comprehensive view of the region's archaeological and seismological past.

6. Research Significance:

- Implementing similar archaeoseismological studies in Ghale Bon can significantly contribute to understanding the regional seismic history and its implications for present populations.

- Such studies can also help to inform local communities about seismic risks and preparedness strategies based on historical patterns.

- Discovering evidence of paleoseismic activities in Ghale Bon (such as liquefaction features, displacement markers, or destruction layers in architecture) would support the case for significant historical earthquakes affecting human settlements.

- Identifying the frequency and impact of past seismic events can inform current seismic risk assessments and preparedness strategies for the local population.

7. Methodology Application:

- The methods used in Nazari et al. (2021) involve:

- **Stratigraphic Analysis**: Examining soil layer sequences for deformation features, such as liquefaction, folding, or tilting that indicate seismic disturbances.

- **Archaeological Contextualization**: Assessing how such disturbances impacted human-designed structures and habitation patterns.

- **Chronology**: Establishing a timeline for the layers to correlate seismic events with specific historical or prehistoric periods.

8. Assessment of Past Earthquake Impacts:

- By identifying and evaluating signs of damage or reconstruction in the archaeological record, researchers can infer the frequency, magnitude, and effects of earthquakes on the population and how societies responded to seismic hazards.

Conclusion

Archaeoseismology in Ghale Bon offers valuable opportunities to investigate the interactions between human activity and seismic events in a historically seismic region. By combining archaeological evidence with geological and geophysical studies, researchers can better understand the history of seismicity and its socio-cultural impacts on ancient communities. Applying the approach detailed by Nazari et al. (2021) in Ghale Bon presents a valuable opportunity to investigate how seismic events influenced ancient settlements and their cultural development. The integration of archaeological data with geological insights can lead to deeper understandings of the complex interactions between humans and their tectonic environment.

c. Behshahr area

- Priority: Moderate

- Technical Reason: This area is located along the fault zone, and trenching could offer insights into late Quaternary activity.

- Possibility: Mixed accessibility; careful planning needed for site selection.

- Geological Characteristics:

  - Located along the fault line with evidence of past seismic activities observed in sediment layering.

  - Technical Characteristics:

  - Accessibility is moderate; closer examination required for specific trench locations.

  - Possible logistical support for excavation based on proximity to urban areas.

<u>Summary</u>

In selecting localities for trenching studies along the Khazar Fault, this list prioritizes areas based on geological significance, accessibility, and previous research insights. Each site presents unique advantages and potential challenges that should be addressed in planning the paleoseismological study. This selection emphasizes key geological and technical characteristics crucial for a successful paleoseismological study along the Khazar Fault. Each site has been evaluated on its potential to reveal insights into historical seismic events and the practicality of trenching operations.

- Khalil Shahr Scarp

- Local Name: **Khalil Shahr**

- **Description**: Located northwest of the city of **Sari**, this area is notable for its well-defined fault scarps. It provides an excellent opportunity to investigate active faulting and seismic history. This site features prominent fault scarps clearly associated with historical seismic activity. The well-defined geomorphic features make it an ideal candidate for trenching, as it can provide insights into displacement events.

1. Geological Context:

- The Khalil Shahr scarp is associated with the Khazar Fault, which is characterized by significant geological features indicative of past seismic activity. This site features pronounced fault scarps indicative of recent seismic activity.

- The scarp represents geomorphic evidence of fault movement, which is essential for understanding fault behavior over time.

- Rationale: High potential for uncovering well-preserved paleoseismic records. The erosion and sedimentation processes may reveal a clear history of past earthquakes.

2. Suitability for Paleoseismological Trenching:

- The presence of the scarp suggests that it is an active structural feature with a history of displacement, making it a prime candidate for trenching to investigate past seismic events.

- Trenching in this location could provide critical data regarding the timing, magnitude, and frequency of historical earthquakes along the fault.

- Depending on the specific locations of access and potential stability issues related to the topography, trenching here may be logistically challenging. The Khalil Shahr scarp is likely more suitable due to its clear geomorphic indicators of fault movement, despite possible access challenges.

- Miankale Peninsula

- Local Name: **Miankaleh**

- Description: Situated along the Caspian Sea, this area has geological formations susceptible to coastal sedimentary processes. Trenching here could reveal critical evidence of paleoseismic events. the Miankale Peninsula is influenced by tectonic uplift and marine sedimentation. The interaction of these processes offers an opportunity to study stratigraphic records relevant to past seismic activity.

1. Geological Context:

- The Miankale area is situated near the shoreline and may have a different sedimentological context compared to more inland scarp locations. The proximity to bodies of water could influence sediment deposition and preservation.

- The area has also experienced tectonic forces due to the active Khazar Fault system.

- Rationale: Coastal excavation could help uncover sediment records associated with seismic events, although accessibility and environmental factors would need to be evaluated.

2. Suitability for Paleoseismological Trenching:

- If geological surveys show evidence of fault-related features or sediment accumulation that might reflect past seismicity, the Miankale area could present significant opportunities for trenching.

- Sedimentary sequences potentially offer insights into earthquake-related sedimentary processes (e.g., liquefaction features).

- Challenges associated with trenching in coastal or water-saturated areas may complicate excavation efforts and data recovery.

- Environmental regulations concerning coastal sites may impose restrictions on excavation and sampling.

- **Miankale area**, while potentially informative, would need thorough preliminary assessments of geological conditions and accessibility to determine its overall feasibility for trenching.

d. Chalus River Valley

- Local Name: **Chalus**

- Description: The valley along the **Chalus River** demonstrates evidence of fault-related landforms and sediment deposits that may record historical seismicity. This site is suitable for trenching to investigate the stratigraphic record of surface ruptures.

e. Noshahr Coastline

- Local Name: **Noshahr**

- Description: The coastal area along **Noshahr** is characterized by specific geologic features influenced by both tectonic forces and marine processes. This site has the potential for uncovering seismic evidence in marine-influenced sediment layers.

Conclusion

Each of these sites is carefully selected based on their geological context and proximity to the Khazar Fault, providing an excellent opportunity for paleoseismological trenching. Each of them can yield valuable data to reconstruct the seismic history of the region, and careful consideration of logistical factors will be essential for successful trenching operations.

Both the **Khalil Shahr scarp** and **Miankale area** hold potential for paleoseismological trenching due to their proximity to the seismogenic Khazar Fault and indications of past seismic activities. In summary, trenching at both locations could yield valuable paleoseismic data, but careful consideration of geological and logistical factors is crucial for successful implementation. Fieldwork and site evaluations would be essential to assess accessibility, logistics, and potential yields from excavation activities.

Sub-Aqua Paleoseismology in the Offshore Area of the South Caspian Basin

Conducting sub-aqua paleoseismology in the offshore areas of the South Caspian Basin, similar to the approach used by Nazari et al. (2014) in their study on the probable tsunami caused by a large earthquake, offers promising opportunities to investigate the seismic history and associated geological phenomena of this region. Here’s an overview of the potential for such studies:

Key Considerations for Sub-Aqua Paleoseismology

Many of the largest earthquakes are fundamentally marine events, generated by submarine subduction zone or other plate boundary earthquakes, as well as volcano-tectonic explosions. A large proportion of the world's population lives near coastlines, thus a high proportion of hazard from active tectonics comes from submarine fault systems and volcanic and landslide generators of tsunami. During and shortly after large earthquakes, in the coastal and marine environment, a spectrum of evidence is left behind. Onshore, land levels change with elastic unflexing of the formerly coupled plates, resulting in coastal subsidence, uplift or lateral shift, and the generation of familiar onshore paleoseismic evidence such as fault scarps, colluvial wedges, damaged trees, landslides, and offset features. If the seafloor is shaken or displaced, another suite of events may result in further geologic and geodetic evidence of the event, including turbidity currents, submarine landslides, tsunami (which may be recorded both onshore and offshore), soft-sediment deformation, as well as virtually all of the evidence normally associated with onshore faults, including coseismic and post-seismic displacement. Offshore and lacustrine records offer the potential of good preservation, good spatial coverage, and long temporal span. Marine deposits also offer opportunities for stratigraphic correlation along the source zone, something typically difficult with land paleoseismology.

Stratigraphic correlation methods have potential to address source zone spatial extent, segmentation, and because of the longer time intervals available, can be used to examine recurrence models, fault interactions, clustering and other phenomenon commonly limited by short temporal records. Offshore deposits can be investigated geologically and geophysically to define their extent, stratigraphic relationships, and timing. Detailed investigations of marine deposits at the millimeter scale is now routine, and high-resolution geophysical techniques allow subsurface mapping and correlation with core samples to delineate mass transport deposits and turbidites. In some cases, direct evidence of earthquake slip is available and can be imaged using geophysical techniques. Many deposits, however, do not have a direct physical link to their causative sources and must be distinguished from other deposits through either regional correlation, dating, or sedimentological character. Submarine deposits may include a wide range of features and structures which overlap with those of onshore deposits. This chapter discusses mostly submarine deposits of transported nature and direct fault observations.

1. Geological Context:

- The South Caspian Basin is characterized by active tectonics and has a history of significant seismic activity, making it a crucial area for studying the relationship between earthquakes and submarine geological features.

- Geological features such as fault lines, sedimentary layers, and structures on the seafloor (e.g., turbidites, landslides) can provide crucial evidence of past seismic events, including earthquakes and tsunamis.

2. Methodological Approach:

- **Marine Geophysical Surveys**: Utilization of remote sensing and geophysical survey techniques, such as multibeam sonar mapping, seismic reflection, and sub-bottom profiling, can help identify fault systems and sediment deposition patterns indicative of past seismic activity.

- **Sediment Core Sampling**: Extracting sediment cores (ex: Haghani et al., 2024) from the seabed to analyze stratigraphy, sediment composition, and geomorphological features can reveal historical earthquake signatures, tsunami deposits, and other associated phenomena.

- **Paleotsunami Research**: Investigating sedimentary layers for evidence of tsunami events (e.g., anomalous coarse sediments, shell layers, or bioturbation patterns) can provide insights into both the size and frequency of past tsunamis in relation to significant earthquakes.

3. Tsunami Vulnerability Assessment:

- By examining past tsunami deposits and the relationship between seismic activity and tsunami generation, researchers can construct models of potential future tsunami risks in the Caspian Sea.

- This information is critical for disaster preparedness and risk mitigation in coastal communities that may be affected by such natural disasters.

4. Interdisciplinary Collaboration:

- Collaboration with marine geologists, seismologists, and oceanographers is essential for a comprehensive understanding of the interactions between tectonic activity, sedimentology, and coastal processes.

- Engaging with local authorities and coastal communities can ensure that research findings are integrated into local disaster management plans and policies.

5. Significance of Research Findings:

- Understanding the history and mechanism of large earthquakes and related tsunami events can inform scientists and policymakers about seismic and tsunami risks in the region.

- The findings may also contribute valuable data for global tsunami models, enriching the scientific understanding of similar seismic zones worldwide.

Conclusion

Sub-aqua paleoseismology in the offshore areas of the South Caspian Basin offers valuable opportunities to analyze historical seismic events and their geological impacts, similar to the work done by Nazari et al. (2014). Implementing this research approach will provide critical insights into the seismic and tsunami risk landscape of the region, which is essential for enhancing resilience and preparedness among affected communities.

پارینه لرزه شناسی

تعاریف و اهداف

پارینه لرزه‌شناسی مطالعه زمین‌لرزه‌های پیش از تاریخ به ویژه تعیین جانمایی، زمان و بزرگای آن‌ها است. در حالی‌که کار زمین‌لرزه‌شناسان بررسی اطلاعات ثبت شده دستگاهی در طی زمین-لرزه‌ها است، پارینه‌لرزه‌شناسان شواهد زمین‌شناختی ایجاد شده در طی هر زمین‌لرزه پارینه را تفسیر می‌کنند. پارینه‌لرزه‌شناسی از پژوهش‌های عمومی زمین‌شناسی است که از حرکات آهسته تا سریع پوسته در درازنای سنوزوئیک پسین (برای نمونه، نو زمین‌ساخت) با تمرکز بر دگرشکلی‌های به نسبت آنی سیمای زمین و رسوبات در طی زمین-لرزه‌ها متمرکز می‌باشد. این تمرکز، مطالعه پراکنش پارینه‌لرزه‌شناسی منفرد در وسعت و دوره‌های زمانی هزاران یا ده‌ها هزار سال پیش را ایجاب می‌کند. این گونه تاریخ پارینه‌لرزه‌ای طولانی به ما کمک می‌کند تا بسیاری از ابعاد نو زمین‌ساختی، مانند طرح‌های منطقه‌ای لرزه‌خیزی و دگرشکلی زمین‌ساختی و نیز رفتار لرزه‌زای گسل‌های خاص را درک کنیم. پارینه‌لرزه‌شناسی نیز بخشی از گستره گسترده‌تری از زمین-شناسی زمین‌لرزه است که شامل جنبه‌های پژوهش‌های دستگاهی مدرن زمین‌لرزه‌ها (زمین‌لرزه‌شناسی)، زمین‌ساخت و زمین‌شناسی ساختاری، دگرشکلی سطح تاریخی (زمین‌سنجی) و زمین‌ریخت‌شناسی

چشم‌اندازهای زمین‌ساختی (زمین‌ریخت‌شناسی زمین‌ساختی) می‌باشد. کتاب‌های Yeats et al. (1997)، Burbank & Anderson (2001) و Keller & Pinter (2001) دیدگاه‌های گوناگون در زمینه پارینه‌لرزه‌شناسی را بیان می‌کنند.

دلیل بیشتر پژوهش‌های پارینه‌لرزه‌ای نیاز جامعه به منظور ارزیابی احتمال و شدت زمین‌لرزه‌های آینده است (Reiter, 1995; Gurpinar, 2005). در دهه پس از انتشار ویرایش این کتاب در سال ۱۹۹۶ پس از میلاد (۱۳۷۵ خورشیدی) زمین‌لرزه‌های مرگباری در سال ۱۹۹۹ پس از میلاد (۱۳۷۸ خورشیدی) در ترکیه با ۱۷.۱۸ نفر کشته، در سال ۲۰۰۱ پس از میلاد (۱۳۷۹ خورشیدی) در هند (۲۰.۰۲۳ کشته)، در سال ۲۰۰۳ پس از میلاد (۱۳۸۱ خورشیدی) در ایران (۳۱.۰۰۰ کشته)، در سال ۲۰۰۴ پس از میلاد (۱۳۸۲ خورشیدی) در اندونزی (با ۲۵۰.۰۰۰ کشته بر اثر مه‌موج همراه با زمین‌لرزه)، در سال ۲۰۰۵ پس از میلاد (۱۳۸۳ خورشیدی) در پاکستان (۸۰.۳۶۱ کشته) و در سال ۲۰۰۸ پس از میلاد (۱۳۸۶ خورشیدی) در ایالت سیچوان، چین (۶۹.۰۰۰ کشته بنا به مرکز ملی اطلاعات زمین‌لرزه ایالات متحده) روی داد. زمین‌لرزه ۲۰۰۴ پس از میلاد (۱۳۸۲ خورشیدی) جزایر سوماترا- آندامان در اندونزی، چهارمین زمین‌لرزه مرگبار در تاریخ بشربود که امدادرسانی جهانی نیز پاسخگوی آن نبود. به‌جز رخداد ترکیه، این زمین‌لرزه‌ها بر روی گسل-هایی که تا به حال زمین‌لرزه با گسیختگی سطحی ایجاد نکرده بودند و

یا به وسیله پارینه‌لرزه‌شناس‌ها مورد مطالعه قرار نگرفته بودند روی دادند.

با این حال، حتی در جاهایی که پارینه‌لرزه‌شناس‌ها به خطر پنهان گسل‌ها اشاره داشته‌اند، دولت‌های محلی از آن اطلاعات برای افزایش آگاهی عمومی از خطرات لرزه‌ای و یا کاهش نشانه‌های زمین-لرزه‌های آینده استفاده نکردند (برای نمونه Bilham & Hough, 2006).

پیش از سال ۱۹۸۰ پس از میلاد (۱۳۵۹ خورشیدی)، ارزیابی خطر زمین‌لرزه در کشورهای صنعتی مانند ایالت متحده، ژاپن و اتحاد جماهیر شوروی تنها در پیشینه زمین‌لرزه‌های تاریخی بود. اگرچه بسیاری از زمین‌شناسان (به عنوان نمونه Allen, 1975) گروه پژوهشی گسل‌های فعال ۱۹۸۰ به خطرناک بودن این نگاه اشاره داشته‌اند، نخستین نقشه جنبش نیرومند قابل پیش‌بینی زمین، تنها از داده‌های تاریخی فراهم آمده است. در سده بیست و یکم کشورها با گسل‌های فعال لرزه‌خیز در هر دو تحلیل منطقه‌ای (برای نمونه Stuchi, 2004, http://zonesismiche.mi.ingv.it/ ستاد گسترش پژوهش‌های زمین‌لرزه، 2005، http://www.jishin.go.jp/main/index-e.html؛ Petersen et al. 2008، http://pubs.usgs.gov//of/2008/1128) ساختگاه‌های ویژه و داده‌های پارینه‌لرزه‌ای را در نظر می‌گرفتند (Gurpinar, 2005). در ایالات متحده آمریکا (USA)

پایگاه داده گسل و چین کواترنری ایالات متحده (زمین‌شناسی ایالات متحده، ۲۰۰۶) شامل خلاصه‌ای از داده‌های پارینه‌لرزه‌ای موجود برای بیشتر گسل‌های فعال شناخته شده می‌باشند.

پارینه‌لرزه‌شناسی، پیشینه‌ی تاریخی و دستگاهی لرزه‌خیزی را با توصیف و پیشینه زمین‌لرزه‌های سترگ پیش از تاریخ تکمیل می‌کند. در بسیاری از کشورها مانند ایالت متحده آمریکا، پیشینه‌ی لرزه‌خیزی سودمند فقط به چند سده پیش برمی‌گردد (Gutenberg & Richter, 1958; Stover & Coffman, 1993) و بسیاری از مناطق گسل‌های فعال پیشینه تاریخی از زمین‌لرزه‌های سترگ را ندارند. برای نمونه، پژوهش‌های گسلش پیش از تاریخ در راستای گسل واساچ (یوتا) نشانگر دوره بازگشت میانه زمین‌لرزه‌هایی با بزرگای ۷ است که به احتمال سه برابر بیشتر از دوره ۱۴۵ ساله استقرار تاریخی است (McCalpin & Nishenko, 1996). در اروپا کاتالوگ زمین-لرزه‌های سترگ تاریخی بیشتر با بازرخداد کامل ۴ تا ۵ سده درنظرگرفته می‌شوند؛ برای نمونه کاتالوگ ایتالیایی کامل (Stuchi et al. 2004) برای زمین‌لرزه‌ها با شدت ۸ و بالاتر تا سال ۱۶۰۰ درنظر گرفته شده است. حتی در بخش‌هایی از چین و خاورمیانه، کاتالوگ زمین‌لرزه به هزاران سال پیش برمی‌گردد (Ambraseys and Melville, 1982; Gu et al. 1989)، مشاهدات تاریخی موجود جهت شناسایی تمام گسل‌های لرزه‌زا کافی نیست. بر روی یک گسلی که بطور غیر یکپارچه (نگاره ۱-۱) لغزیده شده است برای صدها هزار

سال، همانند چین حتی یک پیشینه لرزه‌ای ۳۰۰۰ ساله تنها یک گسیختگی کوچک از پیشینه گسل را پوشش می‌دهد. تاریخ لرزه‌ای بیشتر گسل‌های اصلی، تنها از روش‌های پارینه‌لرزه‌شناسی قابل دسترسی هستند.

در بیشتر موارد پیشینه‌ی لرزه‌ای زمین‌لرزه‌های گسترده (بزرگای گشتاوری Mw>6.5) یا سترگ (Mw>7.8) به جهت شواهد زمین‌شناسی زمین‌لرزه‌های کوچک و میانه که به ندرت ایجاد شده و یا نزدیک سطح زمین باقی می‌مانند به سختی قابل رهگیری هستند. شواهد زمین‌لرزه‌های گذشته می‌تواند محدوده‌ای از دگرشکلی محلی سطح زمین در راستای گسل پوسته‌ای و به دور از گسل لرزه‌ای باشد، مانند: (افرازهای گسلی، برکه‌های فرونشستی، دره رودها با انحراف جانبی، پادگانه‌های دریایی تک چین‌خورده، دریاچه‌های به تله افتاده) تا نشانگرهای بالا آمدگی ناگهانی و یا نشست مناطق گسترده بر فراز یک گسل مرز صفحه‌ای (پادگانه‌های رودخانه‌های منحرف شده، خطوط ساحلی بالاآمده یا فرونشسته، باتلاق‌های کشندی غرق شده) تا نشانه‌های چینه‌شناسی یا زمین‌ریختی لرزش‌های نیرومند زمین و یا مه‌موج (زمین‌لغزش، سنگ‌ریزش، ویژگی‌های روانگرایی، نهشته‌های مه‌موج). یکی از مشخصات اکثر موارد فوق این است که بلافاصله (از دیدگاه زمین‌شناسی) در هنگام و یا پس از رخداد زمین‌لرزه تشکیل می‌شوند.

سیماها (نهشته‌ها یا ریختارها) تشکیل شده در هنگام یک زمین-لرزه با عنوان لرزه‌ای توصیف می‌شوند و به طور معمول با ویژگی‌های غیرلرزه‌ای تشکیل شده به وسیله فرآیندهای فرسایش، رسوب‌گذاری و دگرشکلی غیر مرتبط با زمین‌لرزه‌های سترگ مقایسه می‌شوند. به عنوان نمونه گسل لرزه‌زا ممکن است ناشی از خزش درهنگام زمین-لرزه‌ها یا مقدار اندکی لغزش در طی زمین‌لرزه‌های کوچک تا میانه باشد که هیچ نشانه‌ای از لغزش ناگهانی به جای نمی‌گذارد. از این رو واژه‌ی غیر زمین‌ساختی و غیر لرزه‌ای صفتی بهتر از بی‌لرزه (بدون لرزه‌خیزی مشخص) برای ویژگی‌های غیر مرتبط با لغزش گسل یا لرزش زمین‌لرزه‌های سترگ است. اصطلاح بی‌لرزه بایستی به زمین‌لرزه‌شناسی محدود شود.

پارینه‌لرزه‌شناسان تنها می‌توانند زمین‌لرزه‌های مسبب دگرشکلی-های مشخص را مطالعه نمایند (در قالب واحدهای چینه‌ای دگرشکل یافته، ریختارهای جابه‌جا شده، رسوبات تولیدی زمین‌لرزه). Vittori et al, (1991) و بسیاری از نویسندگان موفق اروپایی پیشنهاد کردند که اصطلاح Seismites برای توصیف تمام ساختارهای زمین‌شناسی و رسوبات در پیوند با زمین‌لرزه به کار برده شود. با این حال این کاربرد دو مشکل را مطرح می‌کند: (۱) تعریف اصلی Seismites تنها به واحدهای چینه‌شناسی حاوی ساختارهای رسوبی تولید شده با لرزش اشاره دارد (Seilacher, 1969; AGI, 2007) و (۲) اطمینان قابل توجهی در رابطه با ساختارهای زمین‌شناسی و چینه‌ها با زمین‌لرزه

وجود ندارد (Wheeler, 2002)؛ بنابراین پیشنهاد می‌شود که واژه "Seismites" به تعریف اصلی آن محدود شود.

یکی دیگر از واژگان مبهم و مورد استفاده در پارینه‌لرزه‌شناسی "رویداد" (بدون تغییر استفاده می‌شد) یا "افق رویداد" است. بسیاری از نشریات پارینه‌لرزه‌شناسی بسیار آزادانه از اصطلاح رویداد به عنوان مترادف زمین‌لرزه استفاده می‌کنند. فرسایش، رسوب‌گذاری، دگرشکلی "رویداد"ها تنها برای برداشت زمین‌لرزه‌ها هستند؛ معمولاً مشخص نیست که زمین‌لرزه یا نوع دیگری از "رویداد" مورد بحث است. در نتیجه با واژه "رویداد" برخی از این ابهام جلوگیری می‌کنند (مانند، Scharer et al. 2007). به عنوان نمونه، " رویدادهای شکست" به طور گسترده‌ای در ترانشه‌های گستره گسلی نزدیک کوه یاکا، نودا، در باختر آمریکا ثبت شده است (Keefer et al. 2004) و افزون بر این، از "شکست" تا "رویداد" باتردید در مورد اینکه آیا شکست در پیوند با لغزش مه‌لرزه‌ای بر روی گسل آشکار بوده، لغزش به وسیله جنبش گسل مه‌لرزه‌ای مجاور رها شده، و یا لرزش به سبب تراکم لرزه‌ای، یا غیرلرزه‌ای بوده است، اشاره دارد. Kelsey et al. (2005) در نمونه‌ای همسان، برای جلوگیری از اشاره به مه‌موج برای همه بسترهای شنی غیرعادی در یک توالی ۷۰۰۰ ساله رسوبات دریاچه‌ای در ساحل اورگان، تمامی فرآیندهای رسوب بستر را "رویدادهای آشفته" نامیدند. حتی ممکن است با استفاده گسترده‌ی اصطلاح "افق رویداد" که ترکیبی از ابهام "رویداد" و "افق" است، ابهام بیشتری ایجاد شود،

اصطلاحی که ممکن است به معنای یک سطح پیشین در برخی زمینه‌های پارینه‌لرزه‌شناسی باشد، بستری با ستبرای محدود در دیگری که به راحتی با "افق" خاک که در بسیاری از تفاسیر پارینه‌لرزه‌شناسی وجود دارد اشتباه گرفته می‌شود. در این میان عبارات خاصی که در پارینه‌لرزه‌شناسی، ممکن است به جای "افق رویداد" استفاده شوند عبارتند از: "دگرشیبی" و "ناپیوستگی"که عباراتی هستند که به طور گسترده در زمین‌شناسی برای بیش از یک سده استفاده می‌شوند (AGI, 2007). "افق زمین‌لرزه" (برای نمونه، Scharer et al., 2007) تا زمانی که معنای "افق" روشن است از ابهام جلوگیری می‌کند.

زمین‌لرزه‌های پارینه طبق تعریف پیش از تاریخ هستند، اما آیا "پیش از تاریخ" یعنی زمان پیش از پیشینه شفاهی یا زمان پیش از حکایات نوشته شده معاصر، یا نوشتارهای به جا مانده از مشاهدات اندکی از زمین‌لرزه‌ها؟ بیشتر پارینه‌لرزه‌شناسان در پی تعریف دیگری برای "پیش از تاریخ" هستند. این تعریف جامع، از ابهام زمانی تحول تاریخ شفاهی به تاریخ نوشتاری در سراسر جهان می‌کاهد. برای نمونه، از سال ۱۸۳۱ پیش از میلاد (۱۲۱۰ خورشیدی) در بخش‌هایی از چین (Gu et al. 1989)، از ۵۵۰ پیش از زایش مسیح در مدیترانه خاوری (Ambraseys and White, 1997) و پس از سال ۱۷۰۰ پس از میلاد (۱۰۷۹ خورشیدی) در نیوزیلند و شمال باختر آمریکای شمالی (Stover and Coffman, 1993). باستان‌شناسی کمک بسیاری به

درک درست از تاریخ زمین‌لرزه‌های سترگ در برخی مناطق نموده است (Vita-Finzi, 1986)؛ بسیاری از آنچه که ما از تاریخ لرزه‌ای در خاورمیانه و گستره مدیترانه پیش از دوران مسیح می‌دانیم از پژوهش-های لرزه‌شناسی باستانی آمده است (به عنوان نمونه، Stiros and Jones, 1996؛ فصل ۲ آ را مشاهده کنید). مرز کهن‌تر بازه پژوهش‌های پارینه‌لرزه‌شناسی به طور معمول از میانه (۴-۶ هزار سال که ۴۰۰۰-۶۰۰۰ سال پیش است) تا اوایل (۷-۱۰ هزار سال پیش) هولوسن است، اما پیشینه زمین‌لرزه‌های مشخص، ممکن است تا اواخر پلیستوسن در مناطقی با دوره بازگشت طولانی (Crone et al. 2003; Keefer et al. 2004) یا با شواهد غیر معمول خوب حفظ شده (برای نمونه، Ota et al. 1993; Marco and Agnon, 2005) گسترش یابد.

پارینه‌لرزه‌شناسی شناخت ما را از برخی زمین‌لرزه‌های تاریخی سترگ افزایش می‌دهد. همچنین در مطالعه زمین‌لرزه‌های پیش از تاریخ، همچون پژوهش‌های پارینه‌لرزه‌شناسی تاریخی (Yeats, 1994) بر اندازه‌گیری مقدار یا گسترش جانبی جابه‌جایی سطحی در گسل یا توصیف اندازه و پراکنش ریختارها یا رسوبات تولید شده به وسیله زمین‌لرزه متمرکز است. پارینه‌لرزه‌شناسی تاریخی شامل مطالعه زمین‌لرزه‌های به نسبت جدید (به عنوان نمونه، ۱۸۸۶ پس از میلاد (۱۲۶۸ خورشیدی) چارلستون، جنوب کالیفرنیا، ایالت متحده آمریکا، Obermeier et al. 1990؛ ۱۸۵۷ پس از میلاد (۱۲۳۶

خورشیدی) فورت تِجُن، گسل سن آندریاس ایالت متحده آمریکا: Sieh, 1978a; Harris and Arrowsmith, 2006؛ ۱۸۱۱–۱۸۱۲ پس از میلاد (۱۱۹۰-۱۱۹۱ خورشیدی)، نیومادرید، میسوری: Tuttle et al. 2002، ۱۷۳۹ پس از میلاد (۱۱۱۸ خورشیدی)، یینچوان، چین، Zhang et al. 1986، ۱۷۰۳ پس از میلاد (۱۰۸۲ خورشیدی)، زمین‌لرزه‌های مرکزی ایتالیا: Blumetti, 1995) تا زمین‌لرزه‌هایی که سده‌های پیش روی داشته‌اند ۱۶۳۸ و ۱۷۸۳ پس از میلاد (۱۰۱۷ و ۱۱۶۲ خورشیدی)، کالابریا ایتالیا: Galli and Bosi (2002, 2003)؛ ۱۵۱۰ پس از میلاد (۸۸۹ خورشیدی)، کندایوما، ژاپن: Sangawa (1986)؛ اولین لرزش زمین‌ساختی بیزانس (سری زمین‌لرزه‌های سترگ در طی دوره بیزانس نخستین از میانه سده چهارم تا میانه سده ششم) بین میانه سده چهارم و میانه سده ششم پس از زایش مسیح: Pirazzoli et al. (1996)؛ سال ۳۱ پیش از زایش مسیح، جریکو، اسرائیل: Reches and Hoexter (1981)). پارینه‌لرزه‌شناسی تاریخی حتی برخی از رخدادهای افسانه‌ای، برای نمونه پیش‌گویی دلفی (Piccardi, 2000; de Boer et al. 2001)، فروپاشی تمدن مسینی در یونان کهن (French, 1996) و ویرانی جریکو در خاور میانه در سال ۱۵۵۰ پس از میلاد (۹۲۹ خورشیدی) (Nur, 1991) را روشن می‌سازد (Nazari and Ghorashi, 2021).

References

AGI (2007). Glossary of Geology (online version). American Geological Institute, Washington, DC http://www.agiweb.org/pubs/glossary/).

Allen, C. R. (1975). Geological criteria for evaluating seismicity. Geol. Soc. Am. Bull. 86, 1041–1057.

Ambraseys, N. N., and Melville, C. P. (1982). A History of Persian Earthquakes. Cambridge University Press, New York. Ambraseys, N. N., and Tchalenko, J. S. (1969). The Dasht-e-Bayaz (Iran) earthquake of August 31, 1968: A field report. Bull. Seis. Soc. Am. 59, 1751–1792.

Ambraseys, N., and White, D. (1997). The seismicity of the eastern Mediterranean region 550–1 BC: A reappraisal. J. Earthquake Eng. 1, 603–632.

Berberian, M., Qorashi, M., Jackson, J.A., Priestley, K., Wallace, T., 1992. The Rudbar- Tarom earthquake of 20 June 1990 in NW Persia - Prilimenary field and seismological observation, and its tectonic significance. Bull. Seismol. Soc. Am. 82 (4), 726–1755.

Bilham, R., and Hough, S. (2006). Future earthquakes on the Indian subcontinent: Inevitable hazard, preventable risk. South Asian J. 12, 1–9.

Blumetti, A. M. (1995). Neotectonic investigations and evidence of paleoseismicity in the epicentral area of the January–February 1703, central Italy, earthquakes. In Perspectives in Paleoseismology (L. Serva and D. B. Slemmons, Eds.), Assoc. Eng. Geol. Spec. Publ. 6, pp. 83–100.

Burbank, D. W., and Anderson, R. S. (2001). Tectonic Geomorphology, 274 p. Blackwell Publishing, Oxford, UK.

Crone, A. J., de Martini, P. M., Machette, M. N., Okumura, K., and Prescott, J. R. (2003). Paleoseismicity of two historically quiescent faults in Australia—Implications for fault behaviour in stable continental regions. Bull. Seis. Soc. Am. 93(5), 1913–1934.

Engdahl, E.R., Van der Hilst, R.D., Buland, R.P., 1998. Global teleseismic earthquake relocation with improved travel times and procedures for depth determination. Bull. Seismol. Soc. Am. 88, 772–1743.

Engdahl, E.R., Villase˜nor, A., 2002. Global Seismicity: 1900–1999, in W.H.K. Lee, H. Kanamori, P.C. Jennings, and C. Kisslinger (editors), International Handbook of Earthquake and Engineering Seismology, Part A, Chapter 41, pp. 665–690, Academic Press.

Galli, P., and Bosi, V. (2002). Paleoseismology along the Cittanova fault: Implications for seismotectonics and earthquake recurrence in Calabria (southern Italy). J. Geophys. Res. 107(B3)(doi: 10.1029/2001JB000234).

Galli, P., and Bosi, V. (2003). Catastrophic 1638 earthquakes in Calabria (southern Italy): New insights from paleoseismological investigation. J. Geophys. Res. 108(B1) (doi: 10.1029/2001JB001713).

Gu, G., et al. (1989). (Eds.) Catalogue of Chinese Earthquakes (1831 B.C.–1969 A.D.). Science Press, Beijing, China. 1983 (in Chinese): English version translated by Z. Li, et al., Science Press, Beijing, 1989.

Gurpinar, A. (2005). The importance of paleoseismology in seismic hazard studies for critical facilities. Tectonophys. 408(1–4),23–28.

Haghani, S., Leroy, S., Bjorn Unkel, I., Reyss, JL., Bristow, Ch., Lahijani, H., Naderi Beni, A., Nazari, H., Ensani, MR., (2024). Morphology of the Sefidrud Delta (Southwest Caspian Sea): a tectonically-driven Gilbert delta, UCCGHA 028 pp. 86, ISBN 978-622-8423-22-7.

Harris, R. A., and Arrowsmith, J. R. (2006). Introduction to the special issue on the 2004 Parkfield earthquake and the Parkfield earthquake prediction experiment. Bull. Seis. Soc. Am. 96(4b), S1–S10.

Jackson, J., Priestley, K., Allen, M., Berberian, M., 2002. Active tectonics of the South Caspian Basin. Geophys. J. Int. 148, 214–245.

Keefer, W. R., and Menges, C. M. (2004). Summary of the temporal and spatial relations of Quaternary faulting during the past 100 k.y. at Yucca Mountain: Evidence for distributive surface ruptures on multiple faults. In Quaternary Paleoseismology and Stratigraphy of the Yucca Mountain Area, Nevada (W. R. Keefer, J. W. Whitney, and E. M. Taylor, Eds.), U.S. Geol. Surv. Prof. Pap. 1689, pp. 197–200.

Keller, E. A., and Pinter, N. (2001). Active Tectonics: Earthquakes, Uplift, and Landscape, 2nd edn., 362 p. Prentice-Hall, New York.

Marco, S., and Agnon, A. (2005). High-resolution stratigraphy reveals repeated earthquake faulting in the Masada Fault Zone, Dead Sea Transform. Tectonophys. 208, 101–112.

McCalpin, J. P., and Nishenko, S. P. (1996). Holocene paleoseismicity, temporal clustering, and probabilities of future large (M > 7) earthquakes on the Wasatch fault zone, Utah. J. Geophys. Res. 101(B3), 6233–6253.

McCalpin, J. P., (2009). Paleoseismology, Academic press, pp. 588, ISBN: 978-0-12-481826-2.

Nazari, H., Ritz JF., Burg, JP., Haghipour, N., Shokri, M.,Ensani, MR., Mohammadi Vizheh, M., Avagyan, A., Fazeli Nashli, H., (2025). Geometry, Kinematics and Archaeoseismology of the Khazar Fault System in northern Iran, the South Caspian Sea, UCCGHA 025, pp. 88, ISBN 978-622-8423-19-7.

Nazari, H., Talebian, M., Ghorashi, M., (2023). Young Deformation and Geodynamics of North Central Alborz, Caspian Faults and North Alborz, UCCGHA and Khazeh publishers, No. 004 pp. 24, ISBN 978-622-5858-42-8.

Nazari, H., Talebian, M., Ghorashi, M., (2023). Seismotectonics and Geodynamic of the South Caspian and Adjacent Areas, UCCGHA and Khazeh publishers, No. 001 pp. 20, ISBN 978-622-5858-39-8.

Nazari, H., Ghorashi, M., (2021). Paleoseismology, Elsevier, Hamrah Elm, Avand Danesh, GSI, RIES, 790 p., ISBN: 978-622-627109-7, Translated from Paleoseismology, second edition, J. Mc Calpin 2009.

Nazari, H., Ritz, J-F., Burg, J-B., Shokri, M., Haghipour, N., Mohammadi Vizheh, M., Avagyan, A., Fazeli Nashli, H., Ensani M., (2021b). Active tectonics along the Khazar fault (Alborz, Iran), Journal of Asian Earth Sciences, V. 219, 104893, https://doi.org/10.1016/j.jseaes.2021.104893.

Nazari, H., Ritz, J-F., Avagyan, A., (2021a). Morphotectonics and Slip rate of the Khazar fault in Central Alborz, (North of Iran), Geosciences, Vol. 31, No. 120, pp. 83-92.

Nazari ,H., Ghorashi, M., Kaveh Firouz, A., Ensani, MR., Baharfirozi, Kh., Azizi, A., Lak, R., Karimi Bavandpour, A., Mohamadi Vizheh, M., Soboti, F., Razavi, A., (2014). Probable Tsunami in the south Caspian Sea by a large earthquake! Iranian Journal of Geology, Vol. 8, No. 32, PP. 57-72.

Nur, A. (1991). And the walls came tumbling down. New Sci. 6, 45–48.

Obermeier, S. F., Jacobson, R. B., Smoot, J. P., Weems, R. E., Gohn, G. S., Monroe, J. E., and Powars, D. S. (1990). Earthquakeinduced liquefaction features in the coastal setting of South Carolina and in the fluvial setting of the New Madrid seismic zone. U.S. Geol. Surv. Prof. Pap. 1504, 1–44.

Petersen, M. D., Frankel, A. D., harmsen, S. C., Mueller, C. S., Haller, K. M., Wheeler, R. L., Wesson, R. L., Zeng, Y., Boyd, O. S., Perkins, D. M., Luco, N., Field, E. H., Wills, C. J., and Rukstales, K. S. (2008). Documentation for the 2008 update of the United States National Seismic Hazard Maps. U.S. Geol. Surv. Open File Rep. OF-08–118, 61 p.

Pirazzoli, P. A., Laborel, J., and Stiros, S. C. (1996). Earthquake clustering in the Eastern Mediterranean during historical times: Paleoseismology. J. Geophys. Res. 101(B3), 6083–6097.

Rashidi, A., (2021). Geometric and kinematic characteristics of the Khazar and North Alborz Faults: Links to the structural evolution of the North Alborz-South

Caspian boundary, Northern Iran, JAES, 213-104755, https://doi.org/10.1016/j.jseaes.2021.104755.

Reches, Z., and Hoexter, D. F. (1981). Holocene seismic and tectonic activity in the Dead Sea Rift. Tectonophys. 80, 235–254.

Reiter, L. (1995). Paleoseismology—A user's perspective. In Perspectives in Paleoseismology (L. Serva, and D. B. Slemmons, Eds.), Assoc. Eng. Geol. Spec. Publ. vol. 6, pp. 3–6.

Richter, C. F. (1958). Elementary Seismology, 768 p. W.H. Freeman, San Francisco, CA.

Safari M., Nazari H., Fazeli Neshli H., Rahimi E., Madihi M., Afshari H., Heydari N. (2021). An analysis of environmental evolution in Ghal-e-ben, Mazandaran, Quaternary of Iran, Vol. 7, N0. 3, pp. 936-966, URL: http://journal.iranqua.ir/article-1-524-fa.html.

Sangawa, A. (1986). Fault displacement of the Kondayama Tumulus caused by earthquake. J. Seis. Soc. Jpn. 39(2), 15–24 (in Japanese with English summary and captions).

Scharer, K. M., Weldon, R. J., III., Fumal, T. E., and Biasi, G. P. (2007). Paleoearthquakes on the southern San Andreas fault, Wrightwood, California, 3000 to 1500 B.C.: A new method for evaluating paleoseismic evidence and earthquake horizons. Bull. Seis. Soc. Am. 97, 1054–1093.

Seilacher, A. (1969). Fault-graded beds interpreted as seismites. Sedimentology 13, 155–159.

Sieh, K. E. (1978a). Prehistoric large earthquakes produced by slip on the San Andreas fault at Pallet Creek, California. J. Geophys. Res. 83, 3907–3939.

Stiros, S. C. (1996). Identification of earthquakes from archaeological data: Methodology, criteria, and limitations. In Archaeoseismology (S. C. Stiros, and R. E. Jones, Eds.), Fitch Lab. Occ. Pap. 7, pp. 129–152. British School at Athens and Institute of Geology and Mineral Exploration, Oxbow Books, Oxford, UK.

Stover, C. W., and Coffman, J. L. (1993). Seismicity of the United States, 1568–1989 (revised). U.S. Geol. Surv. Prof. Pap. 1527, 1–418.

Talebian, M., Ghorashi, M., Nazari, H., 2013. Seismotectonic map of the Central Alborz, Scale 1:750000, Geological Survey of Iran, http://ries.ac.ir/eqhazard/wp/Resualts.

Tatar, M., Jackson, J., Hatzfeld, D., Bergman, E., 2007. The 28 May 2004 Baladeh earthquake (Mw 6.2) in the Alborz, Iran: overthrusting the South Caspian Basin margin, partitioning of oblique convergence, and the seismic hazard of Tehran. Geophys. J. Int. 170, 249–261.

Tuttle, M. P., Schweig, E. S., Sims, J. D., Lafferty, R. H., Wolf, L. W., and Haynes, M. L. (2002a). The earthquake potential of the New Madrid seismic zone. Bull. Seis. Soc. Am. 92(6), 2080–2089.

Tuttle, M. P., Dyer-Williams, K., and Barstow, N. L. (2002b). Paleoliquefaction study of the Clarendon-Linden fault system, western New York State. Tectonophys. 353(1–4), 263–286.

Vita-Finzi, C. (1986). Recent Earth Movements—An Introduction to Neotectonics, 226 p. Academic Press, Orlando, FL.

Vittori, E., Labini, S. S., and Serva, L. (1991). Palaeoseismology: Review of the state-of-the-art. Tectonophys. 193, 9–32.

Wheeler, R. L. (2002). Distinguishing seismic from nonseismic soft-sediment features: Criteria from seismic hazard analysis. In Ancient Seismites (F. R. Ettensohn, N. Rast, and C. E. Brett, Eds.), Spec. Pap. 359, pp. 1–12. Geological Society of America, Boulder, CO.

Yeats, R. S. (1994). Historical paleoseismology. In Proceedings of the Workshop on Paleoseismology, 18–22 September 1994, Marshall, CA (C. S. Prentice, D. P. Schwartz, and R. S. Yeats, Conveners), U.S. Geol. Survey Open File Rep. 94-568, pp. 208–210.

Yeats, R. S., Sieh, K. E., and Allen, C. A. (1997). The Geology of Earthquakes, 576 p. Oxford University Press, New York.