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Review Article

The interaction between geomorphology and man: The case of the Fars arc (southern Iran)

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ABSTRACT

To settle in a given area, man has to deal with the surrounding environment and the geomorphological processes that shaped it. Landscape defines the available resources and landscape changes are related to tectonics, hydrography and variations in climate and biota. To cope with environmental limitations, man developed efficient techniques and capabilities to survive, making the best use of natural resources.

The Fars arc (southern Iran) is known for being the cradle of some of the earliest civilizations in Iran. It comprehends the southeastern sector of the Zagros Mountains, a Cenozoic orogen formed after the collision between Arabia and central Iran. The landscape is dominated by a series of folding structures which isolate internal basins. This configuration, together with arid climate conditions, limited biological resources, and the occurrence of natural disasters such as earthquakes, floods, landslides, water salinity, biological/climatic changes and droughts, all dictated the development and pattern of human settlements.

This paper aims to give a broad overview on the deep influence exerted by geomorphological processes, such as tectonics, earthquakes, landslides, sea level fluctuations, and climate changes, on the emergence and development of human settlements in the Fars arc which, with its long-lasting and documented civilization history, represents an ideal test site to study the interaction between nature and man.

1. Introduction

The adoption of sedentary lifestyle models in a settlement, be it a village or a city, is one of the major challenges faced by man since the beginning of civilization. When a new settlement must be developed, the geomorphological configuration (i.e. topography, hydrology, tectonics, etc.) plays a crucial role in deciding the exact location. For this reason, the study of the geomorphologic configuration of a given area, which comprehends different disciplines such as tectonics, fluvial geomorphology, hydrogeology, and climate, is fundamental to fully understand the mutual influence between nature and man. The landscape defines the resources available to man, and landforms changes are linked to tectonics, hydrography and variations in climate and biota (Reynard et al., 2017). In turn, man, in addition to adapting to the environment that surrounds him, has been and is able to radically change the landscape by building dams, canals, roads, etc.

Iran hosts some of the world's oldest civilizations, with human settlements dating back to 7000 BCE (Alizadeh, 2000; Potts et al., 2006; Askari Chaverdi et al., 2008). Here, the aspects related to the geomorphology of the region interacted with settlements and urbanization in three ways: i) the natural morphologies influenced the building and development of settlements and their communication routes; ii) catastrophic phenomena, such as earthquakes and landslides, determined the abandonment of settlements or increased their vulnerability; iii) geomorphology, as well as other components of the natural environment, allowed the development and maintenance of a society through basic necessities.

The spread of ancient civilizations in Iran is mainly due to its unique geomorphological configuration that made the country conductive to agriculture and trade. It is located between three seas: the Caspian to the north, the Persian Gulf to the south, and the Gulf of Oman to the southeast (Fig. 1a). It is bordered by the Alborz Mountains to the north, the Zagros Mountains to the west, southwest and south, consisting of a series of parallel ridges interspersed with plains (Alavi, 2007), the Armenian Highlands to the northwest, a mountainous region of ~400,000 km^2 with an average elevation ranging between 1500 and

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2000 m a.s.l. (Molin et al., 2023), the Kopet Dagh range to the north-east, and the rugged mountains of Afghanistan further to the east (Fig. 1a). The inner sector of Iran consists of several closed basins lying ~1 km a.s.l. which compose the Central Plateau. The eastern part of the plateau is covered by two salt deserts: Dasht-e Kavir and Dasht-e Lut (Fig. 1a).

In particular, the Zagros Mountains constitute a ~ 2000 km-long SW-verging orogen, extending from eastern Turkey to the Makran area (Fig. 1a), produced by the Cenozoic collision between Arabia and central Iran after the northward subduction of the Neotethys ocean (Ballato

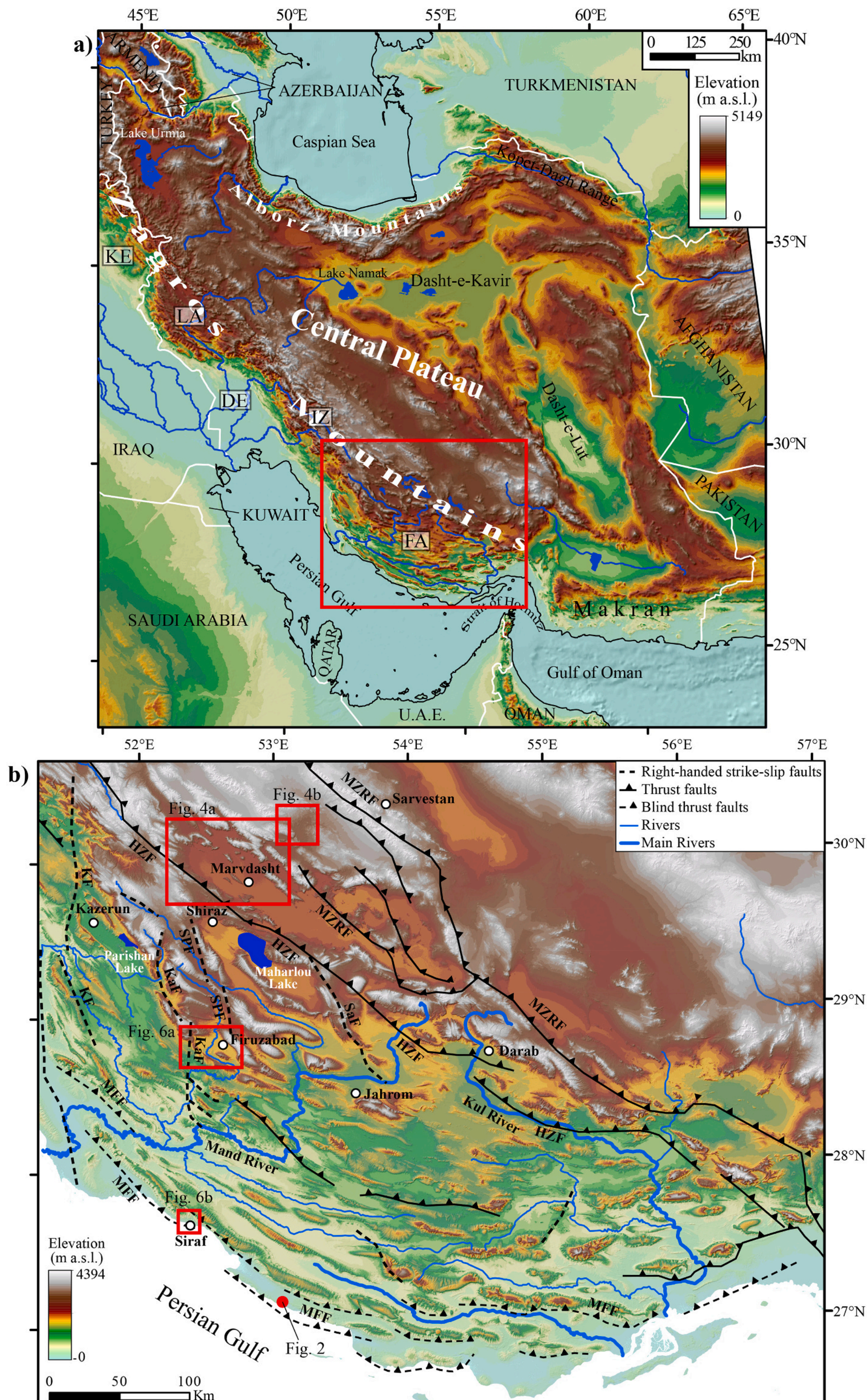

Fig. 1. a) Topography of Iran (ETOPO1 DEM with a resolution of ~460 m; www.ngdc.noaa.gov). The solid black lines indicate coastlines; national borders are in white. In blue the major rivers and lakes. The red rectangle indicates the location of Fig. 1b; b) topography of the Fars arc (SRTM DEM with a resolution of ~90 m; https://srtm.csi.cgiar.org/srtmdata). KE = Kirkuk embayment; LA = Lorestan arc; DE = Dezful embayment; IZ = Izeh zone; FA = Fars arc; MZRF = Main Zagros Reverse Fault; HZF = High Zagros Fault; KF = Kazerun Fault; KaF = Kareh Bas Fault; SPF = Sabz Pushan Fault; MFF = Mountain Front Fault. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

et al., 2011; Bigi et al., 2018; Sarkarinejad and Goftari, 2019; Karasözen et al., 2019). Recent seismicity (Nissen et al., 2011; Sarkarinejad et al., 2017; Karasözen et al., 2019) and GPS data (Sella et al., 2002; Vernant et al., 2004) indicate that the N—S to NNE trending convergence is still ongoing with a velocity of 23–35 mm yr^{-1}. Differences in sedimentary successions, amount of shortening, and structural styles allow to divide the Zagros orogen into five provinces (from NW to SE): Kirkuk embayment, Lorestan arc, Dezful embayment, Izeh zone, and Fars arc (Bigi et al., 2018 and references therein; Fig. 1a).

This study focused on the Fars arc (southeastern portion of the Zagros Mts.) from the area immediately north of the Marvdasht plain to the coast of the Persian Gulf (Fig. 1a, b). It represents the largest tectonic domain of the Zagros orogen, with ~280 km of width and ~65 km of total shortening (Najafi et al., 2020). The landscape is characterized by regular NW-trending concentric anticlines (convex-up plicative structures with older lithologies located at its core) and synclines (concave-up plicative structures with younger lithologies located at its core) folds with homogenous wavelengths of ~15 km (Fig. 1b), composed of 10–12-km-thick pile of Phanerozoic sedimentary cover (Mouthereau et al., 2006). The oldest member of the sedimentary succession is the late Precambrian evaporite of the Hormuz formation (McQuarrie, 2004; Sherkati et al., 2006; Alavi, 2007; Mouthereau et al., 2007; Oveisi et al.,

Fig. 2. View of the middle sector of the Iranian shore of the Persian Gulf coast south of Nayband cape (a) and in proximity of the Apostana port (b) (see the exact location in Fig. 1b). Note the stratification of the lithologies composing the ridges in both localities. The presence of these ridges severely limits the extent of coastal plains (photos by Alireza Askari Chaverdi).

2009; Yamato et al., 2011; Najafi et al., 2014, 2020; Gürbüz and Saein, 2018). Other evaporitic rocks of Permian, Triassic, Jurassic, Eocene, and Miocene age characterize the upper levels of the package (Berberian, 1981). These deposits act as detachment levels driving the SW sliding of the sedimentary rocks (limestones, marls, sandstones, and conglomerates) of the Arabian plate over the basement of the same plate (e.g. Yeats, 2012). In the Fars arc this process, named detachment folding, is considered as the main mechanism for the formation of the concentric folds (Mouthereau et al., 2006; Farzipour-Saein et al., 2013; Najafi et al., 2020). Well-established is also the contribution of inherited basement reverse faults in the folding process such as the Mountain Front Fault, the High Zagros Fault, and the Main Zagros Reverse Fault (Jackson and Fitch, 1981; Berberian, 1995; Talebian and Jackson, 2004; Mouthereau et al., 2006, 2007; Homke et al., 2010; Leturmy et al., 2010; Teknik and Ghods, 2017; Najafi et al., 2018; Karasözen et al., 2019; Fig. 1b).

The drainage system configuration of this portion of the Zagros orogen is influenced by the feedback between active tectonics and climate (Ramsey et al., 2008; Obaid and Allen, 2019) and presents a typical trellis pattern with rivers that follow synclines and, at places, cut into anticlines (Fig. 1b).

Climate is characterized by arid to semi-arid conditions with a strong spatial variation in mean annual temperature and precipitation from north to south. The mean annual temperature is ~10 °C, with the highest values in the southern region, while the long-term mean annual precipitation changes from ~200 mm in the south to >1000 mm in the northwest (Abolverdi et al., 2016). Most of the rainfall events consists of flash floods that cause the deposition of large amounts of material at the foot of the mountain fronts in the form of voluminous alluvial fans. These climatic conditions make most of the water courses ephemeral. In addition, the presence of salt domes all over the region makes most the springs and rivers salty (Raeisi and Stevanovic, 2010; Zarei and Raeisi, 2010; Raeisi et al., 2013; Abirifard et al., 2017). In Fars, two main climatic zones can be recognized (Najafi and Alizadeh, 2023): 1) the mountainous area in the north and northwest, characterized by cool and sub-humid climate with moderate cold winters and mild summers (*sardsīr*); 2) the central-southern portions, marked by warm and arid conditions with cold winters and very hot summers (*garmsīr*).

The coastal sector of the Fars arc is composed of steep ridges rising from the Persian Gulf and isolating coastal plains. These plains result very narrow for most of their length and widen only in limited areas (Figs. 1b, 2a, b). Relative sea level fluctuations and coastal uplift continuously modified the coastal morphology, influencing particularly the depositional dynamics of fan deltas (Vita-Finzi, 1979, 1980; Reyss et al., 1999; Pirazzoli et al., 2004; Oveisi et al., 2009; Wood et al., 2012; Lokier et al., 2015; Pourkerman et al., 2020).

Despite the environmental limitations, the most important dynasties of ancient Iran such as the Achaemenid (550–330 BCE) and Sasanian (224–651 CE) ones developed in this region. Exploitation of limited biological resources and the occurrence of natural disasters such as earthquakes, floods, landslides, soil and water salinity, biological/climatic changes, and droughts contributed to the development of techniques and skills useful for adapting and, in some cases, modifying the environment (Rigot et al., 2022). Thanks to these increasingly efficient adaptive capacities, many settlements developed throughout the region concentrating in piedmonts areas, alluvial plains and valleys where both adequate natural resources and arable lands were available (Askari Chaverdi et al., 2008; Petrie, 2013; Potts, 2016).

This paper describes the influence exerted by geomorphological processes, such as tectonics, earthquakes, landslides, sea level changes, and climate changes, on the development of human settlements in the Fars arc. The region, with its long-lasting civilization history, represents an ideal test area to investigate the mutual interaction between nature and man.

2. Settlement patterns in ancient Iran

An important obstacle in reconstructing the ancient settlements pattern throughout Iran is the scarcity of reliable information on the historical inhabited settlements and their toponyms. A fortunate interlude has been offered by the Persepolis Fortification and Treasury Texts of the Elamite-language administration of Achaemenid Persepolis. These documents abound in toponyms to the extent that Sumner (1986) was able to hypothesize on the hierarchy of these settlements based on their frequencies on the Elamite tablets. In addition, Greek texts from the classical tradition reaching back to imperial Rome, provide several names of cities of that time.

The ancient concept of "city", particularly during the Achaemenid period, has to be modified as compared to the common perception of Mesopotamian and Syro-Palestinian urban settlements, given a remarkable tendency to avoid compact housed blocks and to leave vast green areas within the settlement, according to a "diffuse" urban pattern (Gondet, 2018). For this reason, we prefer to speak of "inhabited settlements".

It is interesting to recall that the bipartition of the Fars territories in the late Achaemenid period (i.e., the time of the conquest by Alexander) in 1) "a region of small agricultural valleys with an archaic type of structure organized in small political units" which did not resist Alexander, and 2) "the mountain regions with a largely pastoral population, apparently independent, but in reality linked to the monarchy by exchange relations" (Leriche, 1977), coincides exactly with the system of anticlines and synclines that characterizes the geomorphological configuration of the region.

The only contribution specifically dedicated to Fars in the Hellenistic period (Callieri, 2007) emphasizes how, in the few settlements studied using archaeological methodology, continuity in settlement life prevailed rather than rupture. This is probably due to the solidity of the economic system established by the Achaemenid dynasty, which passed on to the subsequent Macedonian dynasties without any apparent crisis. Archaeology confirms historian P. Briant's answer to the question "did the destruction of the palaces lead to the destruction of the whole system?" (Briant, 1982): the whole of the documentation "suggests the maintenance (total or partial) of the social and economic organization in Fars during Alexander's lifetime" (Briant, 1982). This situation seems to have lasted until the time of the great territorial expansion of the Arsacid dynasty on the Iranian plateau (the expedition of Mithridates I), as suggested by the events that followed the conquest of the Seleucid capital of Seleucia, on the Tigris, in 141 BCE To avoid the disruption of the Seleucid virtuous management of the Mesopotamian economy, the new masters of the empire did not take possession of the city, but preserved its autonomous status that came to an end only in the 2nd century A.D.

The other important source on the Fars settlements in the Roman imperial age is the Claudius Ptolemy's geographical work. This work presented considerable difficulties that hindered its use due to serious doubts about the reliability of the text contents. However, Callieri (2007) showed that, if the causes of the divergences between the Ptolemy's map and the present configuration are identified, the picture is fully reliable and of great interest.

Ptolemy's chapter on Persia begins with a description of the Fars coast on the Persian Gulf (*Persikòs kòlpos*) and then proceeds with a geographical progression from inland to the coast providing the geographical coordinates of 30 cities roughly mentioned from west to east. Without entering into the complex question of verifying their identifications proposed in the past (see Tomaschek, 1883 for further information), it is instead useful for the present study to highlight some observations of topographical nature. Placing the cities mentioned by Ptolemy in the grid of his coordinates, it is possible to note that all of them are distributed along axes parallel to the coastline and gradually distanced towards the interior (Fig. 3). The location of the settlements along parallel lines between the Zagros mountain range and the coast of

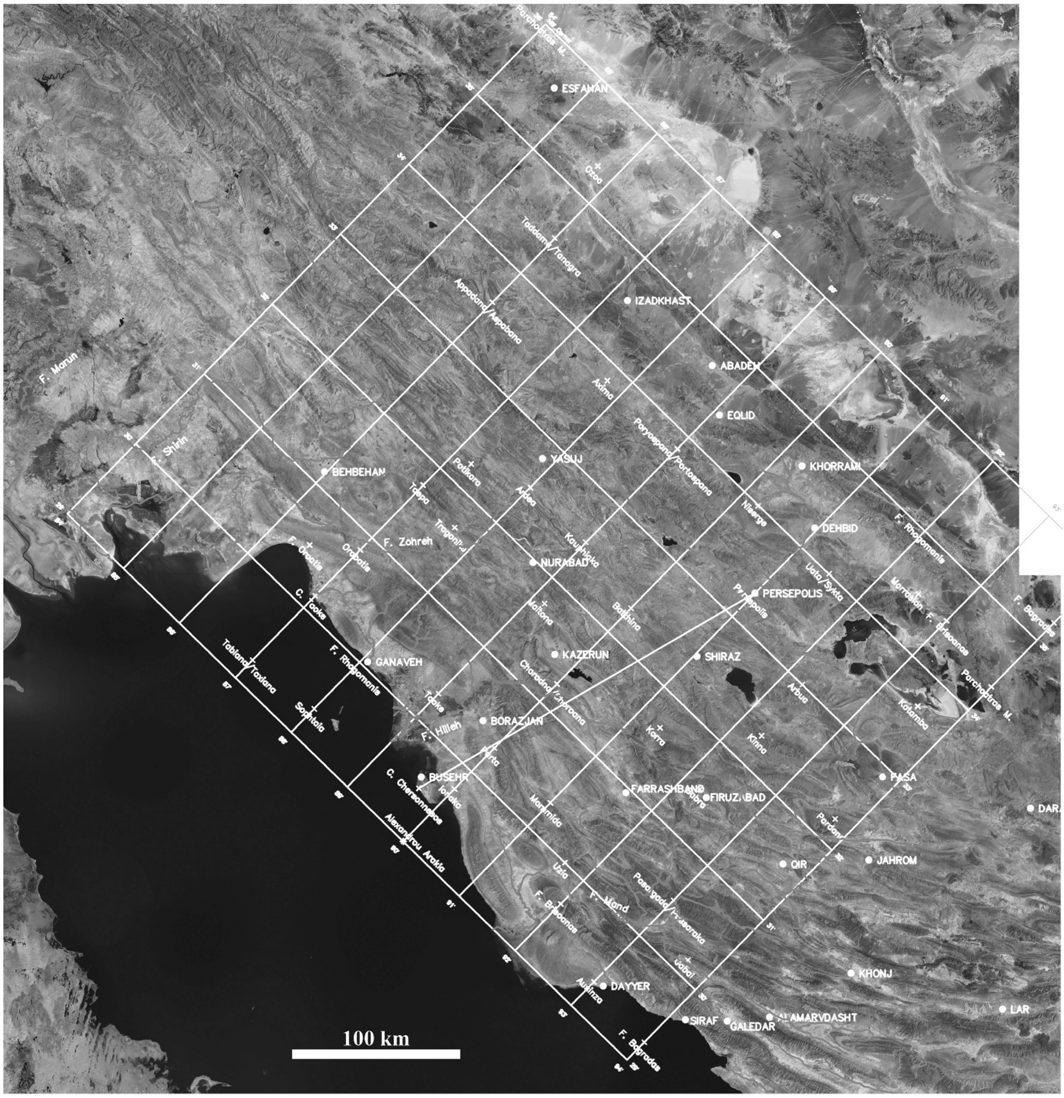

Fig. 3. Landsat image of Fars on which the Ptolemy map is superimposed not using his coordinates, but matching his coastline with that of the satellite image (after Callieri, 2007).

the Persian Gulf is dictated by the topographic configuration of the Fars, consisting of a series of NW-SE-trending long valleys parallel to the coast, with altitudes gradually decreasing towards the coast.

It is in these valleys that we find the waterways that allow agricultural exploitation by various irrigation systems, including the traditional *qanat* systems (see paragraph 3.2). We would expect to find the greatest concentration of settlements in these valleys compared to other areas more suited to pastoral life (see the bipartition of the Fars territories mentioned above) where nomadism or semi-nomadism was the main mode of occupation (Sumner, 1986). The location of settlements reported by Ptolemy therefore corresponds to a real situation. However, an error in the orientation of the parallel curves is evident from the Zagros range (*Parchoatras*) to the Persian Gulf coast. This is undoubtedly linked to the fact that the geographer transposed distances calculated in *stadia* or in *schenoi* or parasangs into degrees of latitude and longitude based on travel routes or sailors' journeys (cf. Pagani, 1990; Rapin, 1998). As Rapin (1998) acutely proposed for Ptolemy's map of Central Asia, it is sufficient to orient the map in Ptolemy's text not along the axes of the geographical coordinates indicated but by superimposing its coastline on the actual coastline, to verify the coherence of the location of the different valleys. The result is surprisingly consistent (Fig. 3). When examining Ptolemy' text one must bear in mind the self-imposed limitations of the geographer, who was content to mention only the most important cities (Ptol.,Geogr.,I·I; Pagani, 1990). To verify the extent to which Ptolemy's text focuses on the examination of "cities and villages" (*poleis kai komai*) in relation to the actual density of settlement, it is useful to compare Ptolemy's text with that of Isidore of Characene which traveled through the Parthian territories in the 1st century B.C. Isodore's text describes various types of occupation: the "village" (*komè*), where there is "a stopping place" (*stathmos*), the "small town" (*komopolis*), the "city" (*polis*) and finally, the "Greek city" (*polis ellenis*). According to Strabo, quoting Apollodorus of Artemita, the last term means "founded by the Macedonians". As *polis hellenis*, Isidore also mentions Artemita in the region of Apolloniatis, which the author says is now called "Chalasar", while "*metropolis*" is applied to Ectabana of Media. Looking at the distribution of the stages along its route, we find that 24 to 28 km separate the stations in Rhaga Media and Choarene, up to 49 km in Comisene, with an average of about 35 km. The length of the distance unit, cited as *schenos*, which according to Strabo was equivalent to 40 *stadia* or a Persian parasangs, corresponds to an hour walk by a caravan. We can deduce that the average distance between the most important settlements is about five to six hours walk. It is this same distance expressed in parasangs (*farsakh*) that Sumner indicated as the average distance traveled by the caravans (Sumner, 1986; Graf, 1994). In

Ptolemy, the distances between the cities mentioned are between 40 and 80 km: the lower distance corresponds roughly to the 5–6 h walk recalled above, the greater distance is double that and probably indicates the existence of a minor, unmentioned station halfway along the route. It seems therefore possible that also for Ptolemy, two centuries after Isidore, the source was a merchant's itinerary (Callieri, 2007).

With this scale, the location of the settlements in suitable biological conditions can be measured, but the amount and distribution of environment resources can change from one valley to another along the Zagros range. For example, in the Fars region, favorable living conditions (i.e., the amount of water and suitable biological resources) are different in the plains of Marvdasht in the north of Fars (Sumner, 1990), in Firuzabad in the center (Callieri, 2021), or in the plains of Lamard and Alamrvdasht near the sea (Askari Chaverdi and Azarnoush, 2004).

3. The importance of water

The Zagros Mts. represent a special hydrogeological province for two reasons: the location and the geological formations. Indeed, the belt is situated to the west of the country, forming a barrier to the west rainy winds, and is characterized by the presence of thousands of meters of calcareous aquiferous rocks of different ages. According to Issar (1969), there are three main aquifers: the carbonates, the Mio-Pliocene conglomerates, and the Pleistocene alluvial fill.

The most important water resources were and are karstic aquifers, characterized by hundreds of springs and big volumes of groundwater, which provide the base flow of the rivers (Karimi et al., 2005; Raeisi and Stevanovic, 2010). The quality of karst springs is related mainly to the lithology of the water route inside the karst aquifer (Raeisi and Stevanovic, 2010). In the case of marls or marly limestones, the water type changes from bicarbonate to bicarbonate sulfate or bicarbonate chloride. Gypsum and anhydrite make the water type mainly sulfate. Intrusion of saline water into karst aquifers is the main source of chloride-type waters (Raeisi and Stevanovic, 2010). In some places, the rivers flowing on a salt diapir or over a terrain covered by gypsiferous clays turn saline drastically decreasing the quality of water (Issar, 1969; Zarei and Raeisi, 2010; Raeisi et al., 2013; Abirifard et al., 2017).

As a result of the general scarcity of water, the density and size of Iran's settlements have always followed the density and size of water resources (Askari Chaverdi et al., 2008; Petrie, 2013; Potts, 2016). Since 5000 years B.C., Iranians adopted different strategies to make maximum use of available surface and deep waters, while also coping with variable weather conditions and sociopolitical issues (Rigot et al., 2022).

Despite the topographic benefits, building settlements on floodplains had significant disadvantages such as shrinking and disappearing water bodies in consequence of drought and flood events, landscape degradation, avulsion of river courses, and the presence of wetlands. For these reasons, most of the early settlements were intermittently occupied (Saatsaz and Rezaei, 2023).

Archaeological evidences report the occurrence of several flood events starting from the fourth millennium B.C. Examples are the sites of Mafin Abad Islamshahr, Meymanat Abad Robat Karim and Qara Tepe of Qomroud in North-Central Iran, as well as the sites of Shuruppak, Kish and Ur in Iraq (Angelakis et al., 2023 and references therein). In particular, the flood of the Tigris and Euphrates rivers in 628 CE, was probably one of the reasons for the fall of the Sasanian dynasty (Blazeri, 1958). Melville (1984) lists 87 disastrous floods that struck Iran from 937 to 1950 CE. Of these 11 affected Fars or surrounding areas. However, more recent events should be added including the 2019 and 2022 ones. Generally, these events are related to the cyclonic rains of late autumn and winter which drive more convectional rainfall in spring and occasionally in summer when violent thunderstorms of brief duration occur (Melville, 1984). Because of the arid nature of the region and the lack of vegetation cover, these storms frequently dissipated into damaging flash floods. Climate changes and the intensification of the North Atlantic Oscillation (Hurrel, 2003) deeply influenced the rainfall regime as well as the flow rate of the major perennial rivers (i.e., Tigris and Euphrates; Kay and Johnson, 1981), as confirmed by data from the Katlekhor cave (Andrews et al., 2020), Gorgan Plain (Shumilovskikh et al., 2016), Lake Hamun (Hamzeh et al., 2017), and Lake Mirabad (Stevens et al., 2006). This drove an increase in number and severity of drought and flood events as it was seen from the 1970s by precipitation observations and river discharge records (Madani, 2014; Modarres et al., 2018; Ghamghami and Irannejad, 2019; Vaghefi et al., 2019; Hedayati-Dezfuli and Fazel-Rastgar, 2020). Climate changes force also variation in land-use. An example is the change from arid to temperate and humid conditions between 6200 and 4300 BCE In this period the number of settlements increased, and a strong deforestation occurred (Nemati et al., 2020). Floods were the consequence of both increased rainfall and deforestation as confirmed also by sedimentological and archaeological investigation in Tape Pardis (Gillmore et al., 2009) and in several other sites in Central and Western Iran (e.g., Tape Zagheh, Sialk, Chogh Bount, Ganj Dareh, Cheshmeh Ali; Saatsaz and Rezaei, 2023).

The first settlements based their inhabitants' survival on irrigated agriculture and developed around surface water resources. However, archaeological studies all around Iran (Sumner, 1986, 1990; Askari Chaverdi and Azarnoush, 2004; Askari Chaverdi et al., 2008; Gillmore et al., 2007, 2009, 2011; Schmidt et al., 2011; Callieri, 2021) evidence that settlement patterns varied locally according to environmental factors and, most importantly, to climate. Indeed, fluctuations in the abandonment of sites, the emergence of new sites and increases or decreases of population were regularly repeated on the Tehran, Qazvin, Kashan, and Marvdasht plains between 6500 and 3000 B.P. (Sumner, 1986; Marghussian et al., 2021). On the contrary, long-lived settlements are or were associated with permanent water sources (Marghussian et al., 2021). A major problem was the absence of a central government that could solve water problems. Things improved during the Achaemenid and Sasanian empires and later in the Islamic age. All the various ethnic groups in Iranian territory were united and efficient water resources policies were developed. In particular, dams (such as "Ramjerd" Dam, "Darius Dam", "Bande-Sang Dokhtaran", "Sad-e Alafi 1 Dam", "Sad-e Alafi 2 Dam", "Sad-e Tang-e Saadatshahr Dam", "Sad-e Shahidabad Dam", and "Sad-i Didegan Dam", "Gompu Dam" in the Fars province; Mays, 2010; De Schacht et al., 2012; Ertsen and De Schacht, 2013; Karami and Talebiyan, 2015), canals, dykes, embankments, and levees were built, greatly increasing the productivity of the land and the flood regulation. Hydraulic works were realized from the foothills all around the plains where the peculiar hydrogeological configuration allows for the formation of springs (Ashjari and Raeisi, 2006).

For example, the Marvdasht plain (northern Fars) lies between the temperate inter-mountain valleys abundantly drained by the Polvar River and characterized by lakes (Fig. 4a). Here, the Persepolis complex was erected on a rectangular platform higher than the plain, at the foot of the Rahmat Mountain (Fig. 4a). For this reason, it was necessary to construct a small dam and build a network of canals to transfer water from the Polvar River and local springs to the complex and surrounding areas (Mays, 2010; Fig. 4a, c). Moreover, two large dams were built along the Polvar River both to prevent flooding and to conserve water for agriculture. The dimensions of the hydraulic infrastructures were ~ 230 m in length and at least 8 m in height. Finally, to further protect the site, the runoff in the Rahmat Mountain was conveyed towards a deep reservoir basin and a 180 m long conduit was realized west of the site to drive the excess water away from the complex (Moradi-Jalal et al., 2010).

In the Pasargadae plain, located immediately north of the Marvdasht basin, a dense network of modern and Achaemenid-period canals and qanats captures water from the Polvar River and several nearby springs and distributes it to the settlements on the plain (Chambrade et al., 2020; Rigot et al., 2022). In addition, in the adjacent Tang-e Bolaghi Valley, the Iranian-French mission has put forward a new and well-grounded interpretation as canals of what according to previous scholars were stretches of roads (Rigot et al., 2022; Figs. 4b, d and 5a, b).

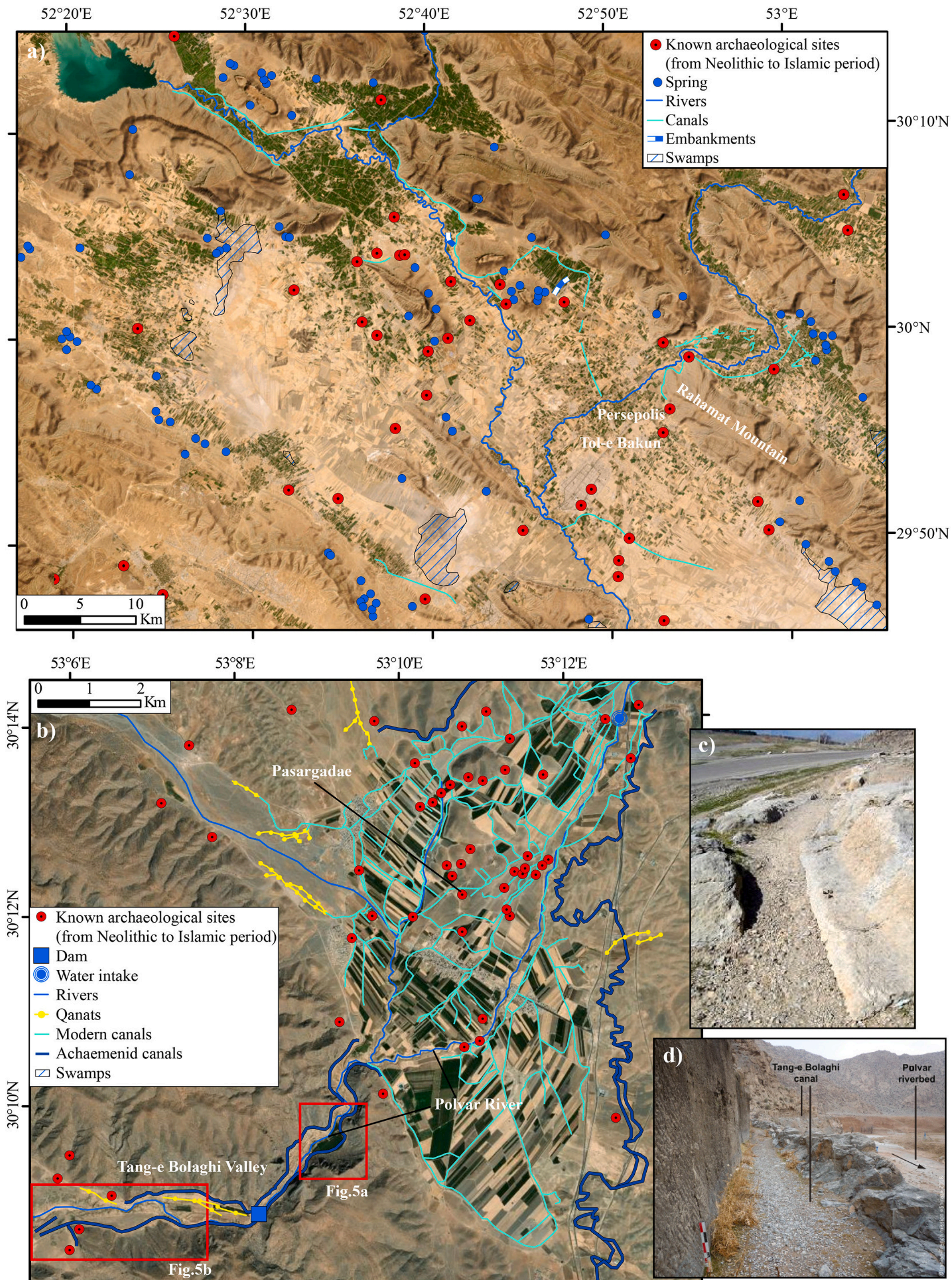

Fig. 4. a) Map of the Achaemenid hydrological traces in the Marvdasht plain according to Boucharlat et al. (2012). The location of ancient settlements is based on Gondet (2011). b) Achaemenid and recent hydraulic structures in the southern part of the Pasargadae plain mapped with the known archaeological sites (after Rigot et al., 2022). c) and d) represent Achaemenid canals dug into rock in the Marvdasht plain (from Moradi-Jalal et al., 2010) and the Tang-e Bolaghi Valley (from Rigot et al., 2022) respectively. The location of both figures is indicated in Fig. 1b. The base map in a) and b) are from Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

These canals, dug mostly in the rock at the foot of the slopes, were used to transfer water from the Pasargadae plain to the southwestern sector (Figs. 4b, 5b). Moreover, a few kilometers from the entrance of the Tang-e Bolaghi Valley, a dam built in the Islamic period, was connected to short networks of underground aqueducts and open-air canals (Rigot et al., 2022; Fig. 4b).

Another example comes from the Firuzabad plain (central Fars), at the border between *sardsīr* and *garmsīr* (Huff, 2008). The geomorphologic configuration of the area experienced important modifications because of anthropogenic activity since the reign of the Sasanian dynasty (Huff, 2008). Indeed, the plain was occupied by a swamp or a wide lake which was drained through canals and aqueducts by the king Ardashir I to build the new city of Ardašīr-Khwarrah (Huff, 2008; Rashidian and Djamali, 2023). In addition, a dense network of Sasanian

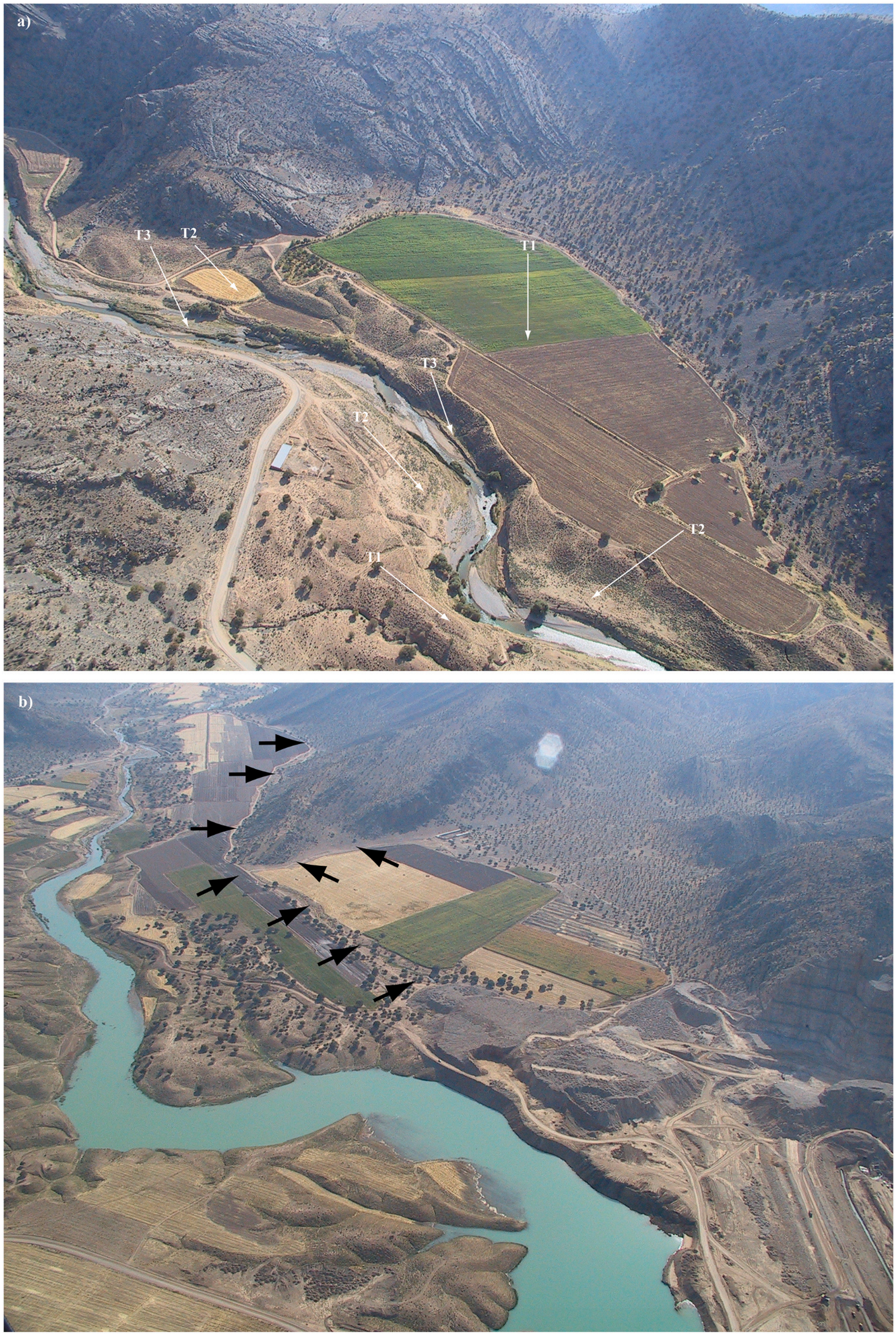

Fig. 5. a) Photo of Tang-e Bolaghi Valley immediately to the south of the Pasargadae plain. The three levels of fluvial terrace reported in Rigot et al. (2022) have been evidenced by white arrows (T1, T2, T3); b) Water system in Tang-e Bolaghi Valley over river terraces consisting in canals (see Fig. 4d). Black arrows indicate the paths of canals at the left bank of the Polvar River. The location of both photos is represented in Fig. 4b (photos by Alireza Askari Chaverdi).

and modern *qanats* and open canals provides water to the entire plain by drawing from the perennial Firuzabad River and the springs (Karimi et al., 2005; Huff, 2008; Raeisi and Stevanovic, 2010; Fig. 6a, b).

Along the Iranian coast of the Persian Gulf, hot arid climate and rough topography forced man to find more efficient solutions to supply drinkable water. At Siraf, for example, the technique was adapted to the geomorphology of the site characterized by the sea to the south and the hills to the north (Fig. 6c). The typical *qanat* wells, usually dug into alluvial sediments (see paragraph 3.2), here were dug into bedrock (sandstones) and interconnected by underground tunnels and/or permeable layers (Whitehouse et al., 2009). In addition, to alleviate flood damage and, at the same time, to preserve rainwater for dry periods, man deeply modified the local watershed by building dams with wells and cisterns behind (Whitehouse, 1974; Whitehouse et al., 2009; Tahmasebi, 2009; Wilkinson et al., 2012; Pourkerman et al., 2020; Fig. 6c, d). These water features at places crossed rock-cut graves located

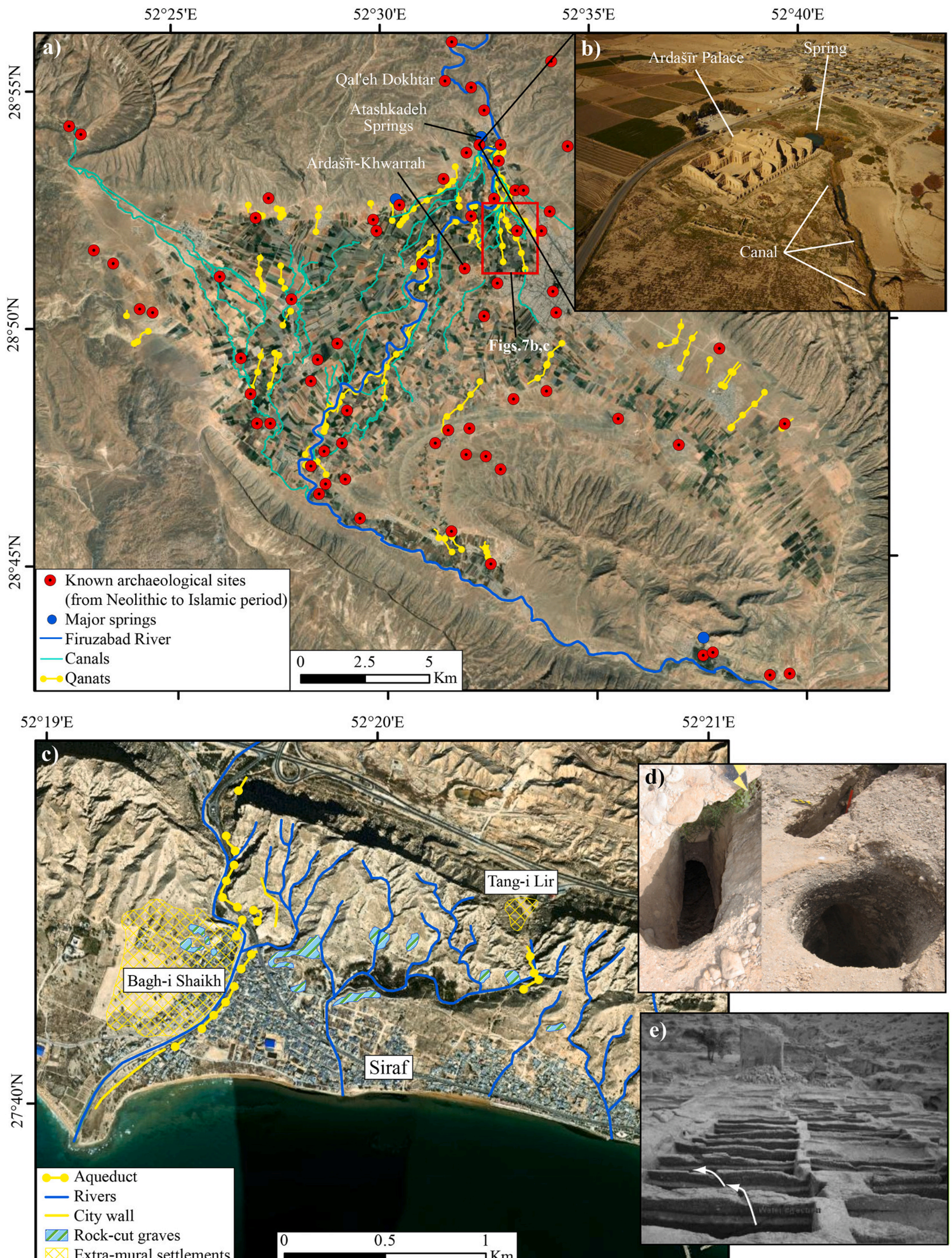

Fig. 6. a) Map of the hydraulic infrastructures in the Firuzabad plain. The location of archaeological sites is from https://whc.unesco.org/en/list/1568/documents. b) Photo of the Ardasir palace located in the northern portion of the Firuzabad plain close to one of the Atashkadeh springs (from https://whc.unesco.org/en/list/1568). c) Aqueducts and hydraulic infrastructures at Siraf (modified after Whitehouse, 1974). d) examples of aqueducts and wells carved into bedrock e) example of reuse of rock-cut graves as water infrastructures (from Tahmasebi, 2009). In particular, in e) is shown the relationship between graves: surface water, passing from one grave to the next one (see white arrows), flows into wells and underground water reserves dug into the rock. The location of figures a) and b) is indicated in Fig. 1b. The base map in a) and b) are from Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

on the relieves to the north of the city (Fig. 6c). There are also evidences of a subsequently reuse of some graves for water storage and drainage (Tahmasebi, 2009; Fig. 6e).

The construction and management of these hydraulic infrastructures required an excellent background of hydrology, civil engineering, climatic hazards, mining, and urban planning and demonstrate man's ability to adapt to environmental conditions and, where necessary, modify them to his own advantage.

While the construction of hydraulic infrastructure has enabled water supply and reduced flood-related risk, it has also altered the natural balance and vulnerability of the land compared to the past. Increasing hydrological abstraction rates, which in turn affects land use and natural habitats, trapping sediments, blocking fish migrations, facilitating forced migration of humans and animals, increasing chemical nutrients in the water, are some of the consequences of dam building which afflicted and afflict the landscape (Saatsaz, 2020). As in the past, Iran is currently plagued by serious water supply problems. Frequent periods of drought lead to an exacerbation of water withdrawals both from underground and from major perennial rivers lowering the water table level and causing subsidence, worsening water quality, increasing soil erosion and desertification (Saemian et al., 2022). Khaleghi and Surian (2019) demonstrated how these phenomena, and in particular damming, sediment mining, and climate variations, have changed the Iranian rivers configuration. Indeed, at present, most of the rivers have undergone incision (1–7 m) and narrowing (from 19% to 73%), although widening (from 22% to 349%) has occurred in some rivers.

3.1. The adaptation of man to climate change and water shortages

The end of the last glacial-interglacial transition at the passage between late Pleistocene and early Holocene represents a crucial event characterized by abrupt climatic changes and the formation of the first farming communities (Hoek et al., 2008; Willcox et al., 2009; Blockley and Pinhasi, 2011). In this regard, the Zagros mountains represent a key region for understanding these processes being one of the earliest regions for cereal and pulse domestication in the Middle East (Nicoli et al., 2023) and the main destination for the eastward expansion of early farming communities (Broushaki et al., 2016).

The first settlements were very vulnerable to severe climate changes and water shortages over long periods.

Indeed, during the Holocene, the region was characterized by the emergence and collapse of many farming communities at the same time as abrupt climate change (Staubwasser and Weiss, 2006). Some studies (e.g., Weeks et al., 2006; Nishiaki, 2010) evidence a correlation between the birth and expansion of Fars settlements at 6300–6200 BCE and a rapid climate change towards cooler and drier conditions (the “8.2 ka abrupt climate change event”; Rohling and Pälike, 2005; Thomas et al., 2007). While the 8.2 ka event caused the movement of communities in the Fars region (Weeks et al., 2006), it also forced to change subsistence practices, as confirmed by the existence of pre-Neolithic communities in the same region (see Weeks, 2013 and references therein).

Moreover, several studies suggested that increased aridity hampered the development of eastern Iranian society and slowed the evolution of the landscape (Lawler, 2011; Walker and Fattahi, 2011). Two examples are Shahr-e Sukhteh and Bam, two Bronze Age settlements in southeast Iran that were abandoned after prolonged droughts at the end of the 3rd Millennium B.C. (Lawler, 2011; Walker and Fattahi, 2011).

Between 2800 and 1100 BCE, people started to manage water scarcity by water systems instead than abandoning their homes. It was at this time that the first water systems were developed to collect, store, and supply water to inhabitants. One of the best examples is the province of Khuzestan (west Iran). Here, because of erratic rainfall and drought, to ensure an adequate irrigation, complex water systems, including canals of various sizes, headgates, distributors, regulators, inlets and outlets, weirs, levees, and storage reservoirs were developed (Tamburrino, 2010). With the introduction of these new technologies settlements, first restricted by the shifting of water courses, become dispersed across the plains (Fazeli et al., 2007).

In the Fars region, paleoclimatic studies (Jones et al., 2014; Brisset et al., 2019) on the lakes of Maharlou and Parishan (see Fig. 1b) revealed their high sensitivity to natural climatic changes and the significant modification of the geochemistry and position of water tables because of human activities. In particular, in the Shiraz basin, the contraction of the Lake Maharlou seems to have corresponded to the construction of new *qanats* and the repair of the older ones (Brisset et al., 2019). Moreover, palynological investigations on both lakes have shown a phase of human activity (from Achaemenid period), with the development of irrigated tree-farming (Djamali et al., 2016; Saeidi Ghavi Andam et al., 2021). A very close human-wetland interaction since the Neolithic period has been evidenced also from sediment cores in several wetland systems of the Persepolis basin and surroundings (Djamali et al., 2018; Aubert et al., 2019).

Finally, Rigot et al. (2022) demonstrated that the adaptation to new geomorphological and hydrogeological conditions related to climate changes occurred also in the Pasargadae plain where the populations of the 1st millennium B.C. took advantage of the level of the river bed (much higher than today) to build a canal system in the deposits of the extensive river terrace (which is now the oldest among three orders; see Fig. 5a, b) and to create large reservoirs to feed irrigation systems downstream all year long (Fig. 4b).

3.2. The qanat technology

The *qanat* system consists of one or more gently sloping tunnels characterized by a series of vertical shaft wells, used to extract and transfer groundwater by gravity to flatter slopes in arid and semi-arid regions (Fig. 7a). The tunnel is semi-elliptical with a height and width of about 1.2 and 0.8 m, respectively (Beaumont, 1971). The bed is usually covered with impermeable materials such as compacted clay to decrease water infiltration (Pouraghniaei and Malekian, 2001). According to Farzadmehr and Nazari Samani (2009), the tunnel slope should be between 0.3 and 0.5%, ensuring a balance between excessive erosion and sedimentation of the tunnel bed. The tunnel can be divided into two parts: i) the water-producing zone, excavated through an aquifer’s phreatic zone and ii) the water transport zone, where water is transported to the ground surface (Salvini, 2001). The first shaft (named “mother-well”) is dug between 10 and 250 m of depth and is used for locating the water table and checking groundwater quality and quantity (Fig. 7a; Ahmadi et al., 2010). Then, along a line between the mother-well and the *qanat* outlet, a series of shafts are excavated at constant intervals to remove the materials from the main tunnel and to provide air circulation and access for maintenance (Fig. 7a). Finally, the water is driven to farms, gardens, and settlements through a network of open canals (Labbaf Khaneiki, 2020). The distance between the mother-well and the *qanat* outlet varies from tens of meters to several tens of kilometers, reaching about 80 km in one of the longest qanats in Zarach city (central Iran; Kobori, 1973; Eghtedari, 1974).

The population knew that the best places to find groundwater were foothills, wadies, dry riverbeds, intermountain basins, and alluvial fans (Semsar Yazdi and Labbaf Khaneiki, 2016). In Iran, most of *qanats* starts from foothills deposits and alluvial fans. This is due to the geomorphological configuration of the region. Indeed, the Zagros Mts. consist of hundreds of anticlines mainly characterized by highly permeable limestones, and synclines composed of low permeability lithologies such as marls and sandstones (Ashjari and Raeisi, 2006; Raeisi and Stevanovic, 2010; Djamali et al., 2018). Foothills deposits and alluvial fans cover the stratigraphic and hydrogeologic contact between the permeable lithologies and the low-permeability ones (Raeisi and Stevanovic, 2010). For this reason, they usually host the regional aquifer.

A *qanat* is not a static system. Some studies carried out in Oman (Wilkinson, 1977; Al-Ghafri et al., 2000; Boucharlat, 2001, 2003) demonstrated that exploitation of water by means of *qanats* may change the groundwater conditions in concomitance, for example, with the decrease or lack of winter-rains for several years. Due to lack of rainfall the aquifer is not recharged, and the water table lowers making the *qanat* less or no longer able to “produce” water (Weisgerber, 2004). In these cases there are three possible solutions (Weisgerber, 2004): 1) the water producing zone could be extended towards the mountains and/or it could be branched out to make the area wider (the resulting intricate networks is pretty visible from aerial photo; see Fig. 7b); 2) the base of the tunnel could be lowered to take water from deeper levels; 3) digging a new tunnel into untouched or neighboring areas.

It is estimated that in Iran there are about 60,000 *qanats* for a total length of 360,000 km and a total water supply of ~750 m^3/s (Kuros,

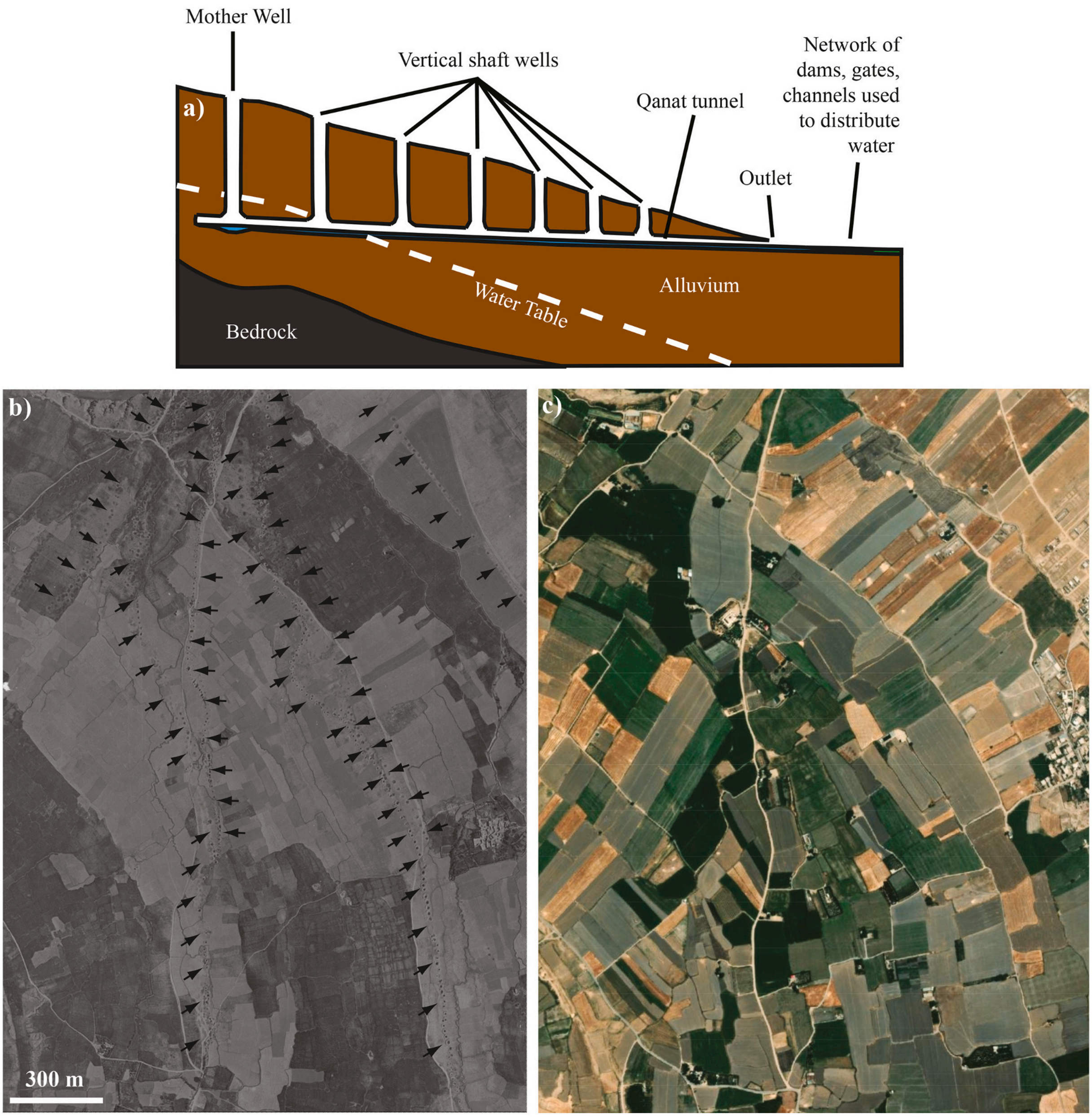

Fig. 7. a) Schematic *qanat* cross section (modified after English, 1968). b) Aerial photo (from National Cartographic Center of Iran – 1973) showing *qanats* in the Firuzabad plain (the black arrows indicate the paths of 6 different qanats); the aligned dark dots correspond to vertical shaft wells. c) Present day satellite image of the same area represented in Fig. 7b which shows how the cultivated lands covered the traces of the pre-existing *qanats* (from Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community).

1981). Other studies estimate the number of functioning *qanats* between 22,000 (Mostafaeipour, 2010) and 36,000 (Semsar Yazdi and Labbaf Khaneiki, 2012).

The progressive urbanization of the region and the intense agriculture use of the plains partly erased the traces of *qanats* (Fig. 7b, c). Over time, due to environmental and geological factors, parts of these obsolete *qanats* collapse causing problems for underground structures and surface infrastructures (Golpasand et al., 2019).

Despite the great number of publications and the detailed knowledge about the building technique, there is still no consensus about the first appearance of *qanats*. Hogarth (1904) first published a theory that *qanats* developed in the sixth century B.C. in Achaemenid Persia. This theory was later espoused by English (1968), Wilkinson (1977) and Goblot (1979). According to the latter, the system comes from mining technology in the eighth century B.C. in the Urartian kingdom (northwestern Iran). The technique was then diffused throughout Western Asia. Despite the great impact of Goblot's work, several authors questioned his model, considering the assumptions on both the date and the origin unfounded (Boucharlat, 2001, 2003, 2017; Salesse, 2001; Magee, 2005; Leveau, 2015). Several studies date the first appearance to ~7000 years ago (i.e., Lisitsina, 1978; McLachlan, 2000). However, none of these datings was based on archaeological criteria (Chauveau, 2001). The oldest well-studied qanats are the ones excavated in the U.A.E. which date back to the Iron Age (1300–300 BCE; Boucharlat, 2017; Charbonnier and Hopper, 2018). However, in a recent study by Fattahi (2015), five samples taken from different layers of a ring-shaped spoil heap have been dated by optically stimulated luminescence at 5200–3300 years ago. However, the cultural and archaeological context of this discovery is still unknown (Charbonnier and Hopper, 2018).

Beyond when they first appeared, the *qanats* were already the result of an advanced state of knowledge of the environment. In fact, their development represented a huge leap forward in the management of water as water resources are no longer linked to the proximity of a watercourse (as in case of canals), but are permanent (Chauveau, 2001; Charbonnier and Hopper, 2018).

4. Human settlements and alluvial fans

The topographic, climatic, and hydrogeological settings in coastal and hinterland sites of Iran limited the development of human settlements. In particular, the local presence of salty rivers, as well as the occurrences of floods, in the present as in the past, made the choice of floodplains as a settlement foundation site very challenging. Indeed, as

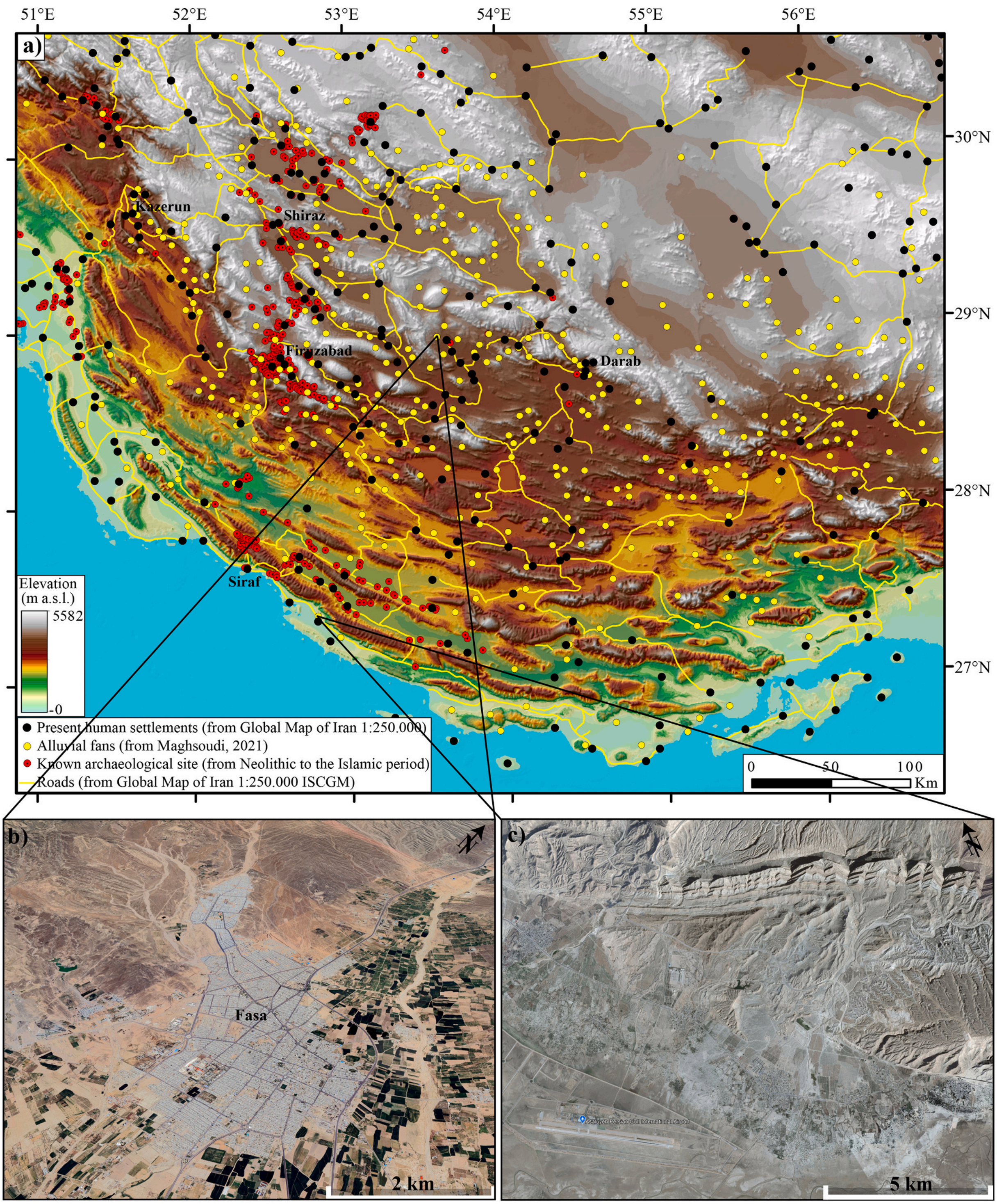

Fig. 8. a) Map of the alluvial fans distribution in the Fars arc over the SRTM DEM (~90 m in resolution). The location of the archaeological sites comes from the available published articles (Carter et al., 2006; Weeks et al., 2006; Askari Chaverdi et al., 2008; Gondet, 2011; Asadi et al., 2013; Petrie et al., 2013; Ghasimi et al., 2016; Eslami et al., 2020; Khanipour et al., 2021; Rigot et al., 2022) and from https://whc.unesco.org/en/list/1568/documents. b) and c) are two examples of human settlements built on alluvial fans (images from Google Earth).

specified above, to survive in these environments, humans have had to develop a range of technologies for both water supply and hydraulic risk mitigation. For these reasons, a number of settlements were developed at the elevated parts within the plains (i.e., river terraces) or on top of alluvial fans (Asadi, 2010; Sardari, 2013; Fig. 8a, b, c).

An alluvial fan consists of a depositional landform forming at the emergence of a confined river into larger areas such as wide valleys or plains. Usually, the surface of these landforms is occupied by ephemeral streams which, much of the time, are dry above ground, but subterranean water flows along the same pathways. Where these subterranean streams flow out of the mountains, the water table comes closer to the surface, and it is more readily accessible through wells (Saatsaz and Rezaei, 2023).

Several studies demonstrated the importance of alluvial fans on human settlements development in Iran (Krinsley, 1970; Beaumont, 1972; Gillmore et al., 2009, 2011; Schmidt et al., 2011; Walker and Fattahi, 2011; Maghsoudi et al., 2014). Indeed, the alluvial fan deposits, composed of fine-grained sediment (i.e. kaolinite; Bayat et al., 2017), and the presence of fresh water through braided channels and *qanat*s provides a suitable area for economic activities, particularly agriculture and pottery production (Maghsoudi et al., 2012). In addition, these deposits represent aggrading surfaces usually located above the active floodplain providing flood protection.

Most of the ancient settlements on the Iranian Plateau were established in a proper distance from the fan apex (Maghsoudi, 2021). This is because near the fan apex channels deeply incise into the sediments as the result of an avulsion and/or internal adjustment of the river to a new gradient (fan head entrenchment - Blair and McPherson, 1994; Harvey et al., 2005).

If, on the one hand, the sedimentological and hydrogeological characteristics of the alluvial fans have favoured the birth and development of human settlements, on the other hand, the extreme mobility of the braided channels on the surface has forced entire communities to continuously move their settlements (Maghsoudi, 2021). Indeed, to have easier access to water resources and to prevent possible damage in consequence of floods, the inhabitants had to change their settlement location to better adapt to the new environmental conditions (Maghsoudi, 2021). For example, the chalcolithic sites Mafinabad and Tape Pardis evidence some irregularity in the number, size, or function of the settlements on the alluvial fan of the Jajrud River in the Tehran Plain (Manuel et al., 2014). This point is also supported by the thoroughly documented site of Cheshmeh-Ali, immediately south of Tehran, which extends from the Late Neolithic period to the Chalcolithic period with more than one phase of settlement (Saatsaz and Rezaei, 2023).

While it is true that the geomorphological characteristics of alluvial fans have influenced the development of human settlements through the whole of Iranian Plateau, the opposite is also true. During the late Holocene, changes resulting from human impact, including the construction of extensive irrigation canal networks and dams during the Sasanian Period (1797–1350 B.P.), caused successive avulsions and the rapid deposition of alluvial fans from ~2500 to 500 years B.P. (Alizadeh et al., 2004; Baeteman et al., 2004; Heyvaert, 2007; Heyvaert and Baeteman, 2007; Walstra et al., 2010, 2011; Heyvaert et al., 2012).

In the Fars arc the relationship between alluvial fans and human settlements is not direct: the locations of most archaeological sites and present human settlements do not coincide with the main alluvial fans (Fig. 8). Examples are the Marvdasht and Pasargadae plains (Fig. 4a, c) and the coastal sector of Siraf (Fig. 6c), where the majority of the mapped archaeological sites is far from the alluvial fans. An exception is the Firuzabad plain where several sites (including the city of Ardašīr-Khwarrah and the Ardašīr palace) developed on the northern alluvial fan where the perennial Firuzabad River and several karst springs ensured a continuous water supply (Rashidian and Djamali, 2023 and references therein; Fig. 6a, b).

5. The impact of relative sea level fluctuations: the Persian Gulf

Beyond the economic importance of the basin as a hydrocarbon generation zone (Saberi and Rabbani, 2015; Ashrafi et al., 2020), the Persian Gulf represented a real "mare nostrum" for the inhabitants of the surrounding areas and was considered a strategic part of the Persian empire from an ideological and economic points of view (Daryaee, 2016; Callieri, 2021).

The Persian Gulf separates the Arabian Peninsula from southern Iran along ~966 km. It covers an area of ~251,000 km^2 with a shallow body of water (max depth ~ 100 m, average depth 40 m; Ashrafi et al., 2020) and presents an average tidal range of the order 1–2 m (Lambeck, 1996; Pourkerman et al., 2020).

Archaeological evidences and the presence of several marine terraces (ancient abrasion platforms or flat shorelines abandoned by the sea after eustatic level lowering) along the coast allowed to quantify the coastal uplift rate between 0.2 and 2 mm yr^{-1} (Vita-Finzi, 1979, 1980; Reyss et al., 1999; Pirazzoli et al., 2004; Oveisi et al., 2009; Wood et al., 2012; Lokier et al., 2015; Farahi Ghasr-Aboonasr and Jara-Muñoz, 2017; Gharibreza, 2017) and the relative sea level (RSL) changes trough the Holocene (Lambeck, 1996; Lokier et al., 2015; Arhan et al., 2020; Pourkerman et al., 2020, 2021).

In detail, from ~14.5 to ~10 ka a rapid sea level rise occurred, from about 105 m to <30 m below the present level, causing the initial inundation of the Persian Gulf (Lambeck, 1996).

At 7.1–6.89 ka RSL rose ~2 m (Lambeck, 1996; Lokier et al., 2015). At the same time, a northward migration of the monsoon rains occurred causing an increase in precipitation over the northern Oman and the central part of the Persian Gulf (Fleitmann et al., 2003; Fleitmann and Matter, 2009; Djamali et al., 2010). This event could have enhanced the erosion on continental zones and, consequently, increased sediment supply/progradation to/of coastal areas (Pourkerman et al., 2020).

Between 5.3 and 4.6 ka, during the Persian Gulf high stand, the Khuzestan plain (northernmost portion of the basin) experienced several RSL short periods oscillations (Heyvaert and Baeteman, 2007). A similar trend has been supposed for the central portion of the Iranian coast from ~2 ka (Pourkerman et al., 2020; Fig. 9). Conversely, a rapid RSL fall seems to have occurred in the Abu Dhabi area during a short period after a high stand reaching an elevation below the current sea level between 1510 and 1240 B.P. (Lokier et al., 2015; Fig. 9).

The barren and inhospitable topographic configuration of the Iranian coast of the Persian Gulf, in addition to causing water and soil scarcity, offers few natural communications (Dewan and Famouri, 1964; Caspers, 1971). For these reasons, the foundation of human settlements along the coast was limited in a relatively small number of intermontane valleys which possess sufficient conditions and resources for survival (Askari Chaverdi et al., 2008). Archaeological surveys in the region proved the existence of settlements starting from the prehistoric period (Stein, 1937; Askari Chaverdi et al., 2008). During the Sasanian age, several ports and forts were built along the coast (Daryaee, 2016). According to Pourkerman et al. (2020, 2021), the foundation and abandonment of these sites depended on the relative sea level (RSL) fluctuations which, in turn, were dictated by eustatic sea level rise, basin subsidence, and local uplifts. In this regards, old manuscripts report abnormal, alternate rising and lowering of the sea level which could be related to large-magnitude inland or under-sea earthquakes (Berberian, 1994).

The continuous environmental changes related to sea level fluctuations caused a progressive shift in the location of the most important harbours from the northernmost portion of the Persian Gulf to the eastern one (Fig. 9), as acknowledged in Medieval Islamic times from Siraf to Bandar Abbas. In particular, at Siraf site, the rising of relative sea level and the increase in wind intensity accelerated the erosion along the coast causing the collapse of part of the foundations of the medieval Siraf. In addition, relative sea level rise drove the marine water intrusion into coastal wells where fresh water was preserved (Pourkerman et al., 2020). For these reasons population gradually move away from the city.

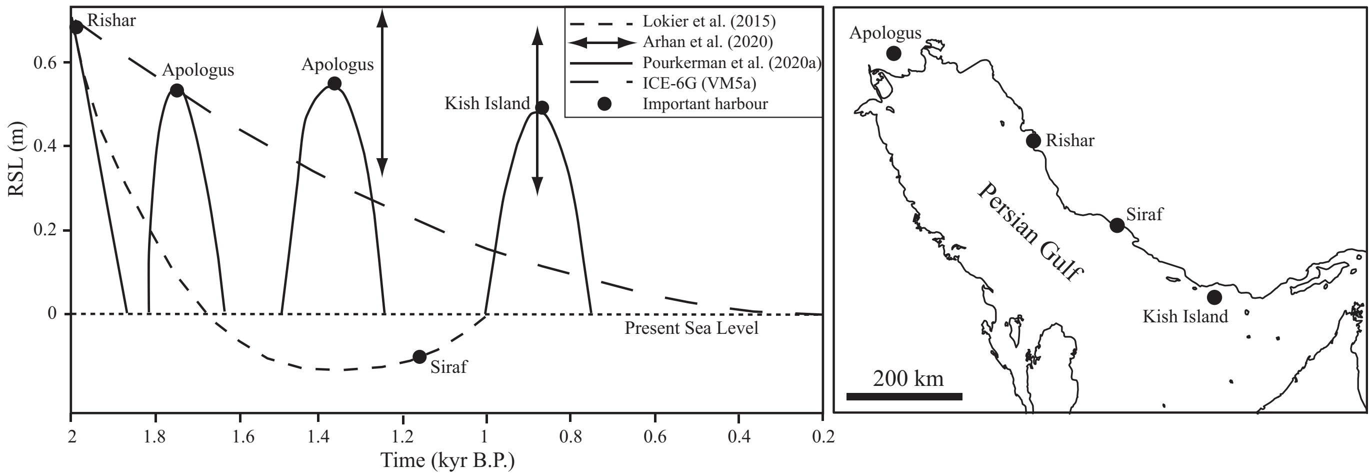

Fig. 9. Relative Sea Level fluctuations since 2 ka according to several studies compared with the ICE-6G (VM5a) model of the glacial isostatic adjustment process (modified after Pourkerman et al., 2020).

6. The influence of geomorphology on trade routes network

The rugged and varied topographical configuration of Iran, characterized by high mountains, plateaux, and alluvial floodplains, represented for the ancient Persian civilizations an enormous obstacle to the construction of a system of road infrastructure useful to connect all the regions of the empire (Colburn, 2013). The need to allow imperial communications to quickly connect the center with the periphery was, according to the sources, satisfied with the so-called "Great Imperial Road", a system of connections based on fast couriers, which allowed the emperor's missives to travel between Sardis (western Turkey) and Susa (at the border between Iran and Iraq) in a fortnight (Graf, 1994). However, apart from this one, the sources testify to the existence of an extensive infrastructure of connectivity consisting of a road network, rivers, and canals for inland travel, and a series of ports and anchorages for seaborne travel (Graf, 1994; Briant, 1996, 2012; Kuhrt, 2007; Potts, 2014). The presence of this network can be traced back at least to the time of Cyrus the Great even if the maximum expansion occurred at the time of Darius I (Henkelman and Jacobs, 2021). Despite the textual records available, the exact configuration of the road network is still

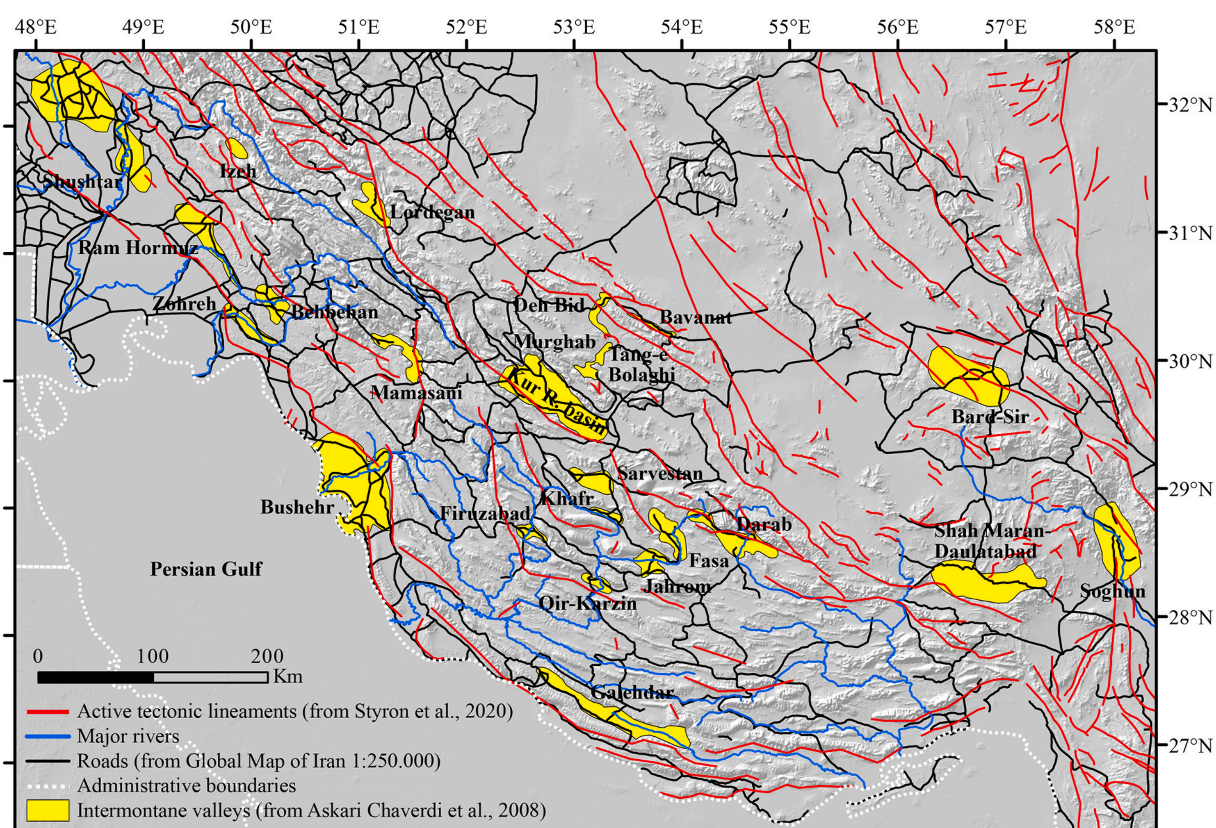

Fig. 10. Patterns of river network, tectonic lineaments, and roads (from Askari Chaverdi et al., 2008) in the Fars arc draped on hillshade of the ETOPO1 DEM. In yellow the intermontane valleys subjected to archaeological surveys while in white the coastline. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

debated (see Henkelman and Jacobs, 2021 and references therein). Archaeological investigations in Fars allowed to individuate segments of road infrastructures at the edges of the Marvdasht plain (Kleiss, 1981; Sumner, 1986) and at Bard Burideh (Nicol, 1970; Briant, 2002) and several stations (see Henkelman and Jacobs, 2021 and references therein). All the evidence available speak of a communication system which connected all the empire with speed higher than, for example, the Roman Empire (Colburn, 2013). Such a level of connectivity was probably at the base of the long-lasting stability of the Achaemenid Empire (Henkelman and Jacobs, 2021).

Several studies evidenced how topographic elements such as river network and tectonic lineaments, contributed to road network design in Fars (Fallah-Tabar, 2000; Force et al., 2010; Fig. 10).

Generally, the Fars river network has a trellis pattern controlled by structural and lithological weaknesses (Ramsey et al., 2008). The main rivers form long valleys that follow synclines, whereas small parallel tributaries flow from the slopes of the anticlines joining the main river segment at a sharp angle (Fig. 1b). Sometimes rivers cross anticlines forming the so-called "watergaps" (Ramsey et al., 2008; Fig. 1b). From Fig. 10 it is clear that some roads strictly follow the course of the main rivers that, when not salty, provided also drinking water for livestock and humans and represented and still represent, with their watergaps, the most convenient, although certainly longer, route to overcome the rugged topography of the Zagros.

Moreover, based on archaeological investigations, field observations and satellite images analysis, Khosravi et al. (2013) found a strong correlation between roads and faulting systems in central Iran, suggesting that tectonic lineaments, and particularly the fault escarpments, gave a great contribution in the realization of the road network (Fig. 10). For example, the Kazerun transverse strike-slip fault, by cutting the folded mountains of western Fars, formed the main ancient passageway from the area southwest of Kazerun to Bishapur, Nurabad, Fahlian, and Yasuj, where there is evidence for ancient settlements (see paragraph 7; Askari Chaverdi and Callieri, 2010; Berberian et al., 2014; Fig. 1b).

7. The impact of historical earthquake

Iran, characterized by active faulting and folding, recent volcanic activities, and high elevation gap along the mountain belt, has been frequently struck by catastrophic earthquakes which caused many casualties, displaced people, damages to agricultural and industrial structures, and waste of natural resources (Berberian, 1996; Fig. 11a, b). Many settlements, especially in the arid and semi-arid regions, are located at or near seismogenic faults at the foothills or in depressions along strike-slip fault. These fault zones, while they are sources of medium- to large earthquakes, they also represent preferential pathways for groundwater and passageways through the mountains. This justifies what Jackson (2006) defines the "fatal attraction" to areas of high seismic hazard. In addition, earthquakes have always been regarded as an act of God and impossible to cope with. For this reason, during the centuries, no action has been seriously pursued to minimize the associated risk (Berberian, 2014a).

Ambraseys and Melville (1982), Berberian (1996), and Berberian et al. (2014) listed archaeological sites and monuments which provided earthquake information on Iran, and namely on Fars arc (Fig. 11a, b). The studies clearly show that large-scale earthquakes devastated ancient settlements since 7000 years ago. Among the others the most important sites are Sagzabad (middle of the 3rd millennium B.C.; Negahban, 1973; Berberian et al., 1993), Ak-Tapa (4000 BCE; Golinsky, 1982), Gowdin-Tapao (4000–3350 BCE; Young Jr., 1968), Marlik (3000–2000 BCE; Negahban, 1990; Berberian et al., 1992), Parthian Nisa (10 BCE-10 CE; Golinsky, 1982), Kangavar Anahita Temple (17th century B.C. and 224–642 CE; Kambakhsh-Fard, 1974), Nishapur (1145 and 1270 CE; Wilkinson, 1975), Masjed-e Jame' of Qaen (1066 CE; Naderi, 1980). The decline of civilization in the cities of Sagzabad, Marlik, Kume, Zarang/Sistan, Siraf, Nishapur, and Jizd seems to have been partly, if not largely, due to large-magnitude earthquakes (Berberian, 1996). Moreover, there are evidences of site abandonment (Berberian, 2014b and references therein) and shifts in settlement location, as well as post-seismic structural innovations after large-magnitude earthquakes (Berberian et al., 2012). In this regard, the seismic event at Sialk, dated ~3800 B.P. (Berberian et al., 2012), is very impressive. In the report of his archaeological activity in the area, Ghirshman (1938) wrote to have found "several skeletons at the depth crushed by falling debris" and "skeletal remains of a mother protecting her two children in her arms". According to Melville (1980), before 1900 A.D, nine destructive earthquakes reduced the size and caused the city of Nishapur/Sadyak to relocate many times. The city of Ray was devastated at least six times in its recorded history (Ambraseys, 1974; Berberian et al., 1985). In Tabriz almost all the monuments were severely damaged by at least eight large-magnitude earthquakes (Berberian, 1996).

Regarding the Fars arc, the sites of Tol-e Spid, Qal'eh Kali, and Bishapur (western Fars) show the best conserved evidences of the occurrence of several medium- to large-magnitude seismic events related to the activity of the Kazerun Fault (Fig. 12a).

In particular, Berberian et al. (2014) found in all sites several deformations in archaeological records and monumental structures that can be explained only with large-magnitude earthquakes (Fig. 12b, c, d). At Tol-e Spid two main events have been dated at 3850–3680 BCE and 3370–3030 BCE with an estimated magnitude of ~7.3 M_w. In the Qal'eh Kali site, there is evidence of a strong ground motion (e.g. collapse, fracturing, toppling, differential settlement) at 400–200 BCE and 100 BCE Finally, at Bishapur at least four seismic events at 293–303 CE, 531–590 CE, 713–762 CE, and 12th century struck the area with an estimated magnitude of 6.9 M_w (Berberian et al., 2014).

Other evidences come from Siraf in the central portion of the Iranian Persian Gulf coast (Pourkerman et al., 2020). Archaeological investigations reported significant damages in concomitance of the 978 (Ms 5.3) and 1008 CE (Ms 6.5) earthquakes, which forced Sirafi merchants to transfer their bases south, to Sohar (northern Oman; Al-Muqaddasi, 1906; Berberian and Tchalenko, 1976). This event, together with other factors such as relative sea level and climate changes, drove the final decline of Siraf in the 13th century A.D. (see Pourkerman et al., 2020).

The recently discovered Early Achaemenid monumental gate of Tol-e Ajori in the Persepolis plain has given new and solid evidence for another strong earthquake, which in the stratigraphic sequence is followed by the abandonment of the construction and should fall in the post-Achaemenid period (Askari Chaverdi and Callieri, 2020).

In the 20th century ~126,000 persons died in destructive earthquakes. The Tabas-e-Golsan earthquake of 16 September 1978 (Ms = 7.4; Berberian, 1979) and the Rudbar-Tarom earthquake of 20 June 1990 (Ms = 7.4; Berberian et al., 1992) were the most catastrophic ones.

Earthquakes impact not only on the buildings and people but also on water supplies and river networks.

There are reports of changes in well water levels, qanat and spring water flow immediately following earthquakes (see Berberian, 1994). Muir-wood and Ling (1993) suggest that these effects are strictly dependent on the kinematic of faults. A significant normal faulting component as well as strike-slip events expel water, while revers faulting do not. For example, the 1824 CE earthquake located north-west of Shiraz caused a substantial increase in water table level, as reported in Ambraseys and Melville (1982).

The effects of an earthquake are visible also on the drainage system. Significant changes in the direction of the river course have been documented in Iranian geological records. The Sefid Rud River, flowing along the western continuation of the Khazar fault (Alborz range), bends of about 90° while crossing the active Manjil and Khazar faults (Berberian, 1983; 1992); moreover, in the delta area, after a slip on the Khazar Fault, the Pleistocene beach barrier which kept the delta confined was completely destructed allowing the northward expansion of the delta itself (Berberian et al., 1992). In the Fars arc, an example is

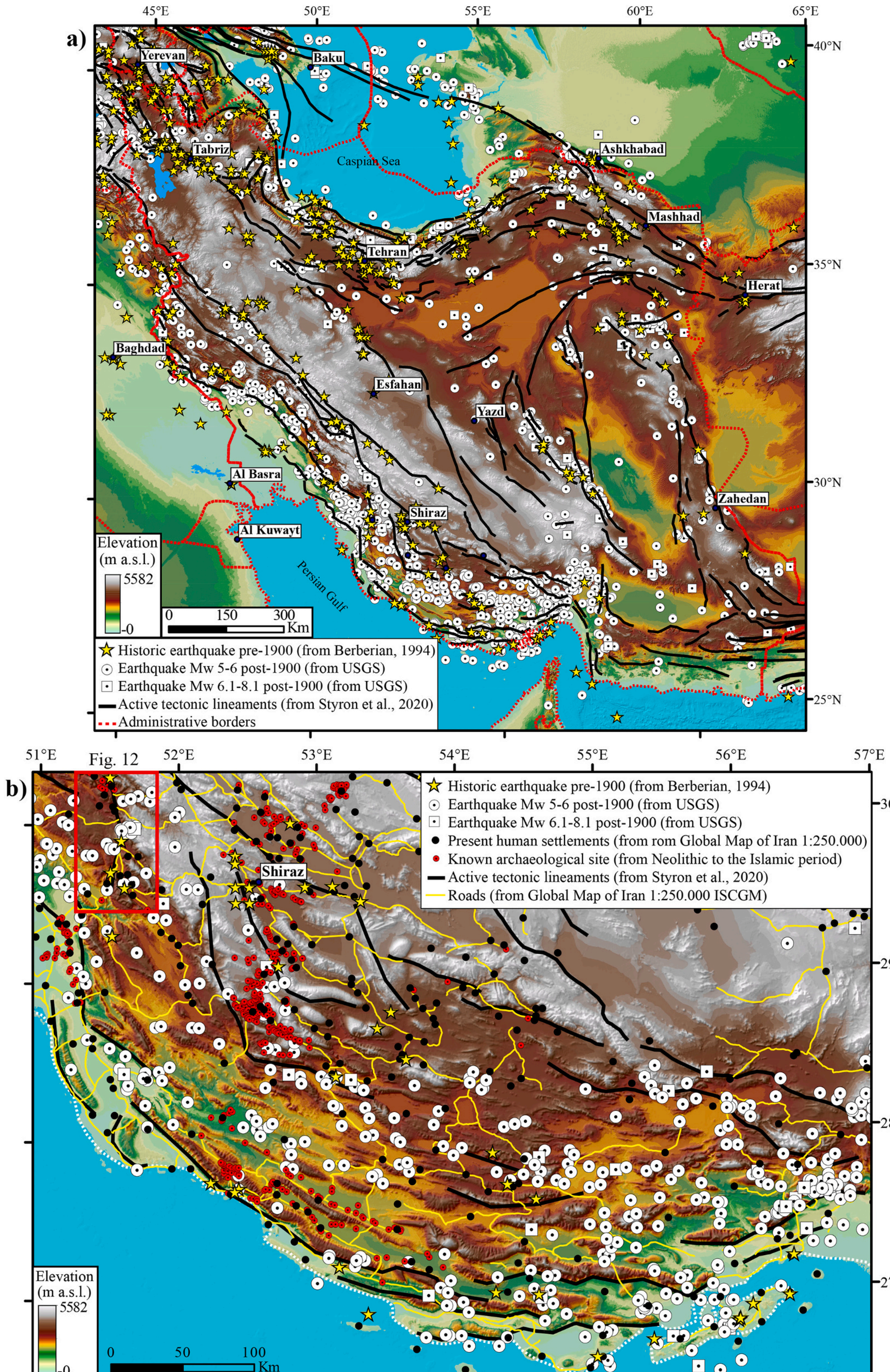

Fig. 11. Distribution patterns of historical earthquakes pre-1900 (Berberian, 1994) and post-1900 (5–8.1 Mw; USGS database) in Iran (a) and in the Fars arc (b). Active tectonic lineaments are from the Global Active Faults database by Styron and Pagani (2020). The location of the archaeological sites comes from the available published articles (Carter et al., 2006; Weeks et al., 2006; Askari Chaverdi et al., 2008; Gondet, 2011; Asadi et al., 2013; Petrie et al., 2013; Ghasimi et al., 2016; Eslami et al., 2020; Khanipour et al., 2021; Rigot et al., 2022) and from https://whc.unesco.org/en/list/1568/documents.

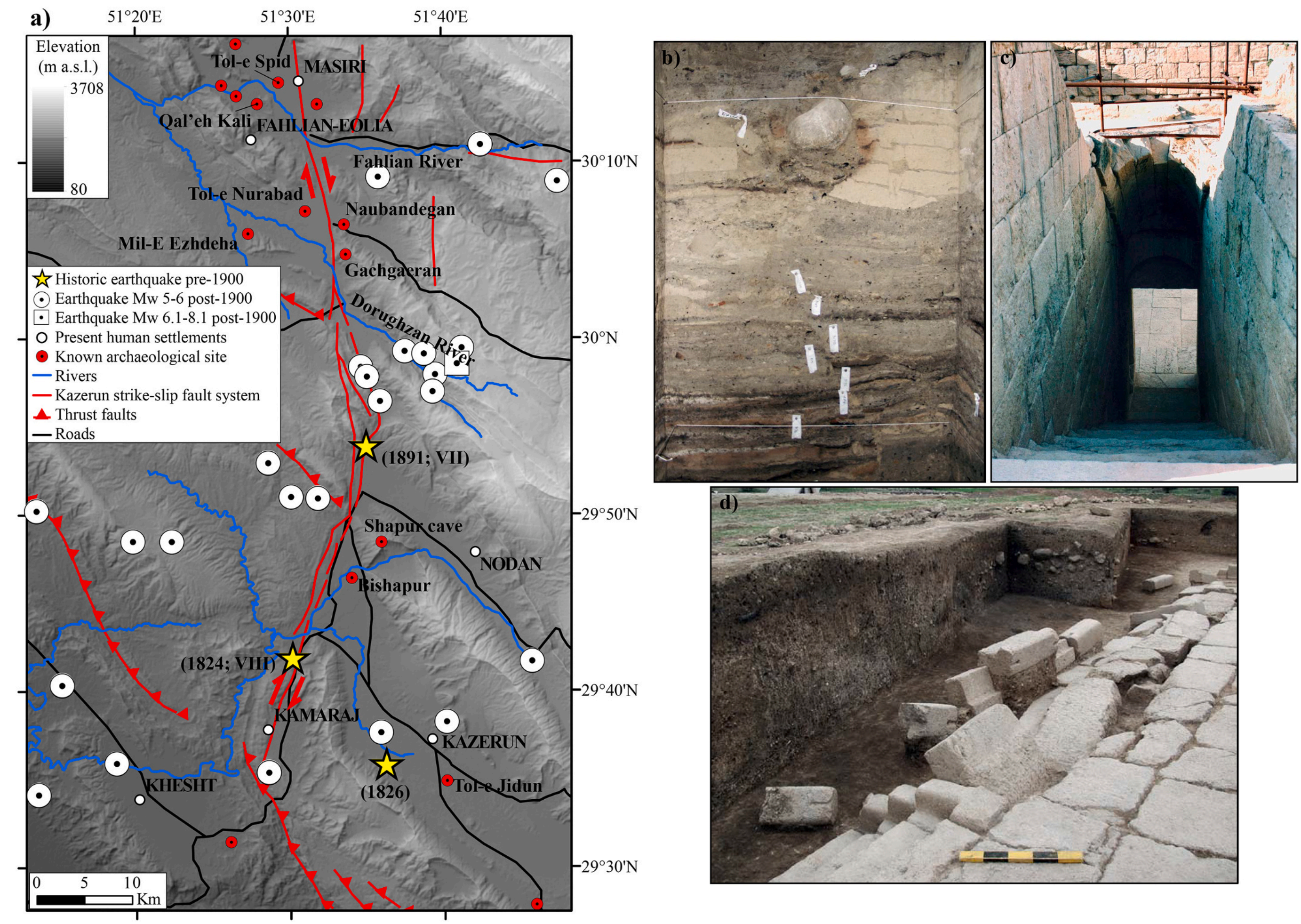

Fig. 12. a) Faults and earthquake map of the Kazerun right-lateral strike-slip fault system over the ~90 m-in-resolution SRTM DEM (modified after Berberian et al., 2014). Red circles indicate known archaeological sites in the area (from Berberian et al., 2014) whose names have been specified in lowercase letters for those mentioned in the text. The names written in capital letters, on the other hand, are the names of the major cities in the area (small white circles). The yellow stars are pre-1900 earthquakes from Berberian (1994) (data in parentheses indicate the year and, where possible, the intensity of the earthquake). Big white circles and squares indicate post-1900 earthquakes from USGS database. Note the right-lateral course diversion of the Fahlian and Dorughzan rivers. b), c), and d) are examples of damages to ancient structures caused by earthquakes at Tol-e Spid, Bishapur, and Qal'eh Kali respectively (from Berberian et al., 2014). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

given by the Fahlian and Dorughzan rivers, in the Mamasani area, which, in coincidence with the Kazerun Fault, present a right-lateral displacement of ~6 km (Berberian et al., 2014; Fig. 12a).

In some cases, such a dramatic change resulted in abandonment of settlements, as for example the city of Shahr-e Sukhteh, and even whole civilizations (e.g. Tal-e Iblis in Kerman; Berberian et al., 2014).

Another dangerous effect of an earthquake occurring under the sea or near the coast is tsunamis. The Iranian coast has been seismically active, and large-magnitude earthquakes affected the entire area in the past (Berberian, 1981, 1983). An example is again the ancient Siraf. Here, the earthquakes in 978 (Ms 5.3) and 1008 CE (Ms 6.5) generated tsunamis which sank several ships and flooded the coastal plain submerging part of the port (Berberian and Tchalenko, 1976).

Berberian (1994) compiled a detailed list of pre-1900 earthquake in Iran (from 1.8 Ma to the end of the 19th century). Seen on the map (Fig. 11a, b), most of the epicenters perfectly align with the tectonic lineaments we know to be active at present (see Styron and Pagani, 2020). Moreover, if we compare the locations of the pre-900 earthquakes with the post-1900 ones, it is evident that some lineaments are seismogenic since long time (Fig. 11a).

In the Fars region, the majority of the pre-1900 epicenters are concentrated in two main areas: the northwestern and the coastal ones (Fig. 11b). To the northwest (Shiraz region) the earthquakes mainly align with the following tectonic lineaments: Kazerun, Kareh Bas, Sabz Pushan, High Zagros, Beriz, and Lar faults. Analysis of bedrock displacement along the Kazerun Fault (western side of the Fars Arc) gives a total offset in the order of ~8 km (Authemayou et al., 2006). East of the lineament, the Kareh Bas and Sabz Pushan contribute to distribute right-lateral slip across western Fars (Tavakoli et al., 2008; Sarkarinejad et al., 2018). Bedrock offsets of these faults speaks to a total displacement ranging from ~7 to ~13 km (Authemayou et al., 2006). These right-lateral faults in western Fars are characterized by several segments tens of km long and represent the only exposed seismically active faults (Nissen et al., 2011).

Along the coast of the Persian Gulf the earthquakes seem to relate with the segments of the Mountain Front Fault, a "master blind thrust" (Berberian, 1995) with throw changing from ~2–4 km in Fars (Blanc et al., 2003; Molinaro et al., 2005; Emami et al., 2010) to ~6 km more in the Dezful Embayment (Berberian, 1995; Sherkati et al., 2006).

Recently, a study on the 2019–2020 Khalili seismic sequence in the central-southern Fars arc (5.7 M_w with a rupture length and maximum slip of 20 km and 0.5 m, respectively) revealed a close relationship between anthropogenic activities, related to the near active gas field, and earthquakes (Jamalreyhani et al., 2021). The Simply Folded Belt of the

Zagros Mts. contain 90% of Iran's hydrocarbon reservoirs including ~17% of Earth's total natural gas from 36 gas fields, most of which are in the Fars arc (Vergés et al., 2011; Esrafili-Dizaji and Rahimpour-Bonab, 2013). In the past, some earthquakes have been related to reservoir impoundment (Kangi and Heidari, 2008), mining (Mansouri-Daneshvar et al., 2018), and groundwater pumping (Kundu et al., 2019).

8. The impact of landslides

Landslide is considered a catastrophic natural hazard causing damage to life, farmlands, communication systems, and infrastructures. For this reason, it has profound effects on the economy and society (Schuster and Highland, 2001; Kjekstad and Highland, 2009; Alimohammadlou et al., 2013; Zhang et al., 2014; Del Soldato et al., 2019).

In Iran, landslides are one of the most common and significant natural hazards. Data from January 2003 to September 2007, indicate an annual economic loss of 12.7 billion USD in consequence of 4900 landslides concentrated mainly along the Alborz and Zagros mountains (Dehnavi et al., 2015). The reasons can be attributed to the presence of high elevations with steep slopes and active deformation and seismicity (Bahrami et al., 2020). The Zagros range is affected by several prehistoric and present-day landslides such as Seymareh (Harrison and Falcon, 1937, 1938; Watson and Wright, 1969; Shoaei and Ghayoumian, 1998; Shoaei, 2014; Delchiaro et al., 2019, 2022), Gahar and Sepid Dasht, in Lorestan province, and Abikar-Karkane-olya, in Chahar Mahal and Bakhtiari province (Ghazipour and Simpson, 2017 and references therein; Fig. 13a). In particular, the Seymareh landslide is considered one of the largest landslides in the world involving in a single event (9.8–8.71 ^{14}C ka; Roberts and Evans, 2013) ~30 km^3 of material (Harrison and Falcon, 1938). It blocked the course of Seymareh and Kashan rivers with the formation of three lakes (Seymareh, Jaidar, and Balmak lakes; Roberts and Evans, 2013; Shoaei, 2014) and an extended area of fertile soil where the city of Darreh Shahi developed (Harrison, 1946).

Ghazipour and Simpson (2017) investigated the distribution and size patterns of historical landslides along the Zagros Mountains (Fig. 13a). The results show that landslides are more and smaller in the south and southeast (Fars arc), particularly along the coast, while the northern portion (Lorestan arc) has fewer but larger landslides.

It seems that, in terms of triggering landslides, tectonics, lithology, and precipitation are the most important parameters (Ghazipour and Simpson, 2017; Bahrami et al., 2020). In particular, the alternation of soft (marl) and hard rocks (limestone) along steep hillslopes has a profound impact on landslides triggering (Bahrami et al., 2020). In the case of the Seymareh landslide, the infiltration of water during heavy rainfall at the Pabdeh marl/Asmari limestone interface provided lubrication which, together with the undercutting of Asmari limestone by Seymareh River and a high magnitude earthquake, contributed to trigger this giant landslide (Harrison and Falcon, 1937, 1938; Watson and Wright, 1969; Shoaei and Ghayoumian, 1998; Shoaei, 2014).

According to Ghazipour and Simpson (2017), 20% of landslides in the Fars occurred in highly elevated carbonate rocks while more frequent small landslides fall in the evaporites and fine clastic rocks domains at lower elevation (Fig. 13b).

Another important landslide triggering factor is undoubtedly earthquake. There are numerous examples of earthquake-induced landslides in Iran beyond the already mentioned case of the Seymareh one. Among the most significant seismic events ($\geq$ Mw 7) that have generated landslides it is worth mentioning: the 1977 Khurgu earthquake (Berberian and Papastamatiou, 1978); the 1978 Tabas earthquake (Berberian, 2014a, 2014b); the 1990 Rudbar earthquake (Ibrion et al., 2015a); the 1990 Manjil earthquake (Zaré, 1993); the 2003 Bam earthquake (Ibrion et al., 2015b); the 2017 Sarpol Zahab earthquake (Cheaib et al., 2022). In particular, the Khurgu earthquake caused several rockfalls one of which destroyed a village (Berberian and Papastamatiou, 1978); similarly, after the Rudbar earthquake, ~100 landslides completely buried some villages causing several fatalities (Ibrion et al., 2015a).

Archaeological investigations showed that landslides represent one of the causes of settlement destruction and abandonment (Jones and Thompson, 1965; Johnson, 1987). An example is the Tepe Mehr Ali site, in northern Fars. Here archaeological excavations on a cone-shaped mound evidenced the presence of a settlement populated between 5000 and 3400 years B.C. (Sardari Zarchi and Rezaei, 2007; Sardari Zarchi, 2009). Successively the site was abandoned in consequence of an earthquake-induced landslide which destroyed much of the settlement (Heydarian et al., 2017).

Currently, out of the 415 settlements in the Zagros region, 65 of them, including their access roads, fall within the zone of large landslides (>10^4 m^3) high density (>2 landslides per 1023 km^2; Fig. 13a, b; Ghazipour and Simpson, 2017). In these places the reactivation of old landslides could cause damage and fatalities.

9. Summary and future perspectives

The emergence and development of human settlements are closely linked to the geomorphological processes that shaped and shape a given region. The availability of drinking water, the presence of fertile soil and raw materials for construction are among the main needs that a community must secure. On the other hand, processes such as landslides, earthquakes and tsunamis, have left and leave deep marks on the world's civilizations decreeing the demise and abandonment of entire settlements and causing numerous deaths. These two aspects represent the two sides of the same coin: geomorphology. Indeed, the geomorphological configuration of a given area plays a major role in the development of a civilization, for better or worse. To survive man was forced to adapt to different environmental conditions. Adaptation has led to the development of techniques that make most of the environmental resources available. The improvement of these techniques has allowed man to modify the environment for which they were invented. This has made man a real morphogenetic agent, able to influence what had previously influenced him.

Since geomorphological configuration is the result of the complex interaction between Earth surface and deep processes, to fully understand the mutual influence between nature and man, it is necessary to analyze all the different aspects that characterize the landscape.

The Fars arc, which has been home to some of the world's oldest civilizations, is an ideal area to investigate such an influence. The region is part of the Zagros mountain belt, formed after the collision between Arabia and central Iran in the Cenozoic. The collision between the two plates caused the corrugation of the Earth's crust with the formation of extensive folding structures composed of a succession of long anticlines, which constitute the reliefs, and synclines, which correspond to valleys. From a lithologic point of view the anticlines are mainly composed of more permeable and hard rocks such as limestones or dolomites while in the synclines softer and less permeable marls and sandstones outcrop.

The newly formed belt represented a barrier to the west rainy winds and contributed to the progressive drying and warming of the central, eastern and southern regions of Iran. In particular, the Fars region is characterized by a arid climate with short and catastrophic rainy events which feed an overall ephemeral river network characterized by a trellis pattern: rivers flow in the synclines and, at places, cut into anticlines forming a watergap. The extreme rainfalls cause the transport of sediments from the inner sector of the drainage basins to the mountain fronts forming huge alluvial fans. Because of their position, these morphologies cover the stratigraphic and hydrogeologic contact between the anticlines permeable lithologies and the synclines low-permeability ones, hosting the regional aquifer.

This geomorphological configuration influenced the pattern of human settlements over time. As evidence of this, the division in valleys and mountains settlements reported in both ancient Persian and Greek sources coincides very well with the succession of synclines and anticlines running parallel to the coast, typical of this region. The earliest

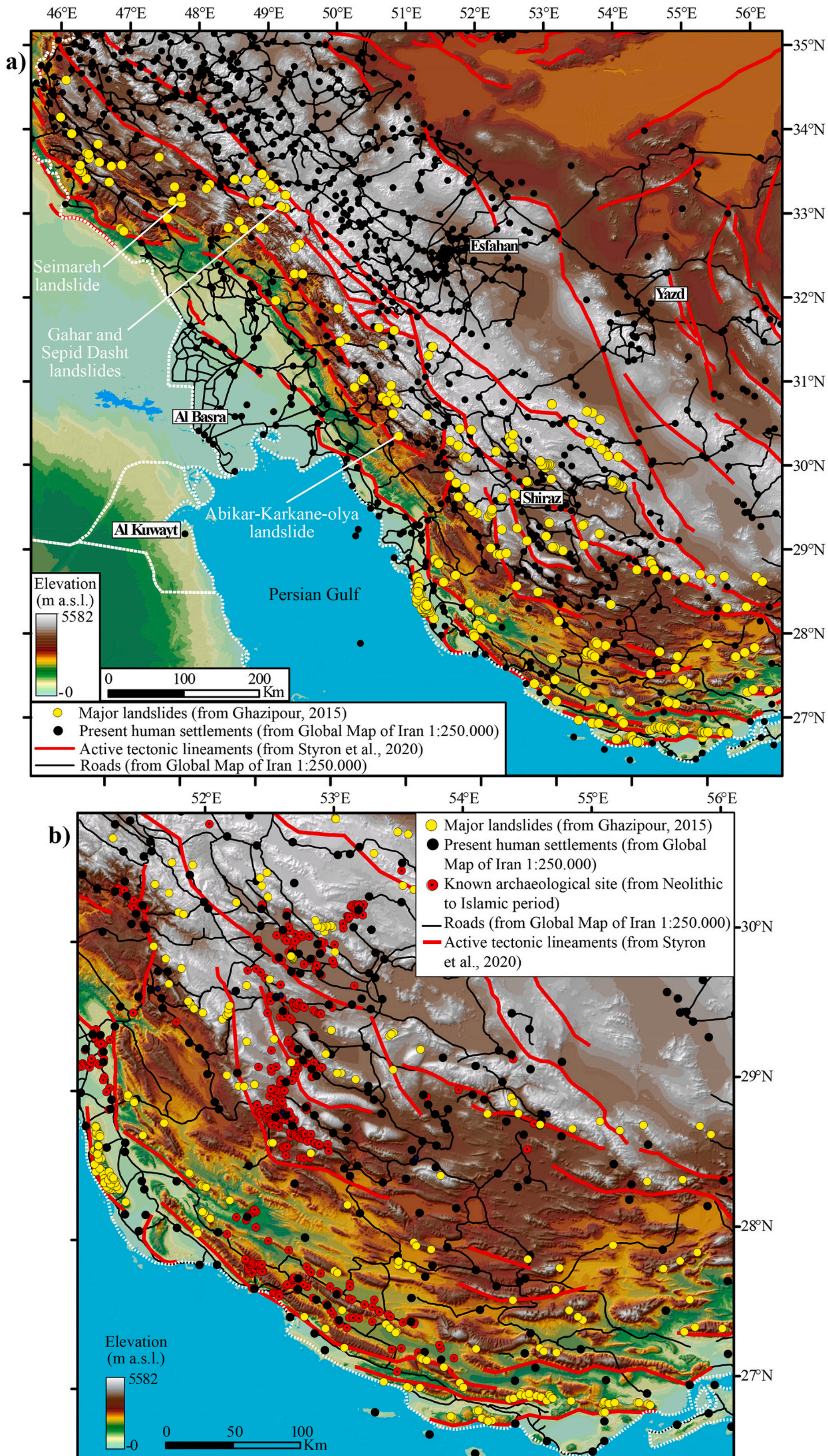

Fig. 13. Patterns of landslides (from Ghazipour, 2015), active tectonic lineaments (from GEM database by Styron and Pagani, 2020), present human settlements (from the Global Map of Iran © ISCGM/National Cartographic Center, Iran), known archaeological sites (from Carter et al., 2006; Weeks et al., 2006; Askari Chaverdi et al., 2008; Gondet, 2011; Asadi et al., 2013; Petrie et al., 2013; Ghasimi et al., 2016; Eslami et al., 2020; Khanipour et al., 2021; Rigot et al., 2022; and from https://whc.unesco.org/en/list/1568/documents), and roads (from the Global Map of Iran © ISCGM/National Cartographic Center, Iran) along the Zagros mountain belt (a) and in the Fars arc (b).

settlements were deeply dependent on water, so they arose mainly near major perennial rivers or on alluvial fans where supply was direct and secure throughout the year. However, the dynamism of such environments, characterized by the continuous migration of waterways and frequent flooding forced humans to move constantly. With the advent of agriculture, communities became settled. Man begins to modify his surroundings through the construction of water infrastructures both for water supply (i.e., qanats, canals, cisterns, wells) and for flood defense (i.e., dams, embankments). In some cases, the modification of the landscape was radical, as in the case of Siraf where the geomorphological configuration of the area and the hot arid climate forced humans to build dams with wells and cisterns in the relieves to the north of the city, modifying the local watershed.

Water supply techniques vary from area to area depending on geomorphological configuration and climate, which, from sub-humid in northern Fars, becomes hot-arid along the coast. Climate and climatic variations have also played a role in exacerbating some processes such as floods and droughts.

The continuous search for water to cope with arid and semi-arid climate, has led humans to build their settlements even in areas of high geological hazard. In this regard, the Fars arc is a region with several critical issues: in fact, in addition to the aforementioned floods, related to intense precipitation concentrated in short period of time, there are earthquakes, which are evidence of the still ongoing uplift and deformation of the Zagros Mountains, changes in the relative sea level, and the occurrence of landslides and tsunamis. The high concentration of settlements near seismogenic faults, for example, is justified by the fact that such lineaments, in addition to representing a faster and more direct passage through the reliefs, are the preferential pathways for groundwater to rise. This would also explain the reconstruction (in some cases more than once) of a site destroyed by an earthquake in the exact same location. The exception is the site of Persepolis. Here, after a disastrous earthquake which destroyed the imperial paradise of Tol-e Ajori, built on the Marvdasht floodplain, the royal citadel was rebuilt on the rock a little further east. In some cases, earthquakes caused the abandonment of a settlement, as in the case of the port of Siraf. Here, as along much of Iranian Persian Gulf coast, steep ridges rise from the sea isolating narrow coastal plain. The widespread presence of several levels of marine terraces testifies a continuous change in coastline dictated by relative sea level fluctuation and local tectonics. This made possible the urbanization only in a relatively small number of places characterized by water resources and arable land. Moreover, the variation of coastline with time deeply influenced the foundation and abandonment of these cities.

The tectonic lineaments together with drainage system strongly influenced also the road network which preferably follows the major perennial rivers, that allow for the water supply, and the principal tectonic lineaments, which cut the reliefs forming a direct route from inland to the coast.

The combination of seismogenic faults and high topography makes this region particularly prone to landslides that have caused destruction and death in numerous settlements over time.

Although the bibliography on Iran and particularly on Fars Arc is voluminous both archaeologically and geologically, there are several questions that are still unanswered or half-answered and on which future research have to concentrate. The deep connection between geomorphology and archaeology makes the study and new discoveries of the one extremely useful and crucial to understanding the other. Evidence of this is archaeoseismology, which studies the traces left by past earthquakes on archaeological monuments and strata (Berberian, 2014b). In the Fars arc, characterized by several active tectonic lineaments, such data could expand our knowledge about the temporal and spatial distribution of medium- to large-magnitude earthquakes and their recurrence periods. At the same time, they would help in understanding the causes behind the birth and abandonment of ancient settlements and their spatial arrangement. An example are the recent discoveries at Tol-e Ajori, near Persepolis (Askari Chaverdi and Callieri, 2020).

The study of landscape and its evolution over time has profound influences on the study of the pattern of human settlements and on the communication routes between one settlement and another. To date, only small segments of the dense road network which connected the inner part of the Fars to the coast have been discovered. Still uncertain, for example, is the road that connected the important military and economic port of Siraf to the city of Firuzabad.

Little is known also about the evolution of alluvial fans and river terraces that characterize the valleys and plains of the Fars arc. In particular, a chronology of depositional and incision events is almost completely missing. That would allow a close correlation between archaeological sites and geomorphological processes.

Another aspect related to the evolution of the landscape is the one related to climate and its variations. As specified above, climate changes dictated the birth and the abandonment of the Neolithic settlements and, subsequently, forced man to modify his subsistence techniques. In the Fars region very little is known about the climatic variations that characterized the Holocene.

Finally, poorly studied is the recent evolution of the coastline of the Persian Gulf. As already written above, the interaction between variation in relative sea level and tectonics has changed over time the Iranian coast and has decreed the birth and abandonment of several ports. The strategic and commercial importance of the Persian Gulf in the past suggests for the presence of additional undiscovered ports. A cross study that considers the tectonic events, the variation of the sea level and the bathymetry of the sea is indispensable in order to determine the navigability and the possible presence of harbour installations.

Concluding, Iran, and particularly the Fars region, is one of the best examples of how the geomorphological configuration, together with climate, affects and directs the development of human settlements: it forces man to find increasingly efficient ways to survive in a context of an environment continually modified by geological processes. For this reason, future geomorphological studies of this region are crucial to unravel the processes that have shaped the landscape and, by so doing, to fully understand the long-lasting mutual influence between nature and man.

Declaration of competing interest

The authors report there are no competing interests to declare.

Data availability

Data will be made available on request.

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